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Host Lab: www.lewas.centers.vt.edu

LEWAS LAB

LabVIEW Enabled Watershed Assessment System

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Acknowledgements

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Editorial Staff

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Disclaimer

The opinions, findings, and conclusions or recommendations expressed in this proceedings are those of the authors and do not necessarily reflect the views of the National Science

Foundation or Virginia Tech.

Summary

This Research Proceedings includes papers of undergraduate research that was conducted on Virginia Tech campus during summer 2011 as part of an NSF/REU Site on Interdisciplinary Water Sciences and Engineering. This NSF/REU Site follows a very successful NSF/REU Site that was implemented at VT during 2007-09. Research Proceedings of 2007-09 Site are available at: www.lewas.centers.vt.edu. Twenty-six undergraduates (16 women + 10 men) participated in our 2007-09 Site. A renewal proposal was submitted to the National Science Foundation in summer of 2009 which wasn't successful. Again, another renewal proposal was submitted in summer of 2010 which was successful and funding was received to continue the Site work for three years (i.e., 2011-13).

Investigation of interdisciplinary research issues in water sciences and engineering is the key goal of this REU Site. Faculty members from five departments (Engineering Education, Civil and Environmental Engineering, Biological Sciences, Crop and Soil Environmental Sciences, and Geosciences) and an NGO mentored 11 excellent undergraduates (10 NSF/REU fellows + 1 NSF/REU Site staff) who were recruited out of a nation-wide competition. Ten graduate students from these departments assisted the faculty mentors and got a valuable experience in mentoring undergraduate research students. Figure 1 shows a word cloud of the keywords that describe the research activities undertaken during the 10-week research at VT.

Figure 1: Word Cloud of Keywords – 2011 Research Work

In their research paper titled "Improving the Health of Copper Creek by Determining Levels of Fecal Pollution" Catherine (an REU Fellow from Smith College) and her co-authors investigated the health of Copper Creek in Virginia by determining the types and concentrations of fecal-indicator bacteria present in the water. Their investigation showed that there were high levels of *E. coli* and *Enterococci*, indicator bacteria of fecal contamination, as well as other pathogenic bacteria such as *Shigella*, present in the water. Miles (an REU Fellow from Virginia Tech) and his co-authors investigated long-term fate of coastal oil deposits using a case study of the Deepwater Horizon petroleum rig which exploded in April 2010 in the Gulf of Mexico releasing an estimated 4.9 million barrels of crude oil. In addition to enhancing the knowledge and understanding of depletion of coastal petroleum deposits from the spill, results from this research are expected to improve experimental techniques for assessing dissolution of extremely insoluble non-aqueous phase liquids (NAPLs). Their paper is titled "Experimental Procedure to Observe Dissolution Characteristics of Weathered Petroleum from the 2010 Deepwater Horizon Blowout." In a paper titled "Sensory Perception of Metals in Drinking Water and the Role of Saliva in

Metallic Flavor Production," Alex (an REU Fellow from Hobart and William Smith Colleges) and her co-authors evaluated variability in human population for detecting metal contaminants in drinking water. Twenty- eight subjects aged 18 – 82 years old participated in the study and individual and population flavor thresholds were determined for copper and iron in drinking water. The findings confirmed widely variable sensitivities for human detection of metallic flavor. Dusty (an REU Fellow from Wichita State University) and his co-authors discussed development of a LabVIEW Enabled Watershed Assessment System (LEWAS) which monitors environmental parameters on VT campus in a real-time. Their paper is titled "LabVIEW Virtual Instrument Development and Implementation for Environmental Monitoring in Real Time" and discusses the integration of software and hardware components of LEWAS. Kinsey (an REU Fellow from VT) and her co-author contributed a paper titled "Analysis of Macroinvertebrate Density and Distribution in Stroubles Creek, Virginia" to describe a study that used macroinvertebrate samples from six sites in Stroubles Creek in Montgomery County, Virginia to bioassess the effectiveness of a stream restoration project completed two years prior to the study. Results indicated slight improvement based on metrics used in the Virginia Stream Condition Index (VASCI) but still indicate impairment. In a paper titled "Nitrate in the Occoquan Reservoir", Alex (an REU Fellow from the College at Brockport, SUNY) and her co-authors reported analysis of data (redox potential, pH, DO, and temperature at the sediment water interface), collected in June and July 2011, from the Occoquan reservoir which is a shallow, eutrophic reservoir. Final products included several macros for each dataset, user manuals, and trouble-shooting tips which have the potential to significantly speed up the data analysis process in the future of this project. Rodrigo (an REU Fellow from Florida State University) and his co-authors wrote a paper titled "Dissolution of Apatite as a Function of Grain Size" and investigated the use of apatite in permeable reactive barriers (PRBs) for immobilizing uranium in groundwater. Data collected from this project can be used to determine the most efficient size of apatite for constructing an effective PRB for uranium immobilization. In a study focused on rainwater harvesting, Maya (an REU Fellow from Saint Louis University) and her co-authors assessed the potential of rainwater harvesting in commercial buildings for non-potable uses of water for the First and Main shopping center in Blacksburg, Virginia. Based on the roof area and rainfall data, the optimum tank size for this site was determined to be between 45,000 and 60,000 gallons. The study also examined barriers in implementing rainwater harvesting systems. Their paper was titled "Evaluating Sustainability of Rainwater Harvesting Systems for Commercial Buildings." Victoria (an REU Fellow from Tarleton State University) and her co-authors documented their research results in a paper titled "Characterizing the Effects of Macropores on Hyporheic Zone Hydraulics in Meander Bends." The authors collected data across a well-defined meander bend to quantify the effect of a 3cm-diameter constructed macropore on meander bend hydrology and solute transport. Their results provide strong evidence that macropores act as preferential flowpaths and may therefore have a profound impact on hyporheic zone function in meander bends and in turn, stream health and water quality. Chris (an REU Fellow from N C State University) and his co-authors in their paper "Reducing Problems Associated with Partial Replacement of Lead Service Lines" investigated the role of galvanic cells produced by partial lead service line replacements that can put consumers at risk of elevated lead in water. In their experiments, a 3" dielectric and a 12" dielectric (with a grounding strap) reduced the galvanic current by 50% and 75%, respectively. It was found that lead in water could be reduced by 75% with a 12" dielectric with a grounding strap. Stephanie (an REU Site staff member) and her co-authors contributed a paper titled "Calibration of Real-Time Water Quality Monitoring Devices" discussing the important details in theory, maintenance, and calibration of the HydroLab Sonde MS5 and SonTek Argonaut SW which are the integral part of LEWAS hardware and measure the water quantity and quality data from a stream site on VT campus in a real time.

REU Fellows made two YouTube videos to document their experiences over 10-week period"

http://www.youtube.com/watch?v=0IpNMI_c33M
http://www.youtube.com/watch?v=-rT-VFtLh94

Research Papers

Improving the Health of Copper Creek by Determining Levels of Fecal Pollution

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ABSTRACT

Unique fish, mussels, snails and amphibians are in danger of losing their habitat in the Copper Creek watershed, one of the most biodiverse regions in the United States, due to fecal contamination. This watershed is a top priority for federal and state conservation efforts as they work to preserve the biodiversity of the region. The purpose of this project is to investigate what is endangering the health of Copper Creek by determining the types and concentrations of fecal-indicator bacteria present in the water. Results showed that there were high levels of *E. coli* and *Enterococci*, indicator bacteria of fecal contamination, as well as other pathogenic bacteria such as *Shigella*, present in the water. The main contributors to fecal contamination were predicted to be livestock (mostly cattle) and humans; yet, preliminary tests proved that humans have contributed little to the fecal load on the stream. In conclusion, to prevent the stream from reaching a point of no return, proper action must be taken immediately, such as restoring riparian vegetation, limiting direct access to the water, implementing agricultural Best Management Practices (BMPs), modifying septic systems if necessary, and educating the local communities about the protecting the ecosystem.

Keywords: fecal-indicator bacteria; *E. coli*; environmental microbiology; human; cattle

Introduction

Background

The Upper Tennessee River Basin is home to one of the most biodiverse areas in the United States, and one of the most diverse aquatic faunal assemblages on Earth. In fact, it was named among only a few unique biodiversity “hotspots” among U.S. watersheds (Hanlon, Petty, & Neves, 2009). Within this area lies the Copper Creek watershed, the most biologically significant tributary to the Clinch River and one of the most diverse streams in Virginia.

Problem

In 1992, Copper Creek also ranked number one for the most significant agricultural water quality and erosion problems in the Clinch River basin (Hanlon et al., 2009). Recent surveys of freshwater fish living in Copper Creek have suggested that the number of species of fish, 71 species between 1965 and 1992, is declining (Hanlon et al, 2009). There is also a threat to the freshwater mussels found in Copper Creek; in 1980 there were 23 species of freshwater mussels (Hanlon et al., 2009). Several surveys since then have noted a sudden decline in mussel abundance and diversity, especially for those already threatened or endangered (Hanlon et al., 2009). Scientists have been studying these mussels because of their relatively long life cycle (greater than 20 years); and, therefore, demonstrate a delayed yet prolonged response to water quality problems. Federal and state agencies, including the Virginia Department of Environmental Quality (DEQ) and the U.S. Fish and Wildlife Service (FWS), have made the Copper Creek a top priority due to its abundance of the rich diversity and large quantity of threatened and endangered species. In fact, Copper Creek harbors nine federally endangered or threatened species, three candidate species for federal listing, and 12 species of concern. In 2010, DEQ published the Impaired Waters 303 (d) list, where approximately 31km of the 97km of Copper Creek and its tributaries are listed as impaired for recreational use due to *E. coli* (Virginia Department of Environmental Quality).

Causes of Concern

The majority of residences and livestock operations are concentrated in the valley floodplain of the Copper Creek watershed. Additionally, many livestock operations, such as fenced pastures, allow cattle to access the stream channel directly. In a watershed with approximately 10,000 head of cattle and 1,609 individual farms, there is significant potential for fecal contamination in this watershed (NRCS Soil Conservation specialists, Russell and Scott Counties, personal communication with Annie Hassall-Lawrence, 2009). The most apparent causes of fecal impairment to Copper Creek are from cattle and humans. Cattle contribute excess nutrients, pathogens, as well as sediment from the eroding hill-slopes and stream-banks. Leaking and/or incorrectly sited septic systems may also contribute pathogens from human waste. Since most homes in the watershed were built several decades before septic system regulations were put in place, these may be the sites of direct contributors to fecal contamination (Russell County Health Department Supervisor, Brian Stanley, personal communication with Annie Hassall-Lawrence, 2009). Another concern is the karst topography of the region, which contains sinkholes and caves that convey surface water runoff that may be contaminated directly into groundwater, which flows to streams with limited soil filtration. These watershed characteristics have made fecal contamination likely to occur in the stream. Wildlife (deer) may be a contributor to fecal contamination as well, but are not the focus of this project as wildlife does not threaten the biodiversity of the watershed.

After numerous surveys were conducted on mussels and other fauna in the Copper Creek watershed, absolute density estimates decreased significantly from 4.07 mussels/m^2 in 1981 to 0.63 mussels/m^2 in 2005 (Hanlon et al., 2009). One of the notable reasons for this vast decrease in mussels and fauna is the great loss of riparian buffers along the stream banks. "Nearly half of the stream banks in Copper Creek have inadequate riparian vegetation to provide even minimal sediment control" (Hanlon et al., 2009). Although forest cover in Copper Creek increased by 18.8% from 1992 to 2002, riparian vegetation has been disappearing for the last 30 years (Hanlon et al., 2009). Riparian buffer widths of about 9m or more are considered effective for sediment control; yet, about 45% of the stream banks of Copper Creek have inadequate riparian vegetation (Hanlon et al., 2009). When stream-side riparian buffers were removed, cattle had more access to the creek, the stream banks became more destabilized, and the extra sediment in the stream began ruining the mussel ecosystem. "Riparian buffers are vegetated areas adjacent to water bodies that protect water resources from nonpoint source pollution and provide bank stabilization and aquatic and wildlife habitat" ("Riparian Buffers," n.d.). Essentially, riparian buffers not only protect the wildlife of Copper Creek by controlling sediment, but can effectively prevent surface runoff, which can be contaminated with fecal bacteria and pathogens, from reaching the water.

Historical data

Fecal pollution caused by human or ruminant animals greatly influences the health of water bodies that are unsafe for humans and for wildlife in the ecosystem. Copper Creek has been impaired for several years, as evidenced in the historical data from DEQ (Appendix A). *Escherichia coli* (*E. coli)* densities measured by DEQ over a 12-month assessment period, between 2005 and 2011, ranged from 2 to 550 colony-forming units per 100mL (CFU/100mL) for all three main study field sites, with average values of 184 CFU/100mL, 147 CFU/100mL, and 50 CFU/100mL for sites 1, 2 and 3 respectively. To classify as impaired due to *E. coli*, 10% of Copper Creek must exceed 235 *E. coli* CFU/100mL over a 12-month assessment period. Approximately 18% of the DEQ data from Copper Creek is above this limit; therefore, this watershed is considered impaired for fecal contamination due to *E. coli*. By analyzing the historical data of Copper Creek, including temperature, DO levels, and pH, it would appear as though Copper Creek is healthy and in good condition (Appendix A). However, the *E. coli* density would indicate otherwise, as is directly related to fecal pollution that is endangering this vital habitat.

Goal and Objectives

The goal of the REU project was to investigate and explore the extent and types of pollution, specifically fecal pollution, in the Copper Creek watershed. The primary objectives of the project were determined:

1. Is there fecal contamination in Copper Creek?

2. What types of fecal-indicator bacteria were present?
3. How much and to what is the extent is pollution from cattle or humans specifically?

The long-term goals and objectives of the project in Copper Creek are to deploy microbial source tracking methods to determine the relative contributions of all livestock, not only cattle, plus human waste (concentrations and loads). The outcome of research will include results that can guide decision-making on a case-by-case basis to implement livestock exclusion, such as fencing, agricultural Best Management Practices (BMPs), restore riparian vegetation, modify septic systems as needed, and educate the local communities about the importance of preserving the unique biodiversity of Copper Creek.

Research Methods

Study Area Description

Copper Creek is a major tributary to the Clinch River in the Upper Tennessee River watershed. The Copper Creek watershed is 34,638ha or about 344km^2, with a stream length of roughly 97km (Hanlon et al. 2009). It flows in a southwesterly direction, from just northeast of Dickensonville in Russell County to the Clinch River near Clinchport in Scott County (Figure 1). Elevations in the watershed range from 792m, in the headwaters, to 378m, at the mouth to the Clinch River. The stream is a warm-water habitat throughout, even with the significant groundwater inputs because of the karst topography. The primary land uses in the watershed are livestock (40.9%, mainly cattle), forestry (57.7%) and crop production (1.3%) (Hanlon et al. 2009). The upper watershed has a higher percentage of pasture and livestock compared to the lower watershed, and there is no active mining in the watershed. Three water quality monitoring stations were established recently within Copper Creek (Figure 1) by the U.S. Fish and Wildlife Service (FWS). Site 1 is located near the headwaters just below the first major tributary, Little Copper Creek. Site 2 is downstream of Jesse's Branch. These sites were chosen because tributaries upstream from site 2 have 57-65% watershed land use in pasture, while the tributaries downstream from this location have only 30-51% land use in pasture. Site 3 is located just upstream of the confluence with the Clinch River.

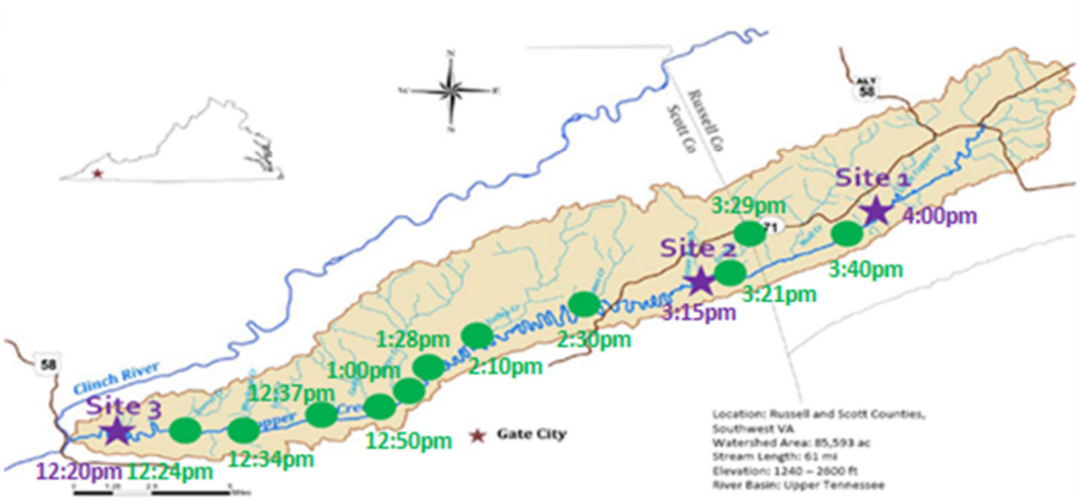


Figure 1. Study Area Map of All Sample Sites on Copper Creek

Sample Collection

Samples were collected at the three main FWS sites (stars), with an additional eleven sites along on the stream, to provide a more accurate depiction of its health, as shown in Figure 1 (green dots). Although there are automatic sample collectors at the three main sites, samples were collected manually in the free flowing channel portion of the stream to obtain the most current state of the water. The stream-water samples were collected using the standard hand-dip method as opposed to a depth-width integrated sampling method because the stream was expected to be well-mixed (Myers et al. 2007). Horse and cow fecal samples were also collected at one location near the banks of site 2:10pm, a tributary of Copper Creek. Samples were collected and were processed using sterile technique for indicator bacteria to ensure quality control. All of the laboratory equipment used for collection and processing were first cleaned and sterilized, using an autoclave that sterilizes equipment and media at 10psi and 121°C. Samples were collected in sterile plastic bottles and were transported on ice. The two fecal samples collected were placed into plastic bags and were kept on ice until processing in our laboratory. The fourteen samples were transported to the lab and processed within 24 hr (membrane filtration). After this, DNA extraction, end-point PCR, and gel electrophoresis were performed.

Sample Analysis Based on Objectives

1. Is there fecal contamination in Copper Creek?

The basic method of analyzing water samples for fecal contamination has been standardized by the U.S. Environmental Protection Agency (EPA) and the U.S. Geological Survey (USGS), and we have been using these methods throughout my research at Virginia Tech. Consistent with EPA Method 1603 for *Escherichia coli* (*E. coli*) and Method 1600 for enterococci in water by membrane filtration, the water samples were filtered through sterile, white, gridded 47mm diameter and 0.45µm membranes, which retains the bacteria (Oshiro 2002). Tests for *E. coli* and enterococci are used as measures of recreational water quality. These criteria were developed to promulgate recreational water standards based on established relationships between health effects and water quality (Oshiro 2002). The reusable sterile filters were first cleaned using ethanol and deionized water. Any excess fluid was collected using a pad from gridded membrane packet. Once the membrane was on the filtration apparatus, each sample was mixed several times, the 5mL- and 20mL-volumes were transferred with a sterile pipette, and each was poured over a membrane (Myers et al. 2007). Once vacuum was applied to the filter, the water was pulled through the membrane, the same cycle was repeated for all 14 samples, in the order of smallest to largest volumes (Myers et al. 2007). For each filtration for different volumes from the water samples, each membrane containing the bacteria was placed onto selective media (modified mTEC and mEI Agars) using sterilized steel forceps (Myers et al. 2007). Afterwards, the agars were incubated for three days to allow the colonies to grow to a large size for easy enumeration (Myers et al. 2007).

Once the plates were removed from the incubator, the target colonies that formed on each membrane plate were enumerated and recorded. On the modified mTEC agar, the *E. coli* colonies were magenta or purple in color, and were round, raised, and smooth. On mEI, the enterococci colonies had blue halos around them after the incubation period (Myers et al. 2007). Quality control was maintained by recounting the colonies. The colonies were recounted until the results agreed within five percent (Myers et al. 2007). To recount them, the plates were rotated 90 degrees several times to obtain different views. The counting method detailed by USGS was used, which advised to use a preset pattern of side-to-side counting (Myers et al. 2007). The EPA guidance for counting also suggested counting the *E. coli* on modified mTEC medium that are red to magenta under natural light (Myers et al. 2007). For enterococci, following EPA recommendations, the colonies with a blue halo were counted using a fluorescent illuminator that magnifies the plates (Myers et al. 2007).

2. What types of fecal-indicator bacteria were present?

In addition to determining *E. coli* and enterococci Colony-Forming units (CFU)/100mL, it is standard procedure in most commercial laboratories to perform tests using the EPA-approved Heterotrophic Plate Count (HPC) method. HPC is designed to determine the density of aerobic or anaerobic heterotrophic bacteria in water. Since it is not nutrient-specific, all present bacteria will be allowed to grow. Using low-nutrient growth PCA and R2A poured agars, 0.5mL of a water sample was distributed evenly over a poured plate. Since the basis of the project was environmental microbiology, each medium was allowed to incubate at room temperature (about 22˚C) and at 37˚C conditions, temperatures that occur in natural waters. Additionally, these incubation temperatures for each medium for each water sample promoted the growth of only aerobic bacteria, which are mostly present in the environment. Although HPC cannot distinguish between bacteria and is only representative of a small amount of the sample, it is a still good measure of the general bacterial composition of a water sample.

To produce further results for the project, Biolog® MicroStationTM ID System was used to identify the specific bacteria that grew on the HPC plates. The MicroStationTM is a semi-automated system that employs carbon source utilization technology to identify environmental and pathogenic microbes ("MicroStationTM," 2007). This new system had not been used yet in the Hagedorn lab for experimenting with unknown environmental microorganisms found in water samples. To identify the bacteria, bacteria of interest from the incubated HPC plates were isolated and placed onto blood agar base with 5% sheep blood. After allowing the blood agar plates to incubate for 24h at 37˚C, small amounts of isolated bacteria were collected and mixed with inoculum A or B, until the inoculum were 90-95% clear. Once the inoculum were prepared, the mixed fluid was transferred into 96-well microplates, which would be entered into the MicroStationTM machine that identified the microbes present ("MicroStationTM," 2007).

The water samples collected from Copper Creek were further analyzed with differential media, an alternative to Biolog®. Other bacterial cultures in the samples, on HPC plates, were isolated onto new differential media: Salmonella Shigella agar (SS), Xylose Lysine Deoxycholate (XLD) agar, Hektoen Enteric agar (HE), and the same blood agar base with 5% sheep blood that was used for Biolog®. SS agar contains sources of nitrogen, carbon and vitamins that allow *Salmonella* and *Shigella* to grow, bacteria that cause a number of public health problems and illnesses, as well as *E. coli* (Acumedia, 2008). XLD agar is used for the isolation and differentiation of enteric pathogens, principally *Shigella* and *Providencia* bacteria (Acumedia, 2008). HE agars are moderately selective media that are particularly useful in cultivating *Shigella* species, but other bacteria such as *E. coli* and *Enterococcus* are also able to grow (BD, 2009). Blood agar base with 5% sheep blood is very rich in nutrients and is primarily used for detection hemolytic activity of streptococci and other fastidious microbes ("Columbia CAN agar," n.d.). Each agar was mixed and poured onto petri dishes until becoming solid. Each petri dish was divided into four sections for different colonies from different HPC plates and mTEC plates for each sample. The target colonies of interest from the HPC and mTEC plates were smeared onto the different sections of all four agars and were placed in a 4˚C refrigerator for 24h. The next day, the different reactions of the bacteria to the agar were recorded for each petri dish of each sample.

3. How much and to what is the extent is pollution from cattle or humans specifically?

To determine the sources of fecal contamination in Copper Creek, standard microbial methods were utilized for DNA extraction, polymerase chain reaction (PCR), and gel electrophoresis. For the ten weeks of research, end-point PCR was used in the Hagedorn lab, but the long-term objective of this project and future ones is to adapt the best microbial source markers for qPCR, or real-time PCR, a method that produces much quicker results, eliminates the tedious process of gel electrophoresis, and allows for much quicker action in informing local authorities about the sources of fecal contamination. In addition, qPCR produces quantitative results that provide information on the sources of fecal pollution, as well as the densities of fecal indictor bacteria.

With the use of a fluorometer, the concentrations of optical brightener levels were obtained for each of the water samples from Copper Creek. Optical brighteners are dyes that absorb ultraviolet light rays and re-emit them in the blue, visible spectrum. They are important in water quality since high-concentration levels of optical brighteners are indicators in the preliminary identification of failing or poorly functioning septic systems, sewage, storm drain cross-connections, and the differentiation between human and animal waste. Optical brighteners are present in nearly every aspect of the daily lives of humans, including toilet paper, laundry detergent, shampoo and conditioner, most paper, and most fabrics. Tests with the fluorometer allowed the link to be made between fecal pollution and human influences. A test tube was labeled and filled with each of the 14 water samples, inserted in the fluorometer at time zero, placed under ultraviolet light for four hours, and re-tested on the fluorometer after the four hours elapsed. Optical brighteners photo-decay; therefore, testing for their ability to disintegrate in the water samples is necessary to predict how they will act in the environment.

In end-point PCR, agarose gel is the final result, and there are many limitations to this traditional method of PCR. The process of performing end-point PCR and arriving at only qualitative results after gel electrophoresis is very time-intensive, takes several days to produce results, and has low precision and sensitivity ("Real-Time PCR vs. Traditional PCR," n.d.). However, at the time of the project, end-point PCR methods were used, while qPCR is not far in the future for use on this project. To begin traditional PCR, each component of the master mixture was prepared for the number of reactions that are being completed. For all 14 samples, general *Bacteroides* and human-specific *Bacteroides* markers were used to test for positive or negative results for sources of fecal contamination. If the gel showed it was positive for a certain sample for human-specific *Bacteroides*, the source of fecal contamination for the sample would be humans. First, 28 small 200µL PCR tubes were labeled, 14 for each sample site, indicating whether general or human-specific markers were used. Then, the components of the PCR were prepared. For all 28 samples, the master PCR mix consisted of several chemicals: 350µL of Promega PCR master mix, 28µL of diluted BSA, 28µL of forward primers (Bac32 for general *Bacteroides*, HF183 for human-specific *Bacteroides*), 28µL of reverse primers (Bac708 for both general and human-specific *Bacteroides*), and 196µL of nuclease free water. Once each master mixture was prepared for each marker, 22.5µL of each master mix was transferred, using a sterile pipette tip, into each respective PCR tube, labeled earlier. Then, for each sample of DNA extracted, 2.5µL of template DNA was transferred to each PCR tube. Each 200µL PCR tube was centrifuged briefly, to avoid any of the liquid sticking to its sidewalls. The fluid was pipetted from the bottom, and then each tube was placed into two Eppendorf Mastercycler Gradient thermalcyclers; one programmed for the general *Bacteroides* marker and the other for the human-specific *Bacteroides* marker. It was important to make sure the tubes were correctly labeled because each marker required certain temperature cycles. This process lasted several hours, and the tubes were incubated at 4˚C until gel electrophoresis was performed with the PCR product (Crozier & Scott, 2009).

To begin gel electrophoresis, the last step in determining the source of fecal contamination using traditional PCR methods, two 1% agarose gels were made by adding cold, refrigerated 1X TAE fluid to 0.5g agarose powder until each was at a mass of 50g. Each mixture was carefully brought to a boil by constant stirring on a hotplate and allowed to cool. Once the mixtures were poured onto leveled Biorad® rigs, which had taped sides to prevent spilling, with 20 wells, the gels were placed in a Ziploc bag for about 30min to cool them and prevent any evaporation of any liquid. Then, 5µL of frozen PCR product for each sample was mixed to 2µL 6X blue running dye and then pipetted, using a new sterile tip for each sample, into each well of the gel. Before adding the PCR product to the gel, the gel was labeled, and the order of the samples in the wells was recorded. Then, cold 1X TAE was added to each gel until there was fluid about 2cm above it, and both gels were run at 120V for 45min. When gels were not cold, there was a high probability of inaccurate results. After 45min, the gels were stained using 2µL of 10,000X SYBR green and were submerged in 20mL of 1X TAE for 20min. Finally, each stained gel was visualized under UV light and photographed. A known PCR product was always run with the unknowns from Copper Creek to determine if PCR worked and if the bands displayed were in the correct position. When there was a fuzzy band under 100bp, it was interpreted as a primer-dimer and not as a positive result (Crozier & Scott, 2009).

Results and Discussion

1. Is there fecal contamination in Copper Creek?

Since the membranes on the mTEC and mEI agar plates were incubated for longer than prescribed (approximately 90h as opposed to 24h), some of the counts on the fecal bacteria colonies could have been slightly inaccurate due to this extra time, which allowed other bacteria besides *E. coli* and enterococci to grow. Still, after many recounts, the density of target colonies was consistent, shown in Figure 2. In order for an area of Copper Creek to become impaired for fecal coliforms, the density of the fecal bacteria must exceed the EPA standard for Virginia, 235 *E. coli* CFU/100mL and 104 enterococci CFU/100mL. Ten of 14 collected samples were above either standard, and eight sites were impaired for both *E. coli* and enterococci.

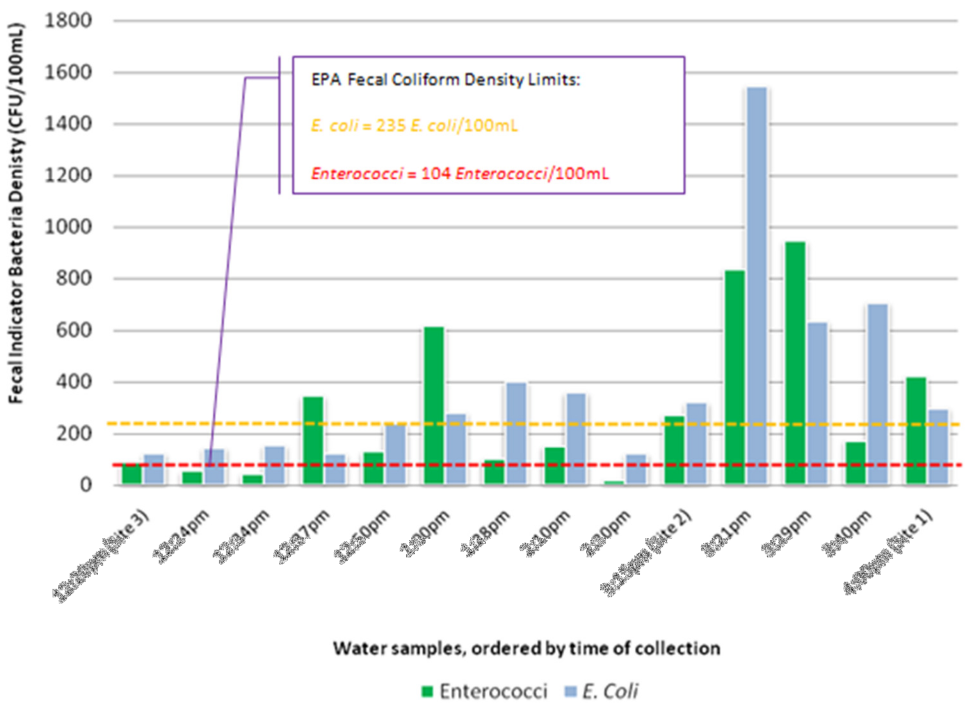


Figure 2. Fecal Indicator Bacteria Enumeration Results for Copper Creek

Based on a comparison of the densities of fecal indicator bacteria and densities of cattle, other livestock, and human septic systems in Copper Creek, the observational methods in the field visit and the microbial methods performed in the laboratory were parallel. At sample sites where livestock were visible within the floodplain or had direct access to water, levels of *E. coli* were at their greatest and exceeded the EPA limits in recreational waters. These sites were at 12:34pm, 12:37pm, 1:00pm, 2:10pm, 3:15pm (site 2), 3:21pm, 3:29pm, and 3:40pm, as shown in the table in Appendix B. Samples 12:34pm and 12:37pm were collected by an obvious cow pasture nearby and from a livestock watering hole that flowed directly into Copper Creek. At the 1:00pm sample site, there were horses grazing only a few yards away in the floodplain as well as many minnows visible in the water. At sample site 2:10pm, there were many, obvious sources of fecal contamination: hoof-markings leading into the creek with no fencing, cattle feces on a stream bank, and horse feces on the bridge over the stream. Sites 3:15pm, 3:21pm, 3:29pm and 3:40pm were within the headwaters of Copper Creek and were also within the region of impairment, as listed on the DEQ 303 (d) list of impaired waters. These sites were also part of the Grassy Creek tributary to Copper Creek, which had much evidence of cattle and other livestock within the floodplain and with direct access to the stream. With more farms with ruminants on hills, there was a large possibility that fecal bacteria and pathogens associated with them were carried in surface runoff that led to the stream. Additionally, few clearly designed riparian buffers were observed.

2. What types of fecal-indicator bacteria were present?

In the test for Heterotrophic Plate Counts (HPC), PCA and R2A agars were allowed to incubate for several days at different temperatures to promote any aerobic bacteria that were naturally occurring in the water samples. For the water samples of interest, which were the samples with the highest *E. coli* CFU/100mL, over 10,000 colonies had grown per milliliter per plate, as shown in Photo 1. There was an enormous bacterial load in Copper Creek. They were not enumerating due to the large colony density, but there were far more bacteria in the stream than expected.

The Biolog® MicroStationTM ID System was a failure in classifying and identifying the environmental microbes present in the Copper Creek water samples. All procedures were followed precisely; yet, only four out of 34 microplates were read and identified. The other 30 microplates resulted in "False Positive" results. The four samples identified are shown in Table 2.

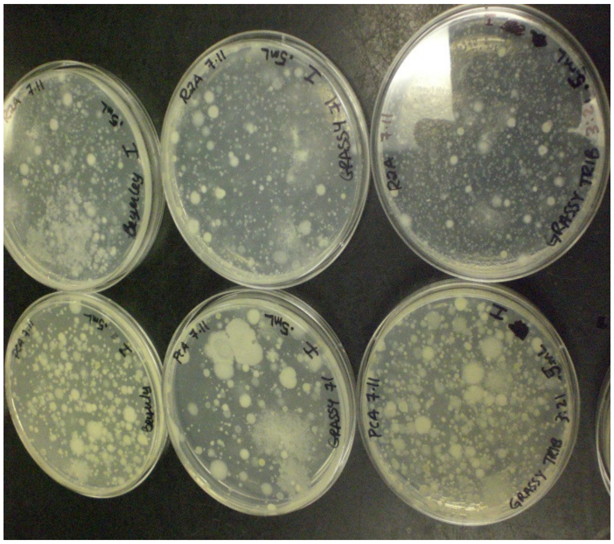
Table 1. Identified Positive Results for Biolog® System

Plate Type	Protocol	Sample ID	ID Result	Probability
GEN III	A	Site 1-4	Species ID: Aeromonas bestiarum	0.975
GEN III	B	Site 1-6, Room Temperature	Species ID: Aeromonas bestiarum	0.944
GEN III	A	Site 2-7	Genus ID: Bacillus	0.857
GEN III	A	3:21pm-8	Species ID: Serratia marcescens ss marcescens	0.896

As an alternative to the minimal bacterial classification in the Biolog® system, differential media tests were conducted. The differential media had many more results and were easily identifiable, as shown in Photo 2. These tests for the Copper Creek water samples proved that *E. coli* and enterococci are present in them, as well as other enteric microorganisms that have pathogens associated with them, as shown in Table 2 and Appendix C.

Table 2. Site 1 Differential Media Results

Differential Media	Isolated Bacteria Sample Source	Growth	Reaction	Microorganism
SS	mTEC (5mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
SS	PCA (Incubated at 37˚C)	Fair to good growth	Colorless colonies	*Shigella*
SS	PCA (Incubated at room temperature)	Complete Inhibition	No reaction	*Enterococcus*
SS	R2A (Incubated at 37˚C)	Complete Inhibition	No reaction	*Enterococcus*
XLD	PCA (Incubated at room temperature)	Partial inhibition	Red colonies (where recovered)	*Enterococcus*
XLD	R2A (Incubated at room temperature)	Partial inhibition	Yellow to yellow-red colonies	*E. coli*
XLD	PCA (Incubated at 37˚C)	Partial inhibition	Yellow colonies	*E. coli*
XLD	mTEC (5mL)	Partial inhibition	Yellow colonies	*E. coli*
HE	mTEC (20mL)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	*E. coli*
HE	R2A (Incubated at room temperature)	Partial inhibition	Small yellow colonies, salmon to orange halos	*Enterococcus*
HE	PCA (Incubated at 37˚C)	N/A	Green, nearly transparent	Uninoculated
HE	R2A (Incubated at 37˚C)	N/A	Green, nearly transparent	Uninoculated



Photos 1 & 2. Heterotrophic Plate Count Test and Differential Media Bacterial Identification Results

3. How much and to what is the extent is pollution from cattle or humans specifically?

There were few results in determining the extent at which cattle and humans were endangering the health of Copper Creek. DNA extraction and end-point PCR were successful for all the samples; however, when the gels were made and tested, many of the wells were torn and not much information resulted from putting the gels under ultraviolet light. No conclusions could be drawn from these methods. In addition, the DNA primers used in PCR were only general and human-specific *Bacteroides* markers, not cattle-specific, which was not the ideal design set-up. Nevertheless, some data was still useful. Based on the data recorded in Table 3, there were low concentrations of optical brighteners in the Copper Creek water samples.

Table 3. Optical Brightener Concentrations in Copper Creek Samples

	Optical Brightener Levels (unitless)	
Water Sample (ordered by time)	**At time zero**	**After 4 hours**
12:20pm	17.2	10.1
12:24pm	16.4	11.9
12:34pm	16.9	11.3
12:37pm	21.3	14.1
12:50pm	16.6	9.5
1:00pm	12.4	5.7
1:28pm	16.5	9.86
2:08pm	10.2	4.56
2:30pm	15.8	9.66
3:15pm	19.9	11.2
3:21pm	17	8.25
3:29pm	15.9	6.58
3:40pm	29.3	18.9
4:00pm	21.2	11.7

Conclusions

1. Is there fecal contamination in Copper Creek?

Contrary to the historical data collected by Virginia DEQ, the majority of Copper Creek, since the date of water sample collection on July 6, 2011, has been impaired due to fecal coliforms (in particular *E. coli*) and enterococci. The stream is impaired beyond the 31.1km near its headwaters that DEQ had stated in 2010. Therefore, there is much more fecal contamination in Copper Creek than was originally expected.

2. What types of fecal-indicator bacteria were present?

There were numerous types of bacteria that indicate fecal pollution present in the waters of Copper Creek. The bacterial load and diversity of bacteria were much greater than hypothesized. Based on the differential media test, there were mostly *E. coli* and enterococci present, but some other microorganisms such as *Shigella* and hemolytic streptococci had grown on the media. In addition, results concluded that the Biolog® system was not useful for water quality or environmental microbiology purposes. In the future, the procedures for using the Biolog® system would have to be modified to purify the bacterial cultures more, and more preliminary identification would have to be used.

3. How much and to what is the extent is pollution from cattle or humans specifically?

Supported by low optical brightener concentration levels, human contribution to the fecal contamination of Copper Creek was much less than expected. Nevertheless, the fluorometry tests only provided preliminary results to conclude that humans have a small impact on the fecal load within the stream, and further procedures with microbial source tracking, using the correct DNA primers, must be performed to confirm this conclusion. Additionally, a direct correlation was found between great densities of livestock, mostly cattle, in the floodplain or near the stream to higher fecal coliform counts. The more livestock were near the stream, the more colonies of *E. coli* and enterococci were found in the water.

Recommendations for further research.

The overall goals and objectives of the Copper Creek project are outlined as follows:

a. Use *Bacteriodes*-specific DNA primers, or markers, to indicate total fecal contamination
b. Determine best suited human-specific *Bacteriodes* markers by testing human septage samples
c. Determine best suited cattle-specific markers by testing farm manure and fields samples.
d. Adapt best markers for qPCR

Furthermore, solutions must be implemented to prevent the situation from worsening. If proper action is not taken as soon as possible, the biodiversity of Copper Creek may be lost forever. Some common solutions to reducing fecal contamination are:

a. Restoring riparian vegetation along the banks of the stream
b. Constructing fences to prevent access
c. Implementing agricultural Best Management Practices (BMPs)
d. Modifying septic systems if necessary
e. Educating local communities about the pollution of Copper Creek

Peer Feedback on Presentations

Five-minute presentation feedback

Although it was only five minute PowerPoint presentation, most of the REU group, including the primary author, was very nervous to present on their research. The primary author had not given a formal presentation to peers in several months, and she felt that poor public speaking would distract from a thorough visual presentation. The author had not planned the appropriate amount of time to practice the oral presentation, which was reflected in the feedback received. The major critiques received were that the obvious nervousness and lack of confidence in the information presented. In addition, the group also felt that the PowerPoint itself, in addition to the oral presentation, was too informal. Nevertheless, every group member had effectively articulated the point of this project. They had correctly noted that the focus of the research was to find the source of fecal contamination in Copper Creek from cattle and leaking septic systems. They also addressed the main introductory point: motivation and importance of this research at Copper Creek. The main thing take-away from this initial feedback was that the primary author must be more formal and must engage the audience in such a way by demonstrating my passion and excitement for the research, instead of humor.

Ten-minute presentation feedback

For this second presentation, many improvements were made and the feedback received had reflected the author's diligence. More focus was placed on building confidence level with the material, using more pictures and fewer words to articulate key points, and using personal anecdotes to make the presentation more enjoyable. Fortunately, the REU group noticed these differences and noted that a vast improvement was made from the first presentation. Overall, the primary author received an A- grade. In this presentation, a B+ grade was still expected from the primary author because not enough time was allotted for rehearsing before the presentation. Almost every REU group member had noted that the photos were described very well and that they were used effectively to articulate the research project. Overall, peers had the correct take home presentation: the research was to investigate the fecal contamination, by humans or cattle, of Copper Creek to determine its health. One of the feedback comments was really helpful and summarized everyone's comments: "good job of connecting with the audience; good use of images; try to avoid the use of jargon like 'all that jazz'…" Once again, remaining formal was still an issue, but this feedback was used to strengthen my final presentation. From the feedback, the take home message was to practice more, act confident, be more formal, and express enthusiasm in order to connect to the audience.

Fifteen-minute presentation feedback

The feedback for this rehearsal presentation really made the final presentation outstanding. Most of the questions had easy responses, and most of the REU group mentioned that the primary author's PowerPoint presentations were improving vastly from week to week. Most of the students commented on speaking louder or slowing down during the methods and results sections to explain further. They also enjoyed the pictures used and thought the photos served a great purpose. Additionally, Dr. Lohani and Dr. Younos mentioned changing the logical flow of the presentation slightly, as well as reducing the introduction to the problem time to only three or four minutes. The feedback was very appreciated by the primary author and it gave her a boost of confidence for an excellent oral presentation.

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References

Acumedia Manufacturers, Inc. (2008). *SS Agar (7152)*. Retrieved from http://www.neogen.com/Acumedia/pdf/ProdInfo/7152_PI.pdf

Acumedia Manufacturers, Inc. (2008). *XLD Agar (7166)*. Retrieved from http://www.neogen.com/Acumedia/pdf/ProdInfo/7166_PI.pdf

BD Diagnostic Systems. (2009). *BD™ Hektoen Enteric agar (HE agar)*. Retrieved from http://www.bd.com/resource.aspx?IDX=8970

Columbia CNA agar with 5% sheep blood. (n.d.). Retrieved August 1, 2011, from http://www.exodusbreeders.com/PDF_equine/MI_BO_ColumbiaAugar/ColumbiaCNAAgar.pdf

Converse, R. R., Blackwood, A. D., Kirs, M., Griffith, J. F., & Noble, R. T. (2009). Rapid qPCR-based assay for fecal bacteroides spp. as a tool for assessing fecal contamination in recreational waters. *Water Research*, *43*, 4828-4837. doi:10.1016/j.watres.2009.06.036

Copper Creek watershed. (2011). Copper Creek: Cooperative Conservation Partnership Initiative. *U.S. Fish and Wildlife Service: Virginia Field Office*. Retrieved July 6, 2011, from http://www.fws.gov/northeast/virginiafield/partners/copper_creek-CCPI.html

Crozier, B., & Scott, K. (2009). Bacteroides: DNA Extraction, Amplification, and Visualization. *Roanoke College.*

Diamond, J.M., Bressler, D.W., Serveiss, V.B. (2002). Assessing relationships between human land uses and the decline of native mussels, fish, and macroinvertebrates in the Clinch and Powell River Watershed, USA. *Environmental Toxicology and Chemistry*, *21*(6), 1147-1155.

Furet, J., Firmesse, O., Gourmelon, M., Bridonneau, C., Tap, J., Mondot, S., Doré, J., & Corthier, G. (2009). Comparative assessment of human and farm animal faecal microbiota using real- time quantitative PCR. *FEMS Microbiology Ecology*, *68*(3), 351-362. doi:10.1111/j.1574-6941.2009.00671.x

Hanlon, S.D., Petty, M.A., & Neves, R.J. (2009). Status of native freshwater mussels in Copper Creek, Virginia. *Southeastern Naturalist*, *8*(1), 1-18. doi: 10.1656/058.008.0101

MicroStation™ ID System. (2007). Retrieved July 27, 2011, from http://www.biolog.com/pdf/00A022rBML1ML2brochureDec2006.pdf

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., & Brady, A.M.G. (2007). Fecal indicator bacteria. *U.S. Geological Survey Techniques of Water-Resources Investigations Book 9* (pp. 1-53). Retrieved from http://water.usgs.gov/owq/FieldManual/Chapter7/index.html.

Oshiro, R.K. (2002). Method 1600: *Enterococci* in Water by Membrane Filtration Using membrane-Enterococcus Indoxyl-β-D-Glucoside Agar (mEI). *United States, Environmental Protection Agency, Office of Water.*

Oshiro, R.K. (2002). Method 1603: *Escherichia coli* (*E. coli*) in water by membrane filtration using modified membrane-thermotolerant *E. Coli* agar (modified mTEC). *United States, Environmental Protection Agency, Office of Water.*

Real-Time PCR vs. Traditional PCR. (n.d.). *Applied Biosystems*. Retrieved August 1, 2011, from http://www6.appliedbiosystems.com/support/tutorials/pdf/rtpcr_vs_tradpcr.pdf

Riparian buffers: what are they and how do they work? (n.d.). In *Department of Soil Sciences, North Carolina State University*. Retrieved July 27, 2011, from http://www.soil.ncsu.edu/publications/BMPs/buffer.html

Shanks, O. C., Atikovic, E., Blackwood, A. D., Lu, J., Noble, R. T., Domingo, J. S., Seifring, S., Sivaganesan, M., & Haugland, R. A. (2008). Quantitative PCR for detection and enumeration of genetic markers of bovine fecal pollution. *Applied and Environmental Microbiology*, *74*(3), 745-752. doi:10.1128/AEM.01843-07

Stoeckel, D.M., Stelzer, E.A., Stogner, R.W., & Mau, D.P. (2011). Semi-quantitative evaluation of fecal contamination potential by human and ruminant sources using multiple lines of evidence. *Water Research*, *45*(10), 3225-3244. doi:10.1016/j.watres.2011.03.037

2010 Impaired Waters Fact Sheets, Cause Group Code: P14R-01-BAC – Copper Creek, Moll Creek and Valley Creek. (2010). *Virginia Department of Environmental Quality*. Retrieved on July 28, 2011.

Yampara-Iquise, H., Zheng, G., Jones, J.E., & Carson, C.A. (2008). Use of a bacteroides thetaiotaomicron-specific A-1-6, mannanase quantitative PCR to detect human faecal pollution in water. *Journal of Applied Microbiology*, *105*, 1686-1693. doi:10.1111/j.1365-2672.2008.03895.x

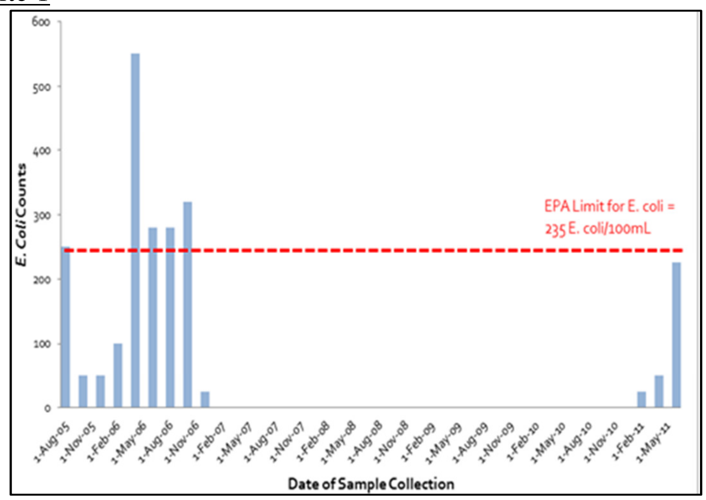
Appendix

Appendix A

Table. Virginia Department of Environmental Quality (DEQ) Historical Data for Copper Creek

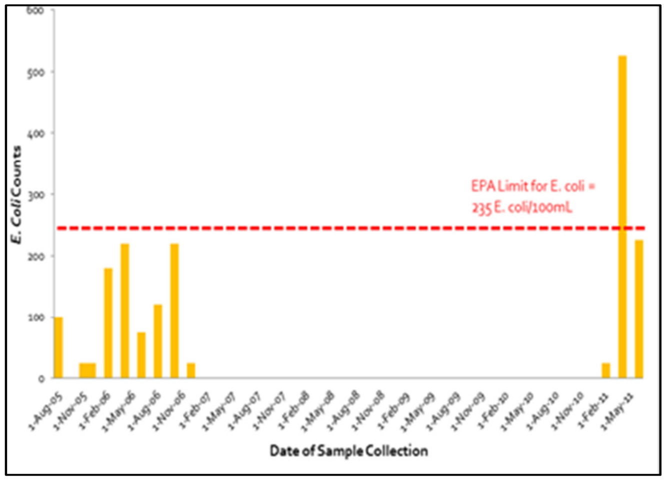
Site 1

Date	*E. Coli* Counts	Temp C	pH	DO
9-Aug-05	250	18.53	8.32	8.13
31-Oct-05	50	6.04	8.15	11.7
13-Dec-05	50	1.24	8.33	13.32
23-Feb-06	100	7.93	8.19	NULL
18-Apr-06	550	12	7.8	10.1
14-Jun-06	280	16.7	7.9	8.7
7-Aug-06	280	22.2	8.1	7.5
18-Oct-06	320	14.4	8.1	9.4
14-Dec-06	25	6	8.3	13
7-Feb-11	25	3	8.4	13
21-Apr-11	50	12.6	8.5	11.1
2-Jun-11	225	19.65	8.36	8.49



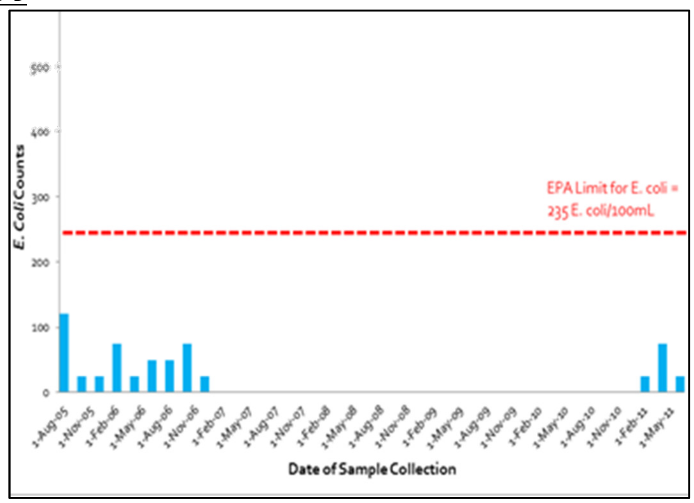
Site 2

Date	*E. Coli* Counts	Temp C	pH	DO
9-Aug-05	100	13.77	8.36	12.01
15-Nov-05	25	2.81	8.34	13.76
13-Dec-05	25	7.8	8.2	NULL
23-Feb-06	180	14.6	7.8	10
18-Apr-06	220	17.7	7.9	9
14-Jun-06	75	21.7	8.2	8.4
7-Aug-06	120	13.7	8.2	10
18-Oct-06	220	6.9	8.5	13.2
14-Dec-06	25	3.7	8.5	13.2
7-Feb-11	25	17.3	8.5	9.9
27-Apr-11	525	22.45	8.46	8.18
2-Jun-11	225	8	8.25	13.17



Site 3

Date	*E. Coli* Counts	Temp C	pH	DO
9-Aug-05	120	2.6	8.4	13.69
31-Oct-05	25	8.21	8.22	NULL
13-Dec-05	25	17.6	8	9.7
23-Feb-06	75	20.5	8	8.4
18-Apr-06	25	25.3	8.3	7.9
14-Jun-06	50	14.1	8.2	9.6
7-Aug-06	50	6.6	8.6	12.8
18-Oct-06	75	4.3	8.6	13.1
14-Dec-06	25	17.4	8.5	9.1
7-Feb-11	25	19.6	8.1	6.8
27-Apr-11	75	19.3	8.3	8.7
2-Jun-11	25	23.5	8.4	8.5



Appendix B

Table. Sample site observations on July 6, 2011

Sample Site	Observations, Points of Interests
12:20pm (Site 3)	Official sample site with USFWS, turbid
12:24pm	Limited sources of fecal pollution, no cattle or people found. Shallow water (below knee).
12:34pm	Shallow and cloudy water. Mostly sunny. Obvious cow pasture nearby, many bales of hay.
12:37pm	Cattle watering hole, small lagoon flowing into Copper Creek
12:50pm	Ballamy, cloudy and fast-flowing water. White house nearby with pipe sticking out of it.
1:00pm	Many minnows, low level of water. Horses grazing several yards away. More bales of hay found.
1:28pm	Mostly sunny, more vegetation within water. More trees by water.
2:10pm	Tributary, cattle prints found walking towards stream. Cattle fecal sample collected on stream-bank, horse feces found on bridge over stream
2:30pm	No animals visible nearby. Stratification of rocks.

3:15pm (Site 2)	Completely cloudy. Turbid, brown, and narrow stream. Houses nearby with livestock.
3:21pm	Drizzling. Much more vegetation near banks. Tributary, running into Grassy Creek, found through an animal pen. Cow inside of water, direct access.
3:29pm	More riparian vegetation. Nearby, livestock on a hill; contaminated surface runoff potential is high.
3:40pm	Drizzling. Deeper water. High banks; erosion. Many cattle found in floodplain of creek and some with direct access to it.
4:00pm (Site 1)	Cloudy. Wider river and more vegetation along low stream-banks. No cattle seen in the immediate area.

Appendix C

Table 1. Site 1 Differential Media Results

Differential Media	Isolated Bacteria Sample Source	Growth	Reaction	Microorganism
SS	mTEC (5mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
SS	PCA (Incubated at 37˚C)	Fair to good growth	Colorless colonies	*Shigella*
SS	PCA (Incubated at room temperature)	Complete Inhibition	No reaction	*Enterococcus*
SS	R2A (Incubated at 37˚C)	Complete Inhibition	No reaction	*Enterococcus*
XLD	PCA (Incubated at room temperature)	Partial inhibition	Red colonies (where recovered)	*Enterococcus*
XLD	R2A (Incubated at room temperature)	Partial inhibition	Yellow to yellow-red colonies	*E. coli*
XLD	PCA (Incubated at 37˚C)	Partial inhibition	Yellow colonies	*E. coli*
XLD	mTEC (5mL)	Partial inhibition	Yellow colonies	*E. coli*
HE	mTEC (20mL)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	*E. coli*
HE	R2A (Incubated at room temperature)	Partial inhibition	Small yellow colonies, salmon to orange halos	*Enterococcus*
HE	PCA (Incubated at 37˚C)	N/A	Green, nearly transparent	Uninoculated
HE	R2A (Incubated at 37˚C)	N/A	Green, nearly transparent	Uninoculated

Table 3. Site 2 Differential Media Results

Differential Media	Isolated Bacteria Sample Source	Growth	Reaction	Microorganism
SS	PCA (Incubated at 37˚C)	Complete Inhibition	No reaction	*Enterococcus*
SS	mTEC (5mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
SS	mTEC (20mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
SS	R2A (Incubated at 37˚C)	Complete Inhibition	No reaction	*Enterococcus*
XLD	PCA (Incubated at room temperature)	Complete Inhibition	No reaction	*E. coli*
XLD	R2A (Incubated at 37˚C)	Complete Inhibition	No reaction	*E. coli*

XLD	mTEC (20mL)	Partial inhibition	Yellow colonies	*E. coli*
XLD	mTEC (5mL)	Partial inhibition	Yellow colonies	*E. coli*
HE	mTEC (5mL)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	E. coli
HE	mTEC (20mL)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	*E. coli*
HE	PCA (Incubated at room temperature)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	*E. coli*
HE	R2A (Incubated at 37˚C)	N/A	Green, nearly transparent	Uninoculated
5% Sheep Blood	mTEC (5mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
5% Sheep Blood	mTEC (20mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
5% Sheep Blood	R2A (Incubated at room temperature)	Partial inhibition	Opaque, white to gold-colored colonies	*Staphylococci*

Table 3. Site 3 Differential Media Results

Differential Media	Isolated Bacteria Sample Source	Growth	Reaction	Microorganism
SS	mTEC (5mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
SS	mTEC (20mL)	Partial inhibition	Pink to rose-red colonies	*E. coli*
SS	PCA (Incubated at 37˚C)	Fair to good growth	Colorless colonies	*Shigella*
SS	R2A (Incubated at 37˚C)	Fair to good growth	Colorless colonies	*Shigella*
XLD	mTEC (5mL)	Partial inhibition	Yellow colonies	*E. coli*
XLD	mTEC (20mL)	Partial inhibition	Yellow colonies	*E. coli*
XLD	R2A (Incubated at 37˚C)	Partial inhibition	Red colonies (where recovered)	*Enterococcus*
XLD	PCA (Incubated at 37˚C)	Partial inhibition	Yellow to yellow-red colonies	*E. coli*
HE	mTEC (5mL)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	E. coli
HE	mTEC (20mL)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	*E. coli*
HE	PCA (Incubated at 37˚C)	Partial inhibition	Yellow-orange colonies, salmon to orange halos	*E. coli*
HE	R2A (Incubated at 37˚C)	Partial inhibition	Small yellow colonies, salmon to orange halos	*Enterococcus*
5% Sheep Blood	mTEC (5mL)	Good growth	Translucent, grayish, large matt, hemolysis	*Hemolytic Streptococci*
5% Sheep Blood	mTEC (20mL)	Good growth	Translucent, grayish, large matt, hemolysis	*Hemolytic Streptococci*

5% Sheep Blood	PCA (Incubated at 37˚C)	Good growth	Translucent, grayish, large matt, hemolysis	*Hemolytic Streptococci*
5% Sheep Blood	R2A (Incubated at room temperature)	Partial inhibition	Opaque, white to gold-colored colonies	*Staphylococci*

An Experimental Procedure to Observe Dissolution Characteristics of Weathered Petroleum from the 2010 Deepwater Horizon Blowout

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ABSTRACT

On the 20th of April, 2010, the Deepwater Horizon petroleum rig in the Gulf of Mexico exploded, resulting in the release of an estimated 4.9 million barrels of crude oil. This affected the aquatic ecosystem of the Gulf of Mexico, and the persistence of hydrocarbons along the Gulf shore remains a problem. Little research has been conducted to predict the long-term fate of coastal oil deposits from this particular event, and there is uncertainty of the timing and mode of depletion of these hydrocarbon contaminants. A National Science Foundation (NSF) funded RAPID response research project has been launched at Virginia Tech to determine the role of physical geometry on the long-term fate of coastal petroleum deposits, and the aim of this specific study was to characterize the dissolution of these deposits. Dissolution is a critical factor in the biodegradation of non-aqueous phase liquids (NAPLs), and a transfer rate coefficient between the oil and aqueous phase is an important parameter for depletion modeling. The complex composition of the oil called for direct assessment of field samples, and a laboratory procedure was developed to observe dissolution under abiotic conditions. The procedure involved creating spherical tar balls from sampled deposits and submerging them in a static setting with artificial saltwater media. The effect of submergence duration on the amount of hydrocarbons that partition to the aqueous phase was examined. Total petroleum hydrocarbons (TPH) were quantified by gas chromatography (GC-FID & GC-MS) and total organic carbon (TOC) concentrations were also measured to provide supporting observations. In addition to enhancing the knowledge and understanding of depletion of coastal petroleum deposits from the spill, results from this research will improve experimental techniques for assessing dissolution of extremely insoluble NAPLs.

