Runoff Water Quality from Highway Cut Slopes in Pyritic Rock Formations: Characterization and Potential Treatment

Tennessee Department of Transportation

Final Report

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Cover page photo: Road cut through Chattanooga shale east bound I-640, Nashville, Tennessee

Photo by J. Schwartz, July 2014

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16. Abstract

Road construction through pyritic (sulfidic) rock formations has the potential to cause episodic runoff acidification and impairment to aquatic biota when acid producing materials (APM) are exposed to precipitation. State highways departments (DOTs) across eastern United States in the Appalachia region have recognized the need to handle APM during road construction projects, including Pennsylvania, Virginia, and Tennessee. These state DOTs have developed testing, material handling, and disposal guidance. Although much is known about acid material drainage (AMD) chemistry, treatment options, and potential harmful impacts from it, little is known about the water quality generated from post-construction road cuts through APM, and what hydrogeological conditions may produce harmful levels of acidic waters containing sulfates and dissolved metals. The project objectives were to: 1) characterize the water quality from APM highway cut slopes to assess whether long-term environmental issues occur to receiving streams; 2) assess the potential effectiveness of on-site treatment applications at road cuts through a physical model experiment; and 3) by a review of AMD treatment literature assess the possibility of using passive treatment solutions for the level of acid pollution generated from road cuts in Tennessee. Characterization of runoff water quality from highway cut slopes through pyrite geology was conducted at ten monitoring stations in Middle and East Tennessee. The ten stations were located among five different surficial geologic formations; they were the Chattanooga Shale, Fentress Formation, Sandsuck Formation, Great Smoky Group (Anakeesta Formation), and the Snowbird Group: Roaring Fork Sandstone. The influence of various environmental factors was investigated on their effect on runoff water quality, which included: rock formation type and age of cut, cut slope and aspect, vegetation, and rainfall magnitude and intensity. Runoff pH and other chemical parameters varied widely between sites and within sites among different runoff events. Site mean pH ranged from 4.29 to 6.27, and the full sample event range was between 2.97 and 7.70. Site means for acid neutralizing capacity (ANC) ranged from -0.82 to 29.85 meq/L, and did not correlated per site with mean pH values. The fact that pH and ANC did not correlate suggests complex and unique biogeochemical processes are occurring among the study sites. Availability of base cations from the pyritic formation or an adjacent over- or under-burden sedimentary formation that contribute to the runoff greatly controls the ANC. Site means for sum of base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) ranged from 1.15 to 40.24 meq/L. Decreased pH can result from the displacement of base cations from the rock with Al complexes, where the base cations act as counter ions to electrochemically balance leached sulfate and other acid anions. Overall, rock formation type was the dominant controlling factor for water chemistry of road cut runoff. The findings suggested that there are minimal effects from seasons, storm event magnitude, and road cut characteristics of slope and aspect. Also, it suggests the older the road cut the likelihood of acidic runoff is small and that planting vegetative cover at runoffs can be used as an effective management strategy to minimize acidic runoff. Useful information was obtained from an outdoor experimental study which consisted of constructing four container panels to place pyrite rock, and for three of the four panels install treatments to limit or prevent exposure to the rock, and subjected to both simulated and natural rainfall. The treatment types were: 1) soil/vegetation cover, 2) shotcrete, and 3) a geosynthetic membrane liner. One panel with exposed pyrite rock (no treatment) served as the experimental design control, and provided unique data on runoff chemistry and ion export from the bare rock surface. For the simulated rainfall experiment, pH increased from approximately 3.6 to above 6.0 within four hours. However, rapid oxidation occurred where the next day the initial pH was near 3.6 however reached pH values above 6.0 within two hours. Runoff ANC from the pyrite rock remained low during the simulations due to the lack of base cations to neutralize the acid anions. Mineral ions from the rock surface are quickly washed off as observed by the rapid decline in conductivity within the first hour of rainfall and basically diminished of ion source within two hours of rainfall. Shotcrete and a geosynthetic membrane liner were found to be effective to protect runoff water quality. The treatment consisting of soil/vegetation was more complex, and runoff quality needs further investigation. From the experiments, several roadside treatment options are available; they include: limestone beds and oxic/open channels, aerobic wetlands, settling ponds, bio-reactors, and pebble quicklime. Design of these treatment options are described in the guidance document “*Guidelines for Acid Producing Rock Investigation, Testing, Monitoring and Mitigation*” by Golder Associates.

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Runoff Water Quality from Highway Cut Slopes in Pyritic Rock Formations: Characterization and Potential Treatment

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List of Acronyms

AA	Acid anions
AWWA	American Water Works Association
Anakee	*Geology*: Great Smoky Group: Anakeesta Formation
ANC	acid neutralizing capacity
ANOVA	Analysis of Variance
AP	Acid potential
AMD	Acid material drainage
APM	Acid producing material
BC	Base cations
Chat	*Geology*: Chattanooga Shale
CMC	Compound maximum concentrations
CN	Curve number (hydrology runoff parameter)
DEM	Digital elevation map
EDTA	Ethylenediaminetetaacetic acid titrimetric method
Fentr	*Geology*: Fentress Formation
gpm	Flow rate, gallons per minute
HDPE	High density polyethylene
HP	Horsepower
IC	Ion chromagraph
ICP-OES	Inductively-coupled plasma optical emission spectrometer
LC_{50}	Lethal concentration for 50% of the test organisms
LSD	Least significance difference
NP/NNP	Neutralization potential; Net neutralization potential
NRCS	Natural Resource Conservation Service
P	Precipitation / rainfall (depth units, cm)
P_e	Runoff volume (depth units, cm)
PPA	Potential peroxide acidity
psi	Pressure, pounds per square inch
RFV	Rainfall (storm) event volume (depth units, cm)
RFIA	Rainfall (storm) event average intensity (cm/hr)
RFIM	Rainfall (storm) event maximum intensity (cm/hr)
S	Potential maximum retention (hydrology runoff parameter)
Sand	*Geology*: Sandstuck Formation
Snowb	*Geology*: Snowbird Group: Roaring Fork
Stree	Vegetation class: sparse tree cover
TDEC	Tennessee Department of Environment and Conservation
TDOT	Tennessee Department of Transportation
TVA	Tennessee Valley Authority
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

Executive Summary

Runoff Water Quality from Highway Cut Slopes in Pyritic Rock Formations: Characterization and Treatment

Road construction through pyritic (sulfidic) rock formations has the potential to cause episodic runoff acidification and impairment to aquatic biota when acid producing materials (APM) are exposed to precipitation. State highways departments (DOTs) across eastern United States in the Appalachia region have recognized the need to handle APM during road construction projects, including Pennsylvania, Virginia, and Tennessee. These state DOTs have developed testing, material handling, and disposal guidance. Specifically, the Tennessee Department of Transportation (TDOT) has encountered APM on several projects in the past decade, which required projects to address special environmental and permitting issues. In order to assist TDOT when APM are encountered on a highway construction site, TDOT (2007) developed Special Provision 107L and standard drawings for material treatment. The document "*Guidelines for Acid Producing Rock Investigation, Testing, Monitoring and Mitigation*" was prepared by Golder Associates to provide technical assistance for APM assessment and management (TDOT 2007). In general, extensive research has been conducted on water quality and remediation of acid mine drainage from sulfidic geologic rock formations. Although much is known about acid material drainage (AMD) chemistry, treatment options, and potential harmful impacts from it, little is known about the water quality generated from post-construction road cuts through APM, and what hydrogeological conditions may produce harmful levels of acidic waters containing sulfates and dissolved metals. The project objectives were to: 1) characterize the water quality from APM highway cut slopes to assess whether long-term environmental issues could occur to receiving streams; 2) assess the potential effectiveness of on-site treatment applications at road cuts through a physical model experiment; and 3) by a review of AMD treatment literature assess the possibility of using passive treatment solutions for the level of acid pollution generated from road cuts in Tennessee.

Characterization of runoff water quality from highway cut slopes through pyrite geology was conducted at ten monitoring stations in Middle and East Tennessee. The ten stations were located among five different surficial geologic formations; they were the Chattanooga Shale, Fentress Formation, Sandsuck Formation, Great Smoky Group (Anakeesta Formation), and the Snowbird Group: Roaring Fork Sandstone. The influence of various environmental factors was investigated on their effect on runoff water quality, which included: rock formation type and age of cut, cut slope and aspect, vegetation, and rainfall magnitude and intensity. In addition, the runoff water quality was assessed to its potential toxic impacts to aquatic biota.

Runoff pH and other chemical parameters varied widely between sites and within sites among different runoff events. Site mean pH ranged from 4.29 to 6.27, and the full range from individual sample events was between 2.97 and 7.70. Site means for acid neutralizing capacity (ANC) ranged from -0.82 to 29.85 meq/L. Mean ANC did not correlate with mean pH values per site, which suggests complex and unique biogeochemical processes occur among the study sites. Where runoff flows over a sedimentary formation adjacent to the pyritic formation base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) enter into the runoff greatly controlling ANC. Site means for sum of base cations (Sum BC) ranged from 1.15 to 40.24 meq/L. Decreased pH can result from the displacement of base cations from the rock with Al complexes, where the base cations act as counter ions to electrochemically balance leached sulfate and other acid anions. The lack of available base cations can decrease runoff pH. Other than the dominant oxidation of pyrite

(FeS_2) exposed to water and air, other key geochemical processes affecting pH and ANC, and the overall water quality, includes desorption/adsorption of sulfate ions, hydrolysis and precipitation of dissolved metals, silicon and other mineral weathering, cation/metal exchange (Cu, Cd, Zn, Mn, others), and aluminum dissolution and mobilization. The elevated levels of observed Fe and Al demonstrated metal hydroxides likely formed in the runoff because of the differences between total and dissolved fractions. The mean dissolved concentrations for Fe and Al ranged from 0.13-1.63 mg/L and 0.33-39.00 mg/L, respectively. The overall wide range of chemical parameters and concentrations measured also suggests that other environmental factors may play a role in runoff chemical transformations. External to the road cut rock, surface nitrogen and organics may influence runoff water quality through nitrogen mineralization and nitrification, formation of organic acids, or sulfur/metal adsorption onto organics. These non-pyritic surface processes can affect acidity and proton availability, which in turn influences the runoff pH. The water quality characterization of each road cut site was affected by a unique suite of biogeochemistry processes and controlled by local dominant environmental factors. The factors were found to support assessing risk of harmful runoff acidification.

Geologic rock formations appeared to be the dominant controlling factor for water chemistry of road cut runoff for based on the ten study locations. The mean pH was lowest for the Anakeesta Formation (pH = 4.29), and its mean ANC of 1.83 meq/L was relatively low compared to other sites. Compared with the other formations, the Anakeesta formation exhibited lower concentrations of acid anions (sulfate) and base cations, but higher concentrations of dissolved metals including Al, Fe, Cu. Mn, Si, Cd, and Zn. The Chattanooga Shale and the Roaring Fork Sandstone had mean pH values below 6.0 (5.41 and 5.88, respectively). The runoff chemistry from the Chattanooga Shale was much different than all other formations. Runoff from the Nashville I-840 Chattanooga shale sites contains very high levels of acid anions, base cations, and dissolved metals. Site averages for conductivity exceeded 2,500 μS/cm. The Nashville sites were fairly new road cuts and they appear to be weathering at a high rate exporting ions in the runoff, in particular higher concentrations of dissolved silicon was observed compared with the other sites. Overall runoff from the Chattanooga Shale contained relatively high levels of dissolved Al, Ba, Cu, Zn, and Ni compared to other rock formations. In general, the runoff chemistry of the Roaring Fork Sandstone was more similar to the other geologic formations. The Fentress and Sandsuck formations had mean pH values above 6.0. The runoff chemistry from these two formations was similar to the others except for the Chattanooga Shale as noted above. With the observed differences of dissolved metals among the rock formations it suggests the basic mineral composition of the local rock appears to greatly influence runoff chemistry from hydrolysis and precipitation of dissolved metals, silicon and other mineral weathering, and cation/metal exchange.

In addition to geologic rock formations, vegetation cover or the lack thereof appeared to influence runoff chemistry from the road cut study sites to some degree. With no vegetative cover with exposed bare rock, runoff ion concentrations were much greater compared to sites with grass and/or tree cover. The highest median pH among the cover types was with trees at 6.4. This outcome suggests that the availability of organic matter from the trees may be playing a role in metal/sulfate adsorption, and sulfur, nitrogen, and cation cycles. Tree cover also protects the rock surface from low intensity rainfall event per leaf interception and evaporation. Runoff chemistry was not correlated with rainfall volume and storm maximum intensity, but average intensity was found to influence the export of sulfate, sum of acid anions (Sum AA), and Sum BC indicating higher intensities have the potential to flush ions from the site. Seasons did not have any significant effect on runoff chemistry among the study sites. Though our study did not find many relationships with season and weather-related controls, some evidence indicates these variables could influence runoff chemistry from APM. More recently constructed road cuts (young) were found with runoff chemistry with higher concentrations of Sum AA, Sum BC, and dissolved metals. In particular, 'young' sites were higher in dissolved Al and Si indicating mineral weathering rates to be greater compared to the middle and old age sites. The difficulty in interpreting the potential effect of the factors is that data co-varied with the more dominant factors of geologic formation and vegetation. More data from a larger set of study sites would be needed to better statistically evaluate these factors. Overall, the findings do suggest that there are minimal effects from seasons, storm event magnitude, and road cut characteristics of slope and aspect. Also, it suggests the older the road cut the likelihood of acidic runoff is small and that planting vegetative cover at runoffs can be used as an effective management strategy to minimize acidic runoff.

Useful information was obtained from an outdoor experimental study which consisted of constructing four container panels to place pyrite rock, and for three panels different treatments were installed to limit or prevent exposure to the rock. Treatment types were: 1) soil/vegetation cover, 2) shotcrete, and 3) a geosynthetic membrane liner. The panels were subjected to both simulated and natural rainfall. One panel with exposed pyrite rock (no treatment) served as the experimental design control, and provided unique data on runoff chemistry and ion export from the bare rock surface. For the simulated rainfall experiment, pH increased from approximately 3.6 to above 6.0 within four hours. However, rapid oxidation occurred where the next day the initial pH was near 3.6 however reached pH values above 6.0 within two hours. Runoff ANC from the pyrite rock remained low during the simulations due to the lack of base cations to neutralize the acid anions. The Sum AA consists primarily of sulfate, and the rapid decrease in SO_4^{2-} concentrations were measured. Mineral ions from the rock surface are quickly washed off as observed by the rapid decline in conductivity within the first hour of rainfall and basically diminished of ion source within two hours of rainfall. This rapid decline in dissolved metal ions was measured for all metal, but importantly observed with iron and aluminum. These two metal ions are the most relevant to pyrite oxidation and the potential for surface water toxicity, however all the metal ions were found to decline throughout the rainfall simulation period. The dissolved aluminum concentration dropped below 0.2 mg/L with two hours.

During the natural rainfall monitoring from the pyrite rock control, the runoff pH remained low between 3.00 and 3.74 during this six-month period indicating that freshly exposed pyrite geology will take a longer time period to reach a condition where the surface pyrite has completely oxidized. Sulfate export from the rock surface was the major driver for runoff acidification. Elevated levels of dissolved Fe and Al were observed for the runoff from the exposed rock caused by pyrite oxidation and Anakeesta shale weathering. A dilution effect was also observed where pH increased with storm event size (rainfall depth), and conductivity, sulfate, and dissolved iron decreased. With the information also from the simulated rainfall experiments it appears that there is a limited availability of sulfate to cause runoff acidification. This experiment investigated water quality changes from exposed pyritic rock only; in contrast the ten-site characterization study included the potential influence of other geologic formations and site soils adjacent to the exposed pyritic formation, which can contribute base cations to runoff reducing acidification.

Potential water quality impairments of runoff from road cuts were assessed by comparing site chemistry to TDEC regulatory limits on specified chemicals, in addition to published toxicity exposure limits. The dominant concern in runoff that has been in contact with geologic rock formations considered as APM is the chemical parameters resulting from geochemical acidification processes. These parameters primarily include pH, ANC, and dissolved Al. Other dissolved metals can be a concern depending on hardness where lower hardness concentrations increase toxicological effects. Site averages for runoff pH ranged from acidic to neutral waters where five of the ten sites exceeding a pH of 6.0 and four sites had average pH values below 5.0. Within sites, pH values varied widely, for example the Jamestown 2 site had an average pH of 4.48, but the range was from 3.45 to 7.07. The sites with a pH less than 6.00 are below the state's water quality standards, which pH values are to be between 6 and 9. There is no state water quality standard for dissolved Al, however literature indicates that concentrations should not exceed 0.2 mg/L. Based on a site average, all road cut sites except the Jamestown 3 site exceeded this toxicity threshold. Dissolved Al in runoff was very high at the Nashville I-840 site, indicating a unique geochemical condition under rock/soil acidification. Though the road cut dissolved Al concentrations were above that threshold, runoff events are generally short and runoff is diluted as it comingles with the receiving stream. Though some exceedances were observed with pH and dissolved Al, runoff water quality was at levels easily treated using best available technology.

Guidelines on addressing the environmental impacts from acid rock drainage (ARD) at road cut construction sites were developed and published by TDOT with Golder Associates (TDOT 2007). The guidance document "*Guidelines for Acid Producing Rock Investigation, Testing, Monitoring and Mitigation*" was comprehensive and focused on testing, handling, and disposal during highway construction. The TDOT (2007) document also summarized water treatment options for post-construction mitigation of the site runoff. Passive treatment systems are best suited for ARD with low acidity (< 800 mg $CaCO_3$ /L) and low flow rates (< 50 L/s). Therefore, mass loadings from road cut sites should be less than about 100 to 150 kg $CaCO_3$ /day. Relevant to highway runoff from road cuts through pyritic rock are passive systems. In the TDOT (2007) document, several passive treatments were identified as preferred treatment methodologies because of ease of construction, low maintenance, and treatment longevity. They were: limestone beds and oxic/open channels, aerobic wetlands, settling ponds, bio-reactors, and pebble quicklime. These treatments are viable options for on-site passive treatment if the road cut site conditions warrant their construction.

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1. INTRODUCTION

1.1 Overview

Exposed pyrite geologic formations with acid producing material (APM) combined with rainfall (water) generates sulfuric acid and can be transported as runoff (Pye and Miller 1990; Fox et al. 1997; Rimstidti and Vauhgan 2003; Hammarstrom et al. 2005). A pyritic rock or soil formation may produce acid when excavated and exposed to air, water, and mediated by Thiobacillius bacteria. Sulfide minerals, most commonly pyrite, produce this acid as a byproduct of the breakdown of the sulfur. This can cause environmental issues where impact can occur from pH change and the material may require special handling and procedures. APM can be found statewide within Tennessee. However, it is predominately found east of the Tennessee River in shales, sandstones, and some siltstones. In Region 1 the Anakeesta formation, the Chattanooga shale, as well as many Pennsylvanian formations contain APM. In Region 2, APM is often associated with Precambrian formations of the Ocoee Supergroup, Devionian Chattanooga Shale, the other Pennsylvanian-age shales. In Region 3 acid producing materials are often found in the Chattanooga Shale.

On highway construction sites, naturally occurring potentially APM may be found in any soil or rock horizon on any project type. Tennessee Department of Transportation (TDOT) has encountered APM on several projects in the past decade, in which these projects present special environmental and permitting issues. In order to assist TDOT when APM are encountered on a highway construction site, TDOT developed Special Provision 107L and standard drawings for material treatment. The document "*Guidelines for Acid Producing Rock Investigation, Testing, Monitoring and Mitigation*" was prepared by Golder Associates to provide technical assistance for APM assessment and management (TDOT 2007). Pre-construction requires sufficient drilling to identify, sample and test historically problematic and potentially problematic formations shall be completed in general accordance with the document (Byerly 1990, 1996). Drilling must be sufficient to show the horizontal and vertical extent of problem layers on the project identifying areas that must have special treatment and provide quantity calculations. During the project design and construction phase, TDOT routinely uses the document for specifying proper handling of APM spoils from highway projects, consisting of removal, disposal, blending, capping, and/or encapsulating APM.

For highway construction projects with potential APM, an acid-based accounting of the samples is required. TDOT maintains a laboratory testing contract with firms capable of providing the appropriate tests. This includes an assessment of the paste pH, Acid Potential (AP), Net Neutralization Potential (NNP) per calcium carbonate deficiency or net acid-base account value, as well as tests of total sulfur and pyritic sulfur (Sobek et al. 1978). All samples are assessed for whether or not they are representative of the material out in the field. Multiple parameters may be needed in order to assess whether or not a soil or rock can produce acid in the field. Additionally, site assessments of the same material placed in the field may also need to be completed or addressed. This approach to environmental mitigation of APM is expensive, thus driving the need to better understand the potential extent of the environmental problem.

Runoff from these cut slopes may enter nearby streams, which can become acidified and potentially harm aquatic life (Huckabee et al. 1975; Mathews and Morgan 1982; Kuchen et al. 1994). Based on numerous acid mine drainage and acid rain studies, many references have described the potentially harmful effects of stream acidification on biota. Most toxicological studies focus on the acute lethal end-point. However, sub-lethal stress on trout can occur from episodic acidification events, and the degree of biota stress is dependent on the extent of pH change during stormflow, and the duration and frequency of events (Gagen et al. 1993; Baldigo et al. 2009; Neff et al. 2009). In general, toxic effects of pH on fish and macroinvertebrates can be classified as follows: 1) slight impairment = pH 5.5 to 6.4; 2) moderate impairment = pH 5.0 to 5.5; 3) severe impairment = pH 4.0 to 5.0; and 4) lethal = pH < 4.0. Stream with acid neutralizing capacity (ANC) less than 0 μeq/L are considered acidic (Wigington et al. 1996). Tennessee Department of Environment and Conservation (TDEC) recommends an ANC greater than 50 μeq/L during baseflow unless evidence suggests streams naturally occur below this concentration. Although pH and ANC provide water quality targets for stream acidification, these constituents may be surrogate for the toxic effects of dissolved aluminum. Dissolved aluminum in the form of inorganic monomeric aluminum (Al_{IM}) is regarded as the most toxic dissolved metal for fish and macroinvertebrates in acidified stream waters (Neville and Campbell 1988). Fish gill ion transport is disrupted by replacing needed calcium on gill surfaces with increased Al_{IM} concentrations (Booth et al. 1988; Ingersoll et al. 1990). Driscoll et al. (2001) suggests that Al_{IM} concentrations above 2.0 μmol/L as an appropriate threshold for toxicity. TDEC water quality criteria per Chapter 004-40-03 require a pH between 6.0 and 9.0, and no pH change over 1.0 unit within a 24-hour period. Although much is known about the harmful impacts from acid mine drainage, little is known about the water quality generated from post-construction road cuts through APM, and what hydrogeological conditions may produce harmful levels of acidic waters containing sulfates and dissolved metals.

As noted above, road cuts occur through different geologic rock formations (e.g., Anakeesta metamorphic rock, Chattanooga shale) and varying orientations of inclined rock layers. The export of acidic waters from road cuts may be dependent on the design with respect to whether cut slopes are vertical or near-vertical, and length of exposure. The type of rock, soils, and vegetation also controls sulfate export from drainage surfaces, large or small (Cai et al. 2010, 2011a,b; Neff et al. 2012). A basic study on the runoff chemistry and hydrological export of sulfate and dissolved metals can provide useful information on the extent of the problem and if at levels potentially causing environmental harm. In addition, this information can provide the necessary data to design various treatment options.

Various on-site and permanent treatment options are available for APM runoff, including limestone channels and constructed wetlands (Byerly 1990). Performance of treatment options is not well known from highway cut slopes because of a lack of information on cut slope runoff and water quality. Knowing the amount of sulfate and protons [H^+, pH] generated from exposed highway cut slopes with different local geologies and geotechnical engineering designs is critical for designing successful treatment systems. Over-designed systems could increase construction costs, and under-designed systems could harm the environment. More detailed information of how much acid runoff is generated is especially needed in environmentally sensitive areas.

1.2 Project Objectives

The project objectives were to: 1) characterize the water quality of AMD from highway cut slopes to assess whether long-term environmental issues occur to receiving streams; 2) assess the potential effectiveness of on-site treatment applications at road cuts through a physical model experiment; and 3) assess the possibility of using passive treatment solutions to treat expected levels of acid pollution from road cut sites. Monitoring sites of different hydrogeological conditions were selected, sampled for runoff water, and characterized for chemical properties, which could be compared with federal and state water quality standards. Physical model experiment provides information on the runoff water quality for three treatments: soil/vegetation, shotcrete, and geoliner, amendments compared to an untreated control. With information on the runoff chemistry, it provides the basis to assess what possible passive treatment options are available to reduce acidity and transport of other harmful pollutants, i.e., dissolved monomeric aluminum. This research is proposed to examine more cost efficient and environmentally safe ways to deal with APM from cut slopes.

It is noted that the U.S. Geological Survey (USGS) also conducted concurrently an investigation of AMD water quality from road cuts through APM. Their investigation examined water from rock seams and examining micro-scale biogeochemistry. The USGS generated a bibliography for acid-rock drainage and selected acid-mine drainage issues related to acid-rock drainage from transportation activities (Bradley and Worland 2015). The University of Tennessee at Knoxville (UTK) collaborated with the USGS staff on data exchange or other supportive activities.

1.3 Scope of Work

Following the project's three objectives, the scope of work included:

- Section 2.0: Characterization of Runoff Water Quality from Road Cuts through APM
- Section 3.0: Experimental Testing of Treatments for AMD Highway Cut Slopes
- Section 4.0: Passive Water Quality Treatment Options at Road Cuts through APM

Details of the study methods for each scope of work are described in the individual sections, as listed above. Results and conclusions are presented per section. The Executive Summary serves as the overall summary and project conclusions.

2. Characterization of Runoff Water Quality from Road Cuts through APM

2.1 Introduction

Road construction through pyritic (sulfidic) rock formations has the potential to cause episodic runoff acidification and impairment to aquatic biota when acid producing materials (APM) are exposed to precipitation (Huckabee et al. 1975; Mathews and Morgan 1982; Morgan et al 1982; Kuchen et al. 1994; DeNicola and Stapleton 2002). In addition to water quality impacts, acidic runoff with high sulfate levels can degrade highway construction materials (concrete and metals), and effect soil and rock stability of road cut fill materials through excessive ion dissolution and/or crystal development causing material upheaving (Miller et al 1976; Vear and Curtis 1981; Berube et al. 1986; Pye and Miller 1990; Sahat and Sum 1990; Byerly 1996; Ji et al. 2006). State highways departments in the eastern United States have recognized the need to handle APM during road construction projects, including Pennsylvania, Virginia, Tennessee, and others in which they have developed testing, material handling, and disposal guidance (Ammons et al. 1990; Byerly 1996; Orndorff and Daniels 2002; Hammarstrom et al. 2005; Siceree 2006; Scheetz and Ellsworth 2007; TDOT 2007). Recent APM guidance for highway construction has greatly reduced severe environmental problems that have resulted in the past such as fish kills and mineral-stained waters; however little is known about post-construction runoff water quality. This study focused on characterizing runoff water quality from existing road cuts through sulfidic rock formations in East and Middle Tennessee.

Extensive research has been conducted on water quality and remediation of acid mine drainage from sulfidic rock formations (Bigham and Norstrom 2000; Baker and Banfield 2003; Bird 2003; Rimstidti and Vauhgan 2003; Grande et al. 2004; Sracek et al. 2004; Johnson et al. 2005). This acid mine drainage research provides the fundamental background on the biogeochemical processes that occurs with groundwater seeps and surface runoff, including the microbial mediation of sulfide oxidation on pyrite rock surfaces (Nordstorm 2000; Fowler et al. 2001; Rohwerder et al. 2003; Kock and Schippers 2008; Hallberg 2009). Fundamentally, pyrite (FeS_2) reacts with water and oxygen where sulfide oxidation and ferrous iron (Fe^{3+}) is converted to ferric iron (Fe^{2+}) as follows:

$$FeS_2 + 14Fe^{3+} + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (1)$$

$$FeS_2 + 3.5O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (2)$$

$$Fe^{2+} + 0.25O_2 + H^+ \rightarrow Fe^{3+} + 0.5H_2O \quad (3)$$

The rate of reaction in Equation 3 is pH dependent, where at low pH values around 2 to 3 the rate is very slow and no bacteria can assist in the production of protons (EnviroSci Inquiry 2011). At pH values around 5 the reaction is much faster. Ferrous iron may be converted to the commonly yellow-orange flock termed yellowboy in stagnant pools of water:

$$4\ Fe^{3+} + 12\ H_2O \rightarrow 4\ Fe(OH)_3^{-} + 12\ H^+ \quad (4)$$

The above reaction is the hydrolysis of iron, which is pH dependent. Solid formation and precipitation occurs when the pH is above 3.5. This reaction in itself provides acidity. Another reaction which creates a self-propagating reaction by the oxidation of additional pyrite to ferric iron (Equation 5). This reaction is very rapid and continues until either ferric iron or pyrite is depleted.

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \Rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \quad (5)$$

The overall summary reaction, which included the creation of yellowboy is as follows:

$$4\ FeS_2 + 15\ O_2 + 14\ H_2O \Rightarrow 4\ Fe(OH)_3^{-} + 16\ H^{+} + 8\ SO_4^{2} \tag{6}$$

The loose porous rust $Fe(OH)_3$ can slowly transform into a crystallized mineral form written as $Fe_2O_3.H_2O$, the familiar red-brown staining. This red-brown staining can be observed on exposed road cut through pyritic rock formations.

The basic research on environmental geochemistry established from studying the acid mine drainage provides critical information interpreting the potential effects of water quality from post-construction road cuts through pyritic formations. A few studies examined runoff water quality from exposed pyritic rock surfaces other than road cuts, such as landfills, natural slopes, and excavated APM (Miller et al. 1976; Morgan et al. 1982; Fox et al. 1997; Igarishi and Oyama 1999). These studies found water to have high levels of free acidity (pH < 5), and elevated levels of dissolved metals (Al, Cu, Fe, Mn, and Zn). Sufficient availability of oxygen formed yellowboy and reddish-brown iron precipitates. One of the first papers published on runoff water quality from road cut through pyritic rock was by Cendreo et al. (1977) in Spain. Their study measured pH and %S (percent sulfur by weight) at eight road cuts observing a wide range of pH values from 2.5 to 8.0, and %S from trace amounts to 0.72%. As expected with the weathering of pyrite, runoff pH above 5 to 6 were directly correlated with %S content above 0.2%. Cendreo et al. (1997) also noted poor vegetation cover occurred at highly acidic sites. Adams et al. (1999) studied one road cut site near Buchanan, Georgia through a pyritic schist, and the receiving stream Kiser Creek. Springs and seeps from the rock cut site kept water flowing in the drainage ditch year-round, and pH measures ranged from 2.4 to 6.9, and averaged 3.8. This road-side water contained sulfate concentrations between 62 and 195 mg/L, and dissolved iron between 0.13 and 0.18 mg/L. The pH values of waters within all stream monitoring locations downstream of the road-cut runoff effluent were above 6.0.

Orndorff and Daniels (2004) conducted a survey of acid material drainage (AMD) from road cuts through the state of Virginia, examining runoff and rock chemistry for 25 sites. The focus on this study was classifying the potential severity of acidic runoff from different geologic formations with pyrite using the potential peroxide acidity (test), total S, and “fizz test” (Sobek et al 1978) on rock samples. Water samples were collected in a dug shallow well at the road cut base or an available ditch for 10 of the 25 sites. Orndorff and Daniels (2004) found water chemistry to vary widely among these ten sites. They found pH to range from 2.5 to 7.1 (average pH = 4.54) and total sulfur ranged from 7 to 543 mg/L. Dissolved metals also varied to a large extent among sites and even from the same site. Dissolved Fe ranged between < 0.1 to 249.3 mg/L with most concentrations below 1.0 mg/L, dissolved Al between < 0.1 to 254.5 mg/L with most concentrations below 20 mg/L, dissolved Cu between < 0.1 to 0.29 mg/L, and dissolved Zn between < 0.1 to 10.4 mg/L. These wide ranges in water chemistries indicate multiple environmental factors apparently control the runoff water quality from road cut sites.

Runoff from road cuts through pyritic rock can be potentially harm to aquatic life because waters become acidified and may contain toxic dissolved metals (Huckabee et al. 1975; Bacon and Mass 1979; Mathews and Morgan 1982; Morgan et al. 1982; Kuchen et al. 1994). Based on numerous acid mine drainage and acid rain studies, many references have described the potentially harmful effects of stream acidification on biota (Driscoll et al. 1980; Fromm 1980; Exley et al. 1991; DeLonay 1993; Hermann et al. 1993; Simonin et al. 1993; Harvey and Jackson 1995; Newman and Dolloff 1995). Most toxicological studies associated with acidified waters focus on the acute lethal end-point of pH or dissolved Al. However, sub-lethal stress on fish can occur from episodic acidification events, and the degree of biota stress is dependent on the extent of pH change during stormflow, and the duration and frequency of events (Caroline et al. 1992; Gagen et al. 1993; MacAvoy and Bulger 2004; Baldigo et al. 2009; Neff et al. 2009). In general, toxic effects of pH on fish and macroinvertebrates can be classified as follows: 1) slight impairment = pH 5.5 to 6.4; 2) moderate impairment = pH 5.0 to 5.5; 3) severe impairment = pH 4.0 to 5.0; and 4) lethal = pH < 4.0. Although pH provides water quality targets for stream acidification, pH may be surrogate for the toxic effects of dissolved Al. Dissolved Al in the form of inorganic monomeric aluminum (Al_{IM}) is regarded as the most toxic dissolved metal for fish and macroinvertebrates in acidified stream waters (Neville and Campbell 1988). Inorganic aluminum increases with decreases in pH and predominate in waters below pH 5.0 (Driscoll and Postek 1995; Sullivan and Cosby 1998). Driscoll et al. (2001) suggests that Al_{IM} concentrations above 0.2 mg/L as an appropriate threshold for toxicity. Like H^+ (pH) toxicity, the primary mechanism of Al toxicity is disturbance of gill ion transport (Booth et al. 1988) when pH is 4.2–4.8 (most severe at pH 4.5), and asphyxia when pH is 5.5–6.4 (most severe at pH 6.1) (Neville and Campbell 1988). In general toxic metal ions including dissolved Al compete with metal cations (particularly Ca^{2+}) on fish gills (Di Toro et al. 2001) and facilitate greater loss of critical blood ions (mostly Na^+). In waters of low hardness, less dissolved Ca^{2+} is available and fish are more vulnerable to Na^+ ion loss induced by elevated pH and dissolved Al (Cleveland et al. 1991; Ingersoll et al. 1990). Although much is known about the harmful impacts form acid mine drainage, little is known about the water quality generated from post-construction road cuts through APM, and what hydrogeological conditions may produce harmful levels of acidic waters containing sulfates and dissolved metals.

The study objectives were to: 1) characterize the runoff water quality from existing road cut through pyritic rock formations and APM to assess acidity conditions, export of dissolved metals, and other chemical parameters; 2) investigate environmental factors than may be influencing the water chemistry of road cut runoff, including geological rock formation, vegetative cover, and road cut type, age, slope, and aspect; and 3) assess whether runoff water quality may potentially cause impairment, a stressed environment for aquatic biota. This study is unique compared to the limited previous published articles on road-cut water quality, in that the chemical parameters analyzed only included pH and sulfur, and Orndorff and Daniels (2003) measuring a few dissolved metals. No study compared anion-cation balances and a comprehensive suite of water quality parameters. In addition, environmental factors that possible can affect runoff chemistry other than rock type had not be investigated to date.

2.2 Methods

2.2.1 Study Area

Runoff from highway cut slopes through pyrite geology was collected at ten monitoring stations in Middle and East Tennessee (Figure 2.1). The ten stations were located among five different surficial geologic formations; they were the Chattanooga Shale, Fentress Formation, Sandsuck Formation, Great Smoky Group (Anakeesta Formation), and the Snowbird Group: Roaring Fork Sandstone (Table 2.1). Site photos are shown in Appendix A, and state-wide surficial geology maps for pyritic rock formations are in Appendix B. Additional site information on the road cuts was compiled in Table 2.2 consisting of formation type and age of cut, cut slope and aspect, and vegetation.

Figure 2.1. Tennessee state map showing locations of the ten runoff monitoring stations (shown as white squares). Image Credits: *Google and Google Earth image overlay*.

2.2.2 Rainfall and Runoff Hydrology

Rainfall volumes per storm event and study site were estimated from Tennessee Valley Authority (TVA) published data. TVA weather station data were used because installation of full weather stations at each site was cost prohibitive. Tables 2.3 and 2.4 summarize the TVA weather stations locations in latitude and longitude, and the weather stations used to compile rainfall volumes per road cut monitoring station. For each storm event in which water samples were collected, an estimate of event rainfall volume (in units of depth) was computed using a weighted approach based on distance absolute deviations. An absolute deviation represents the linear distance in lat./long. degrees between a weather station and the monitoring site.

Runoff volumes from the road cut monitoring sites were collected from rock walls using plastic roof gutters (Figure 2.2). Roof gutters were attached with stainless steel bolts and any space between the rock wall and the gutter were filled with a synthetic polymer foam and/or caulk adhesive. Gutters were sloped at least with a 2% grade into a downspout, which collected water was directed to passive collection systems consisting of two or three flow divider buckets and a terminal collection bucket, all of which were 5-gal (18.9 L) in size (Pinson et al. 2003). Based on Pinson et al. (2003), the flow dividers consisted of a stainless-steel circular crown containing 22.5^{o} V-notch weirs, with the crown screwed onto the bucket (Figure 2.2). The first and second dividers consisted of 12 V-notches in order to handle the high initial flow rate, whereas if used the 3rd divider had 24 notches. Once the bucket completely filled, water and sediment overflow was evenly divided among the V-notches, and flow from a single notch was

Table 2.1. Study site highway locations in Tennessee, rock formations, and general site notes.

Site Name	County	Latitude	Longitude	Highway	Formation	General Site Notes
Grainger 1	Grainger	36°21'1.52"N	83°20'16.76"W	SR-32	Chattanooga Shale	Near Bean Station; site – contains degraded erosion control mesh behind a wire mesh.
Jamestown 1	Fentress	36°29'49.48"N	84°58'02.75"W	SR-28	Fentress Formation	Gradual slope; recent constructed road cut; vegetated with grass.
Jamestown 2	Fentress	36°29'42.95"N	84°58'05.10"W	SR-28	Fentress Formation	Same conditions as the Jamestown 1 Site
Jamestown 3	Fentress	36°26'28.27"N	84°57'46.52"W	SR-52	Fentress Formation	Vertical cut, older road cut; mature vegetation in places.
Nashville 1	Williamson	35°48'52.44"N	86°58'30.49"W	I-840	Chattanooga Shale	High cut, east of SR 246. Dc on road cut shelf, multiple seeps with various sources - Mfp, Dc, Ou formations.
Nashville 2	Williamson	35°49'17.21"N	86°57'11.81"W	I-840	Chattanooga Shale	East of SR 246. Dc formation at top of road cut. Multiple seeps.
Ocoee 1	Polk	35° 7'13.81"N	84°34'5.49"W	SR-30	Sandsuck Formation	Near the Clear Creek Trailhead, Vertical cut
Ocoee 2	Polk	35° 7'13.90"N	84°34'4.71"W	SR-30	Sandsuck Formation	Same conditions as Ocoee 1 Site
Ocoee 3	Polk	35° 2'35.90"N	84°26'59.61"W	US-64	Great Smoky Group: Anakeesta	East of road to Boyd's Gap overlook. Vertical cut
Sevierville 1	Sevier	35°49'1.80"N	83°27'39.95"W	CR 416	Snowbird Group: Roaring Fork	Bean Station near Dixie Hwy. Vertical Cut.

Table 2.2. Road cut site information on type, age of cut, cut slope, facing aspect, and vegetation.

Site Name	Formation	Type	Age	Cut Slope	Facing Aspect	Vegetation
Grainger 1	Chattanooga Shale	Single cut	< 20 yrs	60°	East	None; forest above cut
Jamestown 1	Fentress Formation	Earthen cover	< 20 yrs	45°	West	Grass cover
Jamestown 2	Fentress Formation	Earthen cover	< 20 yrs	45°	West	Grass cover
Jamestown 3	Fentress Formation	Terraced cut	> 60 yrs	90°	North	Deciduous forest cover with herbal growth
Nashville 1	Chattanooga Shale	Terraced cut	< 20 yrs	90°	North	None
Nashville 2	Chattanooga Shale	Terraced cut	< 20 yrs	90°	North	None
Ocoee 1	Sandsuck Formation	Single cut	> 60 yrs	60°	South	Deciduous forest cover with herbal growth
Ocoee 2	Sandsuck Formation	Single cut	> 60 yrs	60°	South	Deciduous forest cover with herbal growth
Ocoee 3	Great Smoky Group: Anakeesta	Single cut	35-60 yrs	90°	East	Sparse deciduous trees (Stree)
Sevierville 1	Snowbird Group: Roaring Fork	Single cut	35- 60 yrs	90°	West	Deciduous forest cover

Table 2.3. Weather station locations used to estimate storm event volumes at road cut monitoring stations. Weather stations maintained by the Tennessee Valley Authority.

Weather Station Name	Location ID	Station Latitude	Station Longitude
Wolf near Byrdstown	BYGT1	36.56028	-85.07306
Clear Fork near Robbins	CFKT1	36.38833	-84.63028
Columbia	CLBT1	35.66417	-87.03250
Copperhill	CPRT1	35.00389	-84.38695
Higdons Store	EPWG1	34.90333	-84.43611
Etowah	ETOT1	35.33028	-84.52111
Harpeth at Franklin, TN	FRAT1	35.92056	-86.86555
Gatlinburg	GTTT1	35.69167	-83.53445
Morristown	MSTT1	36.27250	-83.22611
Beaver Creek near Monticello	MTCK2	36.79750	-84.89611
Parksville	PKST1	35.09500	-84.64917
Appalachia Powerhouse near Turtletown	TURT1	35.18250	-84.43833

Table 2.4. Road cut monitoring stations and the nearest TVA weather stations used to estimates storm event volumes. TVA Weather Station latitude and longitude locations defined in Table 2.3. Lat., long, and absolute (Δy, Δx) deviations summarized per road cut monitoring station.

Road Cut Site Name	Road Cut Site Lat.	Road Cut Site Long.	TVA Weather Station	Lat. deviation (Δy)	Long. Deviation (Δx)	Absolute deviation
Grainger 1	36.35042	-83.33799	MSTT1	-0.078	0.112	0.190
Jamestown 1	36.49708	-84.96743	BYGT1	0.063	-0.106	0.169
			MTCK2	0.300	0.071	0.372
Jamestown 2	36.49526	-84.96808	BYGT1	0.065	-0.105	0.170
			MTCK2	0.302	0.072	0.374
Jamestown 3	36.44119	-84.96292	BYGT1	0.119	-0.110	0.229
			CFKT1	-0.053	0.333	0.385
			MTCK2	0.356	0.067	0.423
Nashville 1	35.81457	-86.97514	CLBT1	-0.150	-0.057	0.208
			FRAT1	0.106	0.110	0.216
Nashville 2	35.82145	-86.95328	FRAT1	0.099	0.088	0.187
			CLBT1	-0.157	-0.079	0.236
Ocoee 1	35.12050	-84.56819	PKST1	-0.026	-0.081	0.106
			TURT1	0.062	0.130	0.192
			ETOT1	0.210	0.047	0.257
			CPRT1	-0.117	0.181	0.298
Ocoee 2	35.12053	-84.56797	PKST1	-0.026	-0.081	0.107
			TURT1	0.062	0.130	0.192
			ETOT1	0.210	0.047	0.257
			CPRT1	-0.117	0.181	0.298
Ocoee 3	35.04331	-84.44989	CPRT1	-0.039	0.063	0.102
			TURT1	0.139	0.012	0.151
			EPWG1	-0.140	0.014	0.154
Sevierville 1	35.81717	-83.46110	GTTT1	-0.125	-0.073	0.199

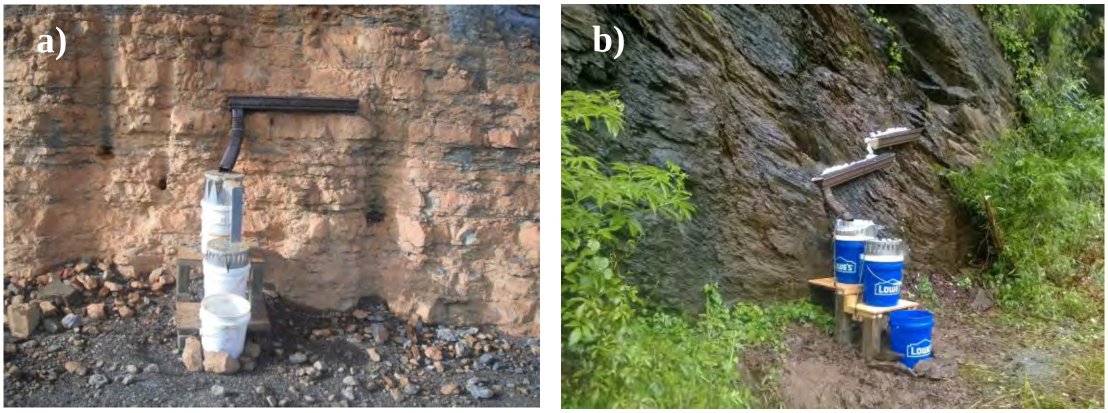

Figure 2.2. Photos of Pinson et al. (2003) flow divider buckets for passive runoff collection at the monitoring sites: a) Nashville 2 (N2) and b) Ocoee 1 (O1).

directed to the next bucket. A triangular leveling device constructed of angle iron and stainless steel adjustment bolts at each corner was used to ensure that the flow divider was level so outlet flow from the buckets was evenly divided. The first flow divider limits the maximum peak runoff rate that can be handled with this arrangement, which for a 12-weir divider is about 30 L/s. Hoomehr et al. (2013) successfully used this collection system for measuring runoff and sediment from coal reclamation sites in East Tennessee. In addition to Figure 2.2 above, also see Appendix A site photos.

The original intent of the Pinson et al (2003) runoff collection devices was to estimate volumes, however the total runoff volumes often exceeded the capacity of the station set-up, typically with three buckets (one 12 V-notch weir, and one 24 V-notch weir). Although runoff per storm event often exceeded the device capacity, they did provide a more thoroughly-mixed water sample for chemical analysis. For all stations and storm events sampled, runoff volumes were estimated using the standard Natural Resource Conservation Service method (NRCS 1986). The basic equations for this runoff estimates are as follow:

$$P_e = (P - 0.2 * S)^2 / (P + 0.8 * S); \quad S = (25400/CN) - 254$$

where, P_e is the runoff depth (cm), P is precipitation depth (cm), S is the potential maximum retention, and CN is the curve number which are obtained from standard NRCS (1986) tables based on the degree of vegetation cover. The event total runoff volume (m^3) was computed by multiplying runoff depth (cm/100) by the site drainage area (m^2). Drainage areas for each station were estimated by a USGS digital elevation map (DEM) and field checked. The CN, computed S, and drainage area for each site are summarized in Table 2.5. Computed runoff volumes for each monitoring station and precipitation depths per storm event are summarized in Appendix C.

2.2.3 Water Sample Collections

Per collection site, runoff from 4 to 5 storm events was collected among different seasons, with the aim to collect 2 summer, 1 fall, 1 winter, and 2 spring runoff samples. Runoff water samples were collected with a minimum of 72 hours of dry weather prior to the storm event. Samples were collected within a maximum of two weeks after the storm event, which could not be avoided with the travel distances among all the sites.

Table 2.5. NRCS rainfall-runoff equation parameters curve number (CN) and potential maximum retention (S) or each monitoring station for metric precipitation depths.

Road Cut Site Name	CN	S	Drainage Area (m^2)
Grainger 1	97	7.86	47.38
Jamestown 1	87	37.95	252.70
Jamestown 2	87	37.95	363.25
Jamestown 3	93	19.12	44.59
Nashville 1	98	5.18	36.23
Nashville 2	98	5.18	27.87
Ocoee 1	93	19.12	44.59
Ocoee 2	93	19.12	37.16
Ocoee 3	93	19.12	52.96
Sevierville 1	93	19.12	39.02

2.2.4 Water Quality Chemical Analysis

Water analyses were conducted at the University of Tennessee, Department of Civil and Environmental Engineering Water Quality laboratory by graduate students. Analyses followed American Water Works Association (AWWA) Standard Methods for use of an ion chromagraph (Dionex™ IC), inductively-coupled plasma optical emission spectrometer (ThermoFisher™, ICP-OES), wet chemistry titration procedures for pH and conductivity. U.S. Environmental Protection Agency (USEPA) and AWWA Standard Methods are the same, but test numbers differ; a cross-referencing list of tests is provided in Table 2.6. Water quality analyses include the following chemical parameters: pH, conductivity, sulfate, nitrate, chloride, calcium, magnesium, and dissolved metals (iron, aluminum, manganese, silica, copper, and zinc). Subsets of the four samples per site were analyzed for total metals. Hardness was computed from calcium, magnesium, and iron (IC/ICP) concentrations (mg/L) rather than using an ethylenediaminetetaacetic acid (EDTA) titrimetric method. Acid neutralizing capacity (ANC) was as an ion balance, where:

$$\text{ANC} = \sum \text{Base Cations} + \sum \text{Dissolved Metals} - \sum \text{Acid Anions}$$

Similar to the modified Molot et al. (1989) version used by Hyer et al. (1995), the change in the concentration sum of acid anions (sulfate, nitrate, chloride, and phosphate), and the sum of base cations (Na^+, K^+, Ca^{2+}, and Mg^{2+}) and dissolved metals (Al^{3+}, Ba^{2+}, Cd^{2+}, Cu^{2+}, Fe^{3+}, Mn^{2+}, Ni^{2+}, Si^{4+}, and Zn^{2+}) was used to determine the relative contribution of each quantity to the total ANC change. Valances for the dissolved metals were assumed as shown. This approach is also consistent with methods used by Wellington and Driscoll (2004) to quantify the contribution of ion concentration change to overall ANC change for water chemistry. A comprehensive summary of the laboratory chemical analysis and parameter estimates are in Appendix D.

2.2.5 Site Water Quality Characterization

Water samples were collected from each of the 5-gallon buckets and analyzed separately. Because complete mixing is assumed as runoff flows from the gutter into the Pinson collection systems and sequentially from one bucket to the other, concentrations of each chemical parameter represents an average of each bucket sub-sample per site and event. Average concentrations were summarized by geologic formation. Mass loadings for each runoff event were computed from the average concentration multiplied by the event flow volume, and site

Table 2.6. Summary of water quality analyses, analytical chemical procedures, equipment, and method references.

Analysis	Procedure	Equipment	Method References
pH	Potentiometric	PC-Titration Plus™	EPA Method 150.1 (laboratory)
Conductivity	Potentiometric	PC-Titration Plus™	EPA Method 120.1
Total Suspended Solids	Membrane Filtration	Vacuum Filtration	Standard Methods 2540D
Anions: (NO_3^-, Cl^-, PO_4^{3-}, SO_4^{2-}) Monovalent Cations: (NH_4^+)	Ion Chromatography	Dionex™ Ion Chromatograph	Standard Methods 4110
Total and Dissolved Metals (Na, K, Mg, Ca, Ba, Cd, Mn, Al, Fe, Cu, Ni, Zn, and Si)	Inductively-Coupled Plasma, Optical Emission Spectrometer	Thermo-Fisher™ Iris Intrepid II	Standard Methods 3120B EPA Method 6010B EPA Method 3005A

export normalized per day. Units for site export of chemical mass loadings were grams per day (g/day), and only computed for ions and dissolved metals.

Results were compared to State Water Quality Standards, and published thresholds for biotic toxicity. The chemical parameters with standards or public thresholds include pH, ANC, and dissolved metals Al and Zn (Table 2.7). In general, a stream pH below 5.5 and dissolved metals (Al, Zn) above 0.2 mg/L can initiate aquatic biota stress and impairment. A detailed summary of toxicological effects from stream water acidification can be found in Appendix E.

TDEC water quality criteria (Rule 0400-40-03-.03) for the designated use Fish and Aquatic Life provide a means to compare the potential environmental impacts from highway road-cuts. The pH value shall not be outside the following ranges: 6.0 – 9.0 in wadeable streams, and values fluctuate more than 1.0 unit over a period of 24 hours. There shall be no turbidity, total suspended solids, or color in such amounts or of such character that will materially affect fish and aquatic life, which is a narrative criterion rather than numeric. The waters shall not contain iron at concentrations that cause toxicity or in such amounts that interfere with habitat due to precipitation or bacteria growth though no numeric limits are provided. Compound maximum concentrations (CMC) for dissolved metals in include: cadmium (2.0 µg/L), copper (13.0 µg/L), lead (65 µg/L), nickel (470 µg/L), and zinc (120 µg/L). However, the CMC for these metals are hardness dependent, and toxicity is reduced with higher hardness levels. Dissolved aluminum does not have a TDEC regulatory limit, but literature indicates that Al concentrations greater than 0.2 mg/L may cause harm to aquatic biota (Table 2.7).

2.2.6 Statistical Analysis

Descriptive statistics were used to summarize site concentrations and mass loadings for water samples per storm event collected in terms of averages, standard deviations, and range (minimums and maximums). Statistics were applied to the site storm event chemistry and environmental factors: season, geology, vegetative cover, road-cut age, aspect, and slope (Table 2.2). Seasons were classified as: spring = March 15 through May 15, summer = May 15 through September 15, fall = September 15 through December 15, and winter = December 15 through March 15.

Analysis of Variance (ANOVA) means separation (Least Significance Difference, LSD) was used to test for significant differences in runoff chemistry among seasons. ANOVA LSD means separation was also used to test for significant differences in environmental site factors,

Table 2.7. Summary of toxic effects of pH, and aluminum and zinc concentrations on fish and benthic macroinvertebrates from published literature.