Keywords: Deepwater Horizon Oil Spill, Hydrocarbon Biodegradation, NAPL Dissolution, Dissolution Rate Coefficient

Introduction

Background

The Deepwater Horizon (DH) catastrophe resulted in the death of eleven crew members and the release of an estimated 4.9 million barrels of crude oil as well as large amounts of natural gas into the Gulf of Mexico (McNutt et al. 2011; Machlis and McNutt 2010; Valentine et al. 2010). In response, about 771,000 barrels of chemical dispersant COREXIT ® EC9500A was injected to disperse the oil (Kujawinski et al. 2011). Oil initially took the form of underwater plumes as it migrated from the wellhead (Camilli et al. 2010), though its long-term fate is complicated by the complex composition of the oil as well as the various chemical and physical weathering processes at play (Prince 2010). The aquatic microbial community shifted in response to the massive flux of oil, and hydrocarbon-degrading microorganisms were readily enriched by the event (Hazen et al. 2010; Hu et al. 2011). It is now understood that the enrichment of hydrocarbon degraders is resulting in active biodegradation of various components of spilled oil (Camilli et al. 2010; Valentine et al. 2010). Cleanup efforts have resulted in the collection of roughly 0.8 million barrels of crude oil, although a large part of the remaining spilled oil has washed ashore, contaminating over 500 miles of coastal marshes and beaches from Louisiana to Florida (Kerr 2010).

Beginning May 15, 2010, oil began to reach the beaches of the Gulf Coast (Louisiana), and by June 1 it had reached Mississippi, Alabama, and Florida (OSAT 2011). In February 2011, the Operational

Science Advisory Team released "Summary Report for Fate and Effects of Remnant Oil in the Beach Environment", identifying three remaining categories of oil in the environment that pose challenges for cleanup: (1) Supratidal Buried Oil (SBO), oil that is buried at a depth of at least six-inches near sensitive habitats; (2) Small Surface Residual Balls (SSRBs), oil that is left behind after beaches are cleaned manually or by machine; (3) Surf Zone Submerged Oil Mats (SOM), sheets of oil that are stuck between sand bars and are susceptible to wave energy.

Through a project underway at Virginia Tech (National Science Foundation CBET Environmental Engineering RAPID Award: #1053221), it has been observed that these oil deposits assume different geometries on the beaches, ranging from small, spherical tar balls to broad, flat sheets. The goal of the overall project is to determine the effect of such geometries on biodegradation, dissolution, and the long-term fate and persistence of the oil. In order to characterize dissolution, a critical factor governing bioavailability, the specific aim of this project was to develop and apply a method for estimating the abiotic dissolution rates of DH petroleum hydrocarbons (PHCs). Dissolution and biodegradation rates will be critical parameters for improving estimates of PHC persistence, which will be modeled using SEAM3D, a transport model developed by Widdowson at Virginia Tech.

Literature Review

Fate of Oil and the role of Biodegradation

Numerous studies were launched shortly after the DH spill to examine the ecological impact of the event and predict potential impacts. Camilli et al. (2010) studied characteristics of the underwater plume created by the blowout using an autonomous underwater vehicle from 19 to 28 June 2010. A plume was detected and characterized to exist around 1100m depth and as far as 35km in lateral distance from the well-head with a velocity of 7.8 cm/s in the southwest direction. Analysis confirmed that the plume existed as a result of the leaking well-head rather than as a result of natural seeps. A lack of oxygen drawdown was observed which was interpreted to indicate that "… the petroleum hydrocarbons did not fuel appreciable microbial respiration on the temporal scales of our study."

Hazen et al. (2010) collected plume and non-plume field samples between 25 May and 2 June, 2010, to evaluate biodegradation characteristics of the oil. Comparing plume to non-plume samples, statistically significant differences were revealed: less oxygen, higher concentration of hydrocarbons, higher cell density and biomass, higher concentrations of 16 taxa in the ɣ-Proteobacteria, and less taxonomic richness in plume relative to non-plume samples. Results suggested that "A variety of hydrocarbon-degrading populations exist in the deep-sea plume and that the microbial communities appear to be undergoing rapid dynamic adaption in response to oil contamination." Hu et al. (2011) also found an increase in microbial activity linked to the spill. Satellite measurements revealed an anomaly in August 2010 of increased biomass that correlates well with the spatial location of dispersed oil. Kessler et al. (2011) studied the fate of methane gas released from the blowout, concluding that most of it was metabolized by methanotrophic bacteria.

Although these studies do not deal directly with coastal deposits, understanding deep-sea processes and the previous conditions of the oil is important in predicting the oil's long-term fate.

Dissolution

No published studies evaluating the dissolution of DH PHCs in the coastal environment could be found, although the role of dissolution in biodegradation has been well-established for non-aqueous phase liquids (NAPLs) (Alexander[2] 1994). Borden and Piwoni (1992) examined different models for predicting dissolution of NAPLs, finding that the data fit better with a kinetic rather than equilibrium model. Imhoff et al. (1994) studied the dissolution of trichlorethylene (TCE) in a porous medium. Concentrations were monitored using gamma attenuation while dissolution was occurring, and the dissolution rate coefficient was observed as a function of Darcy flux, TCE volumetric content, and distance into the region of residual TCE. As expected, the rate of dissolution decreased with decreasing pore saturations, indicating the importance of interfacial surface area between the non-aqueous phase and the surrounding water.

Brakstad et al. (2004) studied both dissolution and biodegradation of thin films of hydrocarbons attached to a fiber in a flow-through system. The rate of dissolution was considered to be a function of a mass transfer coefficient, the specific surface area of the exposed oil, and the difference between maximum oil concentration in the aqueous phase and the measured concentration in the aqueous phase. Results indicated that dissolution accounted for most of the depletion of all naphthalene groups and one of two PAH groups, while biodegradation contributed mostly to the depletion of the *n*-alkanes and the other PAH group.

Such studies highlight the difficulty and importance of quantifying dissolution of NAPLs, and knowledge of dissolution characteristics applies to the DH deposits.

Problem Statement

Biodegradation and Dissolution

Natural seeps of oil have been active for millions of years and have stimulated the evolution and enrichment of numerous oil-degrading bacteria (Prince 2010). Because petroleum is a rich source of organic matter, microorganisms break-down and consume hydrocarbons in the presence of an electron acceptor, nutrients, and water, where the hydrocarbon serves as the electron donor (Madigan & Martinko 2006). Biodegradation pathways and rates depend on the composition of the hydrocarbon, which is determined by its source and the modes of transport and subsequent weathering it undergoes.

Because oil-degrading bacteria inhabit the aqueous phase, biodegradation of oil is greatly limited by its bioavailability and thus its presence in the aqueous phase. The way in which bacteria access oil can involve a complex combination of processes. Alexendar (1994) described three possible mechanisms in which microbial utilization of compounds in the non-aqueous phase takes place: 1) only the chemical that partitions to the aqueous phase is available to the cells, 2) the cells excrete chemicals that disperse the compounds into small enough droplets for consumption, and 3) the cells have a way of attaching to and consuming compounds that are still in the non-aqueous phase. Evidence suggests that mechanisms 2 and 3 are possible, as biodegradation of extremely low-solubility compounds has been observed at rates higher than the rate of the compound entering the aqueous phase. This being said, studies have shown strong correlation between solubility/dissolution and biodegradation, and therefore, considering mechanism 1, the rate of dissolution is an essential component of the biodegradation of low-solubility compounds.

To model the depletion of oil that is biologically consumed only in the aqueous phase, it is necessary first to understand how the oil enters the aqueous phase: dissolution. Dissolution is the transfer of a compound from its insoluble phase into the aqueous phase. The rate of dissolution for an individual compound is proportional to the difference between the maximum possible concentration in the aqueous phase (solubility) and the actual concentration (Watts 1998). NAPLs are compounds which have very low solubility and therefore are in the aqueous phase in only small amounts.

Assuming negligible degradation in the non-aqueous phase and that microbial activity does not significantly enhance solubility, the amount of abiotic dissolution determines the available mass of hydrocarbon available for biodegradation. A mass-balance rate can be composed for the substrate entering *and* leaving the aqueous phase via dissolution and biodegradation, respectively:

$$\frac{dM}{dt} = R_{dis} - R_{bio} \qquad [1]$$

where:

$\frac{dM}{dt}$ = rate of change of substrate mass in the aqueous phase

R_{dis} = rate of dissolution (entry into aqueous phase)

R_{bio} = rate of biodegradation (depletion)

Biodegradation rates may be predicted using a number of kinetic models, such as power functions, logarithmic, Monod, zero-, first-, and second-order kinetics, as well as other variations (Alexander[1] 1994; Borden and Piwoni 1992; Waddill and Widdowson 1998). The focus of this study is on abiotic dissolution, so biodegradation rates are equal to zero and the kinetics of each compound in the aqueous phase is described by the rate of dissolution.

A mass transfer coefficient, K, can be used to describe the rate of dissolution of a single compound into the aqueous phase from the oil phase (Watts 1998):

$$\frac{dC}{dt} = K\left(C_s - C(t)\right) \qquad [2]$$

where:
$\frac{dC}{dt}$ = rate of dissolution
K = mass transfer coefficient
C_s = maximum (equilibrium) concentration in aqueous phase
$C(t)$ = concentration of compound in aqueous phase at time, t

These kinetics describe the transfer of individual compounds, however a single model to describe the multiple components of the oil in question may be developed later.

Purpose of Investigation

This study explores the dissolution of DH petroleum deposits as an essential component of depletion modeling. A static submergence system was developed and applied in which spherical samples of shoreline petroleum deposits were submerged in seawater medium for varying durations, enabling the estimation dissolution rate coefficient.

Research Methods

Experimental Procedure

A static submergence system (Figure 2) was constructed in which glass wool and glass beads surround a spherical petroleum tar ball held within a separatory funnel. Synthetic seawater (Table 1) was prepared and added to the apparatus where it was incubated for a range of time periods, allowing for dissolution to occur, and was then sampled from the bottom of the separatory funnel. Abiotic conditions were achieved by adding mercuric chloride ($HgCl_2$) as a microbial inhibitor at 0.2 g/L.

Petroleum Samples

Six petroleum tar balls were hand-crafted from field samples of coastal petroleum deposits collected at Dauphin and West Point Islands, Alabama. A mass of 1.8 g was used as the target mass for each tar ball, and individual samples were broken and rejoined to achieve comparable masses: average mass 1.7960 g, standard deviation of $7.4449*10^{-3}$. The six evenly weighed pieces were separated then rolled into sphere-shaped balls with a diameter of 0.5 (+- 1/32) inch (Figure 1). Samples were carefully moved and stored at 6^{o}C.

Figure 1 - (A, B, C Left to Right) A: Raw sampled deposit, B: Crumbled for weight distribution, C: Final, hand-crafted tar ball diameter ~0.5 inch

Static Submergence System

A 250 mL glass separatory funnel was used as the dissolution testing apparatus (Figure 2). The system was sacrificed and re-constructed between each experiment, and beads and wool were removed for cleaning and drying between tests. Each test was set-up in the following fashion. Glass wool was placed inside the bottom of the empty separatory funnel to prevent beads from clogging or escaping through the effluent valve and also to reduce the effluent flow-rate. A layer of glass beads of mean diameter 1 mm was then added, filling roughly to the centerline of the funnel. A tar ball was carefully removed from storage and inserted on top of the glass beads in the center of the funnel. The remaining glass beads were then added to cover the sample. Two sheets of glass wool were added on top of the beads, nearly filling the funnel entirely. The total mass of glass beads used was 369.33g measured before the first experiment, and they were re-measured between test series A and B for a new mass of 367.77g.

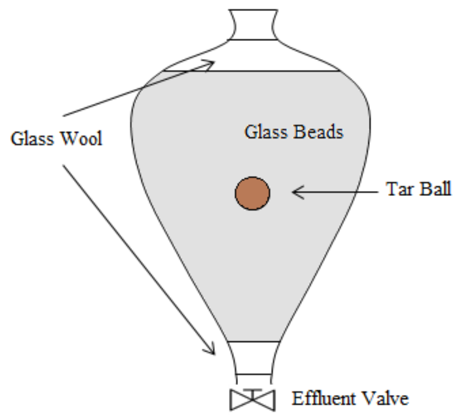

Figure 2 - Static Submergence System: 250mL glass separatory funnel with glass wool, glass beads, and confined petroleum tar ball

Filling and Draining

Media was prepared using the chemical composition listed in Table 1 below; compounds were added in the order listed. After preparation, media was added until the separatory funnel was completely filled, roughly 160mL per test. After filling, static conditions were maintained for the designated amount of time. The spent media was then drained out the bottom and sampled in 50mL tubes. The total volume released was roughly 125mL for all tests. After draining, the top layer of glass wool was removed, and the petroleum tar ball was carefully removed along with some surrounding glass beads. Tested tar balls were stored in 50mL tubes at 6^{o}C.

Table 4 - Seawater Media Composition per 1L H_2O

Compound	Mass (g)
NaCl	23
NH_4Cl	0.5
KCl	1.3
KH_2PO_4	0.2
$CaCl_22H_2O$	0.1
Na_2SO_4	2.84
$MgCl_26H_2O$	1
$NaHCO_3$	2.5
*$HgCl_2$	0.2

**Mercuric chloride added as a microbial inhibitor*

Flushing and Cleaning

Glass beads and wool that were displaced during removal of the tar ball were added back into the separatory funnel for the cleaning process. 200mL of Methylene Chloride (MeCl) was then added to the separatory funnel in two doses of roughly 100mL in order to rid the system of remaining hydrocarbons. The solution – mostly MeCl - was drained through the effluent valve and sampled to fill a total of four 50mL tubes. 400mL of nanopure water was added in similar fashion as the MeCl; however only the first 50mL of effluent was sampled which contained most of the MeCl. The nanopure water was a convenient method to rid the system of MeCl and also to wash away any remaining water-soluble compounds from the system. The glass wool and glass beads were removed and placed in a glass bowl which was baked alongside the separatory funnel at a temperature of 130deg C for 1 hour or until no moisture or capillary attraction between beads was visible.

Analytical Methods

Gas Chromatography

Gas chromatography (GC) was selected for measuring total petroleum hydrocarbons (TPH) in effluent samples because of the ability to evaluate individual hydrocarbons. GC-FID and GC-MS were used, and both instruments required preparation of samples via liquid-phase extraction using the solvent methylene chloride (MeCl). 30mL of MeCl was mixed with 50mL of effluent sample to strip the sample of any hydrocarbons, and an additional 10mL MeCl was used to rinse instruments. The 40mL of MeCl was then heated and concentrated via evaporation to a total of 1mL for GC-ready vials.

Total Organic Carbon

Problems were initially encountered in the liquid-phase extraction method for GC, and Total Organic Carbon (TOC) was chosen as a secondary measure to support GC findings. TOC was also chosen because of the relative simplicity of preparing samples, and because it only required the use of roughly 6mL of sample rather than the 50mL required for GC. TOC can only provide a measure of organic carbon and does not distinguish between individual hydrocarbons as GC does, however results from the two methods are still comparable using a total mass basis discussed below.

Results and Discussion

Submergence experiments were performed for 1, 2, 4, 8, 12, and 24 hours, and all time intervals were performed twice except for the 4-hour test.

Analytical Techniques

First attempts at using GC-FID showed poor efficiency during the liquid-phase extraction process. This process was refined and attempted many times, using different instruments as well as changes in mixing, sampling, and MeCl evaporation techniques. A reliable extraction method was finally achieved that incorporated the addition of sulfuric acid at 20 mL/L to decrease the pH and allow proper stripping of the hydrocarbons. GC-MS was used rather than GC-FID because the extremely low hydrocarbon concentrations were difficult to infer using GC-FID.

Total Organic Carbon

TOC measurements were obtained to provide an independent indicator of dissolution, and also to compare submergence TOC concentrations to untested saltwater media. TOC was measured for the second 50mL of effluent sample, and results are reported in Table 2 and illustrated in Figure 3 below. Test identities A and B refer to the order in which duplicates were performed: the first round of experiments are named A, which were held in 6 ^{o}C storage for a few weeks, and B tests were performed second and were analyzed no more than one and a half weeks after testing. TOC was also measured for raw seawater media, referred to as seawater blank.

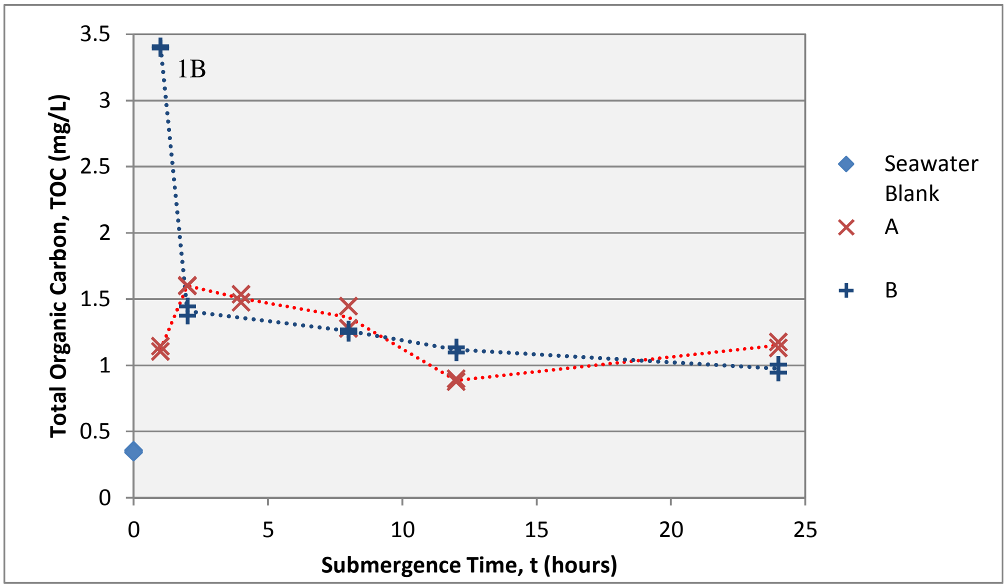

Figure 3 - TOC vs Time of Submergence

Sample 1B contained the highest TOC, contrary to the expectation that dissolution would increase with time of submergence. Results for test 1A do not agree with the high value seen in 1B, so it is possible that contamination or some external factor caused the peculiar data point; further repeats of a 1-hour test are necessary to be certain of a correct value for 1-hour TOC. The high value may be the result of shearing of oil particles from the tar ball, something that is more likely for used tar balls (test runs B) than for first-time tar balls (A). Nonetheless, average values for TOC were all higher in dissolution test samples than the seawater blank, ranging from 1.0018-1.505 mg/L versus 0.3490 mg/L, respectively. This indicates that values for TOC are affected by the presence of a tar ball and consequently dissolution.

Table 5- TOC vs Time of Submergence Data

	TOC (mg/L)		
Time (hrs)	A	B	Mean
1	1.1235	3.4020	2.2628
2	1.6005	1.4095	1.5050
4	1.5050	-	1.5050
8	1.3615	1.2580	1.3098
12	0.8862	1.1175	1.0018
24	1.1525	0.9757	1.0641
Seawater Blank	0.3490		0.3490

Overall Mean (excluding Blank & 1B)	**1.2390**
Overall STDEV (excluding Blank & 1B)	**0.2298**

Short-term equilibrium and boundary layer

Excluding 1B, the mean TOC for test runs is 1.2390 mg/L with a standard deviation of 0.2298. The fact that results did not show the expected trend of increasing TOC versus time may indicate that the maximum possible dissolution was reached within the first hour of testing. It is unlikely that equilibrium was reached throughout the entire system within the first hour, but a hydrocarbon-saturated boundary layer around the tar ball may have developed. If this is the case, increases in hydrocarbon concentration in the surrounding media would occur via diffusion of those hydrocarbons that have already entered the aqueous phase near the tar ball; such a process depends on aqueous-phase diffusion rather than purely dissolution. A hydrocarbon-rich boundary layer that does not quickly spread throughout the system would cause surrounding media to remain low in hydrocarbon concentration, diluting effluent samples.

Gas Chromatography

Illustrated in Figure 4 below, Gas Chromatography Mass Spectrometry (GC-MS) results indicate that alkane chains C16-C25 were present in detectable concentrations for test runs 1B, 8B, and 24B. Concentrations were measured using GC for the first 50mL of effluent sample.

Preferential Dissolution

57mg of raw petroleum deposit was dissolved into 10mL MeCl, and GC-MS analysis was performed to determine the ratio of alkane constituents. Results are provided in Figure 4 in units of milligrams of specific hydrocarbon per gram of petroleum deposit. Comparing the makeup of the raw sample to the ratio of hydrocarbons from dissolution experiments, it can be seen that alkanes C21, C22, and C23 did not undergo dissolution proportionally to their composition in raw deposits. A possible explanation for this is preferential dissolution among different hydrocarbon chains. Solubility is expected to decrease with increases in hydrocarbon chain length, however this trend was not observed. Further work is necessary to be certain of this, and this highlights the complexity of evaluating dissolution of a mixture of compounds.

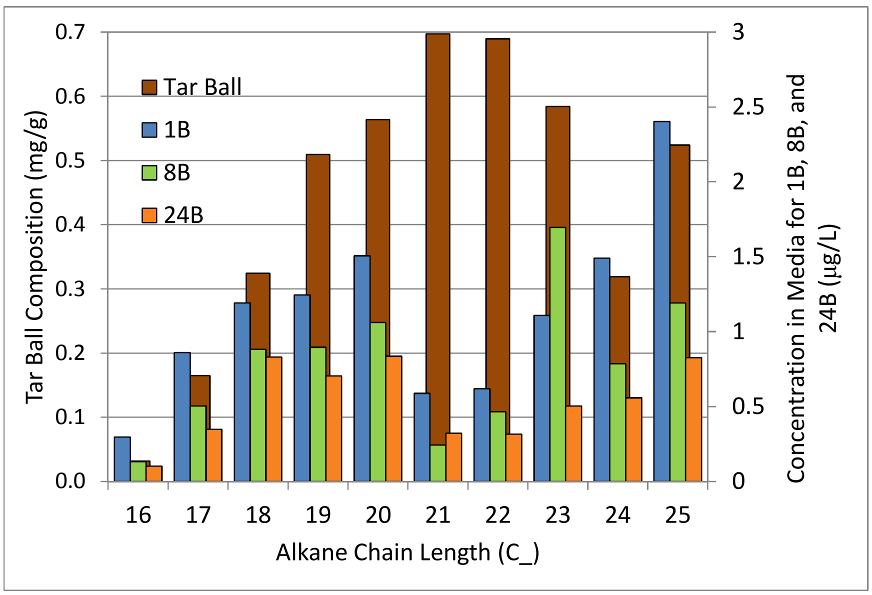

Figure 4 - GC-MS Alkane Concentrations: 1B, 8B, 24B plotted against tar ball compositional ratios

TOC and GC Comparison

Concentrations are, except for C23, ranked from high to low in the order 1B, 8B, 24B. This agrees with TOC results (Figure 3, Table 2). GC and TOC data were compared on a total mass basis (Figure 5), in which tested samples are assumed representative of the entire 160mL of submerging media. It is likely that, because of the boundary layer discussed earlier and the diluting effect of the surrounding media, the order of sampling heavily affected the concentrations. This would cause different concentrations among the first, second, and third 50mL effluent samples for each experiment. This is also an explanation as to why, for the case of 1B, 8B, and 24B, measured TOC/TPH decreased with time. Individual 50mL samples are not necessarily representative of the entire system and results would be more reliable if all effluent samples were combined, including the rinsing MeCl and nanopure water.

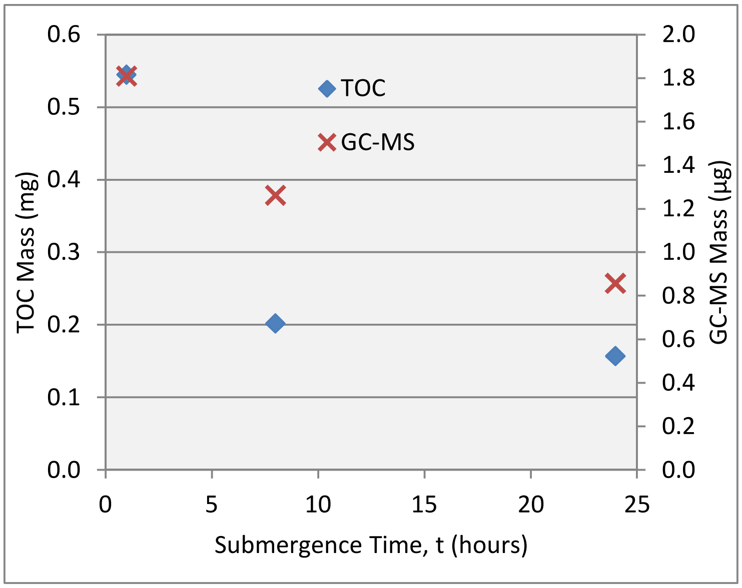

Figure 5 – TOC & GC Comparison: total mass ranked from high to low - 1B, 8B, 24B

Additional Factors

One factor that was not considerably analyzed was the presence of sand grains within each tar ball. Surface area between the aqueous and oil phase is known to play a role in the dissolution of NAPLs (Imhoff et al. 1994, Alexander[2] 1994, Brakstad et al. 2004), and therefore the presence of sand grains and use of glass beads may have affected dissolution.

Tar balls were reused for multiple tests because of their irreplaceable value - sampling is no longer permitted in the Gulf coast. Reuse is also justified because of the heterogeneity of sample composition. No two tar balls are completely identical in composition, and considering the trace concentrations being measured, this may affect the ability to compare data; so, all experiments of the same submergence time used the same tar ball. For the case of little dissolution and no biodegradation, a tar ball would remain almost unchanged before and after submergence.

The chemical composition of the seawater media was not considered as a parameter affecting dissolution. However, no experimental comparisons were made to be sure of this. The influence of adding mercuric chloride ($HgCl_2$) is also uncertain, but is not likely to have a significant impact given that it would contribute little to the high overall ionic strength of seawater. Microbial analysis may be of value to verify that bacterial growth was minimal, and the presence of bacteria would also contribute to TOC.

Conclusions and Future Work

A simple, inexpensive, and quick approach was developed to observe the dissolution of coastal petroleum deposits from the 2010 Deepwater Horizon (DH) Blowout. A static system in which tar balls are submerged under artificial seawater for varying durations was designed and implemented in an abiotic setting. Numerous analytical methods were used to obtain dissolution versus time data from submergence media. Though data was not sufficient enough to allow calculation of a transfer-rate coefficient between the oil and aqueous phase, a greater understanding of dissolution characteristics of sampled oil deposits was obtained. Valuable lessons were also learned regarding the experimental procedure and analytical methods. The difficulty in measuring dissolution rates demonstrates the complexity of predicting the long-term fate of oil from the spill, a topic that will remain a high priority in the future.

Future Work

To counter the issue of extremely low concentrations of TPH in the effluent samples, a system that requires less media is desirable. Using less total media would decrease the impact of dilution from media that does not ever come near the petroleum tar ball. Implementing a dynamic rather than static system is also an alternative which would allow media to constantly be replenished around the tar ball and eliminate the influence of a boundary layer. This could be done with a low-flow system or one that allows mixing of the media. Another advantage of a dynamic system is homogeneity among samples, something which may have heavily affected the analysis of static experiments. Future tests of this kind are necessary to yield increasing dissolution with time and support the determination of a dissolution rate coefficient.

Presentations and Feedback

Throughout the ten week NSF-REU program, each student was required to present their work to the group a total of three times in addition to the final presentation in front of all mentors and participants. Presentations started out at 5-minutes and increase to 10, and finally 15 minutes. During each session, feedback was given and sharead among students, allowing the improvement of everyone's oral presentation.

5-Minute Presentation

This was the first presentation, and most struggled with the act of actually speaking to the audience. Directions for feedback were for the audience to write what each student though the take-home message was, and most students interpreted it well or at least something similar. This presentation was more of a chance to get used to talking in front of people than anything else because the specific aim of the project had not yet been clearly defined.

10-Minute Presentation

This presentation included some details on the experimental procedure and issues in obtaining results, as well as what was planned for the future. The audience was asked to write down the take-home message, 5 keywords, and to grade the presentation A-F. Again most people understood the take-home message and nailed some of the keywords, and the average grade received was around an A-. People seemed impressed more by speaking skills and confidence, not necessarily with the scientific credibility of the work being done. Consciousness of the scientific validity of the presentation began to grow, a concern kept through the end of the program.

15-Minute Presentation

By this point, most people had grown comfortable with speaking to the group, so better presentations were those that explained the research, results, and conclusions in a clear manner. Feedback was more open, and a few people suggested to spend less time on the introduction. Results and conclusions had not yet been finalized, and communicating the half-complete findings was difficult. This implied the need to draw conclusions and explain them confidently, something that was heavily practiced awaiting the final presentation.

The presentation sessions were one of the most helpful parts of this program. Communication and public speaking are essential components of research, and there's not doubt that all fellows improved as a result of these practice sessions.

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References

Alexander, M. 1994. Kinetics. *Biodegradation and Bioremediation*: Chapter 6. Academic Press. San Diego, CA. 71-101.

Alexander, M. 1994. NAPLS and Compounds with Low Water Solubility. *Biodegradation and Bioremediation*: Chapter 11. Academic Press. San Diego, CA. 131-148.

Borden, R.C. and M.D. Piwoni. 1992. Hydrocarbon dissolution and transport: comparison of equilibrium and kinetic models. *Journal of Contaminant Hydrology* 10: 309-323.

Brakstad, O.G., K. Bonaunet, T. Nordtug, O. Johansen. 2004. Biotransformation and dissolution of petroleum hydrocarbons in natural flowing seawater at low temperature. *Biodegradation* 15: 337-346.

Camilli, R., C.M. Reddy, D.R. Yoerger, B.A.S. Van Mooy, M.V. Jakuba, J.C. Kinsey et al. 2010. Tracking Hydrocarbon Plume Transport and Biodegradation at Deepwater Horizon. *Science* 330: 201-204.

Hazen, T. C., E.A. Dubinsky, T.Z. DeSantis, G.L. Andersen, Y.M. Peceno, N. Singh et al. 2010. Deep-Sea Oil Plume Enriches Indigenous Oil-Degrading Bacteria. *Science* 330: 204-208.

Hu, C.M., R.H. Weisberg, Y.G. Liu, L.Y. Zheng, K.L. Daly, D.C. English et al. 2011. Did the northeastern Gulf of Mexico become greener after the Deepwater Horizon oil spill?. *Geophysical Research Letters* 38: 1-5.

Imhoff, P.T., P.R. Jaffe, G.F. Pinder. 1994. An experimental study of complete dissolution of a nonaqueous phase liquid in saturated porous media. *Water Resources Research* 30: 307-320.

Kerr, R.A. 2010. Gulf Oil Spill A Lot of Oil on the Loose, Not So Much to Be Found. *Science* 329: 734-735.

Kessler, J.D., D.L. Valentine, M.C. Redmond, M. Du, E.W. Chan, S.D. Mendes et al. 2011. A Persistent Oxygen Anomaly Reveals the Fate of Spilled Methane in the Deep Gulf of Mexico. *Science* 331: 312-315.

Kujawinski, E.B., M.C.K. Soule, D.L. Valentine, A.K. Boysen, K. Longnecker, and M.C. Redmond. 2011. Fate of Dispersants Associated with the Deepwater Horizon Oil Spill. *Environmental Science & Technology* 45: 1298-1306.

Machlis, G.E., and M.K. McNutt. 2010. Scenario-Building for the Deepwater Horizon Oil Spill. *Science* 329: 1018-1019.

Madigan, M.T., and J.M. Martinko. 2006. Petroleum Biodegradation. *Brock Biology of Microorganisms* 11th edition*:* Chapter 19. Pearson Prentice Hall. Pearson Education, Inc. Upper Saddle River, NJ. 651-652.

McNutt, M., R. Camilli, G. Guthrie, P. Hsieh, V. Labson, B. Lehr, D. Maclay, A. Ratzel, and M. Sogge. 2011. Assessment of Flow Rate Estimates for the Deepwater Horizon/Macondo Well Oil Spill. Flow Rate Technical Group report to the National Incident Command. Interagency Solutions Group, March 10 2011.

Operational Science Advisory Team (OSAT). 2011. Annex B: Spatial Oil Distribution. *Summary Report for Fate and Effects of Remnant Oil Remaining in the Beach Environment*. Department of the Interior. p1-64.

Prince, R.C. 2010. Bioremediation of Marine Oil Spills. *Handbook of Hydrocarbon and Lipid Microbiology* 1st edition*:* Chapter 16. Springer-Verlag Berlin Heidelberg. 2618-2626.

Valentine, D.L., J.D. Kessler, M.C. Redmond, S.D. Mendes, M.B. Heintz, C. Farwell et al. 2010. Propane Respiration Jump-Starts Microbial Response to a Deep Oil Spill. *Science* 330: 208-211.

Waddill, D.W., and M.A. Widdowson. 1998. Three-Dimensional Model for Subsurface Transport and Biodegradation. *Journal of Environmental Engineering* 124: 336-344.

Watts, R.J. 1998. Light and Dense Nonaqueous Phase Liquids. *Hazardous Wastes: Sources, Pathways, Receptors*: Chapter 3. John Wiley & Sons, Inc. Hoboken, NJ. 170-177.

Sensory Perception of Metals in Drinking Water and the Role of Saliva in Metallic Flavor Production

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ABSTRACT

Humans interact with the surrounding environment and protect themselves using their five senses. This study evaluated human population variability for detecting metal contaminants in drinking water. Twenty- eight subjects aged 18 – 82 years old participated . Individual and population flavor thresholds were determined for copper and iron in drinking water. Synthetic saliva was used to assess the roles of lipids, proteins, and nitrite on metallic flavor production as measured by the thiobarbituric acid reactive substances (TBARS). Individual thresholds ranged from 0.07 to 14.14 mg/L Cu^{+2} and the overall population threshold was 1.004 mg/L Cu^{+2} while individual thresholds ranged from 0.004 to 14.142 mg/L Fe^{+2} and the overall population threshold was 0.071 mg/L Fe^{+2}. Many subjects > 50 and a few subjects ≤50 years were insensitive to metallic flavor. For copper, the population thresholds for the ≤50 and > 50 years age groups were 0.78 mg/L Cu^{+2} and 1.34 mg/L Cu^{+2}, respectively. While the respective population thresholds for iron were 0.040 mg/L Fe^{+2} and 0.139 mg/L Fe^{+2}. Standardized olfactory assessment found poor sensitivity for Fe^{2+} and Cu^{+2} corresponded with conditions of mild, moderate, and total anosmia. The findings confirm widely variable sensitivities for human detection of metallic flavor. Aging and/or impairement of olfactory functions may be contributing factors. Both salivary lipids and proteins are involved in metal-induced oxidative reactions with ferrous and cupric, while in the absence of lipids, proteins are minor contributors to salivary oxidation.

Keywords: Taste, Odors, Metals, Copper, Iron, Drinking water quality

Introduction

Humans interact with the environment using all five of their senses. Sensory assessment is the first line of defense for health safety and survival, thus it is essential to our well-being. There is natural variability in the human senses. This also means that there is variability in the human population to detect contaminants. Sensory detection of ingested metals is crucial to prevent metal poisoning and the inability to detect metals poses serious concern. Humans all over the world and of all ages are exposed to metals in their drinking water. Often they may not even be aware of this exposure. Metallic and related off-flavors are among the most commonly reported taste complaints in drinking water (Suffet et al. 1996). Consumer complaints of metallic flavor in drinking water are usually caused by dissolved iron or copper from the distribution system, premise plumbing, or groundwater. Metal pollution and contamination is most common in groundwater due to dissolution of metals into aquifers (Concha 2010). Iron occurs naturally in groundwater or comes from the corrosion of pipes in distribution systems (Volke et al. 2000, World Health Organization 2011). Occurrence of off-tastes and odors in drinking water is perceived as unsafe by consumers which results in consumer complaints and consequently imposes notable cost to utilities (McGuire 1995). Taste-and-odor events have been linked with several drinking water illness outbreaks in developed countries; however, health officials and water utility personnel often overlook consumer complaints of off-tastes, odors, and/ or colors (Hrudey 2004). Metallic flavor complaints are also common among cancer patients due to the effects of cancer therapy and radiation (Hong et al, 2008). A better understanding of mechanisms and perception of metallic flavor can benefit the consumer and water industry, as well as the medical and scientific community.

Both copper and iron are flavor- producing metals and can be sensed by humans much below the regulatory limits which may present serious concerns. Levels of iron and copper in drinking water can cause bitter- metallic tastes. Although copper is an essential nutrient, copper contamination in drinking water was recognized as the source of 27 illness outbreaks in the United States from 1991 to 2006 (Craun et al. 2010). High levels of copper can also cause gastrointestinal upset. Iron is an essential element as well and is not typically considered to be a toxic metal. However, it has been shown that high iron intake is associated with increased risk of cancer (Peto 2010; Zacharski et al. 2008). Excessive iron accumulation in the body has been associated with aging, heart disease, Alzheimer's disease, and Parkinson's disease to name a few (Papanikolaou and Pantopoulos 2005). This is due to the ability of iron and copper to promote oxidative reactions.

Metallic flavored drinking water complaints are frequent. 14-20 % of all taste complaints were described as metallic in a survey of North American utilities (Suffet et al. 1996). Even though metallic flavor sensations in humans are common, their causes are not well understood. Metallic flavor is recognized to be a slight taste sensation attached to a major retronasal-odor sensation from metal induced lipid oxidation in the oral cavity. The sensation has been described as metallic, sweet, bitter and astringent (Ömur-Özbek and Dietrich 2011; Hong et al. 2010, Lim and Lawless 2006). Metallic sensation is usually perceived as strongest for ferrous, followed by cupric and cuprous salts (Ömur-Özbek and Dietrich 2011).

Metallic flavors are caused, to a certain extent, by lipid oxidation. Lipid oxidation is caused by free radicals attacking lipid membranes in the oral cavity (Ömur-Özbek and Dietrich 2011) and salivary lipids that are produced through the salivary glands (Larsson et al, 1996). Metals act as catalysts in the free radical processes that breakdown polyunsaturated fats (Spanier 1991), while salivary nitrite has been shown to inhibit lipid oxidation in meat products under acidic conditions (Gorelik et al, 2007). There are several products that are produced in the lipid oxidation process. Reactions byproducts induce odorous aldehydes and ketones. One of the major compounds is malondialdehyde (MDA) which is a secondary byproduct of lipid oxidation (Figure 1) (Marnett 1999). Thus, an indirect measurement of MDA can be made colorimetrically after its controlled reaction with thiobarbituric acid in a method called thiobarbituric acid reactive substance (TBARS). Salivary proteins also play an important role in interaction of saliva with metals and thus may influence flavor perception. A recent study has shown that interaction of salivary protein, alpha- amylase, with copper impacts its solubility and thus contributes to the sensation of astringency associated with the flavor of copper in drinking water (Hong et al, 2009). Another major salivary protein, mucin, has also been shown to have a high affinity for copper (Tang, 2010).

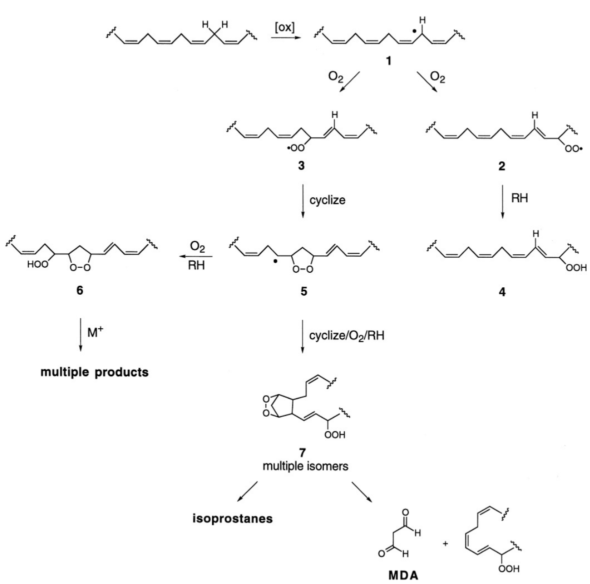

Figure 6: Lipid oxidation pathways

Source: Marnett 1999

In this study, our objectives were to measure the flavor recognition thresholds for copper and iron in water for 15 younger subjects (≤ 50 years) and 15 older subjects (> 50 years). As a component of sensory perception, we assessed the role of olfaction on the individual variations in flavor recognition thresholds for iron and copper. Additionally, since lipid oxidation is necessary for metallic flavor; we utilized synthetic saliva to investigate the individual and interactive influences of fatty acids, proteins, and nitrite in the production of metallic flavor, as measured by the thiobarbituric acid reactive substances (TBARS), a biochemical indictor of lipid oxidation.

Research Methods

*Human Subjects***.** Twenty-eight human subjects participated in this study over the course of several weeks. Subjects were recruited from the community, students, faculty and staff of Virginia Tech and Blacksburg, Virginia through paper and email flyers. Before the subjects began the study they signed an informed consent form explaining the details of the study and the risks of participation. This study was approved by the Institutional Review Board (IRB) at Virginia Tech. The subjects were also asked to fill out a survey to collect basic information such as: age, gender, health, nutritional supplements, and dental appliances. The panel was composed of healthy adults with no previous experience, but was aware that the focus of the study was metallic flavoring in drinking water. The subjects varied in age from 18-82 years old. The group consisted of 8 males and 20 females.

*Flavor Threshold Determination***.** One-of-five forced choice procedure tests (American Standards for Testing Materials (ASTM) 1997) were performed in ascending concentration. Ferrous and cuprous solutions were prepared fresh daily. Nanopure® water was used for reagent water; this water is completely taste and odor free. The concentrations tested were 0.0025, 0.005, 0.01, 0.025, 0.05, 0.1, 0.25, 0.5, 1.0, 2.5, 5.0, 10.0, and 20.0 mg/L. The iron stock samples were prepared using food grade ferrous sulfate salt (Fisher, Fair Lawn, NJ, CAS 7782-63-0) and copper using food grade cupric sulfate salt (Fisher, Fair Lawn, NJ, CAS 7758-99-8). The concentrations were verified using Atomic Absorption Analysis (Perkin Elner 5900). The samples were served in taste-and-odor free 3-oz Solo plastic cups. The cups were filled with 20 ml of the iron or copper sample and/or reagent water. Only one sensory session per person was conducted per day. A single test and concentration per day was required to avoid any effect of aftertaste, which is common with metallic flavor. The subjects were advised not to consume any food or beverages for at least one hour prior to each sensory testing session. The taste tests were conducted in either the Food Sciences and Technology Lab at Virginia Tech or a quiet room with no distracting odors or sounds. At each testing session, the subjects' oral pH was measured using a pH indicator strip (Cen-Med/ Fisher M95883). To familiarize the panelists with metallic flavor, at their first session they were given reagent water with a 10 mg/L of iron or copper concentration. At each session, subjects received 5 cups each labeled with a different 3-digit number. Four of the cups contained only reagent water and one cup contained the ferrous or cuprous solution. The cups were presented in a random order such that the odd solution could be in any of the five positions. The panelists were instructed to taste the samples from left to right without going back and re-tasting any of the samples, instructed not to swallow the sample but expectorate after tasting, wait 1 minute in between samples, and to select the metallic tasting sample and mark it on their score sheet.

The best estimates of thresholds (BET) were calculated by the geometric mean method, which calculates the threshold as the geometric mean of the highest incorrect concentration and the lowest correct concentration. The group threshold was calculated as the geometric mean of all individual geometric mean threshold values. Population threshold estimates were determined separately for those less than 50 years old and those older than 50 years old. The population split at 50 years old was chosen based on the WHO dietary guidelines that specifies reduced dietary intake of iron at 50 years of age and older.

Olfactory Assessment. To assess the role of olfaction on the individual variations in recognition flavor thresholds for metallic flavor, panelists also completed the University of Pennsylvania smell identification test (UPSIT) (Sensonics, Inc., Haddon Heights, NJ). UPSIT is a scratch and sniff smell identification test composed of four booklets. The test includes 40 scratch-and-sniffs multiple choice questions. Within the booklets, panelists used a pencil to scratch off a small portion of the label which then releases an odor and the subject selects the odor description that corresponds to their smell experience. Based on their age and test score, the olfactory diagnosis for the panelist was established. Olfactory diagnosis includes normosmia, mild microsmia, moderate microsmia, severe microsmia, total anomisa, and probable malingering.

Salivary Oxidation Experiments. 1) Artificial Saliva Sample Prepation: artificial saliva was prepared according to the recipes utilized by Tang (2010) and Hong et al (2006). This contained a mixture of inorganic components, consisting of NaCl (0.1256 g), KCl (0.9639 g), KSCN (0.1892 g), KH2PO4 (0.6545 g), Na2SO4 (0.3366 g), NH4Cl (0.178 g), CaCl2 (0.172 g) and NaHCO3 (0.6308 g), dissolved in 1000 ml nanopure water to make saliva stock solution. Both 0.216 g of mucin (from porcine pancreas, Sigma, St. Louis, MO; CAS No. 84082-64-4) and 20, 000 units, 0.541 g, of α-amylase (from Aspergillus oryzae, Aldrich, Milwaukee, WI; CAS No. 9001-19-8) were mixed in 100 mL of the inorganic saliva mixture to make the protein-spiked saliva solution. To make the lipid-amended saliva solution, 30 mg of linoleic acid (ACROS, New Jersey, USA, CAS No. 60-33-3) was added to 100 mL of the inorganic saliva mixture. Linoleic acid was used, as it is one of the major components of the oral membrane lipids as well as a constituent of total salivary lipids (Larsson et al, 1996). Nitrite-amended saliva solutions contained 250 µM of NO_2^- using sodium nitrite salt (insert supplier,CAS No.). Reported concentrations of nitrite in human saliva range from 60 – 1600 µM (Gorelik et al, 2007).

2) Lipid Oxidation (LO) in Saliva Samples: salivary oxidation experiments were conducted on artificial saliva samples that contained or excluded different salivary constituents in order to examine the extent of LO under each condition. Test samples consisted of: a) artificial saliva (AS) solution that contained only the inorganic constituents noted above, b) AS solution amended with linoleic acid (AS + Lipid), c) AS solution added with alpha-amylase and mucin (AS + Protein), c) AS solution containing with both proteins and lipid (AS + Lipid + Protein), and d) AS solution spiked with proteins, lipid, and nitrite (AS + Lipid + Protein + Nitrite). As set of each test samples were separately spiked with ferrous iron and cupric copper at concentration of 180 µM. Additionally, test samples consisiting of AS + Lipid, were treated with varying concentrations of the two metals in order to examine the effect of metal concentration on the level of LO induced by each metal. The concentration series for both ferrous and cupric consisted of 0, 4.5, 9, 18, 45, 90, 180, and 360 µM. Upon addition of the metals, all test samples were placed in a 37 °C water bath for 15 minutes to simulate the temperature in the oral environment. The 15-minute time was based on a typical salivary flow rate of 5 mL per fifteen minute. At the end of the incubation period, samples were immediately cooled and analyzed for lipid oxidation using the widely used method of thiobarbituric acid reactive substances (TBARS) (Spanier, 1991). The TBARS method was modified to work with liquid samples and to enhance readings at low concentrations (Wang, 2009).

Measuring Lipid Oxidation. Lipid oxidation was monitored by thiobarbituric acid reactive substances (TBARS), a colorimetric measurement of lipid oxidation product. Two reagents solutions were prepared. Solution I was prepared from 1.875 g of thibarbituric acid, 2.53 g sodium doedecyl sulfate, and 59.5 ml of 80% acetic acid. The solution was then brought up to 500 ml with reagent water and the pH was adjusted to 3.4 using sodium hydroxide. Solution II was prepared by mixing n-butanol and pyridine at the ratio volume of 15:1 respectively. First two ml of solution I was added to one ml of each sample and well mixed using a Vortex mixer. The samples were then placed in a 95º C water bath for one hour and immediately cooled in an ice bath. Next two ml of solution II were added to each sample. Following this, the samples were centrifuged at 3000 rpm for fifteen minutes. Finally one ml of the supernatant was placed in a cuvet and the absorbance was measured at 532 nm using Spectronic 21D spectrophotometer.

Results and Discussion

The subjects were able to detect the metallic flavor in the samples. The best estimate threshold levels for the individuals ranged from 0.071 to 14.142 mg/L Cu^{+2} and the overall population threshold was 1.004 mg/L Cu^{+2} while individual thresholds ranged from 0.004 to 14.142 mg/L Fe^{+2} and the overall population threshold was 0.071 mg/L Fe^{+2}. The population thresholds for each the group were 0.780 mg/L Cu^{+2} for the younger population and 1.344 mg/L Cu^{+2} for the older population. In contrast, the population thresholds were 0.040 mg/L Fe^{+2} for the younger population and 0.139 mg/L Fe^{+2} for the older population.

Figure 2 portrays the relationship between iron and copper thresholds. The overall relationship shows no correlation between iron and copper thresholds, R^2=0.001.

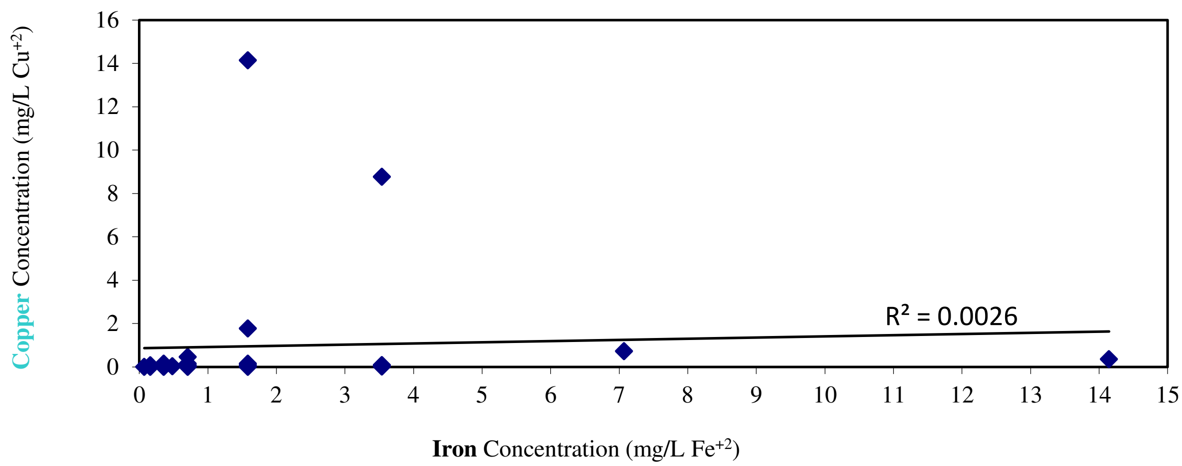

Figure 7: Copper vs. Iron Flavor Threshold

Figure 3 displays the differences between copper and iron as well as age. The older group had higher thresholds than the younger group. The copper threshold was higher than the iron threshold for both the younger and older individuals. Iron had a stronger correlation than copper especially for the older population, R^2=0.27 vs. R^2=0.07.

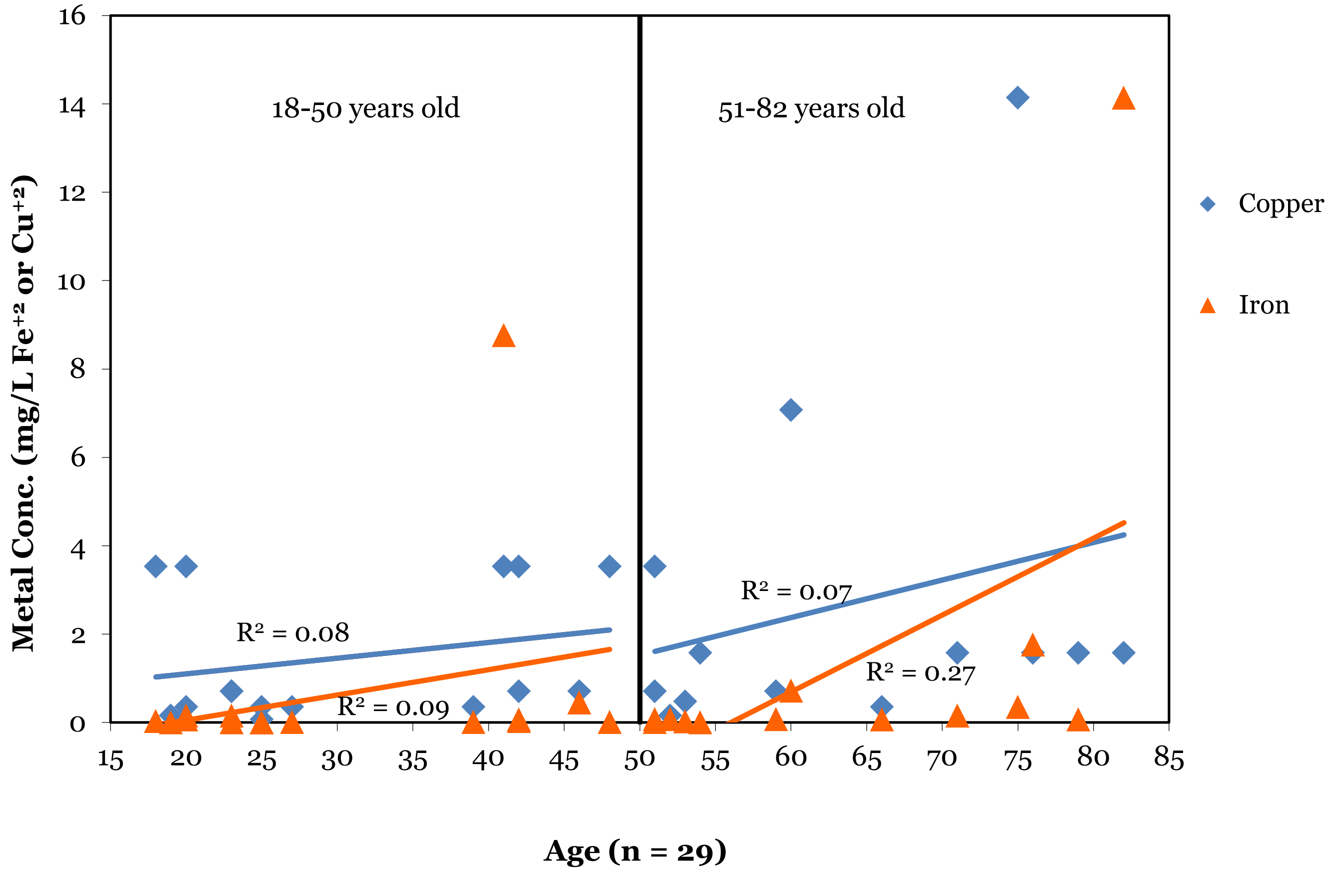

Figure 8: Iron and Copper Thresholds and Age

The relationship between copper flavor threshold and olfactory assessment is shown in Figure 4. The majority of the panelists were diagnosed with normosmia. Based on Figure 4 the <50 population had higher UPSIT scores and lower BET than the >50 population.

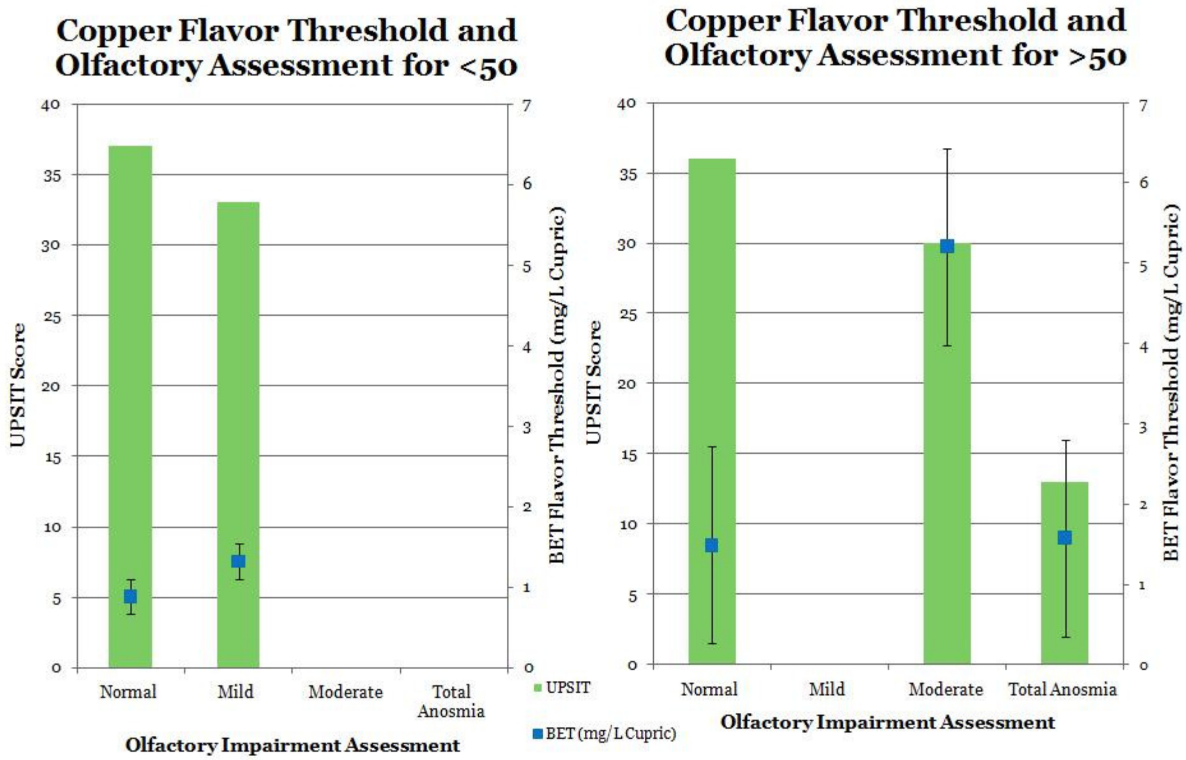

Figure 9: Copper Flavor Thresholds and Olfactory Assessment

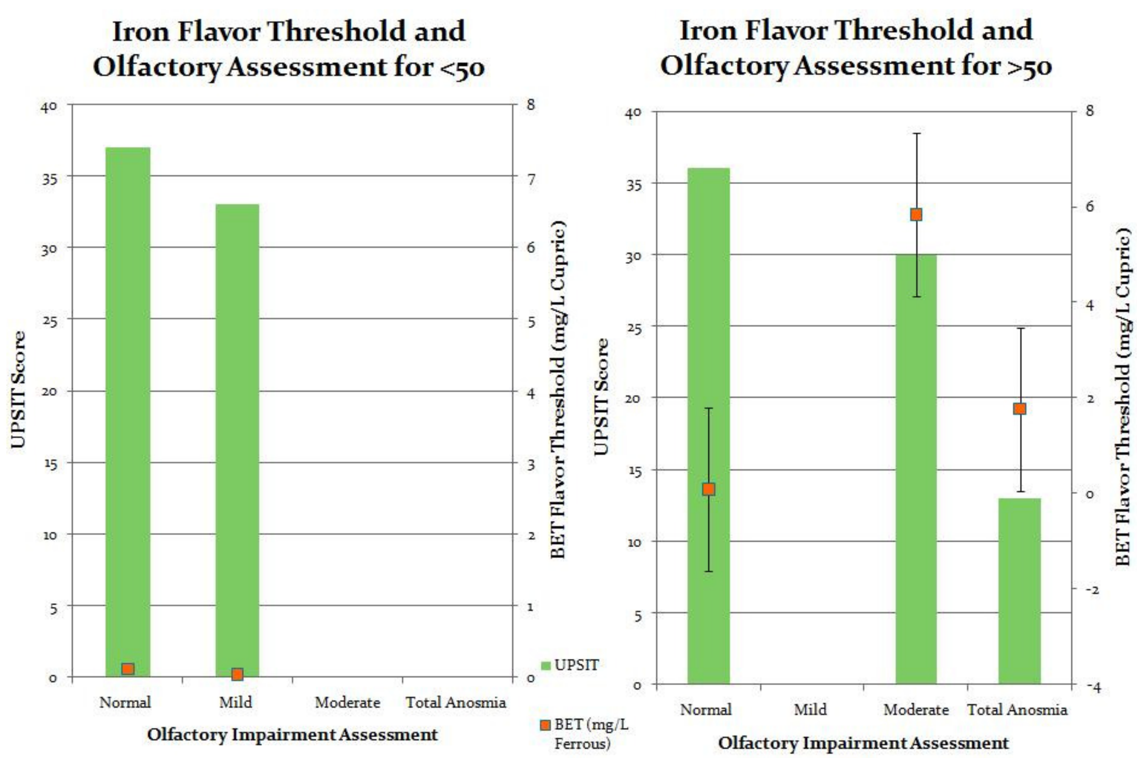

Figure 10: Iron Flavor Thresholds and Olfactory Assessment

Salivary Oxidation Experiments

Lipid oxidation experiments with artificial saliva indicated that both salivary lipids and proteins are involved in metal-induced oxidative reactions with ferrous and cupric. In the absence of lipids, protein oxidation is a minor contributor, while in their presence, proteins promoted salivary lipid oxidation at notably higher levels than in the presence of the lipid alone (Figure 5). The presence of nitrite in the artifical saliva solution containing both proteins and lipid, slightly reduced, but did not inhibit lipid oxidation (Figure 5). In artificial saliva solutions containing lipid, lipid oxidation increased with increasing concentrations of the metals. However, the metal induced lipid oxidation was considerably higher for Fe^{+2} than Cu^{+2} and started to occur at relatively high Cu^{+2} concentrations of 180 – 360 µM (Figure 6).

Lipid oxidation was analyzed using the TBARS method (Figure 5 and Figure 6). Metal induced lipid oxidation was considerably higher for Fe^{+2} than Cu^{+2} (Figure 5). Lipid oxidation in artificial saliva occurs in the presence of lipids and/or proteins. The presence of nitrite slightly reduced, but did not inhibit lipid oxidation (Figure 6).

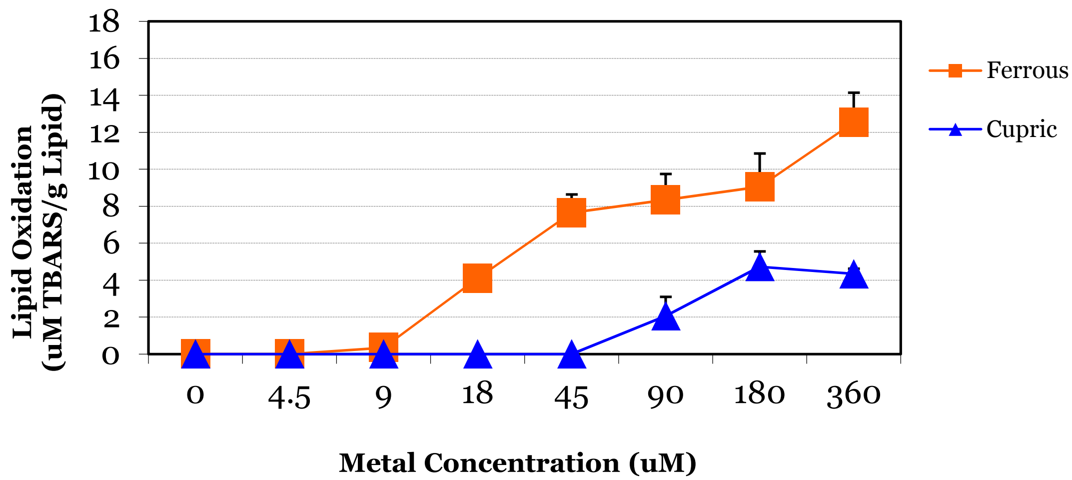

Figure 5: Lipid Oxidation in Artificial Saliva

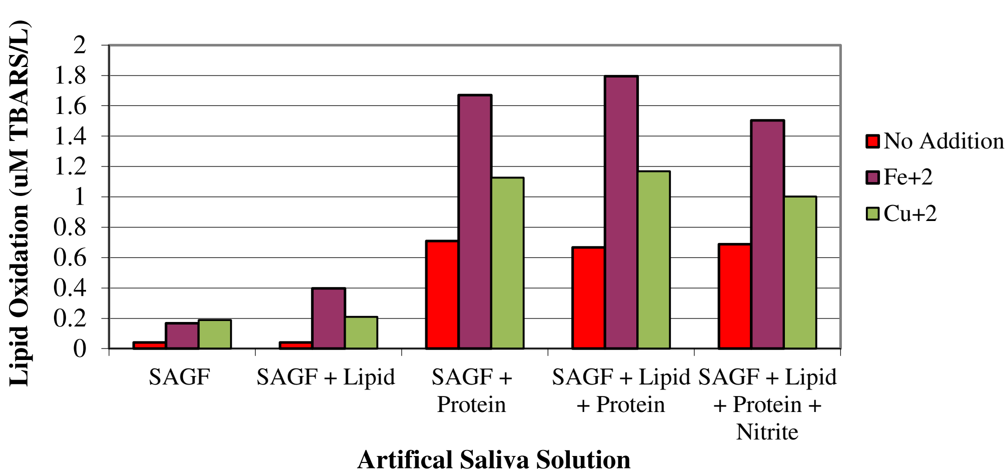

Figure 6: Lipid Oxidation in Artificial Saliva

Conclusions

No correlation between iron and copper thresholds was found, R^2=0.001. This suggests that there is a notably weak relationship between iron and copper flavor threshold recognition. Metallic flavor perception intensity varied by age when subjects ingested iron and copper in reagent water. The older individuals perceived the metallic flavor less strongly and had higher thresholds than the younger group for both iron and copper. This implies an age-dependent sensitivity to iron and copper indicating as people age they are less sensitive to metallic perception. These results are also similar for the olfactory assessment, suggesting as people age their smell functions are less sensitive as well. Iron promotes metal induced lipid oxidation considerably more than copper does. The presence of lipids and/or proteins enhances lipid oxidation while the presence of nitrite slightly reduces, but does not inhibit lipid oxidation.

Peer Feedback on Presentations

Peer feedback is a core skill for collaboration with my peers and colleagues. Feedback from my peers has greatly enhanced my oral presentation skills. The valuable suggestions from my peers have truly given me ownership over my research and work. I have been able to gain a fresh perspective from week to week and this has enabled me to gain the self confidence that I was lacking in the beginning of my internship.

On the five minute presentation, I was extremely nervous, still not totally familiar with my topic, and uncomfortable talking in front of everyone. Many of the comments my peers left me noticed that I seemed very nervous. I needed to be more confident and enthusiastic in what I am presenting in order for the audience to be captivated. The group commented that it would be beneficial to make my slides less wordy and use more pictures. I took this constructive criticism seriously in preparing the ten minute presentation.

The next presentation went much more smoothly than the first. I think I made many improvements from my 5 minute presentation to my 10 minute presentation. On the Wednesday before the presentation, I rehearsed my presentation with Dr. Dietrich, Susan, and a few of the grad students that work in the same lab as me. They also gave me feedback and constructive criticism to improve my work for that Friday. This was completely beneficial; I was more confident and less nervous for this presentation and my peers noticed this as well. The group got a better understanding of my topic and for the most part took home the exact keywords I expected them to as well as the main message. It was suggested that I continue to work on my presentation skills specifically making eye contact with the audience.

I took my peers advice when preparing my fifteen minute presentation. I practiced ahead of time with my research group per usual. Many of my peers noticed I seemed much more confident which was a confidence booster in itself. I added many more pictures and fewer words to help captivate the audience and keep their attention. I received mostly positive feedback from not only my peers but Dr. Lohani and Dr. Younos as well. I believe I am well prepared for the final presentation.

The ability to give an oral presentation is a learned skill and one that is perfected with practice. I am confident that I will overcome my lack of confidence in oral presenting by applying the techniques that many of my peers have suggested. Because peer feedback is a two- way process, I found peer review to be very helpful in suggesting different perspectives and providing me with valuable feedback to enhance my work.

Acknowledgements

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References

American Standards for Testing Materials (ASTM). 1997. Standard Practice for Determination of Odor and Taste Thresholds by a Forced Choice Ascending Concentration series Method of Limits. E 679-79; American Society for Testing of Materials (ASTM): Philadelphia, PA, 34-39.

Concha, G.; Broberg, K.; Grander, M.; Cardozo, A.; Palm, B.; Vahter, M. 2010. High level exposure to lithium, boron, cesium, and arsenic via drinking water in the Andes of Northern Argentina. Environmental Science & Technology, 44, (17), 6875-6880.

Craun, G. F.; Brunkard, J. M.; Yoder, J. S.; Roberts, V. A.; Carpenter, J.; Wade, T.; Calderon, R. L.;Roberts, J. M.; Beach, M. J.; Roy, S. L. 2010. Causes of Outbreaks Associated with Drinking Water in the United States from 1971 to 2006. Clinical Microbiology Reviews, 23, (3), 507-528.

Gorelik, S., R. Kohen, R., Ligumsky, M., Kanner J. 2007. Saliva plays a dual role in oxidation process in stomach medium. Archives of Biochemistry and Biophysics, 236-243.

Hrudey, S. E.; Hrudey, E. J. 2004. Safe Drinking Water: Lessons from Recent Outbreaks in Affluent Nations. International Water Association, 514.

Hong, J. H.; Duncan, S. E.; Dietrich, A. M. 2010. Effect of copper speciation at different pH on temporal sensory attributes of copper. Food Quality and Preference, 21, (1), 132-139.

Hong, J. H., Duncan, S. E., Dietrich, A. M., O'Keefe, S. F., Eigel, W. N., Mallikarjunan, K. 2009. Interaction of copper and human salivary proteins. Journal of Agricultural and Food Chemistry, 6967-6975.

Larsson, B., Olivecrona, G., Ericson, T. 1996. Lipids in human saliva. Archives of Oral Biology, 105 110.

Lim, J.; Lawless, H. 2006. Detection thresholds and taste qualities of iron salts. Food Quality and Preference 2, 17, (6), 513-521.

Marnett, L. J. 1999. "Lipid peroxidation--DNA damage by malondialdehyde." Mutation Research, 424.

McGuire M.J. 1995. Off- flavor as the consumer's measure of drinking water safety. Water Sciences and Technology, 31, 11, 1-8.

Ömur-Özbek, P.; Dietrich, A. M. 2011. Retronasal perception and flavour thresholds of iron and copper in drinking water. Journal of Water and Health, 1-9.

Papanikolaou, G.; Pantopoulos,K. 2005. Iron metabolism and toxicity. Toxicology and Applied Pharmolocoly, 199-211.

Peto, M. V. 2010. Aluminum and iron in humans: bioaccumulation, pathology, and removal. Rejuvenation Research, 13, 5, 589-598.

Spanier, A. M. a. R. D. T. 1991. "A rapid, direct chemical assay for the quantitive determination of thiobarbituric acid reactive substances in raw, cooked, and cooked/stored muscle foods. "Journal of Muscle Foods, 165-176.

Suffet, I.; Corado, A.; Chou, D.; McGuire, M.; Butterworth, S. 1996. AWWA Taste and Odor Survey. Journal American Water Works Association, 88, 4, 168-180.

Volke, C.; Dundore, E.; Schiermann, J.; Lechevallier, M. 2000. Practical evaluation of iron corrosion control in a drinking water distribution system. Water Research, 34, 6, 1967-1974.

Wang, H. 2009. "Determination of thiobarbituric acid reactive substances (TBARS) for water base liquid food with low oxidation." Unpublished.

World Health Organization (WHO). Iron in drinking-water. Background document for preparation of WHO Guidelines for drinking-water quality. http://www.who.int/water_sanitation_health/dwq/chemicals/iron/en/ (Accessed July 2011).

Zacharski, L. R.; Chow, B. K.; Howes, P 530 . S.; Shamayeva, G.; Baron, J. A.; Dalman, R. L.; Malenka, D. J.; Ozaki, C. K.; Lavori, P. W. 2008. Decreased cancer risk after iron reduction in patients with peripheral arterial disease: Results from a randomized trial. Journal of the National Cancer Institute, 100, 14, 996-1002.

LabVIEW Virtual Instrument Development and Implementation for Environmental Monitoring in Real Time

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ABSTRACT

The use of LabVIEW as data acquisition (DAQ) software in a real-time remote stream monitoring system of the impaired Stroubles Creek watershed, in Montgomery County, VA, is field tested by the LabView Enabled Watershed Assessment System (LEWAS) Lab. Knowledge of LabVIEW, the utilization of Virtual Instruments or programs (created by the LEWAS Lab to receive data from monitoring hardware), and an understanding of the necessary parameters needed to characterize the health of a stream and its reaction to various weather conditions, forms the development and use of a Unified Virtual Instrument that can successfully communicate with a water quality sonde, a weather station, and a stream discharge flow meter simultaneously. From this communication, LabVIEW Web Publishing is utilized to make stream and weather data remotely accessible.

Keywords: real-time remote stream monitoring, data acquisition, LabVIEW, watershed management, interdisciplinary engineering

Introduction

Data collection is an essential part of managing water resources. The quality of water in various water bodies is degraded due to population growth, urbanization, and industrial pressures (Caraco, 1995; National Research Council, 2000; World Resources Institute, 2003; Boothe, 2005). Therefore, there is a need to develop effective systems for monitoring water data in a timely manner. Data is important because it allows assessment of a stream's health and helps in determining the effectiveness of restoration activities. Traditional data collection methods consist of infrequent visits to an outdoor stream location. Problems in this method occur because not enough data can be acquired and the data takes too much time to process, which leads to gaps in understanding the fluctuations of water quality data. Real-time remote monitoring of a multitude of parameters can fill these gaps with high resolution data and provide a complete picture of water quality. A LabVIEW Enabled Watershed Assessment System (LEWAS) Lab is developed for real-time water monitoring in the Stoubles Creek Watershed. The LEWAS Lab employs students from civil engineering and electrical and computer engineering disciplines. They work in conjunction to develop and operate the system. The civil engineering students handle the instruments and the sensors, and are responsible for calibrating the instruments properly and maintaining a high confidence and accuracy in the data. The electrical and computer engineering students are accountable for the communication between LabVIEW and the hardware, and for making the data remotely available. Further details on the lab can be found in Delgoshaei et al. (2010).

The goal of this study is to integrate LabVIEW, a programming and data acquisition software, into the development of a real-time water monitoring system that is being developed for Stoubles Creek in Montgomery County, VA. The following objectives are outlined to meet this goal:

1. Learning LabVIEW
2. Understanding the existing LEWAS Lab Virtual Instruments for the stream monitoring hardware (the Sonde, Weather Station, and Flow Meter)
3. Understanding the integration of the Virtual Instruments and Data Acquisition Hardware
4. Debugging the existing LEWAS Lab Virtual Instruments
5. Creating the Unified Virtual Instrument that in a single interface simultaneously communicates with the LEWAS Lab stream monitoring hardware

Background

Overview of a Real-Time Remote Stream Monitoring System

A real-time remote stream monitoring system (Figure 1) typically consists of sensors and data acquisition software that can acquire, store, transmit, and analyze data. The software should be able to remotely control components of the sensors (sample rate, sample time, ect.), and the data must be accessible remotely and in real-time. (Kenny 2008). Real-time access to data ensures that decisions made concerning the health of the stream are more appropriate and faster in implementation when compared to traditional methods. Figure 1 shows the cycle of a real-time remote stream monitoring system in the context of the LEWAS Lab.

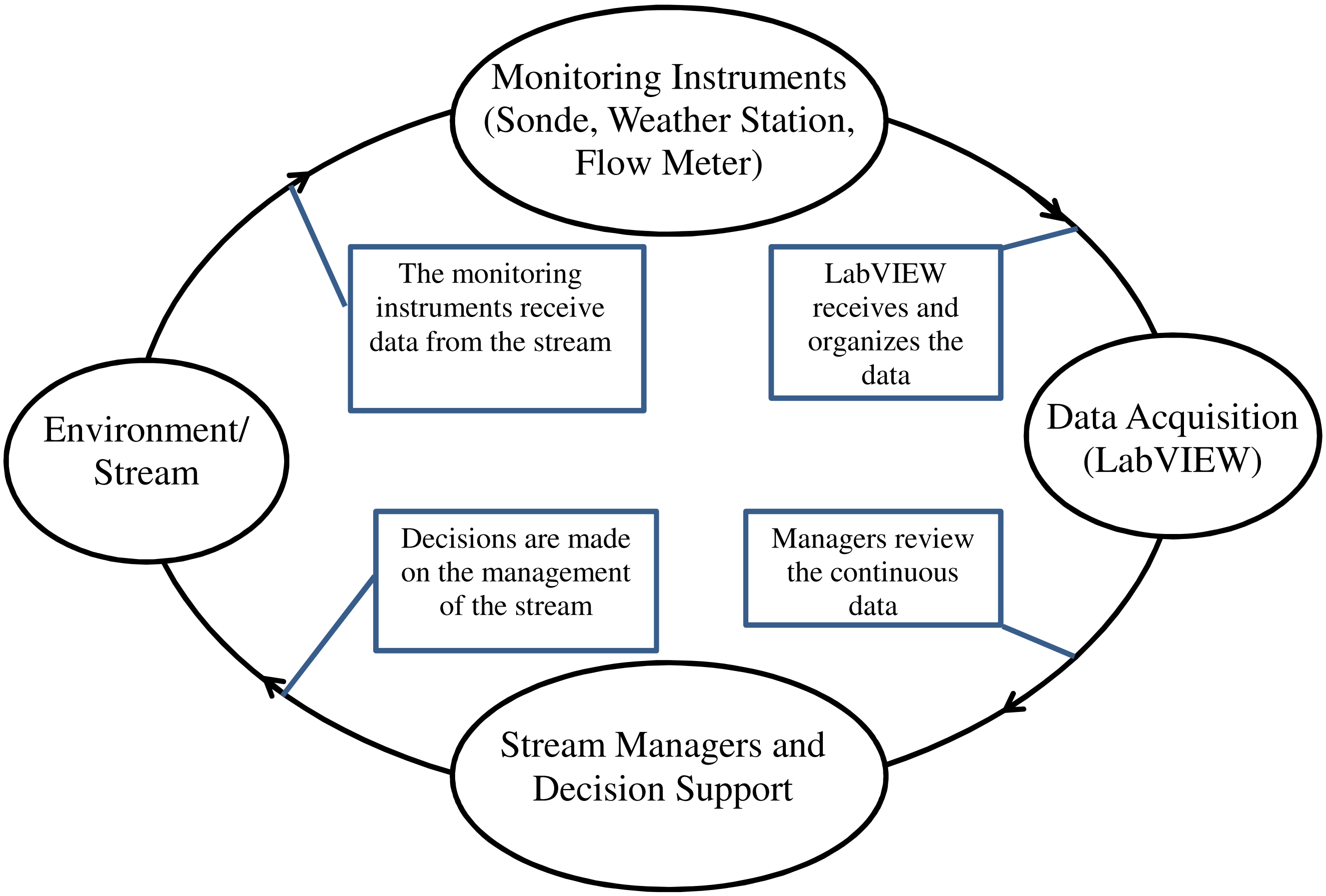


Figure 1: Flow of data and decisions through LEWAS. Adapted from Kenny et al (2008)

Study Site

The site of this study is located in the town of Blacksburg, VA. This town is located at the head waters of the Stoubles Creek watershed. Many pollutants flow into the stream from the town and campus of Virginia Tech. This is especially true with the increased construction in recent years (Figure 1 and Figure 2). LEWAS Lab's outdoor site is located on Webb branch of Stroubles Creek and is located upstream of a Duck Pond (Figure 4).

Figure 2: Residence Hall Construction on Virginia Tech's Campus. http://www.pdc.facilities.vt.edu/mediawiki/index.php/File:C_newres_20090626-5.JPG

Figure 3: Construction of Dining Hall on Virginia Tech's Campus. http://www.pdc.facilities.vt.edu/mediawiki/index.php/File:C_newres_20090626-5.JPG

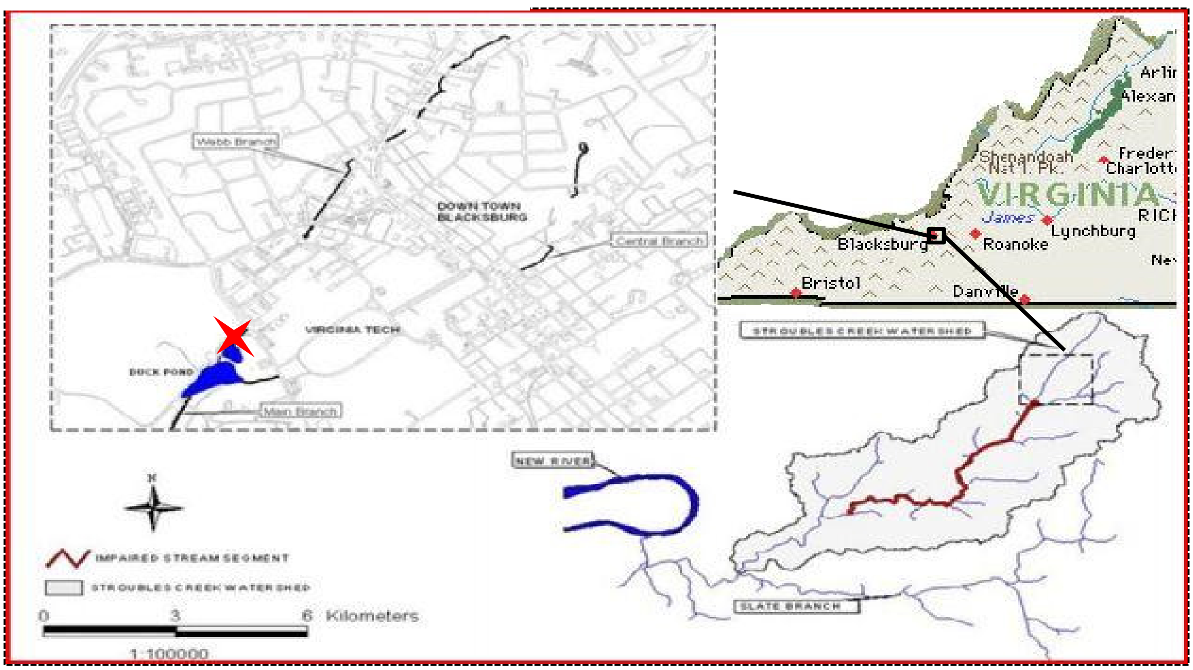


Figure 4: Stroubles Creek Watershed Real-Time Remote Water Monitoring System Site which is indicated by the red star.

Research Methods

Learning LabVIEW

LabVIEW is a powerful software and is commonly used to receive data and control data acquisition instruments. Because of a lack of experience of the lead author, in the LabVIEW programming environment, a lot of work was needed to understand the past work of the lab. This started with a material review and exercises that illustrated LabVIEW's general capabilities. LabVIEW for Engineers (Larsen 2011) proved to be the most useful tool in learning LabVIEW. A Remote Desktop Connection was utilized to work from my computer on a lab desktop that has LabVIEW 8.6 installed on it. This connection was used to work through many of the examples in the book and create basic programs also known as Virtual Instruments (VIs) in LabVIEW; one of which converts a temperature from Fahrenheit to Celsius or vice versa (see Figure 5). A virtual instrument is made up of a front panel and a block diagram. As shown in Figure 5**,** the front panel is the user interface that contains controls (inputs) and indicators (outputs) (Larsen 2011). The block diagram (Figure 5) includes the programming logic. Also, the inputs and outputs of the front panel correlate to the inputs and outputs in the block diagram (Figure5).

Sequential programming languages such as C follow a "control flow" model where the order of statements that appear in the code (control flow) determines program execution, whereas LabVIEW follows a data flow model where availability of data at the input of computational nodes determines program execution. In other words, a node will execute when it receives its necessary inputs regardless of the location in the program. The latter is better suited for data acquisition applications such as environmental monitoring. For example, the addition node in Figure 5 requires two inputs. The constant "32" fulfills one of them from the logic of the block diagram. The second input for the addition node is fulfilled after the initial temperature is entered and sent through the multiplication node where it is multiplied by 1.8. Once these two inputs have values, the addition node will execute and yield the output temperature.

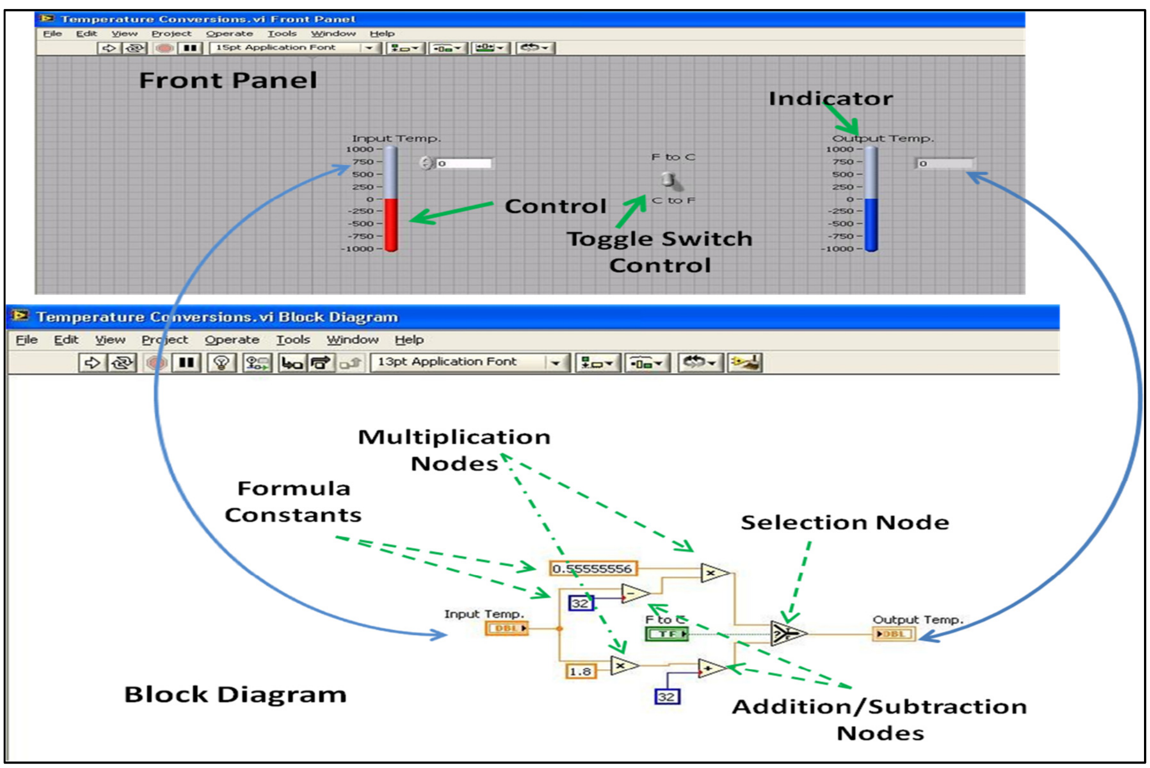


Figure 5: The front panel and block diagram relationship of the temperature conversion program

Understanding the LEWAS Lab Virtual Instruments for the Stream Monitoring Hardware

The existing VIs in LEWAS were created to individually control and receive data from each of the data collecting devices (e.g. sonde, weather station, and flow meter). Understanding the inner workings of each of these three programs was vital to creating the Unified VI. The VI for the sonde is shown in Figures 6 and 7. Specifically, Figure 6 shows the block diagram of the sonde's VI. The VI imports a string (a sequence of characters) of data into LabVIEW through an RS-232 cable using serial port communication. The controls on the left side of the front panel are used to set up this communication (Figure 7). The string is split into a substring using a Sub-VI or function which sends each of the parameters to their respective charts and data outputs. The charts in the block diagram correspond to the charts in the front panel that the user observes. Below in Figure 6 and Figure 7 the virtual instrument for the sonde is shown. For more information on the LEWAS VIs, you can view the papers of Kenny et al. (2008), Prabakaran et al. (2010) which are referenced at the end of this paper.

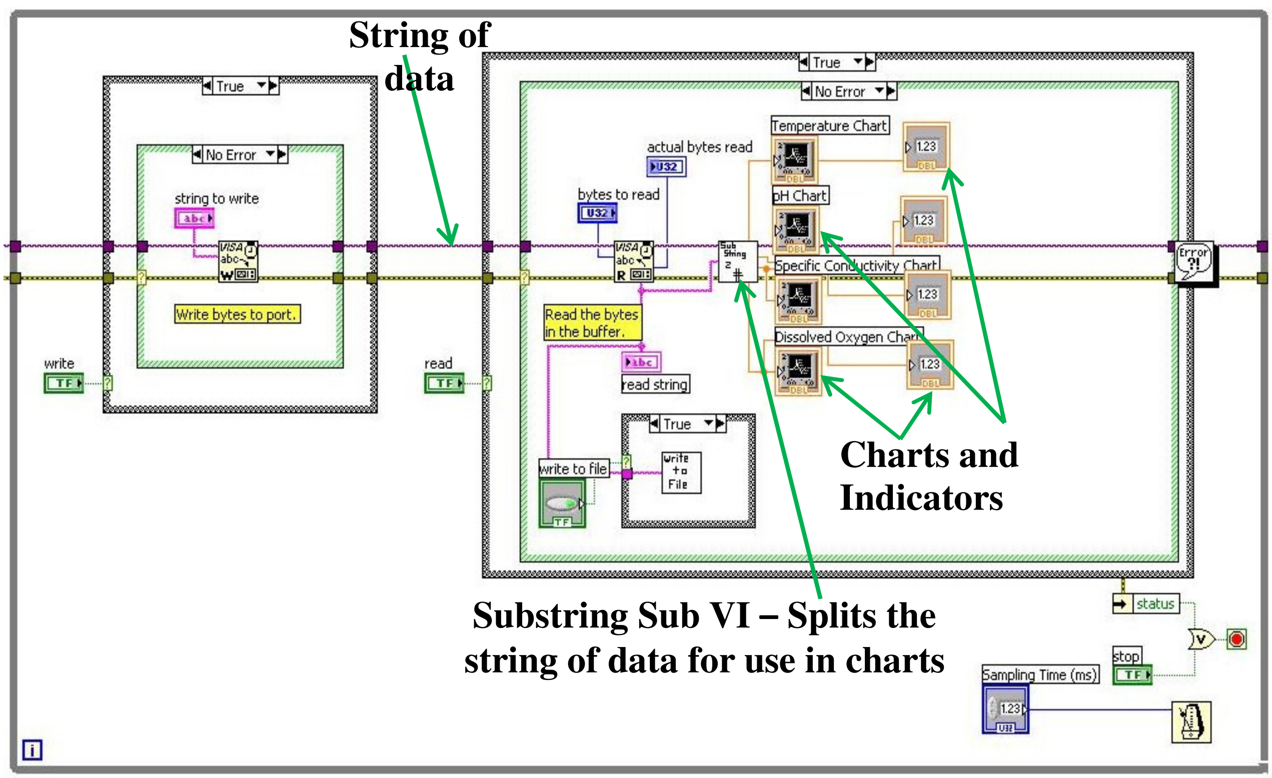


Figure 6: The Block Diagram of the Sonde's Virtual Instrument

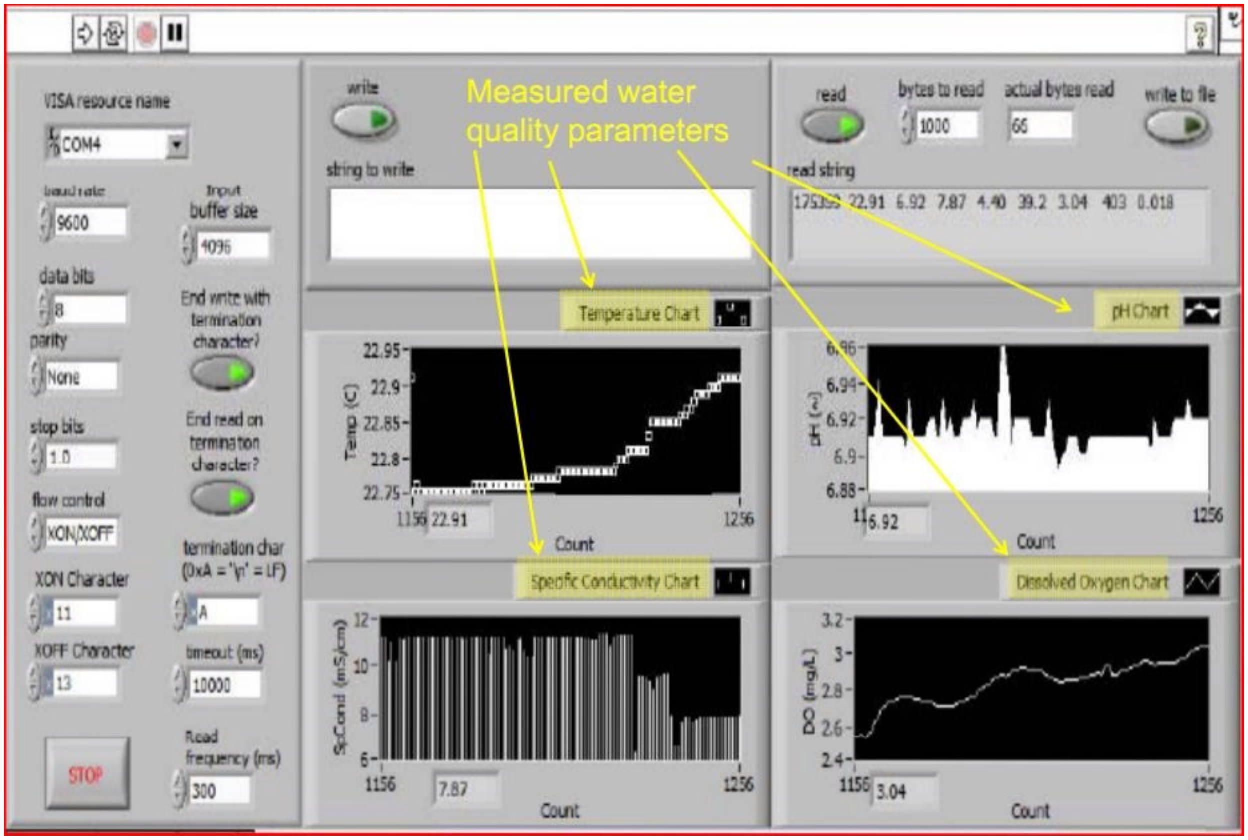


Figure 7: The Front Panel of the Sonde's Virtual Instrument

Understanding the Integration of the Virtual Instruments and Data Acquisition Hardware

Creating a Unified VI requires a perspective of how the LEWAS Lab data acquisition instruments work, which parameters are needed to get an accurate picture of the health of the stream, and where the instruments will be placed. For more detailed information on the devices used by the LEWAS Lab see the paper of Welch et al 2011.

In order to measure water quality, LEWAS uses the Hydrolab MS 5 Sonde (See Figure 8 and 9). This device has a total of five sensors: Dissolved Oxygen, pH, Temperature, Conductivity, and Turbidity. The sonde sits in a bracket as shown in Figure 9 with the end that contains the sensors being low enough to keep the sensors constantly in the water.

Figure 8: Hydrolab MS 5 Sonde

Figure 9: The Hydrolab MS 5 Sonde being tested at the outdoor Stroubles Creek Site

To collect data on weather conditions, the LEWAS Lab is employing the Vaisala WXT 520 Weather Station (See Figure 10). The weather station measures air temperature, barometric pressure, humidity, wind speed and direction, and the amount of precipitation during a storm event. When these parameters are compared with those of the other instruments, a complete picture of how the stream reacts to various weather conditions can be developed. The sensors are located on the top of the Weather Station, and it is best utilized when mounted on a pole as shown in Figure 11.

Figure 10: Vaisala WXT 520 Weather Station

Figure 11: Weather Station site

Figure 12: Sontek Argonaut SW Flow Meter

To quantify stream discharge, a Sontek Argonaut SW Flow Meter (Shown in Figure 12) will be deployed. This device utilizes acoustic doppler technology and is capable of measuring water level (stage) and velocity. This data is then utilized by the device to compute flow, mean- velocity, and channel area. The flow meter will be placed in the bottom of the stream. The flow meter requires the user to input the cross sectional area of the stream (shown in Figure 13) as well as a velocity - flow index relation equation.

Shown below in Figure 14 is a diagram of how the outdoor site will eventually be setup. The solar panels mounted on a light pole near the site will charge two – 24 volt batteries that will power an embedded computer system and the data monitoring hardware. Data will flow from the sonde, weather station, and flow meter to the embedded computer system. Data will be transmitted to clients using the wireless system of campus. See Delgoshaei et al. 2010 for further details.

Figure 13: A transect to develop the cross sectional area of the stream at the flow meter's location

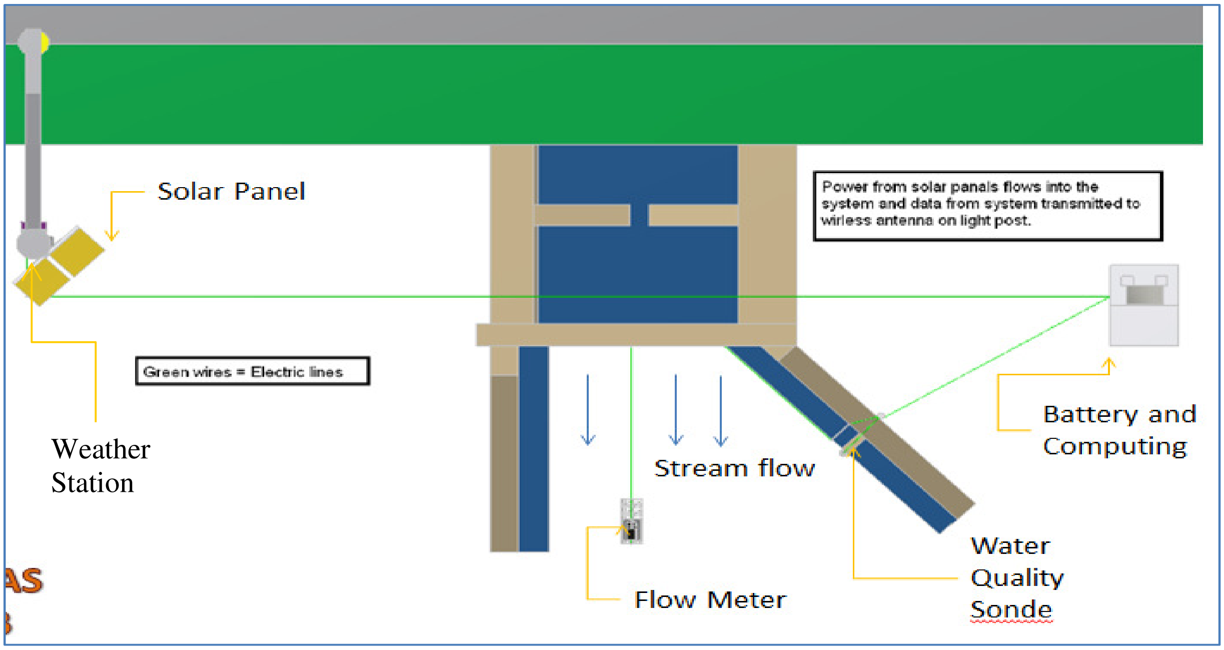


Figure 14: LEWAS Lab Stroubles Creek Watershed Real-Time Remote Stream Monitoring System Site Overview

Debugging the LEWAS Lab Virtual Instruments

To create a Unified VI that operates the sonde, weather station, and flow meter in the same interface, the LEWAS Lab VI's needed to be debugged.

The VI for the sonde did not have any errors. However, the parameters previously decided on (Temperature, Dissolved Oxygen, pH, and Conductivity) did not include turbidity; which is a measurement of the clarity of water. It was decided that a measurement of turbidity was needed to fully understand the water quality of the stream. The sonde was sent to the manufacturer, Hach, to have the additional sensor put on. When it returns, the VI will need to be edited to include a chart for turbidity.

After field tests and a review of the strings of data entering LabVIEW, an error was found in the weather station VI. The weather station outputs four different types of strings. Only three of the strings are utilized by the LEWAS Lab, one for wind data; one for temperature, humidity, and pressure; and one for precipitation. The strings are separated by a case structure (show in Figure 15) that sends each string to its respective set of charts. The program was setup so that when an unanticipated string entered the VI it was set as a default and sent to the same case as the charts for the temperature, humidity, and pressure parameters. The string unused by the LEWAS Lab caused an error in the data as the unwanted string was split and sent to the charts of temperature, humidity, and pressure. To correct the error, the default case was changed so that no action is taken when an unanticipated string enters the VI. This fix immediately stabilized the data.

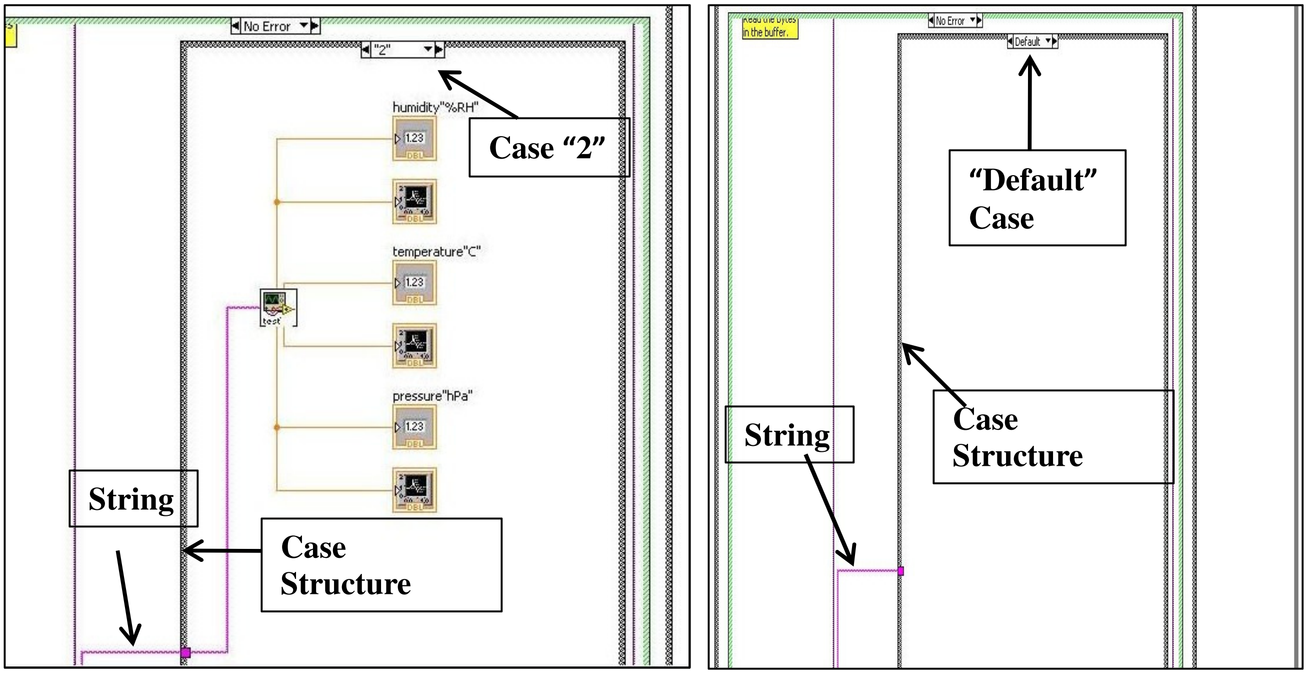
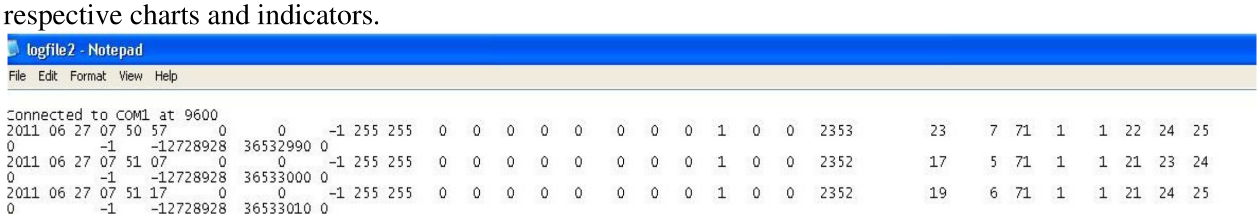


Figure 15: The debugged Case Structure for the Weather Station Block Diagram

The flow meter also needed some minor changes made to its VI. After discussion, it was decided that the parameters X-Velocity, Y-Velocity, Stage, Flow, Area, Volume, Reset Type, and Reset Time should all be displayed. At that time, the VI was set to output only the Stage, Flow, Area, and Volume. To display the desired parameters, the functionality of the Argonaut SW Flow Meter was reviewed. From the manual, the order of data in the string of 36 parameters that are output by the flow meter was discovered. The flow meter was then connected to the desktop computer in the lab using an RS-232 connector. Software called SonUtils designed by Sontek to communicate with the flow meter was utilized to view the string of data that the flow meter outputs. A few iterations of the string were copied and pasted to Microsoft Notepad (Shown in Figure 16); where the string was analyzed and it was discovered which parameter matched each number. With this knowledge, a function known as a Sub –VI in LabVIEW was created and placed in the flow meter's block diagram. From the string, the Sub-VI extracted the eight parameters desired. At the output of the Sub-VI, the parameters were wired to their respective charts and indicators.



logfile2 - Notepad
File Edit Format View Help

```
Connected to COM1 at 9600
2011 06 27 07 50 57       0       0     -1 255 255  0  0  0  0  0   0  0  0  1  0  0  2353      23    7  71  1   1  22  24  25
0          -1     -12728928  36532990 0
2011 06 27 07 51 07       0       0     -1 255 255  0  0  0  0  0   0  0  0  1  0  0  2352      17    5  71  1   1  21  23  24
0          -1     -12728928  36533000 0
2011 06 27 07 51 17       0       0     -1 255 255  0  0  0  0  0   0  0  0  1  0  0  2352      19    6  71  1   1  21  24  25
0          -1     -12728928  36533010 0
```

Figure 16: Three iterations of the flow meter's output string

Creating the Unified Virtual Instrument

As discussed in order to simultaneously view the data output from the sonde; weather station; and flow meter, a Unified VI was needed. It was decided that an interface with three tabs (one for each of the instruments) would be the best way to organize the VI. Before undertaking this task, it was unknown whether running the three programs concurrently on a single block diagram would cause any errors or timing issues.

LabVIEW Web Publishing

A LabVIEW tool called Web Publishing was researched on National Instrument's website. A step by step guide was followed to test the details of this process on the Temperature Conversion VI (from Figure 5 above). With the lab desktop computer acting as a server, Web Publishing allowed the Temperature Conversion VI to be accessed remotely over the internet by a client computer (a Dell INSPIRON 1545 with the Windows Vista Home Premium operating system installed). Web Publishing was later utilized to make the Unified VI remotely accessible.

Results and Discussion

Unified VIs Block Diagram

The Unified VI simultaneously runs each of the LEWAS Lab VIs on the block diagram (Figure 17). At the time of the initial integration a timeout error caused the Unified VI to be inoperable. This problem was traced to the flow meter's block diagram where it was found that LabVIEW was looking for data faster than the flow meter was sending it (every 10 seconds). After not receiving data for nearly 10 seconds, the flow meter's block diagram would timeout and stop the entire VI. The timeout setting was increased to 60 seconds and the error ceased to occur. However, it should be noted that if the flow meter's settings are changed so that it outputs data every minute or longer, the Unified VI timeout control on the flow meter's front panel will need to be increased, or the error will occur again. Three controls were also added to the VI so that the user can define which programs will execute. For instance, if only the weather station and flow meter are connected, the block diagram for the sonde can be excluded from executing so that the computer does not waste resources looking for data from that instrument.

In Figure 17, each of the programs bring in data (in computer language) through the Visa Com Port. This data is then sent to the Visa Read Function which converts it to a string or sequence of characters. The string is then sent to the Sub VI for each program; which splits it into the subsets of each parameter. The weather station block diagram has one additional step because of the multitude of strings that the weather station outputs. In this block diagram there is a case structure, which selects which Sub VI and set of parameter charts the string is sent to. Also, each program is enclosed by a case structure. This allows for the user to define which programs will execute using the True/False Control on the left side of each block diagram (this corresponds to the Instrument Operation Controls in Figure 18).

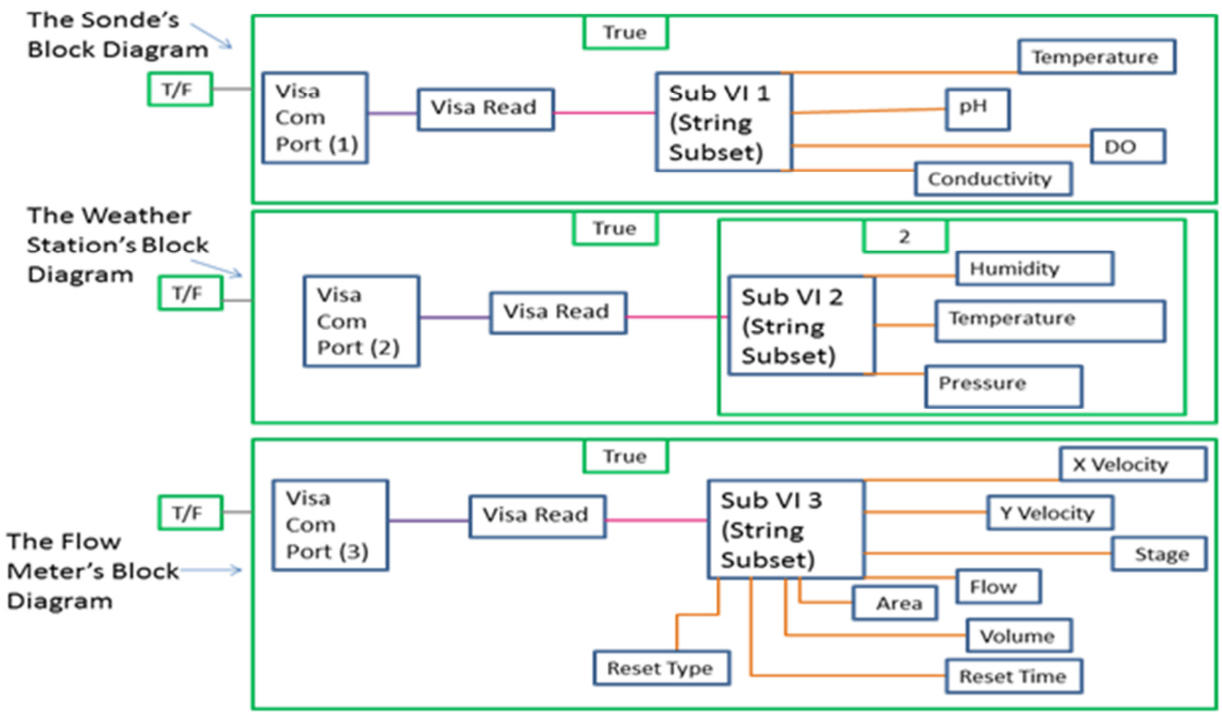


Figure 17: A Simplified Version of The Unified VI's Block Diagram

Unified VIs Front Panel

A tabbed interface was created in the front panel of the Unified VI (Figure 18) to merge the three LEWAS Lab VIs. Three Instrument Operation Controls were added to the front panel to allow the user to define which programs operate.

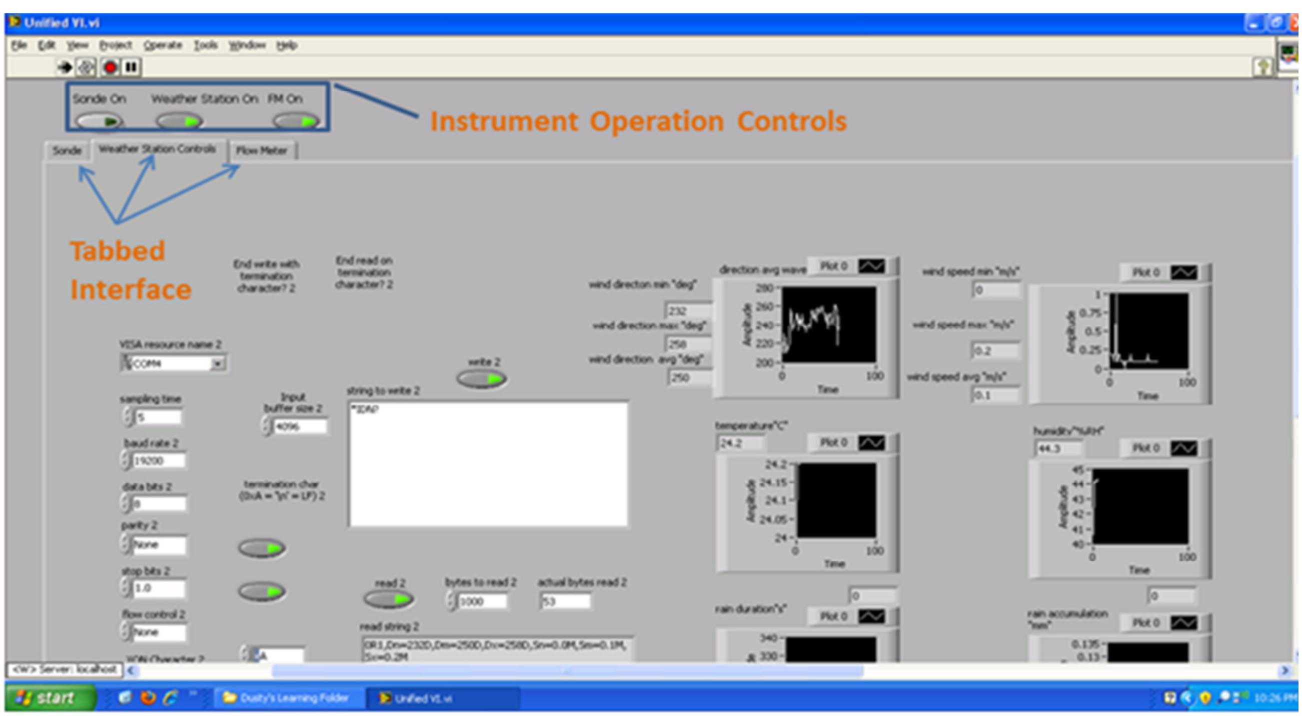


Figure 18: The Unified VI's Front Panel

LabVIEW Web Publishing

In order to remotely access the desktop version of the Unified VI, LabVIEW Web Publishing was utilized. For LabVIEW Web Publishing to be operational, the server computer must have a full version of LabVIEW or a version of the LabVIEW Professional Development System installed and the published VI in memory. The client computer requires that LabVIEW Run-Time Engine is installed. The Run-Time Engine add-on must be in the same version of LabVIEW that the server computer is running. All versions of LabVIEW Run-Time Engine are free and available for download on National Instrument's website.

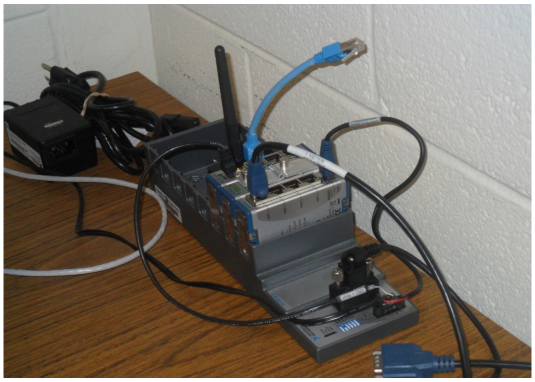


Figure 19: The field deployable CompactRio

Web Publishing the Unified VI allows a laptop with the monitoring instruments connected and deployed at the site location to act as a server. A client computer can then be used to execute the data remotely. With this setup, an audience can remotely view real- time stream data. At the completion of the site, an embedded computer called a Compact Rio (Figure 19) will be used rather than a laptop. It is field deployable and more reliable than a desktop or laptop. Due to the ruggedness of the CompactRio, the desktop version of the Unified VI must be converted into a LabVIEW FPGA (Field Programmable Gate Array). This conversion will allow the program to continuously execute on the embedded CompactRio. The CompactRio will utilize the Web Publishing tool used in this project to allow continuous and remote access to the Unified FPGA and the real-time stream data.

Conclusion

This research provided an opportunity for the lead author to conduct interdisciplinary work in the LEWAS Lab in collaboration with students in electrical/computer and civil engineering. Knowledge of LabVIEW, the existing LEWAS LabVIs, and the necessary parameters that characterize the health of a stream led to the development a Unified Virtual Instrument that can successfully communicate with the sonde, weather station, and flow meter simultaneously. This Unified VI was also made remotely accessible via LabVIEW Web Publishing. These accomplishments will help in implementing real-time remote water monitoring on the Webb Branch site of Stroubles Creek Watershed on Virginia Tech's campus.

This work completed a part of the LEWAS outdoor lab and is to be followed by:

1. Creating a FPGA (Field Programmable Gate Array) version of the Unified VI and making it operational on the embedded field computing system,
2. Completing the development of the wireless networking that will allow the data to be remotely accessible, and
3. Installing all hardware components and the related data wires and power cables

Once the LEWAS site is completed, it will have many research and educational applications. It will also provide an example for the creation of other real-time remote stream monitoring systems throughout the state of Virginia and the nation to help sustain a high quality of water for future generations.

Peer Feedback on Presentations

In weeks two; six; and nine, presentations were given by each of the NSF/REU fellows to their peers. These presentations increased in length from five minutes in week two to fifteen minutes in week nine. In each of these presentations, feedback was given to their colleagues by the REU fellows. In week two, each of the fellows wrote down one sentence that described what they wanted the other fellows to understand from their presentation. Subsequently at the end of each presentation, the fellows in the audience wrote a sentence describing what they learned from it. Each of the REU students was then given their original statement, and the sentences describing what the other students had learned from their presentation. The lead author initially found this to be only slightly useful. However, many people wrote that they mainly learned about the functionality of LabVIEW and not the implications of it on Stroubles Creek. This allowed the lead author to put more focus on the implications of my research in future presentations. In week six this same procedure was followed, except that now key words were added to the intended message and understood message feedback. This again only proved to be slightly effective as the only consistent feedback received was that the lead author needed to be more lively during the presentation, which had been realized immediately after giving it. For the third presentation, the feedback changed to any questions or suggestions that the other REU fellows had. This was the most useful feedback received during the program. The questions and suggestions allowed each of the lead author's slides to be scrutinized individually. This showed any gaps that the audience had in understanding the message. For example, the questions "What is a virtual instrument?" and "What is a string?" were asked that caused direct additions to be made to the presentation. Overall, this entire process aided the lead author in showing which areas of research needed to be further understood, so that they could be explained entirely.

Acknowledgments

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References

Delogoshaei, P., Lohani, V. K., & Green, C. (2010). *Introducing Dataflow Programming in a Freshman Engineering Course with Applications in Sustainability Education*. American Society for Engineering Education.

Green, C. (2011). *Design and Application of a Remote Water Quality and Quantity Lab for Research and Education.* MS Project in Environment and Civil Engineering. Spring 2011.

Hach Environmental, 2011. http://www.hachenvironmental.com/

Kenny, J., Delgoshaei, P., Gronwalk, F., Lohani, V. K., and Younos, T. (2008). "Integration of LabVIEW into Stroubles Creek Watershed Assessment." *2008 NSF REU proceedings of Research: Research Opportunities in Interdisciplinary Watershed Sciences and Engineering at Virginia Tech.*

Larsen, R. (2011). *LabVIEW for Engineers*. Upper Saddle River, New Jersey: Prentice Hall.

Lohani, V. K., Delgoshaei, P., & Green, C. (2009). "Integrating LabVIEW and Real-Time Monitoring into Engineering Instruction." *Proceedings of the 2009 ASEE Annual Conference and Exposition,* Austin, TX, June 14 – 17, 2009, 18 pages.

National Instruments, 2011. www.ni.com.

NI Developer Zone, 2011. Web Publishing Tool Dialog Box http://zone.ni.com/reference/en-XX/help/371361E-01/lvdialog/web_publishing_tool_db/. Accessed July 31, 2011.

Prabhakar, S., Delgoshaei, P., and Lohani, V. K., 2011. Integration of Weather Parameters Measurement into LabVIEW Enabled Watershed Assessment System (LEWAS), 3rd ICCAE 2011, January 21 - 23, 2011, Chongqing, China.

SonTek, 2008. Argonaut-SW Description. http://www.sontek.com/argonautsw.html Accessed June 28, 2011.

Welch, S. (2011*). Method Development and Calibration of the LEWAS Real-Time Stream Monitoring Outdoor Laboratory.* 2011 NSF REU proceedings of Research: Water Sciences and Engineering at Virginia Tech.

World Resources Institute, 2003. A Guide to the Global Environment—Environmental Change and Human Health. The World Resources Institute, The United Nations Environmental Programmer, The United Nations Development Program, and The World Bank, New York, NY, pp. 1 – 369.

Analysis of Macroinvertebrate Density and Distribution in Stroubles Creek, Virginia

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ABSTRACT

This study used macroinvertebrate samples from six sites in Stroubles Creek in Montgomery County, Virginia to bioassess the effectiveness of a stream restoration project completed two years prior to the study. Four rock-filled wire baskets were placed at each site on day one of the study and one basket per site was retrieved at 10 day intervals for 41 days. Macroinvertebrates colonizing the rocks were removed, identified to family, and counted. Results of sampling two years after restoration indicated slight improvement based on metrics used in the Virginia Stream Condition Index (VASCI) but still indicate impairment.