Chemical	**Fish**	**Benthic Macroinvertebrates**
pH		
5.5-6.4		Slightly impacted
5.0-5.5	Reduced growth	Moderately impacted *Baetis muticus*, *Heptagenia lateralis* and *R. semicolorata* absent; Native mayfly *B. alpinus* declined.
4.0-5.0	Reduced abundance; adverse effect to mortality; harmful to the eggs and fry	Severely impacted Lower taxonomic richness; Scarce empididae, *Isoperla rivulorum*, *Rhithrogena* spp. and *Baetis* spp. (Ephemeroptera)
< 4.0	Lethal to salmonids	Significantly fewer individuals and taxa; Reduced abundance resulted primarily from reduced abundance of mayflies (Ephemeroptera)
Aluminum		
Al_{tot}> 0.2 mg/L	Loss of Na and Cl; Measureable reductions in survival and growth; Significant mortality of brook trout	Reduced density of Ephemeroptera and Ceratopogonidae
Al_{tot} > 0.4mg/L		Acute toxicity LC_{50} for *Hyalella azteca* (Crustacea), *Pisidium spp.* (Bivalvia), *Enallagma sp.* (Odonata)
Al_{in} >0.2 mg/L		Mortality of *Gyraulus sp.* (Gastropoda), *Hyalella azteca* (Crustacea), *Chironomids* (Chironomidae)
Zinc		
> 0.047 mg/L	Fish avoidance	
> 0.11 mg/L		Ceriodaphnia dubia abundance reduced by 50%
> 0.219 mg/L	Start to affect survival	

including geology, vegetative cover, road-cut age, aspect and slope. Linear regression was applied to test for relationships between chemical parameters values/concentrations (dependent variable) and rainfall characteristics (independent variables). The rainfall characteristics included storm event volume (RFV, cm), average intensity (RFIA, cm/hr), and maximum intensity (RFIM, cm/hr). Statistical computations were conducted with SPSS v.23.

2.3 Results

2.3.1 Road Cut Site Chemistry

Site runoff chemistry was highly variable among the study sites as observed by the parameter site means, standard deviations, and ranges (Table 2.8). Chemistry differences among sites were due to many environmental factors including: APM geology, vegetative cover, physical conditions as to cut slope and aspect, road cut age, and others. In addition, variability in chemistry is possibly due to rainfall event intensity and volumes, and the seasonal differences in rainfall characteristics and air temperatures were investigated and results summarized in the next

Table 2.8. Summary of site chemistry by parameter. Site identifiers are: G1 is Grainger; J1, J2, & J3 are Jamestown; N1 & N2 are Nashville; O1, O2, & O3 are Ocoee; and S1 is Sevierville. Latitude and longitude coordinates are listed in Table 2.4. Site means, standard deviations (StDev), and range. Appendix D contains the details of all site and storm event chemistry.

Chemical Parameter	SITE									
	G1	J1	J2	J3	N1	N2	O1	O2	O3	S1
TSS (mg/L)	2114 (827) 100 – 2645	172 (146) 39 – 535	72 (18) 39 – 96	46 (8) 35 – 63	2057 (1012) 39 – 3136	350 (94) 135 – 442	351 (245) 38 – 802	131 (124) 37 – 460	51 (10) 39 – 72	83 (40) 38 – 185
Conductivity (µS/cm)	173 (29) 117 – 209	112 (14) 93 – 133	298 (132) 22 – 428	31 (6) 20 – 38	5217 (388) 4686 – 6031	2533 (889) 1451 – 3460	174 (69) 92 – 348	225 (55) 140 – 309	479 (301) 237 – 1147	462 (307) 225 – 1104
Hardness (mg/L)	18.2 (2.6) 15.1 – 23.3	15.0 (2.9) 12.6 – 21.8	35.5 (8.2) 26.9 – 45.5	9.8 (0.6) 9.1 – 11.3	654.3 (79.2) 604.7 – 826.6	670.7 (63.5) 540.0 – 750.7	59.1 (5.8) 48.0 – 67.9	40.0 (4.1) 34.8 – 46.2	30.7 (6.8) 22.0 – 44.1	85.1 (15.2) 72.2 – 121.4
pH [units]	**4.91** (0.34) 4.27 – 5.50	**6.76** (0.26) 6.57 – 7.37	**4.84** (1.48) 3.45 – 7.07	**6.27** (0.19) 5.97 – 6.50	**6.12** (0.40) 5.32 – 6.53	**4.94** (0.74) 3.91 – 6.40	**6.16** (1.13) 4.60 – 7.57	**6.81** (0.98) 4.53 – 7.70	**4.29** (1.01) 2.97 – 6.13	**5.88** (0.77) 4.20 – 6.63
ANC (meq/L)	-0.27 (0.32) -0.73 – 0.18	-0.82 (0.57) -1.35 – 0.23	-7.79 (5.03) -13.87 – -026	0.14 (0.06) 0.03 – 0.24	-4.32 (6.09) -11.37 – 2.88	29.85 (3.74) 24.95 – 36.65	3.48 (0.70) 1.84 – 4.15	1.24 (0.30) 0.74 – 1.89	1.83 (0.97) -0.22 – 3.36	3.02 (0.45) 2.14 – 3.68
Cl^- (meq/L)	0.17 (0.005) 0.16 – 0.17	0.17 (0.01) 0.16 – 0.19	0.46 (0.19) 0.21 – 0.66	0.13 (0.02) 0.09 – 0.18	0.41 (0.07) 0.33 – 0.53	0.42 (0.06) 0.33 – 0.52	0.14 (0.04) 0.08 – 0.21	0.17 (0.01) 0.16 – 0.19	0.19 (0.04) 0.16 – 0.26	0.20 (0.05) 0.16 – 0.30
SO_4^{2-} (meq/L)	1.88 (0.11) 1.71 – 2.03	1.33 (0.44) 0.35 – 1.75	9.23 (5.50) 1.87 – 16.42	0.37 (0.07) 0.28 – 0.50	43.43 (5.53) 36.33 – 49.61	16.22 (2.90) 9.51 – 18.16	0.80 (0.31) 0.42 – 1.51	1.04 (0.10) 0.89 – 1.22	2.05 (0.52) 1.36 – 2.90	2.77 (0.84) 2.15 – 4.62
NO_3^- (meq/L)	0.24 (0.01) 0.22 – 0.26	0.23 (0.01) 0.21 – 0.25	0.55 (0.24) 0.18 – 0.95	0.16 (0.04) 0.10 – 0.24	0.46 (0.10) 0.29 – 0.59	0.54 (0.18) 0.24 – 0.76	0.32 (0.11) 0.19 – 0.54	0.20 (0.01) 0.18 – 0.23	0.25 (0.06) 0.20 – 0.39	0.21 (0.04) 0.16 – 0.30
PO_4^{3-} (meq/L)	0.40 (0.02) 0.38 – 0.44	0.39 (0.02) 0.34 – 0.40	1.09 (0.13) 0.91 – 1.23	0.23 (0.05) 0.17 – 0.37	0.53 (0.28) 0.28 – 0.93	0.92 (0.25) 0.60 – 1.34	0.27 (0.07) 0.18 – 0.39	0.32 (0.02) 0.28 – 0.35	0.38 (0.07) 0.31 – 0.53	0.35 (0.04) 0.30 – 0.44
Sum AA (meq/L)	2.68 (0.13) 2.52 – 2.85	2.12 (0.45) 1.15 – 2.55	11.32 (5.76) 3.44 – 18.49	0.89 (0.10) 0.77 – 1.13	44.84 (5.85) 37.24 – 50.76	18.10 (2.89) 11.41 – 20.14	1.54 (0.41) 0.98 – 2.55	1.73 (0.12) 1.53 – 1.93	2.88 (0.66) 2.15 – 3.96	3.52 (0.95) 2.77 – 5.58
Na^+ (meq/L)	0.21 (0.11) 0.04 – 0.30	0.15 (0.06) 0.00 – 0.22	0.23 (0.41) 0.00 – 1.02	0.07 (0.02) 0.02 – 0.09	1.01 (0.35) 0.04 – 1.26	2.59 (3.82) 0.00 – 11.93	0.47 (0.16) 0.08 – 0.65	0.24 (0.08) 0.08 – 0.40	1.28 (0.71) 0.00 – 2.66	0.60 (0.32) 0.00 – 1.05
K^+ (meq/L)	0.05 (0.01) 0.04 – 0.05	0.017 (0.01) 0.15 – 0.18	0.07 (0.02) 0.04 – 0.09	0.04 (0.00) 0.03 – 0.04	0.02 (0.00) 0.02 – 0.02	0.06 (0.04) 0.04 – 0.16	0.01 (0.00) 0.00 – 0.01	0.03 (0.00) 0.02 – 0.04	0.06 (0.02) 0.02 – 0.09	0.08 (0.01) 0.07 – 0.11
Mg^{2+} (meq/L)	0.76 (0.11) 0.64 – 0.97	0.24 (0.05) 0.19 – 0.35	1.13 (0.14) 0.92 – 1.26	0.16 (0.01) 0.15 – 0.18	13.28 (1.25) 12.11 – 16.36	10.52 (2.91) 3.52 – 12.63	1.31 (0.13) 1.05 – 1.53	0.77 (0.13) 0.62 – 1.03	0.26 (0.10) 0.12 – 0.47	2.25 (0.39) 1.92 – 3.23
Ca^{2+} (meq/L)	0.44 (0.07) 0.37 – 0.57	0.60 (0.12) 0.49 – 0.87	1.05 (0.33) 0.66 – 1.38	0.39 (0.03) 0.36 – 0.45	24.62 (3.27) 22.44 – 31.39	27.06 (2.07) 24.79 – 31.14	2.16 (0.23) 1.75 – 2.51	1.53 (0.15) 1.35 – 1.78	1.34 (0.29) 0.99 – 1.94	2.88 (0.52) 2.42 – 4.08
Sum BC (meq/L)	1.45 (0.26) 1.08 – 1.90	1.15 (0.21) 0.86 – 1.61	2.48 (0.76) 1.78 – 3.74	0.66 (0.04) 0.61 – 0.77	38.94 (4.16) 36.08 – 48.53	40.24 (1.78) 38.70 – 43.87	3.95 (0.47) 2.91 – 4.53	2.56 (0.29) 2.16 – 3.08	2.94 (1.00) 1.13 – 4.68	5.80 (1.08) 4.96 – 8.14
Dis Al (mg/L)	0.72 (0.30) 0.25 – 0.97	0.33 (0.15) 0.00 – 0.56	0.61 (0.38) 0.28 – 1.38	0.11 (0.03) 0.02 – 0.14	2.41 (1.15) 0.04 – 3.40	39.00 (16.17) 0.02 – 50.03	0.26 (0.11) 0.01 – 0.36	0.24 (0.18) 0.00 – 0.61	5.66 (1.92) 2.88 – 9.02	1.77 (0.96) 0.00 – 2.97
Dis Cu (mg/L)	0.06 (0.01) 0.04 – 0.07	0.06 (0.01) 0.04 – 0.07	0.16 (0.04) 0.07 – 0.20	0.02 (0.00) 0.01 – 0.02	0.50 (0.14) 0.22 – 0.63	0.94 (0.26) 0.26 – 1.09	0.04 (0.01) 0.03 – 0.06	0.07 (0.2) 0.04 – 0.12	0.66 (0.27) 0.25 – 1.14	0.31 (0.13) 0.15 – 0.58

Chemical Parameter	SITE									
	G1	J1	J2	J3	N1	N2	O1	O2	O3	S1
Dis Fe (mg/L)	0.16 (0.08) 0.05 – 0.25	0.13 (0.07) 0.05 – 0.22	0.71 (1.08) 0.05 – 2.65	0.05 (0.01) 0.03 – 0.06	0.47 (0.19) 0.08 – 0.62	1.63 (1.20) 0.10 – 3.45	0.04 (0.01) 0.01 – 0.06	0.08 (0.04) 0.02 – 0.13	0.71 (0.29) 0.15 – 1.12	0.33 (0.18) 0.05 – 0.63
Dis Mn (mg/L)	0.66 (0.16) 0.40 – 0.80	0.26 (0.14) 0.00 – 0.34	2.10 (0.29) 1.51 – 2.35	0.07 (0.03) 0.00 – 0.09	2.32 (0.65) 0.96 – 2.65	5.01 (1.72) 1.22 – 6.09	0.02 (0.01) 0.00 – 0.02	0.21 (0.14) 0.00 – 0.49	2.92 (1.33) 0.69 – 4.79	1.56 (0.80) 0.35 – 2.96
Dis Si (mg/L)	5.83 (0.56) 5.48 – 7.14	0.65 (0.18) 0.54 – 1.07	6.05 (1.45) 3.82 – 7.68	2.50 (0.19) 2.30 – 2.88	7.87 (1.45) 6.87 – 11.70	19.66 (5.37) 6.49 – 22.72	7.34 (1.06) 4.74 – 8.55	2.54 (0.38) 2.18 – 3.50	6.36 (2.10) 2.99 – 10.72	2.94 (0.62) 2.35 – 4.19
Dis Zn (mg/L)	0.38 (0.13) 0.19 – 0.50	0.23 (0.10) 0.02 – 0.29	0.11 (0.02) 0.07 – 0.14	0.07 (0.02) 0.03 – 0.09	1.95 (0.73) 0.26 – 2.38	7.61 (3.06) 0.16 – 9.03	0.05 (0.01) 0.02 – 0.05	0.18 (0.11) 0.02 – 0.44	2.44 (1.21) 0.34 – 4.05	1.26 (0.65) 0.23 – 2.11
Dis Ba (mg/L)	0.12 (0.02) 0.09 – 0.14	0.06 (0.01) 0.05 – 0.07	0.23 (0.04) 0.18 – 0.29	0.05 (0.00) 0.04 – 0.06	0.50 (0.08) 0.34 – 0.57	0.46 (0.09) 0.32 – 0.57	0.08 (0.01) 0.07 – 0.09	0.08 (0.01) 0.07 – 0.11	0.47 (0.13) 0.38 – 0.80	0.35 (0.11) 0.21 – 0.57
Dis Cd (mg/L)	0.02 (0.01) 0.01 – 0.03	0.01 (0.01) 0.00 – 0.02	0.07 (0.01) 0.05 – 0.09	0.01 (0.00) 0.00 – 0.01	0.12 (0.05) 0.00 – 0.18	0.13 (0.05) 0.07 – 0.23	0.01 (0.00) 0.01 – 0.02	0.02 (0.01) 0.00 – 0.05	0.16 (0.10) 0.00 – 0.32	0.13 (0.07) 0.02 – 0.28
Dis Ni (mg/L)	0.09 (0.01) 0.07 – 0.11	0.02 (0.01) 0.01 – 0.03	0.12 (0.05) 0.06 – 0.21	0.00 (0.00) 0.00 – 0.00	0.30 (0.12) 0.17 – 0.59	1.87 (0.71) 0.15 – 2.39	0.00 (0.00) 0.00 – 0.00	0.01 (0.01) 0.00 – 0.02	0.12 (0.08) 0.01 – 0.29	0.05 (0.2) 0.01 – 0.08
Total Al (mg/L)	8.91 (1.22) 7.70 – 10.48	1.68 (0.68) 0.95 – 2.31	1.41 (0.96) 0.32 – 2.39	0.64 (0.33) 0.31 – 1.08	57.54 (21.56) 35.20 – 86.9	44.44 (22.92) 23.41 – 70.04	1.15 (0.98) 0.32 – 2.30	1.08 (0.54) 0.75 – 2.03	8.58 (9.12) 1.65 – 22.76	1.13 (0.63) 0.53 – 2.06
Total Cu (mg/L)	0.04 (0.01) 0.03 – 0.06	0.06 (0.01) 0.01 – 0.07	0.17 (0.04) 0.07 – 0.21	0.01 (0.01) 0.00 – 0.03	0.19 (0.21) 0.00 – 0.48	0.72 (0.87) 0.05 – 1.96	0.04 (0.01) 0.03 – 0.06	0.00 (0.01) 0.00 – 0.02	0.00 (0.01) 0.00 – 0.02	0.01 (0.01) 0.00 – 0.02
Total Fe (mg/L)	11.49 (1.88) 9.91 – 14.06	1.63 (0.91) 0.62 – 2.68	3.18 (2.96) 0.35 – 5.76	1.04 (0.80) 0.30 – 2.00	253.9 (135.2) 130.4 – 445.7	320.4 (244.1) 97.6 – 646.9	1.81 (1.66) 0.10 – 3.58	1.48 (2.15) 0.29 – 5.32	7.33 (7.31) 2.62 – 20.05	4.19 (2.22) 1.44 – 5.91
Total Mn (mg/L)	0.71 (0.13) 0.58 – 0.87	0.13 (0.04) 0.07 – 0.17	1.20 (1.25) 0.02 – 2.29	0.22 (0.11) 0.08 – 0.36	2.15 (0.44) 1.53 – 2.56	2.50 (1.04) 1.28 – 3.51	0.15 (0.13) 0.02 – 0.29	0.21 (0.22) 0.04 – 0.59	1.52 (1.35) 0.49 – 3.50	0.33 (0.23) 0.07 – 0.64
Total Si (mg/L)	9.36 (0.68) 8.54 – 10.17	3.46 (1.47) 1.82 – 4.75	4.17 (3.16) 0.56 – 6.93	2.18 (0.54) 1.54 – 2.77	29.78 (6.42) 23.62 – 38.77	19.85 (7.91) 12.22 – 28.16	8.71 (3.23) 5.35 – 12.66	4.63 (0.89) 3.27 – 5.71	9.44 (8.20) 2.00 – 21.29	3.66 (1.14) 1.98 – 5.17
Total Zn (mg/L)	0.19 (0.04) 0.14 – 0.22	0.21 (0.14) 0.03 – 0.34	0.07 (0.03) 0.01 – 0.11	0.06 (0.05) 0.02 – 0.12	2.45 (0.78) 1.65 – 3.44	4.13 (2.08) 1.43 – 6.08	0.20 (0.19) 0.03 – 0.45	0.07 (0.06) 0.03 – 0.17	0.65 (0.50) 0.24 – 1.43	0.22 (0.11) 0.10 – 0.32
Total Cd (mg/L)	0.01 (0.005) 0.00 – 0.01	0.13 (0.21) 0.00 – 0.44	0.02 (0.03) 0.00 – 0.06	0.01 (0.00) 0.00 – 0.01	0.29 (0.24) 0.04 – 0.56	0.07 (0.05) 0.00 – 0.11	0.09 (0.13) 0.00 – 0.28	0.02 (0.01) 0.00 – 0.05	0.01 (0.01) 0.00 – 0.03	0.01 (0.01) 0.00 – 0.03
Total Ni (mg/L)	0.08 (0.03) 0.06 – 0.12	0.15 (0.14) 0.01 – 0.30	0.04 (0.03) 0.00 – 0.08	0.00 (0.00) 0.00 – 0.01	1.36 (0.38) 0.91 – 1.80	1.23 (0.68) 0.50 – 2.12	0.05 (0.10) 0.00 – 0.24	0.02 (0.02) 0.00 – 0.05	0.05 (0.02) 0.03 – 0.08	0.03 (0.02) 0.00 – 0.07

Sample numbers (N) per site for all parameters except total metal concentrations were as follow: G1 = 8, J1 = 9, J2 = 7, J3 = 12, N1 = 11, N2 = 8, O1 = 15, O2 = 13, O3 = 14, and S1 = 12. Four of each of these samples were randomly selected and analyzed for total metal concentrations.

TSS = total suspended solids; Sum AA = sum of acid anions; Sum BC = sum of base cations; Dis = dissolved.

sub-section (2.3.2). In this sub-section, water chemistry of the road-cut runoff is reviewed collectively for the ten study sites, and compared to water quality criteria.

Suspended Solids: The mean concentrations for total suspended solids (TSS) ranged from 48 to 2,114 mg/L among the sites, which was highly variable (Table 2.8). Two sites Nashville 1 and Grainger 1 had the highest mean concentrations above 2,000 mg/L. These two sites were non-vegetated and the source of these suspended solids was unknown. It is possible the solids are iron precipitates, fine sediment such as sand/silt/clay, or organic material that collected in the buckets. Six sites were below 200 mg/L, which would be more typical for runoff waters. The mean concentrations for Nashville 2 and Ocoee 1 sites were approximately 350 mg/L.

Conductivity: Conductivity is an indicator to ion concentrations in waters. The Nashville sites (N1 and N2) had very high conductivity values with means above 2,500 μS/cm, which conductivity correlates with the reported high hardness values (Table 2.8). Consistent with pyritic geologic formations with underburden limestone, the main contributing ions are sulfate, calcium, magnesium, iron, and aluminum. Jamestown 3 has low conductivity in the range from 20 to 38 μS/cm, which road cut was old and highly-vegetated with tree cover. Mean conductivities for the seven other study sites ranged from 112 to 479 μS/cm and these values would be expected for surface waters.

Hardness: Site characteristics for hardness concentrations correlated with the pattern observed with conductivity, where the Nashville sites (N1 and N2) were much higher than all other sites with means of 645.3 and 670.7 mg/L, respectively (Table 2.8). The other sites generally had mean hardness values that were low below 35 mg/L, which would be considered "soft" water. These sites included the Jamestown sites (J1, J2, and J3), Ocoee 3, and Grainger 1. Ocoee sites (O2 and O3) had mean hardness concentrations below 60 mg/L.

Acidity Indictors (pH and ANC): Overall site means for pH ranged from 4.29 to 6.76, and ANC ranged from -7.79 to 29.85 meq/L (Table 2.8). Five sites had mean pH values below 6.0, which were: Grainger 1, Jamestown 2, Nashville 2, Ocoee 3, and Sevierville 1. Four sites had ANC concentrations below zero which indicates a greater concentration of negatively-charged ions compared to positively-charged ions in solution. These sites were: Grainger 1, Jamestown 1 and 2, and Nashville 1. Though the state regulations do not have a water quality standard for ANC, above 50 μeq/L is generally considered healthy for aquatic biota. The Jamestown (1 and 2) sites were relatively in close proximity to each other, likewise so were the Nashville sites (1 and 2) but acidity indicators were very different. This observation illustrates the spatially variable of water quality from road cuts. The USGS measured pH at seeps and generally found lower pH values than from our runoff water samples (M. Bradley, *personal communication*).

Acid Anions: Sum of acid anions (Sum AA) include negatively-charges ions: chloride, nitrate, chloride, and phosphate, in which the sum of these ions and mean concentrations for the study sites ranged from 0.89 to 44.84 meq/L (Table 2.8). The Nashville 1 site had the mean highest concentration, and the Jamestown 3 had the lowest. Nashville 2 and Jamestown 2 were above 10 meq/L. The other sites were all below 3.5 meq/L. In all cases, sulfate (SO_4^{2-}) were significantly greater than the other anions. Sulfate is the by-product of oxidation of pyrite (FeS), therefore this result was expected with a study designed to collect runoff from exposed pyrite geology to air and water. Sulfate concentrations ranged from 0.4 to 43.4 meq/L (17.6 to 2,084.9 mg/L). Most site mean concentrations were below 100 mg/L, which are typical for runoff from pyrite geology. The Nashville 1 and 2 sites with concentrations above 1,000 mg/L are considered very high. Sulfate is the primary driver for runoff acidification unless there are base cation sources that neutralize this acid anion.

Base Cations: Sum of base cations (Sum BC) include positivity-charges ions: sodium, potassium, calcium, and magnesium, in which the sum of the ions and mean concentrations for the study sites ranged from 0.66 to 40.24 meq/L (Table 2.8). Site mean concentrations for Sum BC were greatest at both the Nashville (N1 and N2) sites at 38.94 and 40.24 meq/L, respectively. The Nashville sites included the Chattanooga shale with a limestone overburden exposed to precipitation, which likely is the source of the high levels of base cations. All other sites had mean concentrations of Sum BC were below 6 meg/L, which lower concentrations potentially limit the neutralization capacity at each site. Mean concentrations of calcium and magnesium were consistently greater than sodium and potassium, which is expected from pyritic shales and limestone rock exposed to precipitation. In most cases mean concentrations of calcium was greater than magnesium but not always, for example Grainger 1 and Jamestown 2 magnesium was slightly greater. The overall mean calcium and magnesium concentrations for the Nashville sites were 512.0 mg/L and 147.2 mg/L, respectively. The overall mean calcium and magnesium concentrations for all other sites excluding the Nashville sites were 28.1 mg/L and 10.6 mg/L, respectively.

Aluminum: Site mean concentrations for total Al ranged from 0.64 to 57.54 mg/L, and dissolved Al ranged from 0.11 to 39.00 mg/L (Table 2.8). Nashville 1 site was observed with the very high dissolved concentration. Mean concentrations for dissolved Al for six sites were below 1.0 mg/L, and among those sites pH values were above 6. Dissolved Al is generally more available from soil and rock source with pH below 5.0. Total Al concentrations were very high at both Nashville sites, which was unique among all the study sites. Total Al concentrations were about 9 mg/L for Grainger 1 and Ocoee 3 with all remaining sites with concentrations were below 2 mg/L. With total concentrations greater than dissolved, it appears much of the potentially available Al was bound to soil particles but as noted above is dependent on pH. Aquatic biota is exposed to dissolved concentration and is the concentration that will be reviewed for toxicity in Sub-section 2.3.3.

Iron: Site mean concentrations for total Fe ranged from 1.04 to 320.4 mg/L, and dissolved Fe ranged from 0.05 to 1.63 mg/L (Table 2.8). The Nashville (N1 and N2) sites were observed with the very high total and dissolved Fe concentrations: total concentrations were 253.9 and 320.4 mg/L and dissolved concentrations were 0.47 and 1.63 mg/L, respectively. It is evident from these differences that most the free iron precipitated from ferrous (Fe^{2+}) to ferric (Fe^{3+}) oxidation number, with the precipitate (road-cut red stain, rust) as Fe_2O_3. Figure 2.2a illustrates the red staining on the road cut surface at the Nashville (N1) site. Total Fe concentrations for all other sites were below 12 mg/L. Dissolved Fe concentrations for all other sites were below 0.7 mg/L. Though the total concentrations at the other sites were lower than the Nashville sites, the large lower difference with dissolved Fe was similar indicating the iron was oxidized and precipitates.

Silicon: Site mean concentrations for total Si ranged from 3.46 to 29.78 mg/L, and dissolved Si ranged from 0.65 to 19.66 mg/L (Table 2.8). The Nashville (N1 and N2) sites were observed with the highest total and dissolved Si concentrations: total concentrations were 29.78 and 19.85 mg/L and dissolved concentrations were 7.87 and 19.66 mg/L, respectively. Dissolved Si concentrations for all other sites were mostly below 7 mg/L. Mineralization of silicon was evident from the differences from total and dissolved concentrations, where dissolved concentrations are typical for surface waters with shale and limestone formations.

Zinc: Site mean concentrations for total Zn ranged from 0.07 to 4.13 mg/L, and dissolved Zn ranged from 0.05 to 7.61 mg/L (Table 2.8). The Nashville (N1 and N2) sites were observed with the highest total and dissolved Zn concentrations: total concentrations were 2.45 and 4.13 mg/L and dissolved concentrations were 1.95 and 7.61 mg/L, respectively. The higher mean dissolved Zn for Site N2 compared with total was unexplained and additional site testing is recommended.

Total and Dissolved Metals: Site mean concentrations for total and dissolved metals other than the metals reported above included Cu, Mn, Ba, Cd, and Ni. The mean concentration ranges for dissolved metals, for all sites included: 0.02 – 0.94 mg/L, 0.02 – 5.01 mg/L, 0.05 – 0.50 mg/L, 0.01 – 0.13 mg/L, and < 0.01 – 0.03 mg/L, respectively. Consistent with the other metals, the dissolved metal concentrations were highest at the Nashville sites. Those dissolved metals that may cause impairment are summarized below (Table 2.7, Appendix E).

2.3.2 Environmental Factors Associated with Road Cut Site Chemistry

Runoff chemistry was examined for relationships to various environmental factors, which included rainfall characteristics (storm event volume and intensities), season, and site characteristics including geology, vegetative cover, road cut slope and aspect, and age. Storm event characteristics are summarized in Table 2.9. Statistical analyses were conducted on these data and summarized below.

Rainfall Characteristics: Runoff samples were collected from a range of rainfall event volumes and intensities per site, in which it was assessed to whether event characteristics affected runoff chemistry values. Linear regression analyses were completed with the chemical parameters as the dependent variable and three rainfall event characteristics (volumes, average intensity, and maximum intensity) as independent variable. No significant relationships were observed between chemical parameter values/concentrations and storm event volumes (RFV); all statistical p-levels were greater than 0.9. Chemical ions sulfate (SO_4^{2-}), Sum AA, Sum BC were significantly related to storm event average intensities (RFIA) though weakly correlated as shown in Figure 2.3 ($p = 0.04$, $R^2 = 0.19$; $p = 0.04$, $R^2 = 0.20$, and $p = 0.05$, $R^2 = 0.19$, respectively). Results from these significance relationships were from the larger data set providing greater statistical power ($N_{total} = 109$) , however the poor correlations indicate that many factors other than rainfall intensity influences ion export from the road cut sites. With regards to Sum BC and observed in Figure 2.3, the higher concentrations were from the Nashville sites and these data points strongly influence the statistical results. Dissolved metals were not significantly related to RFIA (p values between 0.18 and 0.32), which indicates metals are less freely available at the rock surfaces exposed to storm events. Chemical parameter values/ concentrations were not significantly related to storm event maximum intensity (RFIM), in which significance levels were greater than 0.85 for the acid anions and base cations, and greater than 0.40 for the dissolved metals.

Seasons: Runoff chemistry was generally not influenced by seasons. Except for a very few chemical parameters, no significant relationships were observed. TSS was found significantly different between winter and summer with means of 75.4 mg/L and 609.6 mg/L, respectively ($p = 0.01$). Differences are likely due to more available organic matter during warm months. Two dissolved metals were found to significantly differ between seasons. Copper was different between winter and spring ($p = 0.03$), and cadmium was different between winter and all other seasons (p = 0.003-0.018). With only dissolved Cu and Cd found to differ from winter to other seasons and the other dissolved metals did not differ, these relationships are unexplained.

Geology: Runoff chemistry was influenced by road-cut exposed formations, which included the five different types: Chattanooga Shale (Chat), Fentress Formation (Fentr), Sandsuck Formation (Sand), Great Smoky Group: Anakeesta Formation (Anakee), and Snowbird Group: Roaring Fork Sandstone (Snowb). A summary of the runoff chemistry is in Table 2.10. The

Table 2.9. Summary of storm event characteristics for estimated volumes, and average and maximum intensities, and runoff volumes. Site means and (standard deviations) and range. Appendix C contains the details of all site and storm event data.

Site	No. of Events	Duration (days)	Rainfall Volume (cm)	Rainfall Average Intensity (cm/hr)	Rainfall Maximum Intensity (cm/hr)	Runoff Volumes (m^3)
Grainger (G1)	8	3.1 (1.46) 1 – 6	3.74 (2.08) 0.61 – 7.52	0.19 (0.09) 0.08 – 0.33	0.76 (0.29) 0.23 – 1.12	1.41 (0.93) 0.08 – 3.15
Jamestown (J1)	9	1.44 (0.73) 1 – 3	2.38 (1.17) 0.76 – 5.18	0.14 (0.10) 0.05 – 0.33	0.69 (0.63) 0.13 – 2.11	1.47 (1.75) 0.02 – 6.01
Jamestown (J2)	7	1.43 (0.97) 1 – 3	2.02 (0.59) 0.76 – 2.54	0.12 (0.07) 0.05 – 0.23	0.05 (0.34) 0.13 – 1.17	1.29 (0.67) 0.02 – 2.07
Jamestown (J3)	12	1.50 (0.80) 1 – 3	2.20 (1.33) 0.71 – 5.84	0.13 (0.10) 0.05 – 0.36	0.66 (0.63) 0.15 – 2.29	0.44 (0.47) 0.02 – 1.80
Nashville (N1)	11	1.65 (0.50) 1 – 2	3.05 (2.73) 0.61 – 7.67	0.21 (0.14) 0.05 – 0.48	0.78 (0.59) 0.15 – 2.11	0.92 (0.82) 0.09 – 2.57
Nashville (N2)	8	1.75 (0.46) 1 - 2	2.81 (2.01) 0.61 – 5.72	0.18 (0.11) 0.05 – 0.38	0.64 (0.40) 0.15 – 1.30	0.64 (0.54) 0.07 – 1.43
Ocoee (O1)	15	2.60 (1.55) 1 – 6	3.08 (3.23) 0.48 – 13.41	0.11 (0.06) 0.03 – 0.23	0.98 (0.69) 0.10 – 2.26	0.81 (1.29) 0.02 – 5.07
Ocoee (O2)	13	2.62 (1.66) 1 – 6	3.28 (3.43) 0.48 – 13.41	0.11 (0.06) 0.03 – 0.23	1.00 (0.74) 0.10 – 2.26	0.74 (1.14) 0.02 – 4.22
Ocoee (O3)	14	2.36 (1.60) 1 – 6	3.41 (4.22) 0.33 – 16.08	0.12 (0.09) 0.03 – 0.33	0.55 (0.45) 0.13 – 1.52	1.18 (2.00) 0.02 – 7.41
Sevierville (S1)	12	2.67 (1.50) 1 - 6	2.85 (1.61) 1.30 – 7.32	0.20 (0.23) 0.08 – 0.91	0.82 (0.73) 0.25 – 2.92	0.57 (0.54) 0.12 – 2.12

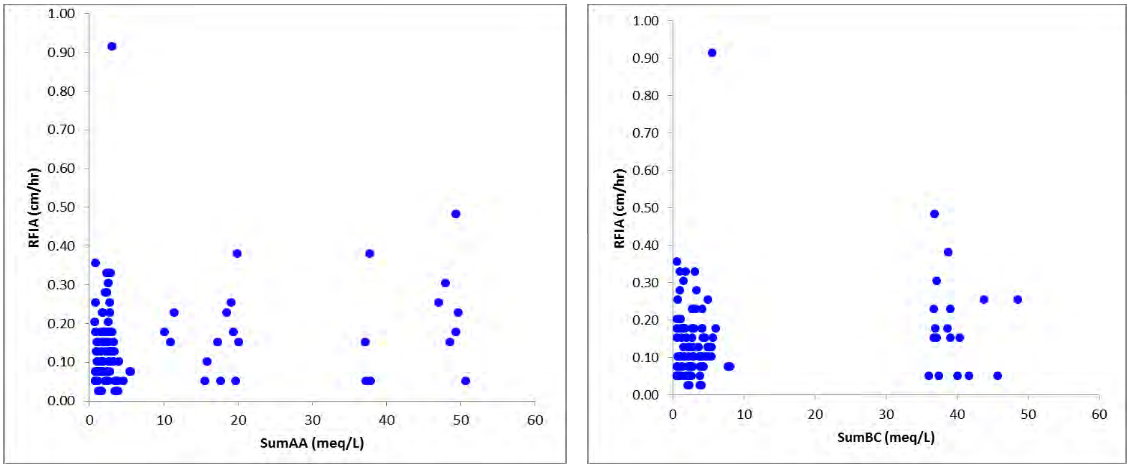

Figure 2.3. Scatterplots of sum of acid anions (Sum AA) and base cations (Sum BC) with storm event average intensity (RFIA). RFIA vs Sum AA ($p = 0.04$, $R^2 = 0.20$), RFIA vs Sum BC ($p = 0.04$, $R^2 = 0.19$).

chemistry among the five formations varied greatly. Mean pH values were: 5.41, 6.07, 6.47, 4.29, and 5.88, respectively. Mean ANC concentrations: 7.00, -2.14, 2.44, 1.83, and 3.02, respectively. The lack of correlation between pH and ANC indicates that the different road cut formations export a unique composition of acid anions, base cations, and dissolved metals (Figure 2.4). For example, the Chattanooga Shale had the greatest mean ANC with a mean pH of 5.41 and the Fentress Formation with the lowest mean ANC and a mean pH of 6.07. The Anakeesta Formation had the lowest mean pH of 4.29 with a mean ANC of 1.83 meq/L.

The runoff chemistry of the Chattanooga Shale was much different from the other rock types studied, apparently dominated by the chemistry at the Nashville (N1 and N2) sites. The Grainger 1 site was another site through the Chattanooga Shale in which road-cut runoff water was collected and analyzed. Runoff conductivity and hardness were much higher compared to the other rock types indicating high concentrations of ions and dissolved metals (Figure 2.5). The mean ANC was 7.00 meq/L, though relatively acidic compared to the other sites it indicated the presence of base cations in greater concentrations than the other sites (Table 2.10). Calcium and magnesium concentrations were significantly greater from the Chattanooga Shale road-cut runoff compared with the other rock types, with means of 18.18 meq/L and 8.75 mg/L. All other rock types were below 3.0 meq/L for Ca^{2+} and Mg^{2+} concentrations. The mean pH of 5.41 indicated acidity from acid anions, which was primarily from sulfate with a concentration of 23.06 meq/L. All other acid anions for this geologic formation were below 1 meq/L. In addition to the higher concentrations of acid anions and base cations, dissolved metals were of greater concentrations in the road-cut runoff from the Chattanooga Shale compared to the other rock types (Figure 2.6).

Table 2.10. Summary of runoff chemistry for the different formations along road-cut exposed to rainfall. Formations are Great Smoky Group: Anakeesta Formation (Anakee), Chattanooga Shale (Chat), Fentress Formation (Fentr), Sandsuck Formation (Sand), and Snowbird Group: Roaring Fork Sandstone (Snowb). Means and (standard deviations) provided per parameter and geologic formation. Letters $^{A, B, C, D}$ indicate significant differences per chemical ($p \leq 0.05$).

Chemical Parameter	Geologic Formation				
	Anakee	Chat	Fentr	Sand	Snowb
TSS (mg/L)	51.1 (10.5) ^{B}	1,567.9 (1,108.7) ^{A}	93.2 (97.7) ^{B}	249.0 (224.7) ^{B}	82.7 (40.0) ^{B}
Conductivity (µS/cm)	479.5 (300.8) ^{B}	2,927.2 (2,207.1) ^{A}	124.2 (125.6) ^{B}	197.8 (66.9) ^{B}	462.1 (306.9) ^{B}
Hardness (mg/L)	30.6 (6.8) ^{B}	470.7 (305.1) ^{A}	17.9 (11.4) ^{B}	50.2 (10.6) ^{B}	85.1 (15.2) ^{B}
pH [units]	**4.29** (1.00) ^{C}	**5.41** (0.77) ^{A}	**6.07** (1.04) ^{B}	**6.47** (1.10) ^{B}	**5.88** (0.77) ^{A}
ANC (meq/L)	1.83 (0.97) ^{C}	7.00 (15.79) ^{A}	-2.14 (4.11) ^{B}	2.44 (1.26) ^{C}	3.02 (0.46) ^{C}
Cl^-(meq/L)	0.19 (0.04) ^{B}	0.34 (0.28) ^{A}	0.22 (0.16) ^{B}	0.16 (0.03) ^{B}	0.20 (0.05) ^{B}
SO_4^{2-}(meq/L)	2.05 (0.51) ^{B}	23.06 (18.50) ^{A}	2.89 (4.56) ^{B}	0.91 (0.26) ^{B}	2.77 (0.84) ^{B}
NO_3^- (meq/L)	0.25 (0.06) ^{B}	0.42 (0.17) ^{A}	0.28 (0.20) ^{B}	0.27 (0.10) ^{B}	0.21 (0.04) ^{B}
PO_4^{3-} (meq/L)	0.38 (0.07) ^{C}	0.61 (0.31) ^{A}	0.49 (0.36) ^{B}	0.29 (0.06) ^{C}	0.35 (0.04) ^{C}
Sum AA (meq/L)	2.88 (0.66) ^{B}	24.42 (18.69) ^{A}	3.89 (5.18) ^{B}	1.63 (0.32) ^{B}	3.52 (0.95) ^{B}
Na^+ (meq/L)	1.28 (0.71) ^{A}	1.24 (2.21) ^{A}	0.13 (0.21) ^{B}	0.36 (0.18) ^{BC}	0.60 (0.32) ^{C}
K^+ (meq/L)	0.06 (0.02) ^{D}	0.04 (0.03) ^{A}	0.09 (0.06) ^{B}	0.02 (0.01) ^{C}	0.08 (0.01) ^{B}
Mg^{2+} (meq/L)	0.26 (0.10) ^{B}	8.75 (5.67) ^{A}	0.43 (0.42) ^{B}	1.06 (0.30) ^{B}	2.25 (0.39) ^{B}
Ca^{2+} (meq/L)	1.34 (0.29) ^{B}	18.18 (11.99) ^{A}	0.62 (0.32) ^{B}	1.87 (0.37) ^{B}	2.88 (0.52) ^{B}
Sum BC (meq/L)	2.94 (1.00) ^{B}	28.21 (17.92) ^{A}	1.27 (0.84) ^{B}	3.30 (0.80) ^{B}	5.80 (1.08) ^{B}
Dis Al (mg/L)	5.66 (1.92) ^{B}	12.75 (19.31) ^{A}	0.31 (0.28) ^{B}	0.25 (0.14) ^{B}	1.77 (0.96) ^{B}
Dis Cu (mg/L)	0.66 (0.27) ^{C}	0.50 (0.38) ^{A}	0.07 (0.06) ^{B}	0.06 (0.02) ^{B}	0.31 (0.13) ^{D}
Dis Fe (mg/L)	0.71 (0.29) ^{A}	0.72 (0.88) ^{A}	0.24 (0.58) ^{B}	0.06 (0.03) ^{C}	0.33 (0.18) ^{B}
Dis Mn (mg/L)	2.92 (1.33) ^{A}	2.62 (1.99) ^{A}	0.64 (0.88) ^{B}	0.11 (0.14) ^{C}	1.56 (0.80) ^{AB}
Dis Si (mg/L)	6.36 (2.10) ^{C}	10.76 (6.64) ^{A}	2.79 (2.19) ^{B}	5.11 (2.56) ^{C}	2.94 (0.62) ^{B}
Dis Zn (mg/L)	2.43 (1.21) ^{A}	3.16 (3.44) ^{A}	0.13 (0.09) ^{B}	0.11 (0.10) ^{B}	1.25 (0.65) ^{C}
Dis Ba (mg/L)	0.47 (0.13) ^{C}	0.37 (0.18) ^{A}	0.10 (0.08) ^{B}	0.08 (0.01) ^{B}	0.34 (0.11) ^{A}
Dis Cd (mg/L)	0.15 (0.10) ^{A}	0.09 (0.06) ^{A}	0.02 (0.03) ^{B}	0.01 (0.01) ^{B}	0.12 (0.07) ^{A}
Dis Ni (mg/L)	0.12 (0.08) ^{D}	0.71 (0.86) ^{A}	0.04 (0.06) ^{B}	0.01 (0.01) ^{C}	0.05 (0.02) ^{B}

Sum AA = sum of acid anions; Sum BC = sum of base cations; Dis = dissolved

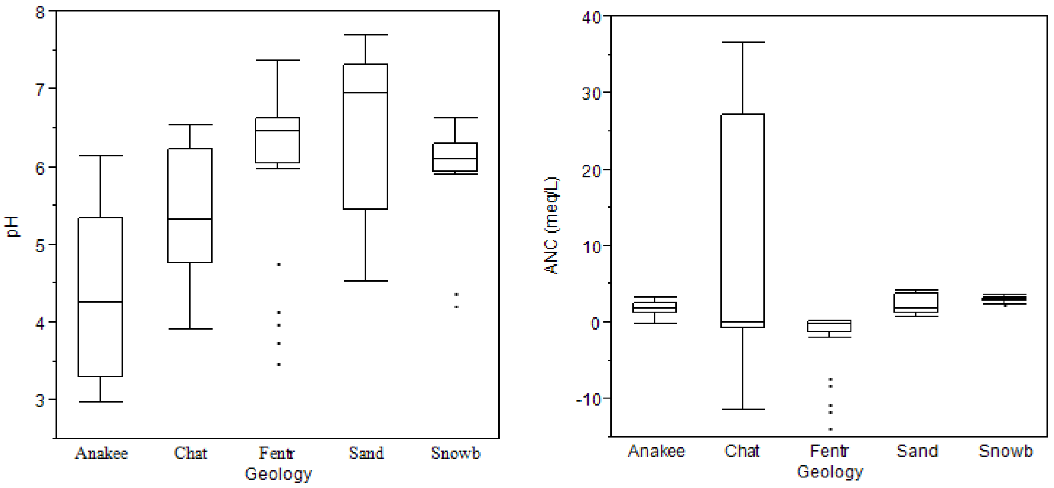

Figure 2.4. Boxplots of runoff chemistry for pH and ANC (meq/L) for the five different road-cut formations. Formations are Great Smoky Group: Anakeesta Formation (Anakee), Chattanooga Shale (Chat), Fentress: Formation (Fentr), Sandsuck Formation (Sand), and Snowbird Group: Roaring Fork Sandstone (Snowb).

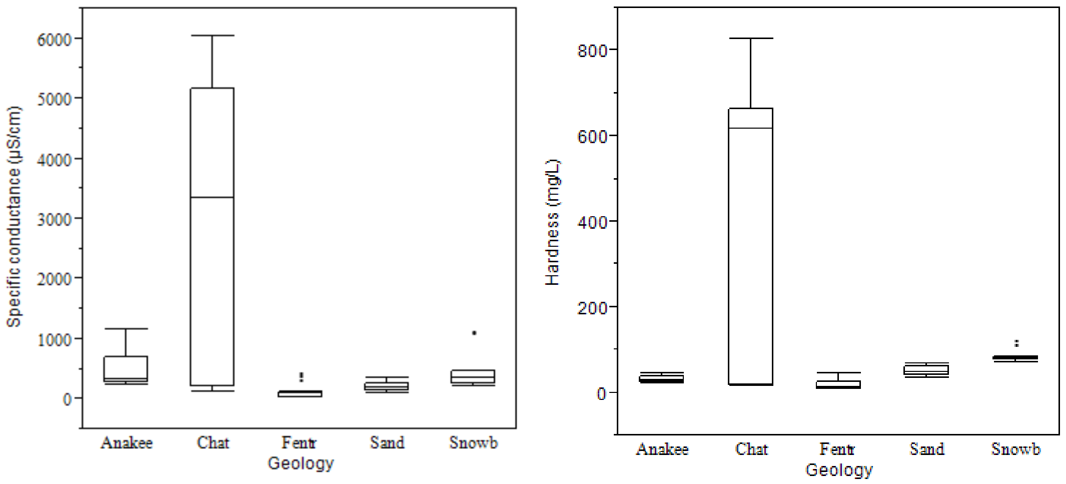

Figure 2.5. Boxplots of runoff chemistry for conductivity (µS/cm) and total hardness (mg/L) for the five different road-cut formations. Formations are: Great Smoky Group: Anakeesta Formation (Anakee) Chattanooga Shale (Chat), Fentress Formation (Fentr), Sandsuck Formation (Sand), and Snowbird Group: Roaring Fork Sandstone. (Snowb).

The runoff chemistry of the Anakeesta Formation was found with the lowest mean pH among the geologic formations studied (Table 2.10, Figure 2.4). ANC was positive with a concentration of 1.83 meq/L governed by the Sum BC concentrations slightly greater than the Sum AA. Other than the Chattanooga Shale, runoff from this rock formation was high in dissolved metals (Figure 2.6). Of the dissolved metals, Al, Fe, Cu, Mn, Si, and Zn were found elevated. It appears that the low pH from the Anakeesta Formation was governed by mineral weathering, hydrolysis and mobilization. Though the mean pH for the Roaring Fork Sandstone (Snowb) had a higher value of 5.88 than the Anakeesta Formation, the governing cause for runoff acidity appears to be the same with metals dissolution and hydrolysis.

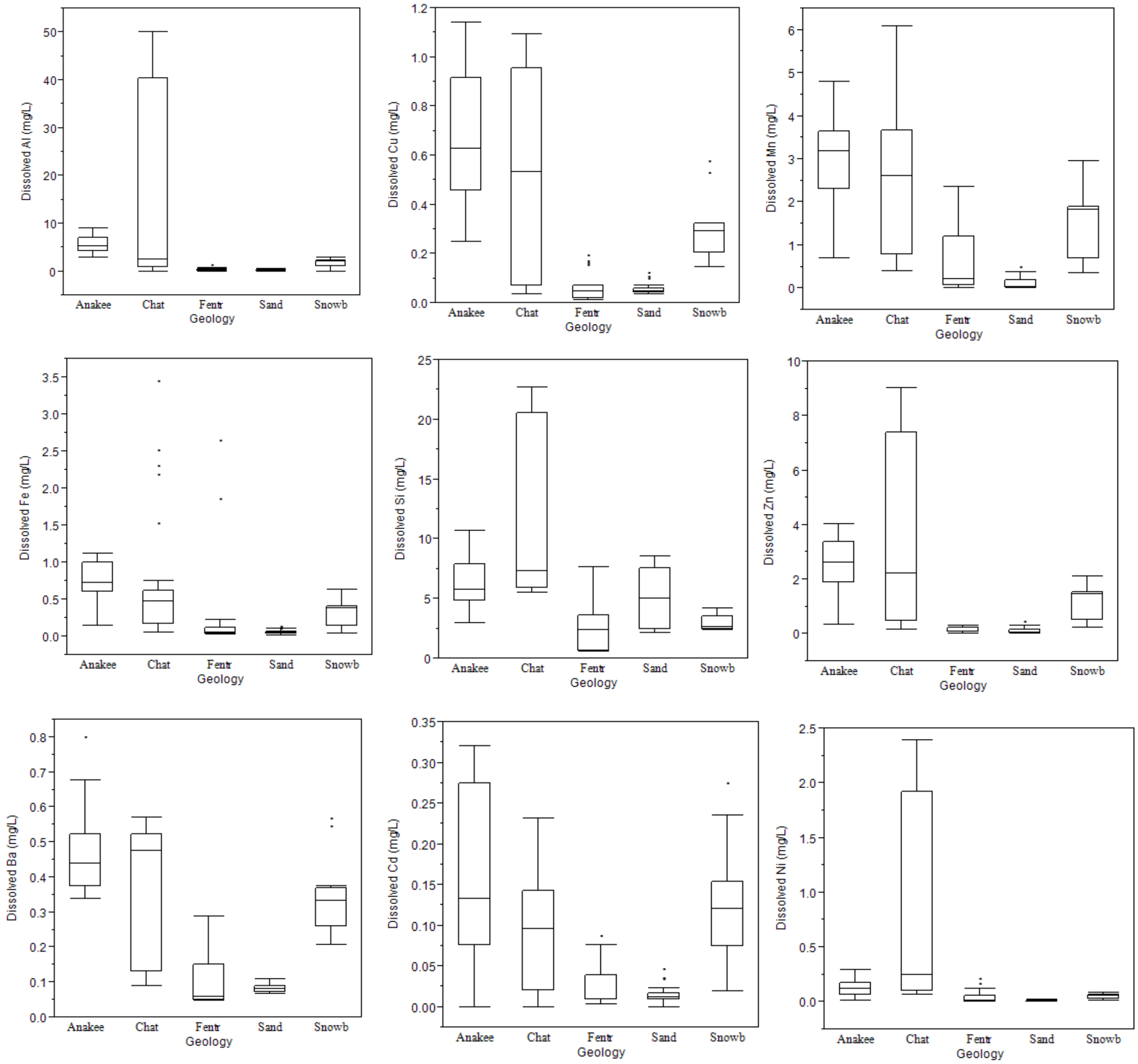

Figure 2.6. Boxplots of runoff chemistry for dissolved metals (mg/L) including Al, Cu, Mn, Fe, Si, Zn, Ba, Cd, and Ni for the five different road-cut formations. Formations are: Great Smoky Group: Anakeesta Formation (Anakee) Chattanooga Shale (Chat), Fentress Formation (Fentr), Sandsuck Formation (Sand), and Snowbird Group: Roaring Fork Sandstone (Snowb).

The runoff chemistry of the Fentress Formation had a pH of 6.01 but its runoff had the lowest mean ANC concentration of -2.14 meq/L compared with the other rock types studied (Table 2.10). The Sum AA concentration was much greater than the Sum BC explaining one cause of the low ANC. Overall, the ion and dissolved metal concentrations were low compared to the other rock types. Ion concentrations, ANC, and pH values were highly variable as observed by the event standard deviation in Table 2.10. With the low conductivity and ANC this site is vulnerable to acidification even through the relatively neutral pH.

The runoff chemistry of the Sandsuck Formation had the highest mean pH (6.47) among the study sites, and a relatively high ANC concentration of 2.44 meq/L. The more neutral acidity at this site was largely governed by the Sum BC and primarily available calcium and magnesium in the runoff. Dissolved iron was especially low along with other dissolved metals. The runoff chemistry of the Roaring Fork Sandstone was similar to the Sandsuck Formation. The mean pH of the Roaring Fork Sandstone was 5.88, and the ANC was 3.02 meq/L.

Vegetative Cover: Runoff chemistry appeared to be influenced by vegetative cover based on the four classes assessed: none, grass, dense forest (forest) and sparse forest (stree). Table 2.2 summarized these classes per study site. Three sites Nashville (N1 and N2) and Grainger (G1) were exposed road cuts with no vegetation (none), and differed significantly in runoff chemistry for sites with vegetation: grass, dense forest (forest) and sparse forest (stree). The chemical parameters that differed significantly included: TSS, conductivity, hardness, sulfate, Sum AA, Sum BC, and dissolved metals ($p < 0.01$). The dissolved metals that very dominantly different from no vegetation and vegetation (all cover types) were Al, Cu, and Fe. Other dissolved metals had a few cases were they were not significantly different, such as Mn was not differ between none and sparse forest (Stree) ($p = 0.48$), and grass and forest ($p = 0.08$). Though it appears that vegetative cover influenced runoff acidification, it is difficult to assess the statistical collinearity between geology and vegetative cover. As observed in Figure 2.5, conductivity and hardness were significantly greater for the Chattanooga shale, which included Nashville (N1 and N2) and Grainger (G1) sites, which were also exposed with no vegetation (Figure 2.7).

The effect of vegetative cover can be interpreted by comparing pH and ANC by the two classification groups: geology and vegetative cover (Figures 2.4 and 2.8). In Figure 2.8, pH for the dense forest cover (Forest) was greatest among the classes and significantly differed for sparse forest cover (Stree) and none ($p < 0.01$). However, it was not significantly different than with grass cover ($p = 0.19$). Cover types grass and none were also similar ($p = 0.10$). The low pH for the sparse forest cover also corresponds with the Anakeesta Formation as observed in Figure 2.4 so this vegetative cover class could not be distinguished as unique with respect to runoff pH. The Chattanooga shale had the highest ANC concentrations which also correlated with no road-cut vegetative cover, which also is associated with the high ion concentrations of hardness, Sum AA, and Sum BC. ANC was significantly different between none and both dense and sparse forest covers ($p < 0.01$), and grass and both dense and sparse forest covers ($p < 0.05$). ANC concentrations were not significantly different between dense and sparse forest covers

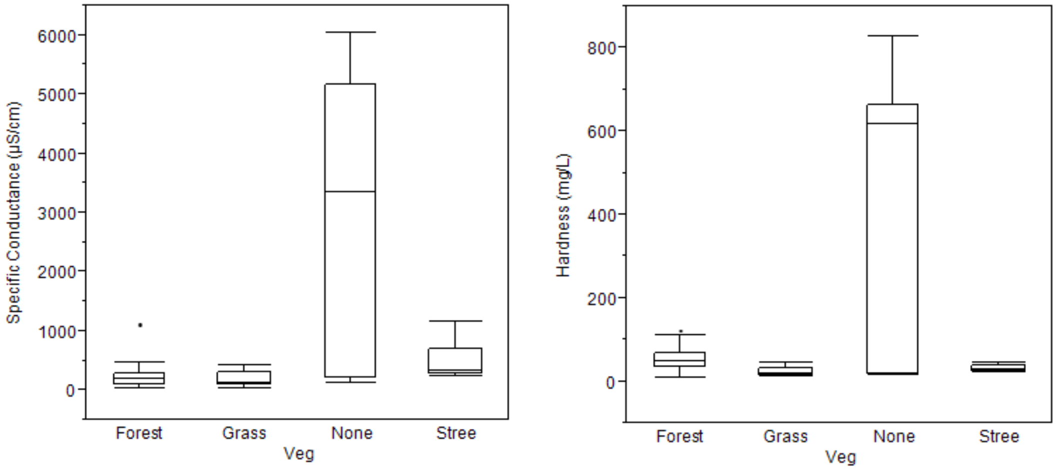

Figure 2.7. Boxplots of runoff chemistry for conductivity (µS/cm) and total hardness (mg/L) for four different road-cut vegetative covers: none (None), grass (Grass), dense forest (Forest) and sparse forest (Stree).