Keywords: water quality, stream restoration, biomonitoring, macroinvertebrate, substrate

Introduction

The United States has made concerted efforts to promote the physical, chemical, and biological health of the country's surface and ground water systems since the establishment of the Clean Water Act in 1972. Unfortunately, the nation's waters are still deteriorating in response to pollution from growing populations and urbanization (Karr & Chu, 1999).

Pollution can be defined as any manmade or man-induced alteration of the physical, chemical, biological or radiological integrity of water (Karr & Chu, 1999). One significant source of pollution is runoff from urban and agricultural areas. Impervious areas in urban space such as parking lots and roadways reduce the amount of natural surfaces that allow storm-water to infiltrate into the ground. More sediment enters the water system through surface runoff than through underground pathways, bringing higher levels of pollutants along with it. Increased sediment flowing at a high velocity through stream channels cuts away at the stream bank, causes more erosion and sediment and creates a feedback loop (Selvakumar, O'Connor, & Struck, 2009). Additionally, clearing vegetation for agricultural fields and urban areas increases the storm-water flow into streams in wet weather conditions. Sediment and pollutants in streams cause water quality degradation and negatively affect water systems.

Monitoring the health of aquatic life is a method that is widely recognized as the most direct assessment of the biological integrity of natural waters (Karr & Chu, 1999). Sedimentation and poor water quality affect the quantity and diversity of aquatic life (Yagow et al., 2006). One type of biological monitoring uses benthic macroinvertebrates, bottom dwelling animals large enough to see without a microscope, as indicators of stream health. These animals are essential species in freshwater environments that provide food for fish and birds and act as a catalyst in breakdown and recycling of organic matter and nutrients. Macroinvertebrates have varying resistances to levels of contaminants that enter streams. Therefore, the presence of certain macroinvertebrates that are more sensitive to levels of pollutants, such as stoneflies and mayflies, can show that a stream is healthier than one composed of predominantly chironomids and worms, which are more tolerant of pollution.

Stream restoration is a way to resolve human impacts on streams. The number of stream restoration projects taking place in the U.S. has increased dramatically in the past decade (Selvakumar, O'Connor, & Struck, 2009). The objective of this study was to evaluate the success of a stream restoration on a stream afflicted by both an urban and an agricultural area. Only about 10% of stream restorations are monitored after the restoration takes place (Selvakumar, O'Connor, & Struck, 2009) which is an alarming statistic based on the fact that over one billion dollars are spent annually on stream restoration in the United States (Bernhardt et al., 2005). Samples of macroinvertebrates were used to biomonitor several sites both upstream from and in the restoration site. A site in a nearby stream with similar structure was used as a comparison and goal for the stream currently in repair. This study aims to assess the goals of the $6,740,997 restoration project completed in the area in question (Yagow et al., 2006).

Research Methods

Restoration

This study was conducted in Stroubles Creek in Blacksburg, Virginia. The Upper Stroubles Creek watershed drains significant portions of the town of Blacksburg and the campus of Virginia Tech. Stroubles Creek is a tributary for the New River, which flows north into the Kanawha River, going on to the Ohio River, Mississippi River, and eventually discharging into the Gulf of Mexico. In Virginia, all state waters are designated for recreational uses and wildlife, so state waters must meet water quality standards set by the United States Environmental Protection Agency (EPA) (Selvakumar, O'Connor, & Struck, 2009). The property is owned by the Virginia Tech Foundation and is located just downstream of the main campus, making it available to university staff and students.

Impervious area in Blacksburg from downtown and the Virginia Tech campus increases the amount of water flowing through Stroubles Creek during wet weather periods, causing stream bank erosion and increased sediment load. The EPA originally listed Stroubles Creek as having benthic impairment in 1996. In 1998 the Upper Stroubles Creek was put on Virginia's 303(d) priority list for benthic impairment of streams, meaning it does not support the Clean Water Act's Aquatic Life Use. Following a stressor identification process established by the EPA, sediment was chosen to be the representative stressor for Stroubles Creek's impairment (VA DEQ and VA DCR, 2003).

The Virginia Tech Department of Biological Systems Engineering then prepared a Total Maximum Daily Load (TMDL) for sediment, along with an Implementation Plan (IP), in 2006 to get Stroubles Creek off of this Impaired Waters List. A TMDL is the total amount of a pollutant that a water body can receive while still meeting state water quality standards. An IP creates strategies to meet the allocations of this pollutant from point sources and nonpoint sources, and factors in a margin of safety as well. The TMDL for benthic impairment of Stroubles Creek aims to reduce the sediment load by 73% of the existing load (VA DEQ and VA DCR, 2003). Some of the primary identified issues of which the TMDL is trying to ease the effects are lack of streamside forest, livestock access to streams, agricultural runoff, peak flows from storm water runoff, and stream channel modifications (Yagow et al., 2006).

Faculty members from Virginia Tech's Department of Biological Systems Engineering (BSE) and volunteers began the Stroubles Creek stream restoration project in 2009. The restoration site included 1.3 miles of the stream and was separated into three zones (Figure 1). The first zone, furthest upstream, consisted of livestock exclusion. This section of the stream was left alone to recover naturally. The second zone extended for .34 miles and included livestock exclusion with bank reshaping and replanting. The banks were reshaped to a stable angle with a backhoe and then stabilized with coir fiber logs and coir fiber matting staked into the ground. Native tubelings and shrubs were planted along the bank to create a riparian buffer zone. The third zone, stretching .54 miles, consisted of livestock exclusion with natural channel design, including inset floodplains that help alleviate pressure from increased flow during storms (Wynn, Hession, & Yagow, 2010). The restoration was completed in 2010.

Field and Laboratory Methods

Benthic macroinvertebrate data were used to evaluate the three zones of restoration and the overall biological health of the stream. Six sampling sites were chosen for this study, as shown in Figure 2. Site 1 is upstream of the restoration reach. Site 2 is 10 meters upstream of the end of the second zone of restoration. Sites 3-6 are all within the third zone of the restoration site. The reference stream for Stroubles Creek as of 2001 is Toms Creek (VA DEQ and VA DCR, 2003), so a seventh site was set up in Toms Creek to act as a comparison and goal for the sites in the area of study. All sites were located in lotic-erosional macro-habitats, commonly known as riffles.

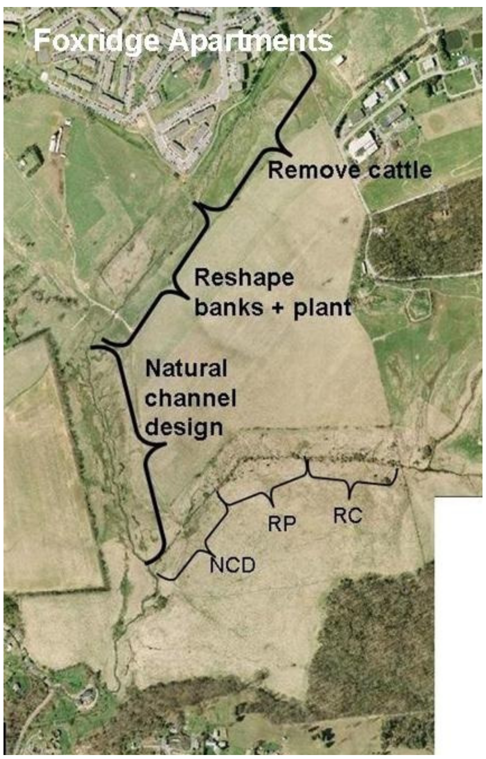

Fig. 1. Map of BSE's restoration plan.

Fig. 2. Six sampling sites in Stroubles Creek.

Substrates composed of cobbles contained in wire baskets were used to sample the macroinvertebrates. Twenty eight wire baskets (30x20x10 cm) were cut from 16-gauge garden fencing, bent to shape, and fastened with Hill's Pig Rings (Figure 3). The baskets were filled with cobbles from Old Dominion Flagstone Inc. in Blacksburg, VA. Four wire baskets were deployed at each site and each basket was tied to a stake on the bank to prevent them from being washed downstream during flash floods (Figure 4).

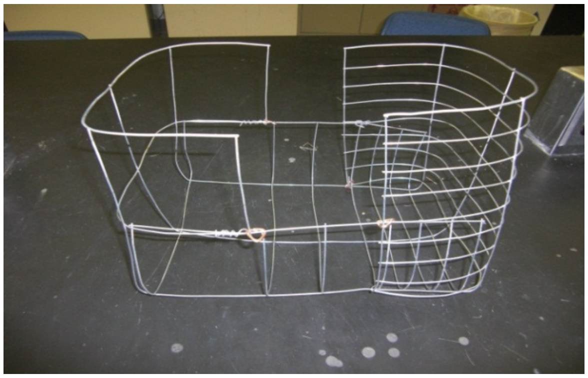

Fig. 3. Rock basket made of 16-gauge garden fencing.

Fig. 4. Rock baskets deployed at Site 4.

One basket per site was then collected on days 8, 20, 30 and 41. To collect a basket, the string securing the basket farthest downstream was cut, and then the basket was lifted into a dip net. The rocks were then placed into a large bucket of water, making sure to hold the basket over the net at all times to catch any organisms that fall off the rocks. All pebbles, sediment and organic material in the net were transferred into a plastic sampling bag. The rocks were then individually rubbed clean by hand in the bucket and wrapped in tinfoil. The tinfoil, used to later measure surface area, was stored in a plastic Ziploc bag and the rocks were thrown back into the water downstream of the site. The water in the bucket was poured through a 0.5 mm sieve to catch all invertebrates and other material left in the bucket. The matter in the sieve was then also transferred into the plastic sampling bag and the bag sealed shut.

Samples were emptied into a shallow white pan and then submerged in water. Organic matter and macroinvertebrates floated to the top and were poured through a set of stacked sieves. The rocks and sediment left in the pan were scanned for snails and clams and discarded. The organic matter was poured back into the white pan and macroinvertebrates were picked out with tweezers and placed into plastic cups labeled by site and date. Samples were preserved in 80% ethanol. Macroinvertebrates were identified to family using keys of Edmunds (1976), McCafferty (1981), Merritt and Cummins (2008), and Bouchard (2004).

Metrics of the macroinvertebrate samples were then used to determine the Virginia Stream Condition Index (VASCI). Metrics are measurable characteristics of a biotic community (Burton & Gerritsen, 2003) that show changes in connection with disturbance to their environment through pollutants and habitat degradation. The VASCI combines eight indices into one score out of 100 and is used by the state of Virginia to determine if a stream is impaired. The eight indices used are EPT taxa, Total taxa, % Ephemeroptera, % Plecoptera plus Trichoptera minus Hydropsychidae, % Chironomidae, % Top 2 dominant taxa, HBI, and % Scrapers. (Table 1)

Table 1. Metrics (grouped by category).

Metric	Variable Name	Definition
Taxa Richness – counts of different taxa within selected taxonomic groups		
Total Taxa	RTOTAL	Number of distinct taxa in the entire sample; measures the overall variety of the macroinvertebrate assemblage
EPT Taxa	REPT	Sum of distinct taxa in the generally pollution-sensitive insect orders of Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies)
Composition – percent abundance (of individuals in sample) of…		
%Ephemeroptera	ZEPT	…mayfly nymphs
%Plecoptera plus Trichoptera less Hydropsychidae	ZPTLH	…stonefly nymphs plus caddisfly larvae not including those in the pollution tolerant family Hydropsychidae
%Chironomidae	ZCHIR	…midge larvae
Diversity – percent abundance in the sample of individuals belonging to…		
% 2 Dominant taxa	Z2DOM	…the two most abundant taxa
Tolerance – counts, proportions or weighted scores of taxa based on ability to survive exposure to stressors		
HBI	HBI	Abundance-weighted average tolerance of assemblage of organisms (Family taxonomic level)
Trophic groups – percent abundance of individuals in the sample whose primary feeding function mechanism for obtaining food is to…		
% Scrapers	ZSCRA	…graze on substrate- or periphyton-attached algae and associated material

*Table and definitions taken from Table 3-3 of *A Stream Condition Index for Virginia Non-Coastal Streams,* Burton & Gerritsen, 2003.

Results and Discussion

The results for the metrics and VASCI index of all sites are found in Table 2. Total number of taxa among sampling sites in Stroubles Creek ranged from 13 to 18. EPT taxa ranged between 2 and 6 and typically had 3, suggesting poor water and habitat quality. This showed a decrease from 2002 where 6 EPT taxa were found (VA DEQ and VA DCR, 2003). Percent of Plecoptera plus Trichoptera minus Hydropsychidae remained at 0 except for Site 4 where the metric was under 1%, showing no change in pollution-intolerant organisms. Thess metrics imply no improvement or pehaps a decline in water quality in Stroubles Creek. However, percent of scrapers ranged from 2-16%, which increased from 5.11% in 2003 (VA DEQ and VA DCR, 2003). Percent of Ephemeroptera increased from 2001, from 3.6% to typically double this number. Mayflies are good indicators of stream health and are sensitive to pollution, so an increase in their numbers points toward an improvement in stream health.

Table 2. Results of Macroinvertebrate Analysis.

	RTOTAL		REPT		ZEPT		ZPTLH		ZCHIR		Z2DOM		HBI		ZSCRA		VASCI
Site	Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score	Metric	Score	
1	17	85	2	25	0.00	0	0.00	0	18.23	90	46.65	97	4.64	54	16.35	45	49.5
2	13	65	3	38	7.89	33	0.00	0	16.03	93	61.48	70	4.82	52	5.02	14	45.5
3	14	70	3	38	2.28	10	0.00	0	9.30	100	81.57	34	4.64	54	2.77	8	39.0
4	16	80	6	75	12.40	52	0.78	10	39.53	67	60.47	72	4.95	50	16.28	45	56.4
5	14	70	3	38	6.44	27	0.00	0	14.92	94	74.92	46	4.41	56	7.12	19	43.7
6	15	75	3	38	6.83	29	0.00	0	21.69	86	65.46	63	4.47	55	16.47	45	48.9
TC	20	100	8	100	23.66	100	7.53	100	25.81	82	45.16	100	4.33	57	36.56	100	92.3

The remaining three metrics decrease in value as water quality improves. Percent of Chironomidae averaged around 18% and ranged from 9 to 39%. High proportions of Chironomidae accompany an abundant source of organic matter, often indicating higher levels of fine sediment (Voshell, 2002). Percent of the top 2 dominant taxa was above 50% for all sites in Stroubles Creek except Site 1. This metric reflects a lack of diversity that is associated with poor water quality. Hydropsychidae was one of the two dominant taxa in all sites and Chironomidae was the other dominant taxa in half of the sites. These organisms thrive on suspended organic matter. The HBI index showed scores within the 4.26-5.00 and 5.00-5.75 category, reflecting 'good' and 'fair' water quality, respectively. Good water quality indicates some organic pollution probable and fair water quality indicates fairly substantial pollution likely (Hilsenhoff, 1988). The average HBI score for the sampling sites was 4.68. This is an improvement of over 10% from the reported score of 5.81 in the Stroubles Creek TMDL (VA DEQ and VA DCR, 2003).

This study may have magnified counts of Chironomidae and Hydropsychidae because of the substrate introduced to the environment. The substrates in the baskets are not typical of Stroubles Creek; the cobbles are larger than the pebbles and sediment that comprise much of the stream bottom. Chironomids are early colonizers, so the systems located at each site may have still been coming to equilibrium when collections were made. Net-spinning hydropsychids are also attracted to the cobbles because they require stable substrates for attachment (Selvakumar, O'Connor, & Struck, 2009). These families were the two dominant taxa in half the sampling sites, including Site 5 (Figure 5).

Individual metrics that make up the VASCI reveal both positive and negative trends. However, the average VASCI score for Stroubles Creek as of 2003 was 37.9 (VA DEQ and VA DCR, 2003) and the average score found amongst sampling sites in this study was 47.6. This is a 10% increase and indicates promising results of BSE's stream restoration site in Stroubles Creek. All of the sites in Stroubles Creek produced a VASCI score less than 60, which is the impairment threshold in Virginia.

The reference site in Tom's Creek produced a VASCI score of 92.3, significantly higher than any of the sites in Stroubles Creek. All metrics for the Tom's Creek site were indicative of better water quality than the Stroubles Creek sites. The substrate used in the rock baskets was similar to the stream bottom of Tom's Creek.

High colonization rates may also be attributable to the MacArthur-Wilson model that proposes that a new habitat has a high invasion rate of new taxa (Dickson & Cairns, 1972). The trend line in Figure 5 for Chironomidae shows initially high populations in Day 8 and 20, with lower succeeding population levels. Other trend lines like Heptageniidae show increasing population levels. The point where colonization rates equal extinction rates is believed to be the equilibrium of the system. From Figure 5, it appears that equilibrium was reached between day 20 and day 30. This study did not collect enough population data to accurately support this theory though.

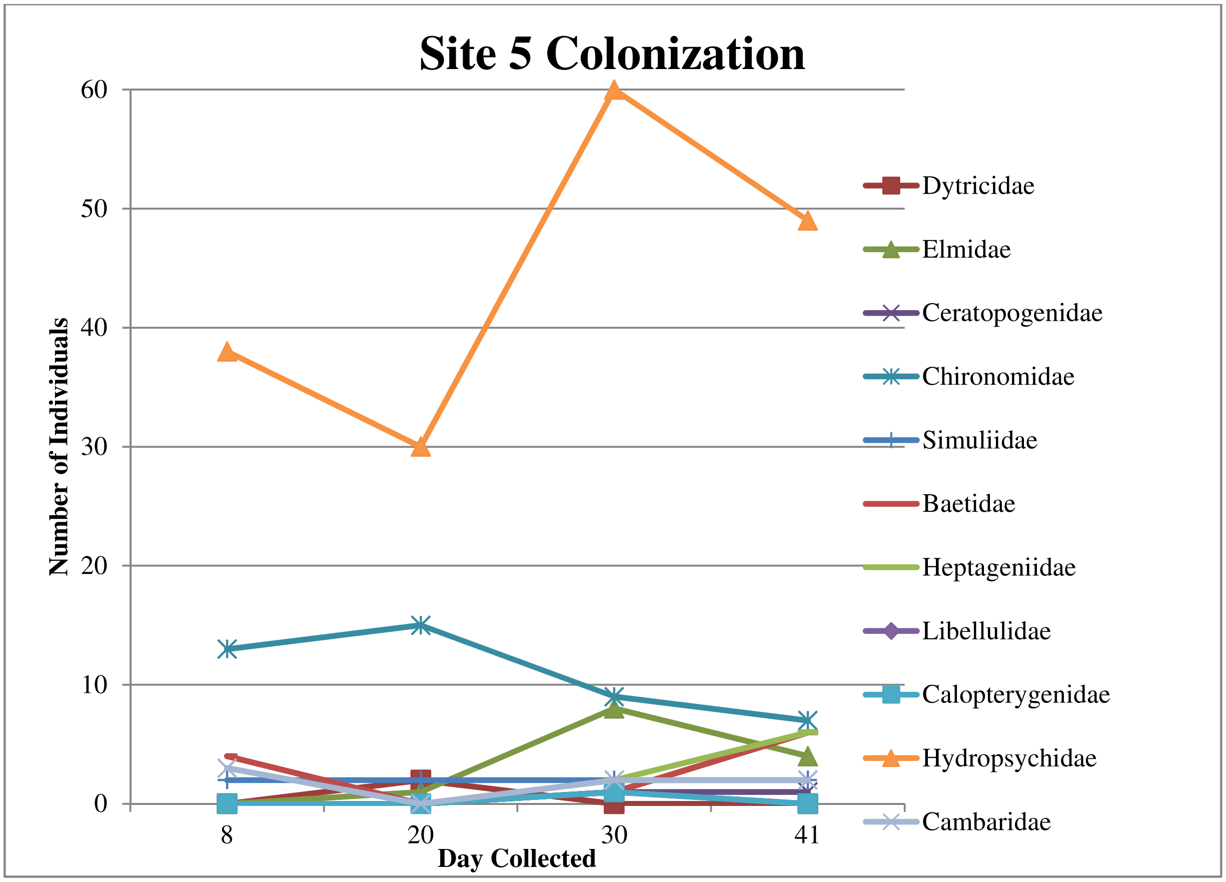

Fig. 5. Graph of macroinvertebrate colonization over 41 days at Site 5.

Macroinvertebrate data completed for VASCI showed an improvement in conditions in the restoration site in Stroubles Creek. One reason that this study is showing a slow recovery could be the influence of wet weather periods. Stroubles Creek experiences extreme flash floods during storms and the current carries substrate, sediment, and organic matter downstream. Macroinvertebrates can become dislodged from their environment during peak flows in storms and washed downstream. Large amounts of organic detritus being carried downstream were caught in the wires of the rock baskets in this study. Several sites experienced more drastic effects of the current; near day 20, Site 3 had one of its baskets completely washed up on the bank, and the rocks were left in a pile on the stream bottom. Other sites occasionally had a basket tip over from the current as well. This disrupted colonization in the most afflicted locations like Sites 2 and 5.

Macroinvertebrate populations also vary by which time of year that collections occurred. Spring and fall are the most common seasons in which to sample. Samples in this study, conducted in summer months, included many immature stages of macroinvertebrates. Metric and index scores from previous years were based on spring and fall sample collections so comparisons of specific taxa population numbers may not be representative of overall trends in stream health.

Conclusions

Macroinvertebrate data in this study show improvement but still indicate impairment. The restoration project itself was not enough to restore populations of invertebrates that indicate good water quality. Two years may not be enough time after the restoration was completed to show significant improvement and biological monitoring should be continued.

The substrate used in this study was not the typical substrate found in Stroubles Creek at this point in its history. Prior to the growth of agriculture and the town of Blacksburg in the past 250 years, the stream bottom of Stroubles Creek was probably composed of cobbles similar to the substrate used in this study. Cobbles are typical of Tom's Creek, the reference site, and the VASCI scores in this study support the idea that macroinvertebrate diversity increases with substrate stability (Allan, 1995). This study demonstrates that a combination of better water quality and appropriate substrate could stimulate a healthier macroinvertebrate community in Stroubles Creek.

Due to the flashiness of the stream, sites should be reviewed and selected based on the ability to resist being washed away in a storm for future research. Sites should also be more spread out within the different zones of the restoration. The sites used for this project were selected largely based on accessibility and ended up being clumped in the last zone of the restoration. At least one site should be within the first zone that was left alone to recover naturally after cattle exclusion. A wider distribution of sampling sites could improve the analysis of different stream restoration methods' effects on benthic macroinvertebrate populations.

The inset floodplains and reshaped banks constructed in the restoration project help manage increased flow but do not control storm discharges into the stream. Best management practices (BMPs) should be put in place in the town of Blacksburg and on the Virginia Tech campus to help slow the entry of water into Stroubles Creek. Reducing discharge from the Stroubles Creek watershed above stream of the restoration site is important in restoring benthic macroinvertebrate populations within the restoration site.

Peer Feedback on Presentations

Part of this 10-week REU program included practice presentations that were presented to the REU fellows after two, six and eight weeks. The first presentation was five minutes and the length of each successive presentation increased by five minutes. The purpose of the presentations was to inform other members of the program about the progress of the projects while providing practice for the final presentation to be given on the closing day in front of all research mentors, fellows and their personal guests. Each time, presenters were given feedback on how to improve their presentation.

The five-minute presentations were conducted on June 10th, just two weeks after the start of the program. As a result, the majority of the content was strictly introduction to each individual's project and sometimes included the start of methodology. Each fellow was asked to write down the main point they hoped the audience would get out of their presentation, along with five keywords. The audience was then asked to write down the main point that they felt was conveyed and five keywords they noticed during the presentation. The presenters received the feedback after all presentations were given. This was a creative method of providing feedback – it is difficult to come up with what main point should be conveyed. This was successful in making the presenters create a specific focus and theme throughout their presentation. Negative feedback was used to develop a stronger, overarching focus that stands out when presenting.

The ten-minute presentations were given on July 8th, which was six weeks into the program. The feedback asked of this presentation was in the form of a take-home message and additional comments. This was similar to the feedback from the first presentation but peers gave different comments about how to improve the presentations. The positive reactions in the feedback reinforced the changes that had been made from the first presentation as well. Constructive criticism pointed out errors and room for improvement.

On July 29th, REU fellows gave their fifteen minute presentations as a full practice for the presentation to be given on the closing day in front of all individuals associated with the program and any personal guests. The audience gave feedback in the form of three questions about the content and suggestions for the final presentation. The questions asked were incredibly helpful in seeing what parts of the presentations needed clarification, and also informative about what subjects sparked curiosity in listeners and could be pursued in the question-and-answer section of the presentation on the final day.

In conclusion, this process was effective in providing feedback and good practice for the final presentation. The progression from five to ten to fifteen minutes was useful in slowly building up to talking for a considerable amount of time. At first there was concern amongst the fellows about finding enough information to talk for five minutes about each project after just two weeks, but this was the perfect point to have an initial introduction to each project. The feedback received was often positive, but any criticisms were always constructive and provided helpful suggestions. It was beneficial that the feedback to be provided was very structured instead of just being comprised of notes about how each fellow presented. The primary author considered herself a fairly strong presenter before this program, but this feedback process increased her confidence and pointed out several of the nervous tendencies that should be avoided. Another helpful factor was listening to so many other presentations. From other presenters, several habits stood out to remember not to do, such as speak too quickly, mumble or include too many words on a slide. Future programs should not be changed; the feedback process is creative, successful, and perfect for this program.

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References

Allan, D. J. (1995). *Stream ecology: structure and function of running waters*. Secaucus, NJ: Kluwer Academic Pub.

Bernhardt, E.S., M.A. Palmer, J.D. Allan, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S.Katz, G.M.Kondolf, P. S. Lake, R. Lave, J. L. Meyer, and T.K. O'Don. (2005). Synthesizing U.S. river restoration efforts. *Science* 308: 636-637.

Bouchard, J. W., Jr. (2004). [Macroinvertebrate key]. *Guide to Aquatic Invertebrates of the Upper Midwest*. University of Minnesota. Retrieved from http://wrc.umn.edu/pubs/watersqq/guidetoaquaticinverts/index.htm.

Burton, J. and J. Gerritsen. (2003) *A Stream Condition Index for Virginia Non-Coastal Streams*. Owens Hill, MD: Tetra Tech, Inc. Retrieved from http://www.deq.virginia.gov/watermonitoring/pdf/vastrmcon.pdf.

Dickson, K. L. and Cairns, J., Jr. (1972, July) The relationship of fresh-water macroinvertebrate communities collected by floating artificial substrates to the MacArthur-Wilson equilibrium model. *American Midland Naturalist*. 88(1):68-75. Retrieved from http://www.jstor.org/stable/2424488.

Edmunds, G. F., Jr., Jensen, S. L., & Berner, L. (1976). *The mayflies of north and central america*. Minneapolis, MN: University of Minnesota Press.

Hilsenhoff, W.L. (1988) Rapid field assessment of organic pollution with a family-level biotic index. *J. N. Am. Benthol. Soc*. 7(1):65-68. Retrieved from http://www.homepage.montana.edu/~wwwbi/staff/kerans/bio439/hilsenhoff.pdf.

Mandaville, S. M. (2002, June). *Benthic macroinvertebrates in freshwaters- taxa tolerance values, metrics, and protocols*. Retrieved from http://www.chebucto.ns.ca/ccn/info/Science/SWCS/H-1/tolerance.pdf.

McCafferty, W. Patrick. (1981). *Aquatic entomology: the fishermen's and ecologists' illustrated guide to insects and their relatives*. Boston, MA: Science Books International, Inc.

Merritt, R. W., Cummins, K. W., and Berg, M. B., eds. (2008). *An introduction to the aquatic insects of North America* (4^{th} ed.). Dubuque, IA: Kendall Hunt.

Karr, J. R., & Chu, E. W. (1999). *Restoring life in running waters: Better biological monitoring*. Washington, DC: Island Press.

Selvakumar, A, O'Connor, T. P. , & Struck, S. D. (2009). Role of Stream Restoration on Improving Benthic Macroinvertebrates and In-Stream Water Quality in an Urban Watershed: Case study. *Journal of Environmental Engineering*, *136*(1), 127-139.

VA DEQ and VA DCR. (2003) *Benthic TMDL for Stroubles Creek in Montgomery County, Virginia.* Richmond, VA: Virginia Department of Environmental Quality and Virginia Department of Conservation and Recreation.

Virginia Tech Stream Team. (2010) *Invertebrate Sample Processing Protocol*. Blacksburg, VA.

Voshell, J. R., Jr. (2002) *A guide to common freshwater invertebrates of north America*. Blacksburg, VA: The McDonald and Woodward Publishing Company.

Wynn, T., Hession, W. C., and Yagow, G. (2010, August 13) *Stroubles Creek Stream Restoration: Final Project Report*. Blacksburg, VA. Retrieved from https://scholar.vt.edu/access/content/group/5a22bf0a-7980-4ed1-a143-

227d6dc82c30/Restoration%20Organization/Stroubles%20Restoration%20WQIF%20Final%20Report.pdf .

Yagow, G., B. Benham, T. Wynn, and T. Younos. (2006) *Upper Stroubles Creek Watershed Draft TMDL Implementation Plan, Montgomery County, Virginia*. VT-BSE Document No. 2005-0013. Submitted February 17, 2006 to the Virginia Department of Environmental Quality and the Virginia Department of Conservation and Recreation. Richmond, Virginia. Retrieved from http://www.deq.virginia.gov/tmdl/implans/stroubip.pdf .

Nitrate in the Occoquan Reservoir

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ABSTRACT

Reservoirs are integral to the vitality of many modern cities. Changes in climate and increased rates of urbanization around the world are putting a strain on water resources. A way to alleviate the pressures on water supplies is the construction of water reclamation and/or reuse facilities. One of the first projects of this kind in the United States began in 1970 on the Occoquan Reservoir in northern Virginia. Still in operation today, the Occoquan is augmented by effluent from the Upper Occoquan Sewage Authority (UOSA). The Occoquan is a relatively shallow, eutrophic reservoir. It undergoes a period of stratification from spring through fall. This isolates the hypolimnion which becomes anoxic as microbial activity uses up the limited amount of oxygen available. Other chemicals such as iron and manganese are then reduced, making them soluble and releasing sorbed phosphorus, decreasing the water quality. A project to explore whether nitrate functions as a terminal electron acceptor in the absence of oxygen in the Occoquan Reservoir is ongoing, with the first phase completed in Summer 2011. Two campaigns conducted in June and July 2011 measured profiles of redox potential, pH, DO, and temperature at the sediment water interface using UNISENSE microsensing equipment. Additionally, raw water quality data provided by UOSA and the Upper Occoquan Monitoring Lab (OWML) was programmed into a user friendly format using Microsoft Excel VBA. Final products produced include several macros for each dataset, user manuals, and trouble-shooting tips. These macros have many limitations but when applied correctly, have the potential to significantly speed up the data analysis process in the future of this project.

Keywords: Occoquan Reservoir, anoxic hypolimnion, nitrate, microsensors, Excel VBA macros

Introduction

Reservoirs play a critical role in the development of urbanized areas. The United States has more than 86,000 impoundments that serve as potable water supplies and irrigation where groundwater is unavailable (Kalff 2002). These life-lines provide a seemingly endless supply of water. However, as severe strains on our water supply become increasingly imminent, new management and conservation practices must be considered. Around the world, rapidly developing countries face the danger of a shrinking supply and a fast growing demand (Rodriguez 2009). One potential solution to alleviate the water crisis is the implementation of water reclamation facilities to augment surface drinking water supplies. Several of these plants have been constructed in the United States and used for decades yet this technique remains somewhat obscure. The level of treatment required can be expensive but the dividends are great, with reclaimed water supplying a fair portion of the total water supply in most cases (Rodriguez 2009).

Many lakes and reservoirs in temperate climates encounter unique, seasonal water quality challenges. This is due to the combination of two limnological processes; stratification plus eutrophication. Stratification is a seasonal development that begins in the spring. Throughout the winter, temperatures in the water column are fairly uniform and conducive to mixing. As the sun warms the surface, cooler, denser water sinks to the bottom faster than mixing distributes the warmer water. As this continues, three distinct layers begin to form with a very stable, undisturbed hypolimnion on the bottom. As the summer season progresses the layers continue to stabilize and the hypolimnion becomes isolated from the rest of the water column until the fall, when mixing occurs once again due to cooler temperatures. This means that oxygen taken up at the surface cannot be distributed to the hypolimnion.

Once the stratified period begins there is a limited supply of oxygen available in the hypolimnion which will not be replaced until the fall turnover (Wetzel 2001).

Eutrophication is a very different process that occurs in lakes and reservoirs that receive input of the nutrients phosphorus (P), nitrogen (N), and carbon (C). These nutrients together promote the growth of algae and plant life. When these plants die, they settle through the water column into the hypolimnion. There, the process of microbial respiration decomposes the organic matter, releasing CO_2 and electrons as by-products. At the beginning of the stratified period when oxygen is available, O_2 readily accepts these electrons and becomes reduced. As the O_2 is used up, the hypolimnion becomes anoxic and chemically reducing (Wetzel 2001). After this point is reached, the oxidation of organic matter proceeds, creating an environment with a lowered redox potential. This enables the reduction of other, more weakly oxidized chemicals present in the sediment such as manganese oxide (Mn^{4+}), nitrate (NO^{3-}), and iron oxide (Fe^{3+}) (Kalff 2002). Sediment fluxes of manganese and iron occurs because in their oxidized state these elements are insoluble, but undergo dissolution when reduced (Santschi et al. 1990). This process also returns P to the water that had previously been sorbed to the solid iron oxides in the sediment (Kalff 2002). The release of these chemicals is particularly problematic for drinking water reservoirs because they are difficult and expensive to remove and are a common consumer complaint due to their undesirable aesthetic properties. Additionally, the internal loading of P exacerbates eutrophication as it is the limiting nutrient for most phytoplankton (Gantzer[2] et al. 2009).

One solution to this problem is the installation of aeration or oxygenation systems which keep the hypolimnion from becoming anoxic by providing a constant supply of air, or O_2,via circular or linear hoses. These systems have proven to be very effective in heavily studied cases in Carvin's Cove and Spring Hollow reservoirs, both located in south western VA. They are generally successful at preventing the dissolution of Mn, Fe, and P. Their functionality is reduced when turbulence from the release of the bubbles disturbs the stratified layers and induces mixing which increases oxygen demand in the hypolimnion (Gantzer[1] et al. 2009). Additionally, these systems require installation, upkeep, and a constant supply of O_2, which are all added costs.

Fig. 1 *View of oxygenation system in Carvin's Cove; notice the line of bubbles reaching the surface parallel with the boat*

It has been hypothesized for decades that nitrate can serve as a terminal electron acceptor in anoxic environments. This theory was supported by evidence of naturally attenuated nitrate levels and the retention of Fe-bound phosphorus in the Occoquan Reservoir in northern Virginia (Randall & Grizzard 1995). It is chemically feasible that denitrification or the reduction of NO^{3-} to N_2 gas can function this way in anoxic zones near the sediment water interface (Santschi et al. et al.1990). This could be particularly relevant in reservoirs that may be augmented by a wastewater reclamation plant which provides a built-in supply of free, controllable nitrate. In the unique case of the Occoquan, moderate levels of nitrate are released into the reservoir because decades of monitoring data clearly show that it is being removed before the water is released downstream (Randall & Grizzard 1995). Figure 2 shows historical data of nitrate levels across the length of the reservoir supporting the case. Sampling station RE30 is located closest to the nitrate release point, while RE02 is closest to the dam at the end.

Depth vs. Nitrate in the Occoquan
August, 2009

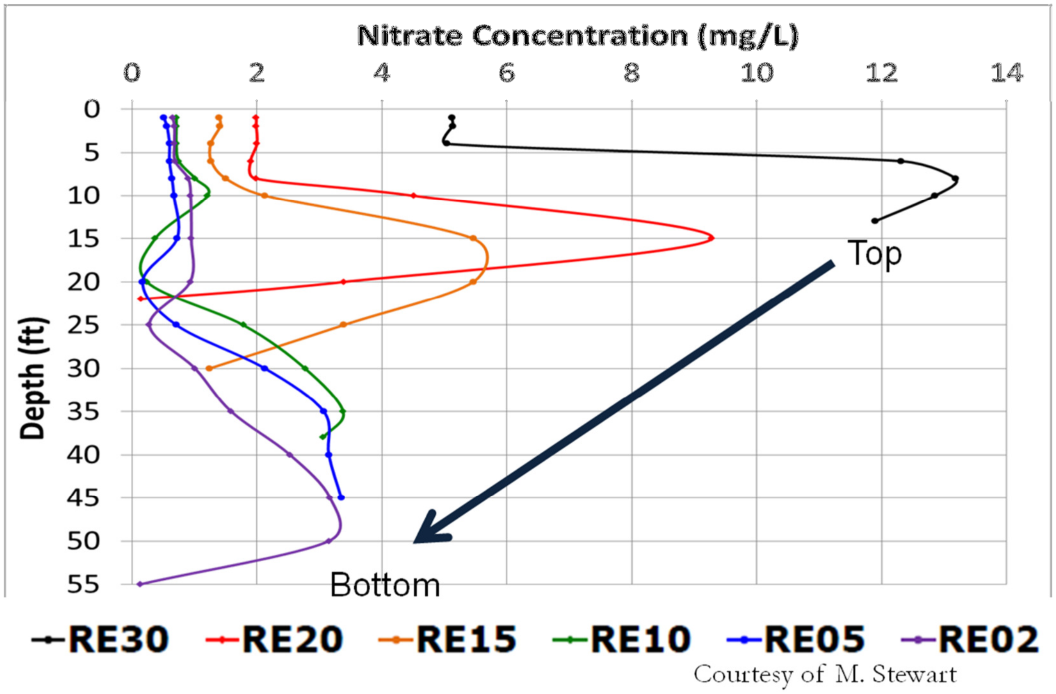


Fig. 2 Historical data from August 2009 of Nitrate levels in the Occoquan. The reservoir gets deeper near the dam at stations RE30. Notice the nitrate plume that hugs the bottom and diminishes along the length of the reservoir.

This project is a case study of the aforementioned Occoquan Reservoir. The Occoquan reservoir system is part of a unique drinking water reuse cycle that supplies water to over 1.5 million people in Fairfax County, VA and the city of Alexandria, VA. The reservoir was impounded in 1957 to supply drinking water to residents in northern VA. As development continued to grow in the previously rural area, it was found that the water quality in the reservoir had degraded considerably. By the early 70's it was determined that the root of this problem was poorly treated effluent stemming from eleven private sewage treatment plants in the Occoquan watershed. To resolve this issue, the Virginia State Water Control Board (SWCB) adopted a policy of water treatment that created the Upper Occoquan Sewage Authority (UOSA) to replace the eleven smaller plants and effectively eliminate sewage as a source of contamination. UOSA operations began in 1978 and continue today meeting the high standards set by the EPA and winning numerous awards for consistently producing water of outstanding quality. It provides for a great study site because of its long history as the first water reclamation plant in the country created for the indirect use as a

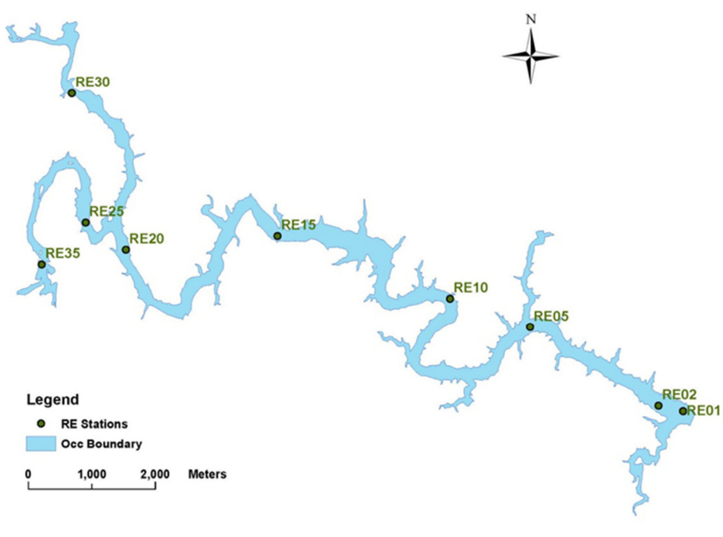


Fig. 1 *Outline of the Occoquan Reservoir; UOSA is located above RE30 while the dam and intake is below RE01.The reservoir is approximately 2.5 miles in length.*
Image courtesy of UOSA

potable source (Rodriguez 2009). For over thirty years UOSA has been measuring the water quality in the effluent discharged to the Occoquan. Additionally, the Virginia Tech Occoquan Watershed Monitoring Lab (OWML) has been working as a third party monitoring establishment since construction of UOSA began in 1973. They also have records of extensive amounts of historical data regarding a variety of water quality parameters throughout the reservoir. Today, the OWML takes samples weekly on the Occoquan at the nine stations depicted in Figure 3. At each station, measurements of a dozen water quality parameters are measured (including nitrate, nitrite and oxygen) at two foot intervals vertically in the water column. Unlimited access to this data makes this a rare opportunity to get a very full picture of what is occurring in the Occoquan. There is a plan to install an oxygenation system in the Occoquan sometime next year at which time another phase of the project will commence.

Objective

The goal of this summer 2011 project is to aid in a larger study investigating whether nitrate is seasonally poising the redox potential in the hypolimnion, and at the sediment-water interface (SWI), of the Occoquan Reservoir. This poising effect, if it is occurring, controls undesirable sediment water fluxes and therefore improves water quality. The field research portion of this project focuses on obtaining in-situ data at the SWI using a unique microprofiling lander manufactured by UNISENSE. Microprofiles of redox potential, dissolved oxygen, pH, and temperature provide an incredibly focused picture of the processes that are occurring at the SWI at the micrometer (10^{-6} m) scale, where important reactions and sediment fluxes take place. Comparable parameters are measured weekly by the OWML, on a macroscale in the water column, from the surface down to a foot above the SWI. This provides valuable background data for the detailed SWI microprofiles. The weekly data collected by UOSA and the OWML include nitrate measurements, as well as other relevant water quality parameters, and this data will be used in conjunction with the microprofiles measured at the SWI. This research will provide a more detailed understanding of indirect drinking water reuse systems and their potential benefits to water quality as well as supply.

A secondary objective of this summers' work was to modify the raw data sets provided by UOSA and the OWML so that they would be more user friendly and conducive to analysis. This was to be done through the use of programming techniques that automate the process of reformatting large volumes of data. During the final analysis, the data from these two sources will be relied upon heavily to help draw conclusions about what is happening in the Occoquan. Having data that can easily be manipulated and graphed is essential to speeding up this process. The following goals were created for this aspect of the project:

1. Create fully functional programs to reorganize data from both UOSA and OWML.
2. Produce user manuals that describe how to use the above programs to someone not versed in Microsoft Excel VBA.
3. Have additional programs that automatically graph several different parameters from the two datasets.

Methods

Several lander field research campaigns on site at the Occoquan reservoir were planned for the summer 2011 stratified season. At the time of this paper, two of the four campaigns have been completed, with another set of campaigns planned for next year's season, after the installation of the proposed oxygenation system. The first campaign commenced on June 19th, 2011 with the teams' arrival in Manassas, VA. Assistance from the Virginia Tech OWML staff was imperative to the success of the campaign, as they provided the boat and also their physical help in lowering the laander to the bottom of the reservoir.

The field day was chosen to be Tuesday June 21st, 2011 because of the availability of the staff and also the correlation with the OWML data which is sampled every Tuesday at the specific site of our data collection. The lander was chosen to be deployed near the uppermost site, RE30 because it is closest to the discharge point from UOSA where nitrate levels are greatest. A dingy was motored out to the

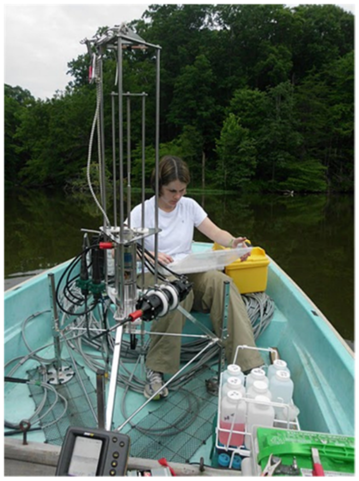


Fig. *4 PhD student Melissa Stewart calibrating sensors prior to deployment, notice solutions in bottles at right.*

selected site, previously scouted for stumps and debris, and anchored for the remainder of the day. A laptop connected to the lander sensors via a cable and an external motherboard was set up to record the voltages output by the sensors, and also to command the motor. Prior to deployment, the microsensors were carefully removed from their protective sheaths and calibrated using premade chemical solutions brought on board. The pH sensor was calibrated using DI solutions of pH 4, 7, and 10 respectively; the DO sensor using an anoxic solution made of sodium ascorbate in sodium hydroxide and a 100% oxic solution of aerated DI water; the temperature sensor, using relatively warm versus cold DI water gauged with a thermometer; and finally, the redox potential using 1g of hydroquinone in solutions of pH 4 and 7 each. After the completion of these preparatory steps, a team of four people and two boats, successfully (no damage to any of the sensors) lowered the lander to the bottom of the reservoir using a rope. The program on the laptop moved the sensors through a total distance of 10cm, three times, collecting data in 10mm increments. Post-analysis of the data collected suggested that the sensors did not completely penetrate the sediment water interface. This was inferred because there was no appreciable change in any of the parameters as was expected. In previous lander campaigns on other water bodies, the level of dissolved oxygen was the target parameter and thus the anoxic boundary layer was used as an indicator of the SWI. Since the entire hypolimnion on the Occoquan was predicted to be anoxic it could not be used to determine the approximate location of the SWI.

A second lander field campaign was conducted on July 12th 2011, following the same procedure as before, with only a variation in the program operating the motor. This new program was designed to cover a greater distance in slightly less detail, and ideally pass through the targeted SWI. During the data collection, early voltage readings on the laptop indicated no significant variations as the sensors were lowered. This suggested the possibility that the lander was tipped over on its side which required it to be re-lowered via the rope. Two more campaigns are scheduled for August and September in order to cover all stages of the stratified period. Unfortunately data from the two initial campaigns is not ready for a full analysis and will not be processed until October.

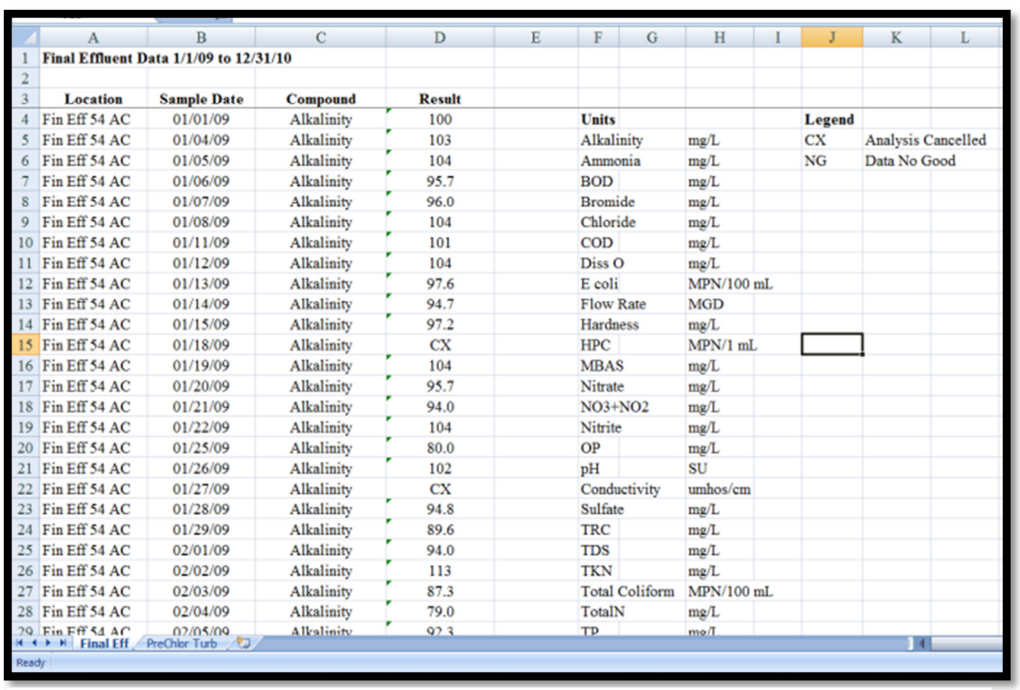
Another aspect of the research group's larger project, which will be completed next year is a 3-D model of nitrate and oxygen plumes' movement along the length of the reservoir. Data from the OWML and from the field research campaigns will be used to validate the modeling efforts. Bathymetry data is an integral part of the modeling process as stated in Singleton et al., and the OWML collected their detailed 5-year bathymetry last year. I gained personal experience with bathymetry data collection assisting graduate student Kevin Bierlein who is preparing to model the effects of bubble plume diffusers in Carvin's Cove Reservoir (CCR) located near Salem, VA. Over a period of three days in June 2011, a series of transects at CCR were taken by tracing zig-zags across the entire surface area of the reservoir, and additionally along the perimeter with a small motor boat. Data from these transects was collected using an Acoustic Doppler Current Profiler (ADCP) and GPS logger which pings sonar to the bottom and back to the equipment marking the depth. The WinRiverII program was used to record the position given by the GPS and the corresponding depth in real-time, effectively producing a 3-D image of the topography of the reservoir when compiled. This same technique will be used for bathymetry collection in the Occoquan this year.

Fig. 5 *Myself at Carvin's Cove Reservoir, assisting with bathymetry this summer.*

Although the raw data from UOSA and the OWML is a fantastic resource, it unfortunately is not documented in a format favorable for analysis. For example, the UOSA dataset is sorted alphabetically by compound (all are listed under "Units" in Fig. 6) and lists concentration levels for every day in a two year period, making the spreadsheet roughly 12,000 cells long (See Figure 6). It also contains some text such as "NG" or "CX" to represent failed tests, as well as many "<" symbols, particularly when levels were below detection limits. Many of the compounds had duplicate entries or certain days when measurements were not taken for some reason. All of these factors limit the graphing capability of the data. For the purpose of this project, which will target certain days or trends, a spreadsheet which contains only numbered data sorted by date is more ideal. The raw data from UOSA is much more simple than OWML simply because of the volume. OWML measures at on average 10 depths for each station at which a dozen parameters are tested, 52 times every year. For that reason the UOSA spreadsheet was used as a learning tool and thus the majority of the work this summer was contributed to that dataset.

Formatting the UOSA data begin with learning how to program in Microsoft Excel VBA (Visual Basic). VBA uses a series of subroutines or macros, to automate computations and any other Excel functions that can be done manually. Each step is a small macro that can be stacked upon another macro to create one master routine. This master macro can perform hundreds of sequential processes in a matter of seconds with just one click of the mouse. To accomplish this, individual macros were created by using the "record a macro" feature in Excel, trial and error, reading Excel help files, and also perusing online forums which often provided sample codes that could be entered and tested. Once a macro that accomplished one task was created, it was saved and tested before moving on to the next one. After several singular macros were created, they were strung together and tested with the original datasheet to ensure that they produced the desired output. The end product was a very long string of code that transformed the original raw data (Figure 6) into the much simpler Figure 9.

In addition to the macros themselves, a detailed manual was produced to work in conjunction to guide any user through the necessary steps and assist with troubleshooting, should something go wrong. A copy of the pre-formatted spreadsheet which the altered data is imported to was also created. This must be uploaded by the user before running the macro. A similar methodology was used to work through the much more complicated OWML data but after several attempts it was determined that there really was no better format for the OWML data, and it would have to remain as is.



	A	B	C	D	E	F	G	H	I	J	K	L
1	**Final Effluent Data 1/1/09 to 12/31/10**											
2												
3	**Location**	**Sample Date**	**Compound**	**Result**								
4	Fin Eff 54 AC	01/01/09	Alkalinity	100		**Units**				**Legend**		
5	Fin Eff 54 AC	01/04/09	Alkalinity	103		Alkalinity		mg/L		CX	Analysis Cancelled	
6	Fin Eff 54 AC	01/05/09	Alkalinity	104		Ammonia		mg/L		NG	Data No Good	
7	Fin Eff 54 AC	01/06/09	Alkalinity	95.7		BOD		mg/L				
8	Fin Eff 54 AC	01/07/09	Alkalinity	96.0		Bromide		mg/L				
9	Fin Eff 54 AC	01/08/09	Alkalinity	104		Chloride		mg/L				
10	Fin Eff 54 AC	01/11/09	Alkalinity	101		COD		mg/L				
11	Fin Eff 54 AC	01/12/09	Alkalinity	104		Diss O		mg/L				
12	Fin Eff 54 AC	01/13/09	Alkalinity	97.6		E coli		MPN/100 mL				
13	Fin Eff 54 AC	01/14/09	Alkalinity	94.7		Flow Rate		MGD				
14	Fin Eff 54 AC	01/15/09	Alkalinity	97.2		Hardness		mg/L				
15	Fin Eff 54 AC	01/18/09	Alkalinity	CX		HPC		MPN/1 mL				
16	Fin Eff 54 AC	01/19/09	Alkalinity	104		MBAS		mg/L				
17	Fin Eff 54 AC	01/20/09	Alkalinity	95.7		Nitrate		mg/L				
18	Fin Eff 54 AC	01/21/09	Alkalinity	94.0		NO3+NO2		mg/L				
19	Fin Eff 54 AC	01/22/09	Alkalinity	104		Nitrite		mg/L				
20	Fin Eff 54 AC	01/25/09	Alkalinity	80.0		OP		mg/L				
21	Fin Eff 54 AC	01/26/09	Alkalinity	102		pH		SU				
22	Fin Eff 54 AC	01/27/09	Alkalinity	CX		Conductivity		umhos/cm				
23	Fin Eff 54 AC	01/28/09	Alkalinity	94.8		Sulfate		mg/L				
24	Fin Eff 54 AC	01/29/09	Alkalinity	89.6		TRC		mg/L				
25	Fin Eff 54 AC	02/01/09	Alkalinity	94.0		TDS		mg/L				
26	Fin Eff 54 AC	02/02/09	Alkalinity	113		TKN		mg/L				
27	Fin Eff 54 AC	02/03/09	Alkalinity	87.3		Total Coliform		MPN/100 mL				
28	Fin Eff 54 AC	02/04/09	Alkalinity	79.0		TotalN		mg/L				
29	Fin Eff 54 AC	02/05/09	Alkalinity	92.3		TP		mg/L				

Final Eff PreChlor Turb

Ready

Fig. 6 *A screenshot of the raw UOSA data, as is. Notice the "Compound" column; this continues alphabetically for each of the twenty-six compounds through the entire two year period. The spreadsheet is 12,000+ cells long*

Results & Discussion

Unfortunately, due to the length of time required for data processing and analysis, no results are yet available from the lander campaigns conducted this summer. Included here is a sample of lander data obtained by former Ph.D. student Lee Bryant in 2008 during her research on Carvin's Cove Reservoir. This is solely to demonstrate the high quality, and extremely detailed SWI profiles that the lander is capable of producing and the type of results expected from the Occoquan. Fig. 7 is a graph of O_2 levels across the SWI during two periods. "HOx on" meaning when the aforementioned oxygenation system (Fig 2) is on, and "HOx off" when it has been turned off. Notice the scale is only that of several millimeters and micromoles and yet there are nearly a hundred data points. The microsensors have created a very clear picture of what is happening to the oxygen. When the oxygenation system is on and preventing anoxia, the hypolimnion doesn't become anoxic until below the SWI (0mm) at which point it quickly goes to zero. Once the oxygenation system is off, it takes little time for the anoxic boundary to extend up through the hypolimnion. Obtaining high resolution results such as this will be necessary to understand how redox potentials, pH, and temperature are playing out at the SWI in the Occoquan.

Depth vs. O2 levels at CCR
August, 2008

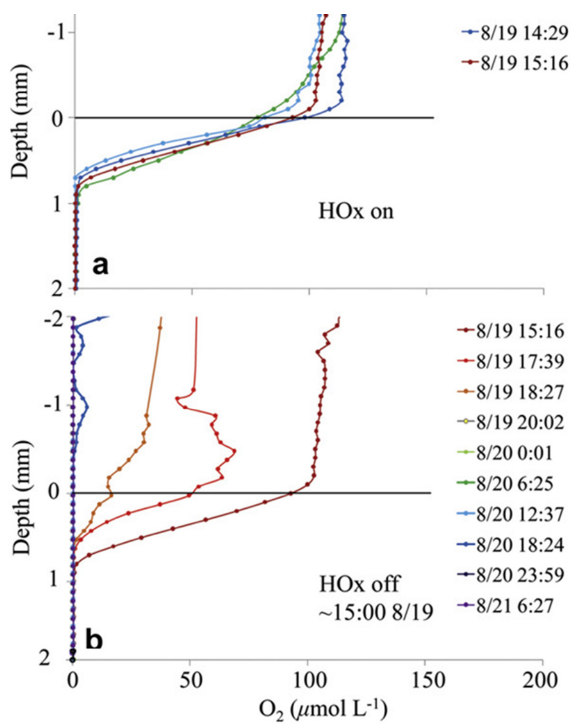


Fig. 7 *A plot of DO levels as a function of depth near the sediment water interface. Notice the scale is only several mm.Figure adopted from Bryant et al. (2011)*

Results from the programming component of the project are summarized by Fig. 8 which is the newly formatted UOSA spreadsheet produced by the complete macro. Notice everything is organized by date, making the spreadsheet much more compact and capable of graphical output if desired. Also, each compound has now been transferred to its own tab so that it is isolated and easily accessible. The most important changes were made using the VLOOKUP function in Excel which transfers each compounds' results from its newly created tab to the final compiled worksheet. Significant alterations made, included removing any duplicate entries, removing less-than signs (<), and also removing any text entries such as CX (test cancelled) and NG (data no good). It is important to keep in mind that the reformatted data set is for analysis only and does not provide the full detail of the raw data. Some compounds that were irrelevant to the study were not included in the final compiled spreadsheet such as flow rate, turbidity, and bacterial counts. The final code has limited flexibility and will not produce results with any other spreadsheet besides the one it was designed for. It is anticipated that the raw data will continue to come in the same form and as long as this is the case, these programs will be practical. The only aspect expected to change is the date of the samples' collection and the number of samples for each compound. These predicted bugs have already been considered for in the program and should not impact its effectiveness.

	Date	Ammonia (mg/L)	DO (mg/L)	COD (mg/L)	Nitrate (mg/L)	NO3+NO2 (mg/L)	Nitrite (mg/L)	TKN (mg/L)	Total N (mg/L)	OP (mg/L)	TP (mg/L)	Flow rate (MGD)	pH	Alkalinity (mg/L)	Cond. (umhos/cm)	TSS (mg/L)	Turbidity (NTU)
2	01/01/09	0.018	9.9	5.6	6.59	6.59	0.0062	0.36	6.98	0.089	0.098	28.09	7.6	100	#N/A	0.3	
3	01/02/09	0.015	10.2	8.8	7.63	7.63	0.0062	0.47	8.1	0.078	0.087	27.75	7.6	#N/A	#N/A	0.3	
4	01/03/09	0.015	10.1	9.6	9.11	9.11	0.0062	0.46	9.57	0.08	0.084	27.97	7.6	#N/A	#N/A	0.3	
5	01/04/09	0.015	9.7	10.5	8.35	8.35	0.0062	0.49	8.84	0.08	0.084	25.81	7.5	103	#N/A	0.3	
6	01/05/09	0.015	9.7	9.2	6.32	6.32	0.0062	0.42	6.74	0.083	0.086	25.69	7.5	104	#N/A	0.3	
7	01/06/09	0.015	9.6	8.7	6.37	6.37	0.0062	0.41	6.78	0.082	0.092	26.9	7.5	95.7	#N/A	0.3	
8	01/07/09	0.015	10.3	8.1	9.49	9.49	0.0062	0.34	9.83	0.084	0.089	41.18	7.5	96	#N/A	0.3	
9	01/08/09	0.015	10.7	6.8	9.94	9.94	0.0062	0.32	10.26	0.088	0.081	47.06	7.5	104	#N/A	0.3	
10	01/09/09	0.015	10.1	7.4	11.49	11.49	0.0062	0.22	11.71	0.083	0.084	40.01	7.6	#N/A	#N/A	0.3	
11	01/10/09	0.015	10.2	8.9	11.62	11.62	0.0062	0.25	11.87	0.087	0.09	39.24	7.6	#N/A	#N/A	0.5	
12	01/11/09	0.015	10	7.4	8.44	8.44	0.0062	0.35	8.79	0.083	0.089	35.24	7.6	101	#N/A	0.3	
13	01/12/09	0.015	10.5	8.3	6.22	6.22	0.0062	0.52	6.74	0.089	0.095	35.24	7.5	104	#N/A	0.3	
14	01/13/09	0.015	10.1	8	9.55	9.55	0.0062	0.36	9.91	0.085	0.085	34.46	7.6	97.6	#N/A	0.3	
15	01/14/09	0.022	10.3	8.1	15.23	15.23	0.0062	0.45	15.68	0.085	0.088	33.86	7.6	94.7	#N/A	0.3	
16	01/15/09	0.024	10.3	7.5	16.94	16.94	0.0062	0.55	17.49	0.11	0.098	33.19	7.6	97.2	#N/A	0.3	
17	01/16/09	0.015	10.6	9.5	18.46	18.54	0.0062	0.54	19	0.087	0.093	28.58	7.6	#N/A	#N/A	0.3	
18	01/17/09	0.015	10.4	8.9	17.3	17.3	0.0062	0.54	17.84	0.1	0.1	29.58	7.7	#N/A	#N/A	0.3	
19	01/18/09	0.015	10.7	9.5	#N/A	12.14	0.0062	0.64	12.78	0.014	0.094	29.04	7.7	0	#N/A	0.3	
20	01/19/09	0.015	10.4	8.1	9.28	9.28	0.0062	0.54	9.82	0.095	0.1	30.14	7.6	104	#N/A	0.3	
21	01/20/09	0.015	10.5	10.4	10.15	10.15	0.0062	0.53	10.68	0.083	0.088	28.34	7.7	95.7	#N/A	0.8	
22	01/21/09	0.015	10.6	9.4	11.63	11.63	0.0062	0.5	12.13	0.077	0.083	27.85	7.5	94	#N/A	0.3	
23	01/22/09	0.015	10.1	8.8	14.55	14.55	0.0062	0.59	15.14	0.079	0.087	28.04	7.7	104	#N/A	0.5	
24	01/23/09	0.015	10.1	9.4	16.24	16.24	0.0062	0.56	16.8	0.044	0.095	25.49	7.6	#N/A	#N/A	0.8	
25	01/24/09	0.015	9.8	9.8	16.17	16.17	0.0062	0.52	16.69	0.097	0.093	28.74	7.7	#N/A	#N/A	0.3	
26	01/25/09	0.015	10	8.7	12.46	12.46	0.0062	0.56	13.02	0.098	0.11	24.52	7.6	80	#N/A	0.3	
27	01/26/09	0.02	10.7	9.3	9.16	9.16	0.0062	0.56	9.72	0.098	0.099	27.46	7.6	102	#N/A	0.3	
28	01/27/09	0.015	10.7	9.1	11.46	11.67	0.0062	0.48	11.94	0.093	0.092	24.27	7.6	0	#N/A	0.8	
29	01/28/09	0.018	9.9	8.7	14.91	14.91	0.0062	0.51	15.42	0.099	0.095	28.47	7.5	94.8	#N/A	0.3	
30	01/29/09	0.015	10.2	8.4	17.17	17.17	0.0062	0.57	17.74	0.088	0.096	30.36	7.5	89.6	#N/A	0.3	

Diss O / Flow Rate / Nitrate / NO3+NO2 / Nitrite / OP / pH / Conductivity / Sulfate / TKN / TotalN / TP / TSS / E coli / Total Colif / Final Eff

Fig. 8 *A screenshot of the compiled data, notice each day only has one entry per compound, any gaps in the data are now listed as #N/A and do not interfere with the graphing process.*

Peer Feedback on Presentations

Throughout the summer we were given opportunities to present our work as it progressed, through 5, 10, and 15 minute presentations given to our group alone. This process culminated in a final 15 minute presentation for our peers, mentors, and any personal guests on the last day of the program. In the first three presentations of the series, we were provided with feedback from our peers regarding the content and quality of our presentation. At the beginning, this feedback was focused around a "take home message", however this seemed to be too vague, as some interpreted that to mean content alone as a measure of how well the presenter communicated their work to the audience. During the second round of presentations the feedback was altered to target keywords as well, although this too, kept much of the focus on content as opposed to quality. Personally, I found that this was informative only in so far that I was aware my audience was understanding the main subject of my talk. This information could have easily been derived from just the title page or the introduction, and thus didn't seem to help much with growth as a presenter. Some of my peers took the liberty of providing aesthetic and communication suggestions for me as well, which is what I found most helpful for improving my presentations skills. I appreciated their honesty which often targeted speaking too quickly and getting out of breath. In future presentations I have taken extra care to rehearse enough so I feel comfortable slowing down the pace. For the third round of presentations, we were asked to have our feedback focus on three questions about the presentation and any suggestions. I believe this version of the feedback process was by far the most helpful. I got a wide range of interesting thoughts and suggestions that I was able to incorporate into the final version of my presentation. Everyone had something constructive to say that really helped me make my presentation much more polished and refined. I wish that the first two rounds had followed a similar format. If I had to make any recommendations for the feedback process it would be to either make the feedback open ended and let each person decide what advice they wish to give, or make a section specifically targeting the quality and comprehensibility of the presentation. It seems that at this level, most presenters at the least are able to inform their audience of their objective, results, and conclusions, rendering "keywords" or factual feedback, somewhat unhelpful as opposed to constructive criticisms. I also found that the feedback from the program directors was incredibly helpful and I wish that I had received their advice prior to the last 15 minute presentation. This is because their suggestions were coming from more experienced presenters and were more concrete than those from my peers. After receiving their feedback I made significant changes that I otherwise wouldn't have and I only wish that I had been able to do that earlier.

Overall, I benefited an incredible amount from this process of building up our presentations from the first 5 minute to the final. Not only did it help me become comfortable with speaking out loud about my project but it was nice to get an early start on the final presentation. The biggest criticism I received was about my tendency to speak very quickly and let my nerves get the best of me and it's been something I've tried to improve. I also had an introduction segment that was a bit too long, but after heavy editing and lots of practice I think I have finally arrived at a point where I have a good balance between each part of my presentation. I also think this process has shown me the importance of good preparation and how beneficial it can be to allow others to critique your work.

Conclusions

Lander & Programming

Due to the timeline of this project, data from the lander campaigns will not be processed and analyzed until October, after the third campaign has concluded and the field work season has ended. Although no conclusions can be drawn at this point regarding nitrate in the Occoquan, the preliminary data looks quite promising. This summer a procedure for lander campaigns was developed and will continue to be used in future campaigns. The lander campaigns completed were overall very successful with only one sensor being damaged and no other accidental mishaps which often can ruin an entire campaign . The progress made in this time period was essential to the completion of the entire project in a timely manner and its future looks very positive.

Regarding the programming component of the work this summer, Microsoft Excel VBA proved to be a well suited platform for the goals set forth. The final products made through this effort will have a significant impact on the future of this project as they will speed up and enhance the data analyzing and comparison process. Faced with a substantial learning curve using Microsoft Visual Basic Editor (VBA), it took several weeks to successfully produce programs that performed as desired. Once this hurdle was overcome, the development of the macros moved forward relatively smoothly. The majority of this work was focused on the simpler raw data set provided by UOSA, and then the skills acquired through that process were applied to help develop a similar program for the much more complex OWML data sets. The macros are efficient so long as the format of the raw data is consistent from year to year. Excel VBA seems to be the most viable form of programming for these purposes, although Matlab was not explored in depth as an option.

Reflection

The project this summer provided an incredible opportunity to partake in relevant and field intensive research with a current Ph.D. student. I had the good fortune to physically assist in the procurement of data that will enable conclusions to be drawn that could potentially impact more than a million people who depend on the Occoquan for their water. This research process gave me hands on experience operating all varieties of equipment used in lake research, those both common and obscure. I also gained knowledge that will serve as a springboard for graduate school or any job in the professional field. I immensely enjoyed the type of research I was able to participate in this summer, and the amount I have learned "by doing" is truly exceptional. The connections I made with my peers and research team will last me a lifetime and I cannot say enough about the positive growth I have made not only as a budding scientist but also as a public speaker.

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I would first like to thank Dr. Lohani for offering me this position and giving me the opportunity to participate in a wonderful research experience. Also; Virginia Tech for hosting us here this summer; Dr. John Little and all the mentors in the CEE department for giving their time and expertise; graduate student Kevin Bierlein and Ph.D. candidate Melissa Stewart for guiding me throughout the summer in my research endeavors; the staff at the VT OWML in Manassas for all their help without whom this project would not be possible; and the Spring Hollow Treatment Facility in Salem, VA for allowing the use of their labs and storage space. Most importantly, the National Science Foundation for providing the funds that support great programs such as this and make them possible for all students.

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References

Bryant, L.D., Gantzer, P.A., & Little, J.C. (2011). Increased sediment oxygen uptake caused by oxygenation-induced hypolimnetic mixing. *Water Res.* In Press, 1-12.

[1]Gantzer, P.A., Bryant, L.D., & Little, J.C. (2009). Effect of hypolimnetic oxygenation on oxygen depletion rates in two water-supply reservoirs. *Water Res.*, *43*(6), 1700-10.

[2]Gantzer, P.A., Bryant, L.D., & Little, J.C. (2009). Controlling soluble iron and manganese in a water-supply reservoir using hypolimnetic oxygenation. *Water Res.*, *43*(5), 1285-94.

Kalff, J. (2002). Limnology: Inland Water Ecosystems. Upper Saddle River, NJ, Prentice Hall.

Randall, C. W. and Grizzard, T.J. (1995). Management of the Occoquan River Basin: A 20-year case history. *Water Sci. & Tech., 32*(5-6), 235-243.

Santschi , P., Höhener, P. et al. (1990). Chemical processes at the sediment-water interface. *Marine Chemistry, 30*, 269-315.

Singleton, V.L., Rueda, F.J., & Little, J.C. (2010). A coupled bubble plume-reservoir model for hypolimnetic oxygenation. *Water Resour. Res., 46*, W12538, doi:10.1029/2009WR009012.

Wetzel, R.G. (2001). Limnology: Lake and River Ecosystems. San Diego, CA, Academic Press

Dissolution of Apatite as a Function of Grain Size

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ABSTRACT

Permeable reactive barriers (PRBs) are a promising method for immobilizing uranium in groundwater. One material under evaluation for use in PRBs is apatite, a phosphorus bearing mineral [$Ca_5(PO_4)_3(F,Cl,OH)$] due to its high sorption capacity for trace elements, widespread availability, and low cost. Previous studies have shown that groundwater that interacts with uranium- and apatite-bearing formations contain a much lower concentration of uranium than expected, due to the formation of autunite [$Ca(UO_2)_2(PO_4)_2 \cdot nH_2O$], a uranyl phosphate mineral that is sparingly soluble. Autunite formation is thought to occur in the leached layer of apatite, as phosphate and calcium released from the dissolving apatite react with the uranium.

To aid in the design of PRBs for uranium immobilization, batch experiments were conducted to determine apatite dissolution rates as a function of grain size. For the experiments, three grain sizes of apatite (149µm-250µm,250µm -420µm, 420µm-841µm) were used. Calcium and phosphate concentrations are measured in solution at specific time intervals during the eight hour experiment. pH and temperature were also monitored. Using calcium as the reaction progress variable, we determined apatite dissolution rates of $2.60 \times 10^{-3} \frac{mmol}{m^2 \cdot min}$, $4.38 \times 10^{-3} \frac{mmol}{m^2 \cdot min}$, and $3.23 \times 10^{-2} \frac{mmol}{m^2 \cdot min}$ with increasing grain size. Calculated dissolution rates were regressed against grain size, but no trend was seen. Data collected from this project can be used to determine the most efficient size of apatite for constructing an effective PRB for uranium immobilization.

Keywords: apatite, remediation, PRBs, uranium

Introduction

Remediation and containment of uranium in aqueous solutions has long been a serious concern due to the serious health complications that may occur from exposure, including kidney dysfunction from chronic ingestion (Wanty et al., 1999). It may also enter the bone structure, where it is a potential carcinogen (Wanty et al., 1999). Uranium contamination of groundwater can occur as a result of industrial waste generation, nuclear fuel processing, and coal pile drainage. It has also led to impediment of potable water use (Fuller et al., 2002). Several techniques have been applied to contaminated aquifers including the “pump-and-treat” method (Figure 1). However, there are several problems with pump-and-treat methods including the requirement to remove large volumes of water to meet mandated regulations, use of active pumps, application of potable water in the remediation process, the presence of geologic complexities like fractures that may hold contaminated water making it difficult to extract, need for aboveground structures, and expensive (Mackay et al, 1989;Morrison et al,2002;Naftz et al.,2002). Due to this, there has been a growing interest in alternative groundwater remediation methods, including the use of Permeable Reactive Barriers (PRBs;Figure 2;Naftz et al.,2002).

One mineral with growing interest for use as a substrate in PRBs is apatite. Two important ions present in apatite are phosphate and calcium, which are critical in the immobilization of uranium. Phosphate has been shown to play an important role in immobilizing trace elements, specifically uranium, by sorption or by precipitation of secondary uranium bearing phosphate minerals (Jerden et al., 2003;Murray et al., 1983). A natural analog for the use of a PRB is the Coles Hill Uranium Deposit, which is located in Pittsylvania County, Virginia and was discovered in 1979 (Figure 3;Marline

Uranium,1983). The concentration profile of uranium at Coles Hill is controlled by the distribution and abundance of different types of phosphate assemblages, which comes from apatite present in the area; apatite is also the most abundant mineral present (Jerden et al., 2003). Analysis conducted by Jerden et al. (2003) suggests that uranium mobilized from the ore during weathering has remained in the saprolite zone (figure 4). The study concluded that the uranium is immobilized during oxidation of the primary ore by the precipitation of a uranium phosphate called autunite ($Ca[(UO_2)(PO_4)]_2$; Jerden et al., 2003). Autunite has low solubility and its dissolution kinetics are slow. Thus, its formation effectively provides a trap for uranium.

As the dissolution of apatite, the source of Ca and phosphate for autunite, is a key factor in determining the efficiency of this type of in situ remediation, understanding its dissolution kinetics is critical. Data collected from this project can be used to determine the most kinetically efficient particle size of apatite for constructing an effective PRB for uranium immobilization.

Background

Mineral Dissolution Kinetics

Apatite has been known to be effective in sequestering dissolved metals to less soluble phases (Arey and Seaman,1999; Jones et al,1998). Other than being one of the most common phosphorus bearing minerals, apatite is being studied because of its high sorption capacity for heavy metals, low solubility of metal phosphates that form following apatite dissolution, and its low cost (Jerden et al,2003). Apatite occurs in three primary forms: hydroxyapatite[$Ca_5(PO_4)_3(OH)$], fluorapatite[$Ca_5(PO_4)_3(F)$], and chlorapatite [$Ca_5(PO_4)_3(Cl)$].

Dissolution rates can either be surface- or transport-controlled. Transport-controlled growth occurs when surface reactions place the atomic units at a very fast rate, so the crystal can grow only as fast as the reactant atoms could get to the surface (Lasaga, 1998). Surface-controlled growth is when the surface reaction rates are exceedingly slow compared to the transport rates, and the overall growth rate is determined by the rate limiting surface reaction(Lasaga, 1998). Therefore, in transport-controlled dissolution, the surface concentration is equal to the solubility of the mineral, and in surface controlled dissolution, the surface concentration is equal to the concentration of the species in the bulk solution (Lasaga,1984). The dissolution rate of apatite has been previously investigated and it was determined that apatite dissolution is surface-controlled. This evidence suggests that there should be small concentration gradients in the reactants within a medium and that the reactant should probably have a low solubility (Lasaga, 1998). This low solubility makes apatite an ideal hosts for toxic metals in the environment, and it also makes it an efficient substrate for PRB remediation (Jones et al., 1998). Surface chemical analyses have also indicated that mineral dissolution is a process controlled by reactions that occur at the surface of the mineral (Lasaga,1984). Temperature also affects mineral kinetics; a system will change from surface controlled to transport-controlled with increasing temperature(Lasaga et al.,1998).

Permeable Reactive Barriers

Currently, a baseline study of the area is being conducted to characterize current conditions. However, Remediating uranium contaminated groundwater is of extreme importance, and understanding the geochemical processes governing the removal are critical. Currently, there is a growing interest in the use of permeable reactive barriers (PRBs) as a form of groundwater remediation. A PRB is an engineered zone of reactive material placed below ground that removes contamination from water flowing through it (Figure 2)(Naftz et al.,2002). The principle behind this method is that contaminants are either immobilized or chemically transformed to a less toxic state by the reactive material present in the PRB. Major advantages of PRBs over a pump-and-treat method are that they may be deployed in remote areas because they require no active pumping scenario since they rely on natural gradients, they do not have to be monitored frequently, and it is projected to be cheaper (Naftz et al., 2002). However, the efficiency of PRBs is controlled by the ability of the material to react with target contaminants, such as uranium. Factors that influence reactivity include dissolution kinetics of the material and the material properties including grain size. Grain size and related surface area can affect dissolution as well as other surface reactions such as adsorption and the results obtained from this study may aid in the construction of PRBs. Remediation of Uranium-contaminated sites is a very expensive process, so by improving understanding of reaction kinetics for apatite, it may be introduced in several applications of remediation.

Methods

Material Characterization and Preparation

The natural apatite used in this study comes from *Ward's*™ *Natural Science* (item number:46-V-0626). The source of the apatite is Ontario, Canada†. Samples were placed in a percussion mortar to reduce the grain size of sample. The samples were then separated into grain sizes of 149µm-250µm, 250µm-420µm, and 420µm-841µm using a series of sieves.

Once the grains were separated, they were cleaned of fine particles using a *Fisher*® Sonic Dismembrator 300. Samples were placed in a 75% ethanol bath. The sonicator ran for several minutes and the supernatant was decanted. This process was repeated until it appeared that the supernatant was clear. The samples were then rinsed with Millipore™ water and then placed in a drying oven for one to two hours at a temperature of 100 ℃.

Although we did not conduct x-ray diffraction on the sample, we believe based on previous knowledge of the location of collection.

Batch Experiments

The dissolution of kinetics of apatite as a function of grain size were determined using batch experiments. Triplicate experiments were conducted using 500 mL Erlenmeyer flasks on a stir table. Two grams of apatite and 500 mL of Millipore™ water were used and mixed at medium to high speed to ensure that the apatite was entrained in solution and this assured that the mixture was adequately mixed. The flasks were sealed using *Parafilm*®**.** Experiments ran for 8 hours and were sampled every half hour for the first hour and then every hour for the remainder of the experiment. At each sampling, six mL of sample were pipetted using a *Finnipipette*®. A new pipette tip was used for each individual flask for every hour of collection. The samples were passed through a 0.22 µm filter and divided evenly into two test tubes for calcium (Ca^{2+}) and phosphate (PO_4^{3-}) analysis. The filters were disposed of after each hour collection. Once a sample was taken, it was placed in a refrigerator to maintain stability of samples for analysis on the following day. Temperature and pH were monitored during the experiment.

Atomic Absorbance Spectrometer

Flame Atomic Absorbance Spectrometry was used in order to determine Ca concentration in experimental solution. Before samples were analyzed, a calibration curve was created using known concentrations. After every 3 samples, a blank sample was tested to assure instrument accuracy. the calibration curve was used to convert the absorbance measurements to concentration. The method detection limit for Ca was determined to be .037 mg/L.

UV/Vis Spectrometer

The Molybdate Method for Phosphate was used to determine PO_4^{3-} concentration using a method modified from Murphy and Riley, 1962; Strickland and Parsons, 1968; Johnson, 1971; Oscarson et al., 1981. This method involves the reaction of the ammonium molybdate in acidic solution with the phosphate ions in the sample to form phosphomolybdic acid. Upon reduction with ascorbic acid, the mixture produces a blue complex. The antimony tartrate is added to increase the rate of reduction. The spectrotometer was set on *fixed wavelength* and the wavelength selected was 880nm. Before samples were analyzed, a calibration curve using known standards was created. The method detection limit was determined to be .002 mg/L.

Calculation of Dissolution Rate

The first step for determining the dissolution rate for apatite is to calculate an average geometric surface area. The geometric surface area was calculated as:

$$A_{geo} = \frac{6V_m}{W_m D_e} \qquad (1)$$

where:

A_{geo}= specific surface area calculated from grain diameter (m^2/g)
V_m = molar volume of flourapatite (m^3/mol)
W_m= molar mass of flourapatite (g/mol)
D_e= average grain diameter (m)

Average grain diameter was derived using:

$$D_e = \frac{D_{max} - D_{min}}{\ln\left(\frac{D_{max}}{D_{min}}\right)} \qquad (2)$$

where:

D_{max}= maximum grain size (μm)
D_{min}= minimum grain size (μm)

Using the values obtained from equations (2), a dissolution rate can be determined using the formula:

$$r = \frac{bV_{soln}}{A_{geo}M_{apatite}} \qquad (3)$$

where:

b= parameter from polynomial fit to data
V_{soln}= volume of solution (L)
A_{geo}= surface area of apatite grains (m^2/g)
$M_{apatite}$ =mass of apatite used in experiment (g)

Results

Concentration vs. Time

The concentration versus time is plotted according to grain size Figure 5 (a-c). Our data for Ca^{2+} is fitted using a 2nd order polynomial, and it does appear to plateau at the end of our 8h experiment. The data are well fitted to a 2nd order polynomial. However, Figure 5 (c) appears to have a slightly different trend than Figure 5 (a-b). Very little deviation is present in this data,

The data for PO_4^{3-} however is not as linear (Figure 6 (a-c)). No trend seems to be apparent and in one case (grain size 420-841;Figure 6 (c)), the concentration of PO_4^{3-} appears to be decreasing. The deviation in the phosphate analysis is much greater than what is seen in the Ca data. However, pH and temperature did increase through the duration of the experiment (table 2(a-c). Rates for 149-250 and 240-420 μm were similar (log r~ -3)(. However, the rate for the largest grain size (420-841μm) was an order of magnitude faster (log r~ -2).

Dissolution Rate Calculation

Using equation (1), an average grain size for each range was determined (table 1). Using this value, we determined dissolution rates for each average grain size by equation 3 (table 1).

Discussion based on preliminary results

Dissolution rates as a function of grain size have not been studied extensively in the past. Most studies also restrict their experiments to other variables including pH, temperature, and type of apatite used (Jerden et al., 2003; Inskeep et al., 1988;Guidry et al., 2003;Jones et al.,1998).

Our data for PO_4^{3-} was not expected, and we were anticipating a general increase in PO_4^{3-}. However, we believe that this may have happened due to adsorption to the surface of the grains or reprecipitation of other minerals like brushite ($CaHPO_4 \bullet 2H_2O$).

Since dissolution rates were normalized to grain size, dissolution rates should have been relatively similar among grain sizes. However, the dissolution rate for the grain size range of 420-841 μm was higher than the other two grain sizes (Table 1). Although few studies have looked at different grain sizes as a function of dissolution in apatite, studies in feldspar dissolution as a function of grain size have seen differences in dissolution rates due to exposed reactive sites (Anbeek,1992). The study also stated that grinding method may also affect dissolution rates (Anbeek,1992).

Future studies can study dissolution as a function of grain size, but also look at specific forms of apatite and determine how that affects dissolution. According to Lasaga (1998), the stirring rate has a significant affect on the transport rate and mechanism; by running experiments at different rates, we can further constrain the application of apatite since the use of PRBS relies on gradients, which prevents the control of water flow. Analyzing a wider array of grain sizes is also crucial since PRBs may be limited to a certain grain size.

Conclusion

In this study, I used batch experiments to determine the dissolution rate of apatite as a function of grain size. Results show that phosphate data did not yield any conclusive results, although it supports the possibility of adsorption or the reprecipitation of another mineral. Future studies can further constrain data presented with this paper, and improve understanding of reaction kinetics of apatite. The data still suggests apatite as an ideal substrate for PRBs, but the implications of phosphate adsorption or reprecipitation must be better understood to determine the effects on autunite precipitation.

Peer Feedback and Presentations

The feedback provided by the interns and Dr. Lohani were very helpful and allowed me to see flaws in my presentation that I was unaware of. I feel the strength of my presentation was aided with this feedback, and I was glad that I was critiqued prior to the final presentation. It allowed me to get comfortable with the material I was discussing and practice my pace. I tend to speak relatively fast when I speak in front of others and by practicing, I was able to slow down to a more appropriate pace.

Acknowledgements

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References

Arrey, J.S., Seamna, J.C., (1999). Immbolization of uranium in contaminated sediments by hydroxyapatite addition.Environmental Sciences and Technology 33,337-342

Drever, James.(1998) The Geochemistry of Natural Waters. New Jersey:Prentice Hall.

Guidry, Michael W. and Fred MACKENZIE. (2003) Experimental Study of Igenous and Sedimentary Apatite Dissolution: Control of pH.,Distance from Equilibrium, and Temperature on Dissolution Rates.*Geochimica*. 67(16).pgs. 2949-2963.

Fuller,C.C., J.R. Bargar, J.A. Davis, and M.J. Piana. (2002) "Mechanisms of Uranium Interactions with Hydroxyapatite: Implications for Groundwater Remediation."*Environmental Science &Technology*.36.2.pgs.158-65.

Inskeep, William P. and Jeffrey C. Silvertooth. (1988) "Kinetics of hydroxyapatite precipitation at pH 7.4-8.4." *Geochimica*.52.pgs.1883-93.

Jerden, James L. Jr, A.K. Sinha, and L. Zelazny. (2003) "Natural Immobilization of uranium phosphate mineralization in an oxidizing saprolite--soil profile: chemical weathering of the Coles Hill uranium deposit, Virgina." *Chemical Geology*.199 pgs.129-57.

Jerden, James L. Jr. and A.K. Sinha.(2006) "Geochemical coupling of uranium and phosphorus in soils overlying an unimined uranium deposit: Coles Hill, Virginia." *Journal of Geochemical Exploration*.91.pgs.56-70

Jerden, J.L. Jr., 2001. origin of uranium Mobilization at Coles Hill Virginia (USA) and its Natural Attenuation within an Oxidizing Rock-Soil-Groundwater System. PhD Thesis,Virginia Polytechnic Institute and State University, Blacksburg,VA

Jerden,James L. Jr., A.K. Sinha. "Phosphate based immobilization of uranium in an oxidizing bedrock aquifer. *Applied Geochemistry*.18.pgs.823-43.

Johnson , DL.1971. " simultaneous determination of arsenate and phosphate in natural waters." EST 5:411-414.

Jones,Valsami E., K.V. Ragnarsdottie, A.Putnis, D.Bosbach, A.J. Kemp, and G. Cressey. "The dissolution of apatite in the presence of aqueous metal cations at pH 2-7. "*Chemical Geology*. (2002)151.pgs.215-33

Mackay,Douglas M. and John A.Cherry. "Groundwater contamination: Pump-and-treat remediation." *Environmental Science & Technology.* 23.6. pgs.630-36

Marline Uranium,(1983). An evaluation of uranium develpoment in Pittsylvania County

Murphy,J. and Riley J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytical Chemistry Acta. 37: 31-36

Murray,F.H., J.R. Brown, W.S. Fyfe, and B.I. Kronberg. "Immobilization of U-Th-Ra In Mine Wastes by Phosphate Mineralization." *Canadian Mineralogist*.21.(1983)pgs.706-10.

Naftz, L.David, Stand J. Morrison,, James A.Davis, and Christopher C. Fuller,eds. Handbook of Groundwater Remediation Using Permeable Reactive Barriers. San Diego: Academic Press,2002. Virginia: report submitted jointly by Marline Uranium and Union Carbide to the Virginia Uranium Administrative Group to the Virginia Uranium Administrative Group to the Virginia

Uranium Administrative Group Pursuant to Section45.1-285.1et seq of the Code of Virginia (1983) (Senate Bill 155), October 15, 1983.

Naftz, L.David, Stand J. Morrison,, James A.Davis, and Christopher C. Fuller,eds. *Handbook of Groundwater Remediation Using Permeable Reactive Barriers.* San Diego: Academic Press,2002.

Nielson MG, Stone J.R, Hansen BP, and Nielson JP. 1995. " Geohydrology, water quality , and conceptual model of the hydrologic system, Saco Maine, USGS WRI Report 95-4027

Oscarson, DW, Huan PM, and Liaw WK.1995. The oxidation of arsenite by aquatic sediments.JEQ9 (4):700-703

Krestou, A., A. Xenidis, and D. Panias. "Mechanism of aqueous uranium(VI) uptake by hydroxyapatite." *Minerals Engineering*.17.373-381.

Lasaga, Antonio C.(1998) Kinetic Theory in the Earth Sciences.Princeton, New Jersey:Princeton University Press.

Lasaga, Antonio C. (1984)"Chemical Kinetics of Water Rock-Interactions." *Journal of Geophysical Research.*89.B6.pgs.4009-25

Ribeiro, Cristina Castro, Iain Gibson, Marion Adolfo Barbosa. (2006) "The uptake of titanium ions by hydroxyapatite particles--structural changes and possible mechanisms." *Biomaterials*.27. pgs. 1749-1761.

Strickland,JDH and Parsons TR.(1968). A practical handbook of seawater analysis. Fish Res. Board Can Bull, 167: Queens Printer, Ottawa, Ontario. 50pp.

Wanty, R.B., Miller, W.R., Briggs, P.H., and McHugh, J.B., (1999).Geochemical processes controlling uranium mobility in mine drainages, in Plumlee, G.S., and Logsdon, M.J., eds., The Environmental Geochemistry of Mineral Deposits: Reviews in Economic Geology Volume 6A: Economic Geology Publishing Company, Littleton, Colorado, pp. 201-213.

Xu, Y., Schwartz, F.W., (1994). "Lead immobilization by hydroxyapatite in aqueous solutions." Journal of Contaminant Hydrology.15, 187-206

Appendix

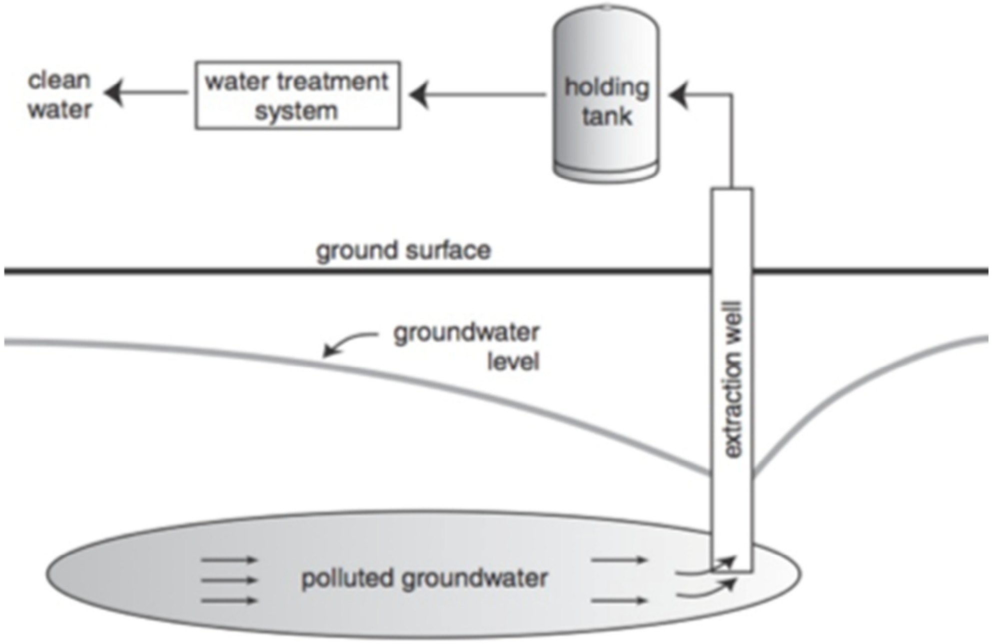


Figure 1: schematic of a Pump and treat system

source:http://remediation.voices.wooster.edu

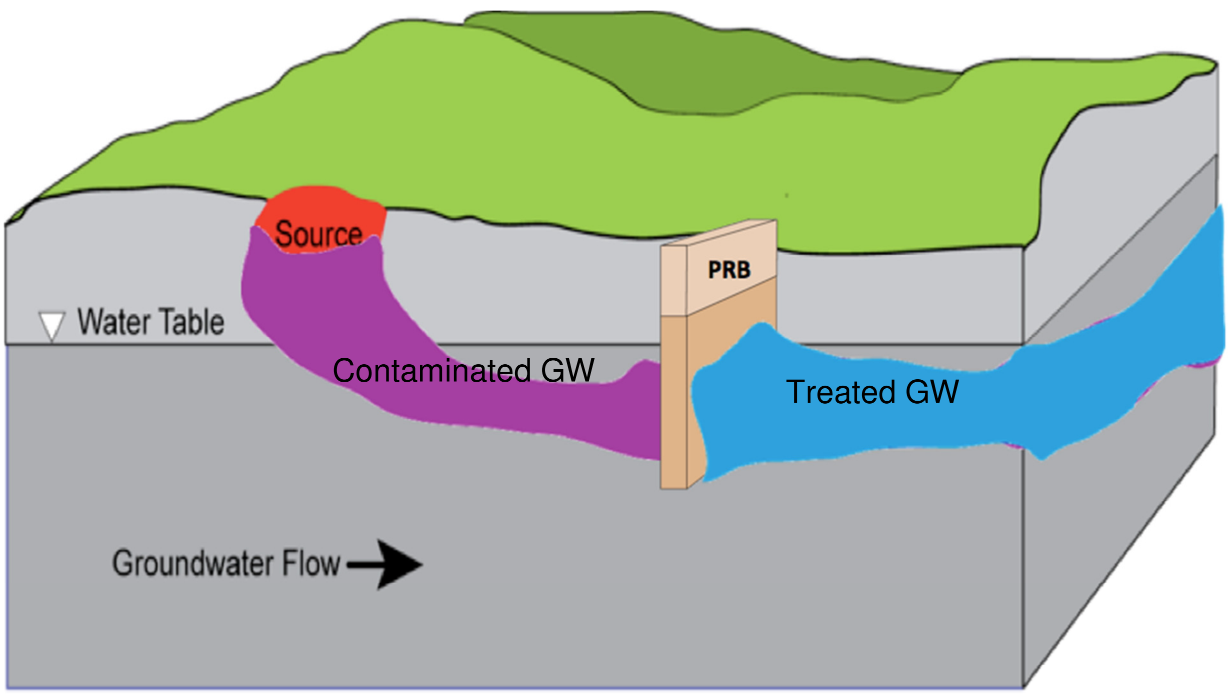


Figure 2: schematic of a PRB

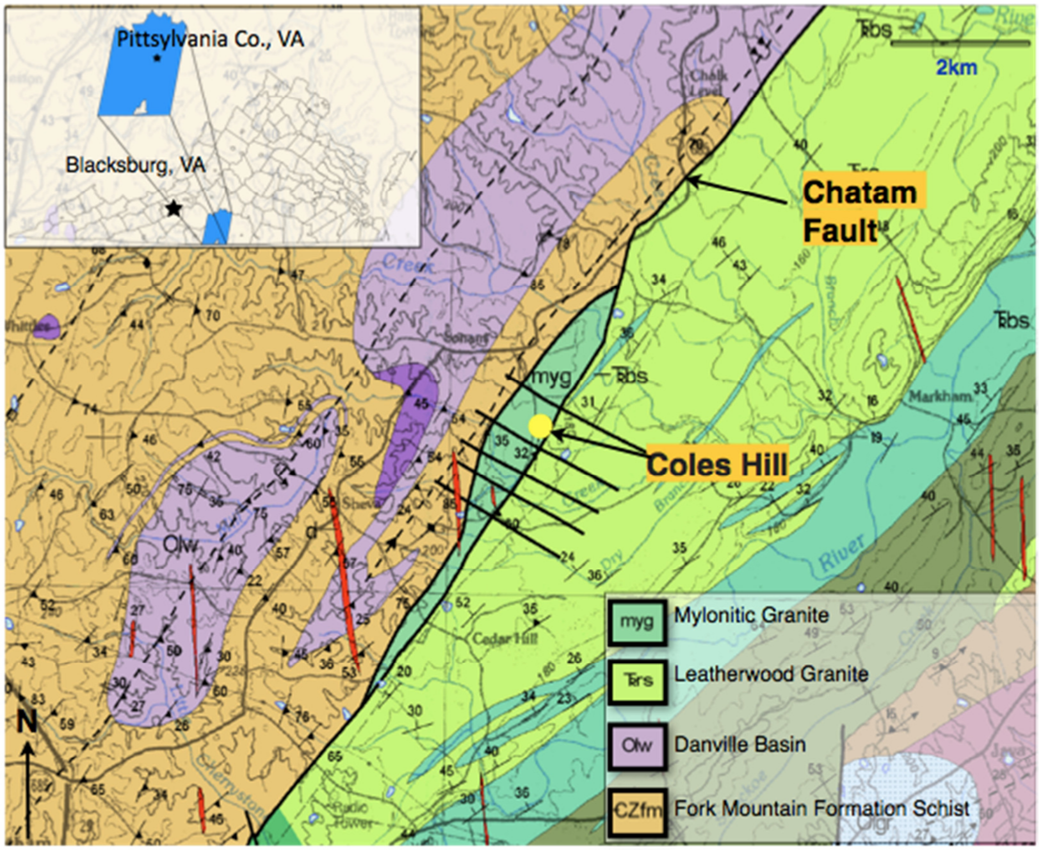


Figure 3:Geologic Map of the Coles Hill Ore

(Henika,2002)

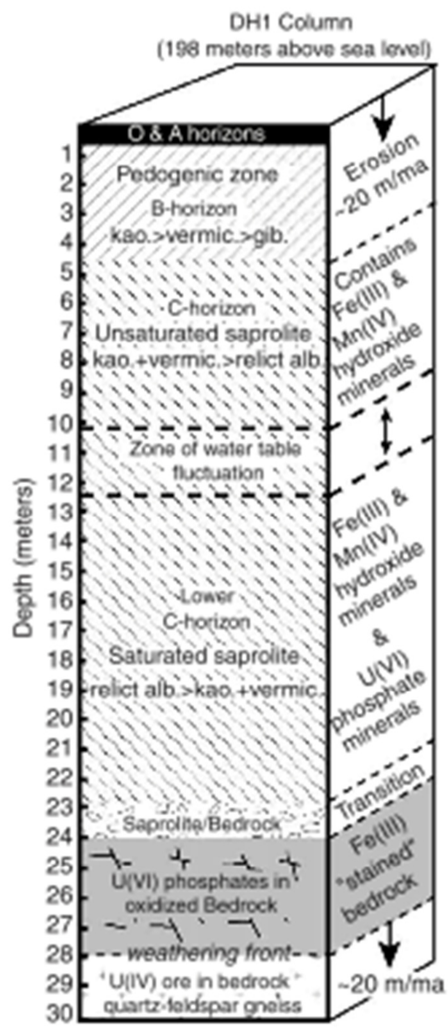


Figure 4: Weathered zones present at Coles Hill

(Jerden et al,2003)

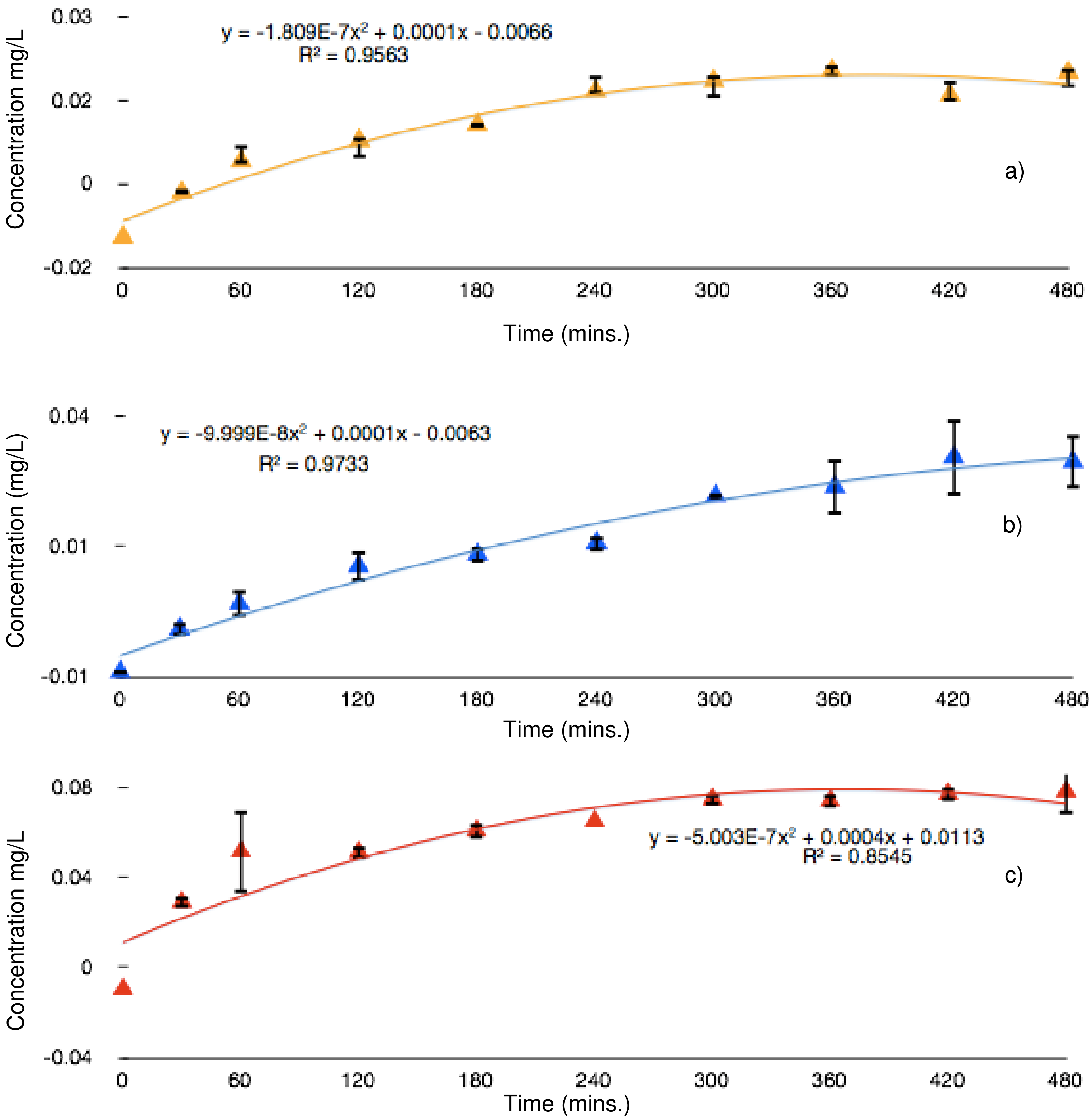
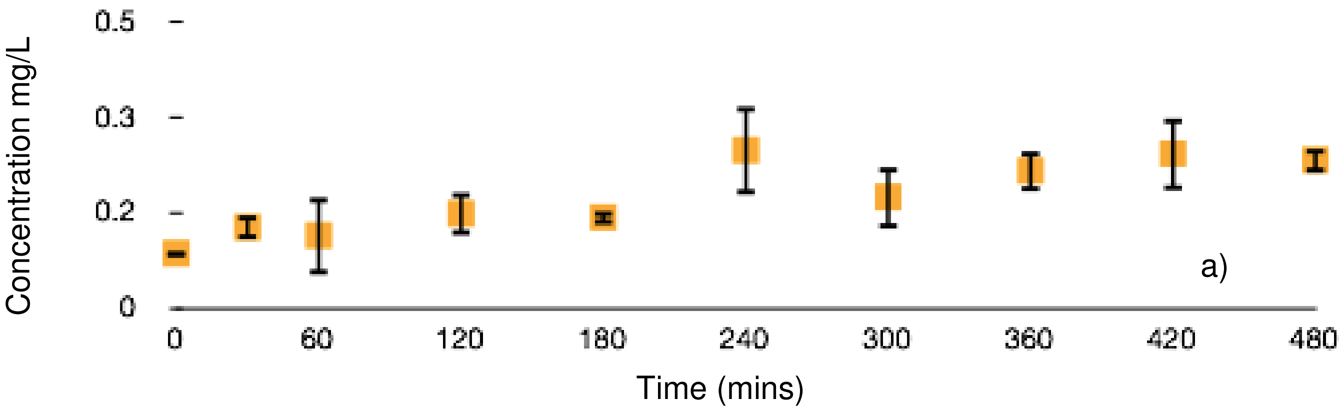


Figure 5: Calcium concentration (mg/L) over time in batch experiments for apatite grain sizes of a) 250-420μm b) 250-420 μm and c) 420-841μm. Data are plotted as averages ± standard deviations from the triplicate experiments



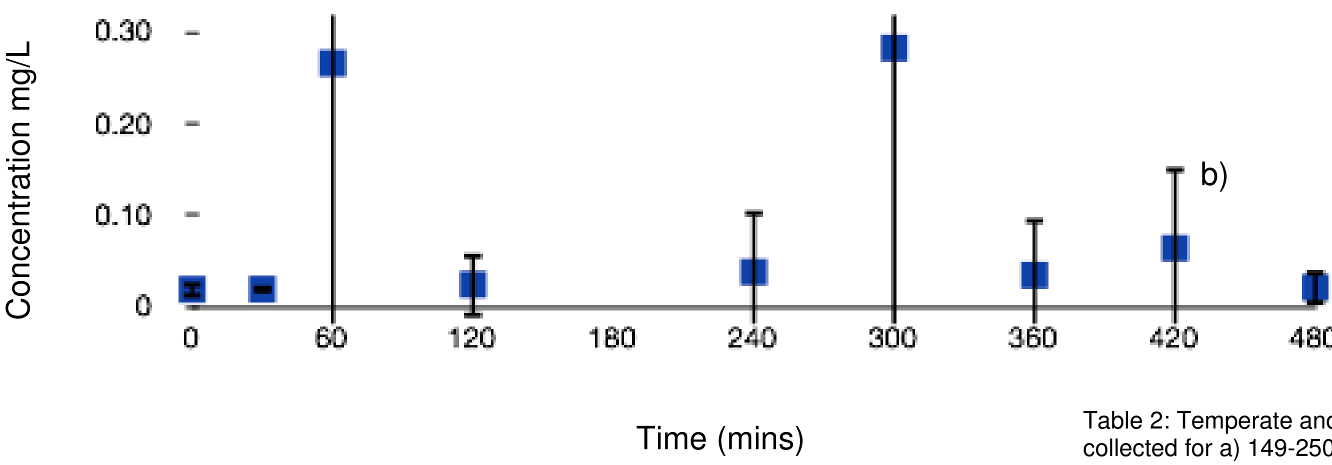


Table 2: Temperate and pH data collected for a) 149-250μm b)250-420 μm and c) 420-841 μm

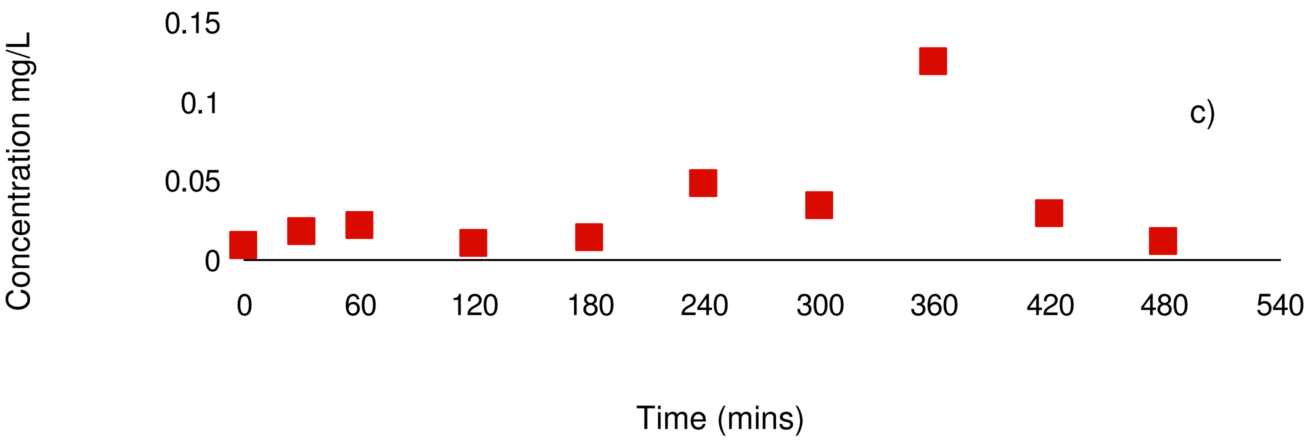


Figure 6: Phosphate concentration (mg/L) over time in batch experiments for apatite grain sizes of a) 250-420μm b) 250-420 μm and c) 420-841μm. Data are plotted as averages ± standards deviations from the triplicate experiments

Grain size range (µm)	Average grain size (µm)	Geometric Surface Area $\frac{m^2}{g}$	Dissolution Rate $\frac{mmol}{m^2 \cdot min}$
149-250	195.16	9.61 x 10^{-3}	2.60E-03
250-420	327.68	5.71 x 10^{-3}	4.38E-03
420-841	604.89	3.10 x 10^{-3}	3.23E-02

Table 1: dissolution rates determined using average grain size

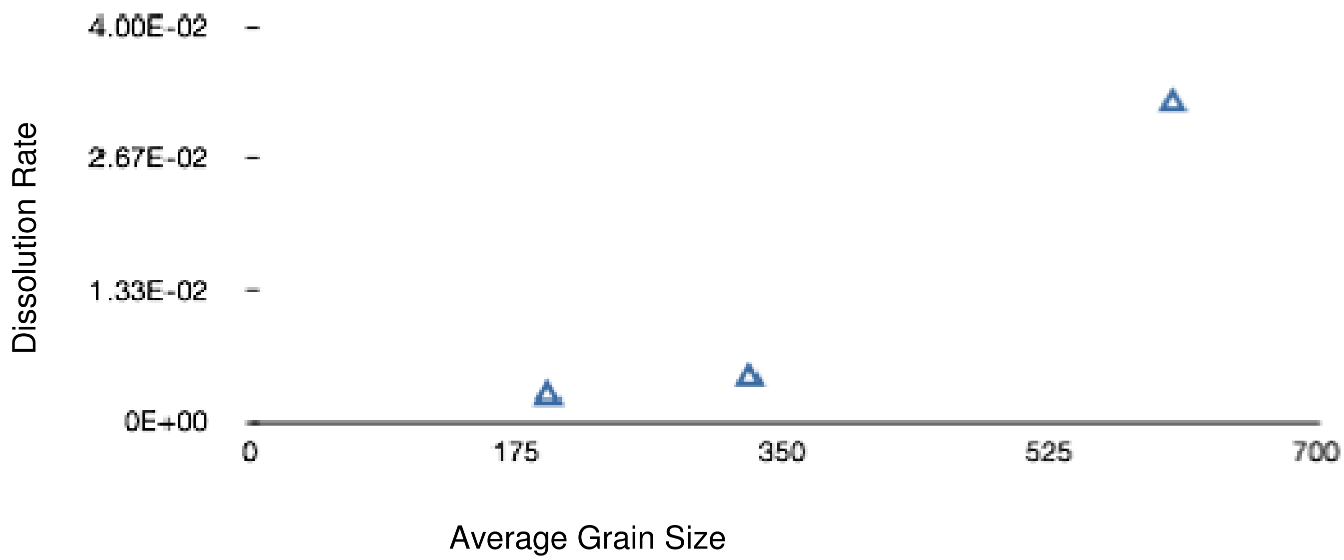


Figure 7: Dissolution rates plotted against average grain size

a)

Table 1: calculated dissolution rates for each grain size range

Time (mins.) grain size:149-250 µm	Temperature (°F)	pH	Ca $\frac{mg}{L}$			Phosphate $\frac{mg}{L}$		
0	72.1	5.18	-0.0382	-0.0382	-0.382	0.1020	0.0901	0.09390
30	72.5	5.37	-0.0626204	-0.8542	-0.0626	0.1559	0.1497	0.1165
60	73.3	5.31	0.1427	0.3024	0.1655	0.2048	0.0826	0.0914
120	75.1	5.55	0.3252	0.3252	0.3100	0.2060	0.1566	0.1315
180	76.5	5.64	0.4393	0.3927	0.4241	0.1610	0.1440	0.1685
240	77.2	5.89	0.7587	0.7131	0.6674	0.2869	0.3446	0.1923
300	77.8	5.93	0.6903	0.7815	0.7359	0.1728	0.2562	0.1516
360	78.2	6.18	0.8271	0.8500	0.8119	0.2067	0.2782	0.2330
420	78.9	6.22	0.5534	0.5990	0.6370	0.2117	0.2569	0.3383

b)

Table 2(a-c): pH and temperature data

Time (mins.)grain size: 250-420 µm	Temperature (°F)	pH	Ca $\frac{mg}{L}$			Phosphate $\frac{mg}{L}$		
0	-	5.54	-0.3592	-0.382	-0.3592	0.0237	0.0080	0.0255
30	-	5.35	-0.0170	-0.1082	-0.0854	0.0225	0.0218	0.0137
60	75.1	5.68	0.0058	0.1884	0.1199	-0.0083	0.7833	0.0237
120	76.8	5.85	0.3024	0.4849	0.3024	0.0613	0.0224	-0.0107
180	78.1	6.15	0.3937	0.5077	0.4393	-	-	-
240	79.4	6.59	0.5306	0.5762	0.4621	-0.0045	0.0450	0.1183
300	80.1	7.02	0.8271	0.8500	0.8728	0.8059	-0.0139	-0.0027
360	80.2	7.24	1.0100	1.0325	0.6903	0.1058	0.0218	0.0118
420	80.2	7.34	1.397	1.0781	0.8728	0.0036	0.0218	0.1666
480	80.3	7.28	1.1694	1.215	0.8728	0.0062	0.0143	0.0431

c)

Time (mins.) grain size:420-841 µm	Temperature(°F)	pH	Ca $\frac{mg}{L}$			Phosphate $\frac{mg}{L}$		
0	72	5.43	-0.382	-0.382	-0.382	0.0139	-0.0032	0.0170
30	72.5	8.67	1.055	1.261	1.1693	0.0252	0.0024	0.0239
60	73.2	8.32	2.926	1.6713	1.6028	0.0227	0.0212	0.0208
120	73.2	8.47	2.128	1.8994	2.1047	0.0227	-0.0095	0.0183
180	76.4	8.51	2.2644	2.538	2.4926	0.0139	0.0137	0.0139
240	77	8.57	-	2.6066	2.6066	0.0866	0.0431	0.0139
300	77.5	8.51	2.9032	2.9488	3.1085	0.0973	-0.0101	0.0139
360	78.2	8.45	3.0401	3.0401	2.8120	0.0139	0.0231	0.3373
420	78.6	8.11	3.109	3.1998	2.9488	0.0145	0.0180	0.0540
480	79.1	8.24	3.154	3.5192	2.6979	0.0139	0.0074	0.0139

Characterizing the Effects of Macropores on Hyporheic Zone Hydraulics in Meander Bends

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ABSTRACT

The hyporheic zone is the area beneath and adjacent to stream beds where the mixing of surface water and shallow groundwater occurs within sediment. Surface water tends to be high in dissolved oxygen with large diel temperature fluctuations, while groundwater tends to be low in dissolved oxygen and high in inorganic solutes with relatively constant diel temperatures. The mixing of these two water bodies can create unique conditions that attenuate pollutants, cycle nutrients, and buffer surface water temperatures. These functions of the hyporheic zone are important to stream ecosystems, aquatic organisms, and overall water quality. Evidence suggests that flow through connected voids (macropores) may play an important role in water and solute exchange and potentially affect hyporheic zone functions. However, no studies have been undertaken to address this, presumably because macropores are difficult to locate and characterize. Here we present data collected across a well-defined meander bend to quantify the effect of a 3cm-diameter constructed macropore on meander bend hydrology and solute transport. Tests were performed when macropore was present and also after macropore was partially plugged with clay. Solute tracer tests showed 28% faster travel times and 25% greater peak tracer levels down-gradient of the macropore compared to the partially plugged macropore. Electrical Resistivity Imaging (ERI) was utilized to track the tracer flowpaths through the meander bend over time. Data generated from ERI indicated the tracer was preferentially transported when the macropore was present and was more dispersed after we partially plugged the macropore. Falling-head tests across multiple depths and locations verified these results with hydraulic conductivities near the constructed macropore 18x higher than average. These results provide strong evidence that macropores act as preferential flowpaths and may therefore have a profound impact on hyporheic zone function in meander bends and in turn, stream health and water quality.

Keywords: Hyporheic zone, macropore, electrical resistivity imaging, hydraulic conductivity

Introduction

The hyporheic zone is the area beneath and adjacent to stream beds where surface water and shallow groundwater mix (Triska et al 1989). The surface stream supplies organic matter and dissolved oxygen while sediment provides high interstitial surface area, enabling biogeochemical reactions and pollutant attenuation within pores spaces and on sediment interfaces (Boulton 1998). Additionally, hyporheic exchange may lag, buffer, or decrease thermal extremes in the surface water. These hyporheic zone functions benefit water quality and create new habitat, yet are conceivably limited by hyporheic flow rates (Arrigoni et al 2008). Darcy's Law is commonly used to determine hyporheic flow rates via $Q = KiA$ ("K" is the hydraulic conductivity, "i" is the hydraulic gradient, "A" is the cross-sectional flow area). Of these variables, transport rates are highly dependent on the hydraulic conductivity which can vary over 8 orders of magnitude in space and time. This variability leads to water preferentially traveling along paths of least resistance in the sediment matrix. Spaces entirely devoid of media theoretically have the highest K. Enlarged or connected void spaces called macropores may therefore dominate hyporheic flow paths and exchange.

While there has been previous research on the importance of macropores in general, there are few studies specifically within the hyporheic zone. Several studies have focused on macropores formed due to bioturbation by macroinvertebrates (Mermillod-Blondin et al. 2004, Nogaro et al. 2006). *Beven and Germann* explored the effect macropores have on water flow in soils. The formation of macropores through fractured bedrock has also been observed (Freeze and Cherry 1979, Domenico and Schwartz 1998). Evidence from such studies suggests that flow through connected voids plays an important role in water and solute exchange and could potentially affect hyporheic zone hydraulics in meander bends. However, no studies have been undertaken to address this. Here we present data collected across a well-defined meander bend to quantify the effect of a 3cm-diameter constructed macropore on meander bend hydrology and solute transport. Electrical Resistivity Imaging (ERI) was utilized to track the tracer flowpaths through the meander bend over time while Solinst level, temperature and conductivity loggers (LTCs) measured the conductivity in nearby monitoring wells. Falling-head tests across multiple depths and locations were conducted to determine hydraulic conductivities. Hydraulic head gradients were also measured with and without the macropore present. A tributary of Tom's Creek at Heritage Park in Blacksburg, VA was the selected research site.

Research Methods

Study Site

The study site is located in Blacksburg, VA at a small tributary of Tom's Creek in Heritage Park (Figures 1 (a) and (b)). The site has well defined meander bends which make it easy to control hydraulic gradients across the meander by construction of an instream weir. The tributary also has a reliable flow and is free of large cobbles which make favorable conditions for creating artificial macropores.

Figure 1(a): Location of tributary in relation to Blacksburg **(b)** Location of tributary in relation to Tom's Creek

The site had been used to conduct prior research in 2010. During this time nine groundwater wells were installed; three upstream, three downstream, one at the meander bend, one in the floodplain, and one in the stream bed (Figure 2). An artificial macropore was created starting on the upstream side of the meander and directed downstream toward well #4 as shown in Figure 2(a). Upon returning to the site in Summer 2011 the condition of the wells were inspected, the macropore was recreated, and the weir was reinstalled. During this time it was also noted that a naturally occurring macropore about 3 cm in diameter and 1 m deep had formed .3 m to the left (when looking downstream) of the artificial macropore (Figure 2a).

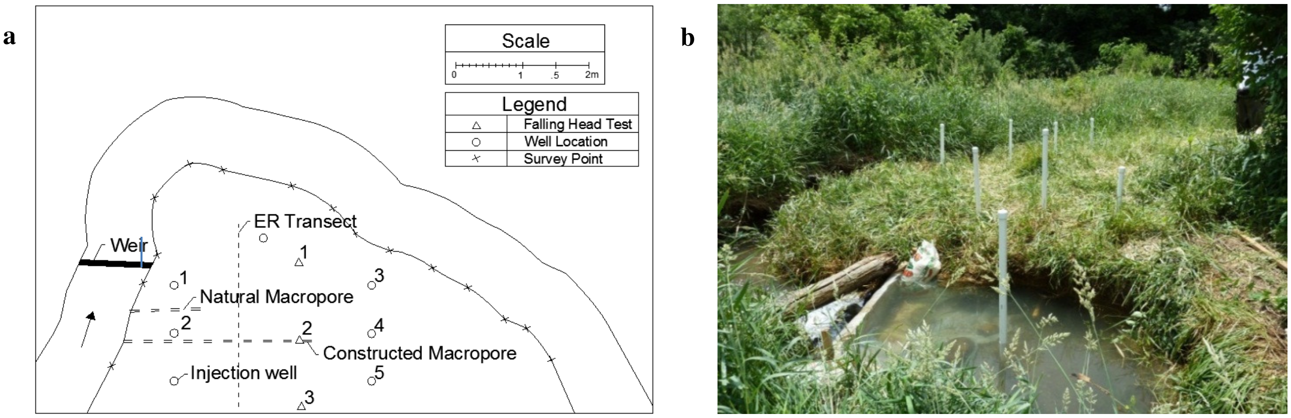


Figure 2: **(a)** Plan view schematic of field site layout. **(b)** Field site looking downstream. All wells are displayed with the exception of the floodplain.