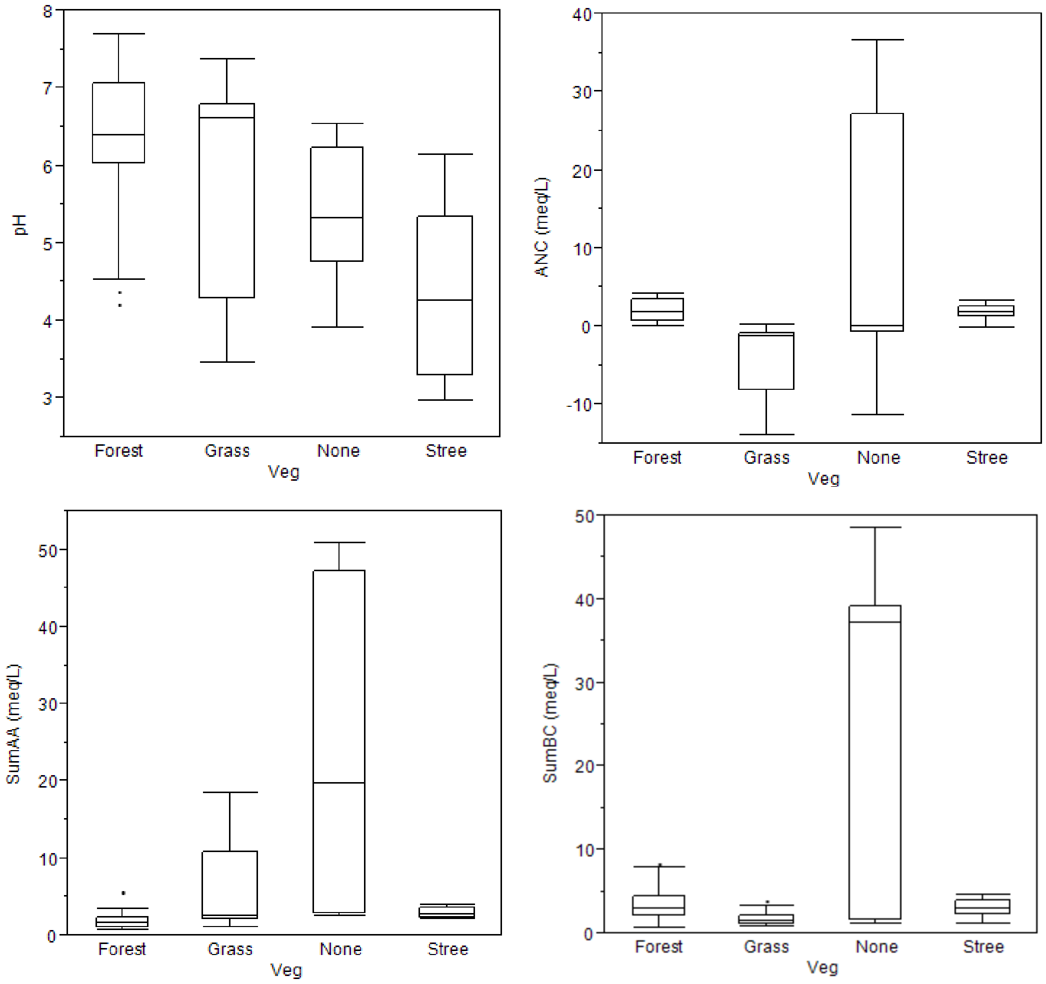

Figure 2.8. Boxplots of runoff chemistry for pH, ANC (meq/L), Sum AA (meq/L), and Sum BC (meq/L) for four different road-cut vegetative covers: none (None), grass (Grass), dense forest (Forest) and sparse forest (Stree).

ranging between 0 and 5 meq/L ($p = 0.93$). Overall, it appears that geology is more dominant than vegetative cover in controlling runoff chemistry but vegetative has an effect. A study specifically designed would need to be implemented to quantify that effect.

Road Cut Age: Runoff chemistry appeared to be influenced by road cut age based on the three classes assessed: old (> 60 yrs), mid (35-60 yrs), and young (< 20 yrs). As observed statistically with the vegetative cover classes, it appears runoff chemistry were strongly governed by three sites Nashville (N1 and N2) and Grainger (G1) which were classified as young, and with no vegetative cover. The sites were also excavated through the Chattanooga Shale. Most the chemical parameters from road cut runoff were significantly different between young and mid-aged sites and young and old sites ($p < 0.05$). The chemical parameters included TSS, conductivity, hardness, pH, chloride (Cl^-), nitrate (NO_3^-), orthophosphate (PO_4^{3-}), Sum AA, Ca^{2+}, Mg^{2+}, Sum BC, and dissolved Si, Ni, Ba, and Cd. Between old and mid-aged sites, pH was also significantly different ($p < 0.01$). ANC concentrations were not differently different among the three classes (Figure 2.9). Dissolved Al was only significantly different between young and old sites ($p < 0.01$). Dissolved Fe was significantly different between young and old sites, and mid and old site ($p < 0.01$), but not between young and mid-aged sites ($p = 0.68$). Dissolved Mn and Zn were similar to that observed with dissolved Fe.

Road Cut Aspect and Slope: The influence of road cut aspect and slope appeared to have the least potential effect on runoff chemistry because outcomes of the statistical analysis resulted in non-significant relationships except for the north aspect. Similarly, as observed with other environmental factors summarized above, runoff chemistry for road cut aspect appeared to be strongly governed by the two Nashville (N1 and N2) sites which were classified as north (Figure 2.10). These two sites were also classified as no vegetation (none), and young road cut age. In Figure 2.10, hardness concentrations were high for the north aspect class compared with east, west and south reflecting the Nashville site concentrations (Table 2.8). Site collinearity among environmental factors, particularly geology and vegetation affects the statistical analysis. Although several chemical parameters tended to be significantly different between the north aspect and the west, east, and south aspects ($p < 0.05$). The chemical parameters included: conductivity, pH, hardness, ANC, SO_4^{2-}, NO_3^-, Sum AA, Mg^{2+}, Ca^{2+}, K^+, Sum BC, dissolved Al and Si. Dissolved Fe was not significantly different among road cut aspects. North facing slopes did tend to receive more shading and colder winter temperatures, but the statistics on season did not show any significant patterns. In general, road cut slopes were not significantly different among the chemical parameters in runoff ($p > 0.2$).

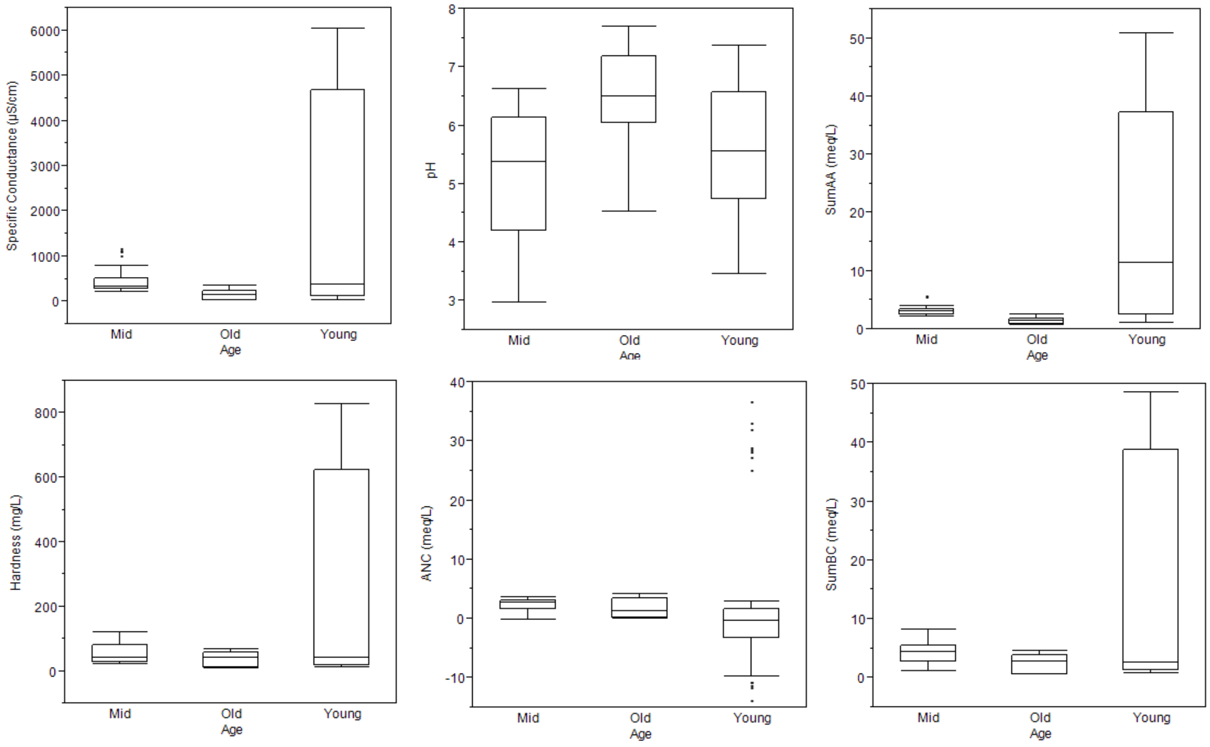

Figure 2.9. Boxplots of runoff chemistry for conductivity (µS/cm), total hardness (mg/L), pH, ANC (meq/L), Sum AA (meq/L), and Sum BC (meq/L) for three different road-cut ages: young, mid, and old.

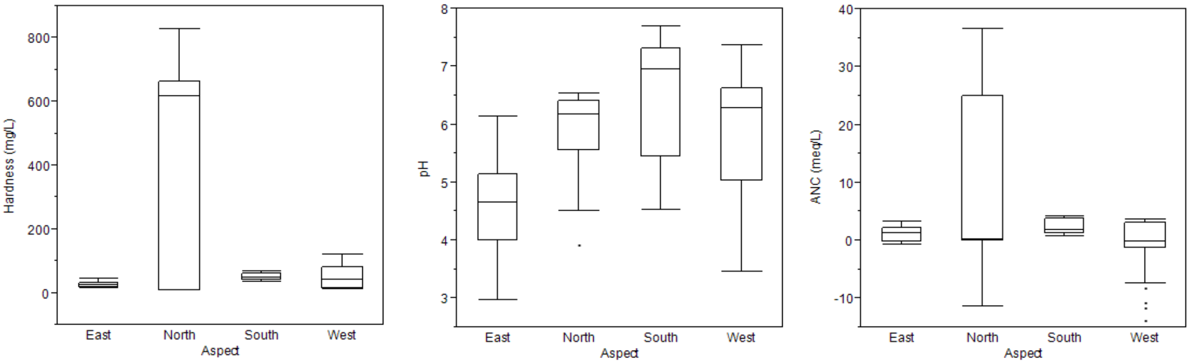

Figure 2.10. Boxplots of runoff chemistry for total hardness (mg/L), pH, and ANC (meq/L) for four different road-cut aspects: east, west, north, and south.

2.3.3 Mass Export of Chemistry Parameters in Runoff from Road Cuts

Mass export of acid anions, base cations, and dissolved metals were computed to quantify the expected loadings and ranges that leave road-cut sites and enter nearby receiving streams (Table 2.11). Per storm event, the chemical parameter concentration (mg/L) was multiplied by the runoff volume (m^3) and divided by the number of runoff days (Appendices D and F). The calculations required a conversion of g/1000 mg and 1000 L/m^3 to obtain units of g/day. These data are needed to assess roadside treatment options because reduction of stormwater runoff acidity is dependent on a mass balance between acid anions, base cations, and dissolved metals, and chemical oxidation, hydrolysis, and different biogeochemical processes.

Sulfate and calcium were the ions measured with the greatest mass exports ranging from < 0.00 to 5,855 g/day and < 0.00 to 1,185 g/day, respectively (Table 2.11). The overall median among all sites was much less than the maximums reported for SO_4^{2-} and Ca^{2+}, which were 24.85 g/day and 8.42 g/day, respectively (Appendix F). Sites with the greatest SO_4^{2-} and Ca^{2+} mass loadings were Nashville (N1 and N2), Jamestown (J2), and Sevierville (S1) sites, which road-cut were through multiple rock formations including the Chattanooga Shale, Fentress Formation, and Roaring Fork Sandstone (Snowb). Among these same sites, Mg^{2+} concentrations were higher compared with the other sites. Mass export of dissolved Al was greatest at the Nashville (N2) site with a maximum event of 29.9 g/day, though the overall median among all sites was 0.21 g/day. Mass export of dissolved Fe was generally low with an overall median among all sites was 0.05 g/day, and a range between < 0.00 and 3.30 g/day. Other than dissolved Si, all other metals exhibited low mass export with overall event medians less than 0.15 g/day.

2.3.4 Potential Water Quality Impairment from Road Cut Site Chemistry

Potential water quality impairment to receiving streams from road-cut runoff were assessed by comparing site chemistry to TDEC regulatory limits on specified chemicals, in addition to published toxicity exposure limits (Section 2.2.5; Table 2.7). The dominant concern in runoff water quality is from its contact with rock formations containing APM and the acidification that results from biogeochemical processes. These parameters primarily include pH, ANC, and dissolved Al. Other dissolved metals can be a concern depending on hardness where higher hardness concentrations reduce toxicological effects. TSS was measured in this study and samples were generally below 200 mg/L, which would be typical for surface runoff during rain

Table 2.11. Site mass loading export (g/day) of acid anions, base cations, and dissolved metals per storm event, and summarized by means, standard deviations (StDev), and range. Site identifiers are: G1 is Grainger; J1, J2, & J3 are Jamestown; N1 & N2 are Nashville; O1, O2, & O3 are Ocoee; and S1 is Sevierville. Latitude and longitude coordinates are listed in Table 2.4.

Chemical Parameter	**SITE**									
	G1	**J1**	**J2**	**J3**	**N1**	**N2**	**O1**	**O2**	**O3**	**S1**
Cl^-	3.05 (2.16) 0.16 – 7.52	7.67 (10.56) 0.01 – 34.80	22.85 (17.32) 0.01 – 1399.6	1.90 (2.54) 0.03 – 9.39	9.45 (11.57) 0.84 – 41.99	4.90 (3.62) 0.80 – 10.50	1.56 (1.96) 0.01 – 7.11	1.66 (1.89) 0.01 – 6.53	2.71 (3.56) 0.01 – 11.88	2.96 (4.20) 0.23 – 12.71
SO_4^{2-}	45.45 (29.56) 2.31 – 102.28	98.42 (155.76) 0.01 – 504.95	564.19 (446.16) 0.01 – 1399.61	6.38 (7.83) 0.11 – 29.62	1345.3 (1619.1) 150.1 – 5855.1	268.45 (219.36) 37.21 – 601.20	12.16 (15.98) 0.09 – 57.86	13.20 (14.63) 0.09 – 49.95	37.06 (49.33) 0.01 – 178.76	52.59 (73.37) 4.07 – 247.08
NO_3^-	7.56 (5.14) 0.37 – 17.77	19.23 (28.23) 0.01 – 92.42	44.65 (30.53) 0.01 – 92.42	3.72 (4.51) 0.10 – 16.45	18.56 (23.56) 1.91 – 85.24	11.72 (11.04) 1.67 – 31.82	6.61 (9.39) 0.03 – 37.45	3.40 (3.95) 0.02 – 13.84	6.03 (7.93) 0.01 – 27.03	5.89 (8.68) 0.39 – 27.03
PO_4^{3-}	6.42 (4.22) 0.34 – 14.48	15.85 (22.39) 0.01 – 73.58	40.75 (26.34) 0.01 – 73.58	2.53 (2.76) 0.05 – 10.17	12.73 (19.78) 0.56 – 69.95	9.16 (5.62) 1.14 – 16.17	2.88 (3.78) 0.01 – 13.61	2.67 (3.06) 0.02 – 10.92	4.86 (6.30) 0.01 – 20.19	5.14 (7.53) 0.37 – 23.42
Na^+	2.78 (2.31) 0.02 – 7.21	4.74 (7.21) 0.01 – 23.30	8.79 (12.14) 0.01 – 24.24	0.65 (0.91) 0.01 – 3.35	15.66 (17.83) 0.06 – 64.51	23.76 (34.49) 0.01 – 104.29	3.25 (4.49) 0.03 – 15.94	1.75 (2.64) 0.01 – 9.78	13.55 (21.34) 0.01 – 65.38	10.05 (19.19) 0.01 – 65.38
K^+	0.94 (0.66) 0.04 – 2,27	8.30 (11.75) 0.01 – 38.64	7.60 (12.70) 0.01 – 38.64	0.56 (0.71) 0.01 – 2.66	0.42 (0.46) 0.04 – 1.69	0.88 (0.79) 0.08 – 2.44	0.09 (0.12) 0.01 – 0.42	0.31 (0.38) 0.01 – 1.39	0.90 (1.46) 0.01 – 5.43	1.35 (1.97) 0.10 – 6.05
Mg^{2+}	4.89 (3.47) 0.20 – 11.46	3.53 (4.55) 0.01 – 15.12	15.01 (10.01) 0.01 – 29.87	0.75 (0.96) 0.02 – 3.57	101.14 (111.62) 11.29 – 394.09	44.03 (38.31) 6.19 – 109.84	4.64 (5.74) 0.04 – 20.84	2.69 (3.23) 0.02 – 10.99	1.16 (1.68) 0.01 – 6.14	8.85 (13.76) 0.92 – 53.76
Ca^{2+}	4.74 (3.54) 0.19 – 11.86	14.18 (17.68) 0.01 – 59.05	26.55 (19.91) 0.01 – 59.05	2.88 (3.50) 0.06 – 13.01	305.94 (336.99) 39.05 – 1185.7	185.84 (142.89) 30.20 – 417.12	12.62 (15.39) 0.09 - 57.02	8.56 (10.46) 0.05 – 37.64	10.81 (13.99) 0.01 – 41.61	20.82 (29.66) 1.91 – 113.49
Dis Al	0.40 (0.31) 0.01 – 1.00	0.49 (0.77) 0.01 – 2.49	0.89 (0.80) 0.01 – 2.49	0.04 (0.06) 0.01 – 0.22	1.68 (2.39) 0.01 – 8.51	14.75 (10.67) 0.01 – 28.89	0.08 (0.11) 0.01 – 0.39	0.09 (0.17) 0.01 – 0.65	1.86 (2.27) 0.01 – 6.48	1.14 (2.05) 0.01 – 6.48
Dis Cu	0.03 (0.03) 0.01 – 0.09	0.08 (0.12) 0.01 – 0.40	0.20 (0.15) 0.01 – 0.40	0.01 (0.01) 0.01 – 0.04	0.31 (0.37) 0.02 – 1.33	0.34 (0.25) 0.01 – 0.69	0.01 (0.02) 0.01 – 0.06	0.02 (0.04) 0.01 - 0.13	0.26 (0.39) 0.01 – 1.27	0.19 (0.36) 0.01 – 1.27
Dis Fe	0.09 (0.07) 0.01 – 0.20	0.22 (0.41) 0.01 – 1.29	0.95 (1.31) 0.01 – 4.86	0.02 (0.03) 0.01 – 0.10	0.31 (0.42) 0.01 – 1.52	0.60 (0.77) 0.01 - 2.34	0.01 (0.02) 0.01 – 0.06	0.03 (0.04) 0.01 – 0.14	0.23 (0.33) 0.01 – 1.17	0.20 (0.37) 0.01 – 1.17
Dis Mn	0.36 (0.29) 0.01 – 0.97	0.39 (0.62) 0.01 – 1.98	2.22 (1.58) 0.01 – 4.86	0.03 (0.04) 0.01 – 0.16	1.48 (1.84) 0.07 – 6.67	1.80 (1.32) 0.06 – 4.11	0.01 (0.01) 0.01 – 0.02	0.08 (0.14) 0.01 – 0.51	1.05 (1.65) 0.01 – 5.68	0.97 (1.76) 0.01 – 5.68
Dis Si	3.02 (2.10) 0.14 – 7.15	0.78 (1.01) 0.01 – 3.37	6.05 (4.43) 0.01 – 13.33	0.98 (1.33) 0.02 – 4.98	4.78 (5.32) 0.67 – 18.88	7.40 (5.78) 0.31 – 16.26	2.15 (2.71) 0.02 – 9.96	0.74 (0.89) 0.01 – 2.95	2.33 (2.88) 0.01 – 9.65	1.62 (2.80) 0.09 – 9.65
Dis Zn	0.21 (0.17) 0.01 – 0.57	0.32 (0.51) 0.01 – 1.62	0.30 (0.54) 0.01 – 1.62	0.03 (0.04) 0.01 – 0.16	1.24 (1.64) 0.05 – 5.87	2.88 (2.14) 0.01 – 5.96	0.01 (0.02) 0.01 – 0.07	0.06 (0.12) 0.01 – 0.46	0.86 (1.39) 0.01 – 4.90	0.81 (1.50) 0.01 - 4.90
Dis Ba	0.06 (0.05) 0.01 – 0.16	0.08 (0.12) 0.01 – 0.38	0.27 (0.18) 0.01 – 0.51	0.02 (0.02) < 0.01 – 0.02	0.32 (0.39) 0.02 – 1.43	0.16 (0.12) 0.02 – 0.35	0.02 (0.03) 0.01 – 0.11	0.03 (0.03) 0.01 – 0.12	0.18 (0.23) 0.01 – 0.80	0.17 (0.27) 0.01 – 0.80
Dis Cd	0.01 (0.01) 0.01 -0.03	0.01 (0.01) 0.01 – 0.02	0.07 (0.06) 0.01 – 0.18	< 0.01 (--) < 0.01 – 0.02	0.06 (0.07) 0.01 – 0.25	0.04 (0.04) 0.01 – 0.11	0.01 (0.01) 0.01 – 0.02	0.01 (0.01) 0.01 - 0.05	0.05 (0.09) 0.01 – 0.34	0.07 (0.12) 0.01 – 0.34
Dis Ni	0.05 (0.04) 0.01 – 0.12	0.02 (0.03) 0.01 – 0.10	0.13 (0.10) 0.01 – 0.30	< 0.01 (--) < 0.01	0.19 (0.23) 0.02 – 0.81	0.74 (0.61) 0.01 – 1.71	< 0.01 (--) < 0.01 – 0.01	0.01 (0.01) 0.01 – 0.02	0.04 (0.06) 0.01 – 0.23	0.03 (0.06) 0.01 -0.23

events (Table 2.8). TSS was observed to be high above 2,000 mg/L at the Nashville 1 and Grainger 1 sites, which likely consisted on eroded silts/sands from the exposed road cuts.

There is no state water quality standard for conductivity, however the USEPA proposed a limit of 300 μS/cm, in which a study by Pond et al. (2008) found impairment to a mayfly family (EPA 2010). Conductivity is a surrogate measure of ions in a water sample, and in waters from the Appalachian coal mining areas the ions of greatest concentrations are typically sulfate and calcium. Hardness is generally correlated with conductivity. Five of the ten sites exceeded 300 μS/cm, with the Nashville (N1 and N2) sites far exceeding this conductivity with site averages over 2,500 μS/cm (Table 2.8). Runoff from the Nashville sites contained high levels of acid anions, base cations, and dissolved metals.

Site averages for runoff pH ranged from acidic to neutral waters where five of the ten sites exceeding a pH of 6.0 and four sites had average pH values below 5.0 (Table 2.8). Within sites, pH values varied widely, for example the Jamestown 2 site had an average pH of 4.48, but the range was from 3.45 to 7.07. The sites with a pH less than 6.00 are below the state's water quality standards, which pH values are to be between 6 and 9. Treatment options are discussed in Section 4.0.

There is no state water quality standard for ANC, however TDEC recommends for TMDL management a target of > 50 μeq/L^{-1}. In general, streams with ANC less than 0 μeq L^{-1} would be considered acidic. Four of the ten sites had averages below 0 μeq L^{-1} and due to the high event variability average ANC did not correlate exactly with their corresponding average pH values. The Nashville 2 site had a high average ANC concentration of 29.85 meq/L resulting from the high concentrations of base cations and dissolved aluminum.

There is no state water quality standard for dissolved aluminum, however literature indicates that concentrations should not exceed 0.2 mg/L (Baldigo and Murdoch 1997; Schwartz et al. 2014). Based on a site average, all road cut sites except the Jamestown 3 site exceeded this toxicity threshold (Table 2.8). Dissolved aluminum in runoff was very high at the Nashville 2 site, indicating a unique geochemical condition under rock/soil acidification. Dissolved aluminum in the form of inorganic monomeric aluminum (Al_{IM}) is regarded as the most toxic dissolved metal for fish and macroinvertebrates in acidified stream waters (Driscoll et al. 1980; Driscoll 1985; Hermann et al. 1993). Fish gill ion transport is disrupted by replacing needed calcium on gill surfaces with increased concentrations of monomeric aluminum (Appendix E). Increased dissolved Al can also cause excessive whole body loss of sodium in trout, resulting in loss of ion regulation. A duration or dose threshold should be considered in particular since stream acidification is episodic in nature (Gagen et al. 1993). Baldigo and Murdoch (1997) found significant mortality of brook trout when dissolved aluminum exceeded 0.20 mg/L for more than two days. Though the road cut dissolved aluminum concentrations were above that threshold, runoff events are generally short and runoff is diluted as it comingles with the receiving stream. Most the research has been conducted on trout, therefore how this dissolved Al threshold transfers to other fish species is not well known.

Dissolved iron does not have a state water quality standard, but in high concentrations in groundwater or seeps in which the water is anaerobic then becomes exposed to oxygen will form a $Fe(OH)_3$ precipitate. This iron precipitate forms an orange-yellow flock (yellowboy) at the bottom of pools. In excessive it may be harmful to benthic macroinvertebrates (Barbour et al. 1999).

Of the dissolved metals analyzed for as part of this study that have state water quality standards, they include cadmium, copper, nickel, and zinc. State CMC standards are as follows cadmium (0.002 mg/L), copper (0.013 mg/L), nickel (0.47 mg/L), and zinc (0.12 mg/L). These standards do not account for hardness. Without accounting for hardness, site averages for cadmium and copper were exceeded for the dataset. In the case of cadmium, it is possible the results are due to the ICP-OES instrument tolerance limit. Five of the ten sites had averages for nickel that exceeded the threshold, and seven sites had averages for zinc that exceeded the threshold. These metals will form precipitates at higher pH levels, thus there are treatment options which are discussed in Section 4.0.

2.4 Discussion and Conclusion

Runoff water quality from road cuts through pyritic rock formations were characterized among ten study sites in Middle and East Tennessee. Sites were monitored for over one year obtaining water samples through all four seasons. Sites were selected to vary environmental factors including geologic rock formation, vegetation cover, and road cut type (age, slope and aspect). In additional to the standard chemical parameters used as indicators, pH, ANC, conductivity, hardness, and TSS, chemical parameters included a comprehensive set of anions, cations, and total/dissolved metals to better understand the biogeochemical processes occurring at the study sites. Very few studies have been conducted on runoff chemistry from road cuts through pyritic rock formations, and none have examined the possible influence of different environmental factors on runoff chemistry. Of the three published articles identified, chemical analyses were limited to pH and total sulfur (Cendro et al. 1977) and pH, total sulfur (sulfate), and a few dissolved metals including Fe and Al (Adams et al. 1999; Orndorff and Daniels 2004).

As with the previous studies (Cendro et al. 1977; Adams et al. 1997; Orndorff and Daniels 2004), pH and other chemical parameters varied widely between sites and within sites among different runoff events. For example, Orndorff and Daniels (2004) reported a pH range from 2.5 to 7.1, dissolved Fe from < 0.1 mg/L to 249.3 mg/L, and dissolved Al from < 0.1 mg/L to 254.5 mg/L for different rock formations in Virginia. Adams et al. (1997) reported pH values between 2.4 and 6.9 for a road cut site in Georgia. In this study, site mean pH also varied widely from 4.29 to 6.27, and the full sample event range between 2.97 and 7.70 (Table 2.8). Other chemical parameters varied widely in this study, and the fact that pH and ANC did not correlate suggests complex and unique biogeochemical processes are occurring among the study sites. Availability of base cations (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}) from the pyritic formation and/or an adjacent over- or under-burden sedimentary formation can control runoff ANC. Decreased pH can result from the displacement of base cations from the rock with Al complexes, where the base cations act as counter ions to electrochemically balance leached sulfate and other acid anions (Cronan and Schofield 1990; Fernandez et al. 1993; Cai et al. 2010). The lack of available base cations can decrease runoff pH. Other than the dominant oxidation of pyrite (FeS_2) exposed to water and air (Pye and Miller 1990; Rimstidt and Vauhgan 2003; Rohwerder et al. 2003), other key geochemical processes affecting pH and ANC and the overall water quality includes desorption/adsorption of sulfate ions, hydrolysis and precipitation of dissolved metals, silicon and other mineral weathering, cation/metal exchange (Cu, Cd, Zn, Mn, others), and aluminum dissolution and mobilization (Dahlgren et al. 1993; Mitchell et al. 2001; Essington 2004; Palmer et al. 2004; Houle et al.2006; Sokolva and Alekeeva 2008). These processes can occur at groundwater seeps where water is exposed to oxygen and with the rainfall that becomes in contract with rock surfaces.

The wide range in values of chemical parameters observed in the runoff sampled from this road cut study suggests that other environmental factors may play a role in determining the water quality at any particular location and period of time. If runoff comes in contain with surface soils with organic matter, sulfur and metal adsorption onto organics is possible potentially increasing pH and shifting dissolved metal concentrations (Spratt et al. 1998; Lawrence 2002; Inandar et al. 2004). Also under this environmental condition, microbial activity in organic-rich soils can produce acidity through nitrogen mineralization and nitrification and formation of organic acids (Gobran et al. 1998; Deyton et al. 2009; Gonzalez 2018). Mullholland (1993) notes that depending on the near sub-surface pathways of water initiated from precipitation, water chemistry varies due to differences in controlling biogeochemical processes.

Though many environmental can influence runoff chemical quality at road cut sites, rock formation type appeared to be the controlling factor determining runoff water chemistry (Table 2.10; Figures 2.4-2.6). The mean pH was lowest for the Anakeesta Formation (pH = 4.29), and its mean ANC of 1.83 meq/L was relatively low compared to other. Compared with the other formations, the Anakeesta formation exhibited generally low concentrations of acid anions (sulfate) and base cations, but higher concentrations of dissolved metals including Al, Fe, Cu. Mn, Si, Cd, and Zn. The Chattanooga Shale and the Roaring Fork Sandstone had mean pH values below 6.0 (5.41 and 5.88, respectively). The runoff chemistry from the Chattanooga Shale was much different than all other formations, which sites included Nashville (N1, N2), and Grainger (G1). Runoff from the Nashville sites contains very high levels of acid anions, base cations, and dissolved metals. Site averages for conductivity at the Nashville sites exceeded 2,500 μS/cm, but it was relatively low for the Grainger at 173 μS/cm. The Nashville sites are fairly new road cuts and those sites appear to be weathering at a high rate exporting ions in the runoff compared to the other sites, particularly the higher concentrations of dissolved silicon. Overall runoff from the Chattanooga Shale contained high levels of dissolved Al, Ba, Cu, Zn, and Ni. The runoff chemistry of the Roaring Fork Sandstone was more similar to the other geologic formations. The Fentress and Sandsuck formations had mean pH values above 6.0. Runoff chemistry from these two formations was similar to the other rock formations except for the Chattanooga Shale as noted above.

With the observed differences of dissolved metals among the rock formations it suggests the basic mineral composition of the local rock appears to greatly influence runoff chemistry; however no data were availability on the exact mineral composition of the study site's rock formations. Other published studies observed a few correlations sulfur content, but none completed a comprehensive analysis of mineral and metal composition. For example, Centrero et al. (1977) correlated %S with pH, where %S estimates below 0.2% were generally above a pH of 5 to 6. Orndorff and Daniels (2003) conducted PPA and %S on rock but there was no significant correlation with runoff pH and dissolved metals. In some cases, PPA values above 25 mg/L ($CaCO_3$ equivalence) results in higher concentrations of dissolved metals. A more comprehensive examination of mineral content could provide additional information on the geochemical processes influencing runoff acidification such as mineral weathering and aluminum dissolution, hydrolysis and precipitation of dissolved metals and silicon, and cation/metal exchange. These chemical reactions are defined as the following:

Al dissolution: $Al(OH)_3 + 3H^+ = Al^{3+}\ 3H_2O$
Cation/metal (M) exchange: $M\text{-exch} + nH^+ = M^{n+} + nH\text{-exch}$
Mineral weathering: $SiO_2 + 4H^+ = Si^{4+}\ 2H_2O$
$M\text{-}SiO_4 + 4H^+ = H_4SiO_4 + M^{4+}$ (M = base cation and/or metal)

Though chemical reactions on the rock surface associated with weathering, Adams et al. (1999) observed that the comingling of waters from seeps and runoff from different rock surfaces affected water chemistry. It is evident that the waters leaving road cut sites potentially undergo several biogeochemical transformations influencing the pH, sulfate, and dissolved metals. As with others, they observed the iron precipitate yellowboy in ponded pools of water at the road cuts. Many environmental factors appear to influence road cut runoff, and further study is needed to more specifically quantify chemical relationships between the parent minerals and runoff water quality, and the comingling of flow paths through different rock types. .

In addition to rock formations affected runoff water quality at road cut sites, it appears that vegetation cover or the lack thereof can possibly influence runoff chemistry to some degree (Figures 2.7 and 2.8). With no vegetative cover with exposed bare rock, ion concentrations in runoff were much greater compared to sites with grass and/or tree cover. Figure 2.7 shows the differences among cover types for conductivity and hardness, and Figure 2.8 shows the differences for ANC, Sum AA, and Sum BC. Median pH for no cover was approximately 5.3. The highest median pH among the cover types was with trees at 6.4, which included the Ocoee (O1 and O2) sites, Jamestown (J3) site, and Sevierville (S1) site. This outcome suggests that organic matter availability from the trees may be playing a role in metal/sulfate adsorption, and sulfur, nitrogen, and cation cycles (Cape et al. 1992; Johnson and Lindberg 1992; Draaijers et al. 1997; Mitchell et al. 2001, Barker et al. 2002; Holzmueller et al. 2007; Cai et al. 2010). Tree cover also protects the rock surface from low intensity rainfall event per leaf interception and evaporation.

The other environmental factors investigated included rainfall event volume and intensity, seasons, and road cut types (age, slope, and aspect). Runoff chemistry was not correlated with rainfall volume and storm maximum intensity, but average intensity was found to influence the export of sulfate, Sum AA, and Sum BC indicating higher rainfall intensities potentially flush ions from road cuts. Seasons did not have any significant effect on runoff chemistry among the study sites. Though our study did not find many relationships with season and weather-related controls, some evidence indicates these variables could influence runoff chemistry from APM (Olyphant et al. 1991). More recently constructed road cuts (young) were found with runoff chemistry with higher concentrations of anions, cations, and dissolved metals. In particular, 'young' sites were higher in dissolved Al and Si indicating mineral weathering rates to be greater compared to the middle and old age sites. The difficulty in interpreting the potential effect of the factors is that data co-varies with the more dominant factors of geologic formation and vegetation. More data from a larger set of study sets would be needed to statistically evaluate these factors. Overall, the findings do suggest that there are minimal effects from seasons, storm event magnitude, and road cut characteristics of slope and aspect. Also, it suggests the older the road cut the likelihood of acidic runoff is small and that planting vegetative cover at runoffs can be used as an effective management strategy to minimize acidic runoff.

Potential environmental impacts of runoff water quality from road cuts through pyritic geologic formations were investigated by comparing the analyses of collected waters to the state's Water Quality Standards. The water collected was directly from the road cut as shown in Figure 2.2 and Appendix A, which does not necessarily infer it's the water chemistry entering the receiving stream. As indicated by Adams et al. (1999), acidity of road cut runoff was greatly reduced prior to entering stream, and there were no downstream effects measured. Their study did not analyze for base cations or many of the dissolved metals so understanding why road cut water acidity was neutralized was left unknown but likely was due to the addition of calcium and magnesium ions. In this study, pH was measured below 6.0 often (Table 2.8). Even sites with a mean pH above 6.0, single events included pH measurements below 6.0. The Tennessee Water Quality Standards require effluent discharges to be between 6.0 and 9.0, unless outside this range represents locally natural conditions. Runoff conductivity was very high at the Nashville road cut sites with a mean above 2,500 μS/cm, which levels could negatively impact certain benthic macroinvertebrates (Pond et al. 2008). In sedimentary rock formations conductivities in the range of 400 to 700 μS/cm are commonly observed. Though there is no Standard for dissolved Al, several studies indicate that levels above 0.2 mg/L can be harmful to fish and some benthic macroinvertebrates (Driscoll et al. 1980; Hermann et al. 1993; Galen et al. 1993; Baldigo and Murdoch 1997). The presence of dissolved organic carbon (not measured) can greatly reduce the toxicological effect of dissolved Al (Driscoll 1985). The study findings observed road cut site exceedances above state Standards for two dissolved metals. State CMC standards for dissolved metals are: cadmium (0.002 mg/L), copper (0.013 mg/L), nickel (0.47 mg/L), and zinc (0.12 mg/L). These standards do not account for water hardness. Without accounting for hardness, site averages for cadmium and copper were exceeded for the dataset. The sites with dissolved metals exceedances were also the sites with higher hardness concentrations which reduce or eliminate the toxic effects of cadmium and copper.

Runoff water quality for this study was similar to that found in the Orndorff and Daniels (2004) study for 25 Virginia sites, inferring water quality from road cuts through pyritic rock formations have expected ranges and event episodic variabilities. The need for site treatment needs to consider whether there is a source of base cations from an overburden or underburden sedimentary rock formation and its exposure to rainfall (Miller et al. 1976; Sobek et al. 2000). For example, a well-vegetated road cut with an adjacent limestone formation would be a low risk site for acidic runoff. In contrast, a vertical road cut bare of vegetation completely through a pyrite shale formation could generate runoff pH below 6.0, low ANC, low hardness, and higher concentrations of dissolved metals, which has a high risk for biological impairment in receiving streams. Findings from the study, coupled with published methods for AP, NP, NNP and PPA could be applied in developing a risk map for runoff acidity and toxic metals. As observed from this study (Table 2.8), runoff chemistry was at levels/concentrations that are treatable with passive methods (Morgan et al. 1982; Gazea et al. 1996; Webb et al. 1998; Gibert et al. 2005; Johnson et al. 2005; Sheoran and Sheoran 2006; Nyquist and Greger 2009; Ray et al. 2009; Cruz Viggi et al. 2010). The potential for runoff treatment options at pyritic road cuts will be described in more detail in Chapter 4.0.

3. Experimental Testing of Treatments for APM Highway Cut Slopes

3.1 Introduction

Acid producing material (APM) removed from highway construction projects through pyritic formations must be handled according to special disposal requirements. These requirements are described in the Tennessee Department of Transportation document Special Provision 107L and standard drawings for material treatment (TDOT 2007). Though APM handling has been well developed, little was known about acidification of runoff from the completed road cut surface. A few studies examined runoff water quality from exposed pyritic rock surfaces at road cuts and natural land surfaces (Miller et al. 1976; Morgan et al. 1982; Fox et al. 1997; Igarishi and Oyama 1999). These studies found water to have high levels of free acidity (pH < 5), and elevated levels of dissolved metals (Al, Cu, Fe, Mn, and Zn). Yellowboy and reddish-brown iron precipitates forms with sufficient availability of oxygen. A study by Orndorff and Daniels (2004) is the only study closely related to characterization of water quality from road cuts in the Appalachian region. They found ranges in pH from 2.5 to 7.1, and total sulfur from 7 to 543 mg/L. Dissolved metals in the runoff were highly variable between sites and storm events. Similar results were found in this study (Chapter 2) with ranges in pH from 4.29 to 6.76. Sulfate concentrations ranged from 17.6 to 2,084.9 mg/L. Results indicated that variability was primarily dependent on the geologic formation in which the road cut was constructed and whether vegetative cover was present. Road cut age appeared to be another factor to runoff acidification, with older road cuts being less acidic. It appeared from this study that vegetative cover could be an effective design and/or management strategy to reduce the potential for acidic runoff leaving highway road cuts. In addition to vegetative cover, there is a research need to explore other options for road cut design to prevent acidic drainage from road cuts.

In order to provide TDOT additional design options, an experimental study design was developed to explore the possible use of different cover materials over exposed pyritic rock. As noted above, vegetation was one material, but needs to include soil and vegetation together. Soil at the rock interface may serve as a sink for sulfate ions if soil water pH remains low and sulfate concentrations are elevated from microbial processes at the surface. Soils also provide a source of base cations to neutralize soil acidity. Soil and vegetation reduce exposure of the pyritic rock surface to rainfall, and vegetation consumes nitrate therefore reducing soil acidity. In general, the biogeochemical processes associated with this cover are complex and rely on natural environmental factors such as seasons (cold/hot), and moisture (wet/dry). Highways departments have used shotcrete as a stabilizing material for rock road cuts to prevent weathering and spalling (Qiao and Zhou 2017; Hayward Baker 2018; Hitech Rockfall 2018; Prometheus 2018). Shotcrete application is the spraying of concrete, Portland cement, aggregate and water, by a pneumatic pressurized gun or nozzle applied to a thickness of three to six inches, which can be unreinforced or reinforced with welded wire mesh or steel fibers. An innovative highway project used shotcrete and vegetation cover to form a ‘green wall’ and effectively stabilize a vertical rock slope (Medla et al. 2017). Not only can shotcrete stabilize rock surfaces, its use can neutralize runoff acidity because it’s a silica calcium based product. Geosynthetic membrane liner products are many, and have been used for many applications (Fettig 2018; Geosynthetica 2018). Solmax (2018) integrated a geoliner and grass vegetation system for construction sites (GSE Lite Earth™). Most applications at highway construction sites are on soil surfaces with moderate slopes. Few examples in literature were found where geoliners were used on vertical rock surfaces. If geoliners are to be used on vertical rock surfaces engineered attachments will be needed to insure long-term durability of that material.

The objective of this study was to test possible designs for road cut cover materials to prevent precipitation contact with exposed pyrite geology and limit export of acid pollutants in runoff. The materials selected for study included soil/vegetation, shotcrete, and a geosynthetic membrane liner. The project Task 2 consisted of a field laboratory-scale experiment, which was modified from the originally proposed full-scale highway road-cut application and testing. The reason for the task scope change was the manufacturer declined to guarantee their product and its application on pyritic rock road cuts. This study did not assess cover material performance for durability only its ability to reduce acid runoff.

3.2 Methods

3.2.1 Experimental Set-up

The experimental design included constructing four container panels to place pyrite rock, and three of the four panels treatments were installed to limit or prevent exposure to the rock. The treatment types were: 1) soil/vegetation cover, 2) shotcrete, and 3) a geosynthetic membrane liner. One panel with exposed pyrite rock (no treatment) served as the experimental design control. The basic construction design of the container panel is shown in Figure 3.1. Four container panels were constructed on UTK's Facilities Planning Division property (5723 Middlebrook Pike, Knoxville, Tennessee 37996-0040). The study site was located at an outdoor location on the property so that the pyrite rock was exposed to sunlight and rainfall that would naturally occur at a road cut. A rainfall gauge was installed at the study site. The study design included a two-phase rainfall exposure methodology. The first phase consisted of exposing the four panels with artificial rainfall from a precipitation simulation tower (Figure 3.2). The second phase consisted of exposing the four panels to natural rainfall for about a six-month period.

Anakeesta pyritic rock collected from a rockslide which occurred on May 28, 2015 in the Great Smoky Mountains National Park (with National Park Service permission) was used for this study. Rock pieces varied in size from approximately 0.5 ft to 2-ft A-axis length. Prior to experimental implementation, the collected rock was stored in a cool, dry indoor location on the UTK campus. The rock was geochemically tested by TDOT, and the collected rock was considered pyritic per Golder Associate (2007) document guidelines, with properties determined as follows:

Paste pH	Neutralization Potential (Tons/1000 Tons)	Total Sulfur (%)	Potential Acidity (Tons/Acre)	+$CaCO_3$ (Tons/1000 Tons)	Total Pyritic Sulfur (%)
4.3	35.50	2.670	83.44	-47.94	0.94

The four container panels constructed of wood lumber, plastic gutter runoff collectors, and rainfall simulators were constructed in April 2016 (Figure 3.2). The container panels measure approximately 3-ft by 4-ft in area, with 0.5 ft sidewalls and a sample port at the bottom (Figure 3.1). The panels were inclined at approximately 15° slope allowing for effective drainage and a longer water contact time than with steeper slopes. The Anakeesta rock was placed in each panel container with no mortar or binding material applied between the rocks so not to change the runoff chemistry during the rainfall events. The rock pieces were placed to minimize gap size. Surface areas of the exposed rock to rainfall in each panel were estimated using scaled photographs. The soil/vegetation treatment consisted of turf grass sod purchased at Home Depot, and placed over the rock. The shotcrete treatment used was mixed according to standard AASHTO T.22 materials as described by Part 6, Section 622 of the TDOT Standard Specifications for Road and Bridge Construction document (Januray1, 2015). This material consisted of 4,000 psi concrete with no aggregates, and was applied on the rock surface filling spaces between the rocks, and forming a smooth surface ¾ inch in thickness. The geosynthetic membrane liner consisted of black 36 mil (30 ounce) high pressure liner (HPL) of woven polyester fabric and PVC/Elvaloy/ KEE film manufactured by EPT XTRAM®, which completely covered the rock surface in the panel container. The EPT XTRAM® HPL specifications are in Appendix G.

The rainfall simulator consisted of an 18-ft tall steel tower with PVC water supply pipes and special discharge nozzles to simulate natural rainfall droplets (Figure 3.2). The water supply consisted of city tap water filling a small open surface plastic tank, set for one week for dechlorination, and a 1.5 HP Gould submersible pump was used to delivery water to the nozzles. The nozzles were 1/8-inch diameter size from Spraying System Company (Model # GG-SS 4.3W). These nozzles had a 0.078-inch nominal diameter and a wide angle spray of 120°. The simulation system operated at 10 psi pressure delivering 0.43 gpm, which equates to 2.55-inch depth for a day (approximately 0.21 inch/hr) on the 12 ft^2 container panel area. This flow rate was selected to reflect a storm event intensity of a 1-year 24-hour return frequency for the Knoxville area. Plastic sheeting was placed on the simulation tower as shown in Figure 3.2 to eliminate spray dispersion from wind.

The simulated rainfall experiments at a rate of approximately 0.21 inch/hr were conducted for a period of 4.317 hours for an initial test, followed by one-day rest, and then run for a period of 2.383 hours. This simulation was conducted for the pyrite rock and soil/vegetation panels. The sample frequency for runoff water was: 0.00, 0.833, 1.667, 2.383, 3.117, 3.833, 4.133, and 4.317 hours for the initial test. The frequency for the second run on the second day was: 0.00, 0.833, 1.667, and 2.383 hours. The simulation for the shotcrete and geoliner treatments, and sample frequency for monitoring was a single day for 0.00, 0.833, 1.667, 2.383, 3.117, 3.833, and 4.133. Water from the source tank pool was collected at the beginning and end of each simulation experiment. Runoff water samples from each simulation and test and container panel were analyzed for chemical parameters at UTK Water Quality Laboratory. The source tank water was also analyzed for chemistry.

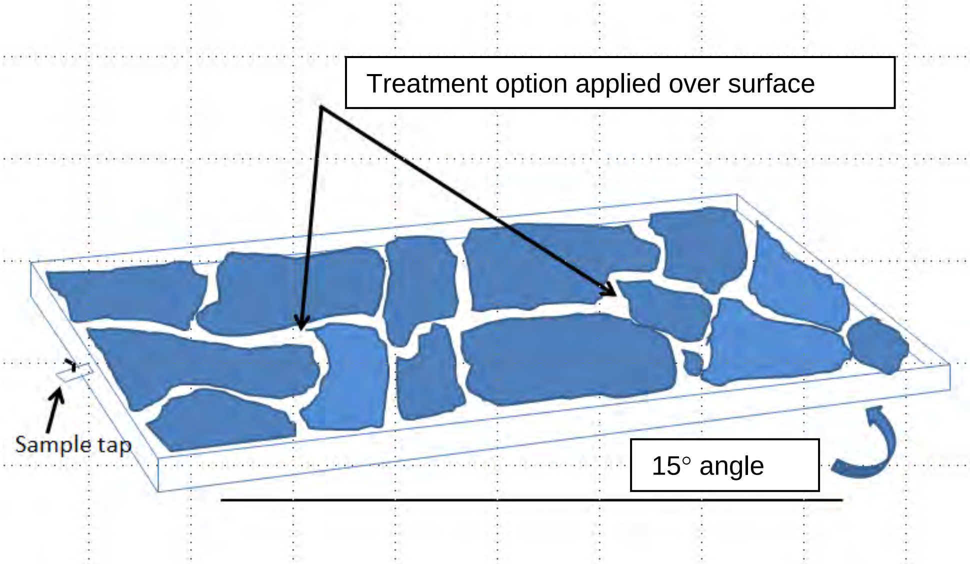

Figure 3.1. Schematic of the experimental test panel with pyritic rock.

Figure 3.2. Photos of the experiment set-up on Middlebrook Pike, Knoxville, Tennessee showing Anakeesa Formation rock treatment trays (*upper right photo* – exposed rock and *lower right photo* – soil/grass), and the rainfall simulator (*lower left photo*).

After the stimulated rainfall experiments, the four test panels were exposed to natural rainfall from June 2016 through December 2016, where runoff water samples were collected and samples analyzed at the UTK Water Quality Laboratory. Runoff volumes from natural rainfall for each of the treatment panels were measured by water depth measurements in the bucket. For very large storms exceeding the bucket capacity, a linear regression relationship was developed from the measurements within the bucket's capacity (Table 3.1). This experiment was conducted for a six-month period to investigate treatment performance under natural climatic conditions. Water chemistry data of the runoff for both the stimulated rainfall experiment and natural rainfall can be found in Appendices H and I, respectively.

Table 3.1. Linear regression relationships for the four 12-ft^2 area panels, one control and three treatments. Runoff volume ($\forall$) is in ft^3, and rainfall depth (RD) is in inches.

Treatment	**Regression Equation**	**Correlation**	**Significance**
Pyrite Rock	$\forall r = -0.01720 + 0.96575 (RD)$	$R^2 = 0.988$	$P < 0.001$
Soil/Vegetation	$\forall v = -0.01431 + 0.57838 (RD)$	$R^2 = 0.934$	$P < 0.001$
Shotcrete	$\forall s = -0.00048 + 0.96575 (RD)$	$R^2 = 0.961$	$P < 0.001$
Geoliner	$\forall g = -0.00002 + 0.71862 (RD)$	$R^2 = 0.969$	$P < 0.001$

Note: the y-intercept in the linear regression equation represents hydrologic initial abstraction.

3.2.2 Water Quality Chemical Analysis

Water analyses followed American Water Works Association (AWWA) Standard Methods for use of an ion chromagraph (Dionex™, IC), inductively-coupled plasma optical emission spectrometer (ThermoFisher™, ICP-OES), wet chemistry titration procedures for pH and conductivity. U.S. Environmental Protection Agency (USEPA) and AWWA Standard Methods are the same, but test numbers differ; a cross-referencing list of tests is provided in Table 2.6. Water quality analyses include the following chemical parameters: pH, specific conductance, sulfate, nitrate, chloride, calcium, magnesium, and dissolved metals (iron, aluminum, manganese, silica, copper, and zinc).

3.2.3 Data Analysis

Simulation rainfall and runoff chemistry data were summarized per experimental treatment and the control as chemical parameter concentration plots over time to qualitatively observe changes during the simulation event. The main goal was to observe how long pyrite oxidation would continue and influence runoff pH, and the export of sulfate and iron from the exposed rock surfaces. Per chemical parameters, chemical units/concentrations were plotted against experimental time to examine the change over the simulation period. A qualitative assessment of the patterns observed was interpreted with regards to the effectiveness of the treatments by comparing the control (pyrite rock panel) with the three different treatments.

Natural rainfall and runoff chemistry data were summarized per experimental treatment and the control for each storm event measured. Statistical analysis was conducted on event mean concentrations per treatment using a single-factor ANOVA to test whether collectively there was a significant difference among the four treatments. In order to test significant differences between individual treatment combinations, a two-sample t-test (assuming unequal variances) was used. Chemistry from the rainfall water was also statistically compared to the treatment runoff chemistries. In addition, runoff volumes were compared with runoff chemistry to assess the influence of storm event magnitude on the chemistry. A regression model was used to assess whether runoff chemistry was influenced the volume magnitude of the storm event.

3.3 Results

3.3.1 Simulated Rainfall Experiments

As would be expected the runoff chemistry of the control panel with the exposed pyrite rock changed over the simulation period. The pH increased from approximately 3.6 to above 6.0 within four hours (Figure 3.3). However, rapid oxidation occurred where the next day the initial pH was near 3.6 however reached pH values above 6.0 within two hours. Runoff ANC from the pyrite rock remained low during the simulations due to the lack of base cations to neutralize the acid anions (Figures 3.4-3.6). The sum of acid anions (Sum AA) consists primarily of sulfate, and the rapid decrease in SO_4^{2-} concentrations can be observed in Figure 3.7. Mineral ions from the rock surface are quickly washed off as observed by the rapid decline in conductivity within the first hour of rainfall and basically diminished of ion source within two hours of rainfall (Figure 3.8). This raid decline in dissolved metal ions can be observed for iron and aluminum in Figures 3.9 and 3.10. These two metal ions are the most relevant to pyrite oxidation and the potential for surface water toxicity, however all the metal ions were found to decline throughout the rainfall simulation period (Table 3.2). The dissolved aluminum concentration dropped below 0.2 mg/L with two hours. These plots from the rainfall simulator experiments demonstrate that runoff chemistry from exposed pyrite rock changes rapidly with acidification conditions occurring for about an hour for an intensity of approximately 0.21 inch/hour (equivalent to 1-year 24-hour return frequency, Knoxville area).

The soil/vegetation treatment using turf grass sod purchased commercially at Home Depot results in runoff chemistry changes for ANC, sum of base cations (Sum BC), Sum AA, conductivity, and sulfate; however, runoff pH remained approximately the same during the experimental runs at about 6.8 (Figures 3.4-3.10). ANC declined on day 1 (D1), but increased on day 2 (D2). The chemistry with the turf grass is complicated with sum of base cations remaining constant on D1 but declining rapidly on D2, whereas the sum of acid anions was observed to decline on both days. The complex chemistry for this treatment was likely due to the nitrogen-phosphorus-potassium fertilization and calcium liming of turf sod. Overall, the runoff pH was moderated from the soil and grass vegetation compared with the pyrite rock control. However, in order to better understand the chemistry and the potential use of grass sod as a treatment further research on the biogeochemical processes would be needed. It appears some sulfate and potassium were present with export occurring at different rates, and mineralization/nitrification occurring on the second day with moist soil conditions for the microbial community (Table 3.2).

The runoff chemistry for shotcrete and geoliner treatments remained relatively constant through the first day of rainfall simulations (Figures 3.4-3.10). Because of that observation, a second day of simulations was not conducted. The runoff pH was approximately 9.0 and 7.8 for the shotcrete and geoliner treatments, respectively. The runoff ANC was approximately 2.0 meq/L and 1.3 meq/L for the shotcrete and geoliner treatments, respectively. ANC was generally low because it essentially consisted of rain water with low ion content. The sum of base cations and conductivity were elevated initially for the shotcrete treatment, but quickly declined after one hour, which was due to high levels of calcium being washed off (Table 3.2). This result would be expected because shotcrete is a calcium-based product. Both these treatments would be effective controls for potential acidification of runoff from exposed pyrite rock along newly constructed road cuts.

A summary table of the runoff chemistry for the pyrite rock panel (control), the three treatment panels (soil/vegetation, shotcrete, and geoliner), and the water supply (source) tank is expressed as minimums and maximums (Table 3.2).

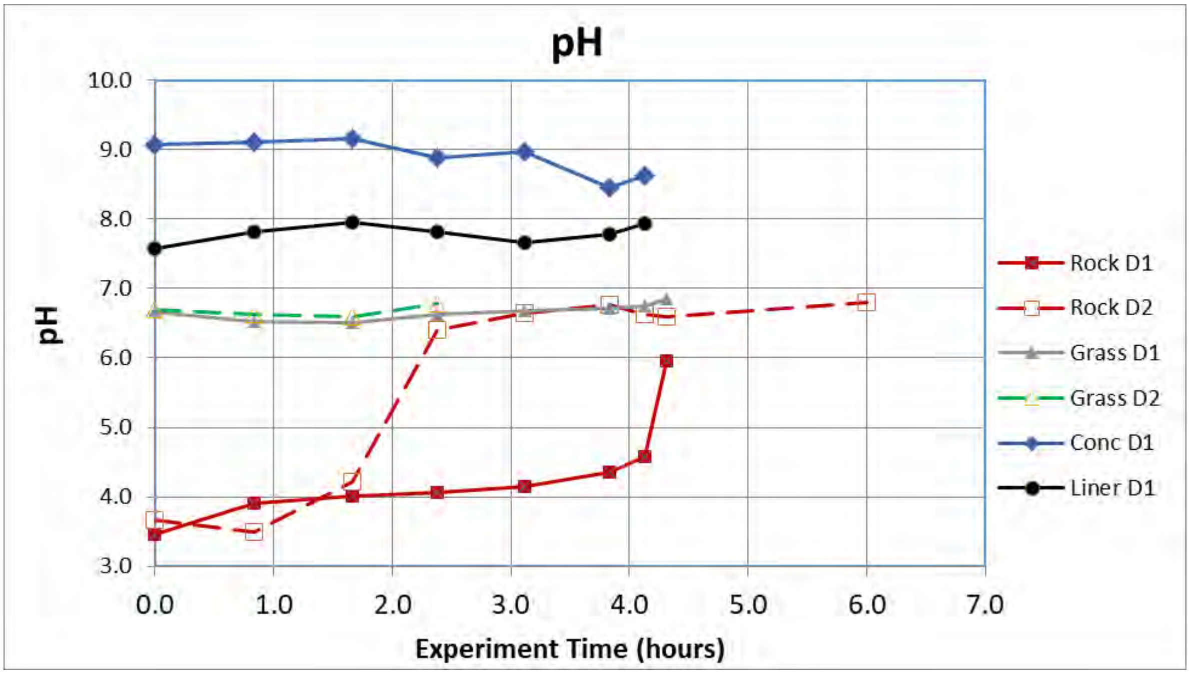

Figure 3.3. Runoff pH from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

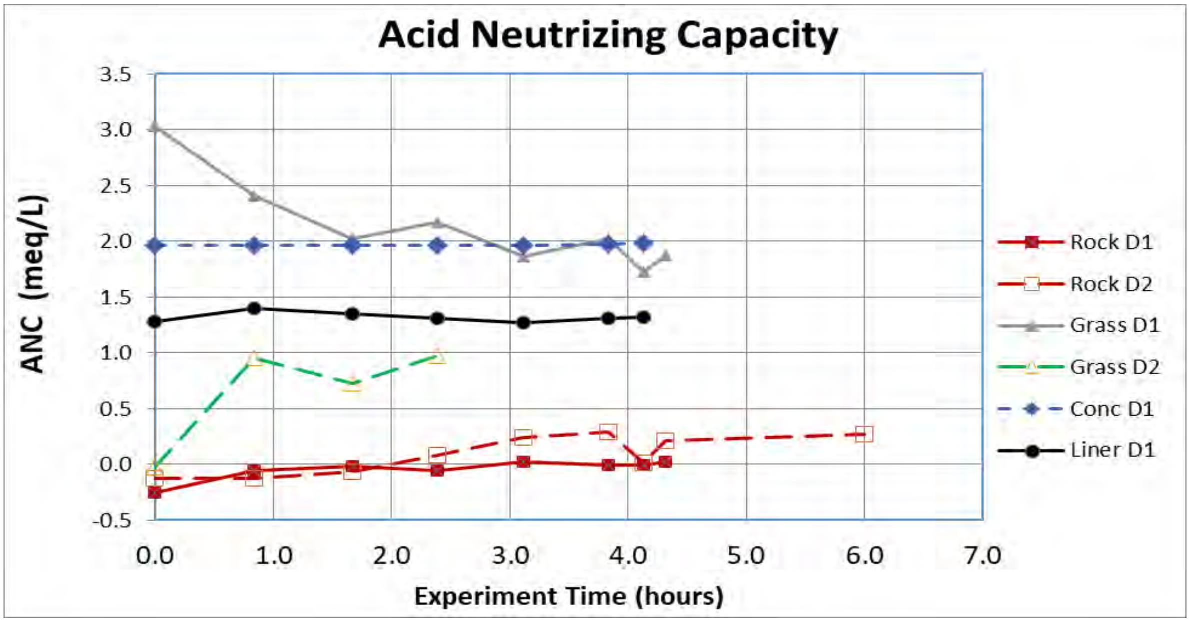

Figure 3.4. Runoff ANC (meq/L) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

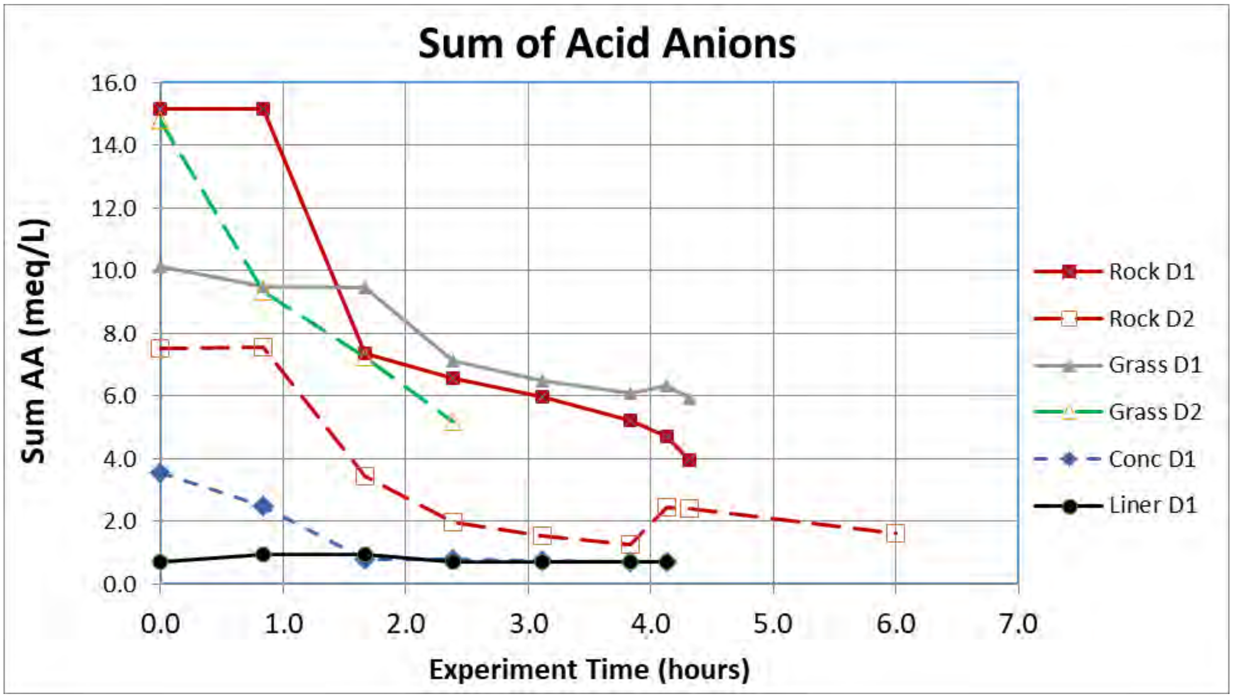

Figure 3.5. Runoff sum of acid anions (meq/L) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

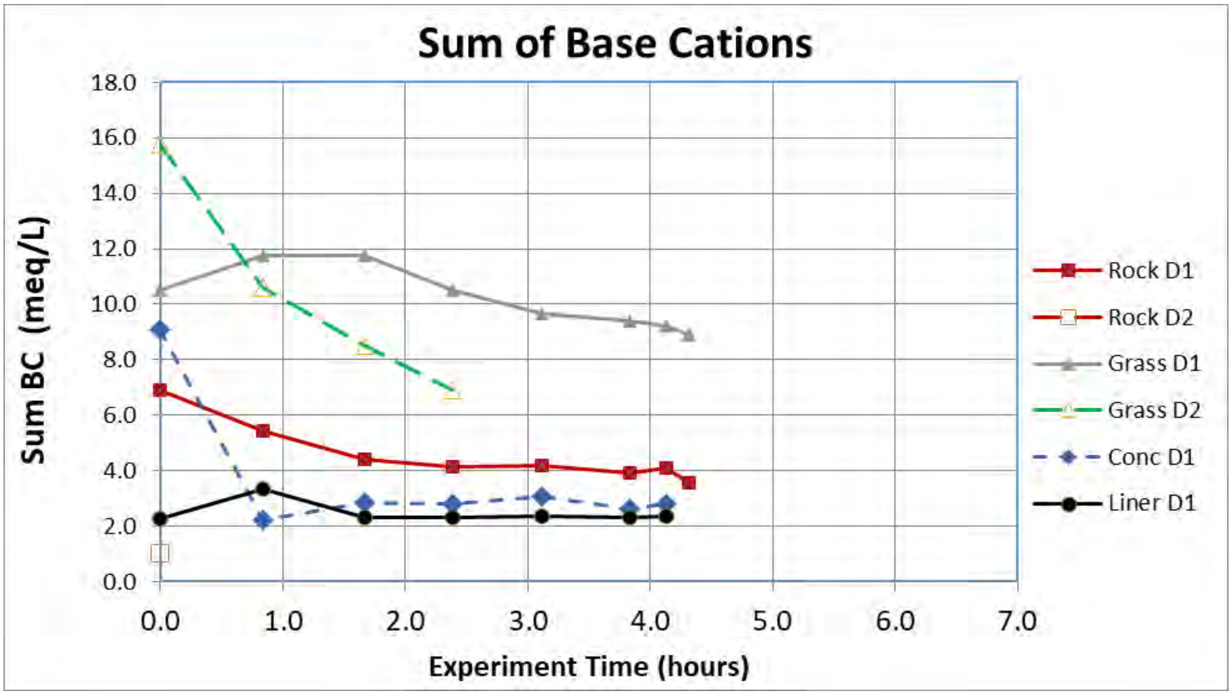

Figure 3.6. Runoff sum of base cations (meq/L) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

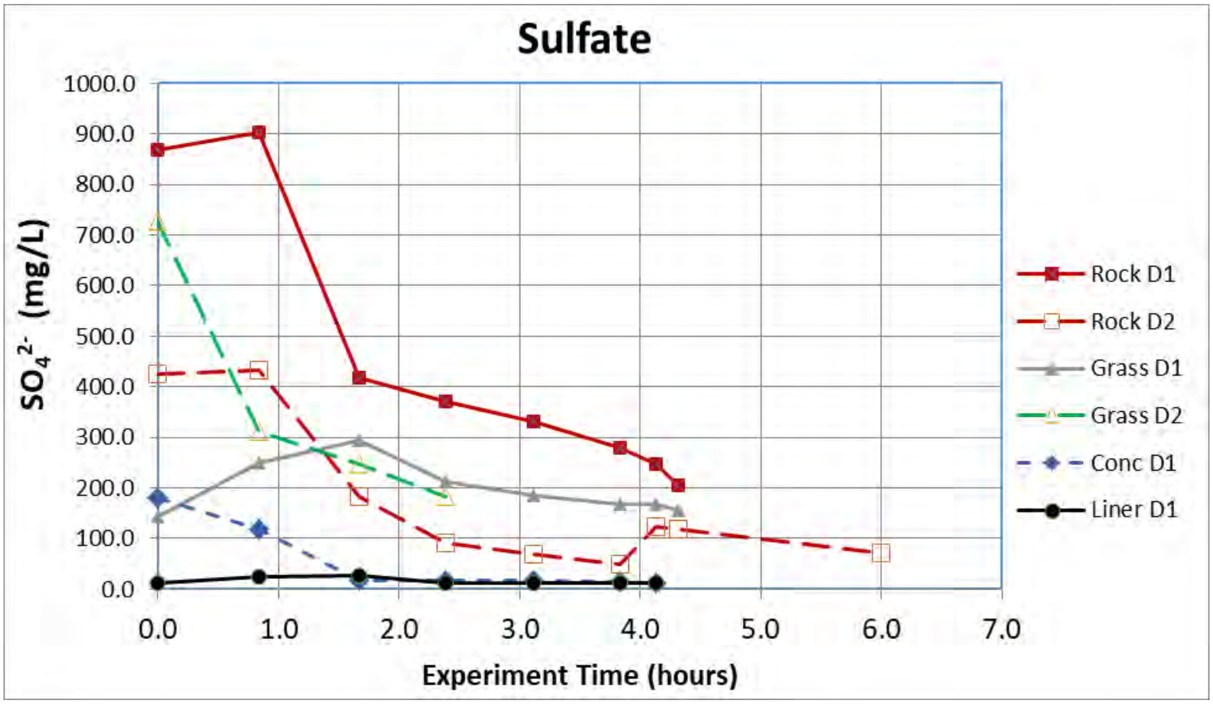

Figure 3.7. Runoff sulfate (mg/L) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

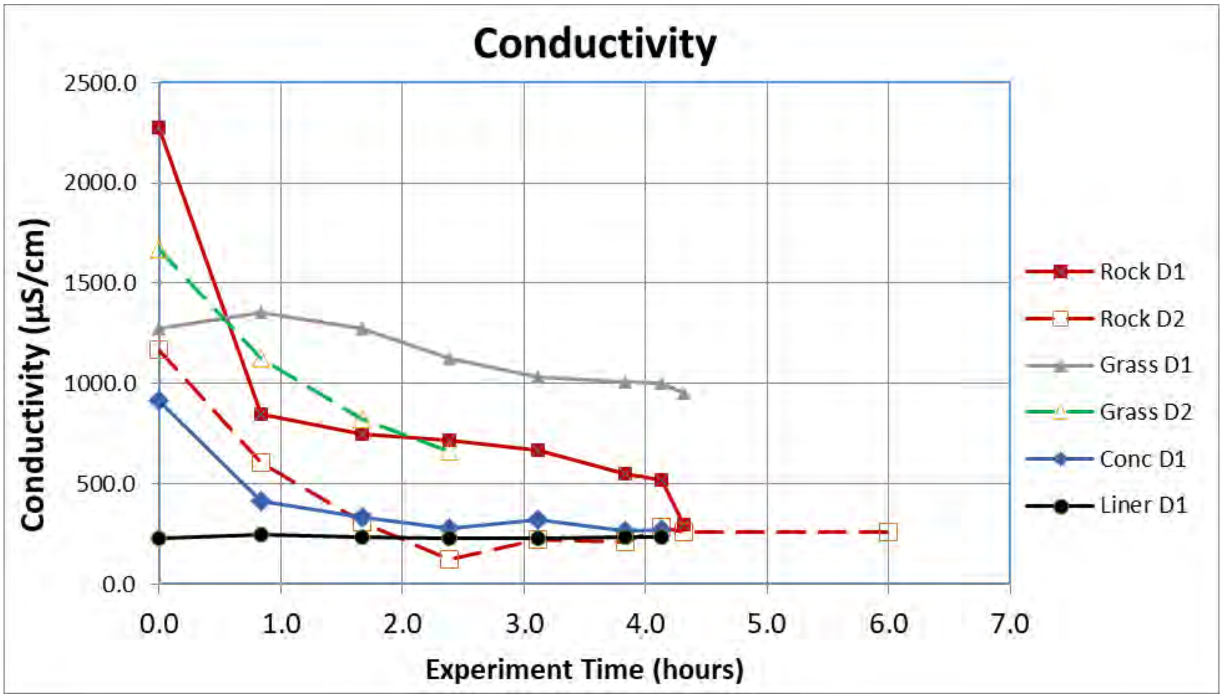

Figure 3.8. Runoff conductivity (µS/cm) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

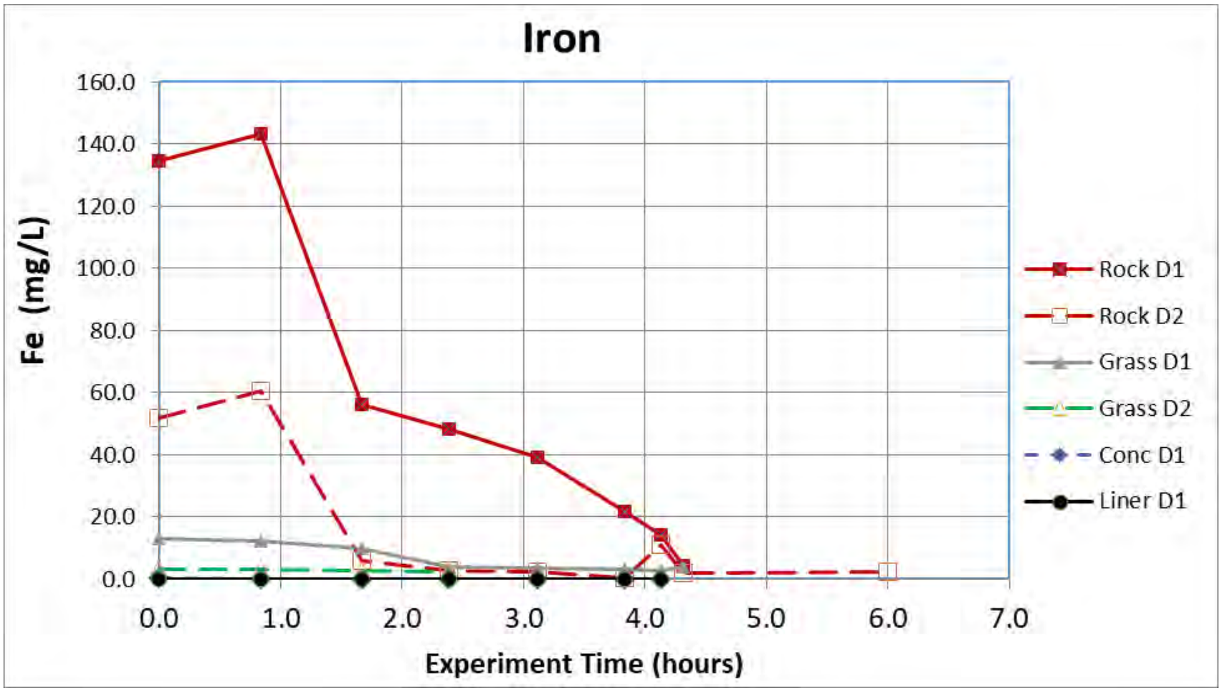

Figure 3.9. Runoff dissolved iron (mg/L) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

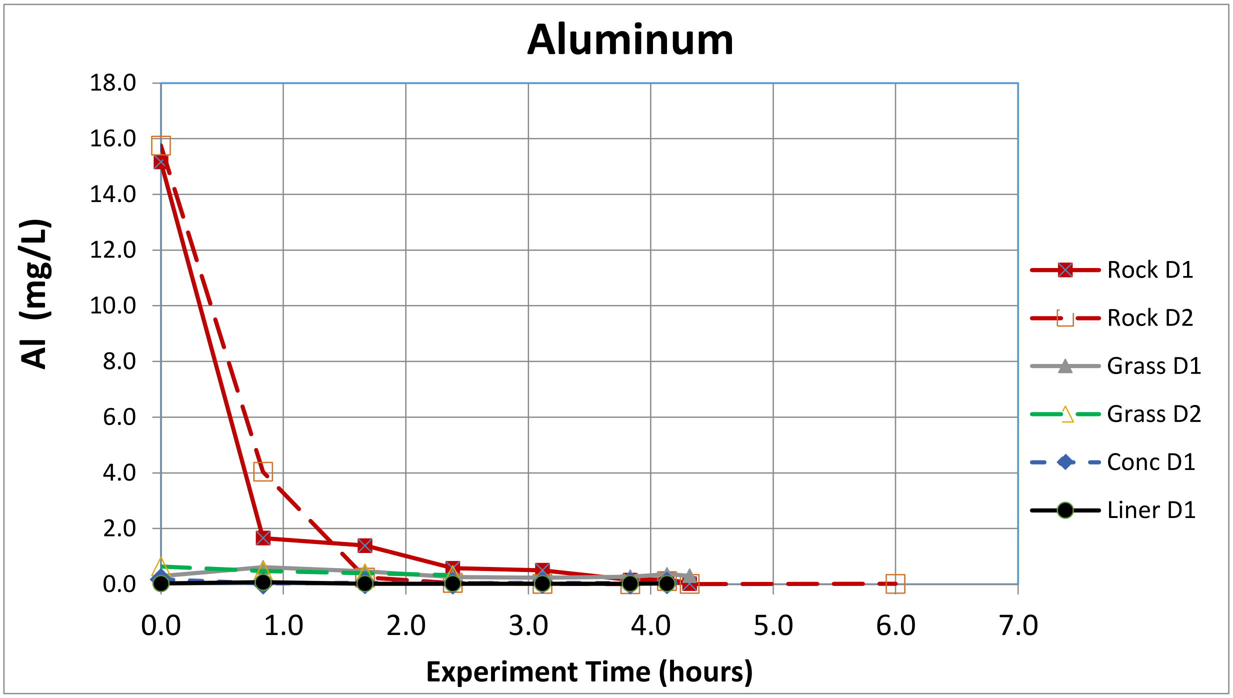

Figure 3.10. Runoff dissolved aluminum (mg/L) from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner) for day 1 (D1) and day 2 (D2).

Table 3.2. Summary of runoff chemistry from rainfall simulator experiments for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner). Water chemistry from the tank source was reported (Pool). Summary reported as the range (maximums and minimums).

Chemical Parameter	**Runoff per Control, Treatment, and Water Source**				
	Rock	**Grass**	**Conc**	**Liner**	**Pool**
Conductivity (µS/cm)	95.5 – 2273.8	951.8 - 1354.2	266.5 – 916.8	225.7 – 246.1	216.0 -239.3
pH [units]	3.47 – 5.95	6.51 – 6.84	8.44 -9.16	7.58 – 7.96	7.74 – 7.89
ANC (meq/L)	-0.25 – 0.03	1.72 – 3.03	1.28 – 1.97	1.28 – 1.40	1.21 – 1.43
Cl^-(mq/L)	19.2 – 32.9	108.6 - 250.13	16.5 – 22.2	15.9 - 18.3	13.1 – 18.8
SO_4^{2-}(mq/L)	203.9 – 903.1	144.2 – 295.1	13.1 – 179.3	12.5 – 25.6	10.8 - 13.8
NO_3^- (mq/L)	1.5 – 11.7	12.2 – 34.7	0.04 – 0.97	0.03 – 2.33	0.02 – 1.17
Sum AA (meq/L)	3.96 – 15.16	5.93 – 10.11	0.70 – 3.54	0.69 – 0.94	0.57 – 0.76
Na^+ (mq/L)	8.6 – 11.7	6.6 – 10.1	9.8 – 51.1	8.2 – 17.2	0.7 – 8.3
K^+ (mq/L)	2.1 – 4.2	172.5 -215.9	7.9 – 202.0	1.8 - 35.7	0.2 – 1.9
Mg^{2+} (mq/L)	13.5 – 33.7	12.5 – 22.9	4.38 – 7.29	5.32 - 6.77	0.59 -7.08
Ca^{2+} (mq/L)	38.8 – 72.6	59.4 – 90.2	19.1 – 26.7	24.7 – 27.3	2.35 – 25.49
Sum BC (meq/L)	3.54 – 6.88	8.88 – 11.77	2.20 – 9.10	2.25 – 3.33	0.21 – 2.20
Dis Al (mg/L)	0.03 – 15.17	0.24 – 0.61	0.03 – 0.17	0.02 - 0.07	0.00 – 0.02
Dis Cu (mg/L)	0.01 – 0.63	0.02 - 0.06	0.01 – 0.02	0.01 - 0.02	0.00 – 0.01
Dis Fe (mg/L)	4.13 – 143.50	2.59 – 13.04	0.01 – 0.22	0.00 – 0.04	0.00 – 0.01
Dis Mn (mg/L)	5.08 – 25.16	0.44 – 4.53	0.01 – 0.19	0.00 - 0.03	0.00 – 0.00
Dis Si (mg/L)	1.97 – 3.15	3.31 -10.36	3.30 – 12.51	2.71 – 6.58	0.00 - 2.60
Dis Zn (mg/L)	0.46 – 6.15	0.07 – 0.25	0.01 – 0.07	0.02 – 0.08	0.01 - 0.06
Dis Cd (mg/L)	0.000 - 0.001	0.001 – 0.002	0.001 -0.001	0.001 -0.001	0.001 – 0.001
Dis Ni (mg/L)	0.33 – 3.07	0.04 – 0.13	0.00 – 0.00	0.00 – 0.00	0.00 – 0.00

Sum AA = sum of acid anions; Sum BC = sum of base cations; Dis = dissolved

3.3.2 Natural Rainfall Monitoring

In general, the runoff chemistry from the pyrite rock panel (control) and three treatments: soil/vegetation (turf grass), shotcrete, and geoliner did not significantly change over the six month (June – December 2016) monitoring periods (Figures 3.11-3.19). In addition, the runoff chemistry was variable over this period (Table 3.3). The runoff pH remained low between 3.00 and 3.74 during this six-month period indicating that freshly exposed pyrite rock will take a longer time period to reach a condition where the surface pyrite has completely oxidized. The rain water pH was above 6 for most storm events. The runoff pH from the soil/vegetation (turf grass) treatment generally ranged between 5 and 6, and it was above 6 for the shotcrete and geoliner treatments. Though runoff sulfate remained constant over the six-month period, it declined significantly for the soil/vegetation treatment. Related to the decline in sulfate, conductivity and sum of acid anions also declined. Sulfate was likely a fertilizer additive to the turf grass sod (soil/vegetation treatment), and was it was depleted after about three months. Sum BC for the turf declined over the monitoring period which was likely due to calcium depletion from lime additions to the turf grass soil. As observed with the simulated rainfall experiments, complex biogeochemical; processes occurred and further study is needed to assess how soil/ vegetation can be used as a treatment for road cut sites through pyritic rock formations.

Statistical analysis to determine whether there was a significance difference among the pyrite rock control and three treatments: soil/vegetation (turf grass), shotcrete, and geoliner used a

Table 3.3. Summary of runoff chemistry from natural rainfall from June to December 2016 for the exposed pyrite rock control (Rock), and treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner). Water chemistry of the rain water was also reported (Rain). Summary data reported as the average, standard deviation (StDev), and range (maximums and minimums).

Chemical Parameter	**Runoff per Control, Treatment, and Rain**				
	Rock	**Grass**	**Conc**	**Liner**	**Rain**
Conductivity (µS/cm)	891.4 (436.2) 163.2 – 1740.0	558.8 (571.9) 115.8 – 2360.0	122.1 (130.5) 7.5 – 614.0	14.6 (15.5) 0.8 – 55.3	18.9 (20.8) 1.2 – 75.5
pH [units]	**3.29** (0.18) 3.00 – 3.74	**5.58** (0.62) 4.71 – 6.58	**6.95** (0.39) 5.95 – 7.74	**6.29** (0.39) 5.24 – 7.00	**6.34** (0.31) 5.89 – 6.96
ANC (meq/L)	1.43 (6.25) -18.81 – 12.92	-0.43 (4.89) -17.53 – 9.64	1.03 (1.19) 0.07 – 5.61	0.22 (0.54) -0.01 – 2.53	0.43 (0.90) -0.01 – 3.49
Cl^-(mq/L)	1.98 (4.28) 0.10 – 20.68	45.88 (57.92) 2.53 – 219.19	6.26 (26.69) 0.03 – 131.39	1.55 (5.48) 0.06 – 27.00	1.22 (3.13) 0.03 – 12.15
SO_4^{2-}(me/L)	1.95 (1.86) 0.19 – 6.86	69.11 (89.89) 7.53 – 420.42	2.49 (6.19) 0.05 – 30.81	1.06 (1.03) 0.04 – 4.17	7.64 (22.71) 0.21 – 88.78
NO_3^- (mq/L)	99.20 (88.29) 35.61 – 351.79	395.76 (337.29) 48.97 – 1580.58	22.50 (27.76) 1.83 (138.27)	1.50 (2.34) 0.14 – 9.64	4.92 (12.18) 0.23 – 47.60
PO_4^{3-}(mg/L)	0.25 (0.32) 0.03 – 1.13	1.66 (4.25) 0.00 – 16.31	0.07 (0.21) 0.00 – 0.74	0.02 (0.03) 0.00 – 0.09	0.02 (0.02) 0.00 – 0.06
Sum AA (meq/L)	6.45 (5.50) 0.28 – 25.70	4.40 (4.98) 1.05 – 20.75	0.58 (1.39) 0.03 – 6.58	0.10 (0.20) 0.01 – 0.91	0.27 (0.76) 0.01 – 2.96
Na^+ (mq/L)	1.93 (1.49) 0.02 – 3.84	2.26 (4.51) 0.27 – 21.02	3.00 (3.38) 0.00 – 15.72	0.41 (0.54) 0.04 – 2.65	0.55 (0.80) 0.00 – 3.20
K^+ (mq/L)	0.54 (0.85) 0.04 – 3.97	13.15 (11.37) 9.83 – 32.94	11.23 (9.90) 0.11 – 44.89	0.51 (1.09) 0.01 – 5.03	0.88 (1.87) 0.03 – 5.51
Mg^{2+} (mq/L)	17.74 (13.58) 2.77 – 51.33	14.64 (13.27) 3.99 (61.20)	4.09 (7.85) 0.04 – 31.39	0.24 (0.36) 0.05 – 1.59	0.71 (1.45) 0.01 – 5.58
Ca^{2+} (mq/L)	19.18 (23.55) 3.92 – 101.32	37.38 (35.79) 10.84 – 148.27	13.39 (21.74) 0.88 – 95.90	5.08 (13.30) 0.46 – 62.11	11.28 (28.30) 0.10 – 110.63
Sum BC (meq/L)	2.51 (1.71) 0.43 – 5.84	3.51 (2.84) 1.36 – 13.36	1.42 (1.86) 0.05 – 8.10	0.30 (0.73) 0.05 – 3.40	0.67 (1.61) 0.01 – 3.49
Dis Al (mg/L)	18.18 (15.60) 0.00 – 59.21	0.63 (0.38) 0.07 – 1.58	0.03 (0.02) 0.01- 0.05	0.01 (0.01) 0.00 – 0.06	0.04 (0.05) 0.00 – 0.13
Dis Cu (mg/L)	0.58 (0.62) 0.07 – 2.56	0.02 (0.02) 0.01 – 0.11	0.01 (0.01) 0.00 – 0.04	0.01 (0.01) 0.00 – 0.02	0.01 (0.02) 0.00 – 0.06
Dis Fe (mg/L)	76.38 (70.12) 10.41 – 284.27	2.64 (1.99) 0.49 – 8.71	0.29 (0.31) 0.02 – 1.04	0.06 (0.10) 0.00 – 0.40	0.22 (0.34) 0.00 – 0.99
Dis Mn (mg/L)	12.25 (11.25) 1.23 – 45.40	2.86 (2.36) 1.16 – 10.78	1.28 (4.43) 0.01 – 20.49	0.01 (0.02) 0.00 – 0.06	0.02 (0.03) 0.00 – 0.08
Dis Si (mg/L)	0.84 (0.65) 0.20 – 3.08	2.17 (1.14) 0.86 – 5.20	1.87 (1.38) 0.59 – 7.05	0.06 (0.09) 0.00 – 0.41	0.23 (0.64) 0.00 – 2.51
Dis Zn (mg/L)	1.55 (1.61) 0.19 – 6.30	0.16 (0.15) 0.05 – 0.62	0.03 (0.06) 0.00 – 0.24	0.02 (0.04) 0.00 – 0.13	0.01 (0.01) 0.00 – 0.04
Dis Cd (mg/L)	0.00 (0.00) 0.00 – 0.00	0.00 (0.00) 0.00 – 0.00	0.00 (0.00) 0.00 – 0.00	0.00 (0.00) 0.00 – 0.00	0.00 (0.00) 0.00 – 0.00
Dis Ni (mg/L)	1.04 (0.94) 0.14 – 3.85	0.06 (0.06) 0.02 – 0.26	0.02 (0.06) 0.00 – 0.27	0.00 (0.00) 0.00 – 0.00	0.00 (0.00) 0.00 – 0.01

Sum AA = sum of acid anions; Sum BC = sum of base cations; Dis = dissolved single-factor ANOVA for the tested parameters, pH, conductivity, ANC, sum of acid anions, sum of base cations, sulfate, dissolved iron, and dissolved aluminum. All ANOVA tests were significantly different ($p < 0.001$).

The chemical parameters pH, conductivity, ANC, sum of acid anions, sum of base cations, sulfate, dissolved iron, and dissolved aluminum were significantly different between the pyrite rock control and the three treatments using a statistical t-test with no exceptions (Table 3.4). Conductivity and sum of base cations between pyrite rock control and soil/vegetation were not significantly different. Both the control and the treatment had high concentrations of calcium for the control and soil/vegetation treatment compared with the shotcrete and geoliner treatments and rain water (Table 3.3). Runoff from the geoliner treatment and rain water were essentially the same water therefore no significant difference occurred for most chemical parameters, except dissolved metals were found to be different. These two dissolved metals were likely found to be significantly different due to the low concentrations of the metals and low variance. There also was a lack of significant differences for sulfate and sum of acid anions for treatments pairs: shotcrete and rain water, and shotcrete and geoliner. Overall, the results indicate that shotcrete and geoliner are effective treatment measures to prevent runoff acidification, and the soil/ vegetation (turf grass sod) needs further study.

Table 3.4. Statistical results for runoff treatment/control/rain pairs using a t-test for chemical parameters from the natural rainfall events from June – December 2016. Control = pyrite rock (Rock), Treatments = soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

Control/Treatment/ Rain Pairs		**Chemical Parameter: Statistical Test Significance Level**						
		pH	**Cond**	**Sum AA**	**Sum BC**	**Sulfate**	**Dis Fe**	**Dis Al**
Rock	Grass	< 0.001	0.016	0.003	0.206	< 0.001	< 0.001	< 0.001
Rock	Conc	< 0.001	< 0.001	< 0.001	0.004	0.008	< 0.001	< 0.001
Rock	Liner	< 0.001	< 0.001	< 0.001	< 0.001	0.025	< 0.001	< 0.001
Rock	Rain	< 0.001	< 0.001	< 0.001	< 0.001	0.011	< 0.001	< 0.001
Grass	Conc	< 0.001	0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Grass	Liner	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Grass	Rain	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Conc	Liner	< 0.001	< 0.001	0.063	0.001	0.285	0.002	0.006
Conc	Rain	< 0.001	< 0.001	0.197	0.003	0.159	0.286	0.162
Liner	Rain	0.396	0.256	0.195	0.174	0.299	0.047	0.034

Cond = Conductivity; Sum AA = sum of acid anions; Sum BC = sum of base cations; Dis Fe = dissolved iron; Dis Al = dissolved aluminum

3.3.3 Relationships between Runoff Chemistry and Natural Rainfall Volumes

Because of the importance of understanding the potential acidification of runoff from exposed pyrite rock two additional analyses were conducted with water chemistry from the control panel. The two analyses included 1) examining the influence of rainfall magnitude on runoff chemistry for pH, conductivity, sulfate and iron; and 2) the influence of dry days between storm events on runoff chemistry. A summary of rainfall depth and runoff volumes for the control panel and treatments is in Table 3.5. As the magnitude of the storm event increases, there were general trends of increased pH, decreased conductivity and dissolved iron, and

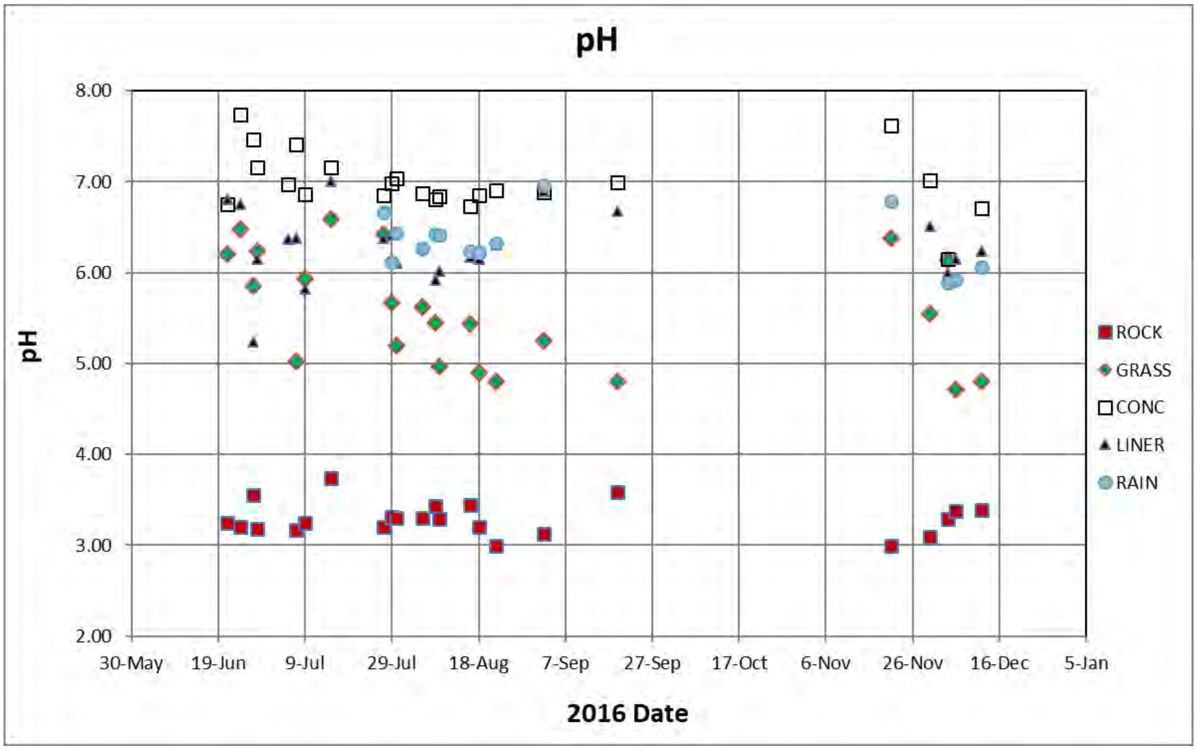

Figure 3.11. Runoff pH from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

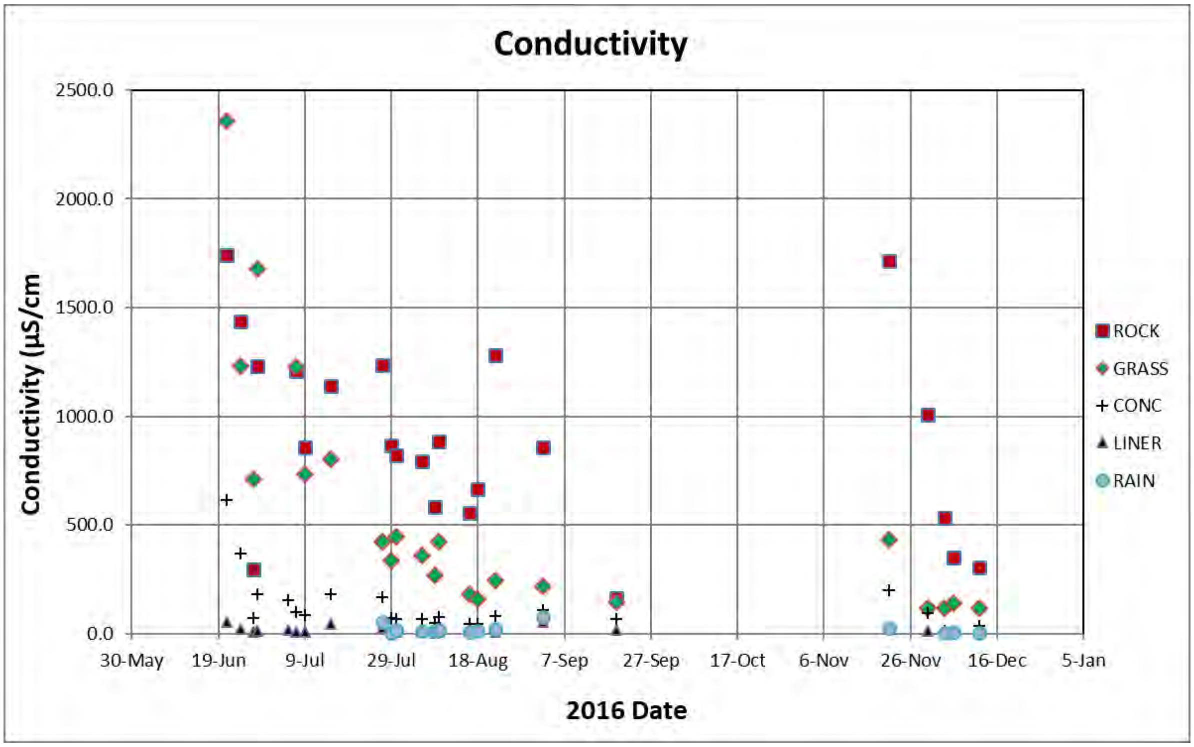

Figure 3.12. Runoff conductivity (µS/cm) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

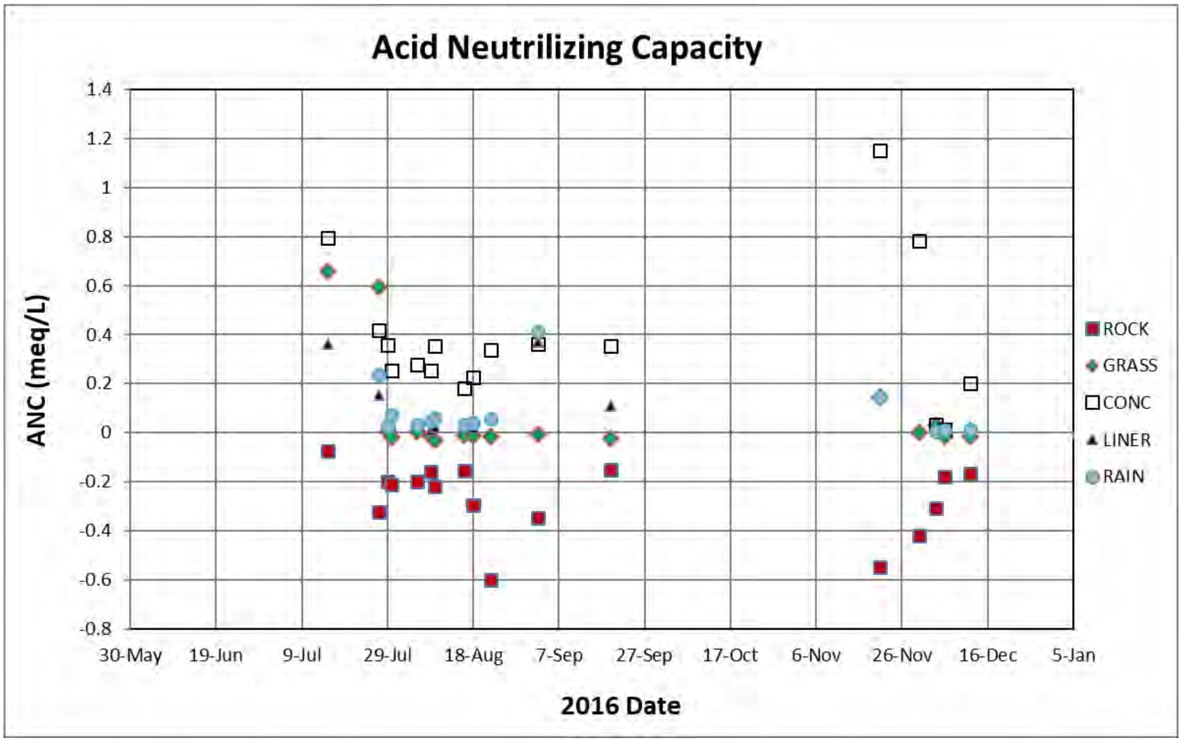

Figure 3.13. Runoff ANC (meq/L) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

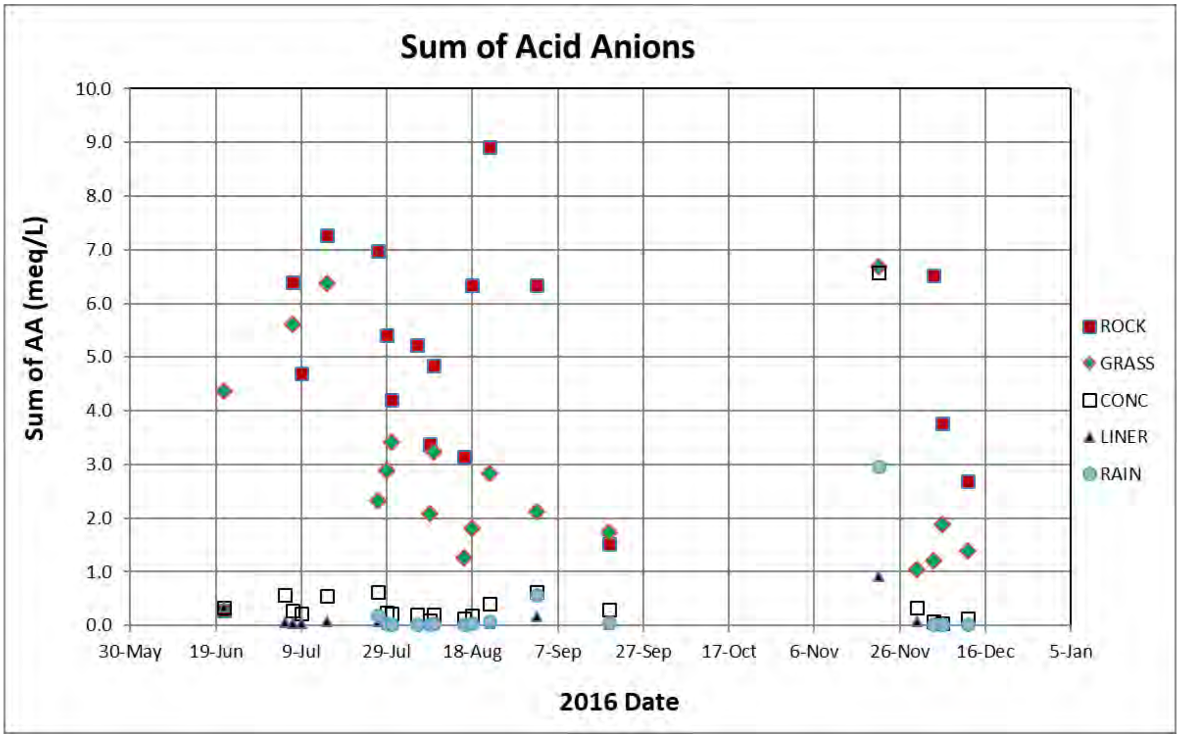

Figure 3.14. Runoff sum of acid anions (meq/L) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

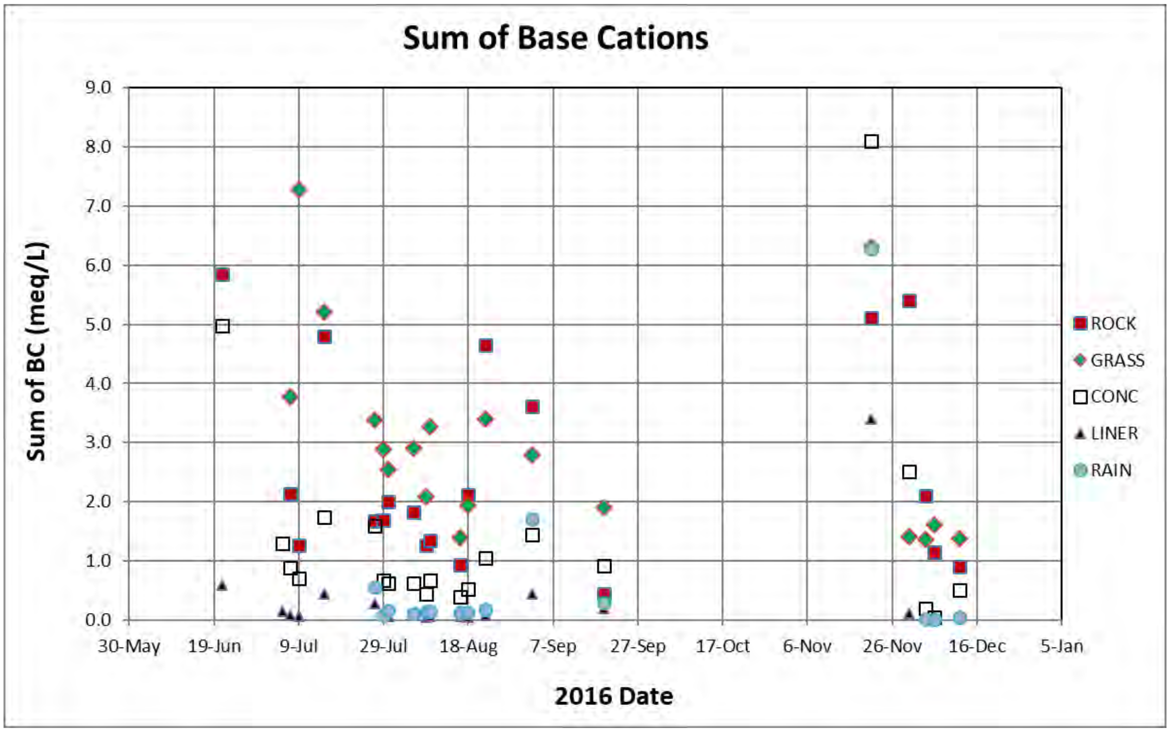

Figure 3.15. Runoff sum of base cations (meq/L) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

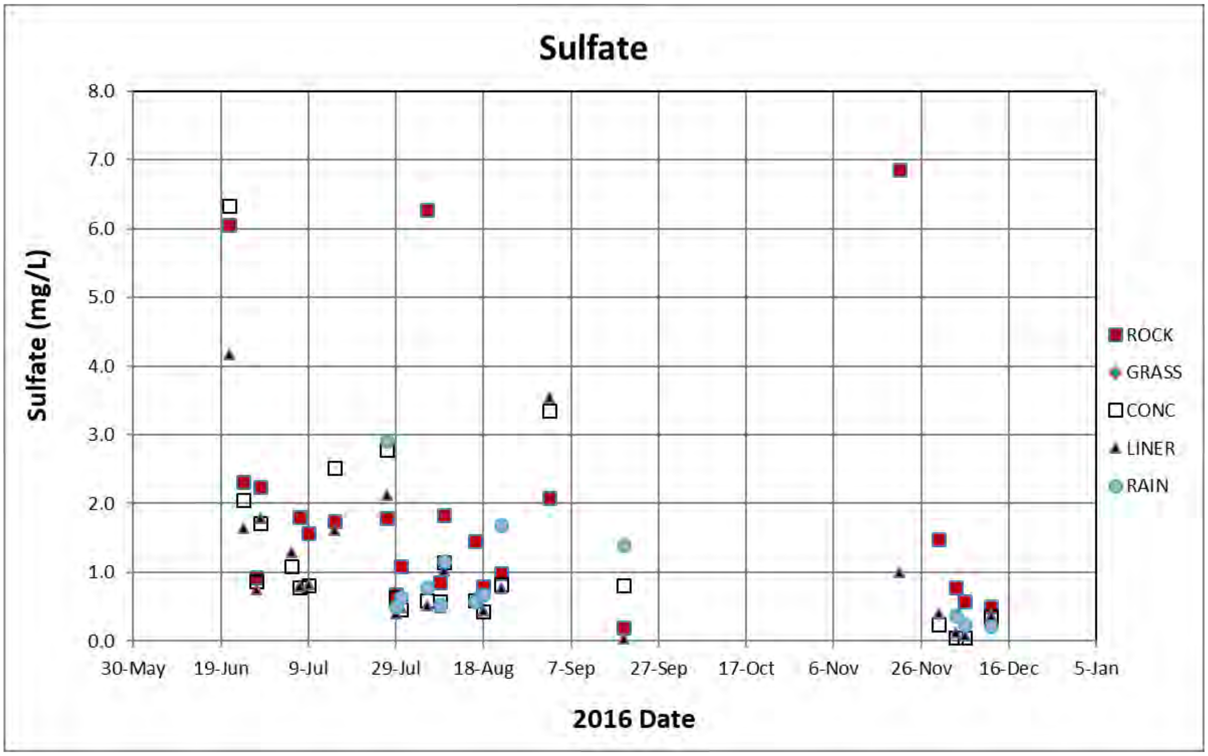

Figure 3.16. Runoff sulfate (mq/L) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

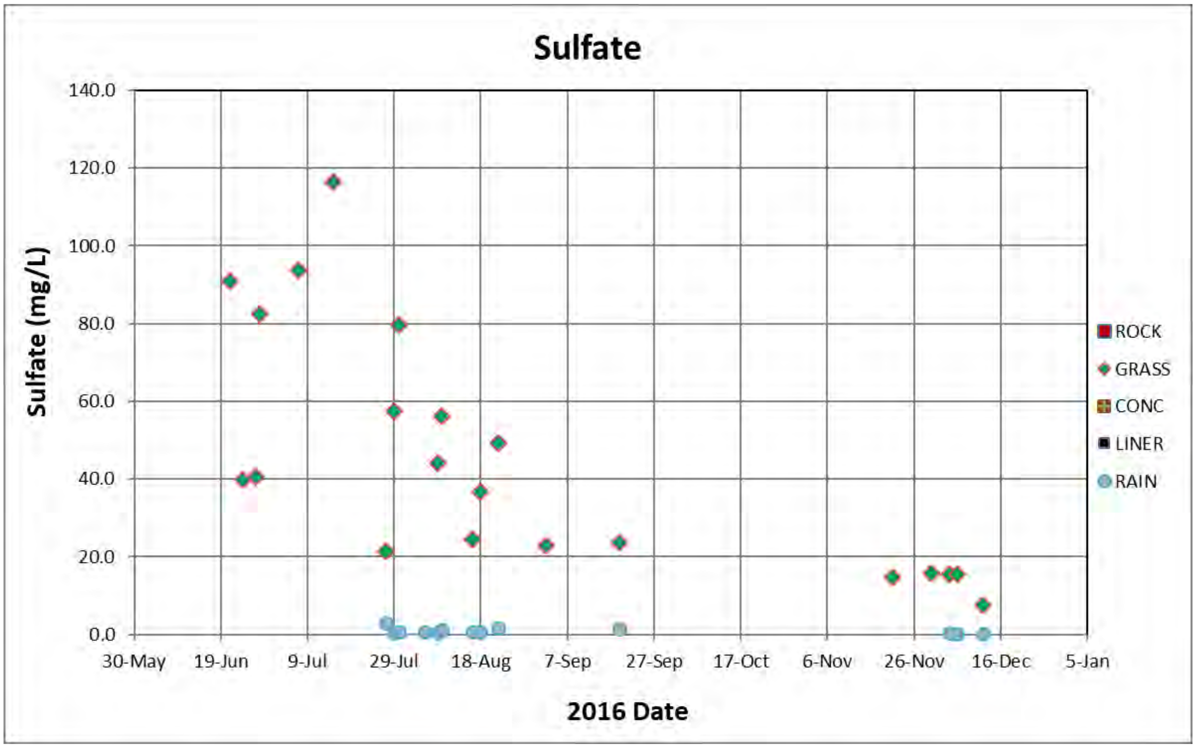

Figure 3.17. Runoff sulfate (mq/L) from natural rainfall (June – December 2016) for the treatment soil/vegetation (Grass),and rain water (Rain).