Solute Transport

Solute tracer tests were used in conjunction with ERI testing to track how water moves through the macropore and the hyporheic zone over time. A salt tracer solution was used because it decreases resistivity along its path of travel. The hypothesis was that the macropore would exhibit a dramatic decrease in resistivity over time because it acts as a preferential flow path for the tracer. To perform the experiment, the pre-mixed salt solution was dripped into an upstream well at a steady rate up-gradient and upstream of the macropores. A HOBO pressure transducer was installed in the floodplain to monitor atmospheric pressure, taking readings every 15 minutes. Solinst LTCs recorded conductivity to confirm the tracer presence and travel through the meander bend. Water levels were determined by correcting pressure data from the LTCs for atmospheric pressure. The LTCs were placed at 5 well locations (Figure 2(a)) and the resulting data show the temporal and spatial trends of the tracer transport (discussed later).

Electrical Resistivity Imaging

Electrical Resistivity Imaging is a geophysical technique where electrical current is driven into the subsurface and voltage is read to estimate the spatial and temporal distribution of subsurface electrical resistivity (Ward et al 2010). Combined with a salt tracer, ERI allows for the identification of different soil types and preferential flowpaths. In our study, we first used ERI to characterize the background conditions of the sediment matrix before any tracer solution was added. Salt solution was injected over 6.5 hours and tracer flowpaths were tracked over time using ERI. ERI was performed with the macropore present and again when the macropore was partially plugged, as a control.

ERI data were collected along the transect line (Figure 2a) using an IRIS Syscal Pro Resistivity Meter. Twelve metal stakes, called electrodes, were driven about 6 inches into the ground along the transect line (Figure 3a) and serve as locations to inject current and read voltage. A single resistivity value is calculated by injecting current at two electrodes and reading voltage at two other electrodes, called a quadripole(Figure 3b). The spacing between the two current electrodes determines the depth of sediment that is investigated; the greater the separation, the deeper the penetration. For each scenario, with and without the macropore, 118 quadripoles were collected to measure background conditions, and 118 quadripole sets after tracer injection began to track the flowpaths of the solute. The meander bend was given sufficient time to flush out the tracer solution between the two macropore configurations. The generated resistivity data is used to create a model showing the conductance throughout the sediment matrix.

a

b

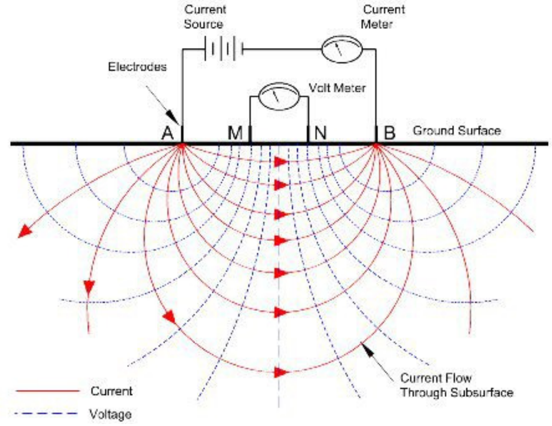


Figure 3: (a) ERI transect line. **(b)** Basic schematic of ERI process (source: http://www.nga.com/Geo_ser_DC_tech.htm)

Falling Head Tests

Falling head tests were conducted at various depths and locations in order to verify the data produced from ERI and to determine accurate hydraulic conductivity values for the sediment matrix. Three locations were chosen across the meander bend; directly in the meander bend, directly above the macropore, and in the floodplain.

The tests were first performed using a custom built multi-level piezometer (Figure 4a). Holes of a particular size and spacing were drilled into a PVC pipe, creating a well screen. Then a smaller PVC pipe was inserted into the larger one and moved up and down to expose desired length of well screen. Unfortunately several problems were encountered while implementing this instrument. The auger hole was slightly larger than the piezometer which led to short circuiting, causing water that was added to escape through the top of the borehole. Also, the thickness of the sediment shield surrounding the well screen did not allow water to flow through the piezometer at a high enough rate. After considering possible solutions it was decided that a Solinst drive-point piezometer would be a more accurate tool to implement the falling head tests (Figure 4(b)). First, the three locations were marked and measured using the wells already in place as references (Figure 2(a)). The first test was performed in the location directly in the meander. The piezometer was driven into the ground until the 8cm well screen was just below the surface of the water table. Water was then added until it reached the brim of the piezometer and was held at a constant level for ~10 seconds. A InSitu pressure transducer was used to collect the atmospheric pressure, to measure background water depth, and to measure the water depth in the piezometer as the test progressed. Measurements were taken every 0.250 seconds. The data were sent directly to a field computer and the results were displayed in a depth v. time graph. The method was then repeated for every 4~8 cm interval of soil depth until the piezometer was about 1.2 meters below the water table. The process was repeated in the floodplain and directly above the location of the partially plugged macropore. Then all three tests were repeated with the macropore present.

A

B

Figure 4: (a) Custom built multi-level piezometer. **(b)** Drive point piezometer. It consists of a metal drive-point with 8cm well screen attached to a 1.27 cm diameter metal pipe 2.5 m long. The piezometer was driven to a desired depth using a drive hammer and metal head cap.

Results and Discussion

Electrical Resistivity Imaging

The generated resistivity data were inverted to create a cross-sectional model showing the resistivities throughout the sediment matrix beneath the ER transect. Figure 5 (a) and (b) display the results of the background ERI data collected. The constructed macropore is located at X=0, Z=-0.4. The geologic structures in A and B are quite similar with and without the macropore. However, it is evident that areas near the macropore show to be less resistive. A naturally occurring macropore was found at X=.5, Z=-0.3 and was left unchanged through the experiment. The region above and to the left of the artificial macropore that appears to be more conductive in B was holding excess water which saturated the area during storm events.

Figure 6 is a time elapsed display focused on the area near the macropore from the start of the tracer injection. It can be seen in the case of the constructed macropore that the lower resistivity due to the tracer is more centrally focused within the macropore whereas it is more spread out for the partially plugged macropore. This indicates the tracer is preferentially transported in the macropore location for the constructed macropore scenario. The partially plugged macropore (right column) appears to act less as a preferential flowpath, with greater dispersion and solute tracer penetrating to the natural macropore (centered near X = 1.0 m, Z = -0.5 m) and deeper into the subsurface.

Solute Transport

Figure 7 plots the levels of conductivity, measured from the Solinst LTCs, versus the time since the drip began. These results confirm that the macropore acts as a preferential flowpath and dominates the transfer of solute to the downstream mid well (#4). The plots of wells 3-5 show the solute reached the well sooner when the macropore was present than when it was partially plugged. Higher peaks in conductivity were also seen when the macropore was present. This shows that less solute was transported through the preferential flow path when the macropore was partially plugged. Solute was actually not transported to wells #1 and #2 and these results are consistent with conductivity measurements taken in stream. The sharp variations in conductivity are due to a storm event that occurred between hours 5 and 10 since the drip started.

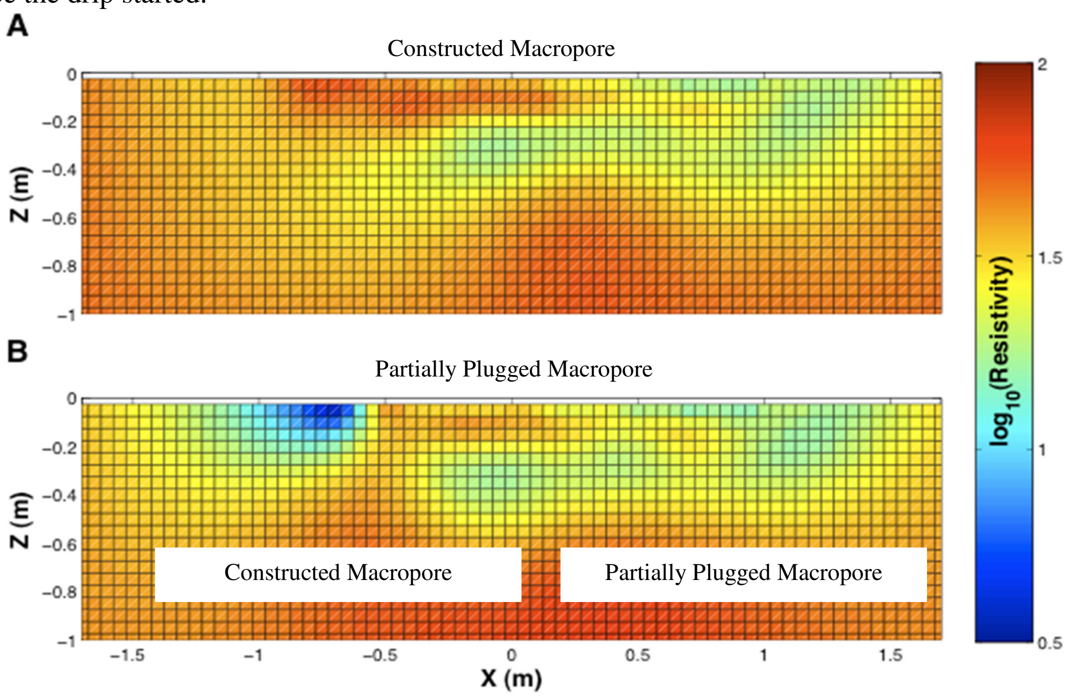


Figure 5: (a) Background (no tracer) electrical resistivity images for the surface-connected macropore. (b) Background electrical resistivity images for the disconnected macropore

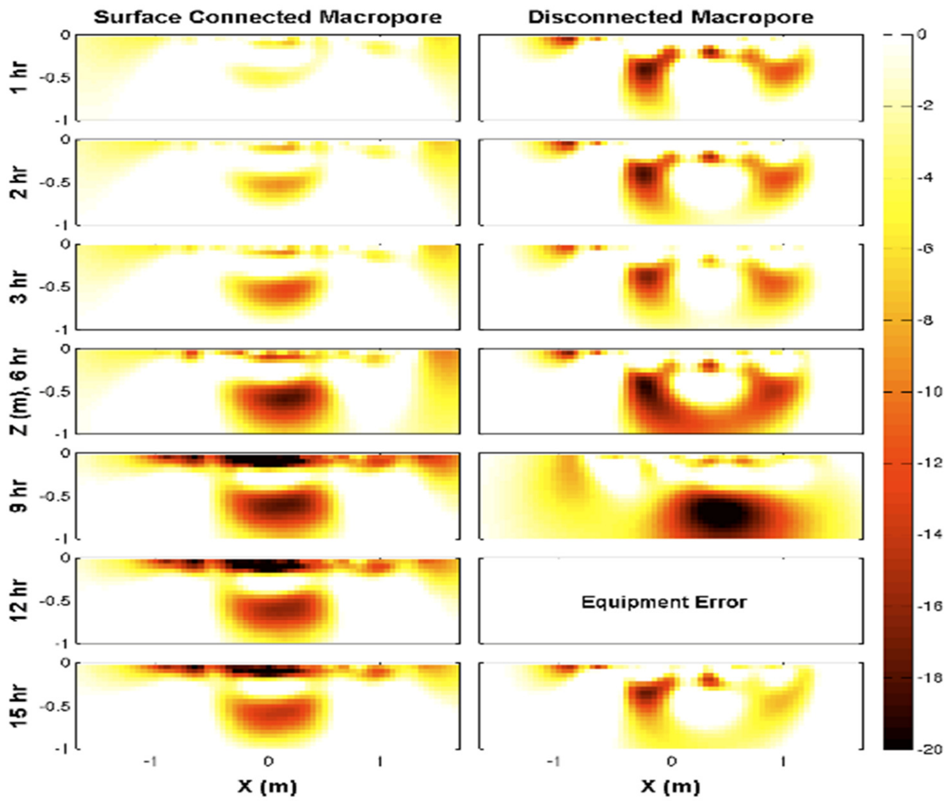
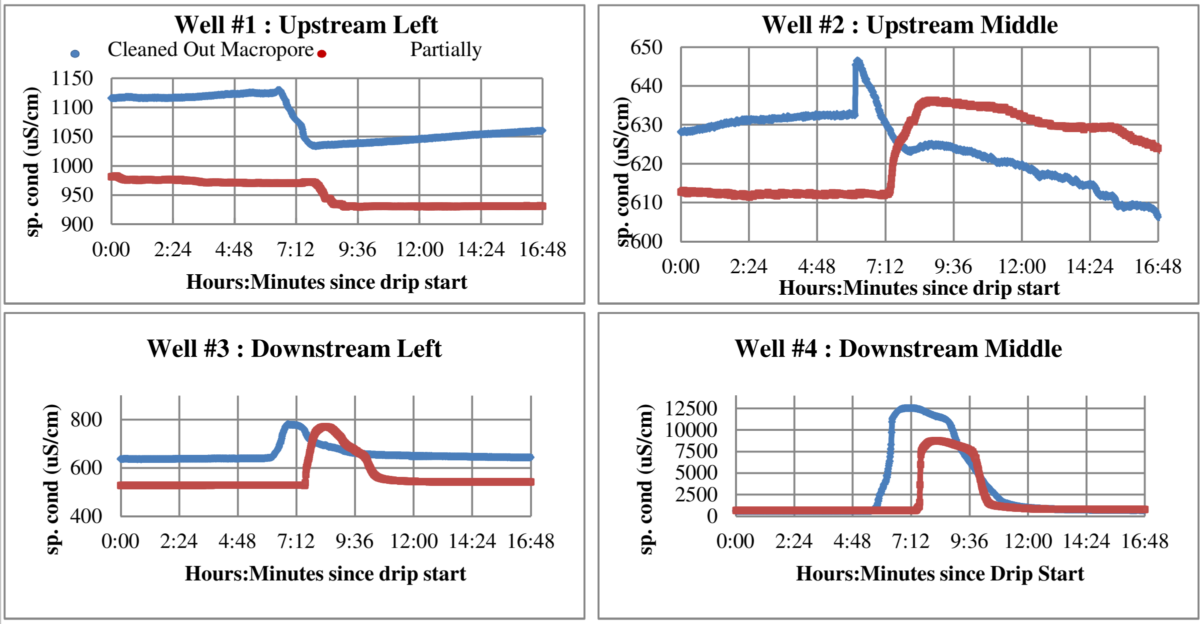


Figure 6: Time-lapse electrical resistivity imaging during salt tracer movement through the meander bend for the constructed macropore (left column) and partially plugged macropore (right column) scenarios. Color indicates the decrease in electrical resistivity due to the tracer (as percent change from background).



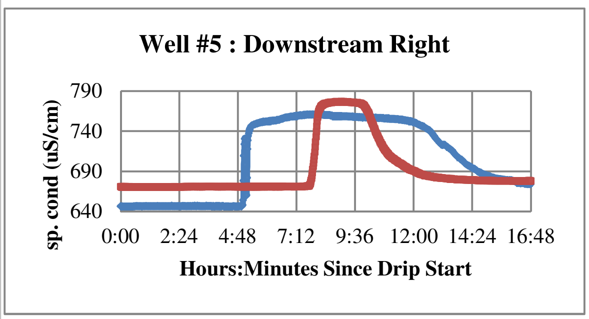


Figure 7: Influence of Macropores on Solute Transport. Each chart displays the conductivity versus time since the drip started for each of five wells. Blue indicates the constructed macropore scenario and red represents the partially plugged macropore

Hydraulic Gradients

This study also addresses the effect of macropores on hydraulic head gradients in meander bends. Head gradients were calculated from recorded hydraulic heads for the cases of a constructed macropore and a partially plugged macropore. A large storm event affected the data from hours 5-10 since the drip started. Disregarding the data taken during this time, an increase of 27% from the partially plugged scenario was observed from well #2 to #1(Figure 4) when the macropore was present. The head gradient also increased by 8% from well #2 to #4 with the macropore present. These results indicate that the macropore increased the head gradients of the meander bend and as a result is pulling water in from the stream. Figure 8 reflects the head gradients between wells #1, 2, and 4.

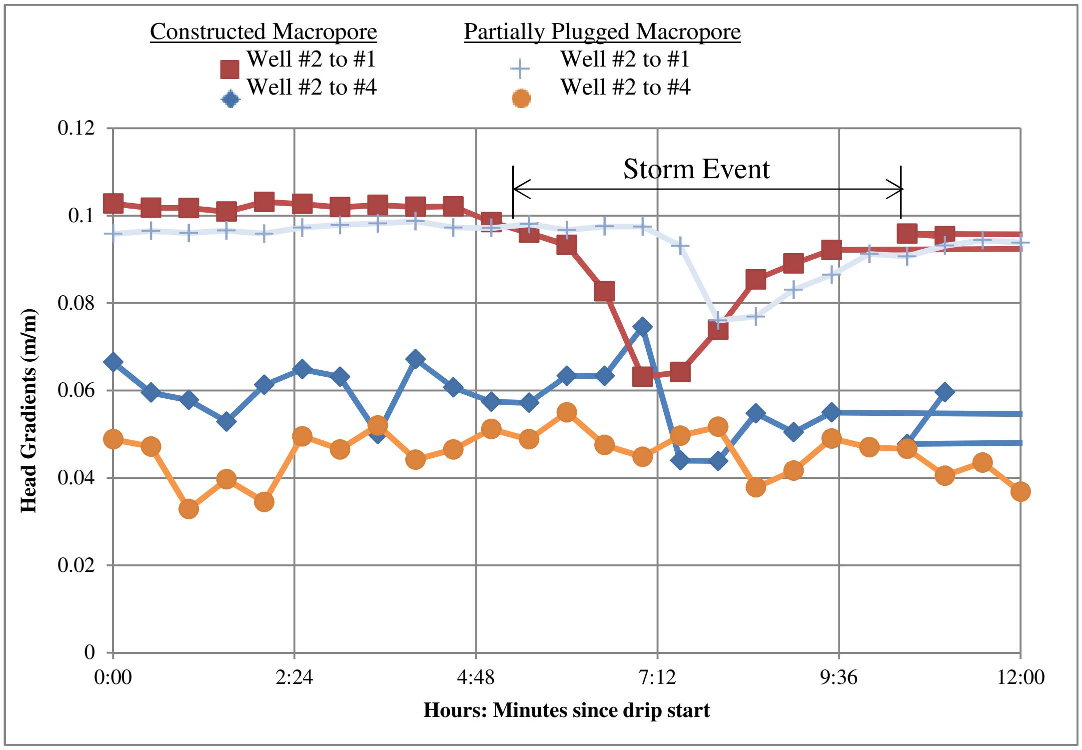


Figure 8: Influence of macropores on hydraulic gradients. Hydraulic head gradients were calculated from recorded hydraulic heads for the cases of a constructed macropore and a partially plugged macropore.

Falling Head Test

Figure 9 displays the hydraulic conductivity results of the falling head tests performed at the meander, directly above the macropore, and in the floodplain. Results show large variations in hydraulic conductivity for various depths at each location. It is evident that the hydraulic conductivity rapidly increases where any portion of the well screen overlaps the macropore. This increase is 18x greater than the average of all the data points collected at the macropore location.

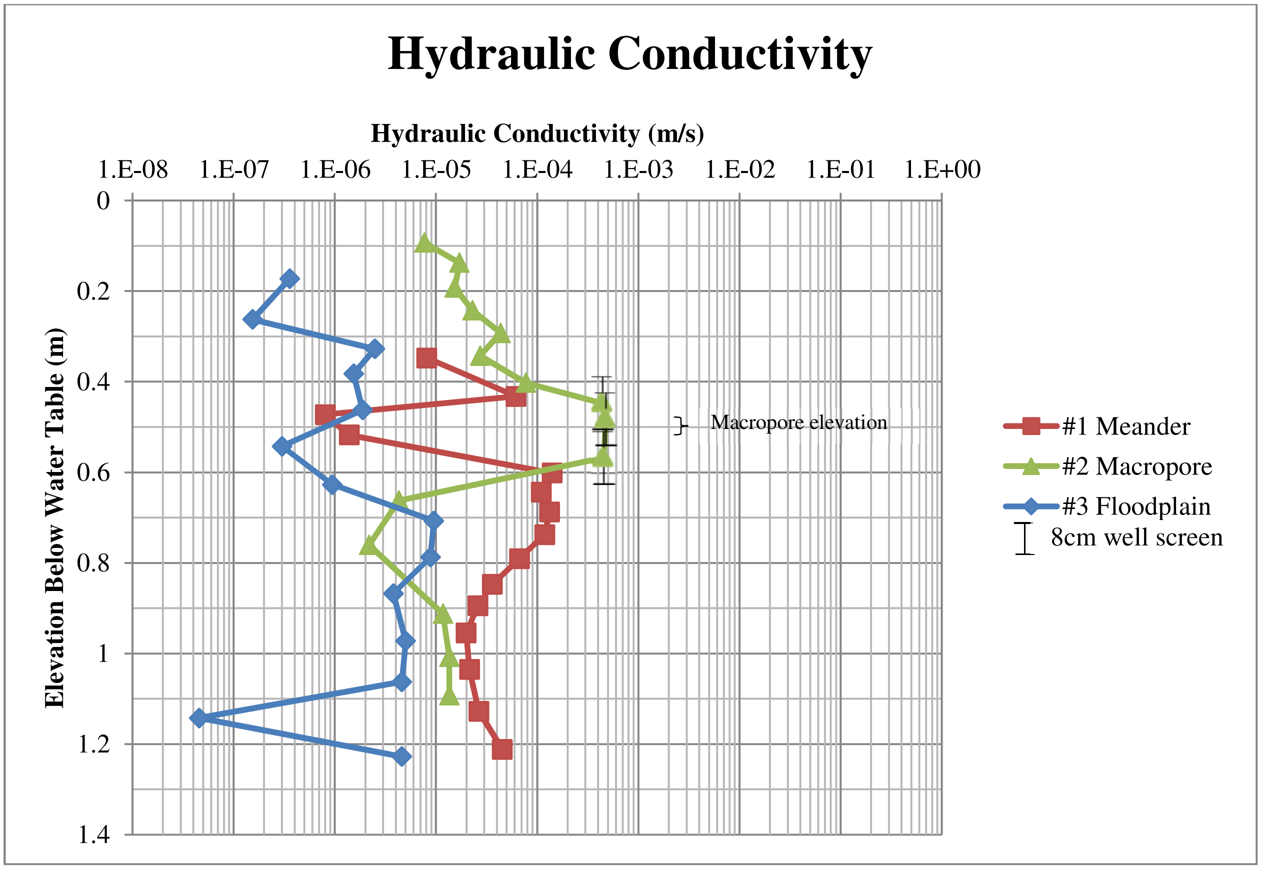


Figure 9: Hydraulic conductivity across the meander bend

Peer Feedback on Presentations

5 – min feedback

From the primary author's viewpoint the feedback for the first presentation, given on June 10, was somewhat helpful. Many of the students were still confused on what areas the feedback was intended to cover. The suggested method of listing keywords and the main point of each presentation was a good idea for this first presentation since there was not a lot of information to present. Much of the comments received indicated that more detail needed to be provided to define words that may be unfamiliar to the audience and to provide background on testing methods. This was helpful in developing the PowerPoint for the next presentation.

10 – min feedback

For the second presentations on July 8th, implementing the same method of feedback was not quite as effective. If the overall flow, presentation style, and visual appeal had been assessed instead of only the key words and main point that came across to the audience it would have been more helpful. The feedback received indicated that the main ideas had been clearly communicated to the audience but unfamiliar terms needed to be more clearly defined.

15 – min feedback

The feedback for the 15 minute presentations on July 29th was very helpful in modifying the PowerPoint for the final presentation. The questions asked revealed what was not clearly communicated to the audience through the presentation. The suggestions were also helpful in improving the aesthetics of the presentation and the presentation style. Making corrections noted in the feedback also helped to boost confidence for the final presentation.

Conclusion

A single macropore constructed in a meander bend in a low order stream has proven to have important implications to solute transport and meander bend hydrology. Salt tracer injections showed the macropore acted as a preferred path, exhibiting 25% greater peak tracer levels, and enabled 28% faster travel times when compared to the case of the partially plugged macropore. Electrical resistivity imaging also demonstrated high temporal resolution allowing us to see preferential transport in the constructed macropore and slower, dispersed transport for the partially plugged macropore. Falling head tests showed significantly higher (18x) hydraulic conductivites than the average at the location of the constructed macropore. These results provide strong evidence that macropores act as preferential flowpaths and may therefore have a profound impact on hyporheic zone function in meander bends and in turn, stream health and water quality. Future studies should be undertaken to address the hydraulic significance of macropores on the reach and watershed scales. Furthermore, studies should be performed to identify the effects of macropores on ecological functions of the hyporheic zone, including biogeochemical cycling, pollutant attenuation, and surface water temperature buffering.

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References

Arrigoni, A.S., G.C. Poole, L.A.K. Mertes, S.J. O'Daniel, W.W. Woessner, and S.A. Thomas. 2008. Buffered, lagged, or cooled? Disentangling hyporheic influences on temperature cycles in stram channels. Water Resources Research. **44**:13

Beven, K., and P. Germann. 1982. Macropores and Water Flow in Soils. Water Resources Research 18:1311-1325.

Boano, F., C. Camporeale, R. Revelli, and L. Ridolfi. 2006. Sinuosity-driven hyporheic exchange in meandering rivers. Geophysical Research Letters **33**.

Boulton, A. J., S. Findlay, P. Marmonier, E. H. Stanley, and H. M. Valett. 1998. The functional significance of the hyporheic zone in streams and rivers. Annual Review of Ecology and Systematics **29**:59-81.

Domenico, P., and F. Schwartz. 1998. Physical and chemical hydrogeology. John Wiley and Sons, Inc., New York, NY.

Fetter, C.W. 1988. Applied Hydrogeology. Merrill Publishing Company. Columbus, Ohio. Pg. 571

Freeze, R. A., and J. A. Cherry. 1979. Groundwater. Prentice-Hall, Inc, Englewood Cliffs, NJ.

Mermillod-Blondin, F., J. P. Gaudet, M. Gerino, G. Desrosiers, and M. C. des Chatelliers. 2003. Influence of macroinvertebrates on physico-chemical and microbial processes in hyporheic sediments. Hydrological Processes **17**:779-794.

Nogaro, G., F. Mermillod-Blondin, F. Francois-Carcaillet, J. P. Gaudet, M. Lafont, and J. Gibert. 2006. Invertebrate bioturbation can reduce the clogging of sediment: an experimental study using infiltration sediment columns. Freshwater Biology **51**:1458-1473.

Northwest Geophysical Associates, Inc. “DC Resistivity Technique.” Web. 11 July 2011. <http://www.nga.com/Geo_ser_DC_tech.htm>

O'Connor, B. L., and J. W. Harvey. 2008. Scaling hyporheic exchange and its influence on biogeochemical reactions in aquatic ecosystems. Water Resources Research **44**.

Triska, F. J., V. C. Kennedy, R. J. Avanzino, G. W. Zellweger, and K. E. Bencala. 1989. Retention and Transport of Nutrients in a 3rd-Order Stream in Northwestern California - Hyporheic Processes. Ecology **70**:1893-1905.

Ward, A. S., M. N. Gooseff, and K. Singha. 2010. Imaging hyporheic zone solute transport using electrical resistivity. Hydrological Processes **24**:948-953.

Reducing Problems Associated with Partial Replacement of Lead Service Lines

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ABSTRACT

Galvanic cells produced by partial lead service line replacements can put consumers at risk of elevated lead in water. The use of a dielectric has been considered as a possible solution to the problems of galvanic corrosion, but it can also decrease the effectiveness of electrical grounding and increase the likelihood of electrocution. Both of these problems can be circumvented by use of a grounding strap to maintain electrical continuity with use of a sufficiently long dielectric to decrease the extent of galvanic corrosion. A 3" dielectric and a 12" dielectric (with a grounding strap) reduced the galvanic current by 50% and 75%, respectively. Lead in water could be reduced by 75% with a 12" dielectric with a grounding strap. It is possible to reduce galvanic corrosion during partial service line replacements without compromising the effectiveness of the electrical ground.

Keywords: Copper, Lead, Galvanic Corrosion, Current, Dielectric

Introduction

The potential harmful effects of lead contaminated drinking water have been understood since the 1850's and include infant mortality, neurological effects, and digestive problems (Triantafyllidou, 2011). From the 1850's until around 1950, lead service lines were often used to connect homes to water mains. The total number of lead service lines as of 1950 was unknown, but the estimated number was around 3.3 million service lines installed in the United States (Triantafyllidou, 2011).

In 1991, the United States Environmental Protection Agency finally attempted to reduce lead in water hazards US EPA, 2011) via the Lead and Copper Rule (LCR). This rule stated that if the maximum concentration of lead in potable water was 15 ppb in more than 90% of high-risk homes sampled, actions including public education, corrosion control and lead service line replacement are required to reduce consumer exposure to lead (US EPA, 2011). Initially, 100% of the lead service line was to be replaced in homes, but the water industry successfully argued that they were responsible for replacing only the portion of the lead pipe up to the service line (Renner, 2010). Consequently, when lead service line replacement occurs, only the portion owned by the water utility is replaced, resulting in a "partial" lead service line replacement.

It was initially hoped that replacing part of the lead pipe would reduce lead in water. However, there is no data confirming the effectiveness or benefits of partial replacements, which can cost between $850 and $7,000 per home. Indeed, in recent years researchers have become concerned that partial replacements might actually increase the lead in water due to galvanic corrosion (Sandvig, 2008).

Galvanic Corrosion

Galvanic corrosion arises whenever two different metals are electrically connected and immersed in water (Francis, 2001). A potential difference between the two metals results in a galvanic current; one metal is protected while the other is sacrificed. All galvanic cells have two different metals and some form of electrolyte (i.e., water) for electrons and charge transfer. This potential difference is measured as voltage. The characteristics of the metals are what determine which metal will be oxidizing into solution and which metal will be reduction cite. The defining characteristic is the reaction potential. These reaction potentials are generally given in values of half reactions. Metals with low reduction potentials fall under the reducing agent category, and therefore will easily oxidize while metals with high reduction potentials fall under the oxidizing agent category, and will easily reduce. Oxidation and reduction refers to the ionic charge of the ion. When the ion is reducing the ionic charge becomes more negative. Ions that are oxidizing have ionic charges that are becoming more positive which indicate that the metal is going into solution. Reduction potentials of metals considered in this experiment can be found in the table below (Nave, 2010).

Table 1 - Reduction Potentials of Metals

Cathode Half-Reactions	Standard Potentials E (volts)
Fe 2+(aq) + 2e- -> Fe(s)	-.41
Pb 2+(aq) + 2e- -> Pb(s)	-.13
Cu 2+(aq) + e- -> Cu+ (aq)	.16
Cu +(aq) + e- -) Cu(s)	.52

The reducing aspect of this reaction is where galvanic corrosion becomes problematic. The term galvanic corrosion comes from the unwanted depletion of the anodic metal.

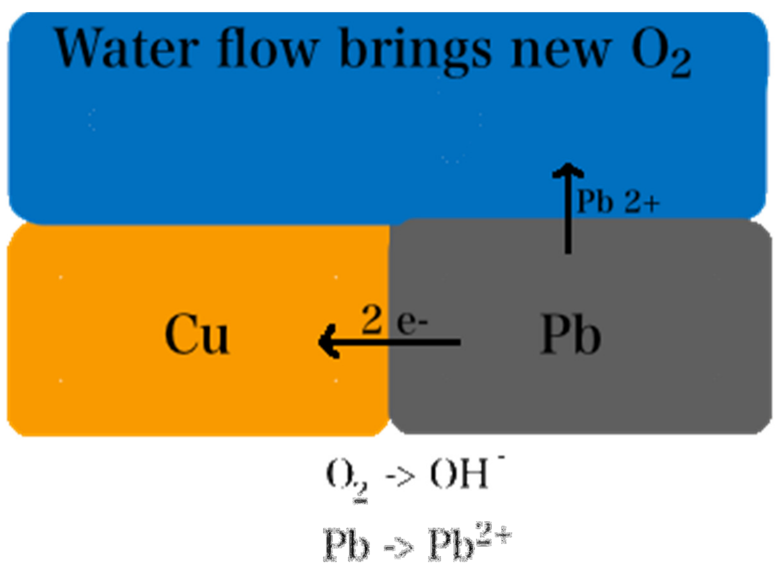

Figure 11 - Typical Copper-Lead Galvanic Cell

Figure 1 shows the chemistry behind galvanic corrosion in partial replacements. The replacement causes a reaction potential difference causing the anode, in this cell it is lead, to be sacrificed as the galvanic cell takes the electrons from the pipe. This not only causes direct corrosion of lead into the water, but over time creates lead rust that can come of due to the flow of the water causing lead concentration spikes at unknown times.

Dielectrics

The idea of putting a dielectric separating the lead and copper, to stop galvanic corrosion because it prevents electrical contact between the two metals, has been proposed. But the dielectric can make grounding less effective, unless a grounding strap is also installed to maintain electrical continuity and prevent electrocution of consumers. It was initially assumed that use of a grounding strap in conjunction with a dielectric, would completely defeat the purpose of a dielectric. However, to the extent that increased distance between the dissimilar metals can increase the electrical resistance for internal corrosion, benefits might still be achieved (Figure 2). If it were possible to identify a length of dielectric that would reduce or eliminate galvanic corrosion, while a grounding strap was installed, it could be possible to reduce lead in water and the likelihood of galvanic corrosion while still meeting the electrical code.

The goal of this research is to explore whether or not insertion of longer dielectrics between two dissimilar metals, can reduce galvanic corrosion and the level of lead in drinking water when a grounding strap is used.

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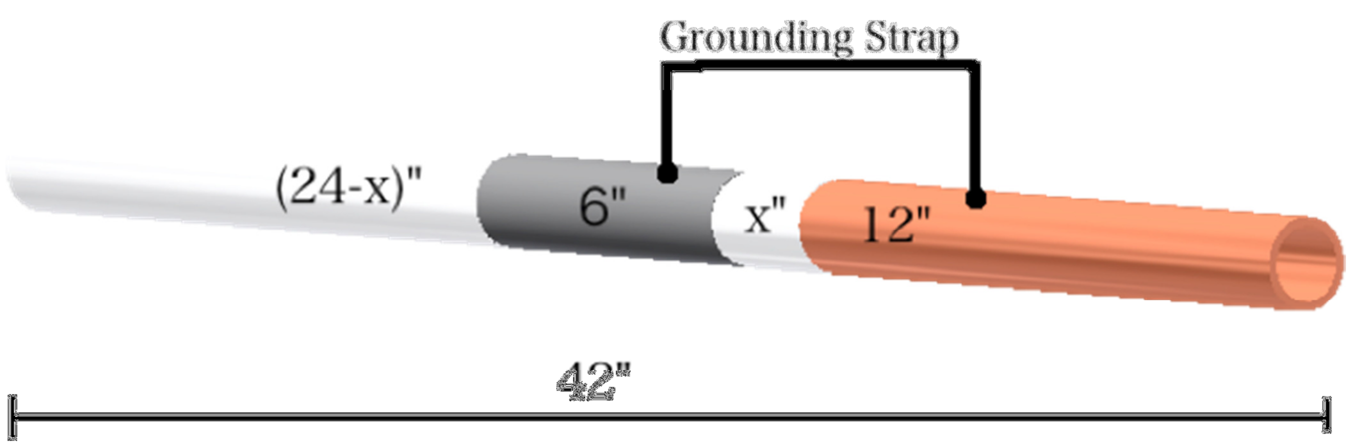

Figure 12 – Diagram of Grounding Strap and Experiment

Figure 2. The insertion of a dielectric of distance X" between the lead and copper pipe segments, creates a potential barrier to galvanic corrosion even though a grounding strap satisfies electrical continuity to mitigate the potential for electrical shocking in homes.

Research Methods

Materials

The materials used for this experiment were as follows. I used forty feet of three-fourths inch inner diameter PVC piping. The forty feet was cut into smaller sections. Initially, I cut the piping into twenty-one twenty-four-inch pieces. The PVC is used to separate the lead and the copper, which is the overall purpose of the experiment. PVC from the two feet pieces is cut into one-fourth inches, one inch, three inches, twelve inches, and left at twenty four inches. The section left after cutting is then 23 ¾, twenty-three, twenty-one, twelve, and zero respectively. These pieces will be the part of the pipe that keeps the length, and therefore volume, of the pipe constant.

After the PVC was cut, a sixty-inch piece of lead piping with three-fourth inner diameter, and about an inch outer diameter, to Brett Farmer at the CEE Structures Lab on Plantation Road. The lead was cut into six-inch segments.

The copper piping is also three-fourths inner diameter. These pipes come in ten-foot section, and are cut into twenty-one twelve-foot pieces. The copper resembles the replacement piping that water companies installed following EPA ruling regarding partial pipe replacement. The lead resembles the original piping installed that still remains in the ground on the homeowner's side of the property line.

The experiment uses triplicates of the various series to strengthen statistical power and provide better estimates of the true means of each series. There are seven series total; the first five each have dielectric spacers composed of PVC in lengths of ¼, 1, 3, 12, and 24 inches. The sixth series was created to directly mimic a direct connection between lead and copper and have no gap between the metals. The last series was used as a control with only lead pipe. The series with ¼ inch spacing is similar to the direct connection except that electrical measurements can be taken since the metals are not in contact with each other continuously. Together there are 18 simulated partials with an additional 3 controls.

After all the piping is cut, I cut two inch pieces of tygon. Tygon spacers are put in between each of the pieces of piping for two reasons. The first reason is that the pipes need to be able to be leak free, and tygon is an easy way to connect the pipes for this purpose. The second reason I use tygon to connect the pipes is so that the metals are in no way electrically in contact with each other. This separation allows for the measurements of currents to be taken, and a current other than zero proves that there is some sort of galvanic effect going on between the two pipes.

After the pipes have been built, They are wash with a pre-rinse so that any detached pieces of lead can be washed out to make sure the lead leaching concentrations are due only to galvanic corrosion, and not due to residual particles still left on the pipes from when the pipes were cut. The first wash is done three times with distilled water, and then again with tap water.

The experiment begins by filling the pipes with tap water. The tap water is flushed for ten minutes to make sure the pipes that run through the building don't affect the tap water. This flush is mainly to make sure the water we are putting into the pipes of the experiment is coming from the service main and not water that has been tainted by the premise plumbing. Free chlorine, total chlorine, and pH measurements are taken of pure tap water to make sure that the water conditions are staying relatively standard. A control of just water from the Blacksburg tap is also measured for lead concentrations.

The pipes are filled and the water sits in the pipes for two days. After two days, the water is poured into a sampling bottle. The pipes are forty-two inches long and have a three-fourths inch diameter. The volume of each pipe is approximately 330 mL. After the first pour, the pipes are then filled and dumped again two 3 days later. At the end of this interval, current measurements are taken. Current measurements are taken both in stagnant and fresh water conditions. The two different conditions are taken to show that there is a decrease in current over time. This decrease in current over time reiterates that the galvanic corrosion is occurring. To be specific, the oxygen is being taken out of the water, which is the reducing side of the galvanic equation. This being said, if the same water was left in the pipes over a very long period of time, the current would eventually approach zero. In reality, the water running through the pipes is always fresh and always contains oxygen so we are not protected from this feature. The process over a week is dumped Monday, Wednesday, and Friday and this creates a weekly composite for each of the 21 replicates.

After the stagnant currents are taken, the pipe is dumped into the same bottle it was two days ago, and then it is refilled. The last dump happens two days after currents are taken. Water is still dumped in the last bottle. This makes for a liter of water after a total time of one week. The liter of water is used to represent the sample. The sample is acidified to 2% with nitric acid. After forty-eight hours, a ten-milliliter sample is taken from the bottle and ran in the Inductively Coupled Plasma Mass Spectrometry (ICP-MS). The ICP-MS requires that samples be at 2% nitric acid by volume. This works well, because the acid helps dissolve the particulate lead.

Results and Discussion

The purpose of Figure 3 through 5 is to prove that the effectiveness of the PVC insert can be estimated based on the simple equation V = i*R. Figure 6 depicts results from the experiment and prove that lead leaching can be projected based on current and voltage measurements.

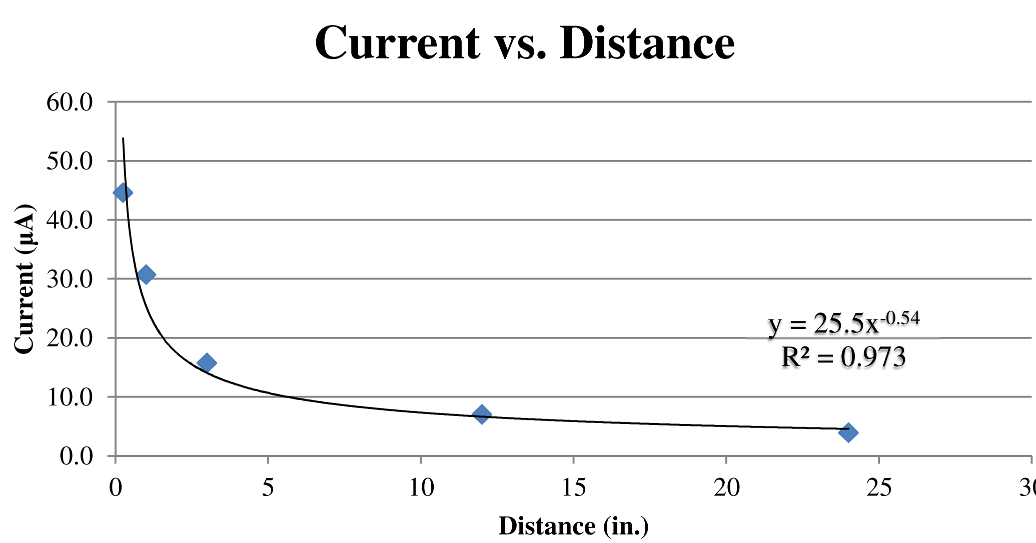

Figure 13 – Galvanic Current vs. Distance

Figure 3 is used to describe the relationship between distance and current. This is the primary indicator of galvanic corrosion, because the only way a current can occur is through the water. Currents were taken, and the pattern was not surprising in that the further you separated the metal pipes, the less current there was between them. The suggested explanation was that the PVC insert was giving the pipes more resistance. As the PVC insert got larger, there was a larger volume of water between the two metals, which created more resistance. To find if the effectiveness can be predicted by the equation V = i*R, the correlation between the equation and the system must first be established. This correlation can be found by measuring current, resistance, and voltage. Measuring resistance was not feasible with the multimeter, so the resistances were calculated using current and voltage measurements. Figure 4 explains the relationship between the resistance and the distance.

The effective resistance was calculated based on measurement of the galvanic current and the voltage according to the equation R = V/i

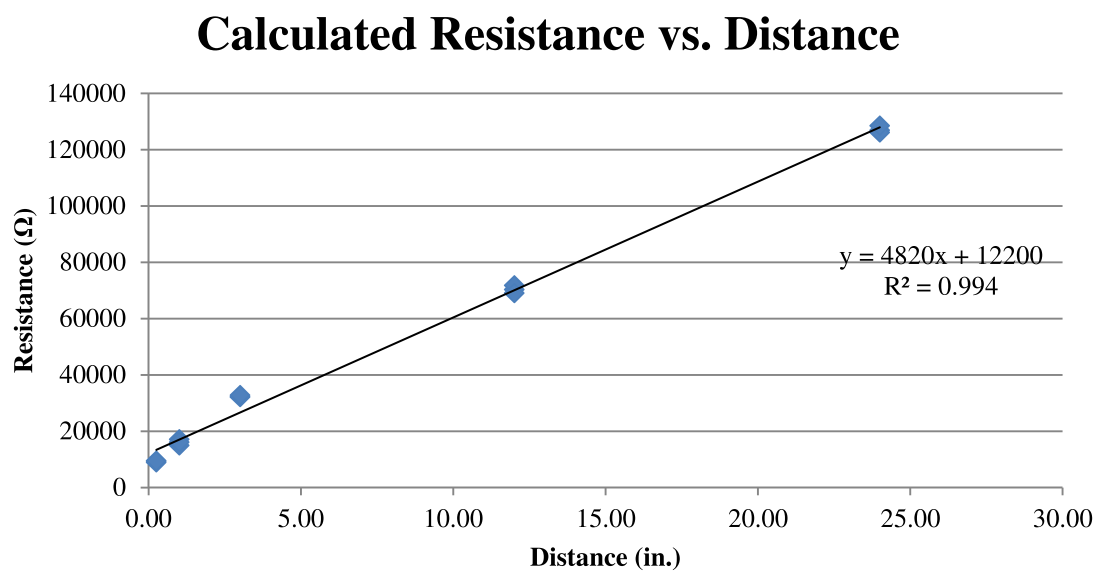

Figure 4 – Calculated Resistance vs. Distance

Figure four shows the relationship between the calculated values of resistance, using the standard DC current equation, and distance, or length of PVC insert, between the two metal sections of piping. This strong linear correlation proves that our system follows the pattern of a normal DC current. If this statement is true, then a relationship between the calculated values of resistance and measured current should have an inverse relationship.

Proof of an inverse relationship will effectively provide a way to speculate how effective a dielectric separation will be.

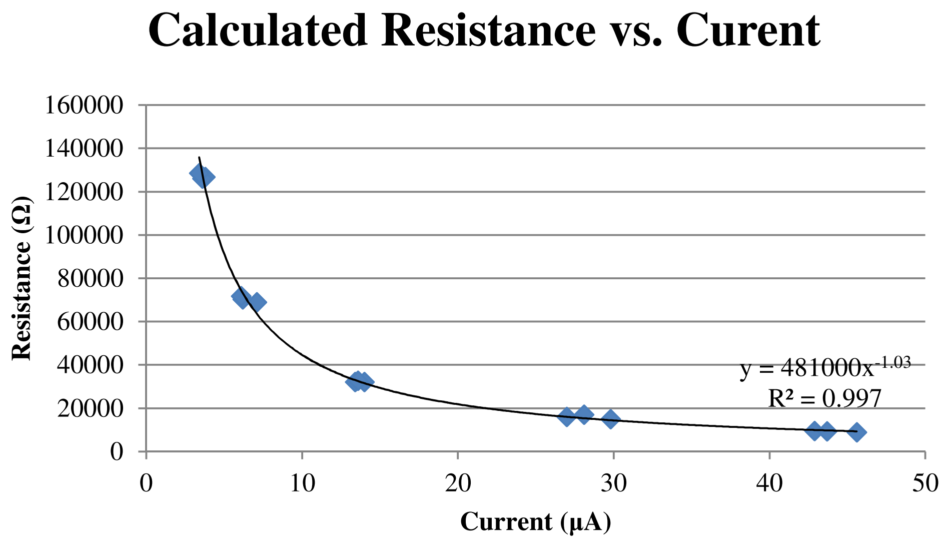

Figure 5 – Calculated Resistance vs. Galvanic Current

Figure 5 essentially confirms the expected relationship. In fact, with an R-squared value of .997 the relationship is actually exceptionally reliable. This inverse relationship confirms that the resistance in water is a function of distance, and can be related to the current between the two metals.

Following the investigation regarding the relationship between resistance and current, is the investigation of the main question: Can a PVC insert with a grounding strap potentially save homes while still remaining within the regulations regarding the grounding of homes.

Initially, the hypothesis was that the larger the dielectric insert, and therefore the larger electrical separation, the less galvanic corrosion that would end in less lead release. This was actually found to be very true in the data of our experiments.

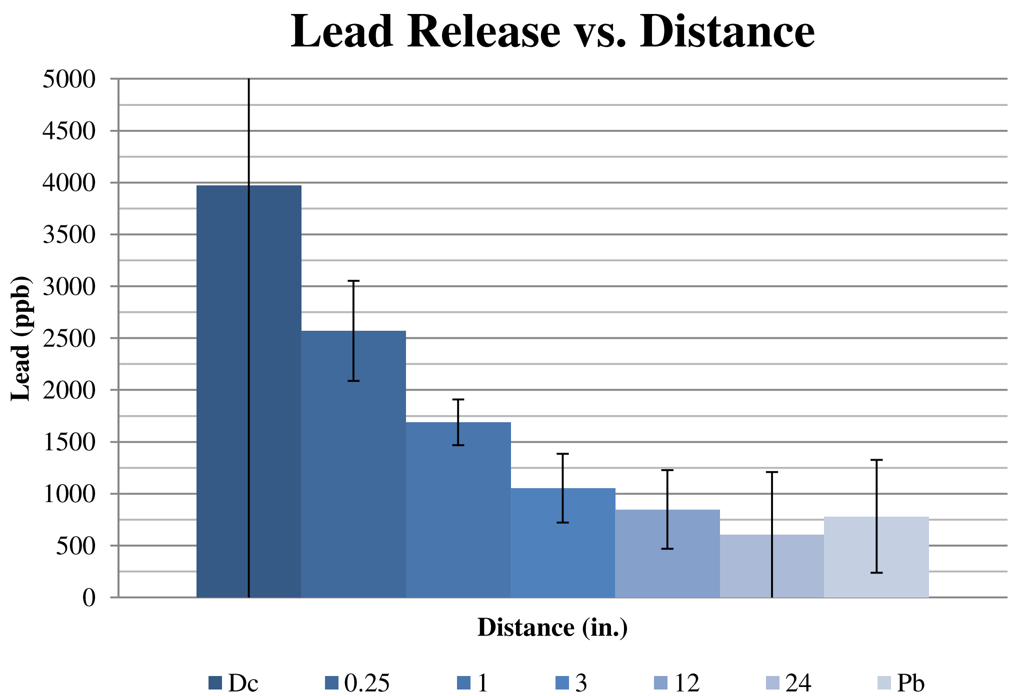

Figure 4 – Lead Release vs. Distance

Figure 6 is a bar graph describing the data we found for a weeks worth of data. It is easy to see the correlation between the size of the insert, and the amount of lead released into the water. The amount of lead leached decreased by about half just moving from a quarter of an inch to three inches. This shows that there is a major benefit in separating these two metals. One thing to note is the difference in the 24-inch set and the set containing only lead. Initially this did not make any sense, because even if the two feet completely reduced the galvanic effect to zero, the numbers should have been relatively the same. The problem actually lies in the set up of the experiment.

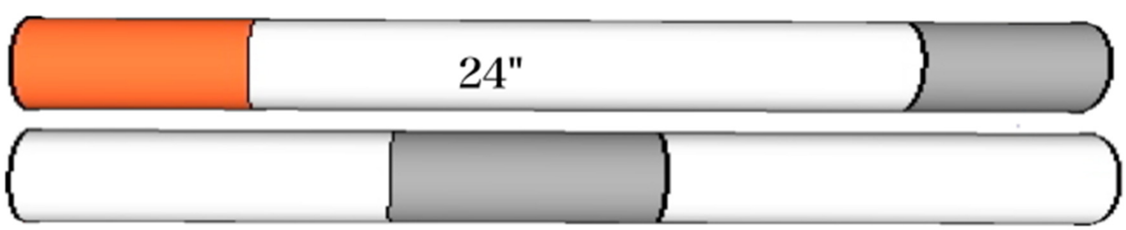

Figure 14 – 24 Inch and Lead Control Diagram

Figure 7 represents the 24-inch separation and the lead only sets. The lower levels of lead in the two-foot separation may be due to the position of the lead. As seen in figure seven, the lead segment has only one direction to defuse which differs from that of any of the other setups as well as the lead only set up. The segment composed of only lead gives the lead the ability to defuse to both sides. This is the only proposed hypothesis to the lower levels in the 24-inch set up.

The data we received regarding the lead leaching correlates well with the measurement for currents. This actually helps show that the proposed hypothesis is correct. The hypothesis was that galvanic corrosion would decrease as distance increased. Our measurement of galvanic corrosion is based on both current between the two metals, and lead leaching. The lead leaching is proven in figure 7.

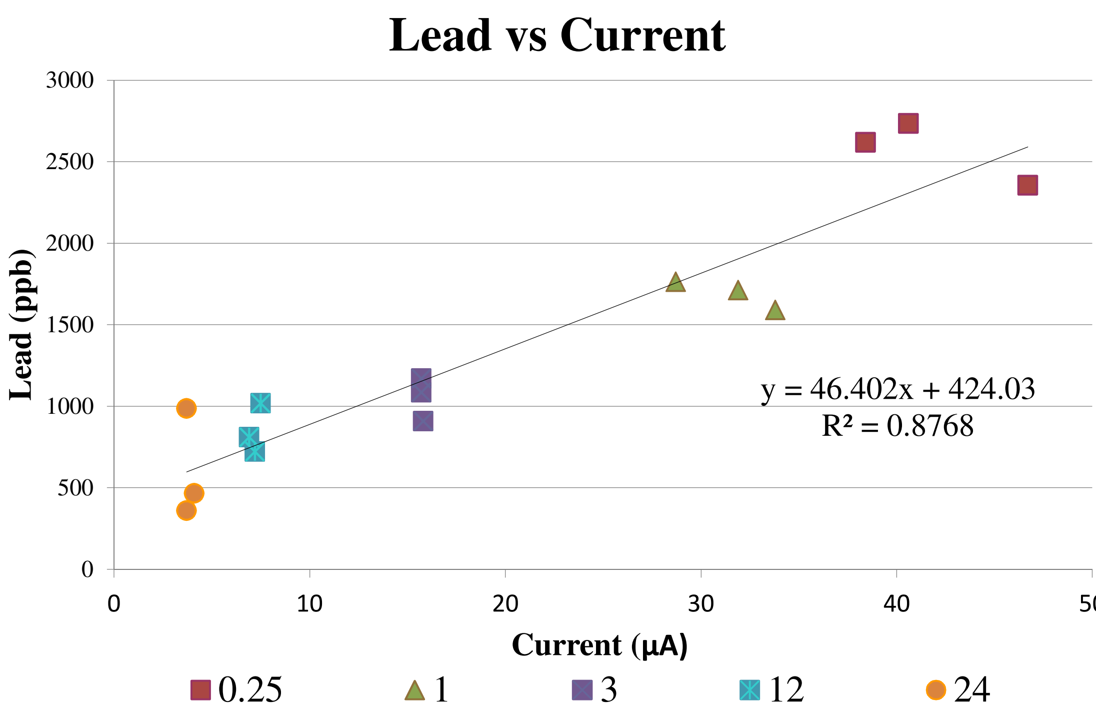

Figure 15 Lead vs. Current

Figure 8 confirms that the current between the lead and copper pipes is related to the lead release. This proves the existence of the galvanic corrosion, and has a linear correlation between the two.

Peer Feedback on Presentation

Presenting in front of a group of people has always been something that I thought I could do, and I quickly learned during this REU that was not necessarily the case. Maybe I'm better at talking when I am expecting a chuckle, or I tend to get a little more nervous in the academic setting. I am not entirely sure where the fear's source is, but it is definitely something that's on my to-work-on list.

The first presentation was supposed to be a five-minute presentation. This was supposed to be more of an informative presentation to let the other interns as well as the program directors what exactly we were spending our time on, if we were finding any immediate successes or setbacks, and any other broad information regarding the initial stages of our summer. To my dismay, I felt as though I had completely bombed the first presentation. For starters I had an orange background, which was an absolute mistake from a scientific standpoint. Even if you were colorblind you would have realized I didn't spend enough time preparing my speech, or even my slides. After reading the feedback from the other students I gathered that I had at least gotten the point that copper piping combined with lead piping was not a very good combination, but other than that I had basically confused them. This was definitely a learning experience on all fronts from preparation to articulation. Back to the drawing board. A few of the more common questions were: “I’m not entirely sure what you are doing” and “I understand the explanation of the chemistry but what is the ultimate goal?”

A few weeks later, we had our ten-minute presentation. Slightly more motivated, and holding a flashlight in a cave, compared to walking around New York City with my eyes closed, I was in a much better position for my next presentation. I fixed up the slides, and made sure I had enough information to last the allotted time. I changed from orange to white, the more accepted color for presentations in the scientific world. I tried to make sure I had specific slides that answered previous questions. I also gave this presentation a bit more practice and took it much more serious. This time I was less nervous, which I think was in part just being more prepared. After the presentation was over I was able to smile a bit more, but I FORGOT THE PAPER SLIDE! Ugh. I was one of maybe two students who forgot, but luckily this wasn’t a very big deal. After reading my peer reviews I had realized I had gone too far. Now my slides were too wordy. I had found a way to better inform my listeners, but I wasn’t making enough eye contact. I also wasn’t as engaged. These were all easy things to fix; it was just a matter of doing it.

The fifteen-minute presentation was quite the eye opener. I really felt the repercussions of not practicing enough. I’m glad I was able to learn this in front of just my peers. After this experience, I have really learned the importance of practicing and definitely spent more time preparing for the final presentation that will be in front of upwards of 40 people. I feel as though I have spent enough time preparing for the final presentation and I am much more confident. Only time will tell, but I am much more convinced about success on August 5th. I am even starting to feel a bit excited about the day, because it will be a great way to end the REU and now I feel fully prepared.

Conclusions

- When two dissimilar metal pipes are filled with water, if a dielectric is placed between them and the metals are externally bridged electrically with a grounding strap, the effective resistance between the metals increases linearly with distance.
- The net result is that the galvanic current can be decreased as the length of the dielectric is increased, which in turn, decreases the extent of lead in water contamination. Use of the grounding strap maintains the effectiveness of the home grounding system to reduce the likelihood of electrocution and electrical shocks.
- Application of these principles can allow for partial lead service line replacement without long-term risks from direct galvanic corrosion.

Acknowledgments

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References

Nave, C.R. (2010). Standard electrode potentials. Retrieved from http://hyperphysics.phy-astr.gsu.edu/hbase/chemical/electrode.html#c1

Francis, R. (2001). Galvanic corrosion: a practical guide for engineers. Houston, TX: NACE International.

Renner, R. (2010). Reaction to the solution: lead exposure following partial service line replacement.

Environmental Health Perspectives, 118(5), Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2866705/ doi: PMC2866705

Sandvig, A., Kwan, P., & Kirmeyer, G., Maynard, B., Mast, D., Trussell, R., Trussell, S., Cantor, A., Prescott, A., US Environmental Protection Agency, American Water Works Association. (2008). Contribution of service line and plumbing fixtures to lead and copper rule compliance issues (ISBN: 978-1-60573-031-7). U.S.A.: Awwa Research Foundation. Retrieved from http://www.waterrf.org/ProjectsReports/PublicReportLibrary/91229.pdf

Swertfeger, J.; Hartman, D.J; Shrive, C.; Metz, D. H.; and DeMarco, J., 2006. Water Quality Effects of Partial Lead Line Replacement. Proceedings of the 2006 Annual AWWA 538 Conference. San Antonio, TX.539

Triantafyllidou, S., & Edwards, M. (2011). Galvanic corrosion after simulated small-scale partial lead service line replacements. Manuscript submitted for publication, Department of Engineering, Virginia Polytechnic Institute and State University, Blacksburg, Virginia.

United States Environmental Protection Agency, Office of Water. (2011). Lead and copper rule Retrieved from http://water.epa.gov/lawsregs/rulesregs/sdwa/lcr/index.c

Calibration of Real-Time Water Quality Monitoring Devices

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ABSTRACT

The success of the LEWAS Lab relies on the precise calibration of its water quality and quantity monitoring devices. The purpose of this paper is to illustrate the important details in theory, maintenance, and calibration of the HydroLab Sonde MS5 and SonTek Argonaut SW.

Keywords: Real-Time, Water Quality Monitoring, Stroubles Creek, Sonde, SonTek Argonaut SW

Introduction

Stroubles Creek is designated as impaired by the Virginia Department of Environmental Quality (VDEQ) (Stroubles, 2006). The stream runs through the Town of Blacksburg, through the Virginia Tech campus and into a detention pond called Duck Pond, where it is then designated as bethnic impaired. Impairment, as declared by the EPA, means the water is, “too polluted or otherwise degraded to meet the water quality standards” (EPA, 2011). Stroubles Creek was declared bethnic impaired because the water contained little to no bethnic populations due to the quality of the water.

Stream impairments are caused by nonpoint sources of pollution throughout a stream’s watershed area. Agricultural runoff, livestock access to streams, increasing development and peak flows from stormwater runoff, stream channel modifications, downtown business wastewater disposal, and improper disposal of grass clippings and trash are all examples of nonpoint source pollution that can lead to impairments. (Stroubles, 2006). All of the examples above have been identified as stressors on Stroubles Creek.