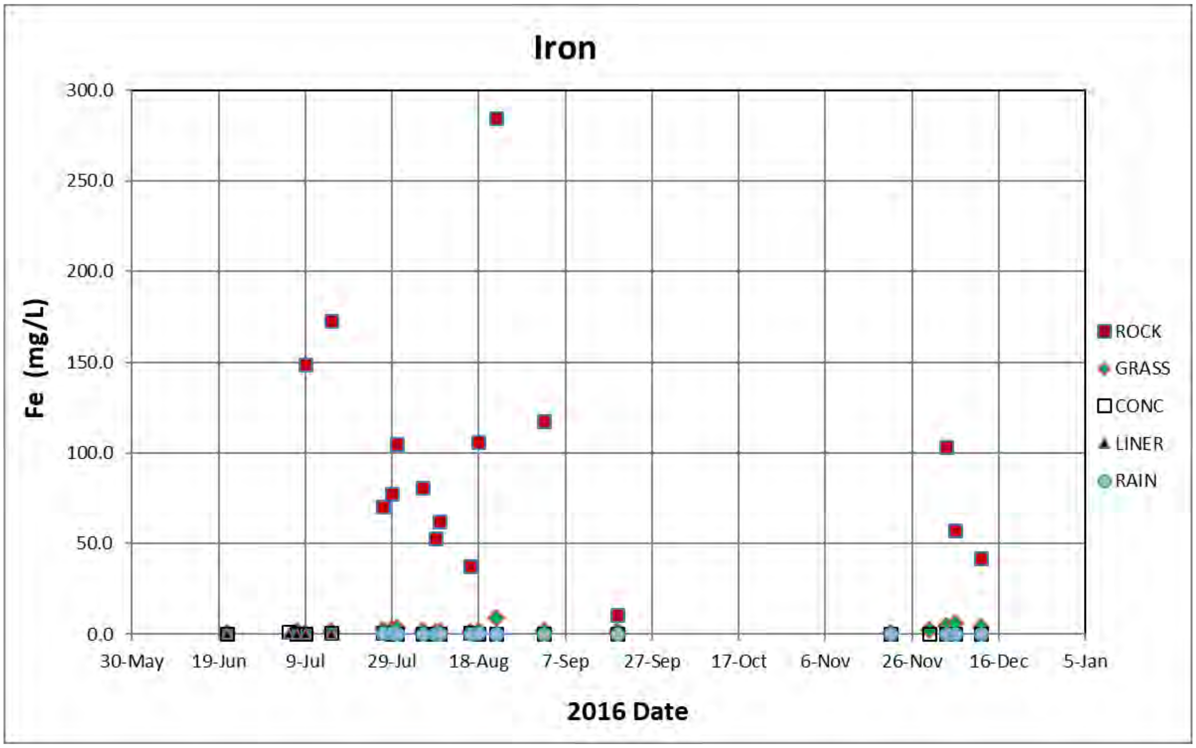

Figure 3.18. Runoff dissolved iron (mq/L) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

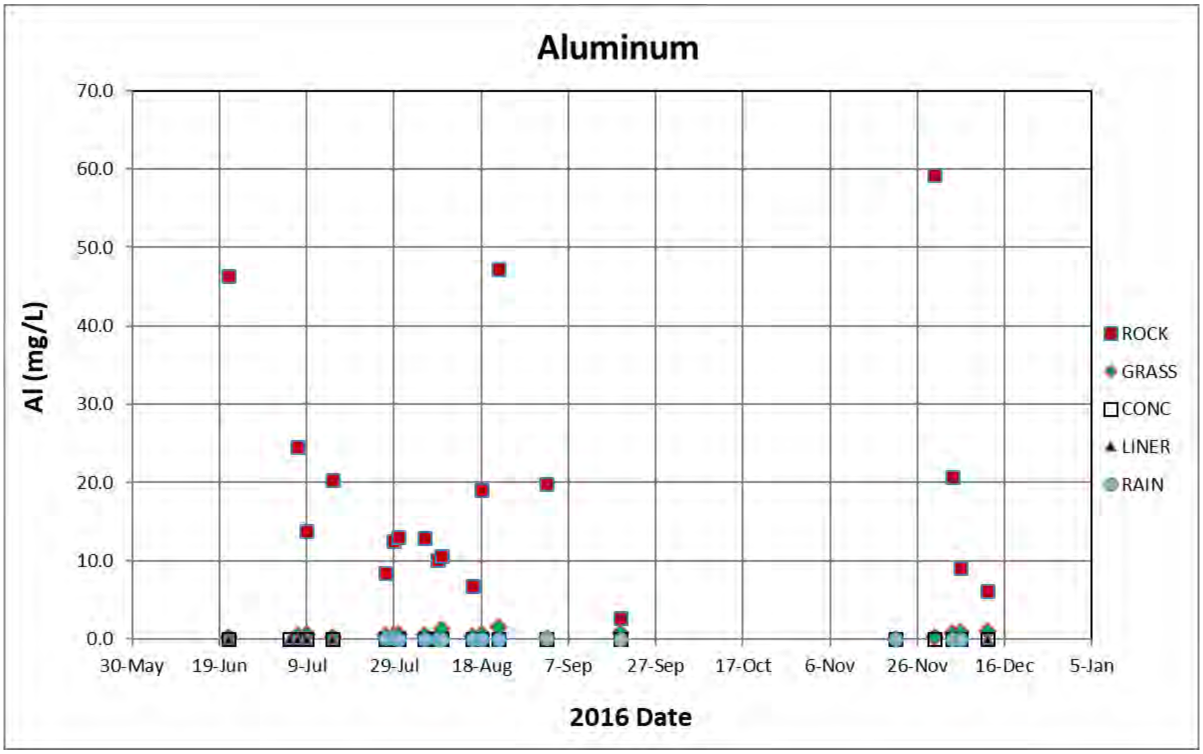

Figure 3.19. Runoff dissolved aluminum (mq/L) from natural rainfall (June – December 2016) for the exposed pyrite rock control (Rock), treatments: soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner), and rain water (Rain).

variable trend for sulfate (Figure 3.20). No correlations were found between number of dry days between storm events and runoff chemistry. In general, there appears to be a limit to the amount of ion mass loading that can be washed off for a storm event; therefore a dilution effect occurs for larger storm events.

3.4 Discussion and Conclusion

In this study, runoff from simulated and natural rainfall onto exposed pyrite rock and three material "treatment" covers were collected and chemically analyzed to assess their performance to reduce to eliminate acidification. The exposed pyrite rock was used as the experimental control, but also provided valuable information as to how long would exposed "freshly cut" pyrite rock would generate acidity and changes based on different magnitude storm events. The "freshly cut" pyrite rock represents a road cut with newly exposed surfaces. In this experiment, Anakeesta rock from a landslide on Clingman's Dome Road in the Great Smoky Mountains National Park was collected the day of the landslide on May 28, 2015. The rock was stored in a cold, dry indoor location at the University of Tennessee until the experimental set-up could be constructed, and the experiments implemented. The material covers selected for this study included soil/vegetation, shotcrete, and a geosynthetic membrane liner, which are three of the feasible covers that could be incorporated into roadway design if necessary. An experiment using constructed panel containers testing these covers for effects on runoff water quality had not be conducted before by others so it offers new information to better understand how runoff from road cut sites through pyritic rock could be managed for protection of receiving surface waters.

Table 3.5. A summary of storm events for the natural rainfall monitoring between June – December 2016 consisting of storm event depth (inch) and estimated runoff volumes for the pyrite rock control panel (Rock) and three treatments soil/vegetation (Grass), shotcrete (Conc), and geoliner (Liner).

Storm Event		Rainfall Depth (inch)	Runoff Volumes (ft^3) for Control/Treatments			
No.	**2016 Date**		**Rock**	**Grass**	**Conc**	**Liner**
1	June 21	0.05	0.031	0.015	0.022	0.048
2	June 24	0.32	0.292	0.171	0.142	0.242
3	June 27	1.54	1.470	0.876	0.684	1.118
4	June 28	0.20	0.176	0.101	0.088	0.155
5	July 5	0.54	0.504	0.298	0.240	0.400
6	July 7	1.25	1.190	0.709	0.555	0.910
7	July 9	0.79	0.746	0.443	0.351	0.579
8	July 15	0.24	0.215	0.125	0.106	0.184
9	July 27	0.27	0.244	0.142	0.120	0.206
10	July 29	0.73	0.688	0.408	0.324	0.536
11	July 30	0.34	0.311	0.182	0.151	0.256
12	August 5	1.16	1.103	0.657	0.515	0.845
13	August 7	0.07	0.050	0.026	0.031	0.062
14	August 8	1.77	1.692	1.009	0.787	1.284
15	August 9	0.50	0.466	0.275	0.222	0.371
16	August 16	1.93	1.847	1.102	0.858	1.399
17	August 18	1.14	1.084	0.645	0.507	0.831
18	August 22	0.38	0.350	0.205	0.169	0.285
19	Sept. 2	0.15	0.128	0.072	0.066	0.119
20	Sept. 19	0.88	0.833	0.495	0.391	0.644
21	Sept. 27	0.16	0.137	0.078	0.071	0.127
22	Nov. 21	0.18	0.157	0.090	0.080	0.141
23	Nov. 30	4.77	4.589	2.745	2.121	3.440
24	Dec. 4	1.12	1.064	0.633	0.498	0.817
25	Dec. 6	1.63	1.557	0.928	0.725	1.183
26	Dec. 12	1.04	0.987	0.587	0.462	0.759

The simulated rainfall experiment applied an intensity of 0.21 inch/hour equivalent to a 1-yr, 24-hr return frequency (for the Knoxville area) in order to observe rapid changes in runoff chemistry within a few hours of a storm event start. Runoff acidification occurred from the exposed pyrite rock panel with the initial pH measured as about 3.6, and increased to about 6.0 within four hours (Figure 3.3). Because the pyrite rock lacked base cations (Figure 3.5), ANC remained about 0 meq/L throughout the simulated rainfall period (Figure 3.4). After one day rest, reapplication of simulated rainfall found that once exposed to air rapid oxidation occurred with the initial pH measured at about 3.6 as the day before. However, the day 2 simulation observed the pH over time to increase to 6.0 more quickly within two hours. Sulfate export from the rock surface was the major driver for runoff acidification, where the pattern of initially high concentration followed a declining concentration over the simulated time mirroring the inverse of the pH pattern (Figure 3.7). Conductivity in this experiment was likely controlled by sulfate

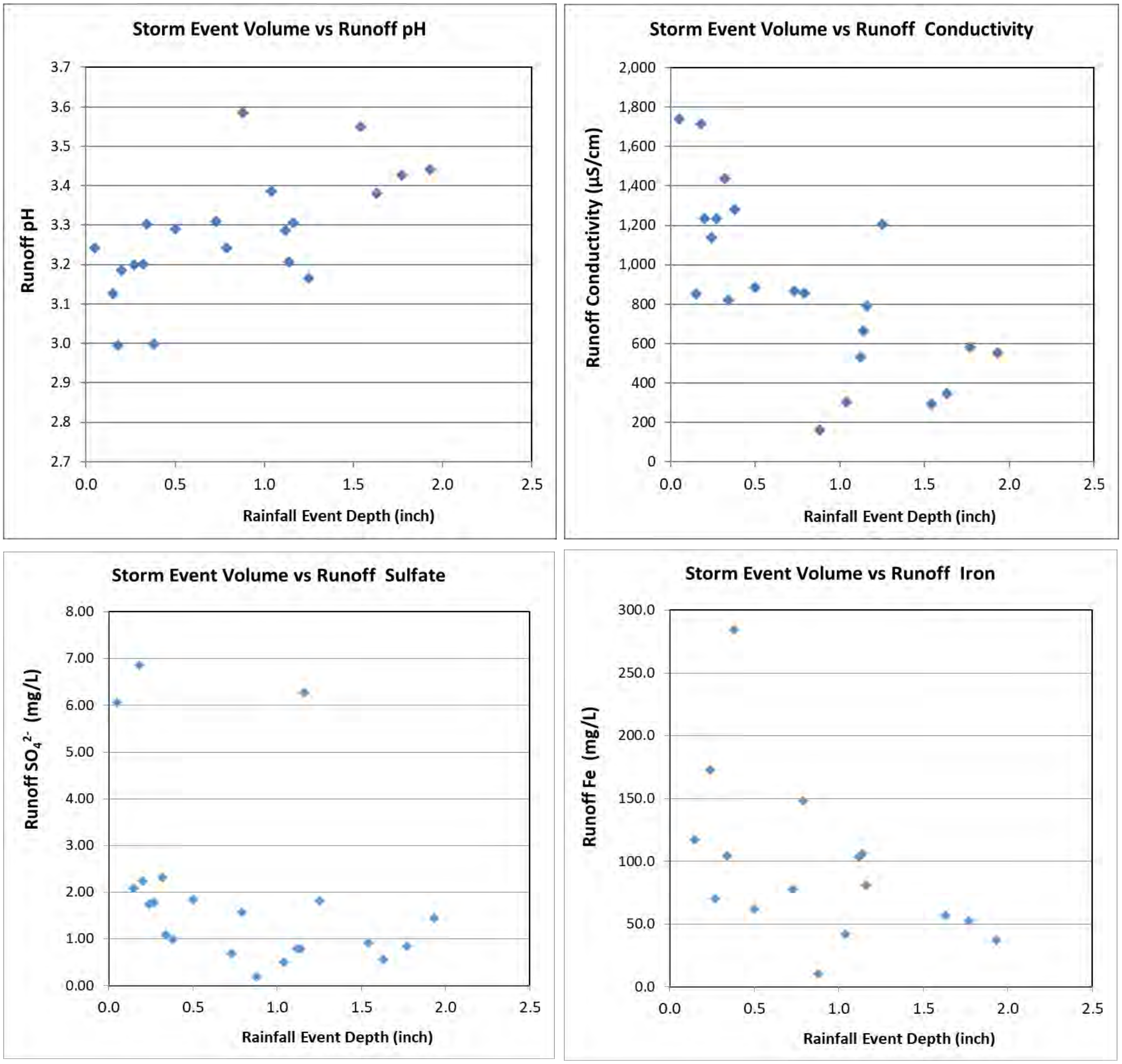

Figure 3.20. Plots of storm event magnitude (depth, inch) from the pyrite rock control panel and chemistry for pH, conductivity (µS/cm), sulfate (mg/L), and dissolved iron (mg/L).

concentrations since the same pattern of decline over the simulated rainfall period (Figure 3.8). Dissolved metals declined rapidly with the first two hours from the start of the simulated rainfall experiment (Figures 3.9 and 3.10, Table 3.2). It appears there is a “first flush” and dilution effect that occurs on the pyrite rock surface. Chemical oxidation and weathering at the surface provides for a metal ion source but that source is rapidly depleted thereby diluting the runoff.

Results of the simulated rainfall experiments demonstrated the available ions that can cause runoff acidification occurs over a short period of time, and as rainfall continues during a storm event a dilution effect occurs from the depletion of available sulfate ions. In addition, pyrite rock appears to have limited base cations to neutralize the initial acidification effect at the start of a storm event. The experiment also demonstrated that the pyrite rapidly oxidizes under exposed air and makes available more sulfate within a day, however the availability of ions may be more limited. The statistical analysis that examined whether there was an effect on the number of days on runoff chemistry found no effect. This finding suggests pyrite oxidation and availability of sulfate for runoff acidification is surface area dependent. Once the initial rock surface has been washed of ions, there must be a period in which it is exposed to air to regenerate the ion source for the next storm. The experiment with natural rainfall monitoring provides further information on a longer term perspective to availability of sulfate and other ions. From an environmental impact perspective primarily aluminum due to its toxicity on aquatic biota, the fact that oxidation and weathering limits metal ion source and dilution occurs relatively quickly is beneficial. Within one hour, the aluminum concentration fell below the toxic levels reported at 2.0 mg/L (Figure 3.10). In addition the pH increased above 6 within four hours.

The material "treatment" covers using shotcrete and geoliner were effective preventing acidification of the runoff from the experimental panel containers (Figures 3.3-3.10). The results from the soil/vegetation cover using turf grass sod were mixed but generally demonstrated that that cover could be effective in reducing runoff acidification. However, results were mixed likely due to applied fertilizers on the sod consisting of nitrogen, phosphorous, potassium, and sulfur. In addition, the sod was likely limed with pulverized dolomite (calcium and magnesium) to control soil pH. With these additives, several biogeochemical processes co-occur including mineralization and nitrification, sulfate adsorption, cation/metal exchange, vegetation update of nitrate, and base cation weathering (Nodvin et al. 1986; Lindberg and Lovett 1992; Manning et al. 1996; Blake et al. 1999; Dubikova et al. 2002; Tipping et al. 2003; Cai et al. 2011a). Therefore, these results from this treatment needs to be carefully assessed and further experimentation is needed with a study design that controls for different chemical soil additives.

The monitoring of the natural rainfall for the additional six months after the simulated rainfall experiments found that the pyrite rock (experimental control) panel acidification of runoff continued for the long- term. The runoff pH remained between 3 and 4 (Figure 3.11). ANC also remained low during this monitoring period reported as less than 0 meq/L (Figure 3.13). As observed with the simulated rainfall experiment, runoff acidification was dominated by acid anions primarily sulfate (Figures 3.14-3.16). Elevated levels of dissolved iron and aluminum were observed for the runoff from the exposed rock caused by pyrite oxidation and Anakeesta shale weathering. The runoff chemistry from the exposed pyrite rock was statistically different from rainwater chemistry indicating the rock affected the runoff water quality, apparently for a period at least six months in duration (Table 3.4). A dilution effect was also observed where pH increased with storm event size (rainfall depth), and conductivity, sulfate, and dissolved iron decreased (Figure 3.20). With the information from the simulated rainfall experiments it appears that there is a limited availability of sulfate to cause runoff acidification. This dilution effect was also observed with coal-refuse deposits and exposed shales (Olyphant et al. 1991; Tuttle et al. 2009). It should be noted that that these experiments were for a condition with only pyritic rock. In contrast to the Tennessee characterization study (Chapter 2), it was observed that if other geologic formations and site soils are adjacent to the exposed pyritic formation they contribute to base cations to runoff reducing acidification. However, if a material cover is needed it appears that shotcrete and a geoliner would be effective to exposing pyritic rock to rainfall and generating acidified runoff. The use of a soil/vegetation cover needs further study, but appears it could be effective if soil fertilizers were adequately controlled and managed for the long-term. Overall, this study provides alternatives for TDOT if control of acidified runoff is needed. The potential for treatment of acidified runoff in the drainage below the road cut is reviewed in the next chapter (Chapter 4).

4. Passive Water Quality Treatment Options at Road Cuts through APM

4.1 Introduction

Guidelines on addressing the environmental impacts from acid material drainage (AMD) at road cut construction sites were developed and published by TDOT with Golder Associates (TDOT 2007). The guidance document "*Guidelines for Acid Producing Rock Investigation, Testing, Monitoring and Mitigation*" was comprehensive and focused on testing, handling, and disposal during highway construction. The TDOT (2007) document also summarized water treatment options for post-construction mitigation of the site runoff. In general, treatment of AMD has been extensively studied primarily addressing the impacts of surface mining in the Appalachian region and other regions of the world with similar geologic formations with pyrite. A list of relevant cited literature is summarized in Section 4.3 below. If runoff quality exceeds levels that may be harmful to aquatic biota (Appendix E) or impacts a public water supply, there may be a need for treatment of AMD from road cuts.

The objective of this task consists of a summary literature review of different runoff treatment options from road cut sites through pyritic rock formations, and an introductory assessment of what treatment options would perform sufficiently with the new knowledge gained from this study's road-cut characterization of runoff chemistry and performance cover treatments (Chapters 2 and 3). The literature review focused on previous work on AMD from highway projects, which are more relevant to the challenges faced by TDOT based on typical topography and right of way constrains in regions with APM. The potential treatment options relevant to these highway construction constraints are summarized in Section 4.2 below.

4.2 Potential Treatment Options

Water treatment of AMD has been developed for both active and passive systems (TDOT 2007). Both systems utilize aggregate carbonate to neutralize the pH and encourage metals precipitation as hydroxides or sulfide minerals (Taylor et al. 2005). Active systems consisted of chemical treatment requiring mechanical infrastructure and their use generally is for highly populated acidic waters with elevated levels of dissolved metals and sulfate. Passive treatment systems are best suited for AMD with low acidity (< 800 mg $CaCO_3$ /L) and low flow rates (< 50 L/s). Therefore, mass loadings from road cut sites should be less than about 100 to 150 kg $CaCO_3$ /day. Relevant to highway runoff from road cuts through pyritic rock are passive systems. In the TDOT (2007) documents several passive treatments were identified as preferred treatment methodologies because of ease of construction, low maintenance, and treatment longevity. They were:

- Limestone beds and oxic/open channels
- Aerobic wetlands
- Settling ponds
- Bio-reactors
- Pebble quicklime

Other identified passive treatments included: vertical flow ponds, oxic limestone drains, anaerobic wetlands, and chemical addition of bases, i.e., caustic soda, soda ash, ammonia, and hydrated lime. Others have reported the addition of organic matter to provide alkalinity, enhance metals adsorption, and create redox reducing conditions which favor precipitation of sulfide minerals (Taylor et al. 2005). In order to design these passive treatment systems, a public domain software package is available termed AMD Treat©. Version 5.0.2 Plus can be downloaded from the following web site: https://amd.osmre.gov/downloads.htm.

In order to design any treatment system the acidity loading most be computed (Taylor et al. 2005). Acidity is the measure of both hydrogen ion concentration and mineral acidity. Mineral or latent acidity includes the potential concentration of hydrogen ions produced by precipitation of metal hydroxides in the water, which reactions are pH dependent. Acidity load refers to the total acidity and flow rate, which forms the measure of mass per time, or more specifically mass $CaCO_3$ equivalent per unit time (or given volume of pass-through water). The following equations can be used to estimate acidity and acidity loads:

$$\text{Acidity (mg/L CaCO}_3) = 50 \times \{3\times[\text{Fe}^{2+} + \text{Fe}^{3+}]/56 + 3\times[\text{Al}^{3+}]/27 + 2\times[\text{Mn}^{2+}]/55 + 1000\times10^{-(\text{pH})}\}$$

$$\text{Acidity Loads (tonnes CaCO}_3\text{ /day)} = 10^{-9} \times 86{,}400 \text{ (conversion factor)} \times \text{flow rate (L/s)} \times \text{Acidity (mg/L CaCO}_3)$$

Oxic/open Limestone Channels/Drains. Oxic/open limestone channels/drains (OLC) armor channels lined with coarse limestone and can be also designed with a series of check dams (Ziemkiewicz and Brant 1996; Cravotta and Trahan 1999; Taylor et al. 2005). Figure 4.1 shows an example of an OLC. OLC is a recommended passive treatment option if the ARD has a pH less than 5.0 and contains total iron less than 20 ppm. The coarse limestone allows for an increase in alkalinity of the water and can remove iron and aluminum via oxide and hydroxide precipitation. Calcium carbonate dissolution occurs over time, but its rate is pH dependent and a function of the precipitates that can coat or amour the limestone rock surface. The design goal is to maintain an adequate flow rate to flush precipitates through the porous spaces with continuous exposure of AMD influent with a minimum contact time of 1 to 3 hours. Channels should be constructed on the steepest possible gradient to maximize water velocity and thereby minimize armoring and plugging. However, slopes should not exceed 10º to maintain coarse aggregate stability. OLC is typically preceded by a retention pond capable of storing a 10-yr 24-hr precipitation event. The average acidity load entering an OLC should be less than 150 kg $CaCO_3$ /day, which can achieve a pH between 6 and 8. According to Skousen (2002), OLC can remove approximately 70% of the dissolved iron, 40-50% of the dissolved aluminum, and 10-20% of the dissolve manganese. The design life has been reported to be between 10 and 20 years (Ziemkiewicz et al. 2002). An example in Tennessee where an OLC has been used was at the Jamestown Study Sites 1 and 3 in Fentress County (Table 2.1). These treatment systems are likely the most applicable to highway construction and road cut locations because of the linear nature of the design and that of the roadway. Space permitting, a small settling pond improves overall performance by providing a location for metal precipitates to settle and makes maintenance less troublesome.

Aerobic Wetlands. Aerobic wetlands are shallow ponds that remain aerated with contact with air at the water surface (Figure 4.1). Wetlands can also be thought of as vegetated settling/ retention ponds that allow for sediment and metal-oxidized precipitates to settle. Aerobic wetlands are a recommended passive treatment option if the ARD has a pH greater than 5.0 and contains total iron greater than 20 ppm. Aerobic wetlands are best suited for the treatment of water with relatively low acidity but elevated ferrous iron concentration, which could be treated by allowing the ferrous iron to oxidize in the aerobic zones of the wetlands and precipitate as iron oxides. These treatment systems are complex with a multitude of biogeochemical and plant-mediated processes occurring that naturally improve water quality (Hedin et al. 1994; Kilborn

Figure 4.1. Example photos of an open limestone channel (top) and a vertical flow wetlands (bottom). Photos from Paul Ziemkiewicz, West Virginia University, 2002.

1999; Milavec 2002; Ziemkiewicz et al. 2002; Taylor et al. 2005). These processes include: sedimentation, filtration, oxidation, reduction, precipitation, adsorption, complexation, chelation, microbial conversion/ immobilization, and plant update of nutrients and metals. . Discharge to the aerobic wetland typically passes through a settling pond before entering the wetland. Hydraulic considerations are needed for designing the pond; typically pond sizing is based on maximum influent flows equating to a 10-yr 24-hr precipitation event. The purpose of the settling pond is to allow settling of iron precipitates and sediments before the flow enters the wetland. Vertical flow wetland design has been described by Kepler and McCleary (1997) to improve treatment performance. The average acidity load entering a wetland should be less than 1 kg $CaCO_3$ /300 m^2 water surface area, which can achieve a pH above 6 and dissolved iron removal between 60-95% (Taylor et al. 2005). Physical space for wetlands can be problematic for some highway projects.

Bio-reactors. Bio-reactors are anaerobic pass-through structures comprising of a substrate of organic matter and limestone aggregate. Bio-reactors are recommended passive treatment options for ARD with a total iron concentration of greater than 20 ppm. These treatment systems are typically vertical flow consisting of three layers from top to bottom: 1) ponded water; 2) limestone-buffered organic substrate; and 3) limestone. Iron, aluminum, and other heavy metals are removed via sulfide and hydroxide precipitation in addition to sorption to hydroxide surfaces and the organic substrate. Bio-reactors rely on sulfate-reducing bacterial activity in which organic matter (carbon) is used to converted sulfate into hydrogen sulfide which is a gas and needs to be ventilated off site. Metal concentrations can be decreased by precipitation of metal sulfides in the reduced anaerobic organic matter layer of the bio-reactor (Eager and Melchert 1992). With the addition of limestone layer, greater alkalinity can be generated to assist in increasing water pH. The life expectancy of these bio-reactors is controlled by the available organic matter. Thus bio-reactors may require more maintenance than the OLC and wetlands described above. In addition, routine nutrient supplements may be needed to achieve adequate microbial growth. The organic matter / limestone aggregate mix can become clogged, requiring maintenance by replacing the bio-reactor media. The average acidity load entering a bio-reactor should be less than 1 kg $CaCO_3$ /200-500 $m^2 \cdot$ day, which can achieve a pH between 6 and 8 (Kilborn 1999). Dissolved oxygen concentrations should remain below 1 mg/L. The location of the bio-reactors should be well ventilated because of odor issues associated with hydrogen sulfide gas. Flow rates through the reactors should be low, approximately less than 1 L/s (Taylor et al. 2005). An additional advantage of bio-reactor is that the space needed is less than that for wetland treatment systems.

4.3 Cited Literature for Acid Rock Drainage Treatment

The following citations were found that provide for a bibliography for AMD treatment. A few of these references may overlap with the overall reference section. The literature and design criteria for treating AMD are readily available but minimally applied to road cut sites through pyritic rock formations. Relevant references are as follow:

Akcil, A., and S. Koldas. 2006. Acid mine drainage (AMD): Causes, treatment and case studies. *Journal of Cleaner Production* 14 (12–13): 1139–1145.

Cendrero, A., R. Anton, and J.S. De Omenaca. 1977. Geochemistry of bedrock; Its effect on the planting and maintenance of roadcuts along the Bilbao—Behobia Motorway (Northern Spain). *Landscape Planning* 4: 173–183.

Costa, M.C., and J.C. Duarte. 2005. Bioremediation of acid mine drainage using acidic soil and organic wastes for promoting sulphate-reducing bacteria activity on a column reactor. *Water, Air, and Soil Pollution* 165 (1–4): 325–345.

Cruz Viggi, C., F. Pagnanelli, A. Cibati, D. Uccelletti, C. Palleschi, and L. Toro. 2010. Biotreatment and bioassessment of heavy metal removal by sulphate reducing bacteria in fixed bed reactors. *Water Research* 44 (1): 151–158.

De Vegt, A.L., Exton, P. A., Bayer, H. G. and Buisman, C. J. (1998). Biological sulphate removal and metal recovery from mine waters. *Mining Engineering*, Vol. 50 No. 11, p 67-70, 1998.

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Appendices

Appendix A: Photo Record of Road Cut Study Sites.

Appendix B: Surficial Pyritic Rock Formations in Tennessee

Appendix C: Monitoring Station Storm Event Precipitation Depths and Runoff Volumes

Appendix D: Water Chemistry for Monitoring Station Storm Events

Appendix E: Literature Review of Toxicity Thresholds to Acidification for Aquatic Biota

Appendix F: Pollutant Export Mass Loadings from Monitoring Station Storm Events

Appendix G: EPT XTRAM® HPL Specifications

Appendix H: Water Chemistry for Middlebrook Pike Experiment: Simulated Rainfall

Appendix I: Water Chemistry for Middlebrook Pike Experiment: Natural Rainfall

Appendix A: Photo Record of Road Cut Study Sites

Grainger 1

Grainger County, 36°21'1.52"N, 83°20'16.76"W
SR-32, Chattanooga Shale

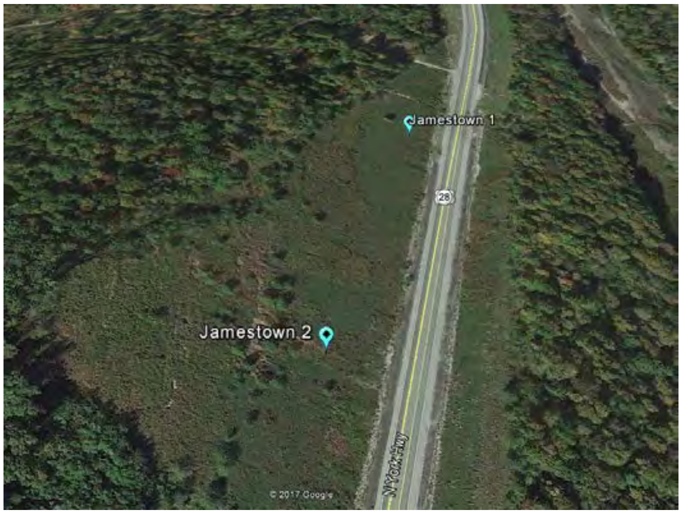
Pinson et al. (2003) devices under construction

Jamestown 1
Fentress County, 36°29'49.48"N, 36°29'49.48"N
SR-28, Fentress Formation

Google Images, 2017

Pinson et al. (2003) devices under construction

Jamestown 2
Fentress County, 36°29'42.95"N, 84°58'05.10"W
SR-28, Fentress Formation



Google Images, 2017

Pinson et al. (2003) devices under construction

Jamestown 3
Fentress County, 36°26'28.27"N, 84°57'46.52"W
SR-52, Fentress Formation

Google Image, 2017

Pinson et al. (2003) devices under construction

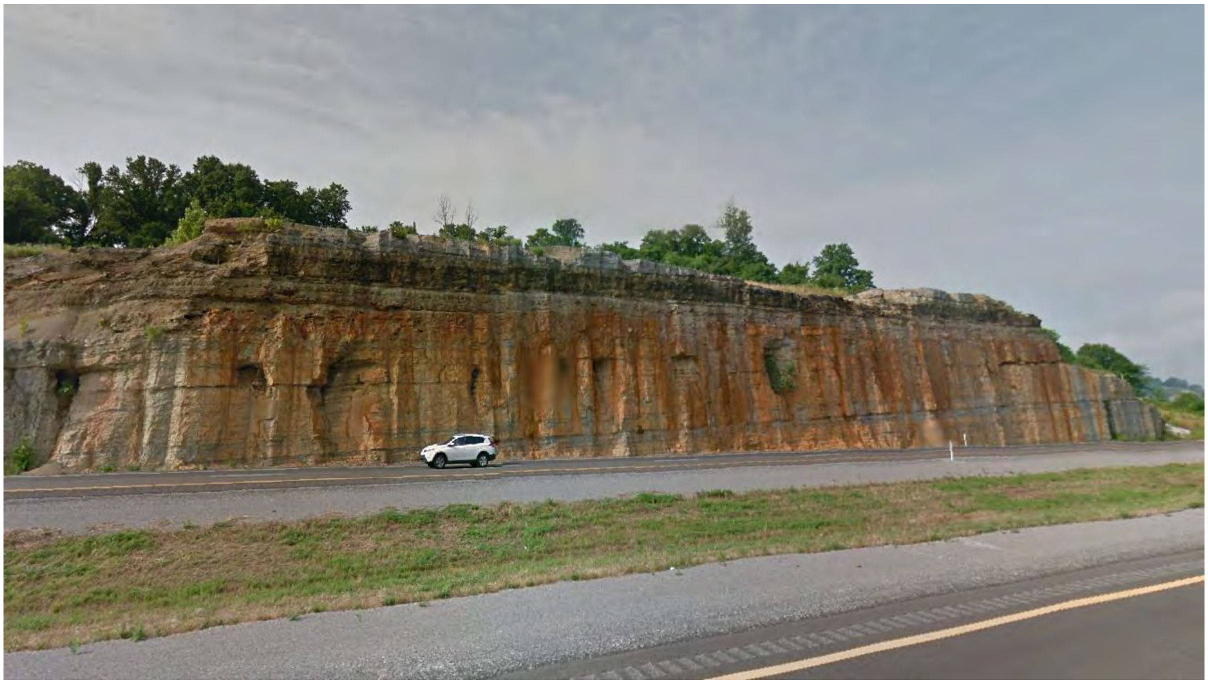
Nashville 1

Williamson County, 35°48'52.44"N, 86°58'30.49"W
I-840, Chattanooga Shale

Google Image, 2017

Nashville 2
Williamson County, 35°49'17.21"N, 86°57'11.81"W
I-840, Chattanooga Shale

Google Image, 2017



Ocoee 1
Polk County, 35° 7'13.81"N, 84°34'5.49"W
SR-30, Sandsuck Formation

Google Image, 2017
Winter photo

Ocoee 1 Site, monitoring equipment on the right of photo.
Summer photo

Ocoee 2
Polk County, 35° 7'13.90"N, 84°34'4.71"W
SR-30, Sandsuck Formation

Google Image, 2017
Winter photo

Ocoee 2 Site, monitoring equipment on the left of photo.
Summer photo

Ocoee 3
Polk County, 35° 2'35.90"N, 84°26'59.61"W
US-64, Great Smoky Group: Anakeesta

Sevierville 1
Sevier County, 35°49'1.80"N, 83°27'39.95"W
Pitman Center Road (CR 416), Snowbird Group: Roaring Fork

Google Image, 2017

Appendix B: Surficial Pyritic Rock Formations in Tennessee

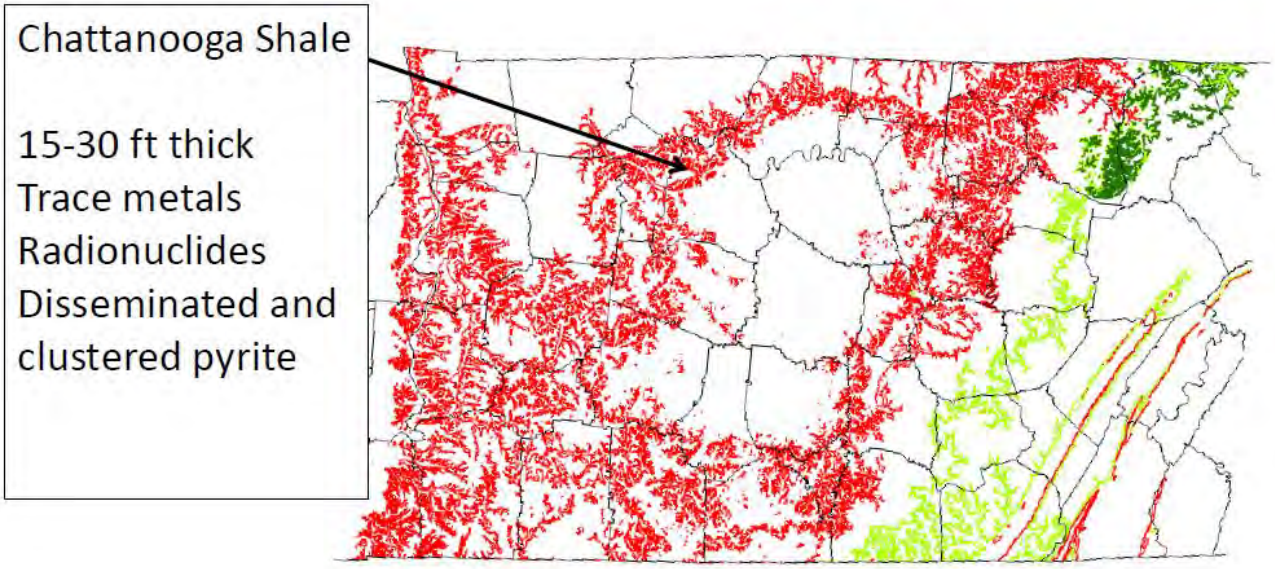
Material obtained from USGS, Nashville Office.

Reference: Michael Bradley

Evaluating acid rock drainage from road cuts in Tennessee

Michael Bradley, U.S. Geological Survey
In cooperation with
Tennessee Department of Transportation

14th Annual Technical Forum
Geohazards Impacting Transportation in Appalachia



Chattanooga Shale

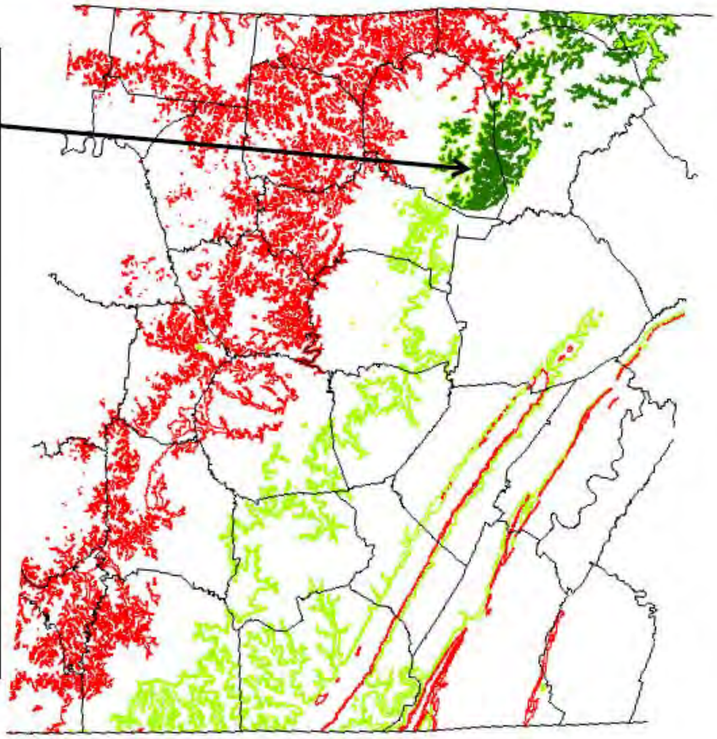
15-30 ft thick
Trace metals
Radionuclides
Disseminated and
clustered pyrite

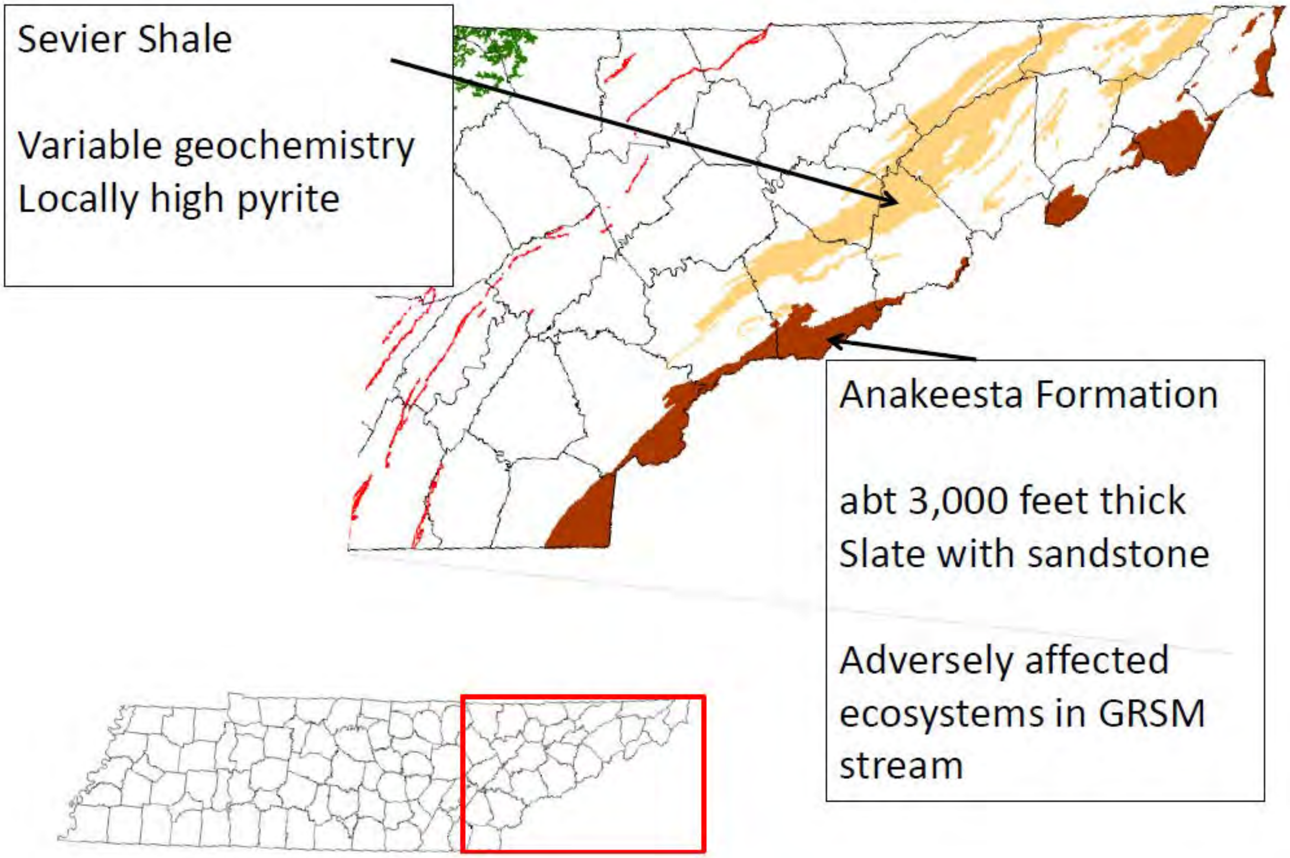
Fentress Formation

Up to 300 feet thick

Lower unit has multiple coal/shale sequences with high pyrite -- variable

Problem primarily in NW Cumberland Plateau





Sevier Shale

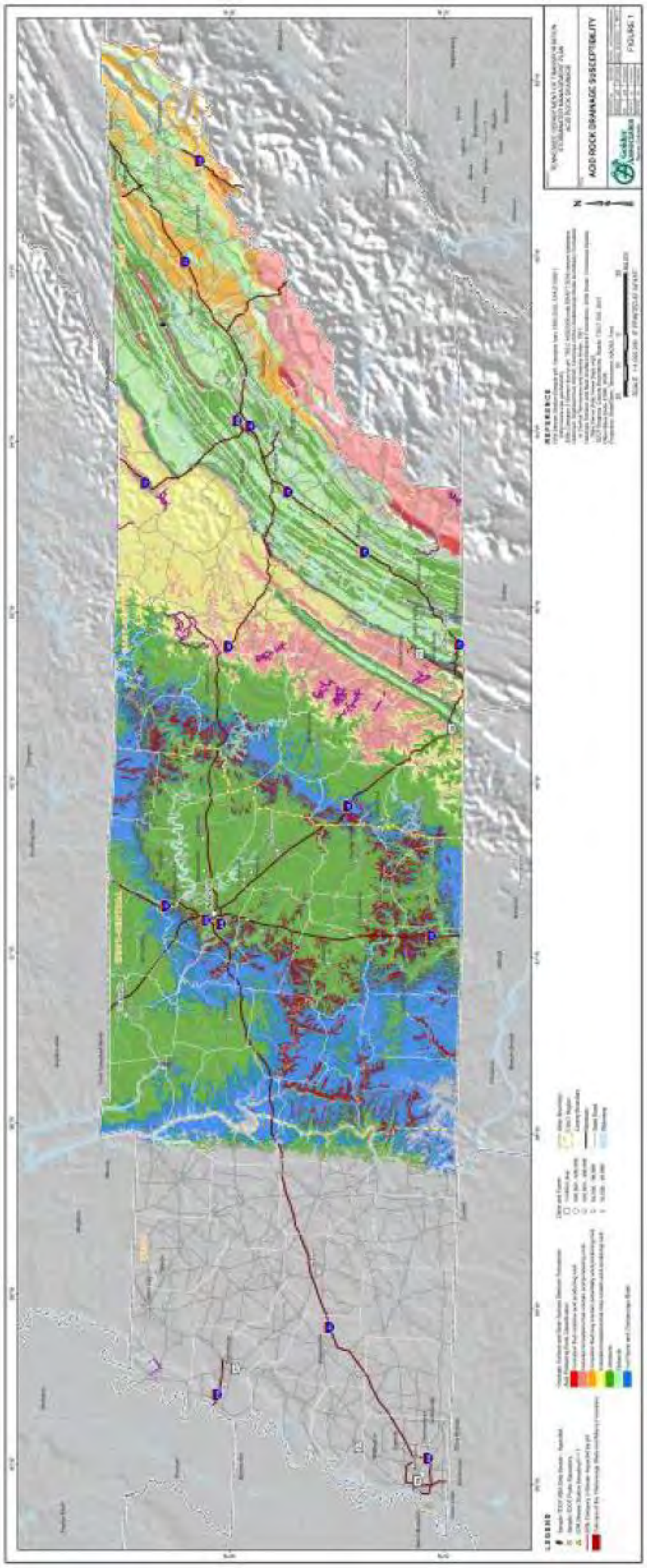
Variable geochemistry
Locally high pyrite

Anakeesta Formation

abt 3,000 feet thick
Slate with sandstone

Adversely affected ecosystems in GRSM stream

Figure from TDOT (2007), Risk map of acid producing rock.



Appendix C: Road Cut Monitoring Stations: Storm Event Rainfall Characteristics and Runoff Volumes.