Bethnic impairment is due to biological changes in a stream such as an increase in nutrients, organic matter, and sediment (Stroubles, 2006). There is a correlation with an increase in nutrient levels (that can result from organic matter and fertilizer runoff) such as nitrogen and phosphorus to the decrease in invertebrate diversity (Yuan, 2010). With an increase in sediment, there is an increase in turbidity, which affects all trophic levels, “through a reduction of available light for primary producers and visual predators” (Larson & Ormerod, 2009).

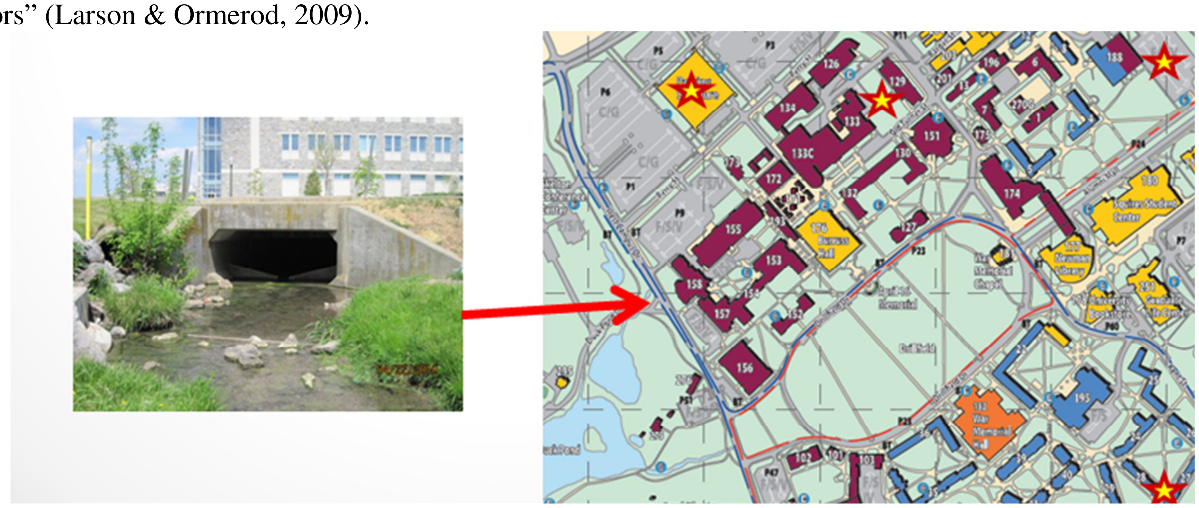


Figure 16: Above illustrates the location of the site and the stars indicate major construction sites on campus that could affect Stroubles Creek downstream.

Stroubles Creek has experienced these impairments due to the increasing urbanization in Blacksburg, VA. With an increase of urban land development around watersheds, “streams characteristically have altered hydrology, increased sediment loads and new sources of pollutants. Numerous studies have documented the relationship between degraded stream ecosystems and urban upland development” (Leavitt, 1998). The alteration of hydrology can result in a significant alteration of a stream’s natural ecology because of a change in the hydrologic regime of the watershed (Leavitt, 1998). There is an indirect relation between change in hydrologic remine and the alteration of the, “composition, structure, or function of aquatic, riparian, and wetland ecosystems through their effects on physical habitat characteristics, including water temperature, oxygen content, water chemistry, and substrate particle sizes” (Richter, Baumgartner, Powell, & Braun, 1996). Each of these characteristics can change in an instant for an urbanized watershed due to the rapid changes in the surrounding area.

Real-time monitoring, “refers to data collected and processed at the same speed it is naturally occurring” (Green, 2011). This type of water quality monitoring allows for easy identification of the rapid changes mentioned above. High resolution sampling gives much more accuracy in data collection than traditional grab samples.

The LabVIEW Enabled Watershed Assessment System (LEWAS) Lab chose Stroubles Creek for its site because of the environmental concerns associated with the Creek and for its close proximity to the Virginia Tech campus. The purpose of the LEWAS Lab is to identify impacts of land use changes on water quantity and quality and to collect high resolution water data in real-time for water sustainability research and education.

There are three monitoring devices that can perform in real-time: the HydroLab Sonde MS5, SonTek Argonaut SW flow meter, and Vaisala weather station, which all help LEWAS in achieving its purpose. The sonde has six parameters with a sensor for pH, temperature, conductivity, dissolved oxygen (DO), turbidity, and oxidation reduction potential (ORP). Each sensor serves its purpose in allowing LEWAS to monitor the stream’s chemical and biological state, while the flow meter computes discharge of the stream. This is helpful in monitoring the stream because flow effects the movement of particles and pollutants downstream.

The objectives of my work were to calibrate the sonde for pH, conductivity, dissolved oxygen (DO), Turbidity, and oxidation reduction potential (ORP) and to conduct velocity and survey measurements in order to develop a regression relationship for the determination of flow.

In order to eliminate and minimize factors that cause inaccurate measurements through instrumentation design and manufacturing, calibration must be performed. Calibration is the process of, “configuring an instrument to provide a result for a sample within an acceptable range” (Advanced Instruments, Inc., 2011). In general, this process involves the instrument using test samples of one or more known values. A relationship is then formed, “between the measurement technique used by the instrument and the known values. The process in essence “teaches” the instrument to produce results that are more accurate than those that would occur otherwise. The instrument can then provide more accurate results when samples of unknown values are tested in the normal usage of the product” (Advanced Instruments, Inc., 2011). For this reason, the calibration of water quality instruments is important because over time instrument readings tend to drift and loose accuracy.

Methods

Sonde Calibration

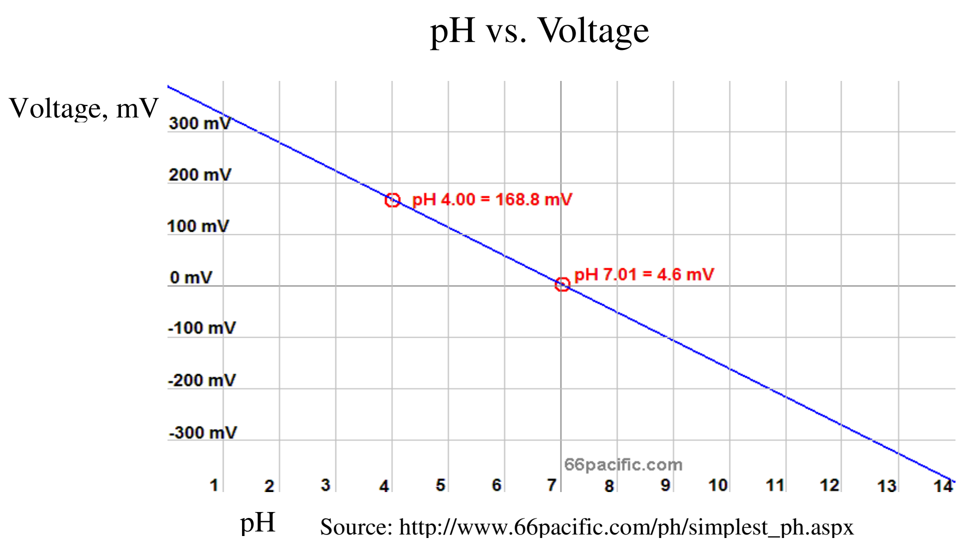
Hach, the company that manufactured the Sonde MS5, created calibration videos on the Hach Environmental’s Website that were used to complete the calibration for each parameter. Below describes the details in the Maintenance and Methods of calibrating the four sensors used as well as the theory behind each parameter.

pH

pH indicates whether a solution is acidic, neutral, or basic. Aquatic organisms must live in a pH range between 6.5 and 8 in order to survive. Deviations from this range can be caused by acid rain and geological changes in the area. Since the Blacksburg area contains limestone, the Stroubles Creek tends to be on the basic side due to the buffering effects of limestone.

<u>Theory</u>

A pH sensor contains two electrodes, one measuring and the other reference. The measuring electrode, which is the glass bulb, is chemically “doped” with lithium ions so that it reacts with the hydrogen ions in the water outside the bulb. The reference electrode remains stabilized with a zero-voltage to complete the circuit in order for the reaction on the glass bulb to occur (Kuphaldt, 2000). The electrochemical reaction generates a voltage across the glass bulb, corresponding to a certain pH level, as shown in Figure 2.



Source: http://www.66pacific.com/ph/simplest_ph.aspx

Figure 17: This graph shows the relationship between voltage measured and the pH level shown by the sensor.

<u>Maintenance</u>

In order to receive accurate data, not only is calibration necessary, but most importantly maintenance of the sensors must be completed on a regular basis. If the reference junction looks worn and the circle is brown, the junction must be replaced. Figure 3 demonstrates the difference in color or a new and old reference junction. However, if the reference junction is not dirty, one can go straight into the calibration process. For the first calibration, the cap was replaced, unscrewed, and the old reference electrolyte from the sensor must be poured out. Then a new salt tablet was put in because the sonde will be deployed for an extended period of time so the salt tablet will, “maintain the saturation level of the electrolyte as the salt slowly leaches through the Teflon junction” (Hach, 2010). The sensor was then filled with new reference electrolyte until a dome formed and then the cap was gently placed on top of the reference tube to make sure no air remained inside. The junction was then turned clock-wise until tightly secured. Small amounts of electrolyte were forced out of the junction indicating that the tube was now air tight.

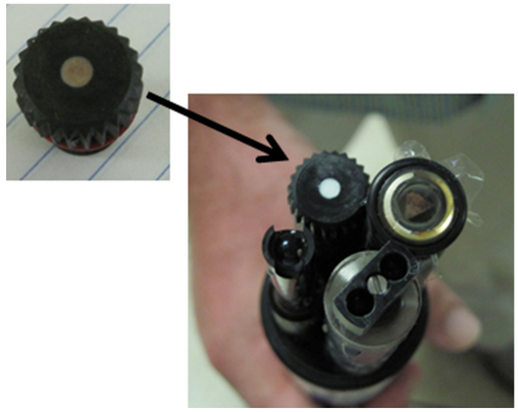


Figure 18: This picture shows the old reference junction cap versus the new one, showing a great different in the Teflon color.

<u>Calibration</u>

First the sonde was connected to the laptop with OTT's Hydras 3, which is the calibration software. Hydras was then started where a screen appears showing that the computer is searching through every port for the sonde and one waits for the blue light flashing on the wire indicating a successful connection to the computer. On the screen there is a button "Operate Sonde" that was pressed, then a "Calibration" tab, and lastly a "pH tab." Before the calibration process begins, the glass bulb must be cleaned carefully with a q-tip and soapy water. The storage cap was then put on and 25% of pH 7 solution was poured in. The sonde was shaken for 6 seconds and the solution was then poured out. PH 7 solution was poured in the cap again, above the sensors this time. After a minute, allowing the pH reading to stabilize, a '7' was put into the box, the "Calibrate" button was pressed and a "Calibration Successful" box appeared. In the same process as with the pH 7 solution, the pH 10 solution was used to calibrate since a higher pH is more likely to be measured in Stroubles Creek. After the completion of the process, '10.01', the value on the pH buffer solution container, was typed in the box. Again, the "Calibrate" button was pressed and a "Calibration Successful" box appeared. To check the calibration, the pH 4 solution was used and the value under "Current Value" should be '4.01,' indicating a successful calibration of the pH sensor. Lastly, the storage cap was emptied, the sensors were rinsed, dried, and stored in tap water. Sensors are not allowed to be dry for extended periods of time and de-ionized water or sample water are not reasonable options for storage water. This is because, "DI water will damage the sensor bulb, and the organisms in sample water will foul the bulb and junction" (Hach, 2010).

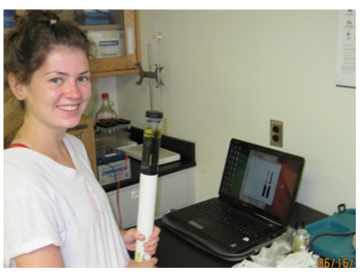


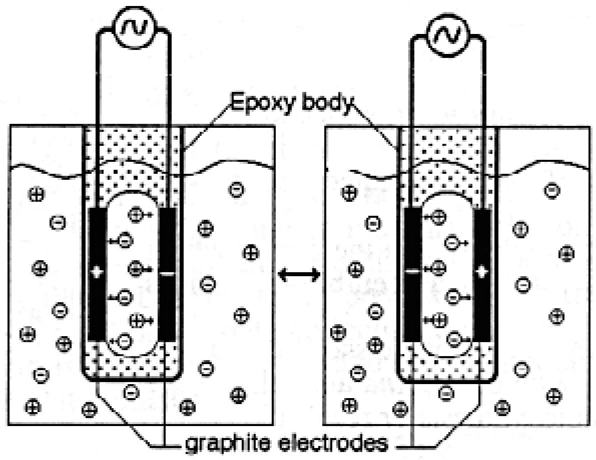
Figure 19: Patiently waiting a minute for the 'Current Value' for pH 7 solution to stabilize.

Conductivity

The conductivity sensor measures the ions (dissolving salts, acids, bases, etc.) in a solution. For a healthy stream, the range should be between 150-500 microsiemens per centimeter. According to the EPA, "increases in conductivity or similar measures of ionic strength are among the most consistently documented water quality changes associated with urbanization" (EPA, 2010). These changes can be caused by road salt, point source discharges (industrial effluents), leaky sewer and septic systems, and concrete weathering. A study found that, "**specific conductance was a significant predictor of invertebrate responses to urbanization**, negatively related to total invertebrate richness, EPT richness, total invertebrate density, and several benthic invertebrate indices" (EPA, 2010).

Theory

In order for the sensor to measure the ions in a solution, the currents between the two electrodes of the sensor must be measured. As shown in Figure 5, "with each cycle of the alternating current, the polarity of the electrodes is reversed, which in turn reverses the direction of ion flow" (NJIT).



Source: http://www-ec.njit.edu/~grow/sensors/CONPROB.htm

Figure 20: Movement of the ions from electrode to electrode, where the polarity changes to continue the movement of ions. This movement allows for the current to be measured.

Using Ohm's Law, conductivity is measured within the proprietor software.

Conductivity = $\frac{G*d}{A}$

Where G is the conductance, d is the distance between the two electrodes, and A is the area of the electrode surface (Hach, 2010).

Maintenance

There is no specific maintenance necessary for the conductivity sensor except to clean the probe's cell and body. A negative impact on the stability and accuracy of the readings will result from debris, organisms, and other contaminants in the sensor cell (Hach, 2010). Thus all sensors should be cleaned with a brush before the calibration of conductivity.

Calibration

Similar to the pH calibration, the sonde was connected to the laptop using the Hydras 3 software. Once the sonde is identified, "Operate Sonde" was clicked, then the "Calibration" tab, and lastly the "Sp Cond [µS/cm]" tab. The first calibration point is a dry point to create a zero point. The sensors were rinsed with de-ionized (DI) water and dried thoroughly. A q-tip as used inside of the conductivity sensor to ensure it was dry. Once the sensors were dried, '0' was typed in the box and "Calibrate" was pressed. 25% of standard solution was poured into the storage cap, shaken for 10 seconds, and poured out. The solution was then refilled above the sensors and a minute was waited until the "Current Value" was stabilized. '1412' µS/cm was typed into the box since the standard solution bottle indicates "1.412 mS/cm." "Calibrate" was then pressed and a "Calibration Successful" box appeared.

In order to check the calibration, sample water from Stroubles Creek was measured by Julie Petruska, Environmental Laboratory Supervisor from the Civil & Environmental Department. She measured the sample at two different times, resulting in different temperatures, and these values were used to compare to the value the sensor read. The sonde read '745 µS/cm' at 23°C. The measurements Julie provided were 660 µS/ and 700 µS/cm from samples collected the day before the calibration was performed. She measured them twice because the change in temperature causes a change in readings. This indicates that temperature could be a factor in the slight difference between the actual values and what the sonde read.

Dissolved Oxygen

Dissolved Oxygen is the concentration of oxygen in the water. Levels of about 4-5 mg/L are desired in order to support aquatic life. Oxygen is produced through photosynthesis and depleted through respiration. There are many factors that if lowered such as temperature, salinity, and atmospheric pressure that can increase the concentration. However, oxygen levels can also be negatively effected through acid drainage, leakage of waters high in carbon (sewage treatment plants, food processing, etc.), and stratification (Radke, 2011).

Theory

The DO sensor consists of a Clark Cell, which “contains two electrodes surrounded by an electrolyte solution and covered with an oxygen permeable membrane” (Hach, 2006). Its function is to create a small electrical current generated by a chemical reaction between the electrodes. Thus current is directly proportional to the amount of oxygen in the sample of water (Hach, 2006). This process is ultimately depleting the oxygen while this process occurs, thus the water surrounding the sensor must either be flowing or a circulator must be used to prevent the readings from decreasing.

Maintenance

The DO must be maintained and the Clark Cell membrane must be replaced periodically in order to keep the sensor’s longevity. The o-ring on top of the sensor was removed and the old membrane and electrolyte was removed. The electrode must be checked to ensure that it is not breaking apart and the cathode should be a bright yellow ring. Figure 6 demonstrates the difference between a functioning and damaged sensor. If the triangle in the center is breaking down, the electrode must be replaced. However, the sensor still functions properly if the color is not completely white for particles over time can seep through the membrane and taint the color. If the cathode is not yellow, toothpaste and a q-tip are used to rub, “the ring in a clockwise motion to prevent accidental damage to the sensor” (Hach, 2010). The sensor was then rinsed several times with the ‘DO’ electrolyte. The sensor was then refilled with electrolyte so that a dome formed on top with no air bubbles. If necessary, tweezers were used to remove any bubbles that had formed. A new membrane was taken out of the packet of membranes with tweezers and placed carefully over the top again making sure no air bubbles formed underneath. The o-ring was then secured. If any bubbles formed in this process, the membrane was discarded and a new one was used to try again. Once successfully replaced, the excess membrane was trimmed with scissors. Before calibration can continue, the new membrane must sit in clean water to relax for at least four hours.

Figure 21: The electrode to the left shows the ideal condition, while those to the right should be discarded and replaced.

Calibration

The sonde must be plugged into the computer with Hydras 3 running and wait for a connection to occur. Once successful, the “Operate Sonde” button was pressed and initialization occurs. Then the “Calibration” tab was pressed and then “DO% [Sat].” The storage water was then dumped from the calibration cup and the sensors were rinsed with clean water (distilled or tap). Water was then poured to just below the o-ring of the sensor, removing any droplets on the sensor with a q-tip. The cap on the cup was taken off and put back on upside down so that the cup is covered, but the cap was not sealed tight. If sealed, the pressure inside the calibration cup could potentially change, causing a miss reading for the sensor. Once the "Current Value" was stabilized, the calculated uncorrected atmospheric pressure, as seen below, was entered into the box and the "Calibrate" button was pressed. A box stating "Calibration successful" appeared.

$$BP' = BP - 2.5(\frac{A}{100})$$

Where:

- BP (corrected barometric pressure in. Hg) and A (altitude in feet) are provided by the National Oceanic and Atmospheric Administration from the Virginia Tech Airport.
- BP (mmHg), the barometric pressure at sea level = 25.4 x BP (in.Hg) = 25.4 x 30.08 in. Hg = 764.03 mmHg
- BP'(mmHg), the barometric pressure at altitude= BP – 2.5(A/100) = 764.03 mmHg – 2.5(2133'/100) = 710.71 mmHg

Turbidity

Turbidity measures the amount of suspended materials in water, which can range from 1 to 1,000 NTUs. According to the USGS, healthy stream ecosystem turbidity values should be between 1 and 50 NTUs (McCunn et al., 2003). Lower turbidity levels allow more sunlight to penetrate the stream, which is utilized by aquatic vegetation. This is generally the reason why lower turbidity values characterize a healthy stream.

Macroinvertebrates have low survival rates from high stream sediment levels (McCunn et al., 2003). There are two mechanisms by which urbanization causes sedimentation in urban streams. The first is construction. Bare earth from construction projects contributes sedimentation to streams via runoff. Also, the increased runoff from urbanization erodes stream banks, which contributes to the sedimentation problem (Finkenbine et al., 2000).

<u>Theory</u>

The self-cleaning turbidity sensor functions by measuring the intensity of light scattering in the water. The greater the intensity of light scattering, the higher the turbidity. Additionally, the sensor is self-cleaning with a motorized pad (Hach, 2006).

<u>Maintenance</u>

The cleaning pad should be replaced when it becomes fouled. To replace the pad, the hex wrench is used. The wiper should never be rotated by hand or operated when the sensor is dry. Before calibration, the sensors and inside the storage cup must be cleaned with a soft brush and mild soap to remove debris and then dried with a lint free towel (Hach, 2006).

<u>Calibration</u>

There are two steps to this calibration, zero point and high-end. For the zero point calibration, the sensors were pointed upwards and the storage cup was filled with approximately 75% of DI water. The cap was screwed tightly onto the storage cap so that the sonde could be turned over slowly so the sensors could point downwards. The sonde must be plugged into the computer with Hydras 3 running and wait for a connection to occur. Once successful, the "Operate Sonde" button was pressed and initialization occurs. Then the "Calibration" tab was pressed and then the "Turbidity [rev]" button was pressed. The value in the box should be '1', then "Calibrate" was pressed. This caused the wipe to make one complete revolution to remove air bubbles from the optics. "OK" was clicked when the "Calibration Successful" window appeared. The "Turbidity [NTU]" tab was then pressed where there are two boxes. "Turbidity [Point]" should have a '1' placed in it and "Turbidity [NTU]" should have a value between 0.3 and 0.6 entered into the box depending on the cleanliness of the sensors. Once the readings were stable, "Calibrate" was pressed. "OK" was clicked when the "Calibration Successful" window appeared.

For the high-end calibration point, a solution higher than the highest value anticipated at the site should be used. 100 NTUs was chosen as the high-end point because from past data collected, Stroubles Creek never went over 40 NTUs for turbidity (Parece et al., 2010). The de-ionized water was poured out of the storage cup and the sensors were dried again with a lint-free towel. The 100 NTU StablCal was swirled for two or three minutes to mix the suspension, but was never shaken, which can create unwanted air bubbles. The StablCal was poured into the storage cup to about 25%. The cap was screwed on tightly and the sonde was shaken. The cap was removed and the solution was poured out. The StablCal was poured into the cup again gently, but to 75% this time. The cap was screwed on and the sonde was gently turned over so the sensors were pointing downwards. The end of the sensor should be fully submerged.

"Turbidity [rev]" button was pressed again and the value in the box remained '1', then "Calibrate" was pressed. This caused the wipe to make one complete revolution to remove air bubbles from the optics. "OK" was clicked with the "Calibration Successful" window appeared. The "Turbidity [NTU]" tab was now pressed where there are two boxes. "Turbidity [Point]" should have a '2' placed in it and "Turbidity [NTU]" should have '100' placed in the box. "Calibrate" was pressed and "OK" was clicked when the "Calibration Successful" window appeared.

Oxidation Reduction Potential (ORP)

ORP is a measure of the ability of the stream to oxidize and reduce chemicals (Striggow, 2009). This parameter is a useful tool in investigating the chemical environment of a stream.

<u>Theory</u>

The ORP sensor measures "the electrical potential between a reference electrode (the pH reference) and a platinum band in contact with the solution" (Hach, 2006). This sensor is integrated with the pH sensor. Similar to the pH sensor, the ORP sensor measures the millivolt output generated from the electrode "on the oxidizing or reducing reactions taking place while the reference electrode generates a constant millivolt output" (Sensorex, 2011).

<u>Maintenance</u>

The platinum band must be cleaned with a soft brush and mild soap water to remove debris. The ORP sensor is a part of the pH sensor, so that must be cleaned before calibration of this sensor as well.

<u>Calibration</u>

The sonde must be plugged into the computer with Hydras 3 running and wait for a connection to occur. Once successful, the "Operate Sonde" button was pressed and initialization occurs. Then the "Calibration" tab was pressed and then the "ORP [mV]" tab was pressed. The sensors are rinsed with de-ionized water and dried. The calibration cup was attached, filled about to 25% with the Zobell's solution, and the storage cap was then screwed on tightly. The sonde was shaken vigorously for six seconds. The cup was then emptied and Zobell's solution was poured in the cup again, but now until the pH sensor and reference were covered. After one minute and once the readings were stabilized, the value on the chart provided on the Zobell solution bottle was entered into the box based on the temperature. "Calibrate" was pressed and "OK" was clicked when the "Calibration Successful" message appeared.

Discharge Relationship Calibration for the SonTek Flow Meter

The SonTek Argonaut SW was chosen for its ability to monitor flow in real-time at depths from 1 ft. (0.3 m) to 16 ft. (5 m). The LEWAS Lab site has a depth of approximately 0.4 m at base flow, which makes this piece of equipment ideal for the site.

<u>Theory</u>

SonTek suggested the "Velocity-Area Method" as the most accurate procedure to calculate flow. The Velocity-Area Method is used to determine discharge of a stream (Q) through the measurement of stream velocity, stage, and cross sectional area (Herschy 1993). After reading Herschy's journal, it was decided to use the 0.6 depth method where the stream velocity was measured at 0.6 of the depth from the surface. These measurements were taken across the cross section of the stream above the flow meter using a Marsh McBirney point velocity measurer. The Velocity-Area Method, which determines the mean velocity and flow of the stream, was performed on several rain events for a 3 month period (9/5/11-11/16/11). The mean velocity (V_m, m/s) is the cross sectionally averaged velocity that when multiplied by the cross sectional area determines the flow of the stream (Q, m^3/s).

In the field a set of independent variables were measured by the SonTek, these are stage (H, m), index velocity (V_i, m/s), and cross sectional area (A, m^2). The index velocity is the vertically averaged mid channel velocity measurement in the stream. Figure 7 shows a distinction between the index velocity, mean velocity, and stage as discussed in Herschy's journal.

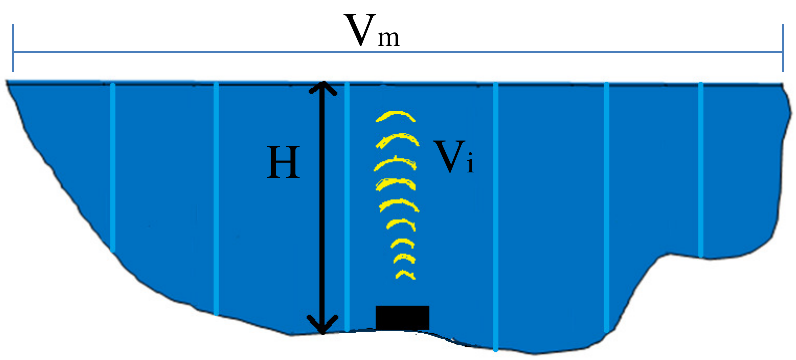


Figure 7: This cross section of the stream represents what each parameter stands for in relation to the Argonaut SW.

<u>Discussion</u>

According to Patino and Ockerman, a multiple regression with V_i and V_i*H as the dependent variables and V_m as the response variable is the best fit. This regression was explored. According to the linear regression performed on JMP Software, using V_i and V_i*H in the same regression is not statistically significant when using V_m as the response variable. When using $V_m = f(V_i, V_i*H)$, the R^2 value is 0.980 and the p values for V_i and V_i*H are 0.850 and 0.0021 respectively. While the R^2 value of this regression is excellent, the high p value for the V_i parameter states that there is a high probability that no relationship exists between V_m and V_i, while the low p value for V_i*H states there is a high correlation between V_m and V_i*H. This allows for V_i to be rejected as a variable in this regression (Agresti, 2007).

With the analysis found above, other relationships were explored. In this paper $V_m = f(V_i*H, V_i*A_i)$, $V_m = f(V_i, V_i*A_i)$, $Q = f(V_i*H, V_i*A_i)$, $Q= f(V_i*H, V_i)$, and $Q= f(V_i*A, V_i)$ were tested to find which relationship fits best. The p values, R^2 values, and F ratios for each respective relationship can be found in Table 1.

Table 6: The table below represents the other relationships questioned in this paper with the variable p values, R^2 values, and F ratios listed.

Function	Variable 1	Variable 2	P_1 Value	P_2 Value	R^2 Value	F Ratio	P total
$V_m = f(V_i{*}H, V_i{*}A_i)$	$V_i{*}H$	$V_i{*}A_i$	0.266	0.848	0.979	367	<0.0001
$V_m = f(V_i, V_i{*}A_i)$	V_i	$V_i{*}A_i$	0.275	0.0021	0.979	366	<0.0001
$Q = f(V_i{*}H, V_i{*}A_i)$	$V_i{*}H$	$V_i{*}A_i$	0.0216	0.0010	0.982	440	<0.0001
$Q= f(V_i{*}H, V_i)$	$V_i{*}H$	V_i	<0.0001	0.0009	0.982	445	<0.0001
$Q= f(V_i{*}A_i, V_i)$	$V_i{*}A$	V_i	<0.0001	0.0180	0.983	449	<0.0001

As shown in Table 1, the relationships $Q= f(V_i{*}H, V_i)$ and $Q= f(V_i{*}A_i, V_i)$ have the smallest p values, with excellent R^2 values, and high F ratios. However, the p value for V_i in $Q= f(V_i{*}A_i, V_i)$ is twenty times that of the p value in $Q= f(V_i{*}H, V_i)$. These relationships were investigated further to determine which relationship was the best fit.

The equations for both $Q= f(V_i{*}H, V_i)$ and $Q= f(V_i{*}A_i, V_i)$ were used to calculate predicted values of flow (Q_{pred}) and were compared to their respective values (Q_{actual}) obtained from the field measurement and the Velocity-Area Method. The residuals and root mean square error values were found. Table 2 and 3 show the results of the comparisons.

Table 7: These values represent the Q calculated vs. the Q predicted for $Q= f(V_i{*}H, V_i)$ with an equation of best fit line of $Q = -0.0047-0.398(V_i) + 1.33(V_i{*}H)$.

Q_{actual} (m^3/s)	Q_{pred} (m^3/s)	Residual	RMSE
0.120	0.109	0.012	0.0124
0.085	0.089	-0.005	
0.089	0.091	-0.001	
0.091	0.094	-0.003	
0.013	0.008	0.005	
0.014	0.011	0.002	
0.016	0.010	0.006	
0.017	0.020	-0.004	
0.024	0.028	-0.005	
0.022	0.025	-0.003	
0.023	0.023	0.000	
0.014	0.023	-0.009	
0.013	0.020	-0.007	
0.014	0.012	0.002	
0.016	0.014	0.002	
0.017	0.015	0.002	
0.028	0.026	0.002	
0.075	0.072	0.003	
0.107	0.110	-0.003	

Table 8: These values represent the Q calculated vs. the Q predicted for Q= f (V_i*A_i, V_i) with an equation of best fit line of Q= -0.0049-0.187(V_i) + 0.971(V_i*A_i).

Q_{actual} (m^3/s)	Q_{pred} (m^3/s)	Residual	RMSE
0.120	0.109	0.011	0.0132
0.085	0.090	-0.005	
0.089	0.091	-0.001	
0.091	0.093	-0.003	
0.013	0.008	0.005	
0.014	0.011	0.003	
0.016	0.009	0.006	
0.017	0.020	-0.003	
0.024	0.030	-0.007	
0.022	0.025	-0.003	
0.023	0.023	0.000	
0.014	0.023	-0.009	
0.013	0.020	-0.007	
0.014	0.012	0.002	
0.016	0.013	0.002	
0.017	0.015	0.003	
0.028	0.026	0.002	
0.075	0.072	0.003	
0.107	0.110	-0.003	

Table 2 and 3 show that Q= f (V_i*H, V_i) is the best relationship due to the lower root mean square value. Figure 8 represents the relationship chosen with the equation of the best fit line: Q = -0.0047-0.398(V_i) + 1.33(V_i*H).

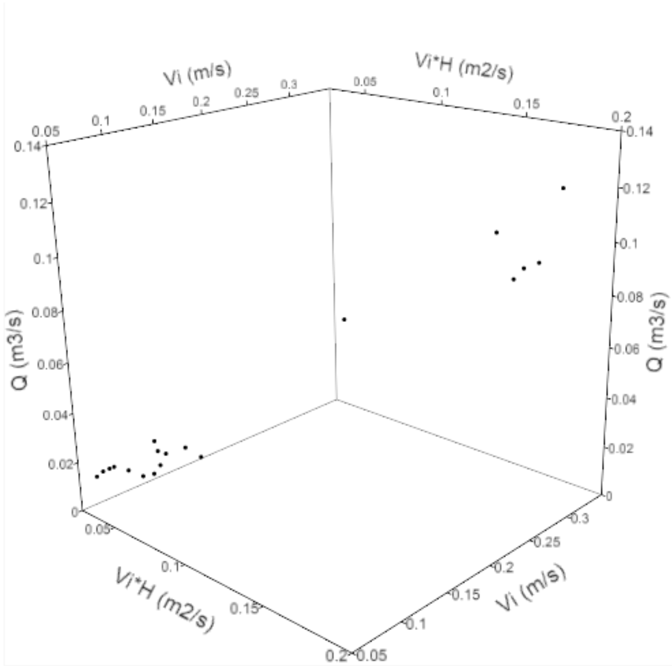


Figure 8: This shows Q= f (V_i*H, V_i) in a 3D scatter plot.

Conclusion

The purpose of this investigation was to find a sound relationship between our dependent variables V_i and H, and the response variable V_m. Through statistical analysis, it is concluded that Q= f(V_i*H, V_i) is the best model with statistically significant p values, a strong correlation between the variables, and a lower root mean square value compared to Q= f(V_i*A_i, V_i).

Recommendations for Future Work

In order to continually collect accurate data, each monitoring device must be maintained in their proper manor. The sonde must be maintained and recalibrated roughly every three weeks. Over time the equation of the best fit line for the SonTek must be updated as seasons change to maintain an accurate regression analysis for the formula to calculate flow correctly.

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References

Advanced Instruments, Inc., 2011. *What is calibration - advanced instruments, inc.*. <http://www.aicompanies.com/index.cfm/ServiceandSupport/CalibrationExplained/What_is_Calibration>

Agresti, Alan. "Statistical Methods for the Social Sciences II." *CHAPTER 11. MULTIPLE REGRESSION AND CORRELATION*. University of Florida, 2007. Web. 16 Dec. 2011. <http://www.stat.ufl.edu/~aa/sta6127/ch11.pdf>

Environmental Protection Agency (EPA), 2011. Impaired Waters and Total Maximum Daily Loads. Accessed June 2011. <http://water.epa.gov/lawsregs/lawsguidance/cwa/tmdl/index.cfm>

EPA, 2010, September 20. *Water/sediment quality*. <http://www.epa.gov/caddis/ssr_urb_wsq2.html>

Finkenbine, J. K., J. W. Atwater, and D. S. Mavinic. "Stream Health After Urbanization." *Journal of the American Water Resources Association* 36.5 (2000): 1149-160.

Green, Chelsea N., 2011. "Design and Application of a Remote Water Quality and Quantity Lab in Blacksburg, Virginia." Virginia Polytechnical Institute, Blacksburg VA.

Hach Hydromet, 2010. Calibration Videos and Transcripts. Accessed June 2011. <http://www.hydrolab.com/web/ott_hach.nsf/id/pa_videos_and_transcripts.html>

Hach Company, 2006. Hydrolab DS5X, DS5, and MS5 Water Quality Multiprobes User Manual. Accessed June 2011. <http://www.stevenswater.com/catalog/products/water_quality_sensors/manual/S5_Manual.pdf>

Herschy, R. "The Velocity-area Method." *Flow Measurement and Instrumentation* 4.1 (1993): 7-10

Kuphaldt, Tony R., 2000. *ph measurement: electrical instrumentation signals*. Accessed July 2011. < http://www.allaboutcircuits.com/vol_1/chpt_9/6.html>

Larson, S., & Ormerod, S.J., 2009. *Low-level effects of inert sediments on temperate stream invertebrates*. Cardiff, U.K.: Blackwell Publishing Ltd.

Leavitt, Jennifer, 1998. "The functions of riparian buffers in urban watersheds." University of Washington, Seattle, Washinton.

Marsh-McBirney INC., 1990. *Marsh-mcbirney, inc. flo-mate model 2000 portable flowmeter instruction manual*. Accessed July 2011. <http://www.marsh-mcbirney.com/manuals/Model_2000_Manual.pdf>

McCunn, Debbie, Sarah Ralph, and Jayson Stevens. "Hylebos Watershed Spring 2003." *UW Courses Web Server*. June 2003. Web. 15 Dec. 2011. <http://courses.washington.edu/uwtoce03/webg1/results.html>

New Jersey Institute of Technology (NJIT). *Conductivity probe*. <http://www-ec.njit.edu/~grow/sensors/CONPROB.htm>

"ORP Technical Education | Support." *Sensorex | PH Electrodes, ORP, Conductivity, Dissolved Oxygen, Free Chlorine, and Other Liquid Analytical Sensors.* Sensorex, 2011. Web. 15 Dec. 2011. <http://www.sensorex.com/support/more/orp_sensor_technical_education>

Parece, T., S. DiBetitto, T. Sprague & T. Younos. 2010. "The Stroubles Creek Watershed: History of development and chronicles of Research." VWRRC Special Report No. SR48-2010. Virginia Polytechnic Institute and State University, Blacksburg, VA.

Patino, Eduardo, and Darwin Ockerman. *Computation of Mean Velocity in Open Channels Using Acoustic Velocity Meters*. Tech. Tallahassee: USGS, 1997.

Richter, B.D., Baumgartner, J.V., Powell, J., & Braun, D.P. (1996). A method for assessing hydrologic alteration within ecosystems. *Society for Conservation Biology*, *10*(4), < http://www.jstor.org/pss/2387152>

Sensorex, 2011. *Conductivity sensor technician education*. Accessed July 2011. <http://www.sensorex.com/support/more/conductivity_sensor_technical_education>

SonTek, 2009. Argonaut-SW Expanded Description. Accessed June 2011. <http://www.sontek.com/pdf/expdes/Argonaut-SW-Expanded-Description.pdf>

Striggow, Brian. *Field Measurement of Oxidation-Reduction Potential (ORP)*. Tech. Athens: U.S. EPA, 2009.

Stroubles Creek IP Steering Committee, Virginia Tech Department of Biological Systems Engineering, and Virginia Water Resources Research Center, 2006. Upper Stroubles Creek Watershed TMDL Implementation Plan.

Radke, Lynda, 2011. *OzCoasts Coastal Indicators: dissolved oxygen*. <http://www.ozcoasts.org.au/indicators/dissolved_oxygen.jsp>

Volland, Walt., 2005. "Solubility of Gases in Liquids, Henry's Law." Online Introductory Chemistry. Accessed July 2011. < http://www.800mainstreet.com/9/0009-006-henry.html>

Yuan, Lester L. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency, (2010). *Estimating the effects of excess nutrients on stream invertebrates from observational data*. Washington, D.C.: Ecological Society of America.

Evaluating Sustainability of Rainwater Harvesting Systems for Commercial Buildings

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ABSTRACT

Significant challenges exist in the current urban water use in the United States. This study sought to examine rainwater harvesting as a possible solution to these challenges. Rainwater harvesting is practiced in the U.S. and around the world to meet various household water needs. However, research is lacking on potential benefits of rainwater harvesting system in commercial buildings. The goal of this study was to assess the potential of rainwater harvesting in commercial buildings for non-potable uses of water for the First and Main shopping center in Blacksburg, Virginia. At the time of the study there were 27 businesses including restaurants, retail stores, and a fitness center. The 6 buildings comprising the shopping mall had a total roof area of 133,415 ft^2.[x] Based on the roof area and rainfall data, the optimum tank size for this site was determined to be between 45,000 and 60,000 gallons. The study also examined barriers in implementing rainwater harvesting systems in commercial buildings which were identified as a lack of communication between land developers and governmental organizations as well as a need for specific guidelines in constructing a building with a rainwater harvesting system.

Keywords: rainwater harvesting, water conservation, sustainability, commercial buildings

Introduction

Water is a necessity to life; and its availability is crucial to sustain domestic, commercial, and industrial needs. Several concerns arise when discussing how to continue the tradition of providing large amounts of clean water to citizens. . One such concern is the decreasing availability of surface as well as ground water resources. The increased land development and urbanization has resulted in increased impervious areas, less infiltration and groundwater recharge and increased surface runoff.[i] In urbanized areas, greater volumes of stormwater accumulate in a shorter time span and peak flow levels are higher.[ii] This condition puts a great strain on water infrastructure, especially since the precipitation gathers contaminants once it makes contact with the ground, and then must be cleaned to meet water quality standards.[ii] A second concern is the need for considerable capital infrastructure to meet increasing water demand. The United States has an aging water conveyance infrastructure desperately in need of repair. The U.S. Environmental Protection Agency estimates that approximately $23 billion per year will be required to keep nation's water and wastewater infrastructure functional in compliance with water quality regulations for the next twenty years.[iii] Alternative solutions must be found to not only address the various challenges to water availability, but also to manage increasing stormwater management demands.

Rainwater harvesting is considered a practical solution to sustainable management of water resources in urban areas. It involves collecting, storing and using captured rainwater from building rooftops for a variety of beneficial uses. In the United States, harvested rainwater is used for non-potable sources including landscape irrigation, flushing toilets, cooling towers and washing laundry.[iv] Several advantages of rainwater harvesting can be noted: 1) using captured rainwater will cause less potable water to be used for non-potable sources, 2) captured rainwater will provide a water source separate from groundwater and thus help to mitigate the decreasing groundwater levels due to over pumping, 3) captured rainwater and use will reduce rooftop runoff to stormwater drainage systems, 4) rainwater water harvesting as a decentralized water infrastructure will decrease demand and stress on centralized water supplies, and 5) potable water savings will contribute to energy saving.

Residential use of rainwater harvesting systems to help alleviate water demand is common around the world, there are few examples of rainwater harvesting on a commercial scale in urban settings.[v] In recent years, with an increasing emphasis on green buildings and site design, rainwater harvesting has seen increased popularity in urban areas as a strategy for sustainable management of water resources. An urban area could encompass hundreds of buildings and therefore rooftops constitute significant percentage of the impervious lands in urban areas. While the results are obviously site-specific, estimates of rooftop area as a percent of impervious area range from 16 – 45%.[vi] Commercial buildings have a large roof area and thus can capture a large volume of water. Businesses in the commercial property would then be able to reduce their water bills by using captured rainwater to supplement their use of municipal water. Although rainwater harvesting has proven to be effective in residential areas, there has yet to be a comprehensive study of a large commercial building complex.

The goal of this study is to study the potential of rainwater harvesting in commercial buildings.

The objectives of this study are:

1. Conduct a literature review to understand the process of rainwater harvesting, specifically focusing on the use of rainwater harvesting in commercial buildings.
2. Adapt an existing model to determine rainwater harvesting system specifications (e.g. tank size, water savings) for a study site in Blacksburg, Virginia.
3. Determine specific barriers, and find potential solutions, to installing a rainwater harvesting system at the study site. Results are expected to be transferable to other commercial settings elsewhere.

Background Information

The Study Site – First and Main Shopping Center, Blacksburg

Blacksburg draws its water from the New River in Virginia. The Blacksburg-Christiansburg VPI Water Authority, which is the single supplier to the Blacksburg area, assures its customers that the water supply is safe and plentiful.[vii] However, it is important even for towns like Blacksburg to consider alternative water sources. Regardless of the water source, decreased precipitation still has an impact on water availability. Several regions of Virginia experienced a drought from 2006 to 2008. In the time span from October 1, 2006 to September 18, 2008, precipitation in the New River Valley was only 80% of the long-term average.[viii] This did not negatively affect Blacksburg's water supply at the time, but there are long-term implications of decreased availability of current water sources.

Decreased precipitation is not the only threat to groundwater levels. Population growth is also a factor, since with more people more water will be demanded.[4] The Virginia Department of Environmental Quality has stated groundwater in several parts of Virginia, including the coastal plain aquifer system, cannot support the increasing water demand. [ix] Furthermore, the groundwater sources in the Arch formation and the fault line areas of Southampton are classified as being critically low.[8] With groundwater so limited, more towns could start using the New River as their primary water source. If this happens, then Blacksburg may be limited in amount of water they can take from the river.[8]

In light of potential challenges to the water supply, it is important to examine other water sources before there is a serious threat of a water crisis. In its 2008 report, the Virginia Department of Environmental Quality suggested a shift to water reuse and conservation in order to continue to match demand. Implementing rainwater harvesting in Blacksburg would provide an alternative water source for an area that relies on water to satisfy all of its water demands.

The site selected for this was the shopping complex known as First and Main in Blacksburg, VA, that was built in 2008.[x] This shopping area consists of 39 business parcels, and 6 separate buildings, and covers an area of 133,415 ft^2. [10] Early in the planning process, incorporating a rainwater harvesting system (RWH) into the site plans was suggested to the developers. However, the final blueprints did not include RWH, and thus it was not part of the complex once it was built.

Figure 1. An Aerial View[xi](left) and a Street View (right) of the First and Main Shopping Complex

Methods

Rainwater Harvesting at Commercial Sites: Case Studies

In order to better understand how to make rainwater harvesting feasible in Blacksburg, Virginia; it was critical to examine other commercial rainwater harvesting sites. From literature review, several existing rainwater harvesting systems for commercial buildings were compared for several factors that include catchment area, cistern size, and amount of rainwater harvested per year. This data was then used as a comparison for the results obtained regarding the rainwater harvesting potential of the First and Main development. Results are given in the section entitled "Rainwater Harvesting at Commercial Sites: Case Studies."

Adapting a Model to Calculate Rainwater Harvesting at First and Main

A model rainwater harvesting system (RWH) design spreadsheet that calculates harvestable rainwater for various conditions was obtained to initiate the study.[11] This model spreadsheet was designed to determine the RWH specifications, i.e., the amount of rainwater that can be captured and the appropriate tank size, for a rainwater harvesting system to be installed in a school in Roanoke, Virginia.[11] Several modifications to this model spreadsheet were needed to make it applicable to the First t and Main study site. Major model input requirements are daily precipitation data, rainwater catchment area (building rooftop areas) and water use data.

Precipitation data for Blacksburg was obtained from the National Climatic Data Center.[xii] Precipitation data from 2008 to 2010 were used in calculations. The process for estimating catchment area and water use data are described below.

Estimating Catchment Area

GIS shapefiles including those that showed land parcels, paved road, paved parking, and buildings in the Town of Blacksburg were downloaded from the Blacksburg GIS database.[xiii] [18] These files were then compiled and pared down to create a single projection file, which showed only First and Main development. The area of each building was then calculated using the "Calculate Geometry" tool, and then total roof area was calculated by using the "Statistics" tool. Total impervious area was also calculated by adding the areas of the paved road, paved parking, sidewalks and, buildings in the projection file of the First and Main development.

After catchment area, and impervious area were calculated, a separate spreadsheet was created in which each business parcel within the development was given a number, and its corresponding area was recorded. A site visit was then conducted, in order to record and match business names with their previously assigned numbers. For the purpose of estimating water use, businesses were then separated into four categories: restaurants, retail stores, fitness centers, and empty space.

Estimating Water Use

The Town of Blacksburg provided a data sheet listing the approximate water use of a business based on business type. [xiv]Approximate water usage of each business was then calculated by multiplying business area by water demand for that type of business. Total water demand was then calculated by adding the water demand of each separate business.

Approximate water use data were also obtained from the Town of Blacksburg Water Utility Services.[xv] . However, this data was not directly used to determine potable and non-potable demand. One reason is that there are only three water meters at the entire development, so water demand per business was not given. The approximate water meter data attained was compared to the calculated water usage based on the aforementioned data sheet specifying water use per business. Since these numbers were relatively close, the calculated demand (instead of approximate demand provided by the town) was used in order to calculate non-potable water usage.

Water captured from rainwater harvesting is usually treated to meet non-potable water standards, and thus would only be used as a non-potable source.[xvi] Due to this fact, it was important to disaggregate water use data, because different types of businesses have a different percentage of non-potable water use. The previously calculated water demand per business was multiplied by the non-potable water use percentage based on the type of business. Non-potable water use percentages for restaurants and retail stores were adapted from "Commercial and Institutional End Uses of Water", a publication by the American Water Works Association.[xvii] Table 1 shows water use estimates used in calculations. The non-potable demand for each business was added to obtain aggregate non-potable water demand for one month. The demand for one month was divided by thirty to approximate non-potable demand for one day.

Table 1 Estimates for Total Water Use and Non-Potable Water Use Based on Business Type

Type of Business	Water Use Per Day (Gal/1000ft^2)[12]	Non-Potable Water Use Per Day (Gal/1000ft^2)[16]
Retail	40	80%
Restaurant	400	45%
(empty)	0	0%
Fitness	115*	18%*

* Water use estimates for the fitness center were calculated using data obtained from New Tech Fitness and Anytime Fitness.[xviii][xix]

Later in the project, access was given to precise water use data for First and Main. This data included exact water meter readings from 2008 to 2011. Since the shopping complex is new, several businesses have moved into or out of the complex since its completion in 2008. The changing number of businesses caused the water meter data to fluctuate. The focus of this study was to calculate potential rainwater harvested for a shopping development that had been well established, implying that most of the business spaces would be occupied. Thus, the maximum water use recorded was used as the basis of comparison for calculations. However, water use decreases during the summer months, so the ratio of summer water use to school year water use was calculated, and then this was multiplied by the calculated school year water use.

Anytime Fitness was moving to the First and Main development during the time of this study was being conducted. Even though this business was not using water during the time, the total and non-potable water use for this business was calculated in order to attain a more accurate estimate of potential water use at the shopping development. The data sheet provided by the Town of Blacksburg did not include estimates for a fitness center. Thus, water use data was collected from New Tech Fitness which is another fitness center in Blacksburg. Water meter data was obtained for the entire building complex in which New Tech Fitness was located. Thus, it became necessary to contact the fitness center directly in order to learn about how many, and what kind of water-using appliances were used as well as the average number of patrons per day. Another spreadsheet was used to estimate how much water each appliance used, and then these numbers were totaled to get find total water use for New Tech Fitness. This number was then divided by thirty in order to get water use per day. The percentage of non-potable water use was calculated by dividing the volume required by non-potable water using utilities by total water usage. Total water usage was then divided by the area of New Tech Fitness in order to obtain an estimate for water use per area.

The water use estimates calculated from New Tech Fitness were then applied to Anytime Fitness by first multiplying the area of Anytime Fitness by the water use per area statistic. Once total water use of Anytime Fitness was calculated, it was multiplied by the non-potable water percentage calculated for a fitness center. Water use during the summer months was calculated the same way it had been calculated for the current businesses at First and Main. The total water use, and non-potable water use of the existing businesses at First and Main were then added to the total water use and non-potable water use estimates(respectively) in order to obtain approximate values of future water use.

Tank Size Calculation

Total roof area, amount of precipitation, and aggregate non-potable water demand were entered into the tank size calculations spreadsheet. Optimal tank size was then calculated by using a series of calculations which took into account the minimum amount of water needed in each tank, and water lost to overflow. Amount of water stored in a tank at the end of every day was calculated by subtracting non-potable water demand for one day from amount of rainwater harvested for that day. A final spreadsheet was created which determined the appropriate tank size based on installation cost, reduction of stormwater runoff, and percentage of non-potable demand that was met by the rainwater harvesting system. Potential rainwater harvested was then determined based on the capacity of the tank which was determined to be most appropriate for the site.

Several separate processes were combined to attain the final results of this study. Figure 2 shows the information that was needed in order to complete all of the calculations explained in the methods.

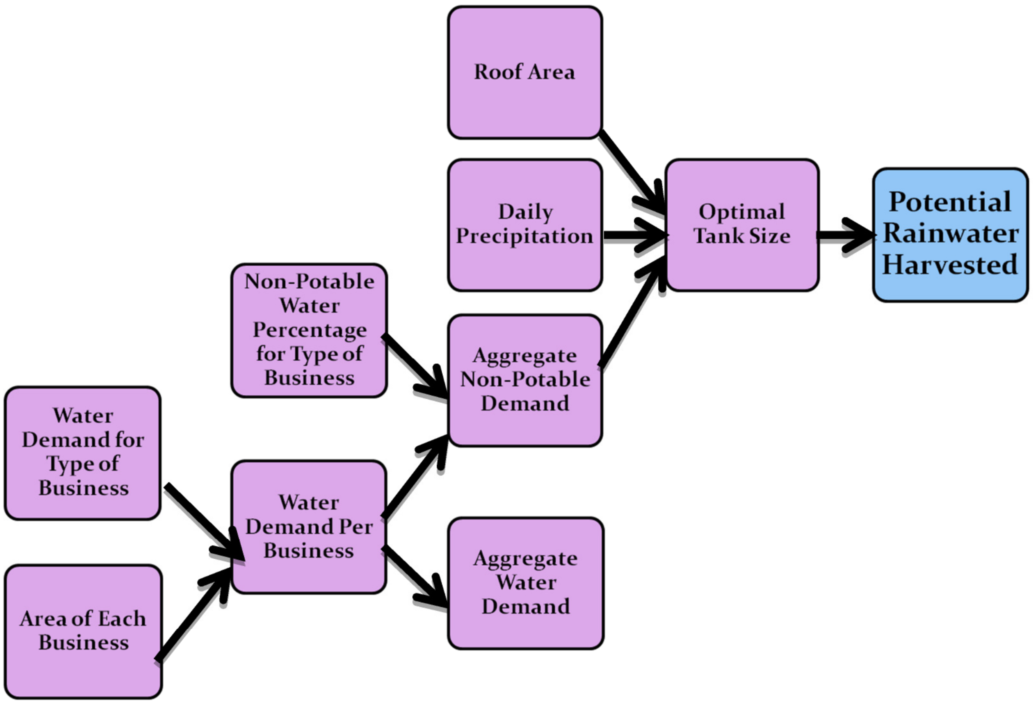


Figure 2. Data Requirements and Results of Calculations Spreadsheet

Barriers to Rainwater Harvesting

The final set of methods for this project involved cultivating an understanding for the problems which stand in the way of making rainwater harvesting more readily used in a commercial setting. In order to examine the potential barriers, and provide potential solutions, interviews were conducted with Matt Stolte, a town engineer for Blacksburg, as well as Meredith Jones, a local developer, in order to get a better sense of the challenges facing Blacksburg specifically. Information gathered from the previously conducted literature review was then used to understand how the various hurdles to installing a rainwater harvesting system at a commercial site can be overcome. The barriers specific to Blacksburg were then matched with solutions from other sites in order to make recommendations for how to effectively implement a rainwater harvesting system in Blacksburg.

Results and Discussion

Rainwater Harvesting at Commercial Sites: Case Studies

During the literature review portion of this study, several different commercial sites utilizing rainwater harvesting around the world were examined. One such site was a Safeway grocery store located in Thamesmead, South London, United Kingdom.[xx] This study was unique because it was not installed for solely practical purposes, but to determine if rainwater harvesting would be practical in other parts of London. The authors determined that if the entire roof (4,400m^2) was used as a catchment area, then 82% of the demand, for toilet use, would be met.[11] The payback period of installing a cistern at this site was 12 years, which is longer than is usually considered economically feasible but because of the environmental benefits the system was installed. The study site which was most similar to the First and Main shopping complex was Daimler Chrysler Potsdamer Platz, in Berlin, Germany, since it was a multi-building complex. Very little information was provided about this site, so an in depth comparison was not possible. Table 1 shows varying features of commercial rainwater harvesting sites.

Table 2. A Comparison of Commercial Rainwater Harvesting Sites Around the World

Building	Location	Type of Building	Use of Rainwater	Catchment Area (ft²)	Rainwater Collection(gal/yr)	Cistern Size(gal)
Fokuoka Dome[xxi]	Fukuoka, Japan	stadium	flushing toilets, irrigation	278,785	13,957,794	396,258
Safeway[11]	South London, UK	supermarket	flushing toilets	23,681	181,539	3,846
Cougar Elementary School[4]	Manassas Park, VA, USA	school	flushing toilets, urinals	61,500	1,300,000	69,800
Sumida City Office[5]	Sumida City, Japan	office building	toilet flushing	53819	1230513	264,172
Belss-Luedecke Strasse[13]	Berlin, Germany	building estate	toilet flushing, garden watering	120,555*	641,938	42,267
Daimler Chrysler Potsdamer Platz[13]	Berlin, Germany	shopping complex	toilet flushing, artificial pond, irrigation	344,445**	unknown	924,602
Wells Branch Recreation Center[xxii]	Austin, TX, USA	recreation center	irrigation	10,000	unknown	37,000
Lady Bird Johnson Wildflower Research Center[14]	Austin, TX, USA	research center	irrigation	17,000	300,000	70,000

*catchment area reflects the sum of rooftop area (7000 m²), and combined street, parking, and pathway areas (4200 m²)

**catchment area reflects the sum of 19 separate buildings in the complex

Although rainwater harvesting is commonly used in developing countries, use of rainwater harvesting in commercial buildings seems to be unique to post-industrial countries. The most common use of the harvested water in the commercial sites studied was toilet flushing, and irrigation. Table 2 indicates that rainwater harvesting can be used at many different types of buildings, owing to the fact that study sites ranged from sports arenas to schools to shopping complexes. Variables which were not included in the table include rainfall patterns (e.g. relatively constant precipitation throughout the year, or periodic precipitation events), cost limitations, and system efficiency. The exclusion of these factors provides a partial explanation as to why there is no direct correlation between tank size, catchment area, and rainwater harvested.

Figure 3 shows the projection file that was made to calculate the rooftop area as well as the impervious area for the First and Main development.

First and Main Case Study Estimating Rooftop and Impervious Areas – Using GIS

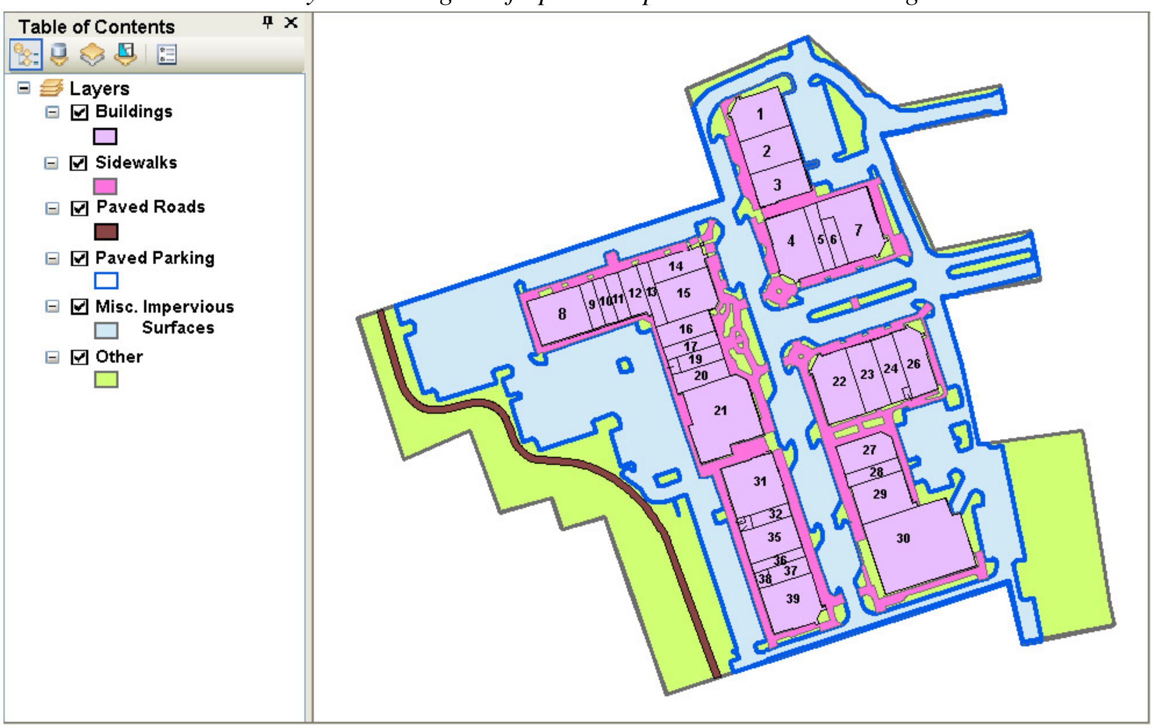


Figure 3[xxiii] First and Main Projection File

Using the projection file, total area of First and Main was calculated to be 569,732 ft^2, the total impervious area was 413,056 ft^2, and roof area was calculated to be 133,414 ft^2. Impervious area constituted 73% of the total area of the development, and roof area constituted 23% of the total area. Roof area was about 1/3 of the area of this site. If the roof were to be used as a catchment surface, then stormwater runoff from impervious surfaces would be reduced by 1/3.

Estimating Water Use in Commercial Buildings

Table 3 shows approximate water use for the First and Main shopping center (in gallons per day). "Calculated water use" refers to water use approximations specific to the type of business multiplied by area of each business. Current calculated water use excludes projected water use of Anytime Fitness, and Approximate water meter data was obtained from Blacksburg Utility Services. Calculated water use including Anytime Fitness was determined by adding current water use to the water use approximations attained from information provided by New Tech Fitness.

Table 3 Total and Non-Potable Water Use at the First and Main Development

	School Year, September-May (gal/day)	Summer, June-August (gal/day)
Current Water Use (Meter Data)	9,483	7,817
Current Water Use (Calculated)	12,363	10,190
Projected Water Use (Calculated)	13,655	11,255
Projected Non-Potable Use (Calculated)	6,713	5,533

Rainwater Harvesting Potential, Tank Size and Water Savings

The various inputs described in Figure 2 were added into the final calculations spreadsheet. The final excel model computations showed how much water would be provided based on the size of the tank used at First and Main. The cistern sizes evaluated ranged from 5,000 gallons to 90,000 gallons and increased on a 5,000 gallon increment. The amount of water, and money, saved per year based on the amount of rainwater harvested were also calculated. (Appendix 1) Figure 4 was generated using the data in Appendix 1, and it shows the relationship between tank size and percent of non-potable demand met by rainwater harvested.

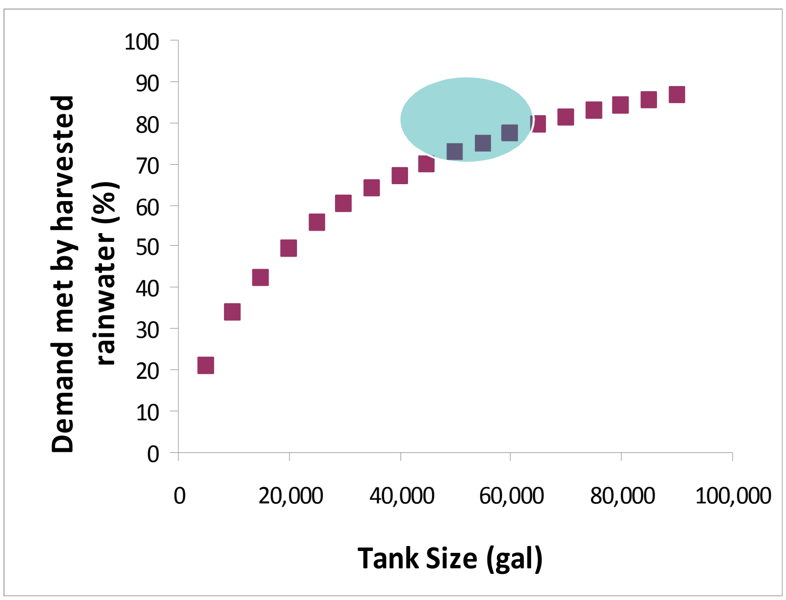


Figure 4. Percentage of Non-Potable Demand Met vs. Tank Size at First and Main

The direct results of installing a rainwater harvesting system at the First and Main development were largely dependent on the tank size that was selected. The 5,000 gallon tank was only able to meet Non-potable water demand met by the system ranged from 21% for the 5,000 gallon tank to 86% for the 90,000 gallon tank(Appendix 1). There was also a wide range in savings from water use and sewage with \$4,219 in savings per year for the 5,000 gallon storage tank to \$17,355 per year for the 90,000 gallon storage tank. Exact prices for the cisterns could not be determined, because price depends on if the tank is below ground or above ground, and what materials are used to construct it.

Even though considerably more money and water is saved using larger tanks, the price of installation also rises. The changing slope of the curve in Figure 4 indicates the cost benefit ratio of tank installation. When tank size is increased from 5,000 to 10,000 gallons, the slope of the line connecting the two points is very steep. Gradually over time, the curve flattens out, implying that the cost of installation is greater than the benefit of installing a larger tank is decreasing. The slope starts to noticeably level off when the tank size is between 45,000 and 60,000 gallons, implying that the maximum benefit for tank size has been reached. If the installer's focus is the shortest payback period for the greatest benefit, then a 45,000 gallon tank should be used. However, if payback period is not as much of a concern, then a 60,000 gallon tank should be used, because in the long-run there will be a larger amount of money saved. Any of the four tanks in the 45,000-60,000 gallon range would have the greatest saving to initial cost ratio compared to the other tank options. Deciding between these four tanks has to do with personal preference, and preferred payback period.

Barriers and Solutions to Rainwater Harvesting at First and Main

Based on the author's personal communication with an engineer for the Town of Blacksburg (Matt Stolte), a local developer (Meredith Jones), and a literature review, the following thought have been compiled. [xiii] [xxiv]

Matt Stolte primarily spoke about the process of land being developed commercially in the Town of Blacksburg. First, a developer purchases a piece of land, and makes some general plans as to what he wants to be constructed. Then, an architect is hired to draw up specific plans based on the developer's specifications as well as town ordinances. Once the architect makes a set of blueprints that the developer is satisfied with, the plans are submitted to the town. Town engineers then examine these plans to verify that the building plans meet all of the town regulations. If there is a problem with the plans, then they are returned to architect who works with the developer to make modifications. These modified blueprints are then go through a process of resubmission until they are approved. After final approval by the engineers, the town council votes on whether the development can officially be built. Once plans are approved, the developer searches for contractor who then provides a cost estimate for the project. The developer then chooses a single contractor based on projected costs as well as estimated completion time. The contractor then constructs the development.

Rappaport is the development company responsible for the First and Main shopping area. During the design phase of this project, Rappaport considered incorporating a rainwater harvesting system. However, there are several reasons that a rainwater harvesting system never even made it to the blueprints for this site. One such reason is that the Town of Blacksburg is highly particular when it comes to the kind of developments that can be built. Aesthetics are considered as well as various other considerations. One such ordinance which frustrated developers was the ban on big box stores which prevented Rappaport from adding a Walmart to the development. Although the big box regulation did not prevent rainwater harvesting, it does prove as an example of specific ordinances which make incorporating a rainwater harvesting system difficult.

Another issue with rainwater harvesting is that no specific regulatory guidelines are established in the Town of Blacksburg in regards to rainwater harvesting systems. Developers would have to go through the hassle of determining how a rainwater harvesting system could be established with regard to the current building codes. In regard to Virginia codes, rainwater harvesting is a potential way for a building to get credit. However, in order to get the building credit, the harvesting water must be used throughout the year. In many locations, irrigation is the best way to use harvested rainwater, but because it is not used during the winter, a rainwater harvesting system would not meet the qualifications.[xxiv]

Economic feasibility is another problem with installing a rainwater harvesting system. When a rainwater harvesting system was installed for a supermarket in England, the installation of a 14.56m^3 (3,846 gal) cistern cost £7700 ($12,563.32). This means that installation of a rainwater harvesting system can cost a developer an amount of $12,563.32 more than a traditional water conveyance system. Considering that the cistern which would be installed at First and Main could be as large as 90,000 gallons, installation costs would probably be in the order of hundreds of thousands of dollars.

Currently, the price of 1,000 gallons of water in Blacksburg is $3.92 for intake, and $4.65 for sewer water treatment.[xxv] With the total cost of water per 1,000 gallons being $8.57, installing a rainwater harvesting system seems to be more of a hassle than it would be a long-term investment. With all of these barriers making commercial rainwater harvesting difficult, one must carefully weigh the costs and benefits.

Conclusion

Despite challenges, rainwater harvesting is still a promising potential solution to water-related issues in the United States. The case study of the First and Main shopping mall proved that rainwater can significantly reduce reliance on traditional water sources. When determining tank size, it is important to compare installation cost to percentage of demand met and monetary savings per year. It seems that a cistern ranging from 45,000 gallons to 60,000 gallons would be most appropriate for this study site. Absolute cost of installing a cistern cannot be calculated, because of unknown factors such as above ground or underground installation of cistern and cistern material type. .

From discussions with various engineering and building specialists in the Town of Blacksburg, it becomes evident that one cannot focus on monetary savings as a primary objective of rainwater harvesting. Instead, environmental and water sustainability concerns have to play a large factor in deciding to install a rainwater harvesting system. If one focuses on the benefits of reducing stormwater runoff, reducing strain on traditional conveyance systems, and taking some pressure off of groundwater and surface water sources, then rainwater harvesting can be considered a feasible option. However, the key to the long term success of rainwater harvesting will be creating a conversation between developers and government officials. Only if these different groups work together can rainwater harvesting become more widely used in the commercial buildings, causing a long-term positive environmental impact.

This study is unique because it involved calculating rainwater harvesting potential of a series of commercial buildings, as opposed a single building. Calculating water use at this study site also involved a calculation of the percentage of non-potable water use for a fitness center, which had not been clearly documented in the past. Certain limitations did exist such as the use of estimation when calculating the water use of a fitness center. Since water meter data was not consistent, approximate water use calculations were used, to determine appropriate tank size. If approximations were incorrect, then total water use and optimal tank size could also be incorrect. Recommendations for future work include performing a similar case study of another commercial mall, improve upon the estimation of non-potable water use for a fitness center, and survey developers to assess their willingness to implement rainwater harvesting.

Peer Feedback on Presentations

During the ten week NSF/REU fellowship at Virginia Tech, I was required to give a 5-minute, 10-minute, and a practice 15-minute presentation, before the final 15-minute presentation. I found these periodic presentations helpful not only because I was able to practice my public speaking skills, but also because I received peer feedback after each presentation. In my 5-minute presentation I gave an explanation of rainwater harvesting, and introduced my research site. My peer feedback showed me that I explained rainwater harvesting clearly, but that I needed to focus more on the field research that my study would entail.

In the 10-minute presentation, we were expected to talk about methods and objectives as well as background information about my project as well as rainwater harvesting itself. The peer feedback that I received indicated that I focused too much on my literature review, and that my methods and objectives were not very clear. However, I was told that my audience learned a lot about various barriers which prevent the implementation of rainwater harvesting. This helped me realize that I needed to focus on explaining my project in specific, and be less concerned with the background information.

The 15-minute presentation was essentially a "dry run" for the final presentation on August 5th. The peer feedback I received indicated that I needed to be more excited when presenting, focus more on results and conclusions, and make sure to explain how my findings will address various barriers to rainwater harvesting. On a more positive note, almost all of my audience members wrote that I was confident, and had good public speaking skills (with the exception of saying the word "um" many times).

In preparing for my final 15-minute presentation, I made my results and conclusions a more prominent part of my presentation. I also focused on explaining how my findings will help to make rainwater harvesting a more feasible solution to various water issues. In order to make sure that everything I said was clear to understand I practiced my presentation in front of my roommate. Receiving peer feedback for all of my presentations has certainly made my final presentation much better that it would have been if I only gave one presentation at the end of the fellowship. This fellowship will be valuable in the future not only because I have learned research skills, but also because I have learned how to present scientific information to a larger audience, both through writing and speaking.

Acknowledgements

We would like to recognize NSF REU program for funding which provided stipends and other support. Acknowledgements are due to Matt Stolte (engineer, Town of Blacksburg) and Michelle Frazier (Blacksburg Utility), Meredith Jones (developer, MJ Services), Anthony Ferguson (Anytime Fitness), Diana Francis (New Tech Fitness), for helping her attain various pieces of information valuable to her research. Also would also like to acknowledge Tammy Parece for help in learning how to use ArcGIS, and being available to answer any questions.

References

[i] Town of Blacksburg, Department of Engineering and GIS. (2008) *First and Main Development*. Blacksburg, VA: Town of Blacksburg.

[i] Shengtang, Z., Xiaojia, G., Yun, J. (2011) Proceedings from the 2011 International Conference on Computer Distributed Control and Intelligent Environmental Monitoring: *Stormwater utilization as an environmental-friendly method to alleviate urban water resources crisis: Taking Qingdao as an example.* pp. 1722-1725. Changsha, Hunan China

[ii] Burns D., Vitvar T., McDonnell J., Hassett, J., Duncan, J. and Kendall, C. (2005) Effects of suburban development on runoff generation in the Croton River basin, New York, USA, *Journal of Hydrology,* **311***(1-4),266–281.* doi:10.1016/j.jhydrol.2005.01.022

[iii] U.S Environmental Protection Agency. 2007. Reducing Stormwater Costs through Low Impact Development (LID) Strategies and Practices. EPA 841-F-07-006.http://www.epa.gov/ow ow/NPS/lid/costs07/.Accessed July 27, 2011.

[iv] Lawson, S., LaBranche-Tucker, A., Otto-Wack, H. Hall, R., Sojka, B., Crawford, E., Crawford, D., Brand, C. (2009). *Virginia rainwater harvesting manual.* Salem, VA: Cabell Brand Center.

[v] United Nations Environmental Programme. (2002)*An environmentally sound approach for sustainable urban water management: An introductory guide for decision-makers.* Washington, D.C.: United Nations Environmental Programme.

[vi] Akbari, H., L. Shea Rose, and H. Taha. Analyzing the land cover of an urban environment using high-resolution orthophotos. Landscape and urban planning. 63: 1–14

G. W. Higgins, General Manager Blacksburg Christiansburg Water Authority, personal communication, July 15, 2011

[viii]Virginia Department of Environmental Quality: Office of Surface and Ground Water Supply Planning. (2008) *Status of Virginia's water resources: A report on Virginia's water resources management activities.* Richmond, VA: Office of the Governor of Virginia.

[ix] Masterson, J.P., Pope, J.P., Monti, J. Jr., & Nardi, M.R. (2011) Assessing groundwater availability in the Northern Atlantic Coastal Plain aquifer system. In *U.S. Geological Survey fact sheet 2011.* Retrieved from http://pubs.usgs.gov/fs/2011/3019/pdf/fs2011-3019_masterson_508.pdf.

[xi] Europa Technologies.(2011). Google maps. Retrieved from http://maps.google.com/maps ?hl=en &tab=wl on June 20,2011.

[xii] National Climatic Data Center. (2011) [Data file]. Retrieved from http://www7.ncdc.noaa. gov/IPS/cd/cd.html?_page=0&jsessionid=A50481FDDB5BC9A82BAC9B6604E51C59&state= VA&_target1=Next.

[xiii] Matt Stolte, Engineer for the Town of Blacksburg, personal communication, June 1-July 20, 2011.

[xiv] Sarah Lawson, Rainwater Management Solutions, personal communication, June 1-July 2,2011.

[xv] Michelle Frazier, Blacksburg Utility Services, personal communication, July 14, 2011.

[xvii] American Water Works Association Research Foundation. (2000). Commercial and institutional end uses of water. Denver, Colorado: American Water Works Association.

[xviii] Anythony Ferguson, Anytime Fitness, personal communication, July 15,2011.

[xix] Diana Francis, New Tech Fitness, personal communication, July 13-15,2011.

[xx] Chilton, J. C., G.G. Maidment, D. Marriott, A. Francis, and G. Tobias. (2000). Case study of a rainwater recovery system in a commercial building with a large roof. *Urban Water.* 1(4): 345-354. doi: 10.1016/S1462-0758(00)00032-7.

[xxi] Zaizen, M., Urakawa, T., Matsumoto, Y., and Takai, H. (2000). Collection of rainwater from dome stadiums in Japan. *Urban Water, 1(4),*355-359. doi:10.1016/S1462-0758(00)000 28-5.

[xxii] Texas Water Development Board. (2005). *The Texas manual on rainwater harvesting, 3rd edition*. Austin, TX: Texas Water Development Board.

[xxiii]Town of Blacksburg, Geographical Information Systems Office.(2011) [GIS data for the Town of Blackburg, VA, ArcView GIS file June 8, 2011] *Blacksburg GIS Data Distribution*. Retrieved from http://www.gis.lib.vt.edu/gis_data/Blacksburg/GISPage.html

[xxiv] Meredith Jones, personal communication, July 21,2011.

[xxvxxv] Town of Blacksburg, Utility Service. (2011) Utility Service. Retrieved from http://www. blacksburg.va.us/Index.aspx?page=47 on July 24,2011

Appendix

Appendix 1: Rainwater Harvested and Monetary Savings Based on Tank Size for the First and Main Development

Tank size (gallons)	Overflow volume per year (thousands of gallons)	Supplied volume per year (thousands of gallons)	% of demand met by rainwater	Savings from water use ($)	Savings from sewer fees ($)	Total Savings Per Year ($)
5,000	2,603	492	21	1,930	2,289	4,219
10,000	2,307	791	34	3,102	3,680	6,782
15,000	2,110	992	42	3,888	4,612	8,500
20,000	1,944	1,161	50	4,551	5,399	9,950
25,000	1,809	1,300	55	5,094	6,043	11,137
30,000	1,701	1,410	60	5,529	6,559	12,087
35,000	1,620	1,495	64	5,862	6,954	12,816
40,000	1,549	1,569	67	6,152	7,298	13,450
45,000	1,485	1,637	70	6,418	7,613	14,030
50,000	1,424	1,702	73	6,670	7,913	14,583
55,000	1,371	1,757	75	6,889	8,172	15,062
60,000	1,321	1,811	77	7,098	8,420	15,519
65,000	1,277	1,858	79	7,283	8,639	15,921
70,000	1,240	1,899	81	7,443	8,829	16,272
75,000	1,206	1,936	83	7,588	9,001	16,590
80,000	1,177	1,968	84	7,716	9,152	16,868
85,000	1,151	1,998	85	7,831	9,289	17,120
90,000	1,127	2,025	86	7,938	9,417	17,355

NSF/REU Site Announcements

Summer 2011 - Undergraduate Research Fellowships Announcement

National Science Foundation Research Experiences for Undergraduates (REU) Site

INTERDISCIPLINARY WATER SCIENCES AND ENGINEERING

Virginia Tech, Blacksburg, Virginia

Application Deadline March 07, 2011 (Monday)

Applications are invited from qualified and motivated undergraduate students (freshmen, sophomores, juniors and rising seniors) from all U.S. colleges/universities to participate in a 10-week (May 30-August 5, 2011) summer research in interdisciplinary water sciences and engineering at Virginia Tech. *U.S. citizenship* is required. The research program is funded through the National Science Foundation – Research Experiences for Undergraduates (NSF REU) program. The 10-week research will begin on May 30 (arrival day - May 29) at Virginia Tech and end on August 5, 2011 (departure day – August 6). The research internship includes a stipend of $450/week, subsistence costs (dormitory and meals) and round trip travel expenses to Virginia Tech. We have already graduated 26 excellent undergraduate researchers from our site during 2007-09. Application materials, details of possible research projects and other program activities are posted on following website:

Department of Engineering Education: www.enge.vt.edu

Example Projects:

- Biogeochemical Controls on Contaminant Transport and Transformation
- Hydrology and Hydraulics Impacts on Ecological Health of Surface Waters
- Bacterial Contamination of Water Distribution and Plumbing Pipelines
- Water Quality for Human Health and Aesthetics
- Microbial Source Tracking in a Watershed Environment
- Hypolimnetic Oxygenation: Coupling Bubble-Plume and Reservoir Models
- Real-Time Water Monitoring System
- Water-Energy Nexus and Decentralized Water Infrastructure
- Antibiotic Resistance Genes (ARGs) as Emerging Environmental Contaminants
- Analysis of Patterns of Macroinvertebrate Density and Distribution in Stroubles's Creek

Deadline for application submission is **March 07, 2011**. Successful applicants will be informed by March 21, 2011. Please contact **Dr. Vinod K Lohani** (phone: (540)231-9545;

E-mail: vlohani@vt.edu) for questions.

Summer 2011 - Undergraduate Research Fellowships Announcement

National Science Foundation Research Experiences for Undergraduates (REU) Site

INTERDISCIPLINARY WATER SCIENCES AND ENGINEERING

Virginia Tech – Application Deadline March 07, 2011 (Monday)

Program Description: Applications are invited from qualified and motivated undergraduate students (freshmen, sophomores, juniors and rising seniors – engineering and science majors) from all U.S. colleges/universities to participate in a 10-week summer research in interdisciplinary water sciences and engineering at Virginia Tech. *U.S. citizenship* is required. The research program is funded through the National Science Foundation – Research Experiences for Undergraduates (NSF REU) program. This NSF REU site has successfully hosted a total of 26 undergraduate researchers in summers of 2007, 2008 and 2009. Research reports for the 2007 - 2009 participants are documented in the NSF REU Proceedings of Research and posted here: 2007 2008 2009

Successful applicants (hereafter referred to as REU fellows) will join one of the ongoing research projects in water sciences and engineering and conduct research under the supervision of Virginia Tech faculty and graduate students. Research projects address issues related to sustainable management of water resources and water infrastructure, and facilitate opportunities or field research, laboratory work and testing of theoretical concepts. See Appendices 1 and 2 for list of faculty advisors and typical 2011 summer research projects, respectively. The summer research program is complemented by other professional activities. For example, REU fellows will attend weekly forums that facilitate dynamic and interactive discussion on research methods and various facets of water sciences and engineering. Speakers at these forums will include VT faculty members, graduate students and experts from water industry and government. These weekly forums provide an excellent opportunity to REU fellows to learn about commonalities between their various research projects, interact with each other and with research mentors. REU fellows will make frequent presentations to their peers about their research progress and ultimately prepare a research report in collaboration with their research mentors suitable for conference presentation and/or publishing in a refereed journal or other appropriate publications.

Social interaction and networking is a major goal of the program. Several social activities are organized to encourage informal personal interaction between REU participants and the research team and the larger university community. See Appendix 3 for possible recreational activities.

Financial Support: The 10-week internship will begin on May 30 (arrival day - May 29) at Virginia Tech and end on August 5, 2011 (departure day – August 6). The research internship includes a stipend of $450/week, subsistence costs (dormitory and meals) and round trip travel expenses to Virginia Tech.

Application: Application Deadline is March 07, 2011. Submit via surface mail the following documents:

1. Application Form (see next page)
2. A 300-word essay about your interest in water/environment research and professional goals, and indicate top two choices of summer research project and include a brief justification (see Appendix 2). The justification should be part of your essay.
3. Two letters of recommendation in sealed envelopes. *Letters should address candidate's motivation, enthusiasm, reliability, team-work and personality.*
4. College transcripts in sealed envelope from the university registrar's office.

Successful applicants will be announced by March 21, 2011. For questions, please contact:

Dr. Vinod K Lohani, NSF REU Program Director, e-mail: vlohani@vt.edu; Phone: (540)231-9545

NSF REU 2011 Application Form

Interdisciplinary Water Sciences and Engineering

Virginia Tech

Personal Information

Name ____

First Middle Last

Address ____

Street City State/Zip

U.S. Citizen Yes ___ No ___ **Gender** Female ___ Male ___

Ethnicity (optional):

Phone ______________________ **E-mail** ________________________

Academic Information

Undergraduate Major ___________________ **University** ___________________________

Expected Month and Year of Graduation _______________________

GPA/QCA ___________ **Academic Honors** ___________________________________

Professional Reference 1 Name Title Department University

Professional Reference 1 Name Title Department University

Preferred projects (see Appendix 2): #1:-----------------------------#2:---------------------------

Applicant Signature __________________________ **Date of Application** ________________

Required Documents

1. A 300-word essay about your interest in water/environment research and professional goals, and indicate top two choices of summer research project and include a brief justification (see Appendix 2). The justification should be part of your essay.

2. Two letters of recommendation in sealed envelop from the professional references listed above. *Letters should address motivation, enthusiasm, reliability, team-work, and personality.*

3. College transcripts in sealed envelop from the university registrar's office.

Application Submission

Mail the complete application material via surface mail to: **Dr. Vinod K Lohani**, NSF REU Program Director, Department of Engineering Education, 660 McBryde Hall, Virginia Tech,

Blacksburg, Virginia 24061-0218.

Application material must be received by 5:00 p.m., March 07, 2011 (Monday).

Appendix 1. Program Management Team and Research Mentors

Name	Organization	Responsibility	Academic Discipline and Field of Study
Dr. Lohani*	Virginia Tech	Project Director (PI); Program Coordinator; Recruitment & Selection; Assessment; Cohort Experiences/ Professional Development; Dissemination; Research Mentor	Civil and Agricultural Engineering; Hydrologic Modeling; Watershed Instrumentation
Dr. Younos*	The Cabell Brand Center for Global Poverty and Resource Sustainability Studies	Project Consultant Research Mentor and Coordinator of Weekly Seminars and Field Trips	Civil & Environ Eng.; Water Resources; Water-Energy Nexus; Decentralized Water Infrastructure; Watershed Assessment
Dr. Dietrich	Virginia Tech	Research Mentor; Participant Selection	Civil & Environ Eng.; Analytical Chemistry
Dr. Edwards	Virginia Tech	Research Mentor; Participant Selection	Civil & Environ Eng.; Water Infrastructure
Dr. Hester	Virginia Tech	Research Mentor; Participant Selection	Civil & Environ Eng.; Ecohydraulics
Dr. Little	Virginia Tech	Research Mentor; Participant Selection	Civil & Environ Eng. ; Lakes & Reservoirs
Dr. Hagedorn	Virginia Tech	Research Mentor; Participant Selection	Crop & Soil Environ Sciences - Bacteriology
Dr. Schreiber	Virginia Tech	Research Mentor;	Geosciences –

		Participant Selection	**Geohydrology, Sensors**
Dr. Pruden	**Virginia Tech**	**Research Mentor;** **Participant Selection**	**Environmental Engineering; Environmental Contaminants**
Dr. Benfield	**Virginia Tech**	**Research Mentor;** **Participant Selection**	**Biology; Ecology; Macroinvertebrates**
Dr. Sanders	**Virginia Tech**	**Recruitment/Selection**	**Academic Enrichment**
Dr. Muffo	**Independent Assessment Consultant**	**Evaluation/Assessment**	**Academic Assessment**
Dr. Trenor	**Clemson University**	**Evaluation/Assessment/Recruitment**	**Engineering Education Research**

* Project Management

Appendix 2. 2011 NSF REU Potential Research Projects

REU Fellows will join one of the ongoing research projects to conduct individual research under the supervision of their research mentors. Several of these projects are funded through various federal agencies such as the NSF, EPA, and USDA. Typical research projects are described below. Please select your top two choices and enter in the application form.

Project 1. Biogeochemical Controls on Contaminant Transport and Transformation

Mentor: Dr. Schreiber

Our research goal is to examine the biogeochemical controls on contaminant transport and transformation in natural waters. To do this, we utilize hydrologic, geochemical, and biological techniques in the field and laboratory to determine rates of reaction and properties of the medium/contaminant, in order to construct quantitative models that can be used to simulate transport and transformation. Current and previous field sites include abandoned mines, agricultural watersheds, wetlands, and cave systems. The REU participant would conduct field monitoring and/or lab experiments for a project on uranium mobility in natural waters. Experience (and interest) in field sampling, analytical chemistry, and environmental chemistry would be highly beneficial.

Project 2. Hydrology and Hydraulics Impacts on Ecological Health of Surface Waters

Mentor: Dr. Hester

This research aims to understand the mechanisms connecting human activities in stream corridors and watersheds with degradation of aquatic ecosystems and water quality, to allow better informed ecological stream and river restoration design, pollutant attenuation by natural processes, and watershed planning. Current projects include field experiments and associated data analysis to evaluate the effect of human activities such as urbanization on either surface water-groundwater exchange or temperature dynamics in streams and rivers, both of which can strongly impact aquatic organisms and water quality. The REU participant's role will vary but typically entail installing piezometers or using of geophysical techniques to monitor surface water-groundwater exchange; installing, monitoring, or downloading hydraulic and water quality sensors; surveying streambed and floodplain topography; analyzing sensor or survey data; and presenting results in a written report or oral presentation.

Project 3. Bacterial Contamination of Water Distribution and Plumbing Pipelines

Mentor: Dr. Edwards

The growth of pathogens in home plumbing poses a significant human health threat and is currently a primary source of waterborne disease in the US. Two pathogens, Legionella pneumophila and

Acanthamoeba, are of particular concern when present together, because Acanthamoeba can induce rampant growth of L. pneumophila by serving as a host organism. This research will develop techniques to identify and enumerate L. pneumophila and Acanthamoeba using PCR and Q-PCR methodology. When applied to practical experiments in simulated potable water heaters effects of nutrients such as organic carbon on L. pneumophila and Acanthamoeba growth can be established. The goal of this work is to establish organic carbon thresholds in which Acanthamoeba (and by extension L. pneumophila) can proliferate. The REU participant would first develop, and then execute, a sub-set of experiments to address this issue, in collaboration with a graduate student, under the direction of Dr. Edwards. He/She would also write up the results and hopefully, present the work at a major research conference.

Project 4. Water Quality for Human Health and Aesthetics

Mentor: Dr. Dietrich

The increasing demands on the world's water supplies had led to water reuse (wastewater to drinking water) and desalination as being viable means of producing drinking water. Unresolved issues related to use of these non-traditional water supplies include the nutritional content of the water and consumer acceptability. Projects for the REU fellows could include: 1) performing sensory evaluations with human subject to determine suitable mineral content of drinking waters; 2) evaluating the nutritional content of waters processed through different treatments; 3) isolating and identifying the odorous chemicals with gas chromatography/mass spectrometry; 4) performing odor threshold experiments to determine the normal range at which humans can detect and describe tastes and odors; 5) developing documents that communicate the value of drinking water quality and aesthetics to the public.

Project 5. Microbial Source Tracking in a Watershed Environment

Mentor: Dr. Hagedorn

Microbial source tracking is an exciting area of research where Virginia Tech scientists provide national leadership in developing and implementing the concept. The goal of the ongoing research is to trace the source(s) of bacteria in surface and ground-waters using biochemical and molecular fingerprinting techniques. REU participants will be involved in all aspects of current projects, including the field-related work of collecting fecal samples from sewer systems, livestock and wildlife; the laboratory work that consists of isolating fecal bacteria from the collected samples, and then using the fingerprinting techniques on the isolates to classify bacteria according to their originating source. The REU students will have an opportunity to participate in microbial source tracking projects in different types of watersheds.

Project 6. Hypolimnetic Oxygenation: Coupling Bubble-Plume and Reservoir Models

Mentor: Dr. Little

The REU participant will be engaged in a recently funded NSF project entitled "Hypolimnetic Oxygenation: Coupling Bubble-Plume and Reservoir Models." Bubble-plumes are increasingly used to replenish oxygen in the hypolimnion of stratified reservoirs. These devices are required to sustain cold-water fisheries, improve raw water quality in water-supply reservoirs, and mitigate the environmental consequences of hydropower generation. However, bubble-plumes may induce significant mixing that in turn can change stratification, enhance sediment oxygen demand, and cause hypolimnetic warming. The plume action also alters the prevailing vertical density gradient in the water column, which affects the performance of the bubble-plume in a feedback loop.

Project 7: Real-Time Water Monitoring System

Mentor: Dr. Lohani

Dr. Lohani established a sustainability research and education lab with support obtained from a NSF department-level reform (DLR) grant (2004-2009) and our 2007-09 NSF/REU site award. A LabVIEW Enabled Watershed Assessment System (LEWAS) has been tested in this lab for remotely assessing real-time water quality and quantity data from a creek that flows through Virginia Tech campus. LEWAS provides LabVIEW based programmability to user and enables multiple remote access. A water quality sonde is a part of LEWAS and provides the capability to sense temperature, conductivity, dissolved oxygen, and pH of water. In addition, a weather station has also been integrated into LEWAS to allow real-time monitoring of weather parameters like precipitation, temperature, humidity, etc. The data is shared with remote clients via Wireless LAN. The field implementation of LEWAS employs an industrial computer (compactRIO from the National Instruments) as server which can run remotely and continuously without user intervention. It is equipped with three modules for serial communications, non-volatile data storage and wireless communications. Two NSF/REU participants (2008, 2009) worked in this lab as part of their research. An exchange student (undergraduate) from India worked in this lab in summer 2010. The REU participant will participate in integrating software and hardware components of the LEWAS and carry out analysis of real-time water data and associate these with land use activities and rainfall storms in Stroubles Creek watershed. VT campus is located in this watershed.

Project 8. Water-Energy Nexus and Decentralized Water Infrastructure

Mentor: Dr. Younos

Water-energy nexus and watershed-based sustainable management of water resources are high priority research issues. Dr. Tamim Younos conducts research on various aspects of decentralized water infrastructure, water & energy conservation and carbon footprint of water consumption in urban environments at the Cabell Brand Center. Projects that the REU participant can participate include studying energy efficiency and ecological effects of rainwater harvesting and onsite wastewater treatment systems, investigation of watershed-based decentralized low impact development (LID) for urban stormwater management, and design of micro-hydro power generation plants. Case studies are underway in various locations (e.g., Giles County, VA; Hampton Roads, VA).

Project 9: Antibiotic Resistance Genes (ARGs) as Emerging Environmental Contaminants
Mentor: Dr. Pruden

Dr. Pruden's research objective is to apply environmental engineering principles in order to help address one of the most pressing human health problems of this century: antibiotic resistance. A unique aspect of Dr. Pruden's research is the consideration of the antibiotic resistance gene (ARG), or the "drug-resistant DNA," as the contaminant of interest, rather than the host cell. This is considerate of the fact that ARGs can persist and be shared among bacteria, even if the original host cell is killed. Current projects are aimed at tracking urban and agricultural sources of ARGs at the watershed scale as well as examining the potential of water and wastewater treatment to eliminate ARGs. Quantitative real-time polymerase chain reaction (qPCR) is applied to quantify the ARGs of interest. The REU participant will have an array of projects to choose from, for example: effect of advanced oxidation processes on ARGs, fate of ARGs during anaerobic digestion, persistence of ARGs in soil irrigated with reclaimed water, and quantifying ARG expression in response to selectors via reverse transcription PCR.

Project 10: Analysis of Patterns of Macroinvertebrate Density and Distribution in Strouble's Creek

Mentor: Dr. Benfield

Strouble's Creek is a 3rd-4th order stream draining about 80% of the town of Blacksburg and most of the VT campus. Downstream of campus and the Duck Pond, Strouble's Creek passes through several miles of farmland before entering a woodland area and travelling on to the New River. Members of the Biological Systems Engineering Department recently initiated a stream restoration project in Strouble's Creek in an open pastureland reach downstream from campus. I propose an REU project evaluating the effectiveness of the restoration on the macroinvertebrate assemblage in the creek. This would involve but not be limited to quantitatively sampling macroinvertebrates upstream in an open reach and in a wooded reach, at one or more sites within the restoration reach, and at downstream sites. The macroinvertebrates would be identified to the lowest practical taxonomic level and the data would be subjected to a suite of standard multimetric analysis. There would also be a number of geomorphic analyses of the stream bed, banks and associated variables leading to an attempt to explain patterns of macroinvertebrate density and distribution.

Appendix 3

Recreational Activities around Blacksburg, Virginia

Virginia Tech is located in Blacksburg, Virginia and surrounded by the Blue Ridge Mountains. The Appalachian Trail runs through the area and affords many hiking trails. Other hiking trails off the Appalachian Trail include a 2-mile hike to the Cascades Waterfall and Wind Rock, which affords panoramic views of nearby mountain ridges. The New River is located nearby providing kayaking, canoeing, inner tube floating, and fishing during the summer. Other outdoor activities include mountain biking at Pandapas Pond, road biking the Blue Ridge Parkway, and walking, running or biking the Huckleberry trail. The Salem Avalanche, a Class A Affiliate of the Houston Astros, play in nearby Salem, VA.

Live music in both indoor and outdoor venues is available. Friday Night Jamboree in Floyd, VA has been listed as one of the two best places to hear bluegrass music in the United States. Friday nights on Henderson Lawn (located on campus and next to downtown) is an opportunity to hear live music free during the summer. Several restaurants provide live music throughout the week such as Jazz and Bluegrass. Unique eating experiences include local eateries such as Mike's Grill (burgers and fries), More than Coffee (Mediterranean cuisine), Cabo Fish Taco, Boudreaux's (Cajun style food), The Cellar (Greek cuisine), Gillie's (vegetarian fare), Excellent Table (Ethiopian fare) as well as numerous coffee shops located next to campus. Next to campus is The Lyric, a non-profit venue that shows weekly movies and with occasional live performances and a large stadium style movie theatre is located 5 miles away in Christiansburg adjacent to the New River Mall. This is just a sample of the wide varieties of things to do and see in and around Blacksburg.

Cascade Falls, Jefferson National Forest, near Blacksburg, Virginia

Orientation and Concluding Ceremonies

Welcome NSF REU Fellows!

LEWAS Lab Team

- Present Members
  - Faculty Advisor: Dr. Vinod K. Lohani 
  - PhD Candidate: Parhum Delgoshaei (EngE) 
  - Master's student: Mark Rogers (CEE) 
  - Undergraduate students: Stephanie Welch (CEE) 
  - Divyang Prateek (ECE) 

Team Continued

- Past Members
  - Master's students: Chelsea Green (CEE) 
    - Mayank Saraf (ECE) 
  - Past Undergraduate Students:
    - Faizan Qureshi (ECE) 
    - Stephen Holmes (CEE) 

Team Continued

- Past Undergraduate Students Continued
  - Michael Sadowski (CEE) 
  - Sarnia Prabhakaran (ISE) 
- Past NSF-REU Students:
  - Sean Ezrol (CS) 
  - John Kenny (CEE) 


2011 NSF REU Mentors
LEWAS LAB
LEWAS LAB
Interdisciplinary Watershed Sciences
and Engineering


HOLA! I'm Catherine Betances ☺
A little bit about me:
- Originally from the Bronx, NY but slowly becoming accustomed to the New Jersey life.
- Rising Junior at Smith College
- Winter 2011 Fellow for Community Water Solutions in Ghana, where I spent 3 weeks helping a rural community get access to clean water.
- One of my summer goals: go camping and do lots of outdoor activities
- Loves wearing shorts, humidity, fruits, Brazil, Dominican food, tennis, and poetry!
Some of my research and academic interests include:
- Major: Engineering Science
- Minor: Portuguese and Brazilian Studies
- Environmental Engineering
- Water Quality and Water Resources
- Global South Studies and Development
- Recent research: Complicating the Data: An Intersectional Perspective on the Engineering Experience


Alex Kuhl
This summer I'm working with Prof. John Little on Hypolimnetic Oxygenation: Coupling Bubble-Plume and Reservoir Models
I just completed my junior year at SUNY Brockport in upstate NY double majoring in physics & water resources
I'm interested in pursuing a degree/career in environmental engineering
In my free time I enjoy hiking, camping, Ultimate frisbee, puzzles, cards, running, etc...


Kinsey Hoffman
Bethesda, MD Virginia Tech 2014
Biological Systems Engineering
Project 10: Analyzing levels of macroinvertebrates in Stroubles Creek
Mentor: Professor Fred Benfield

Dusty Greer

I grew up on a farm in North Central Kansas.
We grew wheat, milo, and soybeans. We also have over 100 head of cattle. I went to a small high school with 30 in my graduating class. I played football and wrestled while I was in school. I now attend Wichita State and major in Industrial engineering, and am very interested in the efficiency of our health care. While at Virginia Tech, I will be working with Dr. Lohani on the Real-Time Water Monitoring System project.

WSU

Victoria Sicking

Tarleton State University
Senior Environmental Engineering Major

- Research Experience:
  - "Occurrence of Monensin Antibiotics in Bosque Watershed Region" (Spring 2010)
- Future Plans:
  - Peace Corps
  - Graduate School

Alex Gerling

- I am from Fairport, NY and I attend Hobart and William Smith Colleges in Geneva, NY.
- I am a double major in Geoscience and Environmental Studies with a minor in Math.
- My research interests include hydrology and weather.
- In my free time I like to spend time by the water, be with friends and family, listen to music, attend concerts, and have fun!

Christopher George Stamopoulos

ΣΦΕ

Robert Miles Ellenberg

- Hometown: Woodstock, GA
- Home School: VT; Rising senior, CEE
- Academic Interests: Environmental/Water Resources Engineering
- Extra-Curricular: Musician, Radio DJ, Outdoors

Rodrigo Prugue

- Senior at Florida State University
  - Majoring in Geology with a minor in
- Mathematics
  - [illegible]
  - [illegible]
  - [illegible]
- [illegible]
- [illegible]
- Oceanography
- From Miami, FL
- Born in Lima, Peru
- Interested in Hydrology/Environmental
- Engineering
  - [illegible]
- [illegible]
- Enjoy the outdoors
  - [illegible]
  - hiking
  - [illegible]

Maya Rao

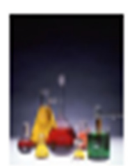
- Research interests:
  - responsible resource use to alleviate poverty
  - Equitable water allocation
- Studying at: Saint Louis University
  - Majors: Environmental Science and International Studies
  - Minor: French
- Interested in the Peace Corps

TIGER BAND

CONCORD MILLS

CHARLOTTE MOTOR SPEEDWAY

Ryan Murphy



CEINT

Center for the Environmental Implications of NanoTechnology

Raymond Pierson

Cornell '18

Biological Engineering & English

University of St Andrews

Interdisciplinary Nature of NSF REU

- **Dr. Schreiber:** Biogeochemical Controls on Contaminant Transport and Transformation
- **Dr. Hester:** Hydrology and Hydraulics Impacts on Ecological Health of Surface Waters
- **Dr. Edwards:** Bacterial Contamination of Water Distribution and Plumbing Pipelines
- **Dr. Dietrich:** Water Quality for Human Health and Aesthetics
- **Dr. Hagedorn:** Microbial Source Tracking in a Watershed Environment

NSF REU 2011 Projects cont'd

- **Dr. Little:** Hypolimnetic Oxygenation: Coupling Bubble-Plume and Reservoir Models
- **Dr. Lohani:** Real-Time Water Monitoring System
- **Dr. Younos:** Water-Energy Nexus and Decentralized Water Infrastructure
- **Dr. Pruden:** Antibiotic Resistance Genes (ARGs) as Emerging Environmental Contaminants
- **Dr. Benfield:** Analysis of Patterns of Macroinvertebrate Density and Distribution in Stroubles Creek

NSF REU Weekly Seminars

June 3 [illegible] [illegible]	Dr. Tamim Younos Dr. Vinod Lohani Dr. Tamim Younos	[illegible] [illegible] [illegible]
June 10 [illegible] [illegible] [illegible]	[illegible] NSF REU Fellows [illegible]	Conflict Resolution [illegible] [illegible]
June 17 [illegible]	[illegible]	[illegible]
June 24 [illegible]	Dr. Vinod Lohani	[illegible]
July 1	4th of July Holiday	4th of July Holiday
July 8 [illegible] [illegible] [illegible]	[illegible] NSF REU Fellows [illegible]	[illegible] [illegible] [illegible]

NSF REU Weekly Seminars

July [illegible] [illegible]	[illegible]	[illegible]
July 22 [illegible]	[illegible]	[illegible]
July 29 [illegible]	[illegible] NSF REU Fellows	[illegible] 15-minute presentation [illegible]
August [illegible] [illegible]	NSF REU Fellows	Final Research Presentations Submit Final Research Report

Housing

- Housing – Graduate Life Center dorms (GLC)
  - Several Facilities offered within the GLC
  - Parking Passes
  - Mail & Linens → Harper Hall

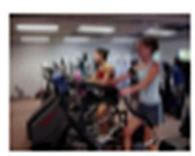
Dining

- D2 – all you can eat style
  - Pass key provided
- Au Bon Pain in Squires
  - Cash/Credit Card accepted

La Patisserie is D2's dessert shop →

VT Facilities

- War Memorial ($5/day)
- Blacksburg Gyms ($42/month or $92/summer)
- Break Zone open to all in Squires
- Library use available



Possible Social Activities

- Weekly/monthly dinners downtown
- See a movie at the Lyric
- Go hiking!
- Have a cookout!
- Live music is readily available at local restaurants and venues.
  - http://www.facebook.com/#!/BlacksburgLiveMusic
- http://www.roanoke.com/news/nrv/nrve/
  - NRV Entertainment

Site Seeing

- Cascades Trip
- Cavern Tour
- Natural Bridge

- Where would you like to visit this summer? – Let us know!

Misc. Information

- Use BT (bus system) – \$.50 per ride
  - http://www.blacksburg.gov/index.aspx?page=885 – for schedule
- New River Mall in Christiansburg
- Farmer's Market
  - Saturday (8am–2pm) and Wednesdays (2–7pm) on Draper Road

NSF/REU Site on Interdisciplinary Water Sciences and Engineering

Concluding Ceremony

Summer 2011 (May 29th – Aug 5th)

Cascades Room - The Inn at Virginia Tech

P R O G R A M

Welcome and Overview of Site Activities	**8:30 a.m.**
Fellows' Research Presentations	**8:45 a.m.**
Part I:	**8:45 a.m. – 10:10a.m.**

R. Miles Ellenberg: Civil and Environmental Engineering, Virginia Tech, VA
Dissolution of Weathered Crude Petroleum from 2010 Macondo Blowout
(Mentors: Drs. Amy Pruden and Mark Widdowson, Gargi Singh)

Catherine Betances: Engineering Science, Smith College, MA
Improving the Health of Copper Creek, Virginia by Determining Levels of Fecal Pollution
(Mentors: Dr. Chuck Hagedorn and Annie Hassall Lawrence)

Chris Stamopoulos: Chemical Engineering, NCSU, NC
Reducing Problems Associated with Partial Replacement of Lead Service Lines
(Mentor: Dr. Marc Edwards and Justin St. Clair)

Kinsey Hoffman: Biological Systems Engineering, Virginia Tech, VA
Analysis of Macroinvertebrate Density and Distribution in Stroubles Creek, Virginia
(Mentor: Dr. Fred Benfield)

Alex Gerling: Geoscience & Environmental Studies, Hobart and William Smith Colleges, NY
Sensory Perception of Metals in Drinking Water and the Role of Saliva in Metallic Flavor Production
(Mentors: Dr. Andrea Dietrich and Susan Mirlohi)

YouTube Videos	**10:10 a.m. – 10:20 a.m.**

Break: 5 minutes

LEWAS LAB
LabVIEW Enabled Watershed Assessment System

Part II 10:25 a.m. - 12:10 p.m.

Alex Kuhl: Water Resources & Physics, The College at Brockport, SUNY, NY
Nitrate in the Occoquan Reservoir
(Mentors: Dr. John Little and Melissa C. Stewart)

Maya Rao: Environmental Science & International Studies, Saint Louis University, MO
Evaluating Sustainability of Rainwater Harvesting Systems for Commercial Buildings
(Mentors: Drs. Tamim Younos and Vinod K Lohani, Mark Rogers)

Dusty Greer: Industrial Engineering, Wichita State University, KS
LabVIEW Virtual Instrument Development and Implementation for Real-Time Environmental Monitoring.
(Mentors: Dr. Vinod K. Lohani and Parhum Delgoshaei)

Victoria Sicking: Environmental Engineering, Tarleton State University, TX
Characterizing the Effects of Macropores on Hyporheic Zone Hydraulics in Meander Bends
(Mentors: Dr. Erich Hestor and Garrett Menichino)

Rodrigo Prugue: Geology, Florida State University, FL
Dissolution Rate of Apatite as a Function of Grain Size
(Mentors: Dr. Madeline Schreiber and Denise Levitan)

Stephanie Welch: Civil and Environmental Engineering, Virginia Tech, VA
Method Development and Calibration of the LEWAS Real-Time Stream Monitoring Outdoor Laboratory
(Mentors: Dr. Vinod K. Lohani and Mark Rogers)

Lunch (Latham DEF) 12: 15 p.m. – 1: 30 p.m.


LEWAS LAB
WELCOME
NSF-REU Site on Interdisciplinary Water Sciences and Engineering
Summer 2011
Concluding Ceremony: August 05, 2011
Cascades Room – The Inn at Virginia Tech


LEWAS Lab Team
Faculty Advisor: Dr. Vinod K. Lohani
PhD Candidate: Parhum Delgoshaei (EngE)
Master's student: Mark Rogers (CEE)
Stephanie Welch (CEE)
Divyang Prateek (ECE)


Research Mentors
Interdisciplinary Water Sciences and Engineering


Welcome REU Fellows!
Great Job!
Virginia

Welcome Guests!

Family Members

Alex Gerling's family; Miles' family; Victoria's dad; Rodrigo's guest

Seminar Speakers/Field trip

Matt, Simoni, Steve, Michele, Mike, Llyn

Graduate Students

Gargi, Garrett, Annie, Justin, Melissa, Susan, Preeti, Amanda, Denise, Laurel

Assessment Expert

John Muffo

University Staff

Tomalei and her colleagues

Site Work (May 29- Aug. 05)

Monday – Thursday: Research with Mentor's group

Fridays: Seminars, Weekly Reflection Papers, Field Trips, Social Activities

YouTube videos

Pre-and Post-Assessment

Weekends: Social Activities

Research Topics

Research Topics

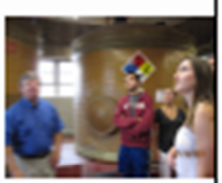
Research Topics

Dissolution rate of Apatite ...

Seminars

- Research
- Conflict Resolution
- The Merits of Service-Learning and Community Engagement
- Ethics in Science & Engineering
- Sustainability and Green Buildings
- Coping with the Town Environmental Issues
- Research and Life: The Graduate Student Perspective

Field Trips



Social Events

Tinker Cliffs, Roanoke VA

Washington DC

Cascades Trail, Blacksburg VA

2007-2009; 2011- :NSF REU Fellows:

2007

2008

2009

2011

THANK YOU

- REU Fellows & family members
- Research Mentors
- Graduate Students
- Seminar Speakers
- Field trip organizers
- Assessment expert
- Fiscal Person (Sabrina)
- VT Staff (Dining, The Inn, University)
- REU Site Staff

Presentations

- Each Fellow gets 15 min. for presentation (will get a signal when 2 minutes are left) followed by 2 min for Q&A.
- YouTube Videos (team 1 & team 2)
- Lunch

Assessment Report by

Dr. John Muffo

NSF REU Interdisciplinary Watershed Sciences and Engineering

John Muffo
Assessment Report
Virginia Tech, Summer, 2011

The following is an independent assessment of the level of success of the program conducted during the summer of 2011. As in 2007 through 2009, my role was mainly to develop the entry and exit survey, to conduct the surveys, and then to conduct the focus group at the end of the summer. I had only minimal contact with the faculty and students during the rest of the time when the students were at Virginia Tech.

ABSTRACT

Overall the experience was a positive one for the students involved. Most came to the program with some commitment to attending graduate school, but wanting to use the experience as an opportunity to explore the matter further. The levels of commitment strengthened over the summer, though not all expect to go on for a Ph.D. immediately from their undergraduate programs.

Not only did they gain a deeper understanding of the processes used in the scientific study of water, but they also reported growth in understanding the ways in which scientists interact with each other and use that knowledge in service to their communities, and in a number of other areas of scientific awareness and maturity. In addition, they seemed to genuinely enjoy each other's company; the *esprit des corps* of the undergraduate students was quite obvious and came through in their comments. The suggestions for improving the program were modest and generally reflected logistical matters. On the positive side, they found a number of the seminar presentations interesting and were complimentary regarding the field trips as well.

Entering Survey

There were ten students who were enrolled in the program during the summer of 2011. One student entered the program late, so there was no pre-test data for him. Consequently, there was entry and exit data for nine of the students; their responses are below, in order of the highest to lowest responses. (The questions were developed in cooperation with the faculty who are the Principle Investigators for the project. They were revised based on the questions asked in 2007-2009.)

Using the following scale:
1=Strongly Disagree; 2=Disagree; 3=Neutral/No Opinion; 4=Agree; 5=Strongly Agree

The entering students provided the following responses upon entry:

- Water research can be challenging. – 4.22
- I have an appreciation for the role of faculty in advising students. – 4.11
- I have an appreciation for the role of graduate students in research. – 4.00

- I have an appreciation for the role of faculty in research. – 3.89
- I have a good understanding of the role of ethics in scientific investigations. – 3.78
- I am aware of many ways in which scientists serve their communities. – 3.56
- I plan on attending graduate school soon after I graduate. – 3.44
- I am aware of the many ways in which scientists from different fields interact with each other in conducting research in water sciences. – 3.22
- There are many opportunities for employment in the water field. – 3.22
- I am confident that I understand how to conduct scientific research. – 3.00
- I plan on going to work soon after I graduate. – 3.00
- I can communicate scientific concepts effectively to a scientific audience. – 2.78
- I understand the processes used to monitor water quantity and water quality. – 2.67
- Social network sites (e.g., Facebook, YouTube, etc.) are a good way to share scientific research results. – 2.56
- I know everything that I need to know to conduct scientific research in the library. – 2.22
- There are winners and losers in environmental conflicts; it's as simple as that. – 1.89
- The use of statistics is not important in water research. – 1.44

The students also answered the following open-ended questions; these were shared with the faculty. Their responses are contained in Appendix I.

- What suggestions do you have for improving the application process for this NSF/REU program?
- Do you have any concerns about the program that you are beginning now? If so, what are they?
- List the top three things that you would like to learn/experience during this 10-week long NSF/REU program.

Exiting Survey

At the completion of the program the students completed the same survey with the same questions. Their responses are below, again in order from the highest to lowest.

- I have an appreciation for the role of graduate students in research. – 4.89

- I have an appreciation for the role of faculty in research. – 4.78
- I have an appreciation for the role of faculty in advising students. – 4.78
- I have a good understanding of the role of ethics in scientific investigations. – 4.67
- Water research can be challenging. – 4.67
- I am aware of the many ways in which scientists from different fields interact with each other in conducting research in water sciences. – 4.56
- I understand the processes used to monitor water quantity and water quality. –4.38
- I am confident that I understand how to conduct scientific research. – 4.33
- I am aware of many ways in which scientists serve their communities. – 4.33
- I can communicate scientific concepts effectively to a scientific audience. – 3.89
- I am aware of many opportunities for employment in the water field. – 3.89
- I plan on attending graduate school soon after I graduate. – 3.67
- I know everything that I need to know to conduct scientific research in the library. – 3.33
- I plan on going to work soon after I graduate. – 3.11
- Social network sites (e.g., Facebook, YouTube, etc.) are a good way to share scientific research results. – 2.22
- There are winners and losers in environmental conflicts; it's as simple as that. – 1.56
- The use of statistics is not important in water research. – 1.44

The students also answered the following open-ended questions. Their responses are contained in Appendix II.

- Please comment on social activities during the 10-week program. Your suggestions for next year are most welcome.
- Please comment on the weekly seminars you attended during the past 10 weeks. Feel free to list the topics you liked and didn't like. Suggestions for next year are most welcome.
- Please comment on the merit and frequency of presentations you made during the last 10 weeks.

Change Over the Summer

One of the more interesting aspects of the survey data is to look at the change over the summer or the difference between the exit responses versus the entrance ones. Of course there are some complicating factors such as ceiling effects, i.e., there is no way to increase a score that is a 5.00 on a 5.00 scale upon entrance, but for most questions one can still look for areas in which the students changed over the ten weeks of the program. Below are listed the questions in order the magnitude of the change in their responses between the time that they began and exited the program. (Note that the numbers in parentheses are negatives.)

- I understand the processes used to monitor water quantity and water quality. – 1.71
- I am aware of the many ways in which scientists from different fields interact with each other in conducting research in watershed sciences. – 1.34
- I am confident that I understand how to conduct scientific research. – 1.33
- I know everything that I need to know to conduct scientific research in the library. – 1.11
- I can communicate scientific concepts effectively to a scientific audience. – 1.11
- I have a good understanding of the role of ethics in scientific investigations. – 0.89
- I have an appreciation for the role of faculty in research. – 0.89
- I have an appreciation for the role of graduate students in research. – 0.89
- I am aware of many ways in which scientists serve their communities. – 0.77
- I have an appreciation for the role of faculty in advising students. – 0.67
- I am aware of many opportunities for employment in the water field. – 0.67
- Water research can be challenging. – 0.45
- I plan on attending graduate school soon after I graduate. – 0.23
- I plan on going to work soon after I graduate. – 0.11
- The use of statistics is not important in water research. – 0.00
- There are winners and losers in environmental conflicts; it's as simple as that. – (0.33)
- Social network sites (e.g., Facebook, YouTube, etc.) are a good way to share scientific research results. – (0.34)

To summarize, the greatest reported gains over the summer were in the areas of understanding the processes used to monitor water quality as well as understanding the ways in which scientists conduct research, interact with each other, and communicate their findings to each other.

Focus Group Results

At the end of the program, at the end of the summer, a focus group was conducted of the ten students who participated in it. They were asked a series of open-ended questions by the evaluator. No faculty or other staff was present. Below is a summary of their responses.

1. What did you like about the program that you just completed?

- It was well organized.
- It was relevant.
- There was a diverse group of students representing diverse fields of study.
- The pairings with research mentors were good matches.
- The amount of structure regarding the research projects was about right.
- We learned from other people about a range of topics.
- The presentations – doing three ourselves and hearing from others.
- The sequencing of the presentations – doing 5, 10, and 15 minute presentations effectively.
- The amount of care from faculty, graduate students, and others. (People are interested and invested in the program.)
- We had the proper amount of freedom and responsibility in doing research, similar to being in graduate school.
- Now know what to expect in graduate school.
- We made some good contacts for future contacts and if we need to ask questions.

2. What concerns do you have about the program just ended?

- The program is ending.
- Not many complaints; it was a great experience.
- Projects can't be completed in depth in ten weeks; what's going to happen to our research projects? It might depend on the project.
- Would liked to have had more meal options, especially when doing off-campus research; also more variety.

3. List the top three things that you learned (within and outside of your discipline) during this program.

- It's impossible to get a research project done in two months.
- Research is incredibly focused, detailed, specific, narrow.
- How important organization and planning can be even months and years in advance.
- How important communication can be in different parts of the lab.
- The nature of research – unforeseen stumbling blocks have to be anticipated.
- One must be flexible in approaching research projects.
- It is important to be interdisciplinary and collaborative with others to get the best work done.
- It is important to communicate with others and hear what others are doing.
- Thinking long-term, the effect of one's work over the long term.
- Everything we do can be important over the long term, including failure.
- Challenges and how to handle those.
- What it's like to be a graduate student; self-analysis, reflection.

4.a. How many of you are motivated to go to graduate school now? – did the NSF REU influence your motivation?

- All ten of those interviewed intend to go to graduate school, though not all necessarily at the doctoral level. (One or two do not want a career in research but want to get at least a master's degree.)
- The program helped motivate most of them, increased their commitment.

4.b. How many of you intended to go to graduate school at the beginning of the summer?

- Nearly all reported that they already intended to go to graduate school.
- Several were "interested in finding out if I was interested."
- One person reported being scared away from pursuing a Ph.D.

5. How do you think that your communication skills improved as a result of this program? [Probing questions – Verbal? Written? Facebook? YouTube? Other?]

- "Through the roof."
- After a week, felt to be at the same level with graduate students and others in the program on a conversational level.
- More comfortable asking questions now.
- Personal confidence increased.
- Surprised by others' sense of genuine curiosity.
- Communicating on a professional level with other adults was a good experience.
- Presentations helped in communicating scientific results and led to fresh thinking.
- Helped public speaking; the 5, 10, and 15 minute structure worked well.
- The entire structure of the program made sense.
- Writing of the report was helpful in learning how to convey ideas to a scientific audience.
- There was no lack of communication between the mentor and graduate student; it was a strong connection.
- Dr. Lohani was good at communicating *what* had to be done and *why*.

6. In what ways, if any, did you find the field trips informative?

- Wastewater treatment helped me see the bigger picture.
- They were education in application, how science is applied in the real world.
- We enjoyed the time with the *people* in the different fields, getting the human involvement talking with people in different fields.
- The stream field trip was not as interesting and informative to several students as the others.
- They do take you out of your comfort zone (e.g., weather service field trip).

7. How satisfied were you with your living environment at Virginia Tech? Your social/cultural environment?

- All ten operated as a group, but eight lived in one area of the graduate residence and two in another, though the two were not very far from the rest of the group. It still caused them to feel somewhat estranged from the rest of the group.
- The current living group dynamic is a strong enhancement to the program.
- They spend a lot of time together; there is a strong sense of a group/family dynamic.
- The Graduate Life Center is a big plus, a good location for them.
- Some would like single rooms.
- Social activities are internally planned; different people organize different activities.

- It was a positive thing to have at least one person from VT in the group.
- A question in the application about who you are might help get a good match of people.
- The social dynamic helped them motivate each other.

8. Other comments?

- The program is well organized.
- Dr. Lohani has done a great job.

Concluding Comments

The group in 2011 differs from that in the three prior years in that that they seemed to be less confident coming in regarding their knowledge of research and library skills. That's the reason that the changes are so large in those areas at the end of the summer – their levels of confidence had reached those of their predecessors in prior years. Other than that, the results are similar to those of the prior years and follow the continuing a pattern of increasingly positive feedback based on what appears to be a strong program that seems to be getting better. The lack of complaints is instructive and unusual in program evaluations.

Socials

Washington DC

Cascades Trail: Blacksburg, VA

Tinker Cliffs: Roanoke, VA