APPENDIX C: ROAD CUT SITE RAINFALL AND RUNOFF ESTIMATES

Site	Date Collected	Rainfall (RF) (days)	RF Average Intensity (cm/hr)	RF Max. Intensity (cm/hr)	Precipitation Depth (cm)	Runoff Depth (cm)	Runoff Volume (m^3)	Runoff Volume * m^3
1. Grainger								
G1	7/21/2014	3	0.18	0.81	4.750	3.922	1.86	10.16
G1	10/10/2014	1	0.30	0.91	3.353	2.565	1.22	6.65
G1	10/23/2014	6	0.18	0.66	7.518	6.651	3.15	17.23
G1	1/29/2015	3	0.08	0.48	1.905	1.206	0.57	3.12
G1	4/16/2015	3	0.20	0.97	3.658	2.859	1.35	7.41
G1	5/18/2015	3	0.10	0.23	0.610	0.165	0.08	0.43
G1	6/9/2015	2	0.33	0.89	3.251	2.468	1.17	6.39
G1	7/6/2015	4	0.18	1.12	4.877	4.046	1.92	10.48
2. Jamestown 1								
J1	7/22/2014	2	0.08	0.33	2.235	0.413	1.04	2.02
J1	7/31/2014	1	0.33	2.11	5.182	2.380	6.01	11.61
J1	9/15/2014	1	0.18	1.17	2.286	0.438	1.11	2.14
J1	12/10/2014	1	0.15	0.51	2.540	0.569	1.44	2.77
J1	1/2/2015	3	0.05	0.33	2.057	0.331	0.84	1.61
J1	1/26/2015	1	0.05	0.13	0.762	0.000	0.00	0.00
J1	4/16/2015	2	0.05	0.25	2.184	0.389	0.98	1.90
J1	6/20/2015	1	0.10	0.46	1.905	0.266	0.67	1.30
J1	7/24/2015	1	0.28	0.97	2.286	0.438	1.11	2.14
3. Jamestown 2								
J2	7/15/2014	1	0.23	0.69	2.388	0.489	1.78	3.43
J2	9/15/2014	1	0.18	1.17	2.286	0.438	1.59	3.07
J2	12/10/2014	1	0.15	0.51	2.540	0.569	2.07	3.99
J2	1/2/2015	3	0.05	0.33	2.057	0.331	1.20	2.32
J2	1/26/2015	1	0.05	0.13	0.762	0.000	0.00	0.00
J2	4/16/2015	2	0.05	0.25	2.184	0.389	1.41	2.73
J2	6/20/2015	1	0.10	0.46	1.905	0.266	0.97	1.86
4. Jamestown 3								
J3	7/4/2014	3	0.05	0.28	0.711	0.048	0.02	0.12
J3	7/15/2014	1	0.15	0.38	1.473	0.396	0.18	0.97
J3	7/22/2014	2	0.08	0.36	2.489	1.105	0.49	2.69
J3	7/31/2014	1	0.36	2.29	5.842	4.044	1.80	9.86
J3	9/15/2014	1	0.20	1.30	2.565	1.164	0.52	2.84
J3	12/10/2014	1	0.18	0.51	2.692	1.264	0.56	3.08
J3	1/2/2015	3	0.05	0.38	2.184	0.874	0.39	2.13
J3	1/22/2015	1	0.08	0.30	1.245	0.268	0.12	0.65
J3	1/26/2015	1	0.05	0.15	0.787	0.071	0.03	0.17
J3	4/16/2015	2	0.05	0.23	2.032	0.764	0.34	1.86
J3	6/20/2015	1	0.10	0.53	2.032	0.764	0.34	1.86
J3	7/24/2015	1	0.25	1.19	2.362	1.007	0.45	2.46

Site	Date Collected	Rainfall (RF) (days)	RF Average Intensity (cm/hr)	RF Max. Intensity (cm/hr)	Precipitation Depth (cm)	Runoff Depth (cm)	Runoff Volume (m^3)	Runoff Volume * m^3
5. Nashville 1								
N1	6/8/2014	1	0.30	1.07	2.210	1.690	0.61	3.35
N1	7/1/2014	2	0.15	0.51	1.600	1.112	0.40	2.20
N1	7/22/2014	1	0.48	2.11	7.671	7.082	2.57	14.03
N1	8/26/2014	1	0.05	0.23	0.610	0.250	0.09	0.50
N1	10/11/2014	2	0.38	1.30	5.436	4.859	1.76	9.63
N1	1/9/2015	2	0.15	0.61	3.277	2.727	0.99	5.40
N1	1/30/2015	2	0.05	0.25	1.168	0.716	0.26	1.42
N1	3/23/2015	2	0.05	0.15	0.737	0.348	0.13	0.69
N1	6/1/2015	2	0.25	1.14	5.715	5.137	1.86	10.18
N1	7/24/2015	1	0.18	0.46	1.575	1.088	0.39	2.16
N1	8/21/2015	2	0.23	0.71	3.505	2.952	1.07	5.85
6. Nashville 2								
N2	7/1/2014	2	0.15	0.51	1.600	1.112	0.31	1.69
N2	8/26/2014	1	0.05	0.23	0.610	0.250	0.07	0.38
N2	10/11/2014	2	0.38	1.30	5.436	4.859	1.35	7.41
N2	1/9/2015	2	0.15	0.61	3.277	2.727	0.76	4.16
N2	3/23/2015	2	0.05	0.15	0.737	0.348	0.10	0.53
N2	6/1/2015	2	0.25	1.14	5.715	5.137	1.43	7.83
N2	7/24/2015	1	0.18	0.46	1.575	1.088	0.30	1.66
N2	8/21/2015	2	0.23	0.71	3.505	2.952	0.82	4.50
7. Ocoee 1								
O1	6/12/2014	3	0.10	0.79	2.642	1.224	0.55	1.49
O1	6/19/2014	2	0.15	0.86	0.940	0.126	0.06	0.15
O1	6/26/2014	4	0.15	2.03	3.962	2.334	1.04	2.85
O1	7/1/2014	3	0.23	2.21	6.248	4.424	1.97	5.39
O1	7/17/2014	6	0.08	0.79	2.007	0.746	0.33	0.91
O1	7/20/2014	2	0.08	0.61	2.438	1.065	0.48	1.30
O1	9/28/2014	1	0.10	0.33	1.092	0.192	0.09	0.23
O1	11/2/2014	4	0.03	0.30	0.787	0.071	0.03	0.09
O1	1/3/2015	1	0.03	0.10	0.483	0.005	0.00	0.01
O1	1/25/2015	2	0.08	2.26	2.388	1.027	0.46	1.25
O1	2/10/2015	1	0.13	0.64	1.245	0.268	0.12	0.33
O1	4/8/2015	1	0.10	0.76	1.651	0.506	0.23	0.62
O1	5/18/2015	4	0.08	0.69	3.886	2.267	1.01	2.76
O1	6/9/2015	1	0.18	0.84	3.023	1.531	0.68	1.87
O1	7/6/2015	4	0.18	1.47	13.411	11.362	5.07	13.85
8. Ocoee 2								
O2	6/26/2014	4	0.15	2.03	3.962	2.334	0.87	2.85
O2	7/1/2014	3	0.23	2.21	6.248	4.424	1.64	5.39
O2	7/17/2014	6	0.08	0.79	2.007	0.746	0.28	0.91
O2	7/20/2014	2	0.08	0.61	2.438	1.065	0.40	1.30

8. Ocoee 2 *continued*

Site	Date Collected	Rainfall (RF) (days)	RF Average Intensity (cm/hr)	RF Max. Intensity (cm/hr)	Precipitation Depth (cm)	Runoff Depth (cm)	Runoff Volume (m^3)	Runoff Volume * m^3
O2	9/28/2014	1	0.10	0.33	1.092	0.192	0.07	0.23
O2	11/2/2014	4	0.03	0.30	0.787	0.071	0.03	0.09
O2	1/3/2015	1	0.03	0.10	0.483	0.005	0.00	0.01
O2	1/25/2015	2	0.08	2.26	2.388	1.027	0.38	1.25
O2	2/10/2015	1	0.13	0.64	1.245	0.268	0.10	0.33
O2	4/8/2015	1	0.10	0.76	1.651	0.506	0.19	0.62
O2	5/18/2015	4	0.08	0.69	3.886	2.267	0.84	2.76
O2	6/9/2015	1	0.18	0.84	3.023	1.531	0.57	1.87
O2	7/6/2015	4	0.18	1.47	13.411	11.362	4.22	13.85
9. Ocoee 3								
O3	7/1/2014	3	0.33	1.52	8.001	6.090	3.23	17.64
O3	7/17/2014	6	0.13	0.86	3.023	1.531	0.81	4.43
O3	7/20/2014	2	0.08	0.38	2.667	1.244	0.66	3.60
O3	9/28/2014	1	0.13	0.38	1.295	0.295	0.16	0.85
O3	11/2/2014	4	0.05	0.36	1.041	0.169	0.09	0.49
O3	1/3/2015	1	0.03	0.18	0.686	0.042	0.02	0.12
O3	1/22/2015	1	0.05	0.36	1.194	0.242	0.13	0.70
O3	1/25/2015	2	0.10	0.23	2.362	1.007	0.53	2.92
O3	2/10/2015	1	0.03	0.13	0.330	0.001	0.00	0.00
O3	4/8/2015	1	0.10	0.36	1.524	0.427	0.23	1.24
O3	5/18/2015	4	0.13	0.33	5.131	3.385	1.79	9.80
O3	6/9/2015	1	0.28	1.17	3.962	2.334	1.24	6.76
O3	7/6/2015	4	0.23	1.19	16.078	13.992	7.41	40.51
O3	8/8/2015	2	0.05	0.23	0.406	0.000	0.00	0.00
10. Seiverville								
S1	7/17/2014	3	0.15	1.45	2.311	0.969	0.38	2.07
S1	7/21/2014	2	0.10	0.51	3.505	1.937	0.76	4.13
S1	7/29/2014	1	0.91	2.92	7.315	5.434	2.12	11.59
S1	8/10/2014	3	0.13	0.69	3.404	1.850	0.72	3.95
S1	8/30/2014	6	0.25	0.79	1.803	0.606	0.24	1.29
S1	11/16/2014	1	0.13	0.61	1.753	0.572	0.22	1.22
S1	1/22/2015	2	0.08	0.25	1.600	0.474	0.18	1.01
S1	1/29/2015	4	0.08	0.25	2.540	1.144	0.45	2.44
S1	4/16/2015	2	0.10	0.48	2.794	1.345	0.52	2.87
S1	5/18/2015	3	0.13	0.76	1.295	0.295	0.12	0.63
S1	6/9/2015	1	0.18	0.66	2.184	0.874	0.34	1.87
S1	7/6/2015	4	0.13	0.43	3.658	2.068	0.81	4.41

* Per 10 m of road cut

APPENDIX C: ROAD CUT RUNOFF ESTIMATES

Road Dimenions and Hydrologic Parameters

1. Grainger Ratio for 10 m
Width = 1.8288 m 5.468066
Height = 25.908 m
Area = 47.38 ft^2
CN = 97
S = 7.86

2. Jamestown 1 Ratio for 10 m
Width = 5.1816 m 1.929906
Height = 48.768 m
Area = 252.70 m^2
CN = 87
S = 37.95

3. Jamestown 2 Ratio for 10 m
Width = 5.1816 m 1.929906
Height = 70.104 m
Area = 363.25 m^2
CN = 87
S = 37.95

4. Jamestown 3 Ratio for 10 m
Width = 1.8288 m 5.468066
Height = 24.384 m
Area = 44.59 m^2
CN = 93
S = 19.12

5. Nashville 1 Ratio for 10 m
Width = 1.8288 m 5.468066
Height = 19.812 m
Area = 36.23 m^2
CN = 98
S = 5.18

6. Nashville 2 Ratio for 10 m
Width = 1.8288 m 5.468066
Height = 15.240 m
Area = 27.87 m^2
CN = 98
S = 5.18

Road Dimenions and Hydrologic Parameters

7. Ocoee 1			Ratio for 10 m
Width =	3.6576	m	2.734033
Height =	12.192	m	
Area =	44.59	m^2	
CN =	93		
S =	19.12		

8. Ocoee 2			Ratio for 10 m
Width =	3.048	m	3.28084
Height =	12.192	m	
Area =	37.16	m^2	
CN =	93		
S =	19.12		

9. Ocoee 3			Ratio for 10 m
Width =	1.8288	m	5.468066
Height =	28.956	m	
Area =	52.96	m^2	
CN =	93		
S =	19.12		

10. Seiverville			Ratio for 10 m
Width =	1.8288	m	5.468066
Height =	21.336	m	
Area =	39.02	m^2	
CN =	93		
S =	19.12		

Review of Runoff Calculations

Precipitation depth (cm) = P (per storm event)
Hydrology Curve Number = CN (same per site)
Drainage Area (Area) is the exposed surface to precipitation
Potential Maximum Retention = S
S = 25400/CN - 254 (metric equation, same per site)

Runoff Depth = P_e (cm) $P_e = (P-0.2*S) / (P + 0.08*S)$
Runoff Depth (P_e) converted from cm to m by dividing by 100
Runoff Volume = P_e (m) * Area (m^2)

Runoff volume per 10 m of road cut = 10 m / (width, m)

Appendix D: Water Chemistry for Monitoring Station Storm Events.

ROAD CUT RUNOFF WATER CHEMSITRY: SUMMARY SHEET

							Acid Anions				Base Cations
Site	Date Collected	TSS (mg/L)	Conductivity (uS/cm)	pH units	Hardness (mg/L)	ANC (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)	Na+ (mg/L)
1. Grainger											
G1	7/21/2014	2309	209	4.93	19.03	-0.240	5.975	92.972	13.911	12.866	5.494
G1	10/10/2014	2282	168	4.77	19.35	0.017	6.185	84.156	14.619	11.912	5.934
G1	10/23/2014	2168	157	4.27	18.20	-0.038	5.916	81.993	15.351	12.481	5.998
G1	1/29/2015	100	117	4.93	16.53	-0.406	6.154	97.299	14.410	12.360	6.562
G1	4/16/2015	2423	182	5.09	15.73	-0.638	5.695	87.349	14.464	12.282	0.958
G1	5/18/2015	2533	174	4.85	15.11	-0.730	6.036	88.412	14.182	12.840	0.820
G1	6/9/2015	2645	170	5.50	23.38	0.181	5.699	95.658	16.124	13.946	6.894
G1	7/6/2015	2449	206	4.93	17.86	-0.326	5.928	92.808	14.599	12.539	5.655
2. Jamestown 1											
J1	7/22/2014	185	110	6.60	14.97	-1.139	6.012	80.013	14.239	12.018	3.486
J1	7/31/2014	535	133	6.60	12.55	-1.358	5.786	83.960	15.366	12.235	3.874
J1	9/15/2014	153	105	6.72	13.92	-1.049	5.967	72.261	14.499	12.694	3.794
J1	12/10/2014	136	109	6.60	15.76	-0.841	6.587	65.152	14.688	12.623	3.642
J1	1/2/2015	39	95	6.97	17.06	-0.865	6.017	70.402	14.687	12.716	3.664
J1	1/26/2015	39	93	7.37	13.38	0.074	6.418	16.835	14.892	11.955	3.244
J1	4/16/2015	152	123	6.63	12.73	-1.234	6.001	68.359	14.248	12.371	0.000
J1	6/20/2015	165	126	6.57	21.77	0.227	6.433	41.789	12.926	10.865	5.098
J1	7/24/2015	141	118	6.75	13.10	-1.162	5.520	76.006	14.719	12.362	3.278
3. Jamestown 2											
J2	7/15/2014	81	371	3.73	44.34	-13.877	17.776	788.005	39.599	29.375	13.649
J2	9/15/2014	79	300	4.13	26.91	-7.483	21.694	384.187	25.215	35.717	0.000
J2	12/10/2014	80	297	3.97	28.56	-8.227	23.477	424.863	28.073	32.453	0.000
J2	1/2/2015	39	428	6.80	27.16	-2.060	7.557	136.213	40.982	28.982	0.000
J2	1/26/2015	96	22	7.07	34.44	-0.259	7.408	89.922	11.132	37.169	0.000
J2	4/16/2015	63	292	4.75	41.39	-11.749	14.166	646.935	33.037	38.827	0.000
J2	6/20/2015	68	382	3.45	45.47	-10.848	21.119	629.866	58.604	38.686	23.579
4. Jamestown 3											
J3	7/4/2014	51	33	6.07	10.28	0.168	3.660	15.583	13.737	7.608	1.606
J3	7/15/2014	63	33	6.20	9.81	0.033	4.352	23.822	10.992	7.680	1.697

							Acid Anions				Base Cations
Site	Date Collected	TSS (mg/L)	Conductivity (uS/cm)	pH units	Hardness (mg/L)	ANC (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)	Na+ (mg/L)
4. Jamestown 3											
J3	7/22/2014	47	34	5.97	9.58	0.154	4.414	20.258	6.503	7.569	1.757
J3	7/31/2014	47	36	6.17	9.25	0.244	5.206	16.425	9.122	5.641	1.857
J3	9/15/2014	39	36	6.20	9.14	0.214	4.446	13.292	9.408	6.363	1.535
J3	12/10/2014	42	34	6.05	9.54	0.156	5.239	13.656	11.175	7.065	1.542
J3	1/2/2015	40	24	6.50	9.43	0.085	4.849	19.794	8.074	6.821	1.546
J3	1/22/2015	59	22	6.27	9.10	0.116	3.579	19.084	10.652	5.627	1.531
J3	1/26/2015	39	20	6.50	9.55	0.165	3.250	15.683	9.412	8.208	1.552
J3	4/16/2015	50	36	6.39	10.04	0.133	4.683	17.101	7.363	7.832	0.416
J3	6/20/2015	35	30	6.45	11.29	0.059	6.440	16.085	15.070	11.755	2.170
J3	7/24/2015	46	38	6.46	10.31	0.184	4.816	20.690	9.624	5.444	1.708
5. Nashville 1											
N1	6/8/2014	3045	4808	6.17	617.80	-9.242	14.517	2213.109	33.961	29.570	29.034
N1	7/1/2014	3014	4991	6.08	621.11	-9.774	16.081	2247.811	32.651	24.138	26.713
N1	7/22/2014	2011	5638	5.32	615.86	-10.924	16.365	2281.844	33.219	27.262	25.142
N1	8/26/2014	1603	5199	6.37	604.70	-0.265	11.882	1766.905	27.283	9.880	21.933
N1	10/11/2014	1724	4891	6.53	644.49	2.509	14.704	1764.356	18.045	9.025	27.402
N1	1/9/2015	601	5226	6.45	616.26	1.081	11.551	1744.212	18.077	9.039	28.125
N1	1/30/2015	39	5164	6.45	624.69	1.659	11.553	1743.903	24.603	8.876	25.114
N1	3/23/2015	3136	5328	5.78	798.83	-3.203	13.369	2381.333	30.245	8.854	1.022
N1	6/1/2015	2211	5425	5.55	826.63	2.877	11.534	2210.103	28.754	9.530	17.700
N1	7/24/2015	2693	4686	6.23	610.67	-10.828	17.776	2286.072	36.574	22.486	28.431
N1	8/21/2015	2545	6031	6.37	616.64	-11.373	18.809	2294.043	33.567	26.889	25.484
6. Nashville 2											
N2	7/1/2014	384	2045	4.71	662.65	28.028	16.612	861.531	40.245	34.068	30.839
N2	8/26/2014	367	1958	4.92	684.20	28.832	18.293	836.095	43.454	33.285	29.287
N2	10/11/2014	320	1451	4.50	664.58	27.177	14.124	871.569	46.985	19.064	34.751
N2	1/9/2015	135	1455	6.40	540.05	31.844	12.669	734.006	20.465	42.538	274.410
N2	3/23/2015	442	3188	5.55	750.67	24.951	16.477	767.379	34.451	23.437	0.000
N2	6/1/2015	361	3355	4.75	736.33	32.996	14.662	839.855	34.543	19.444	47.308
N2	7/24/2015	408	3352	3.91	659.18	28.340	11.567	859.750	14.662	31.038	28.695
N2	8/21/2015	385	3460	4.75	667.89	36.652	14.933	456.263	34.230	29.433	31.386

							Acid Anions				Base Cations
Site	Date Collected	TSS (mg/L)	Conductivity (uS/cm)	pH units	Hardness (mg/L)	ANC (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)	Na+ (mg/L)
7. Ocoee 1											
O1	6/12/2014	422	131	6.83	62.22	3.554	4.446	49.754	22.911	9.634	12.185
O1	6/19/2014	520	230	6.60	59.34	4.022	7.380	29.702	19.044	5.952	15.042
O1	6/26/2014	419	116	6.60	67.87	3.181	5.744	72.578	33.202	10.920	12.964
O1	7/1/2014	560	92	6.92	62.38	3.625	5.104	51.091	19.804	9.318	11.783
O1	7/17/2014	221	348	6.97	64.41	4.121	5.953	28.850	12.539	10.779	11.554
O1	7/20/2014	77	113	6.53	66.29	4.146	4.194	20.010	32.505	10.863	12.064
O1	9/28/2014	475	184	4.68	57.68	3.874	3.360	24.478	15.865	7.191	11.128
O1	11/2/2014	482	183	4.63	57.48	3.451	4.059	48.931	14.508	5.633	11.986
O1	1/3/2015	45	136	7.57	56.92	3.710	3.829	38.396	11.883	5.557	11.438
O1	1/25/2015	45	155	7.33	57.64	3.874	5.628	21.151	14.315	6.935	11.379
O1	2/10/2015	38	96	7.23	54.46	3.764	2.873	20.455	16.595	6.631	11.488
O1	4/8/2015	674	174	4.60	48.00	1.840	6.238	44.745	21.419	9.469	2.154
O1	5/18/2015	343	215	4.61	48.10	1.928	5.428	47.303	22.214	7.486	1.725
O1	6/9/2015	802	264	4.84	61.44	3.771	6.280	34.955	14.275	12.415	13.942
O1	7/6/2015	146	181	6.51	61.52	3.396	5.612	45.683	29.564	10.743	12.581
8. Ocoee 2											
O2	6/26/2014	460	282	7.35	43.81	1.299	6.355	58.387	12.964	10.223	5.641
O2	7/1/2014	248	150	7.17	43.75	1.416	6.489	50.470	13.627	11.120	5.372
O2	7/17/2014	53	256	7.20	38.01	0.741	6.342	55.559	12.490	10.479	1.746
O2	7/20/2014	37	264	7.17	42.60	1.373	6.556	47.355	12.631	10.588	5.095
O2	9/28/2014	182	248	7.38	36.45	1.020	5.637	47.070	11.969	9.782	4.721
O2	11/2/2014	216	224	7.10	34.76	1.001	5.688	42.763	11.560	9.341	3.734
O2	1/3/2015	40	174	7.70	35.77	1.068	5.516	49.380	10.951	9.590	7.137
O2	1/25/2015	39	140	7.40	35.20	1.024	5.671	46.295	11.709	9.612	5.574
O2	2/10/2015	38	170	7.47	36.35	1.090	5.716	43.616	11.723	9.798	5.172
O2	4/8/2015	110	233	4.53	44.72	1.525	6.372	53.614	12.087	10.146	5.677
O2	5/18/2015	162	281	5.47	40.82	1.176	6.282	51.982	14.359	11.127	5.369
O2	6/9/2015	47	309.3	5.45	42.15	1.502	6.750	55.284	12.888	8.836	6.329
O2	7/6/2015	72	189	7.18	46.20	1.886	6.188	47.320	13.117	10.344	9.261

							Acid Anions				Base Cations
Site	Date Collected	TSS (mg/L)	Conductivity (uS/cm)	pH units	Hardness (mg/L)	ANC (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)	Na+ (mg/L)
9. Ocoee 3											
O3	7/1/2014	72	327	3.30	31.88	2.364	5.736	80.733	13.666	10.481	33.537
O3	7/17/2014	56	401	4.37	26.65	1.859	6.357	94.253	14.160	11.682	32.109
O3	7/20/2014	42	237	4.17	25.91	1.479	6.603	75.448	13.672	11.952	23.716
O3	9/28/2014	50	283	5.32	23.90	1.473	5.580	76.963	12.492	9.833	23.148
O3	11/2/2014	56	312	5.43	23.77	1.379	5.533	84.135	12.475	9.786	23.260
O3	1/3/2015	39	1008	3.00	41.19	2.501	9.112	134.589	24.302	14.898	42.824
O3	1/22/2015	39	1147	2.97	44.12	1.785	8.984	138.688	19.902	13.822	33.837
O3	1/25/2015	67	678	3.30	36.92	3.358	7.814	139.225	18.983	16.827	61.085
O3	2/10/2015	39	787	3.52	36.86	2.867	8.840	120.498	18.942	14.559	42.692
O3	4/8/2015	59	316	5.43	21.96	-0.220	6.009	90.043	14.378	9.993	0.000
O3	5/18/2015	51	243	4.55	29.06	0.431	6.316	96.179	13.674	11.325	0.000
O3	6/9/2015	42	385	4.30	29.81	2.886	6.613	65.092	13.357	12.450	40.779
O3	7/6/2015	48	260	6.13	26.41	1.296	6.412	96.508	14.595	10.901	35.295
O3	8/8/2015	55	329	4.21	30.63	2.219	6.092	85.790	13.887	10.918	20.714
10. Seiverville											
S1	7/17/2014	60	429	6.63	80.43	3.190	6.074	122.287	12.872	9.836	17.256
S1	7/21/2014	46	433	6.03	79.63	3.010	6.410	117.202	13.871	11.745	13.576
S1	7/29/2014	185	225	6.07	79.28	3.238	5.994	116.526	10.940	11.045	17.202
S1	8/10/2014	82	257	5.90	77.24	3.007	6.600	114.249	10.332	10.998	13.984
S1	8/30/2014	98	287	6.23	72.15	2.882	5.726	103.272	9.970	9.481	12.786
S1	11/16/2014	106	233	6.40	72.35	2.869	5.700	104.425	11.232	9.620	13.337
S1	1/22/2015	43	1104	4.20	111.41	3.269	10.376	221.674	14.055	14.051	24.239
S1	1/29/2015	38	1089	4.37	121.42	3.683	10.537	213.948	18.431	13.270	16.710
S1	4/16/2015	92	469	6.32	82.12	2.289	6.494	123.745	11.010	10.892	0.000
S1	5/18/2015	89	306	6.25	80.99	2.144	6.417	126.632	14.427	10.462	0.000
S1	6/9/2015	58	374	6.14	84.79	3.616	6.763	108.030	14.468	12.254	22.281
S1	7/6/2015	95	339	6.06	79.85	3.021	6.332	122.643	11.722	10.655	14.660

Dissolved Metals

Site	Date Collected	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Ba (mg/L)	Cd (mg/L)
1. Grainger												
G1	7/21/2014	1.652	10.204	8.578	0.920	0.071	0.245	0.736	5.525	0.470	0.118	0.020
G1	10/10/2014	1.869	9.428	9.759	0.823	0.072	0.167	0.800	5.886	0.469	0.129	0.025
G1	10/23/2014	1.935	9.048	8.943	0.969	0.064	0.205	0.801	5.694	0.476	0.131	0.017
G1	1/29/2015	2.044	8.133	8.170	0.950	0.070	0.224	0.712	5.899	0.502	0.117	0.017
G1	4/16/2015	1.582	7.997	7.681	0.273	0.056	0.050	0.410	5.477	0.194	0.099	0.005
G1	5/18/2015	1.555	7.754	7.306	0.248	0.037	0.048	0.396	5.500	0.187	0.090	0.008
G1	6/9/2015	2.012	11.824	11.432	0.699	0.063	0.126	0.641	7.143	0.301	0.138	0.026
G1	7/6/2015	1.815	9.053	8.604	0.877	0.073	0.205	0.747	5.509	0.464	0.119	0.021
2. Jamestown 1												
J1	7/22/2014	6.344	2.942	11.829	0.416	0.068	0.195	0.327	0.575	0.274	0.069	0.016
J1	7/31/2014	6.425	2.513	9.819	0.413	0.067	0.215	0.329	0.561	0.269	0.064	0.003
J1	9/15/2014	6.537	2.840	10.979	0.307	0.055	0.097	0.334	0.580	0.272	0.065	0.005
J1	12/10/2014	6.110	3.133	12.509	0.291	0.064	0.120	0.338	0.546	0.288	0.067	0.007
J1	1/2/2015	6.374	3.212	13.727	0.284	0.054	0.117	0.331	0.535	0.291	0.067	0.017
J1	1/26/2015	6.806	3.031	10.256	0.284	0.067	0.097	0.341	0.608	0.271	0.063	0.013
J1	4/16/2015	5.759	2.324	10.360	0.000	0.044	0.047	0.003	0.829	0.016	0.053	0.016
J1	6/20/2015	6.398	4.238	17.472	0.557	0.041	0.058	0.026	1.071	0.077	0.055	0.014
J1	7/24/2015	7.083	2.362	10.524	0.440	0.064	0.218	0.332	0.557	0.265	0.067	0.003
3. Jamestown 2												
J2	7/15/2014	3.252	15.047	27.440	0.751	0.161	1.856	2.256	7.508	0.128	0.289	0.064
J2	9/15/2014	2.950	11.136	15.677	0.450	0.194	0.100	1.505	5.387	0.105	0.179	0.065
J2	12/10/2014	2.579	14.455	14.022	0.323	0.161	0.087	2.354	4.696	0.074	0.212	0.087
J2	1/2/2015	2.748	13.999	13.106	0.438	0.154	0.050	2.177	3.819	0.114	0.214	0.074
J2	1/26/2015	1.581	11.269	23.093	0.285	0.195	0.081	2.031	6.510	0.138	0.195	0.064
J2	4/16/2015	3.318	14.600	26.678	0.626	0.171	0.117	2.315	7.678	0.118	0.250	0.047
J2	6/20/2015	3.056	15.294	27.532	1.380	0.070	2.648	2.086	6.716	0.117	0.249	0.076
4. Jamestown 3												
J3	7/4/2014	1.455	2.131	8.102	0.130	0.020	0.047	0.087	2.439	0.080	0.057	0.010
J3	7/15/2014	1.580	1.999	7.768	0.131	0.020	0.044	0.087	2.678	0.084	0.057	0.010

Dissolved Metals

Site	Date Collected	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Ba (mg/L)	Cd (mg/L)
4. Jamestown 3												
J3	7/22/2014	1.555	2.155	7.367	0.141	0.020	0.054	0.081	2.512	0.091	0.057	0.010
J3	7/31/2014	1.476	1.981	7.217	0.124	0.020	0.054	0.087	2.760	0.087	0.050	0.010
J3	9/15/2014	1.381	1.851	7.250	0.121	0.020	0.042	0.080	2.317	0.080	0.050	0.010
J3	12/10/2014	1.382	1.846	7.645	0.121	0.020	0.045	0.081	2.341	0.081	0.050	0.010
J3	1/2/2015	1.375	1.847	7.537	0.121	0.020	0.047	0.080	2.297	0.080	0.050	0.010
J3	1/22/2015	1.383	1.862	7.195	0.121	0.020	0.044	0.080	2.298	0.080	0.050	0.010
J3	1/26/2015	1.394	1.847	7.655	0.121	0.020	0.044	0.081	2.351	0.081	0.050	0.010
J3	4/16/2015	1.537	1.846	8.163	0.018	0.011	0.026	0.004	2.563	0.031	0.052	0.003
J3	6/20/2015	1.583	2.191	9.049	0.082	0.012	0.053	0.005	2.875	0.029	0.048	0.010
J3	7/24/2015	1.506	2.051	8.214	0.131	0.020	0.042	0.084	2.545	0.087	0.053	0.005
5. Nashville 1												
N1	6/8/2014	0.726	154.407	462.806	3.250	0.555	0.592	2.611	7.294	2.384	0.492	0.107
N1	7/1/2014	0.704	153.742	466.763	3.396	0.522	0.608	2.625	7.215	2.232	0.569	0.144
N1	7/22/2014	0.659	153.583	461.681	3.318	0.518	0.593	2.598	7.356	2.286	0.557	0.096
N1	8/26/2014	0.703	151.540	452.646	2.499	0.568	0.513	2.622	7.428	2.337	0.563	0.181
N1	10/11/2014	0.702	165.100	478.937	2.532	0.548	0.449	2.537	7.202	2.203	0.475	0.000
N1	1/9/2015	0.703	147.154	468.586	2.416	0.633	0.522	2.617	7.373	2.300	0.522	0.146
N1	1/30/2015	0.703	159.702	464.522	2.355	0.534	0.468	2.653	7.228	2.315	0.544	0.127
N1	3/23/2015	0.593	179.179	619.533	0.036	0.243	0.114	1.062	11.704	0.718	0.340	0.096
N1	6/1/2015	0.585	198.829	627.718	0.403	0.215	0.081	0.959	9.526	0.263	0.365	0.143
N1	7/24/2015	0.689	161.323	448.727	3.202	0.570	0.620	2.614	7.415	2.239	0.535	0.090
N1	8/21/2015	0.728	150.706	465.383	3.119	0.602	0.552	2.598	6.867	2.151	0.510	0.147
6. Nashville 2												
N2	7/1/2014	2.069	146.711	513.416	48.616	1.090	2.518	5.685	20.624	9.031	0.476	0.137
N2	8/26/2014	1.923	144.556	537.467	41.493	1.070	2.181	6.091	21.979	8.919	0.503	0.116
N2	10/11/2014	1.860	130.541	530.590	40.622	0.955	3.452	6.067	21.171	8.802	0.523	0.164
N2	1/9/2015	6.411	42.774	495.750	44.505	1.093	1.523	5.773	22.168	8.998	0.569	0.232
N2	3/23/2015	1.745	127.750	622.817	0.015	0.261	0.104	1.223	6.492	0.158	0.318	0.089
N2	6/1/2015	1.930	153.450	582.705	40.357	0.966	0.178	3.666	22.715	7.411	0.346	0.075
N2	7/24/2015	1.917	138.741	519.682	50.029	1.065	0.755	5.749	20.556	8.511	0.470	0.137
N2	8/21/2015	1.960	137.758	527.829	46.393	1.027	2.305	5.822	21.589	9.027	0.487	0.074

Site	Date Collected	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Ba (mg/L)	Cd (mg/L)
						Dissolved Metals						
7. Ocoee 1												
O1	6/12/2014	0.321	14.944	47.221	0.321	0.044	0.057	0.020	8.553	0.050	0.084	0.013
O1	6/19/2014	0.392	18.561	40.752	0.362	0.050	0.030	0.020	7.501	0.050	0.090	0.010
O1	6/26/2014	0.335	17.671	50.143	0.305	0.044	0.057	0.020	8.149	0.050	0.084	0.013
O1	7/1/2014	0.350	17.959	44.377	0.306	0.047	0.047	0.020	8.341	0.050	0.087	0.015
O1	7/17/2014	0.315	16.544	47.815	0.328	0.044	0.050	0.020	7.910	0.050	0.084	0.013
O1	7/20/2014	0.332	16.084	50.163	0.342	0.044	0.040	0.020	7.997	0.050	0.087	0.013
O1	9/28/2014	0.290	15.430	42.205	0.278	0.040	0.045	0.020	7.397	0.050	0.080	0.010
O1	11/2/2014	0.298	16.128	41.300	0.288	0.040	0.054	0.020	7.284	0.050	0.080	0.010
O1	1/3/2015	0.298	15.972	40.906	0.275	0.040	0.040	0.020	7.607	0.050	0.080	0.010
O1	1/25/2015	0.297	15.668	41.914	0.277	0.040	0.053	0.020	7.011	0.050	0.080	0.010
O1	2/10/2015	0.305	14.588	39.834	0.291	0.040	0.033	0.020	7.097	0.050	0.080	0.010
O1	4/8/2015	0.234	12.792	35.182	0.010	0.050	0.029	0.005	4.742	0.018	0.074	0.011
O1	5/18/2015	0.250	13.148	34.932	0.009	0.056	0.016	0.002	5.234	0.043	0.073	0.008
O1	6/9/2015	0.381	16.580	44.845	0.240	0.034	0.014	0.002	7.338	0.052	0.066	0.020
O1	7/6/2015	0.328	16.456	45.018	0.309	0.048	0.047	0.019	7.864	0.052	0.083	0.014
8. Ocoee 2												
O2	6/26/2014	1.265	10.501	33.200	0.459	0.108	0.106	0.151	2.465	0.252	0.093	0.020
O2	7/1/2014	1.209	9.566	34.082	0.293	0.097	0.107	0.197	2.888	0.179	0.093	0.035
O2	7/17/2014	0.976	7.954	30.015	0.000	0.042	0.037	0.059	2.433	0.024	0.078	0.011
O2	7/20/2014	1.177	9.189	33.384	0.081	0.047	0.023	0.002	2.747	0.032	0.087	0.009
O2	9/28/2014	0.950	7.768	28.628	0.254	0.053	0.053	0.234	2.214	0.143	0.071	0.010
O2	11/2/2014	0.935	7.521	27.180	0.366	0.054	0.060	0.235	2.175	0.164	0.070	0.010
O2	1/3/2015	0.951	8.298	27.408	0.120	0.070	0.060	0.020	2.242	0.160	0.070	0.000
O2	1/25/2015	0.953	8.173	26.959	0.168	0.060	0.067	0.315	2.190	0.191	0.070	0.017
O2	2/10/2015	0.887	7.861	28.435	0.110	0.047	0.050	0.171	2.189	0.231	0.070	0.017
O2	4/8/2015	1.381	11.828	32.773	0.302	0.060	0.117	0.342	2.679	0.238	0.091	0.023
O2	5/18/2015	1.105	9.524	31.170	0.320	0.054	0.128	0.161	2.500	0.299	0.094	0.034
O2	6/9/2015	1.023	12.477	29.547	0.020	0.070	0.130	0.381	3.500	0.050	0.100	0.010
O2	7/6/2015	1.318	10.407	35.664	0.612	0.121	0.133	0.487	2.795	0.435	0.110	0.046

Dissolved Metals

Site	Date Collected	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Ba (mg/L)	Cd (mg/L)
9. Ocoee 3												
O3	7/1/2014	2.256	2.722	28.450	5.138	0.907	0.703	3.546	5.243	2.732	0.429	0.151
O3	7/17/2014	2.509	2.697	23.303	6.251	0.626	0.653	3.188	5.649	2.790	0.445	0.081
O3	7/20/2014	1.866	3.050	22.114	5.013	0.627	0.742	3.318	4.085	2.581	0.453	0.091
O3	9/28/2014	1.477	2.578	20.713	4.512	0.597	0.613	2.895	5.083	2.385	0.367	0.064
O3	11/2/2014	2.046	2.730	20.451	5.366	0.491	0.587	2.833	4.697	2.366	0.377	0.050
O3	1/3/2015	2.900	4.946	35.132	8.905	0.813	1.115	3.175	7.296	3.269	0.517	0.296
O3	1/22/2015	3.447	4.408	38.705	6.947	0.959	1.008	3.955	4.922	4.046	0.678	0.321
O3	1/25/2015	3.620	4.347	31.565	6.537	1.139	1.004	4.661	10.728	3.819	0.540	0.273
O3	2/10/2015	2.832	5.676	30.137	9.016	0.939	1.043	4.792	7.781	3.643	0.801	0.278
O3	4/8/2015	0.954	1.448	19.772	2.877	0.252	0.741	0.690	5.905	0.339	0.348	0.178
O3	5/18/2015	1.073	1.889	26.962	3.386	0.248	0.204	0.728	8.537	0.471	0.389	0.085
O3	6/9/2015	1.068	1.858	27.804	4.610	0.355	0.145	0.732	7.809	0.500	0.337	0.000
O3	7/6/2015	2.930	3.314	22.462	3.496	0.687	0.633	3.064	2.988	2.647	0.433	0.181
O3	8/8/2015	1.073	2.596	27.279	7.208	0.579	0.753	3.277	8.316	2.534	0.454	0.115
10. Seiverville												
S1	7/17/2014	2.893	25.307	54.725	2.289	0.288	0.399	1.830	2.698	1.512	0.352	0.134
S1	7/21/2014	2.880	25.964	53.263	2.308	0.325	0.405	1.812	2.522	1.534	0.375	0.151
S1	7/29/2014	2.854	25.355	53.523	2.294	0.292	0.403	1.880	2.619	1.548	0.339	0.154
S1	8/10/2014	2.890	25.720	51.132	2.189	0.307	0.391	1.855	2.419	1.467	0.348	0.090
S1	8/30/2014	2.595	23.377	48.436	1.971	0.295	0.335	1.716	2.353	1.348	0.295	0.111
S1	11/16/2014	2.600	23.410	48.613	1.967	0.285	0.322	1.709	2.362	1.347	0.298	0.074
S1	1/22/2015	3.652	34.767	76.123	2.278	0.578	0.524	2.030	4.186	1.983	0.544	0.235
S1	1/29/2015	4.348	39.209	81.579	2.966	0.527	0.627	2.956	3.198	2.106	0.567	0.275
S1	4/16/2015	2.857	26.018	56.013	0.000	0.145	0.088	0.349	3.667	0.245	0.248	0.050
S1	5/18/2015	2.863	25.929	55.015	0.000	0.178	0.046	0.355	3.749	0.231	0.245	0.080
S1	6/9/2015	2.761	26.773	57.941	0.839	0.174	0.076	0.367	2.892	0.258	0.208	0.019
S1	7/6/2015	2.870	25.867	53.615	2.190	0.323	0.369	1.893	2.593	1.480	0.325	0.129

Total I*ons*/ Metals

Site	Date Collected	Ni (mg/L)	Mg^{2+} (mg/L)	Ca^{2+} (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
1. Grainger												
G1	7/21/2014	0.104	11.841	10.446	8.266	0.026	9.906	0.867	8.543	0.185	0.011	0.122
G1	10/10/2014	0.099										
G1	10/23/2014	0.087										
G1	1/29/2015	0.097	7.954	8.237	9.190	0.034	11.719	0.640	9.560	0.144	0.003	0.063
G1	4/16/2015	0.086										
G1	5/18/2015	0.069	7.872	6.753	7.695	0.039	10.287	0.576	9.147	0.216	0.000	0.085
G1	6/9/2015	0.098										
G1	7/6/2015	0.105	7.033	5.781	10.481	0.055	14.064	0.744	10.167	0.222	0.010	0.066
2. Jamestown 1												
J1	7/22/2014	0.020	1.728	8.429	0.947	0.004	0.624	0.069	1.816	0.029	0.002	0.009
J1	7/31/2014	0.017										
J1	9/15/2014	0.020										
J1	12/10/2014	0.020										
J1	1/2/2015	0.020										
J1	1/26/2015	0.013	2.723	14.173	1.248	0.000	1.157	0.121	2.635	0.188	0.001	0.061
J1	4/16/2015	0.009	2.765	11.633	2.306	0.000	2.035	0.144	4.753	0.287	0.435	0.247
J1	6/20/2015	0.021										
J1	7/24/2015	0.030	2.958	12.158	2.216	0.000	2.684	0.168	4.641	0.342	0.091	0.301
3. Jamestown 2												
J2	7/15/2014	0.168										
J2	9/15/2014	0.119										
J2	12/10/2014	0.091										
J2	1/2/2015	0.104	18.410	37.360	0.905	0.000	0.907	0.230	2.470	0.049	0.005	0.023
J2	1/26/2015	0.124	0.586	1.667	0.321	0.000	0.350	0.024	0.555	0.010	0.000	0.003
J2	4/16/2015	0.065	14.013	26.403	2.008	0.000	5.763	2.288	6.712	0.102	0.021	0.076
J2	6/20/2015	0.208	13.796	26.453	2.392	0.004	5.710	2.276	6.929	0.114	0.063	0.038
4. Jamestown 3												
J3	7/4/2014	0.000										
J3	7/15/2014	0.000	2.206	8.907	0.485	0.019	0.472	0.215	1.536	0.079	0.002	0.005

	Total *Ions*/ Metals											
Site	Date Collected	Ni (mg/L)	Mg^2+ (mg/L)	Ca^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
4. Jamestown 3												
J3	7/22/2014	0.000										
J3	7/31/2014	0.000										
J3	9/15/2014	0.000										
J3	12/10/2014	0.000										
J3	1/2/2015	0.000										
J3	1/22/2015	0.000	0.692	2.282	0.678	0.003	1.388	0.241	2.446	0.030	0.001	0.002
J3	1/26/2015	0.000	0.634	2.084	0.311	0.001	0.295	0.080	1.984	0.017	0.001	0.001
J3	4/16/2015	0.000	1.999	9.977	1.083	0.025	2.000	0.361	2.770	0.122	0.001	0.006
J3	6/20/2015	0.000										
J3	7/24/2015	0.000										
5. Nashville 1												
N1	6/8/2014	0.328	283.743	839.358	86.882	0.476	445.666	2.269	38.768	2.671	0.415	1.492
N1	7/1/2014	0.280										
N1	7/22/2014	0.316	242.167	600.945	56.237	0.077	130.386	2.563	29.026	3.442	0.564	1.797
N1	8/26/2014	0.184										
N1	10/11/2014	0.170										
N1	1/9/2015	0.236										
N1	1/30/2015	0.321										
N1	3/23/2015	0.594	202.211	639.621	35.197	0.000	235.758	1.527	23.624	1.655	0.042	0.911
N1	6/1/2015	0.418										
N1	7/24/2015	0.228	208.790	604.462	51.857	0.187	203.682	2.248	27.709	2.036	0.128	1.237
N1	8/21/2015	0.245										
6. Nashville 2												
N2	7/1/2014	2.109	34.443	216.324	23.414	0.048	97.565	1.276	12.220	5.417	0.098	0.987
N2	8/26/2014	1.957										
N2	10/11/2014	2.212										
N2	1/9/2015	2.106										
N2	3/23/2015	0.153	157.660	803.536	57.442	1.957	361.209	3.208	28.159	3.606	0.000	1.303
N2	6/1/2015	2.393	139.745	713.086	26.853	0.205	175.812	1.996	14.023	1.430	0.065	0.503
N2	7/24/2015	1.923	132.163	705.316	70.042	0.673	646.894	3.510	25.015	6.078	0.105	2.123
N2	8/21/2015	2.136										

Total I*ons*/ Metals

Site	Date Collected	Ni (mg/L)	Mg^2+ (mg/L)	Ca^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
7. Ocoee 1												
O1	6/12/2014	0.003										
O1	6/19/2014	0.000										
O1	6/26/2014	0.007										
O1	7/1/2014	0.002										
O1	7/17/2014	0.003										
O1	7/20/2014	0.003										
O1	9/28/2014	0.003										
O1	11/2/2014	0.000										
O1	1/3/2015	0.000										
O1	1/25/2015	0.003	7.405	20.875	0.516	0.001	0.096	0.018	5.374	0.034	0.001	0.000
O1	2/10/2015	0.000	7.269	20.445	0.318	0.003	0.100	0.024	5.352	0.039	0.001	0.000
O1	4/8/2015	0.000	13.560	36.896	2.304	0.000	3.582	0.288	10.312	0.451	0.183	0.037
O1	5/18/2015	0.004	13.616	38.047	0.478	0.009	2.022	0.151	9.840	0.111	0.001	0.000
O1	6/9/2015	0.000										
O1	7/6/2015	0.006	13.043	35.025	2.142	0.000	3.233	0.268	12.658	0.349	0.276	0.236
8. Ocoee 2												
O2	6/26/2014	0.005	9.671	25.595	0.800	0.000	0.719	0.138	4.432	0.051	0.000	0.015
O2	7/1/2014	0.005	3.614	10.410	0.872	0.000	0.523	0.075	4.739	0.029	0.005	0.000
O2	7/17/2014	0.017	8.324	22.439	0.750	0.000	0.286	0.043	5.709	0.050	0.000	0.045
O2	7/20/2014	0.009										
O2	9/28/2014	0.003										
O2	11/2/2014	0.013										
O2	1/3/2015	0.010										
O2	1/25/2015	0.003										
O2	2/10/2015	0.000	8.128	25.817	0.921	0.000	0.565	0.181	4.976	0.069	0.000	0.004
O2	4/8/2015	0.013										
O2	5/18/2015	0.003										
O2	6/9/2015	0.020										
O2	7/6/2015	0.017	5.561	22.194	2.034	0.018	5.321	0.592	3.271	0.170	0.002	0.014

Total I*ons*/ Metals

Site	Date Collected	Ni (mg/L)	Mg^2+ (mg/L)	Ca^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
9. Ocoee 3												
O3	7/1/2014	0.107	1.038	14.497	1.985	0.019	4.397	0.492	3.601	0.239	0.034	0.029
O3	7/17/2014	0.010										
O3	7/20/2014	0.174	0.963	10.354	1.648	0.000	2.774	0.526	2.003	0.317	0.000	0.032
O3	9/28/2014	0.072										
O3	11/2/2014	0.090										
O3	1/3/2015	0.044										
O3	1/22/2015	0.149	6.005	72.580	22.755	0.000	20.054	3.497	21.294	1.433	0.000	0.057
O3	1/25/2015	0.200										
O3	2/10/2015	0.291	4.030	60.318	12.723	0.000	6.821	2.369	14.493	0.889	0.010	0.081
O3	4/8/2015	0.069										
O3	5/18/2015	0.137										
O3	6/9/2015	0.189										
O3	7/6/2015	0.026										
O3	8/8/2015	0.142	1.725	25.434	3.800	0.000	2.618	0.709	5.784	0.394	0.004	0.045
10. Seiverville												
S1	7/17/2014	0.027										
S1	7/21/2014	0.060	19.849	40.867	0.635	0.006	1.441	0.066	3.907	0.120	0.000	0.006
S1	7/29/2014	0.024										
S1	8/10/2014	0.033	8.084	16.859	0.526	0.004	2.107	0.157	1.980	0.096	0.022	0.043
S1	8/30/2014	0.054										
S1	11/16/2014	0.060										
S1	1/22/2015	0.084										
S1	1/29/2015	0.037	66.069	145.245	2.063	0.000	5.843	0.636	5.171	0.319	0.000	0.015
S1	4/16/2015	0.067	24.547	54.314	1.404	0.023	5.911	0.384	3.785	0.290	0.015	0.038
S1	5/18/2015	0.053										
S1	6/9/2015	0.010										
S1	7/6/2015	0.063	24.418	54.002	1.001	0.000	5.649	0.412	3.478	0.287	0.030	0.068

		Acid Anions					**Base Cations**					**Dissolved Metals**
Site	Date Collected	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)	Al^3+ (meq/L)
1. Grainger												
G1	7/21/2014	0.169	1.937	0.224	0.406	2.736	0.239	0.042	0.840	0.429	1.550	0.102
G1	10/10/2014	0.175	1.753	0.236	0.376	2.540	0.258	0.048	0.776	0.488	1.570	0.092
G1	10/23/2014	0.167	1.708	0.248	0.394	2.517	0.261	0.050	0.745	0.447	1.502	0.108
G1	1/29/2015	0.174	2.027	0.232	0.390	2.824	0.285	0.052	0.669	0.409	1.416	0.106
G1	4/16/2015	0.161	1.820	0.233	0.388	2.602	0.042	0.041	0.658	0.384	1.124	0.030
G1	5/18/2015	0.171	1.842	0.229	0.405	2.647	0.036	0.040	0.638	0.365	1.079	0.028
G1	6/9/2015	0.161	1.993	0.260	0.440	2.854	0.300	0.052	0.973	0.572	1.896	0.078
G1	7/6/2015	0.167	1.934	0.235	0.396	2.732	0.246	0.047	0.745	0.430	1.468	0.098
2. Jamestown 1												
J1	7/22/2014	0.170	1.667	0.230	0.380	2.446	0.152	0.163	0.242	0.591	1.148	0.046
J1	7/31/2014	0.163	1.749	0.248	0.386	2.547	0.168	0.165	0.207	0.491	1.031	0.046
J1	9/15/2014	0.169	1.505	0.234	0.401	2.309	0.165	0.168	0.234	0.549	1.115	0.034
J1	12/10/2014	0.186	1.357	0.237	0.399	2.179	0.158	0.157	0.258	0.625	1.198	0.032
J1	1/2/2015	0.170	1.467	0.237	0.402	2.275	0.159	0.163	0.264	0.686	1.273	0.032
J1	1/26/2015	0.181	0.351	0.240	0.378	1.150	0.141	0.175	0.249	0.513	1.078	0.032
J1	4/16/2015	0.170	1.424	0.230	0.391	2.214	0.000	0.148	0.191	0.518	0.857	0.000
J1	6/20/2015	0.182	0.871	0.208	0.343	1.604	0.222	0.164	0.349	0.874	1.608	0.062
J1	7/24/2015	0.156	1.583	0.237	0.390	2.367	0.143	0.182	0.194	0.526	1.045	0.049
3. Jamestown 2												
J2	7/15/2014	0.502	16.417	0.639	0.928	18.485	0.593	0.083	1.238	1.372	3.287	0.084
J2	9/15/2014	0.613	8.004	0.407	1.128	10.151	0.000	0.076	0.917	0.784	1.776	0.050
J2	12/10/2014	0.663	8.851	0.453	1.025	10.992	0.000	0.066	1.190	0.701	1.957	0.036
J2	1/2/2015	0.213	2.838	0.661	0.915	4.627	0.000	0.070	1.152	0.655	1.878	0.049
J2	1/26/2015	0.209	1.873	0.180	1.174	3.436	0.000	0.041	0.927	1.155	2.123	0.032
J2	4/16/2015	0.400	13.478	0.533	1.226	15.637	0.000	0.085	1.202	1.334	2.621	0.070
J2	6/20/2015	0.597	13.122	0.945	1.222	15.886	1.025	0.078	1.259	1.377	3.739	0.153
4. Jamestown 3												
J3	7/4/2014	0.103	0.325	0.222	0.240	0.890	0.070	0.037	0.175	0.405	0.688	0.015
J3	7/15/2014	0.123	0.496	0.177	0.243	1.039	0.074	0.041	0.164	0.388	0.667	0.015

		Acid Anions					Base Cations					Dissolved Metals
Site	Date Collected	Cl- (meq/L)	S04^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)	Al^3+ (meq/L)
4. Jamestown 3												
J3	7/22/2014	0.125	0.422	0.105	0.239	0.891	0.076	0.040	0.177	0.368	0.662	0.016
J3	7/31/2014	0.147	0.342	0.147	0.178	0.814	0.081	0.038	0.163	0.361	0.642	0.014
J3	9/15/2014	0.126	0.277	0.152	0.201	0.755	0.067	0.035	0.152	0.363	0.617	0.013
J3	12/10/2014	0.148	0.284	0.180	0.223	0.836	0.067	0.035	0.152	0.382	0.637	0.013
J3	1/2/2015	0.137	0.412	0.130	0.215	0.895	0.067	0.035	0.152	0.377	0.631	0.013
J3	1/22/2015	0.101	0.398	0.172	0.178	0.848	0.067	0.035	0.153	0.360	0.615	0.013
J3	1/26/2015	0.092	0.327	0.152	0.259	0.830	0.067	0.036	0.152	0.383	0.638	0.013
J3	4/16/2015	0.132	0.356	0.119	0.247	0.855	0.018	0.039	0.152	0.408	0.618	0.002
J3	6/20/2015	0.182	0.335	0.243	0.371	1.131	0.094	0.041	0.180	0.452	0.768	0.009
J3	7/24/2015	0.136	0.431	0.155	0.172	0.894	0.074	0.039	0.169	0.411	0.692	0.015
5. Nashville 1												
N1	6/8/2014	0.410	46.106	0.548	0.934	47.998	1.262	0.019	12.708	23.140	37.130	0.361
N1	7/1/2014	0.454	46.829	0.527	0.762	48.573	1.161	0.018	12.654	23.338	37.171	0.378
N1	7/22/2014	0.462	47.538	0.536	0.861	49.397	1.093	0.017	12.641	23.084	36.835	0.369
N1	8/26/2014	0.336	36.811	0.440	0.312	37.898	0.954	0.018	12.472	22.632	36.076	0.278
N1	10/11/2014	0.415	36.757	0.291	0.285	37.749	1.191	0.018	13.589	23.947	38.745	0.282
N1	1/9/2015	0.326	36.338	0.292	0.285	37.241	1.223	0.018	12.111	23.429	36.782	0.269
N1	1/30/2015	0.326	36.331	0.397	0.280	37.335	1.092	0.018	13.144	23.226	37.480	0.262
N1	3/23/2015	0.378	49.611	0.488	0.280	50.756	0.044	0.015	14.747	30.977	45.784	0.004
N1	6/1/2015	0.326	46.044	0.464	0.301	47.134	0.770	0.015	16.365	31.386	48.535	0.045
N1	7/24/2015	0.502	47.627	0.590	0.710	49.429	1.236	0.018	13.278	22.436	36.968	0.356
N1	8/21/2015	0.531	47.793	0.541	0.849	49.714	1.108	0.019	12.404	23.269	36.800	0.347
6. Nashville 2												
N2	7/1/2014	0.469	17.949	0.649	1.076	20.143	1.341	0.053	12.075	25.671	39.140	5.406
N2	8/26/2014	0.517	17.419	0.701	1.051	19.687	1.273	0.049	11.898	26.873	40.094	4.614
N2	10/11/2014	0.399	18.158	0.758	0.602	19.917	1.511	0.048	10.744	26.530	38.832	4.517
N2	1/9/2015	0.358	15.292	0.330	1.343	17.323	11.931	0.164	3.520	24.788	40.403	4.949
N2	3/23/2015	0.465	15.987	0.556	0.740	17.748	0.000	0.045	10.514	31.141	41.700	0.002
N2	6/1/2015	0.414	17.497	0.557	0.614	19.082	2.057	0.049	12.630	29.135	43.871	4.487
N2	7/24/2015	0.327	17.911	0.236	0.980	19.455	1.248	0.049	11.419	25.984	38.700	5.563
N2	8/21/2015	0.422	9.505	0.552	0.929	11.409	1.365	0.050	11.338	26.391	39.144	5.159

		Acid Anions					Base Cations					Dissolved Metals
Site	Date Collected	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)	Al^3+ (meq/L)
7. Ocoee 1												
O1	6/12/2014	0.126	1.037	0.370	0.304	1.836	0.530	0.008	1.230	2.361	4.129	0.036
O1	6/19/2014	0.208	0.619	0.307	0.188	1.322	0.654	0.010	1.528	2.038	4.229	0.040
O1	6/26/2014	0.162	1.512	0.536	0.345	2.555	0.564	0.009	1.454	2.507	4.534	0.034
O1	7/1/2014	0.144	1.064	0.319	0.294	1.822	0.512	0.009	1.478	2.219	4.218	0.034
O1	7/17/2014	0.168	0.601	0.202	0.340	1.312	0.502	0.008	1.362	2.391	4.263	0.037
O1	7/20/2014	0.118	0.417	0.524	0.343	1.403	0.525	0.009	1.324	2.508	4.365	0.038
O1	9/28/2014	0.095	0.510	0.256	0.227	1.088	0.484	0.007	1.270	2.110	3.871	0.031
O1	11/2/2014	0.115	1.019	0.234	0.178	1.546	0.521	0.008	1.327	2.065	3.921	0.032
O1	1/3/2015	0.108	0.800	0.192	0.175	1.275	0.497	0.008	1.315	2.045	3.865	0.031
O1	1/25/2015	0.159	0.441	0.231	0.219	1.049	0.495	0.008	1.290	2.096	3.888	0.031
O1	2/10/2015	0.081	0.426	0.268	0.209	0.984	0.499	0.008	1.201	1.992	3.700	0.032
O1	4/8/2015	0.176	0.932	0.345	0.299	1.753	0.094	0.006	1.053	1.759	2.912	0.001
O1	5/18/2015	0.153	0.985	0.358	0.236	1.733	0.075	0.006	1.082	1.747	2.910	0.001
O1	6/9/2015	0.177	0.728	0.230	0.392	1.528	0.606	0.010	1.365	2.242	4.223	0.027
O1	7/6/2015	0.159	0.952	0.477	0.339	1.926	0.547	0.008	1.354	2.251	4.161	0.034
8. Ocoee 2												
O2	6/26/2014	0.180	1.216	0.209	0.323	1.928	0.245	0.032	0.864	1.660	2.802	0.051
O2	7/1/2014	0.183	1.051	0.220	0.351	1.806	0.234	0.031	0.787	1.704	2.756	0.033
O2	7/17/2014	0.179	1.157	0.201	0.331	1.869	0.076	0.025	0.655	1.501	2.256	0.000
O2	7/20/2014	0.185	0.987	0.204	0.334	1.710	0.222	0.030	0.756	1.669	2.677	0.009
O2	9/28/2014	0.159	0.981	0.193	0.309	1.642	0.205	0.024	0.639	1.431	2.300	0.028
O2	11/2/2014	0.161	0.891	0.186	0.295	1.533	0.162	0.024	0.619	1.359	2.164	0.041
O2	1/3/2015	0.156	1.029	0.177	0.303	1.664	0.310	0.024	0.683	1.370	2.388	0.013
O2	1/25/2015	0.160	0.964	0.189	0.304	1.617	0.242	0.024	0.673	1.348	2.287	0.019
O2	2/10/2015	0.161	0.909	0.189	0.309	1.569	0.225	0.023	0.647	1.422	2.316	0.012
O2	4/8/2015	0.180	1.117	0.195	0.320	1.812	0.247	0.035	0.973	1.639	2.894	0.034
O2	5/18/2015	0.177	1.083	0.232	0.351	1.843	0.233	0.028	0.784	1.558	2.604	0.036
O2	6/9/2015	0.191	1.152	0.208	0.279	1.829	0.275	0.026	1.027	1.477	2.806	0.002
O2	7/6/2015	0.175	0.986	0.212	0.327	1.699	0.403	0.034	0.857	1.783	3.076	0.068

		Acid Anions					Base Cations					Dissolved Metals
Site	Date Collected	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)	Al^3+ (meq/L)
9. Ocoee 3												
O3	7/1/2014	0.162	1.682	0.220	0.331	2.395	1.458	0.058	0.224	1.423	3.163	0.571
O3	7/17/2014	0.180	1.964	0.228	0.369	2.740	1.396	0.064	0.222	1.165	2.847	0.695
O3	7/20/2014	0.187	1.572	0.221	0.377	2.356	1.031	0.048	0.251	1.106	2.436	0.557
O3	9/28/2014	0.158	1.603	0.201	0.311	2.273	1.006	0.038	0.212	1.036	2.292	0.502
O3	11/2/2014	0.156	1.753	0.201	0.309	2.419	1.011	0.052	0.225	1.023	2.311	0.597
O3	1/3/2015	0.257	2.804	0.392	0.470	3.924	1.862	0.074	0.407	1.757	4.100	0.990
O3	1/22/2015	0.254	2.889	0.321	0.436	3.901	1.471	0.088	0.363	1.935	3.858	0.772
O3	1/25/2015	0.221	2.901	0.306	0.531	3.959	2.656	0.093	0.358	1.578	4.685	0.727
O3	2/10/2015	0.250	2.510	0.306	0.460	3.525	1.856	0.073	0.467	1.507	3.903	1.003
O3	4/8/2015	0.170	1.876	0.232	0.316	2.593	0.000	0.024	0.119	0.989	1.132	0.320
O3	5/18/2015	0.178	2.004	0.221	0.358	2.760	0.000	0.028	0.156	1.348	1.531	0.377
O3	6/9/2015	0.187	1.356	0.215	0.393	2.151	1.773	0.027	0.153	1.390	3.344	0.513
O3	7/6/2015	0.181	2.011	0.235	0.344	2.771	1.535	0.075	0.273	1.123	3.006	0.389
O3	8/8/2015	0.172	1.787	0.224	0.345	2.528	0.901	0.028	0.214	1.364	2.506	0.801
10. Seiverville												
S1	7/17/2014	0.172	2.548	0.208	0.311	3.237	0.750	0.074	2.083	2.736	5.644	0.255
S1	7/21/2014	0.181	2.442	0.224	0.371	3.217	0.590	0.074	2.137	2.663	5.464	0.257
S1	7/29/2014	0.169	2.428	0.176	0.349	3.122	0.748	0.073	2.087	2.676	5.584	0.255
S1	8/10/2014	0.186	2.380	0.167	0.347	3.081	0.608	0.074	2.117	2.557	5.356	0.243
S1	8/30/2014	0.162	2.151	0.161	0.299	2.773	0.556	0.067	1.924	2.422	4.968	0.219
S1	11/16/2014	0.161	2.176	0.181	0.304	2.822	0.580	0.067	1.927	2.431	5.004	0.219
S1	1/22/2015	0.293	4.618	0.227	0.444	5.582	1.054	0.094	2.861	3.806	7.815	0.253
S1	1/29/2015	0.298	4.457	0.297	0.419	5.471	0.727	0.111	3.227	4.079	8.144	0.330
S1	4/16/2015	0.183	2.578	0.178	0.344	3.283	0.000	0.073	2.141	2.801	5.015	0.000
S1	5/18/2015	0.181	2.638	0.233	0.330	3.383	0.000	0.073	2.134	2.751	4.958	0.000
S1	6/9/2015	0.191	2.251	0.233	0.387	3.062	0.969	0.071	2.204	2.897	6.140	0.093
S1	7/6/2015	0.179	2.555	0.189	0.336	3.259	0.637	0.074	2.129	2.681	5.521	0.244

Site	Date Collected	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Si^4+ (meq/L)	Zn^2+ (meq/L)	Ba^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	**ANC** (meq/L)
1. Grainger										
G1	7/21/2014	0.009	0.027	0.787	0.014	0.002	0.002	0.000	0.004	-0.240
G1	10/10/2014	0.006	0.029	0.838	0.014	0.002	0.002	0.000	0.003	0.017
G1	10/23/2014	0.007	0.029	0.811	0.015	0.002	0.002	0.000	0.003	-0.038
G1	1/29/2015	0.008	0.026	0.840	0.015	0.002	0.002	0.000	0.003	-0.406
G1	4/16/2015	0.002	0.015	0.780	0.006	0.001	0.002	0.000	0.003	-0.638
G1	5/18/2015	0.002	0.014	0.783	0.006	0.001	0.001	0.000	0.002	-0.730
G1	6/9/2015	0.005	0.023	1.017	0.009	0.002	0.002	0.000	0.003	0.181
G1	7/6/2015	0.007	0.027	0.785	0.014	0.002	0.002	0.000	0.004	-0.326
2. Jamestown 1										
J1	7/22/2014	0.007	0.012	0.082	0.008	0.001	0.002	0.000	0.001	-1.139
J1	7/31/2014	0.008	0.012	0.080	0.008	0.001	0.002	0.000	0.001	-1.358
J1	9/15/2014	0.003	0.012	0.083	0.008	0.001	0.002	0.000	0.001	-1.049
J1	12/10/2014	0.004	0.012	0.078	0.009	0.001	0.002	0.000	0.001	-0.841
J1	1/2/2015	0.004	0.012	0.076	0.009	0.001	0.002	0.000	0.001	-0.865
J1	1/26/2015	0.003	0.012	0.087	0.008	0.001	0.002	0.000	0.000	0.074
J1	4/16/2015	0.002	0.000	0.118	0.000	0.001	0.001	0.000	0.000	-1.234
J1	6/20/2015	0.002	0.001	0.153	0.002	0.001	0.001	0.000	0.001	0.227
J1	7/24/2015	0.008	0.012	0.079	0.008	0.001	0.002	0.000	0.001	-1.162
3. Jamestown 2										
J2	7/15/2014	0.066	0.082	1.069	0.004	0.004	0.005	0.001	0.006	-13.877
J2	9/15/2014	0.004	0.055	0.767	0.003	0.003	0.006	0.001	0.004	-7.483
J2	12/10/2014	0.003	0.086	0.669	0.002	0.003	0.005	0.002	0.003	-8.227
J2	1/2/2015	0.002	0.079	0.544	0.003	0.003	0.005	0.001	0.004	-2.060
J2	1/26/2015	0.003	0.074	0.927	0.004	0.003	0.006	0.001	0.004	-0.259
J2	4/16/2015	0.004	0.084	1.093	0.004	0.004	0.005	0.001	0.002	-11.749
J2	6/20/2015	0.095	0.076	0.956	0.004	0.004	0.002	0.001	0.007	-10.848
4. Jamestown 3										
J3	7/4/2014	0.002	0.003	0.347	0.002	0.001	0.001	0.000	0.000	0.168
J3	7/15/2014	0.002	0.003	0.381	0.003	0.001	0.001	0.000	0.000	0.033

Site	Date Collected	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Si^4+ (meq/L)	Zn^2+ (meq/L)	Ba^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	**ANC** (meq/L)
4. Jamestown 3										
J3	7/22/2014	0.002	0.003	0.358	0.003	0.001	0.001	0.000	0.000	0.154
J3	7/31/2014	0.002	0.003	0.393	0.003	0.001	0.001	0.000	0.000	0.244
J3	9/15/2014	0.001	0.003	0.330	0.002	0.001	0.001	0.000	0.000	0.214
J3	12/10/2014	0.002	0.003	0.333	0.002	0.001	0.001	0.000	0.000	0.156
J3	1/2/2015	0.002	0.003	0.327	0.002	0.001	0.001	0.000	0.000	0.085
J3	1/22/2015	0.002	0.003	0.327	0.002	0.001	0.001	0.000	0.000	0.116
J3	1/26/2015	0.002	0.003	0.335	0.002	0.001	0.001	0.000	0.000	0.165
J3	4/16/2015	0.001	0.000	0.365	0.001	0.001	0.000	0.000	0.000	0.133
J3	6/20/2015	0.002	0.000	0.409	0.001	0.001	0.000	0.000	0.000	0.059
J3	7/24/2015	0.002	0.003	0.362	0.003	0.001	0.001	0.000	0.000	0.184
5. Nashville 1										
N1	6/8/2014	0.021	0.095	1.039	0.073	0.007	0.017	0.002	0.011	-9.242
N1	7/1/2014	0.022	0.096	1.027	0.068	0.008	0.016	0.003	0.010	-9.774
N1	7/22/2014	0.021	0.095	1.048	0.070	0.008	0.016	0.002	0.011	-10.924
N1	8/26/2014	0.018	0.095	1.058	0.071	0.008	0.018	0.003	0.006	-0.265
N1	10/11/2014	0.016	0.092	1.026	0.067	0.007	0.017	0.000	0.006	2.509
N1	1/9/2015	0.019	0.095	1.050	0.070	0.008	0.020	0.003	0.008	1.081
N1	1/30/2015	0.017	0.097	1.029	0.071	0.008	0.017	0.002	0.011	1.659
N1	3/23/2015	0.004	0.039	1.667	0.022	0.005	0.008	0.002	0.020	-3.203
N1	6/1/2015	0.003	0.035	1.356	0.008	0.005	0.007	0.003	0.014	2.877
N1	7/24/2015	0.022	0.095	1.056	0.068	0.008	0.018	0.002	0.008	-10.828
N1	8/21/2015	0.020	0.095	0.978	0.066	0.007	0.019	0.003	0.008	-11.373
6. Nashville 2										
N2	7/1/2014	0.090	0.207	2.937	0.276	0.007	0.034	0.002	0.072	28.028
N2	8/26/2014	0.078	0.222	3.130	0.273	0.007	0.034	0.002	0.067	28.832
N2	10/11/2014	0.124	0.221	3.015	0.269	0.008	0.030	0.003	0.075	27.177
N2	1/9/2015	0.055	0.210	3.157	0.275	0.008	0.034	0.004	0.072	31.844
N2	3/23/2015	0.004	0.045	0.925	0.005	0.005	0.008	0.002	0.005	24.951
N2	6/1/2015	0.006	0.133	3.235	0.227	0.005	0.030	0.001	0.082	32.996
N2	7/24/2015	0.027	0.209	2.927	0.260	0.007	0.034	0.002	0.066	28.340
N2	8/21/2015	0.083	0.212	3.074	0.276	0.007	0.032	0.001	0.073	36.652

Site	Date Collected	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Si^4+ (meq/L)	Zn^2+ (meq/L)	Ba^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	**ANC** (meq/L)
7. Ocoee 1										
O1	6/12/2014	0.002	0.001	1.218	0.002	0.001	0.001	0.000	0.000	3.554
O1	6/19/2014	0.001	0.001	1.068	0.002	0.001	0.002	0.000	0.000	4.022
O1	6/26/2014	0.002	0.001	1.160	0.002	0.001	0.001	0.000	0.000	3.181
O1	7/1/2014	0.002	0.001	1.188	0.002	0.001	0.001	0.000	0.000	3.625
O1	7/17/2014	0.002	0.001	1.126	0.002	0.001	0.001	0.000	0.000	4.121
O1	7/20/2014	0.001	0.001	1.139	0.002	0.001	0.001	0.000	0.000	4.146
O1	9/28/2014	0.002	0.001	1.053	0.002	0.001	0.001	0.000	0.000	3.874
O1	11/2/2014	0.002	0.001	1.037	0.002	0.001	0.001	0.000	0.000	3.451
O1	1/3/2015	0.001	0.001	1.083	0.002	0.001	0.001	0.000	0.000	3.710
O1	1/25/2015	0.002	0.001	0.998	0.002	0.001	0.001	0.000	0.000	3.874
O1	2/10/2015	0.001	0.001	1.011	0.002	0.001	0.001	0.000	0.000	3.764
O1	4/8/2015	0.001	0.000	0.675	0.001	0.001	0.002	0.000	0.000	1.840
O1	5/18/2015	0.001	0.000	0.745	0.001	0.001	0.002	0.000	0.000	1.928
O1	6/9/2015	0.001	0.000	1.045	0.002	0.001	0.001	0.000	0.000	3.771
O1	7/6/2015	0.002	0.001	1.120	0.002	0.001	0.002	0.000	0.000	3.396
8. Ocoee 2										
O2	6/26/2014	0.004	0.006	0.351	0.008	0.001	0.003	0.000	0.000	1.299
O2	7/1/2014	0.004	0.007	0.411	0.005	0.001	0.003	0.001	0.000	1.416
O2	7/17/2014	0.001	0.002	0.347	0.001	0.001	0.001	0.000	0.001	0.741
O2	7/20/2014	0.001	0.000	0.391	0.001	0.001	0.001	0.000	0.000	1.373
O2	9/28/2014	0.002	0.009	0.315	0.004	0.001	0.002	0.000	0.000	1.020
O2	11/2/2014	0.002	0.009	0.310	0.005	0.001	0.002	0.000	0.000	1.001
O2	1/3/2015	0.002	0.001	0.319	0.005	0.001	0.002	0.000	0.000	1.068
O2	1/25/2015	0.002	0.011	0.312	0.006	0.001	0.002	0.000	0.000	1.024
O2	2/10/2015	0.002	0.006	0.312	0.007	0.001	0.001	0.000	0.000	1.090
O2	4/8/2015	0.004	0.012	0.382	0.007	0.001	0.002	0.000	0.000	1.525
O2	5/18/2015	0.005	0.006	0.356	0.009	0.001	0.002	0.001	0.000	1.176
O2	6/9/2015	0.005	0.014	0.498	0.002	0.001	0.002	0.000	0.001	1.502
O2	7/6/2015	0.005	0.018	0.398	0.013	0.002	0.004	0.001	0.001	1.886

Site	Date Collected	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Si^4+ (meq/L)	Zn^2+ (meq/L)	Ba^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	**ANC** (meq/L)
9. Ocoee 3										
O3	7/1/2014	0.025	0.129	0.747	0.084	0.006	0.029	0.003	0.004	2.364
O3	7/17/2014	0.023	0.116	0.804	0.085	0.006	0.020	0.001	0.000	1.859
O3	7/20/2014	0.027	0.121	0.582	0.079	0.007	0.020	0.002	0.006	1.479
O3	9/28/2014	0.022	0.105	0.724	0.073	0.005	0.019	0.001	0.002	1.473
O3	11/2/2014	0.021	0.103	0.669	0.072	0.005	0.015	0.001	0.003	1.379
O3	1/3/2015	0.040	0.116	1.039	0.100	0.008	0.026	0.005	0.001	2.501
O3	1/22/2015	0.036	0.144	0.701	0.124	0.010	0.030	0.006	0.005	1.785
O3	1/25/2015	0.036	0.170	1.528	0.117	0.008	0.036	0.005	0.007	3.358
O3	2/10/2015	0.037	0.174	1.108	0.111	0.012	0.030	0.005	0.010	2.867
O3	4/8/2015	0.027	0.025	0.841	0.010	0.005	0.008	0.003	0.002	-0.220
O3	5/18/2015	0.007	0.027	1.216	0.014	0.006	0.008	0.002	0.005	0.431
O3	6/9/2015	0.005	0.027	1.112	0.015	0.005	0.011	0.000	0.006	2.886
O3	7/6/2015	0.023	0.112	0.425	0.081	0.006	0.022	0.003	0.001	1.296
O3	8/8/2015	0.027	0.119	1.184	0.078	0.007	0.018	0.002	0.005	2.219
10. Seiverville										
S1	7/17/2014	0.014	0.067	0.384	0.046	0.005	0.009	0.002	0.001	3.190
S1	7/21/2014	0.015	0.066	0.359	0.047	0.005	0.010	0.003	0.002	3.010
S1	7/29/2014	0.014	0.068	0.373	0.047	0.005	0.009	0.003	0.001	3.238
S1	8/10/2014	0.014	0.068	0.344	0.045	0.005	0.010	0.002	0.001	3.007
S1	8/30/2014	0.012	0.062	0.335	0.041	0.004	0.009	0.002	0.002	2.882
S1	11/16/2014	0.012	0.062	0.336	0.041	0.004	0.009	0.001	0.002	2.869
S1	1/22/2015	0.019	0.074	0.596	0.061	0.008	0.018	0.004	0.003	3.269
S1	1/29/2015	0.022	0.108	0.455	0.064	0.008	0.017	0.005	0.001	3.683
S1	4/16/2015	0.003	0.013	0.522	0.008	0.004	0.005	0.001	0.002	2.289
S1	5/18/2015	0.002	0.013	0.534	0.007	0.004	0.006	0.001	0.002	2.144
S1	6/9/2015	0.003	0.013	0.412	0.008	0.003	0.005	0.000	0.000	3.616
S1	7/6/2015	0.013	0.069	0.369	0.045	0.005	0.010	0.002	0.002	3.021

Appendix E: Literature Review of Toxicity Thresholds to Acidification for Aquatic Biota

Fish and macroinvertebrate survival, growth and productivity are dependent on both biological and environmental factors. Long-term acid deposition caused chronic and episodic aquatic acidification, leading to the depression of pH and increase of aluminum and metals. Most studies about the toxicity of stream acidification to salmonids and macroinvertebrate are emphasized on the effects of reduced pH, elevated aluminum and metals concentration to fish abundance and mortality, and macroinvertebrate biodiversity. Few studies also researched the toxicity threshold of nitrate and nitrite to aquatic biota (Westin 1974; Lewis and Morris 1986). As the stream concentrations of nitrate are generally about 100 times lower than the toxicity threshold, current report will not discuss the toxicity of nitrate and nitrite but just pH, aluminum and metals.

E.1. pH

Protons (H^+) could be lethal to fish by causing loss of Na^+ and Cl^- across the gill (Spry and Wiener 1991). The mechanism of acid toxicity to fish and macroinvertebrate is to disrupt ion regulation, leading to a severe deficiency of extracellular ions (Courtney and Clements 1998; Felten and Guérold 2006). Generally, the reduction of pH will lead to the increase of aluminum concentrations in stream to increase the toxicity. However, the co-existing calcium can prolong survival time of fishes at acidic solution. The concentration above 1.4 mg L^{-1} calcium can bring a marked improvement in fishery status even in the most acid lakes with pH 4.3-4.6 (Howells *et al*. 1983). Aqueous calcium reduces the toxicity of both H^+ and aluminum at the gills, presumably by reducing gill membrane permeability and subsequent loss of ions (Spry and Wiener 1991).

Albaster and Lloyd (1980) reported that there is likely harmful to the eggs and fry of salmonids when pH at the range of 4.5 to 5.0. When pH is reduced to 3.5 - 4.0, it is lethal to salmonids. For macroinvertebrate, acidity may affect the biodiversity. The abundance of some species sensitive to acid will be significantly reduced. It was reported that pelecypoda cannot usually tolerate a pH below 4.7-5.5 (Johnson *et al*. 1993). One study about the macroinvertebrate communities in 200 streams of the western Adirondack Mountains found that macroinvertebrate assemblages were usually unaffected above pH 6.4, were slightly impacted at pHs of 5.7-6.4, moderately impacted from pHs of 5.1-5.7, and severely impacted at pHs less than 5.1 (Baldigo et al. 2009). Table E.1 summarizes the effects of different pH to different biota and life stage by different experiments.

E.2. Metals

Acute metal toxicity to salmonids is often characterized by gill damage and the hypersecrection of mucus (Handy and Eddy 1990). Mortalities are related to physiological disturbances to respiration resulting in hypoxia and also ionoregulatory disturbances resulting in body ion depletion.

E.2.1 Dissolved Aluminum

Dissolved aluminum is often regarded as the most toxic metal for fish and invertebrates in acidified waters (Hermann *et al*. 1993). The mechanism of Al toxicity to fish are attributed to the inability of fish to maintain their osmoregulatory balance and respiratory problems associated with the coagulation of mucous on the gills (Driscoll 1985; Exley *et al*. 1991; Hermann *et al*. 1993). Aluminum tends to accumulate on the gill rather than in other organs (Spry and Wiener 1991). The accumulates of aluminum on the gills is presumed to displace Ca^{2+} and cause increased ion and electrolyte loss, loss of ability to adsorb ions, hemo-concentration, and impair oxygen delivery to the fish tissues (Dussault *et al*. 2004). Other than the precipitation of solid $Al(OH)_3$ or cellular

Table E.1. Toxicity threshold values of pH for trout (salmonids) and benthic macroinvertebrates.

Biota name	**Methods**	**pH**	**Co-existing chemicals**	**Effects**	**References**
Fish		4.5	$Ca^{2+} < 0.8$ mg L^{-1}	Lakes will be fishless	Howells *et al.* 1983
Brook trout	Laboratory exposures for 5 months	5.5		Reduced growth	Menendez 1976
Brook trout	field experiments in acid brook water	~5		Reduced growth	Muniz and Leivestad 1979
Brook trout fry	Field exposure to episodic acidification for 20 days in Adirondack Lake	4.8		100% mortality	Van Offelen *et al*. 1994
Brook trout, eggs, larvae and young	Lab exposure for 30 days	4.5		Adverse effects on mortality, growth, behavior and biochemical responses	Cleveland *et al*. 1986
		5.5	Al = 300 µg L^{-1}		
Brook trout	Field exposure to episodic acidification	< 5.0-5.2	Inorganic Al > 100 -200 µg L^{-1}	Trout abundance was reduced	Baker *et al*. 1996
Introduced brook trout, sac fry	In-situ experiment within the North Branch of the Moose River	4.32-4.4	Al_{im} = 0.19-0.21 mg L^{-1} Ca^{2+} = 1.13-1.40 mg L^{-1} DOC = 6.0-6.9 mg L^{-1}	0% survival after 240 hours	Johnson *et al*. 1987
Introduced brook trout, feeding fry		4.53~4.87	Al_{im} = 0.18-0.25 mg L^{-1} Ca^{2+} = 1.08-1.68 mg L^{-1} DOC = 3.8-6.4 mg L^{-1}	0% survival after 336 hours	
Introduced brook trout, young of the year		4.37~4.68	Al_{im} = 0.11-0.34 mg L^{-1} Ca^{2+} = 0.41-1.30 mg L^{-1} DOC = 7.3-9.0 mg L^{-1}	0% survival after 1920 hours	
Introduced brook trout, yearling		4.44~4.68	Al_{im} = 0.11-0.18 mg L^{-1} Ca^{2+} = 0.41-1.03 mg L^{-1} DOC = 8.0-9.0 mg L^{-1}	0% survival after 672 hours	
Rainbow trout	Lab exposure up to 8 weeks	5.2	Ca^{2+} = 12± 7µmol L^{-1}	decreased swimming capacity by 5%	Dussault *et al*. 2004
Juvenile rainbow trout	Lab exposure to synthesize solution for 36 days	5.2	Ca^{2+} = 28 µeq L^{-1}	9-16% reduction of swimming capacity	Wilson *et al*. 1994

Biota name	**Methods**	**pH**	**Co-existing chemicals**	**Effects**	**Reference**
Rainbow trout	Laboratory exposures to sublethal acid conditions over 3.5 months	5.5		Reduced growth	Edwards and Hjeldnes 1977
G. fossarum (Amphipoda), *H. pellucidula* (Trichoptera), *D. cephalotes* (Plecoptera)	Exposure for 24, 72 and 120 h in a stream in France	4.73 ± 0.08	Al_{tot} = 28.4 ±1 µmol L^{-1} Ca^{2+} = 39.1 ±0.6 µmol L^{-1}	Decrease in survival rate and Na^+, Cl^-. *G. fossarum* most sensitive than *H. pellucidula* and D. cephalotes	Felten and Guérold 2006
Benthic macroinvertebra	Exposure to a stream with artificially added HNO_3 to control pH 4.0, 5.5, 6.5 and 7.4 for 7 days	4.0		Significant fewer individuals and taxa. Reduced abundance resulted primarily from reduced abundance of mayflies (Ephemeroptera)	Courtney and Clements 1998
Macroinvertebrate	Native macroinvertebrate in streams affected by episodic acidification in Swiss	< 5.0	Al_{tot} up to 140 µg L^{-1}	Lower taxonomic richness; scarce empididae, *Isoperla rivulorum*, *Rhithrogena* spp. and *Baetis* spp.	Lepori *et al*. 2003
Macroinvertebrate	Native macroinvertebrate affected by episodic acidification in British streams	< 5.7-6		*Baetis muticus*, *Heptagenia lateralis* and *R. semicolorata* absent	Kowalik *et al*. 2007
Baetis alpinus	Native *B. alpinus* affected by episodic acidification	4.5-5.6		Decline to 10-20% during acid episodes	Lepori and Ormerod 2005

internalization of Al^{3+}, Poléo (1995) proposed that the process of aluminum polymerization is a mechanism of acute toxicity of aluminum to fish at pH 5.0-6.0. Also, Poléo (1995) suggested that positively charged Al-hydroxides bind to negatively charged sites of the gill surface to produce Al polymer, leading to severe clogging of the inter-lamellar space. This physical surface effect leads to acute hypoxia. As a result, the toxicity of aluminum applies primarily to fish at the gill-breathing stages. Therefore, mortality of fish by aluminum is primarily due to asphyxia at pH 6.1 and to electrolyte loss at pH 4.5 (Neville and Campbell 1988). In contrast to the adverse effect of high levels of aluminum, low levels of aluminum may protect fish from the effects of high hydrogen ion concentration by blocking the membrane permeability of hydrogen ions (Evans et al. 1988; Herrmann et al. 1993). The toxicity level was determined by the forms of dissolved aluminum (Table E.2). In general, inorganic monomeric aluminum is most toxic to fish, and the aluminum complexed to organic matter has least toxicity (Driscoll *et al*. 1980; Driscoll 1985; Baker *et al*. 1996).

The toxicity of aluminum is affected by other factors, including pH, calcium and DOC, and also by fish stage (Table D.2). It was reported that aluminum at less than 500 $\mu g\ L^{-1}$ at pH 4.8-5.2 demonstrated a toxic effect to brook trout but had no effect at higher or lower pH (Schofield and Trojnar 1980). Calcium can moderate the toxicity of aluminum. Calcium was also shown to reduce plasma ion loss (Muniz and Leivestad 1980). At the conditions with low pH, low calcium and high aluminum concentrations, survival may be reduced, growth may be affected and consequently productivity will be low. Aluminum could complex with DOC to be less toxic (Spry and Wiener 1991; Serrano *et al*. 2008).

The most sensitive stage to acid is the newly hatched fry, but the later swim-up fry is more sensitive to aluminum (Baker and Schofield 1980). The embryo is the life stage least sensitive to aluminum. After hatching, the sensitivity of fish to both acid and aluminum decreases with increasing age- a pattern reported for brook trout (Spry and Wiener 1991). It was suggested that salmonid eggs and yolk sac fry are less vulnerable to the combination of low pH and aluminum than other early life stages (Serrano *et al*. 2008).

Driscoll *et al*. (2001) suggested that the appropriate thresholds for chemical and biological recovery in streams and lakes of the Northeast U S are pH of 6.0 and Al_{IM} of 2.0 $\mu mol\ L^{-1}$. The mortality of fish is also determined to the length of time the fish are exposure. Some studies show that 2 day of exposure to acutely toxic Al_{IM} concentrations the approximate minimum exposure before brook trout begin to die (Gagen *et al*. 1993; Simonin *et al*. 1993; Van Sickle *et al*. 1996; Baldigo and Murdoch 1997). Some other aluminum thresholds were reported in the northeastern US. Significant mortality of brook trout was found when Al_{IM} levels exceeded 0.2 mg L^{-1} for 2 or more days (Baldigo and Murdoch 1997); or when Al_{tot} concentration reached 0.2 - 0.3 mg L^{-1} for 1.5 or more days (Gagen and Sharpe 1987a, 1987b); or when Al_M concentration of 0.1 mg L^{-1} during acid episodes (Simonin *et al*. 1993); or when Al_{IM} and (or) Al_{tot} exceed either 0.2 or 0.3 mg L^{-1} under low Ca (< 2.0 mg L^{-1}), DOC (< 2.0 mg L^{-1}) and pH (4.4 - 5.2) conditions (Van Sickle *et al*. 1996).

E.2.2 Other dissolved metals

Many dissolved metals, especially select heavy metals, were studied about the toxicity to aquatic biota. However, in eastern Tennessee (Blue Ridge region) only five metals in streams were monitored (Al, Cu, Fe, Mn, and Zn). Therefore, review of toxicity threshold values will focus on these five metals. Table E.3 summarized toxicity thresholds values of metals to aquatic biota.

Table E.2. Toxicity threshold values of dissolved aluminum concentrations for trout (salmonids).

Fish name	Methods	Al concentrations		Co-existing chemicals	Effects	References
		Total Al	Inorganic monomeric Al			
Brown trout		7 µmol L^{-1}		pH = 5.0	Loss of Na and Cl from the blood	Muniz and Leivestad 1979
Brook trout fry	Lab exposure to synthesized solutions for 14 days	18-36 µmol L^{-1}		pH = 4.8	Gill damage	Schofield and Trojnar 1980
Brook trout	Lab exposure for 193 days		47 µg L^{-1}	pH = 5.0 Ca^{2+} = 0.5 mg L^{-1}	44% mortality	Mount *et al.* 1988
Brook trout, young-of-the-year	Exposure to stream waters for 30 days during each spring from 1995 to 2000		Median: 4.48 µmol L^{-1} ; Range: 2.02-13.89	Median: pH = 5.03; NO$_3^-$ = 263 µmol L^{-1}	100% mortality	Baldigo *et al.* 2005
Brook trout	Field exposure to episodic acidification for 10 days	> 200 µg L^{-1}		pH < 5.1	10-19% loss of whole-body sodium	Neff *et al.* 2009
Brook trout, young-of-the-year	Exposure to spring episodic acidification for 30 days in the SW Adirondack Mountains (2001- 2003).		> 4 µmol L^{-1}		50-100% mortality during two to four days of exposure	Baldigo and Lawrence 2007
Brook trout, larvae and postlarvae	Lab exposure to softened and dechlorinated water for 13 to 14 days	0.2 mg L^{-1}		pH range from 4.2 to 5.6	Measurable reductions in survival and growth	Baker and Schofield 1982
Adult rainbow trout	Lab exposure to synthesized solutions for 10 days	>10 µmol L^{-1}		Pathological changes were more serve with aluminum at pH 5.4 than at pH 4.7	Cause chloride cell necrosis and a decline in cell numbers	Evans *et al.* 1988

Fish name	Methods	Al concentration		Co-existing chemicals	Effects	References
		Total Al	Inorganic monomeric Al			
Juvenile rainbow trout	26h of exposure to dechlorinated tap water with added aluminum	> 200 μg/L		pH = 6.0	Affect cough rate, which is defined as disruptions in the ventilation pattern.	Ogilvie and Stechey 1983
Juvenile rainbow trout	26h of exposure to dechlorinated tap water with added aluminum	> 500 μg L^{-1}		pH = 6.0	Affect ventilation rate, which is the number of opercular cycles per unit of time.	Ogilvie and Stechey 1983
Rainbow trout	Lab exposure up to 8 weeks	89 μg L^{-1}		pH = 5.1-5.2 Ca^{2+} = 12± 7 μmol L^{-1}	25% survival, decreased swimming capacity by 21%	Dussault et al. 2004
Juvenile rainbow trout	Lab exposure to synthesize solution for 36 days	38 μg L^{-1}		pH = 5.2 Ca^{2+} = 28 μeq L^{-1}	15-21% reduction of swimming capacity	Wilson et al. 1994
Juvenile rainbow trout	Lab exposure to different pH levels with same Al concentration solution for 11 days	2.8 μmol L^{-1}		pH = 6.1	Uptake of O_2 across the gill epithelium was reduced	Neville and Campbell 1988
				pH = 4.5	Increase gill membrane permeability to H^+, Na^+ and Cl^- ions	
Rainbow trout, fingerlings	Exposure to synthesized solution with varied Al and pH (7.0-9.0) for 45 days	5.2 mg L^{-1}		pH range from 7.0 to 9.0	Seriously disturb any natural population of young trout with longer than 6 weeks exposure	Freeman and Everhart 1971

Table E.3. Toxicity threshold values of metals other than aluminum to fish and benthic macroinvertebrates.

Fish name	**Methods**	**Metals**	**Co-existing chemicals and conditions**	**Effects**	**References**
Rainbow trout, swim-up stage	Laboratory exposures to synthesized well water with designed metal concentration	Cd = 1.9 µg L^{-1} Cu = 40 µg L^{-1} Zn = 219 µg L^{-1}	pH = 8.24 Alk = 92 mg L^{-1} Hardness = 103 mg L^{-1} as $CaCO_3$ Ca^{2+} = 25 mg L^{-1} Mg^{2+} = 8.0 mg L^{-1} Na^{+} = 8.3 mg L^{-1} SO_4^{2-} = 18 mg L^{-1} Cl^{-} = 9 mg L^{-1} DOC < 1 mg L^{-1}	Start to affect survival	Besser et al. 2007
Rainbow trout		Zn = 47 µg L^{-1}	112 mg L^{-1} $CaCO_3$ pH = 7.6	Fish avoidance	Black and Birge 1980
Rainbow trout		Zn = 144 µg L^{-1}	25 mg L^{-1} $CaCO_3$ pH = 7.6	Effect on fish ventilation	Cairns et al. 1982
Benthic macroinvertebrate	Exposure to a mixture of Cd, Cu and Zn for 7 days in a stream microcosm	Cd = 1.1 µg L^{-1}, Cu = 12 µg L^{-1}, Zn = 110 µg L^{-1}		Abundance of three mayfly species was reduced by more than 50%	Clements and Kiffney 1994

E.3 References: Toxicity Literature Review

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Appendix F: Pollutant Export Mass Loadings from Monitoring Station Storm Events

APPENDIX F: ROAD CUT RUNOFF MASS LOADINGS SUMMARY SHEET

		Rainfall (RF)	Runoff	Acid Anions				Base Cations			
Site	Date Collected	Rainfall (RF) (days)	Runoff (m^3)	Cl- (g/day)	SO4^2- (g/day)	NO3- (g/day)	PO4^3- (g/day)	Na+ (g/day)	K + (g/day)	Mg ^2+ (g/day)	Ca ^2+ (g/day)
1. Grainger											
G1	7/21/2014	3	1.86	3.70	57.59	8.62	7.97	3.40	1.02	6.32	5.31
G1	10/10/2014	1	1.22	7.52	102.28	17.77	14.48	7.21	2.27	11.46	11.86
G1	10/23/2014	6	3.15	3.11	43.07	8.06	6.56	3.15	1.02	4.75	4.70
G1	1/29/2015	3	0.57	1.17	18.53	2.74	2.35	1.25	0.39	1.55	1.56
G1	4/16/2015	3	1.35	2.57	39.44	6.53	5.55	0.43	0.71	3.61	3.47
G1	5/18/2015	3	0.08	0.16	2.31	0.37	0.34	0.02	0.04	0.20	0.19
G1	6/9/2015	2	1.17	3.33	55.92	9.43	8.15	4.03	1.18	6.91	6.68
G1	7/6/2015	4	1.92	2.84	44.48	7.00	6.01	2.71	0.87	4.34	4.12
2. Jamestown 1											
J1	7/22/2014	2	1.04	3.14	41.79	7.44	6.28	1.82	3.31	1.54	6.18
J1	7/31/2014	1	6.01	34.80	504.95	92.42	73.58	23.30	38.64	15.12	59.05
J1	9/15/2014	1	1.11	6.61	79.99	16.05	14.05	4.20	7.24	3.14	12.15
J1	12/10/2014	1	1.44	9.47	93.64	21.11	18.14	5.23	8.78	4.50	17.98
J1	1/2/2015	3	0.84	1.68	19.62	4.09	3.54	1.02	1.78	0.90	3.83
J1	1/26/2015	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J1	4/16/2015	2	0.98	2.95	33.61	7.01	6.08	0.00	2.83	1.14	5.09
J1	6/20/2015	1	0.67	4.32	28.06	8.68	7.30	3.42	4.30	2.85	11.73
J1	7/24/2015	1	1.11	6.11	84.13	16.29	13.68	3.63	7.84	2.61	11.65
3. Jamestown 2											
J2	7/15/2014	1	1.78	31.57	1399.61	70.33	52.17	24.24	5.78	26.73	48.74
J2	9/15/2014	1	1.59	34.52	611.34	40.12	56.83	0.00	4.69	17.72	24.95
J2	12/10/2014	1	2.07	48.51	877.80	58.00	67.05	0.00	5.33	29.87	28.97
J2	1/2/2015	3	1.20	3.03	54.58	16.42	11.61	0.00	1.10	5.61	5.25
J2	1/26/2015	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J2	4/16/2015	2	1.41	10.01	457.23	23.35	27.44	0.00	2.34	10.32	18.85
J2	6/20/2015	1	0.97	20.39	608.02	56.57	37.34	22.76	2.95	14.76	26.58

		Rainfall (RF)	Runoff	Acid Anions				Base Cations			
Site	Date Collected	Rainfall (RF) (days)	Runoff (m^3)	Cl- (g/day)	SO4^2- (g/day)	NO3- (g/day)	PO4^3- (g/day)	Na+ (g/day)	K + (g/day)	Mg ^2+ (g/day)	Ca ^2+ (g/day)
4. Jamestown 3											
J3	7/4/2014	3	0.02	0.03	0.11	0.10	0.05	0.01	0.01	0.02	0.06
J3	7/15/2014	1	0.18	0.77	4.21	1.94	1.36	0.30	0.28	0.35	1.37
J3	7/22/2014	2	0.49	1.09	4.99	1.60	1.86	0.43	0.38	0.53	1.81
J3	7/31/2014	1	1.80	9.39	29.62	16.45	10.17	3.35	2.66	3.57	13.01
J3	9/15/2014	1	0.52	2.31	6.90	4.88	3.30	0.80	0.72	0.96	3.76
J3	12/10/2014	1	0.56	2.95	7.70	6.30	3.98	0.87	0.78	1.04	4.31
J3	1/2/2015	3	0.39	0.63	2.57	1.05	0.89	0.20	0.18	0.24	0.98
J3	1/22/2015	1	0.12	0.43	2.28	1.27	0.67	0.18	0.17	0.22	0.86
J3	1/26/2015	1	0.03	0.10	0.50	0.30	0.26	0.05	0.04	0.06	0.24
J3	4/16/2015	2	0.34	0.80	2.91	1.25	1.33	0.07	0.26	0.31	1.39
J3	6/20/2015	1	0.34	2.19	5.48	5.13	4.01	0.74	0.54	0.75	3.08
J3	7/24/2015	1	0.45	2.16	9.29	4.32	2.45	0.77	0.68	0.92	3.69
5. Nashville 1											
N1	6/8/2014	1	0.61	8.89	1355.25	20.80	18.11	17.78	0.44	94.55	283.41
N1	7/1/2014	2	0.40	3.24	452.63	6.57	4.86	5.38	0.14	30.96	93.99
N1	7/22/2014	1	2.57	41.99	5855.11	85.24	69.95	64.51	1.69	394.09	1184.65
N1	8/26/2014	1	0.09	1.08	159.98	2.47	0.89	1.99	0.06	13.72	40.98
N1	10/11/2014	2	1.76	12.94	1553.25	15.89	7.95	24.12	0.62	145.35	421.63
N1	1/9/2015	2	0.99	5.71	861.80	8.93	4.47	13.90	0.35	72.71	231.52
N1	1/30/2015	2	0.26	1.50	226.23	3.19	1.15	3.26	0.09	20.72	60.26
N1	3/23/2015	2	0.13	0.84	150.11	1.91	0.56	0.06	0.04	11.29	39.05
N1	6/1/2015	2	1.86	10.73	2056.69	26.76	8.87	16.47	0.54	185.03	584.14
N1	7/24/2015	1	0.39	7.01	901.03	14.42	8.86	11.21	0.27	63.58	176.86
N1	8/21/2015	2	1.07	10.06	1226.70	17.95	14.38	13.63	0.39	80.59	248.86
6. Nashville 2											
N2	7/1/2014	2	0.31	2.57	133.45	6.23	5.28	4.78	0.32	22.72	79.53
N2	8/26/2014	1	0.07	1.27	58.23	3.03	2.32	2.04	0.13	10.07	37.43
N2	10/11/2014	2	1.35	9.56	590.22	31.82	12.91	23.53	1.26	88.40	359.31
N2	1/9/2015	2	0.76	4.81	278.97	7.78	16.17	104.29	2.44	16.26	188.42
N2	3/23/2015	2	0.10	0.80	37.21	1.67	1.14	0.00	0.08	6.19	30.20
N2	6/1/2015	2	1.43	10.50	601.20	24.73	13.92	33.86	1.38	109.84	417.12
N2	7/24/2015	1	0.30	3.51	260.66	4.45	9.41	8.70	0.58	42.06	157.56

N2	8/21/2015	2	0.82	6.14	187.68	14.08	12.11	12.91	0.81	56.66	217.11

		Rainfall (RF)	**Runoff**	**Acid Anions**				**Base Cations**			
Site	Date Collected	Rainfall (RF) (days)	Runoff (m^3)	Cl- (g/day)	SO4^2- (g/day)	NO3- (g/day)	PO4^3- (g/day)	Na+ (g/day)	K + (g/day)	Mg ^2+ (g/day)	Ca ^2+ (g/day)
7. Ocoee 1											
O1	6/12/2014	3	0.55	0.81	9.05	4.17	1.75	2.22	0.06	2.72	8.59
O1	6/19/2014	2	0.06	0.21	0.83	0.53	0.17	0.42	0.01	0.52	1.14
O1	6/26/2014	4	1.04	1.49	18.88	8.64	2.84	3.37	0.09	4.60	13.05
O1	7/1/2014	3	1.97	3.36	33.60	13.02	6.13	7.75	0.23	11.81	29.18
O1	7/17/2014	6	0.33	0.33	1.60	0.70	0.60	0.64	0.02	0.92	2.65
O1	7/20/2014	2	0.48	1.00	4.75	7.72	2.58	2.87	0.08	3.82	11.92
O1	9/28/2014	1	0.09	0.29	2.10	1.36	0.62	0.95	0.02	1.32	3.62
O1	11/2/2014	4	0.03	0.03	0.39	0.11	0.04	0.09	0.00	0.13	0.33
O1	1/3/2015	1	0.00	0.01	0.09	0.03	0.01	0.03	0.00	0.04	0.09
O1	1/25/2015	2	0.46	1.29	4.84	3.28	1.59	2.60	0.07	3.59	9.59
O1	2/10/2015	1	0.12	0.34	2.44	1.98	0.79	1.37	0.04	1.74	4.76
O1	4/8/2015	1	0.23	1.41	10.10	4.83	2.14	0.49	0.05	2.89	7.94
O1	5/18/2015	4	1.01	1.37	11.95	5.61	1.89	0.44	0.06	3.32	8.83
O1	6/9/2015	1	0.68	4.29	23.87	9.75	8.48	9.52	0.26	11.32	30.62
O1	7/6/2015	4	5.07	7.11	57.86	37.45	13.61	15.94	0.42	20.84	57.02
8. Ocoee 2											
O2	6/26/2014	4	0.87	1.38	12.66	2.81	2.22	1.22	0.27	2.28	7.20
O2	7/1/2014	3	1.64	3.56	27.66	7.47	6.09	2.94	0.66	5.24	18.68
O2	7/17/2014	6	0.28	0.29	2.57	0.58	0.48	0.08	0.05	0.37	1.39
O2	7/20/2014	2	0.40	1.30	9.37	2.50	2.10	1.01	0.23	1.82	6.61
O2	9/28/2014	1	0.07	0.40	3.36	0.85	0.70	0.34	0.07	0.55	2.04
O2	11/2/2014	4	0.03	0.04	0.28	0.08	0.06	0.02	0.01	0.05	0.18
O2	1/3/2015	1	0.00	0.01	0.09	0.02	0.02	0.01	0.00	0.02	0.05
O2	1/25/2015	2	0.38	1.08	8.83	2.23	1.83	1.06	0.18	1.56	5.14
O2	2/10/2015	1	0.10	0.57	4.34	1.17	0.98	0.52	0.09	0.78	2.83
O2	4/8/2015	1	0.19	1.20	10.08	2.27	1.91	1.07	0.26	2.22	6.16
O2	5/18/2015	4	0.84	1.32	10.95	3.02	2.34	1.13	0.23	2.01	6.56
O2	6/9/2015	1	0.57	3.84	31.46	7.33	5.03	3.60	0.58	7.10	16.81
O2	7/6/2015	4	4.22	6.53	49.95	13.84	10.92	9.78	1.39	10.99	37.64

		Rainfall (RF)	Runoff	Acid Anions				Base Cations			
Site	Date Collected	Rainfall (RF) (days)	Runoff (m^3)	Cl- (g/day)	SO4^2- (g/day)	NO3- (g/day)	PO4^3- (g/day)	Na+ (g/day)	K + (g/day)	Mg ^2+ (g/day)	Ca ^2+ (g/day)
9. Ocoee 3											
O3	7/1/2014	3	3.23	6.17	86.79	14.69	11.27	36.05	2.43	2.93	30.58
O3	7/17/2014	6	0.81	0.86	12.74	1.91	1.58	4.34	0.34	0.36	3.15
O3	7/20/2014	2	0.66	2.17	24.85	4.50	3.94	7.81	0.61	1.00	7.28
O3	9/28/2014	1	0.16	0.87	12.03	1.95	1.54	3.62	0.23	0.40	3.24
O3	11/2/2014	4	0.09	0.12	1.88	0.28	0.22	0.52	0.05	0.06	0.46
O3	1/3/2015	1	0.02	0.20	2.96	0.53	0.33	0.94	0.06	0.11	0.77
O3	1/22/2015	1	0.13	1.15	17.76	2.55	1.77	4.33	0.44	0.56	4.96
O3	1/25/2015	2	0.53	2.08	37.13	5.06	4.49	16.29	0.97	1.16	8.42
O3	2/10/2015	1	0.00	0.01	0.09	0.01	0.01	0.03	0.00	0.00	0.02
O3	4/8/2015	1	0.23	1.36	20.35	3.25	2.26	0.00	0.22	0.33	4.47
O3	5/18/2015	4	1.79	2.83	43.11	6.13	5.08	0.00	0.48	0.85	12.08
O3	6/9/2015	1	1.24	8.17	80.44	16.51	15.39	50.40	1.32	2.30	34.36
O3	7/6/2015	4	7.41	11.88	178.76	27.03	20.19	65.38	5.43	6.14	41.61
O3	8/8/2015	2	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00
10. Seiverville											
S1	7/17/2014	3	0.38	0.77	15.41	1.62	1.24	2.17	0.36	3.19	6.90
S1	7/21/2014	2	0.76	2.42	44.29	5.24	4.44	5.13	1.09	9.81	20.13
S1	7/29/2014	1	2.12	12.71	247.08	23.20	23.42	36.48	6.05	53.76	113.49
S1	8/10/2014	3	0.72	1.59	27.50	2.49	2.65	3.37	0.70	6.19	12.31
S1	8/30/2014	6	0.24	0.23	4.07	0.39	0.37	0.50	0.10	0.92	1.91
S1	11/16/2014	1	0.22	1.27	23.31	2.51	2.15	2.98	0.58	5.23	10.85
S1	1/22/2015	2	0.18	0.96	20.49	1.30	1.30	2.24	0.34	3.21	7.04
S1	1/29/2015	4	0.45	1.18	23.88	2.06	1.48	1.86	0.49	4.38	9.10
S1	4/16/2015	2	0.52	1.70	32.48	2.89	2.86	0.00	0.75	6.83	14.70
S1	5/18/2015	3	0.12	0.25	4.86	0.55	0.40	0.00	0.11	1.00	2.11
S1	6/9/2015	1	0.34	2.31	36.86	4.94	4.18	7.60	0.94	9.13	19.77
S1	7/6/2015	4	0.81	1.28	24.74	2.36	2.15	2.96	0.58	5.22	10.82

APPENDIX F: ROAD CUT RUNOFF MASS LOADINGS SUMMARY SHEET

		Dissolved Metals								
Site	Date Collected	Al (g/day)	Cu (g/day)	Fe (g/day)	Mn (g/day)	Si (g/day)	Zn (g/day)	Ba (g/day)	Cd (g/day)	Ni (g/day)
1. Grainger										
G1	7/21/2014	0.57	0.04	0.15	0.46	3.42	0.29	0.07	0.01	0.06
G1	10/10/2014	1.00	0.09	0.20	0.97	7.15	0.57	0.16	0.03	0.12
G1	10/23/2014	0.51	0.03	0.11	0.42	2.99	0.25	0.07	0.01	0.05
G1	1/29/2015	0.18	0.01	0.04	0.14	1.12	0.10	0.02	0.00	0.02
G1	4/16/2015	0.12	0.03	0.02	0.19	2.47	0.09	0.04	0.00	0.04
G1	5/18/2015	0.01	0.00	0.00	0.01	0.14	0.00	0.00	0.00	0.00
G1	6/9/2015	0.41	0.04	0.07	0.37	4.18	0.18	0.08	0.02	0.06
G1	7/6/2015	0.42	0.04	0.10	0.36	2.64	0.22	0.06	0.01	0.05
2. Jamestown 1										
J1	7/22/2014	0.22	0.04	0.10	0.17	0.30	0.14	0.04	0.01	0.01
J1	7/31/2014	2.49	0.40	1.29	1.98	3.37	1.62	0.38	0.02	0.10
J1	9/15/2014	0.34	0.06	0.11	0.37	0.64	0.30	0.07	0.01	0.02
J1	12/10/2014	0.42	0.09	0.17	0.49	0.78	0.41	0.10	0.01	0.03
J1	1/2/2015	0.08	0.01	0.03	0.09	0.15	0.08	0.02	0.00	0.01
J1	1/26/2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J1	4/16/2015	0.00	0.02	0.02	0.00	0.41	0.01	0.03	0.01	0.00
J1	6/20/2015	0.37	0.03	0.04	0.02	0.72	0.05	0.04	0.01	0.01
J1	7/24/2015	0.49	0.07	0.24	0.37	0.62	0.29	0.07	0.00	0.03
3. Jamestown 2										
J2	7/15/2014	1.33	0.29	3.30	4.01	13.33	0.23	0.51	0.11	0.30
J2	9/15/2014	0.72	0.31	0.16	2.39	8.57	0.17	0.29	0.10	0.19
J2	12/10/2014	0.67	0.33	0.18	4.86	9.70	0.15	0.44	0.18	0.19
J2	1/2/2015	0.18	0.06	0.02	0.87	1.53	0.05	0.09	0.03	0.04
J2	1/26/2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
J2	4/16/2015	0.44	0.12	0.08	1.64	5.43	0.08	0.18	0.03	0.05
J2	6/20/2015	1.33	0.07	2.56	2.01	6.48	0.11	0.24	0.07	0.20

Dissolved Metals

Site	Date Collected	Al (g/day)	Cu (g/day)	Fe (g/day)	Mn (g/day)	Si (g/day)	Zn (g/day)	Ba (g/day)	Cd (g/day)	Ni (g/day)
4. Jamestown 3										
J3	7/4/2014	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
J3	7/15/2014	0.02	0.00	0.01	0.02	0.47	0.01	0.01	0.00	0.00
J3	7/22/2014	0.03	0.00	0.01	0.02	0.62	0.02	0.01	0.00	0.00
J3	7/31/2014	0.22	0.04	0.10	0.16	4.98	0.16	0.09	0.02	0.00
J3	9/15/2014	0.06	0.01	0.02	0.04	1.20	0.04	0.03	0.01	0.00
J3	12/10/2014	0.07	0.01	0.03	0.05	1.32	0.05	0.03	0.01	0.00
J3	1/2/2015	0.02	0.00	0.01	0.01	0.30	0.01	0.01	0.00	0.00
J3	1/22/2015	0.01	0.00	0.01	0.01	0.27	0.01	0.01	0.00	0.00
J3	1/26/2015	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00
J3	4/16/2015	0.00	0.00	0.00	0.00	0.44	0.01	0.01	0.00	0.00
J3	6/20/2015	0.03	0.00	0.02	0.00	0.98	0.01	0.02	0.00	0.00
J3	7/24/2015	0.06	0.01	0.02	0.04	1.14	0.04	0.02	0.00	0.00
5. Nashville 1										
N1	6/8/2014	1.99	0.34	0.36	1.60	4.47	1.46	0.30	0.07	0.20
N1	7/1/2014	0.68	0.11	0.12	0.53	1.45	0.45	0.11	0.03	0.06
N1	7/22/2014	8.51	1.33	1.52	6.67	18.88	5.87	1.43	0.25	0.81
N1	8/26/2014	0.23	0.05	0.05	0.24	0.67	0.21	0.05	0.02	0.02
N1	10/11/2014	2.23	0.48	0.40	2.23	6.34	1.94	0.42	0.00	0.15
N1	1/9/2015	1.19	0.31	0.26	1.29	3.64	1.14	0.26	0.07	0.12
N1	1/30/2015	0.31	0.07	0.06	0.34	0.94	0.30	0.07	0.02	0.04
N1	3/23/2015	0.00	0.02	0.01	0.07	0.74	0.05	0.02	0.01	0.04
N1	6/1/2015	0.38	0.20	0.08	0.89	8.86	0.24	0.34	0.13	0.39
N1	7/24/2015	1.26	0.22	0.24	1.03	2.92	0.88	0.21	0.04	0.09
N1	8/21/2015	1.67	0.32	0.30	1.39	3.67	1.15	0.27	0.08	0.13
6. Nashville 2										
N2	7/1/2014	7.53	0.17	0.39	0.88	3.19	1.40	0.07	0.02	0.33
N2	8/26/2014	2.89	0.07	0.15	0.42	1.53	0.62	0.04	0.01	0.14
N2	10/11/2014	27.51	0.65	2.34	4.11	14.34	5.96	0.35	0.11	1.50
N2	1/9/2015	16.91	0.42	0.58	2.19	8.43	3.42	0.22	0.09	0.80
N2	3/23/2015	0.00	0.01	0.01	0.06	0.31	0.01	0.02	0.00	0.01
N2	6/1/2015	28.89	0.69	0.13	2.62	16.26	5.31	0.25	0.05	1.71
N2	7/24/2015	15.17	0.32	0.23	1.74	6.23	2.58	0.14	0.04	0.58

N2	8/21/2015	19.08	0.42	0.95	2.39	8.88	3.71	0.20	0.03	0.88

Dissolved Metals

Site	Date Collected	Al (g/day)	Cu (g/day)	Fe (g/day)	Mn (g/day)	Si (g/day)	Zn (g/day)	Ba (g/day)	Cd (g/day)	Ni (g/day)
7. Ocoee 1										
O1	6/12/2014	0.06	0.01	0.01	0.00	1.56	0.01	0.02	0.00	0.00
O1	6/19/2014	0.01	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00
O1	6/26/2014	0.08	0.01	0.01	0.01	2.12	0.01	0.02	0.00	0.00
O1	7/1/2014	0.20	0.03	0.03	0.01	5.49	0.03	0.06	0.01	0.00
O1	7/17/2014	0.02	0.00	0.00	0.00	0.44	0.00	0.00	0.00	0.00
O1	7/20/2014	0.08	0.01	0.01	0.00	1.90	0.01	0.02	0.00	0.00
O1	9/28/2014	0.02	0.00	0.00	0.00	0.63	0.00	0.01	0.00	0.00
O1	11/2/2014	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00
O1	1/3/2015	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00
O1	1/25/2015	0.06	0.01	0.01	0.00	1.60	0.01	0.02	0.00	0.00
O1	2/10/2015	0.03	0.00	0.00	0.00	0.85	0.01	0.01	0.00	0.00
O1	4/8/2015	0.00	0.01	0.01	0.00	1.07	0.00	0.02	0.00	0.00
O1	5/18/2015	0.00	0.01	0.00	0.00	1.32	0.01	0.02	0.00	0.00
O1	6/9/2015	0.16	0.02	0.01	0.00	5.01	0.04	0.04	0.01	0.00
O1	7/6/2015	0.39	0.06	0.06	0.02	9.96	0.07	0.11	0.02	0.01
8. Ocoee 2										
O2	6/26/2014	0.10	0.02	0.02	0.03	0.53	0.05	0.02	0.00	0.00
O2	7/1/2014	0.16	0.05	0.06	0.11	1.58	0.10	0.05	0.02	0.00
O2	7/17/2014	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00
O2	7/20/2014	0.02	0.01	0.00	0.00	0.54	0.01	0.02	0.00	0.00
O2	9/28/2014	0.02	0.00	0.00	0.02	0.16	0.01	0.01	0.00	0.00
O2	11/2/2014	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
O2	1/3/2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
O2	1/25/2015	0.03	0.01	0.01	0.06	0.42	0.04	0.01	0.00	0.00
O2	2/10/2015	0.01	0.00	0.00	0.02	0.22	0.02	0.01	0.00	0.00
O2	4/8/2015	0.06	0.01	0.02	0.06	0.50	0.04	0.02	0.00	0.00
O2	5/18/2015	0.07	0.01	0.03	0.03	0.53	0.06	0.02	0.01	0.00
O2	6/9/2015	0.01	0.04	0.07	0.22	1.99	0.03	0.06	0.01	0.01
O2	7/6/2015	0.65	0.13	0.14	0.51	2.95	0.46	0.12	0.05	0.02

Dissolved Metals

Site	Date Collected	Al (g/day)	Cu (g/day)	Fe (g/day)	Mn (g/day)	Si (g/day)	Zn (g/day)	Ba (g/day)	Cd (g/day)	Ni (g/day)
9. Ocoee 3										
O3	7/1/2014	5.52	0.98	0.76	3.81	5.64	2.94	0.46	0.16	0.11
O3	7/17/2014	0.84	0.08	0.09	0.43	0.76	0.38	0.06	0.01	0.00
O3	7/20/2014	1.65	0.21	0.24	1.09	1.35	0.85	0.15	0.03	0.06
O3	9/28/2014	0.71	0.09	0.10	0.45	0.79	0.37	0.06	0.01	0.01
O3	11/2/2014	0.12	0.01	0.01	0.06	0.11	0.05	0.01	0.00	0.00
O3	1/3/2015	0.20	0.02	0.02	0.07	0.16	0.07	0.01	0.01	0.00
O3	1/22/2015	0.89	0.12	0.13	0.51	0.63	0.52	0.09	0.04	0.02
O3	1/25/2015	1.74	0.30	0.27	1.24	2.86	1.02	0.14	0.07	0.05
O3	2/10/2015	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
O3	4/8/2015	0.65	0.06	0.17	0.16	1.33	0.08	0.08	0.04	0.02
O3	5/18/2015	1.52	0.11	0.09	0.33	3.83	0.21	0.17	0.04	0.06
O3	6/9/2015	5.70	0.44	0.18	0.90	9.65	0.62	0.42	0.00	0.23
O3	7/6/2015	6.48	1.27	1.17	5.68	5.53	4.90	0.80	0.34	0.05
O3	8/8/2015	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10. Seiverville										
S1	7/17/2014	0.29	0.04	0.05	0.23	0.34	0.19	0.04	0.02	0.00
S1	7/21/2014	0.87	0.12	0.15	0.68	0.95	0.58	0.14	0.06	0.02
S1	7/29/2014	4.86	0.62	0.85	3.99	5.55	3.28	0.72	0.33	0.05
S1	8/10/2014	0.53	0.07	0.09	0.45	0.58	0.35	0.08	0.02	0.01
S1	8/30/2014	0.08	0.01	0.01	0.07	0.09	0.05	0.01	0.00	0.00
S1	11/16/2014	0.44	0.06	0.07	0.38	0.53	0.30	0.07	0.02	0.01
S1	1/22/2015	0.21	0.05	0.05	0.19	0.39	0.18	0.05	0.02	0.01
S1	1/29/2015	0.33	0.06	0.07	0.33	0.36	0.24	0.06	0.03	0.00
S1	4/16/2015	0.00	0.04	0.02	0.09	0.96	0.06	0.07	0.01	0.02
S1	5/18/2015	0.00	0.01	0.00	0.01	0.14	0.01	0.01	0.00	0.00
S1	6/9/2015	0.29	0.06	0.03	0.13	0.99	0.09	0.07	0.01	0.00
S1	7/6/2015	0.44	0.07	0.07	0.38	0.52	0.30	0.07	0.03	0.01

ROAD CUT RUNOFF WATER CHEMISTRY: SUMMARY SHEET

MASS LOADINGS

Units: g/day

Chemical Parameter	SITE											
	Grainger 1				Jamestown 1				Jamestown 2			
	Mean	StDev	Min	Max	Mean	StDev	Min	Max	Mean	StDev	Min	Max
Cl-	3.05	2.16	0.16	7.52	7.67	10.56	0.00	34.80	22.85	17.32	0.00	48.51
SO4^2-	45.45	29.56	2.31	102.28	98.42	155.76	0.00	504.95	564.19	446.16	0.00	1399.61
NO3-	7.56	5.14	0.37	17.77	19.23	28.23	0.00	92.42	44.65	30.53	0.00	92.42
PO4^3-	6.42	4.22	0.34	14.48	15.85	22.39	0.00	73.58	40.75	26.34	0.00	73.58
Na+	2.78	2.31	0.02	7.21	4.74	7.21	0.00	23.30	8.79	12.14	0.00	24.24
K +	0.94	0.66	0.04	2.27	8.30	11.75	0.00	38.64	7.60	12.70	0.00	38.64
Mg ^2+	4.89	3.47	0.20	11.46	3.53	4.55	0.00	15.12	15.01	10.01	0.00	29.87
Ca ^2+	4.74	3.54	0.19	11.86	14.18	17.68	0.00	59.05	26.55	19.91	0.00	59.05
Al	0.40	0.31	0.01	1.00	0.49	0.77	0.00	2.49	0.89	0.80	0.00	2.49
Cu	0.03	0.03	0.00	0.09	0.08	0.12	0.00	0.40	0.20	0.15	0.00	0.40
Fe	0.09	0.07	0.00	0.20	0.22	0.41	0.00	1.29	0.95	1.31	0.00	3.30
Mn	0.36	0.29	0.01	0.97	0.39	0.62	0.00	1.98	2.22	1.58	0.00	4.86
Si	3.02	2.10	0.14	7.15	0.78	1.01	0.00	3.37	6.05	4.43	0.00	13.33
Zn	0.21	0.17	0.00	0.57	0.32	0.51	0.00	1.62	0.30	0.54	0.00	1.62
Ba	0.06	0.05	0.00	0.16	0.08	0.12	0.00	0.38	0.27	0.18	0.00	0.51
Cd	0.01	0.01	0.00	0.03	0.01	0.01	0.00	0.02	0.07	0.06	0.00	0.18
Ni	0.05	0.04	0.00	0.12	0.02	0.03	0.00	0.10	0.13	0.10	0.00	0.30

ROAD CUT RUNOFF WATER CHEMISTRY: SUMMARY SHEET

MASS LOADINGS

Units: g/day

Chemical Parameter	SITE											
	Jamestown 3				Nashville 1				Nashville 2			
	Mean	StDev	Min	Max	Mean	StDev	Min	Max	Mean	StDev	Min	Max
Cl-	1.90	2.54	0.03	9.39	9.45	11.57	0.84	41.99	4.90	3.62	0.80	10.50
SO4^2-	6.38	7.83	0.11	29.62	1345.34	1619.13	150.11	5855.11	268.45	219.36	37.21	601.20
NO3-	3.72	4.51	0.10	16.45	18.56	23.56	1.91	85.24	11.72	11.04	1.67	31.82
PO4^3-	2.53	2.76	0.05	10.17	12.73	19.78	0.56	69.95	9.16	5.62	1.14	16.17
Na+	0.65	0.91	0.01	3.35	15.66	17.83	0.06	64.51	23.76	34.49	0.00	104.29
K +	0.56	0.71	0.01	2.66	0.42	0.46	0.04	1.69	0.88	0.79	0.08	2.44
Mg ^2+	0.75	0.96	0.02	3.57	101.14	111.62	11.29	394.09	44.03	38.31	6.19	109.84
Ca ^2+	2.88	3.50	0.06	13.01	305.94	336.99	39.05	1184.65	185.84	142.89	30.20	417.12
Al	0.04	0.06	0.00	0.22	1.68	2.39	0.00	8.51	14.75	10.67	0.00	28.89
Cu	0.01	0.01	0.00	0.04	0.31	0.37	0.02	1.33	0.34	0.25	0.01	0.69
Fe	0.02	0.03	0.00	0.10	0.31	0.42	0.01	1.52	0.60	0.77	0.01	2.34
Mn	0.03	0.04	0.00	0.16	1.48	1.84	0.07	6.67	1.80	1.32	0.06	4.11
Si	0.98	1.33	0.02	4.98	4.78	5.32	0.67	18.88	7.40	5.78	0.31	16.26
Zn	0.03	0.04	0.00	0.16	1.24	1.64	0.05	5.87	2.88	2.14	0.01	5.96
Ba	0.02	0.02	0.00	0.09	0.32	0.39	0.02	1.43	0.16	0.12	0.02	0.35
Cd	0.00	0.00	0.00	0.02	0.06	0.07	0.00	0.25	0.04	0.04	0.00	0.11
Ni	0.00	0.00	0.00	0.00	0.19	0.23	0.02	0.81	0.74	0.61	0.01	1.71

ROAD CUT RUNOFF WATER CHEMISTRY: SUMMARY SHEET

MASS LOADINGS

Units: g/day

Chemical Parameter	SITE											
	Ocoee 1				Ocoee 2				Ocoee 3			
	Mean	StDev	Min	Max	Mean	StDev	Min	Max	Mean	StDev	Min	Max
Cl-	1.56	1.96	0.01	7.11	1.66	1.89	0.01	6.53	2.71	3.56	0.00	11.88
SO4^2-	12.16	15.98	0.09	57.86	13.20	14.63	0.09	49.95	37.06	49.33	0.01	178.76
NO3-	6.61	9.39	0.03	37.45	3.40	3.95	0.02	13.84	6.03	7.93	0.00	27.03
PO4^3-	2.88	3.78	0.01	13.61	2.67	3.06	0.02	10.92	4.86	6.30	0.00	20.19
Na+	3.25	4.49	0.03	15.94	1.75	2.64	0.01	9.78	13.55	21.34	0.00	65.38
K +	0.09	0.12	0.00	0.42	0.31	0.38	0.00	1.39	0.90	1.46	0.00	5.43
Mg ^2+	4.64	5.74	0.04	20.84	2.69	3.23	0.02	10.99	1.16	1.68	0.00	6.14
Ca ^2+	12.62	15.39	0.09	57.02	8.56	10.46	0.05	37.64	10.81	13.99	0.00	41.61
Al	0.08	0.11	0.00	0.39	0.09	0.17	0.00	0.65	1.86	2.27	0.00	6.48
Cu	0.01	0.02	0.00	0.06	0.02	0.04	0.00	0.13	0.26	0.39	0.00	1.27
Fe	0.01	0.02	0.00	0.06	0.03	0.04	0.00	0.14	0.23	0.33	0.00	1.17
Mn	0.00	0.01	0.00	0.02	0.08	0.14	0.00	0.51	1.05	1.65	0.00	5.68
Si	2.15	2.71	0.02	9.96	0.74	0.89	0.00	2.95	2.33	2.88	0.00	9.65
Zn	0.01	0.02	0.00	0.07	0.06	0.12	0.00	0.46	0.86	1.39	0.00	4.90
Ba	0.02	0.03	0.00	0.11	0.03	0.03	0.00	0.12	0.18	0.23	0.00	0.80
Cd	0.00	0.01	0.00	0.02	0.01	0.01	0.00	0.05	0.05	0.09	0.00	0.34
Ni	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.02	0.04	0.06	0.00	0.23

ROAD CUT RUNOFF WATER CHEMISTRY: SUMMARY SHEET

MASS LOADINGS

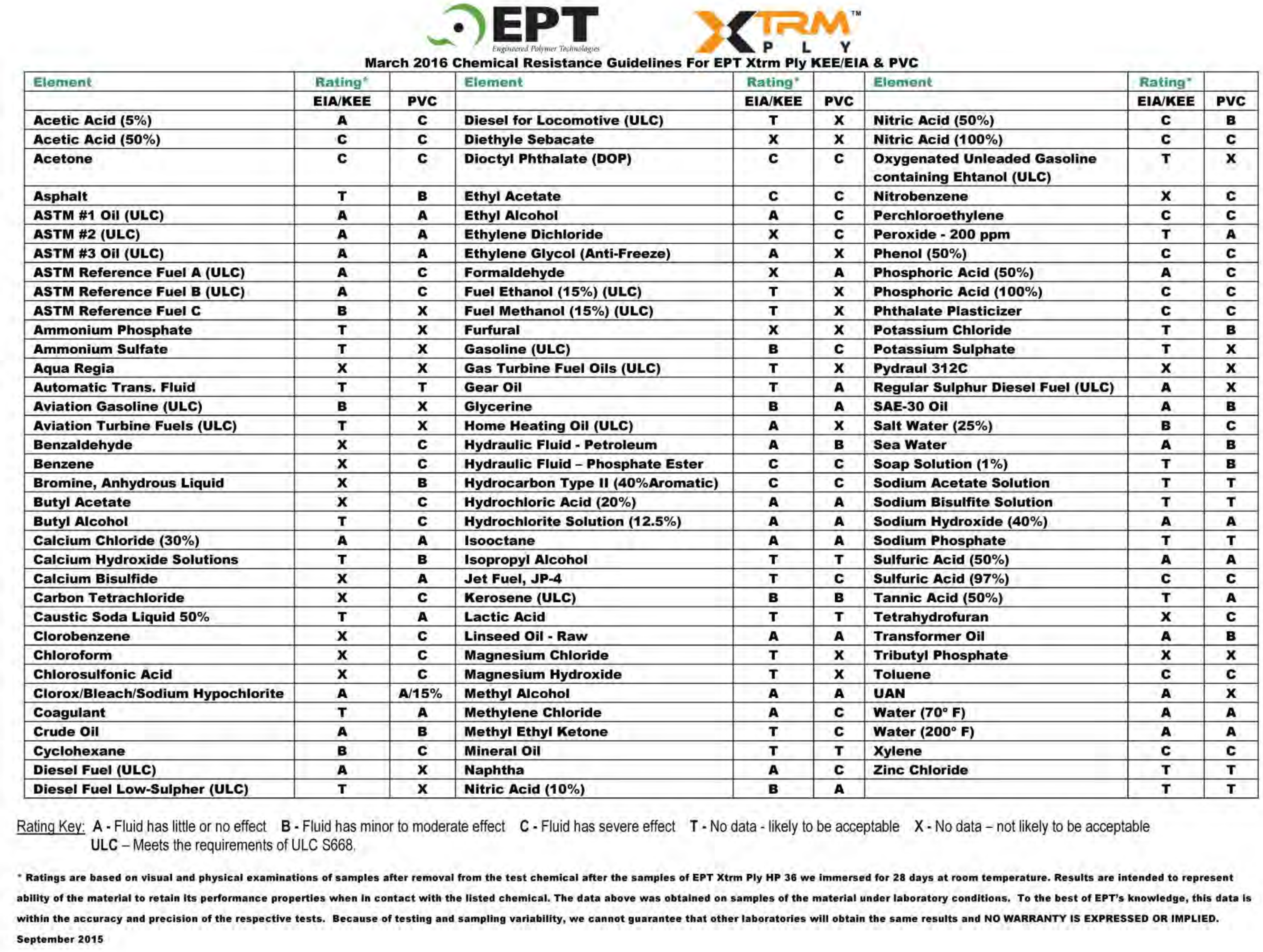
Units: g/day

Chemical Parameter	SITE Seiverville 1 Mean	StDev	Min	Max
Cl-	2.96	4.20	0.23	12.71
SO4^2-	52.59	73.37	4.07	247.08
NO3-	5.89	8.68	0.39	27.03
PO4^3-	5.14	7.53	0.37	23.42
Na+	10.05	19.19	0.00	65.38
K +	1.35	1.97	0.10	6.05
Mg ^2+	8.85	13.76	0.92	53.76
Ca ^2+	20.82	29.66	1.91	113.49
Al	1.14	2.05	0.00	6.48
Cu	0.19	0.36	0.01	1.27
Fe	0.20	0.37	0.00	1.17
Mn	0.97	1.76	0.01	5.68
Si	1.62	2.80	0.09	9.65
Zn	0.81	1.50	0.01	4.90
Ba	0.17	0.27	0.01	0.80
Cd	0.07	0.12	0.00	0.34
Ni	0.03	0.06	0.00	0.23

SUMMARY STATS FOR MASS LOADINGS

min	max	Chemical Parameter	overall median
0.00	48.51	Cl-	1.68
0.00	5855.11	SO4^2-	24.85
0.00	92.42	NO3-	4.50
0.00	73.58	PO4^3-	2.84
0.00	104.29	Na+	2.04
0.00	38.64	K +	0.39
0.00	394.09	Mg ^2+	3.19
0.00	1184.65	Ca ^2+	8.42
0.00	28.89	Al	0.21
0.00	1.33	Cu	0.04
0.00	3.30	Fe	0.05
0.00	6.67	Mn	0.16
0.00	18.88	Si	0.98
0.00	5.96	Zn	0.08
0.00	1.43	Ba	0.05
0.00	0.34	Cd	0.01
0.00	1.71	Ni	0.01

Appendix G: EPT XTRAM® HPL Specifications



EPT Engineered Polymer Technologies XTRM PLY™

March 2016 Chemical Resistance Guidelines For EPT Xtrm Ply KEE/EIA & PVC

Element	Rating*		Element	Rating*		Element	Rating*	
	EIA/KEE	PVC		EIA/KEE	PVC		EIA/KEE	PVC
Acetic Acid (5%)	A	C	Diesel for Locomotive (ULC)	T	X	Nitric Acid (50%)	C	B
Acetic Acid (50%)	C	C	Diethyle Sebacate	X	X	Nitric Acid (100%)	C	C
Acetone	C	C	Dioctyl Phthalate (DOP)	C	C	Oxygenated Unleaded Gasoline containing Ehtanol (ULC)	T	X
Asphalt	T	B	Ethyl Acetate	C	C	Nitrobenzene	X	C
ASTM #1 Oil (ULC)	A	A	Ethyl Alcohol	A	C	Perchloroethylene	C	C
ASTM #2 (ULC)	A	A	Ethylene Dichloride	X	C	Peroxide - 200 ppm	T	A
ASTM #3 Oil (ULC)	A	A	Ethylene Glycol (Anti-Freeze)	A	X	Phenol (50%)	C	C
ASTM Reference Fuel A (ULC)	A	C	Formaldehyde	X	A	Phosphoric Acid (50%)	A	C
ASTM Reference Fuel B (ULC)	A	C	Fuel Ethanol (15%) (ULC)	T	X	Phosphoric Acid (100%)	C	C
ASTM Reference Fuel C	B	X	Fuel Methanol (15%) (ULC)	T	X	Phthalate Plasticizer	C	C
Ammonium Phosphate	T	X	Furfural	X	X	Potassium Chloride	T	B
Ammonium Sulfate	T	X	Gasoline (ULC)	B	C	Potassium Sulphate	T	X
Aqua Regia	X	X	Gas Turbine Fuel Oils (ULC)	T	X	Pydraul 312C	X	X
Automatic Trans. Fluid	T	T	Gear Oil	T	A	Regular Sulphur Diesel Fuel (ULC)	A	X
Aviation Gasoline (ULC)	B	X	Glycerine	B	A	SAE-30 Oil	A	B
Aviation Turbine Fuels (ULC)	T	X	Home Heating Oil (ULC)	A	X	Salt Water (25%)	B	C
Benzaldehyde	X	C	Hydraulic Fluid - Petroleum	A	B	Sea Water	A	B
Benzene	X	C	Hydraulic Fluid – Phosphate Ester	C	C	Soap Solution (1%)	T	B
Bromine, Anhydrous Liquid	X	B	Hydrocarbon Type II (40%Aromatic)	C	C	Sodium Acetate Solution	T	T
Butyl Acetate	X	C	Hydrochloric Acid (20%)	A	A	Sodium Bisulfite Solution	T	T
Butyl Alcohol	T	C	Hydrochlorite Solution (12.5%)	A	A	Sodium Hydroxide (40%)	A	A
Calcium Chloride (30%)	A	A	Isooctane	A	A	Sodium Phosphate	T	T
Calcium Hydroxide Solutions	T	B	Isopropyl Alcohol	T	T	Sulfuric Acid (50%)	A	A
Calcium Bisulfide	X	A	Jet Fuel, JP-4	T	C	Sulfuric Acid (97%)	C	C
Carbon Tetrachloride	X	C	Kerosene (ULC)	B	B	Tannic Acid (50%)	T	A
Caustic Soda Liquid 50%	T	A	Lactic Acid	T	T	Tetrahydrofuran	X	C
Clorobenzene	X	C	Linseed Oil - Raw	A	A	Transformer Oil	A	B
Chloroform	X	C	Magnesium Chloride	T	X	Tributyl Phosphate	X	X
Chlorosulfonic Acid	X	C	Magnesium Hydroxide	T	X	Toluene	C	C
Clorox/Bleach/Sodium Hypochlorite	A	A/15%	Methyl Alcohol	A	A	UAN	A	X
Coagulant	T	A	Methylene Chloride	A	C	Water (70° F)	A	A
Crude Oil	A	B	Methyl Ethyl Ketone	T	C	Water (200° F)	A	A
Cyclohexane	B	C	Mineral Oil	T	T	Xylene	C	C
Diesel Fuel (ULC)	A	X	Naphtha	A	C	Zinc Chloride	T	T
Diesel Fuel Low-Sulpher (ULC)	T	X	Nitric Acid (10%)	B	A		T	T

Rating Key: **A** - Fluid has little or no effect **B** - Fluid has minor to moderate effect **C** - Fluid has severe effect **T** - No data - likely to be acceptable **X** - No data – not likely to be acceptable
ULC – Meets the requirements of ULC S668.

* Ratings are based on visual and physical examinations of samples after removal from the test chemical after the samples of EPT Xtrm Ply HP 36 we immersed for 28 days at room temperature. Results are intended to represent ability of the material to retain its performance properties when in contact with the listed chemical. The data above was obtained on samples of the material under laboratory conditions. To the best of EPT's knowledge, this data is within the accuracy and precision of the respective tests. Because of testing and sampling variability, we cannot guarantee that other laboratories will obtain the same results and NO WARRANTY IS EXPRESSED OR IMPLIED.

September 2015

Appendix H: Water Chemistry for Middlebrook Pike Experiment: Simulated Rainfall

PYRITE GEOLOGY WATER CHEMISTRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Simulated Rainfall

Sample/Tray Type	Date	Time (hrs)	uS/cm Conctvty	pH	measured ueq/L ANC	mg/L Cl	mg/L NO3	mg/L SO4	mg/L Na	mg/L K	mg/L Mg
GRASS = soil/vegetation											
PY001-G01C 160427 GRASS	23-May-16	0.000	1273.56	6.67	3031.3	250.13	34.68	144.19	10.06	215.91	19.28
PY002-G02C 160427	23-May-16	0.833	1354.24	6.52	2407.5	183.23	14.59	248.93	8.58	207.50	22.95
PY003-G03C 160427	23-May-16	1.667	1274.53	6.51	2020.7	155.12	14.68	295.08	7.59	206.47	19.93
PY004-G04C 160427	23-May-16	2.383	1124.84	6.63	2175.8	118.19	16.50	212.42	6.87	189.50	15.86
PY005-G05C 160427	23-May-16	3.117	1031.52	6.68	1867.1	113.64	14.18	186.22	7.22	175.76	14.18
PY006-G06C 160427	23-May-16	3.833	1005.27	6.71	2020.4	110.63	12.20	168.86	7.36	179.34	13.26
PY007-G07C 160427	23-May-16	4.133	1001.39	6.76	1724.3	109.48	26.66	167.00	6.59	177.91	12.71
PY008-G08C 160427	23-May-16	4.317	951.81	6.84	1873.4	108.55	15.95	156.63	7.10	172.48	12.52
PY009-G09C 160429	24-May-16	0.000	1668.21	4.70	-30.8	100.87	10.99	727.41	8.18	182.23	35.97
PY015-G15C 160519	24-May-16	0.833	1125.81	6.63	953.8	97.69	74.80	311.97	9.82	128.97	25.82
PY016-G16C 160519	24-May-16	1.667	821.56	6.59	724.2	76.62	52.76	246.32	8.52	100.00	19.28
PY017-G17C 160519	24-May-16	2.383	660.19	6.79	977.1	57.07	30.42	181.97	7.99	81.37	14.48
ROCK = pyrite rock											
PY001-U01C 160427 ROCK	23-May-16	0.000	2273.80	3.47	-250.7	32.88	11.73	867.40	8.56	4.21	33.67
PY002-U02C 160427	23-May-16	0.833	849.74	3.91	-51.4	19.21	1.96	903.11	8.99	2.47	22.92
PY003-U03C 160427	23-May-16	1.667	745.74	4.01	-20.9	20.50	1.49	418.13	9.41	2.20	21.51
PY004-U04C 160427	23-May-16	2.383	717.55	4.06	-60.0	20.58	1.49	370.31	9.05	2.12	20.15
PY005-U05C 160427	23-May-16	3.117	665.05	4.15	19.1	21.17	1.45	331.58	10.55	2.60	19.76
PY006-U06C 160427	23-May-16	3.833	552.30	4.35	-7.7	23.27	1.47	280.55	10.05	2.37	17.37
PY007-U07C 160427	23-May-16	4.133	516.33	4.58	-7.5	23.51	1.57	248.08	11.65	3.76	17.02
PY008-U08C 160427	23-May-16	4.317	96.50	5.95	26.5	22.72	1.51	203.93	9.69	2.44	13.50
PY009-U09C 160429	24-May-16	0.000	1169.55	3.66	-125.1	21.25	1.71	426.02	10.11	2.47	21.85
PY010-U10C 160504	24-May-16	0.833	607.70	3.49	-123.1	18.61	2.28	433.07	7.57	1.62	13.77
PY011-U11C 160504	24-May-16	1.667	306.37	4.22	-69.8	15.37	2.47	182.65	7.33	1.68	8.68
PY012-U12C 160504	24-May-16	2.383	123.33	6.40	85.0	17.09	1.22	90.85	7.21	1.70	6.70
PY013-U13C 160504	24-May-16	3.117	223.74	6.64	238.7	14.86	1.13	68.11	7.02	1.73	6.56
PY014-U14C 160504	24-May-16	3.833	210.13	6.77	289.3	14.19	2.56	50.09	6.58	1.50	5.91
PY015-U15C 160519	24-May-16	4.133	385.10	4.52	10.4	15.79	1.90	122.69	7.82	1.73	10.84
PY016-U16C 160519	24-May-16	4.317	257.76	6.58	215.1	16.51	1.52	119.52	7.60	1.71	8.10
PY017-U17C 160519	24-May-16	6.000	258.74	6.80	273.7	16.32	0.37	70.31	7.55	1.71	7.67

Simulated Rainfall

					measured						
			uS/cm		ueq/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
Sample/Tray Type	**Date**	**Time (hrs)**	Conctvty	pH	ANC	Cl	NO3	SO4	Na	K	Mg
CONC = shotcrete											
PY018-C18C 160526 CONC	7-Jun-16	0.000	916.82	9.07		22.25	0.97	179.32	51.08	202.05	4.38
PY019-C19C 160526	7-Jun-16	0.833	411.35	9.10		19.95	0.67	118.45	10.19	7.87	7.29
PY020-C20C 160526	7-Jun-16	1.667	332.61	9.16		17.81	0.25	17.07	12.70	24.70	5.62
PY021-C21C 160526	7-Jun-16	2.383	280.12	8.88		17.76	0.08	18.11	10.60	23.82	6.01
PY022-C22C 160527	7-Jun-16	3.117	323.86	8.97	1967.8	17.31	0.05	16.90	12.26	33.48	5.86
PY023-C23C 160527	7-Jun-16	3.833	266.51	8.45		16.54	0.06	14.21	9.81	17.60	6.21
PY024-C24C 160527	7-Jun-16	4.133	274.29	8.63		17.55	0.05	13.08	10.72	19.22	6.45
LINER = geoliner											
PY018-L18C 160526 LINER	7-Jun-16	0.000	225.69	7.58	1276.5	15.95	2.33	12.47	8.25	2.07	6.43
PY019-L19C 160526	7-Jun-16	0.833	246.10	7.82	1397.4	17.98	1.47	23.97	17.15	35.74	5.32
PY020-L20C 160526	7-Jun-16	1.667	231.52	7.96		18.34	0.41	25.60	8.58	2.97	6.60
PY021-L21C 160526	7-Jun-16	2.383	230.55	7.81	1310.2	16.71	0.96	12.60	8.25	1.83	6.61
PY022-L22C 160527	7-Jun-16	3.117	228.60	7.66	1275.1	16.89	0.88	13.20	8.62	1.89	6.77
PY023-L23C 160527	7-Jun-16	3.833	232.49	7.77	1311.4	17.36	0.03	12.90	8.46	1.79	6.75
PY024-L24C 160527	7-Jun-16	4.133	233.46	7.94	1325.0	17.17	0.03	12.76	8.53	1.86	6.76
POOL = water supply tank											
PY009-P09C 160429 POOL	23-May-16	0.000	239.30	7.89	1429.1	14.43	0.42	12.34	7.00	1.75	7.08
PY009-P09D 160429	23-May-16	4.317				14.38	0.02	12.54	0.71	0.20	0.76
PY010-P10C 160504	24-May-16	0.000				13.32	1.08	11.34	5.96	1.45	4.58
PY010-P10D 160504	24-May-16	4.317				18.83	0.16	13.81	0.83	0.24	0.59
PY015-P15C 160519	7-Jun-16	0.000				13.15	1.04	10.78	6.84	1.56	5.68
PY015-P15D 160519	7-Jun-16	0.833				13.85	0.05	11.22	6.93	1.58	5.77
PY018-P18A 160526	7-Jun-16	1.667				14.14	1.16	11.61	7.78	1.64	6.25
PY018-P18B 160526	7-Jun-16	2.383				14.60	0.77	12.63	8.32	1.89	6.32
PY022-P22C 160527	7-Jun-16	3.117	215.97	7.74	1211.0	14.57	1.05	12.50	7.83	1.62	6.27
PY022-P22D 160527	7-Jun-16	3.833				14.48	1.17	11.97	7.88	1.69	6.30

PYRITE GEOLOGY WATER CHEMISTRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Simulated Rainfall

		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Acid Anions	
Date	**Time (hrs)**	Ca	Al	Cu	Fe	Mn	Si	Zn	Cd	Ni	Cl- (meq/L)	SO4^2- (meq/L)
GRASS = soil/vegetation												
23-May-16	0.000	59.39	0.29	0.04	13.04	4.02	3.31	0.22	0.00	0.06	7.066	0.722
23-May-16	0.833	83.08	0.61	0.06	12.15	4.53	8.86	0.25	0.00	0.13	5.176	0.304
23-May-16	1.667	90.20	0.46	0.04	9.76	0.48	10.36	0.15	0.00	0.08	4.382	0.306
23-May-16	2.383	81.08	0.26	0.03	3.83	0.44	9.98	0.09	0.00	0.06	3.339	0.344
23-May-16	3.117	73.79	0.24	0.03	3.42	1.04	9.42	0.07	0.00	0.06	3.210	0.295
23-May-16	3.833	68.05	0.27	0.03	3.06	0.89	8.07	0.08	0.00	0.04	3.125	0.254
23-May-16	4.133	66.66	0.36	0.03	2.59	0.79	9.93	0.08	0.00	0.05	3.093	0.556
23-May-16	4.317	62.44	0.31	0.03	3.74	0.75	10.35	0.10	0.00	0.06	3.066	0.332
24-May-16	0.000	155.34	0.64	0.03	2.91	10.07	15.54	1.25	0.00	0.66	2.849	0.229
24-May-16	0.833	95.12	0.47	0.02	3.25	3.69	6.22	0.41	0.00	0.18	2.760	1.558
24-May-16	1.667	79.55	0.39	0.02	2.80	1.99	5.46	0.28	0.00	0.14	2.164	1.099
24-May-16	2.383	65.46	0.33	0.02	2.28	1.04	4.81	0.19	0.00	0.10	1.612	0.634
ROCK = pyrite rock												
23-May-16	0.000	72.64	15.17	0.63	134.67	25.16	3.15	6.15	0.00	3.08	0.929	0.244
23-May-16	0.833	61.81	1.66	0.19	143.50	15.37	2.49	2.00	0.00	1.04	0.543	0.041
23-May-16	1.667	43.53	1.39	0.19	56.17	14.14	2.59	1.78	0.00	0.94	0.579	0.031
23-May-16	2.383	40.95	0.57	0.15	48.25	12.64	2.55	1.54	0.00	0.83	0.581	0.031
23-May-16	3.117	40.76	0.50	0.11	39.17	11.48	2.55	1.44	0.00	0.79	0.598	0.030
23-May-16	3.833	39.97	0.15	0.04	21.90	9.02	2.28	1.07	0.00	0.62	0.657	0.031
23-May-16	4.133	41.38	0.18	0.03	14.05	8.01	2.23	0.92	0.00	0.55	0.664	0.033
23-May-16	4.317	38.84	0.03	0.01	4.13	5.08	1.97	0.46	0.00	0.34	0.642	0.031
24-May-16	0.000	44.20	15.75	0.61	51.89	23.63	4.65	3.58	0.00	1.68	0.600	0.036
24-May-16	0.833	28.33	4.04	0.25	60.64	8.39	3.09	1.34	0.00	0.68	0.526	0.048
24-May-16	1.667	23.51	0.24	0.04	6.06	3.60	2.48	0.50	0.00	0.27	0.434	0.051
24-May-16	2.383	22.87	0.04	0.01	2.68	1.37	2.33	0.19	0.00	0.11	0.483	0.025
24-May-16	3.117	22.46	0.01	0.01	2.49	1.39	2.30	0.15	0.00	0.10	0.420	0.024
24-May-16	3.833	21.63	0.00	0.00	0.15	0.85	2.11	0.03	0.00	0.06	0.401	0.053
24-May-16	4.133	28.37	0.11	0.04	10.92	5.20	2.62	0.84	0.00	0.39	0.446	0.039
24-May-16	4.317	26.04	0.01	0.01	1.76	2.16	2.32	0.17	0.00	0.13	0.466	0.032
24-May-16	6.000	25.65	0.01	0.01	2.17	1.23	2.42	0.18	0.00	0.12	0.461	0.008

Simulated Rainfall

		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	Acid Anions	
Date	**Time (hrs)**	Ca	Al	Cu	Fe	Mn	Si	Zn	Cd	Ni	Cl- (meq/L)	SO4^2- (meq/L)
CONC = shotcrete												
7-Jun-16	0.000	26.73	0.17	0.02	0.22	0.19	12.52	0.01	0.00	-0.01	0.628	0.020
7-Jun-16	0.833	19.13	0.03	0.02	0.02	0.01	3.29	0.07	0.00	0.00	0.564	0.014
7-Jun-16	1.667	23.77	0.05	0.01	0.02	0.01	4.99	0.02	0.00	-0.01	0.503	0.005
7-Jun-16	2.383	24.62	0.04	0.01	0.02	0.01	3.93	0.02	0.00	-0.01	0.502	0.002
7-Jun-16	3.117	23.78	0.05	0.01	0.02	0.02	4.50	0.02	0.00	-0.01	0.489	0.001
7-Jun-16	3.833	24.99	0.04	0.01	0.01	0.01	3.48	0.02	0.00	0.00	0.467	0.001
7-Jun-16	4.133	26.32	0.05	0.01	0.01	0.01	3.77	0.03	0.00	0.00	0.496	0.001
LINER = geoliner												
7-Jun-16	0.000	26.25	0.02	0.02	0.02	0.01	2.71	0.08	0.00	0.00	0.451	0.049
7-Jun-16	0.833	24.68	0.07	0.02	0.04	0.03	6.58	0.02	0.00	-0.01	0.508	0.031
7-Jun-16	1.667	26.57	0.02	0.01	0.01	0.00	2.80	0.07	0.00	0.00	0.518	0.008
7-Jun-16	2.383	26.96	0.02	0.01	0.01	0.00	2.71	0.07	0.00	0.00	0.472	0.020
7-Jun-16	3.117	27.21	0.02	0.01	0.01	0.00	2.79	0.07	0.00	0.00	0.477	0.018
7-Jun-16	3.833	27.23	0.02	0.01	0.00	0.00	2.78	0.07	0.00	0.00	0.490	0.001
7-Jun-16	4.133	27.29	0.02	0.01	0.00	0.00	2.83	0.08	0.00	0.00	0.485	0.001
POOL = water supply tank												
23-May-16	0.000	0.00	0.02	0.01	0.01	0.00	1.50	0.07	0.00	0.00	0.408	0.009
23-May-16	4.317	3.30	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.406	0.000
24-May-16	0.000	19.53	0.01	0.01	0.00	0.00	2.13	0.06	0.00	0.00	0.376	0.023
24-May-16	4.317	2.35	0.00	0.00	0.00	0.00	0.11	0.01	0.00	0.00	0.532	0.003
7-Jun-16	0.000	23.46	0.01	0.01	0.01	0.00	2.38	0.07	0.00	0.00	0.371	0.022
7-Jun-16	0.833	23.82	0.01	0.01	0.01	0.00	2.42	0.07	0.00	0.00	0.391	0.001
7-Jun-16	1.667	25.16	0.02	0.01	0.01	0.00	2.57	0.08	0.00	0.00	0.400	0.024
7-Jun-16	2.383	25.38	0.02	0.01	0.01	0.00	2.57	0.07	0.00	0.00	0.412	0.016
7-Jun-16	3.117	25.29	0.02	0.01	0.01	0.00	2.56	0.07	0.00	0.00	0.412	0.022
7-Jun-16	3.833	25.50	0.02	0.01	0.00	0.00	2.60	0.07	0.00	0.00	0.409	0.024

PYRITE GEOLOGY WATER CHEMISTRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Simulated Rainfall

					Base Cations					**Dissolved Metals**			
Date	**Time (hrs)**	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)	Al^3+ (meq/L)	Cu^2+ (meq/L)	Fe^2+ (meq/L)	Mn^2+ (meq/L)
GRASS = soil/vegetation													
23-May-16	0.000	2.326		10.114	0.437	5.536	1.587	2.969	10.530	0.032	0.001	0.467	0.146
23-May-16	0.833	4.015		9.495	0.373	5.321	1.889	4.154	11.736	0.068	0.002	0.435	0.165
23-May-16	1.667	4.759		9.447	0.330	5.294	1.641	4.510	11.775	0.052	0.001	0.350	0.017
23-May-16	2.383	3.426		7.109	0.299	4.859	1.306	4.054	10.517	0.029	0.001	0.137	0.016
23-May-16	3.117	3.004		6.509	0.314	4.507	1.167	3.689	9.677	0.026	0.001	0.123	0.038
23-May-16	3.833	2.724		6.103	0.320	4.598	1.092	3.403	9.413	0.030	0.001	0.110	0.032
23-May-16	4.133	2.694		6.342	0.286	4.562	1.046	3.333	9.228	0.040	0.001	0.093	0.029
23-May-16	4.317	2.526		5.925	0.309	4.423	1.030	3.122	8.883	0.034	0.001	0.134	0.027
24-May-16	0.000	11.732		14.811	0.356	4.673	2.960	7.767	15.756	0.071	0.001	0.104	0.367
24-May-16	0.833	5.032		9.350	0.427	3.307	2.125	4.756	10.615	0.053	0.001	0.116	0.134
24-May-16	1.667	3.973		7.236	0.370	2.564	1.587	3.977	8.499	0.044	0.001	0.100	0.072
24-May-16	2.383	2.935		5.181	0.347	2.086	1.191	3.273	6.898	0.037	0.001	0.082	0.038
ROCK = pyrite rock													
23-May-16	0.000	13.990		15.163	0.372	0.108	2.772	3.632	6.884	1.687	0.020	4.823	0.916
23-May-16	0.833	14.566		15.150	0.391	0.063	1.886	3.090	5.431	0.184	0.006	5.139	0.560
23-May-16	1.667	6.744		7.354	0.409	0.056	1.770	2.177	4.412	0.154	0.006	2.011	0.515
23-May-16	2.383	5.973		6.585	0.394	0.054	1.658	2.047	4.154	0.064	0.005	1.728	0.460
23-May-16	3.117	5.348		5.976	0.459	0.067	1.627	2.038	4.190	0.056	0.003	1.403	0.418
23-May-16	3.833	4.525		5.213	0.437	0.061	1.430	1.999	3.926	0.017	0.001	0.784	0.328
23-May-16	4.133	4.001		4.698	0.507	0.096	1.401	2.069	4.073	0.020	0.001	0.503	0.292
23-May-16	4.317	3.289		3.962	0.421	0.063	1.111	1.942	3.537	0.003	0.000	0.148	0.185
24-May-16	0.000	6.871		7.507	0.439	0.063	1.798	2.210	4.511	1.752	0.019	1.858	0.860
24-May-16	0.833	6.985		7.558	0.329	0.042	1.134	1.417	2.921	0.449	0.008	2.172	0.305
24-May-16	1.667	2.946		3.431	0.319	0.043	0.715	1.176	2.252	0.027	0.001	0.217	0.131
24-May-16	2.383	1.465		1.973	0.314	0.044	0.552	1.144	2.052	0.005	0.000	0.096	0.050
24-May-16	3.117	1.099		1.542	0.305	0.044	0.540	1.123	2.013	0.001	0.000	0.089	0.051
24-May-16	3.833	0.808		1.262	0.286	0.038	0.486	1.081	1.892	0.000	0.000	0.005	0.031
24-May-16	4.133	1.979		2.464	0.340	0.044	0.892	1.419	2.695	0.013	0.001	0.391	0.189
24-May-16	4.317	1.928		2.426	0.330	0.044	0.667	1.302	2.343	0.001	0.000	0.063	0.079
24-May-16	6.000	1.134		1.603	0.328	0.044	0.631	1.283	2.286	0.001	0.000	0.078	0.045

Simulated Rainfall

					Base Cations					Dissolved Metals			
Date	**Time (hrs)**	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)	Al^3+ (meq/L)	Cu^2+ (meq/L)	Fe^2+ (meq/L)	Mn^2+ (meq/L)
CONC = shotcrete													
7-Jun-16	0.000	2.892		3.541	2.221	5.181	0.361	1.336	9.099	0.019	0.001	0.008	0.007
7-Jun-16	0.833	1.911		2.488	0.443	0.202	0.600	0.957	2.202	0.003	0.001	0.001	0.000
7-Jun-16	1.667	0.275		0.784	0.552	0.633	0.462	1.188	2.836	0.006	0.000	0.001	0.001
7-Jun-16	2.383	0.292		0.796	0.461	0.611	0.495	1.231	2.798	0.004	0.000	0.001	0.000
7-Jun-16	3.117	0.273		0.763	0.533	0.858	0.482	1.189	3.063	0.006	0.000	0.001	0.001
7-Jun-16	3.833	0.229		0.698	0.427	0.451	0.512	1.249	2.639	0.004	0.000	0.000	0.000
7-Jun-16	4.133	0.211		0.708	0.466	0.493	0.531	1.316	2.806	0.005	0.000	0.000	0.000
LINER = geoliner													
7-Jun-16	0.000	0.201		0.700	0.358	0.053	0.529	1.313	2.253	0.002	0.001	0.001	0.000
7-Jun-16	0.833	0.387		0.925	0.746	0.916	0.438	1.234	3.334	0.008	0.001	0.002	0.001
7-Jun-16	1.667	0.413		0.939	0.373	0.076	0.543	1.328	2.321	0.002	0.000	0.000	0.000
7-Jun-16	2.383	0.203		0.695	0.359	0.047	0.544	1.348	2.297	0.002	0.000	0.000	0.000
7-Jun-16	3.117	0.213		0.708	0.375	0.049	0.557	1.361	2.341	0.002	0.000	0.000	0.000
7-Jun-16	3.833	0.208		0.699	0.368	0.046	0.556	1.362	2.331	0.002	0.000	0.000	0.000
7-Jun-16	4.133	0.206		0.692	0.371	0.048	0.556	1.364	2.340	0.002	0.000	0.000	0.000
POOL = water supply tank													
23-May-16	0.000	0.199		0.615	0.304	0.045	0.582	0.000	0.931	0.002	0.000	0.000	0.000
23-May-16	4.317	0.202		0.609	0.031	0.005	0.062	0.165	0.263	0.000	0.000	0.000	0.000
24-May-16	0.000	0.183		0.582	0.259	0.037	0.377	0.976	1.649	0.002	0.000	0.000	0.000
24-May-16	4.317	0.223		0.758	0.036	0.006	0.049	0.117	0.208	0.000	0.000	0.000	0.000
7-Jun-16	0.000	0.174		0.567	0.297	0.040	0.467	1.173	1.978	0.001	0.000	0.000	0.000
7-Jun-16	0.833	0.181		0.573	0.301	0.040	0.475	1.191	2.007	0.002	0.000	0.000	0.000
7-Jun-16	1.667	0.187		0.611	0.338	0.042	0.514	1.258	2.153	0.002	0.000	0.000	0.000
7-Jun-16	2.383	0.204		0.632	0.362	0.048	0.520	1.269	2.199	0.002	0.000	0.000	0.000
7-Jun-16	3.117	0.202		0.635	0.340	0.042	0.516	1.265	2.162	0.002	0.000	0.000	0.000
7-Jun-16	3.833	0.193		0.626	0.343	0.043	0.519	1.275	2.179	0.002	0.000	0.000	0.000

PYRITE GEOLOGY WATER CHEMISTRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Simulated Rainfall

Date	Time (hrs)	Si2+ (meq/L)	Zn^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	Calculated ANC (meq/L)
GRASS = soil/vegetation						
23-May-16	0.000	0.236	0.007	0.000	0.002	1.306
23-May-16	0.833	0.631	0.008	0.000	0.004	3.554
23-May-16	1.667	0.738	0.005	0.000	0.003	3.492
23-May-16	2.383	0.710	0.003	0.000	0.002	4.307
23-May-16	3.117	0.671	0.002	0.000	0.002	4.031
23-May-16	3.833	0.575	0.003	0.000	0.002	4.061
23-May-16	4.133	0.707	0.002	0.000	0.002	3.759
23-May-16	4.317	0.737	0.003	0.000	0.002	3.897
24-May-16	0.000	1.106	0.038	0.000	0.023	2.655
24-May-16	0.833	0.443	0.013	0.000	0.006	2.031
24-May-16	1.667	0.389	0.009	0.000	0.005	1.881
24-May-16	2.383	0.342	0.006	0.000	0.003	2.226
ROCK = pyrite rock						
23-May-16	0.000	0.224	0.188	0.000	0.105	-0.317
23-May-16	0.833	0.177	0.061	0.000	0.035	-3.556
23-May-16	1.667	0.184	0.054	0.000	0.032	0.016
23-May-16	2.383	0.182	0.047	0.000	0.028	0.082
23-May-16	3.117	0.181	0.044	0.000	0.027	0.345
23-May-16	3.833	0.162	0.033	0.000	0.021	0.060
23-May-16	4.133	0.159	0.028	0.000	0.019	0.396
23-May-16	4.317	0.140	0.014	0.000	0.012	0.077
24-May-16	0.000	0.331	0.110	0.000	0.057	1.991
24-May-16	0.833	0.220	0.041	0.000	0.023	-1.419
24-May-16	1.667	0.177	0.015	0.000	0.009	-0.602
24-May-16	2.383	0.166	0.006	0.000	0.004	0.406
24-May-16	3.117	0.164	0.004	0.000	0.004	0.784
24-May-16	3.833	0.150	0.001	0.000	0.002	0.820
24-May-16	4.133	0.187	0.026	0.000	0.013	1.051
24-May-16	4.317	0.165	0.005	0.000	0.005	0.235
24-May-16	6.000	0.172	0.005	0.000	0.004	0.988

Simulated Rainfall

Date	Time (hrs)	Si2+ (meq/L)	Zn^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	Calculated ANC (meq/L)
CONC = shotcrete						
7-Jun-16	0.000	0.891	0.000	0.000	0.000	6.484
7-Jun-16	0.833	0.234	0.002	0.000	0.000	-0.046
7-Jun-16	1.667	0.356	0.001	0.000	0.000	2.416
7-Jun-16	2.383	0.280	0.001	0.000	0.000	2.288
7-Jun-16	3.117	0.320	0.001	0.000	0.000	2.628
7-Jun-16	3.833	0.248	0.001	0.000	0.000	2.195
7-Jun-16	4.133	0.268	0.001	0.000	0.000	2.373
LINER = geoliner						
7-Jun-16	0.000	0.193	0.002	0.000	0.000	1.752
7-Jun-16	0.833	0.469	0.001	0.000	0.000	2.889
7-Jun-16	1.667	0.199	0.002	0.000	0.000	1.586
7-Jun-16	2.383	0.193	0.002	0.000	0.000	1.800
7-Jun-16	3.117	0.199	0.002	0.000	0.000	1.837
7-Jun-16	3.833	0.198	0.002	0.000	0.000	1.835
7-Jun-16	4.133	0.201	0.002	0.000	0.000	1.854
POOL = water supply tank						
23-May-16	0.000	0.107	0.002	0.000	0.000	0.428
23-May-16	4.317	0.000	0.000	0.000	0.000	-0.345
24-May-16	0.000	0.151	0.002	0.000	0.000	1.222
24-May-16	4.317	0.008	0.000	0.000	0.000	-0.541
7-Jun-16	0.000	0.169	0.002	0.000	0.000	1.584
7-Jun-16	0.833	0.172	0.002	0.000	0.000	1.610
7-Jun-16	1.667	0.183	0.002	0.000	0.000	1.730
7-Jun-16	2.383	0.183	0.002	0.000	0.000	1.755
7-Jun-16	3.117	0.183	0.002	0.000	0.000	1.714
7-Jun-16	3.833	0.185	0.002	0.000	0.000	1.743

Appendix I: Water Chemistry for Middlebrook Pike Experiment: Natural Rainfall

PYRITE GEOLOGY WATER CHEMSITRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Natural Rainfall

								Acid Anions			
Analysis Name 1	Storm Number	Date Collected	Sample/ Tray	Conductivity (uS/cm)	pH units	ANC - meas (meq/L)	ANC - calc (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)
			CONC = shotcrete								
NRF1 160621 CONC-b	1	6/21/2016	CONC	614.0	6.76		5.614232	6.76517	6.3281		
NRF2 160624 CONC-b	2	6/24/2016	CONC	369.7	7.74			1.99124	2.05567	46.98609	
NRF3 160627 CONC-b	3	6/27/2016	CONC	69.5	7.46			0.22506	0.86851	8.90029	0.7389
NRF4 160628 CONC-b	4	6/28/2016	CONC	181.1	7.16			1.02395	1.71907	30.05022	
NRF5 160705 CONC	5	7/5/2016	CONC	154.8	6.98		0.920345	0.87845	1.0868	31.92817	
NRF6 160707 CONC	6	7/7/2016	CONC	99.5	7.41		0.721783	0.68158	0.77936	15.11764	
NRF7 160709 CONC	7	7/9/2016	CONC	82.8	6.87		0.605145	0.63436	0.80814	11.49353	
NRF8 160715 CONC	8	7/15/2016	CONC	180.1	7.16	0.79286122	1.386325	0.83566	2.52484	29.07725	0.00304
NRF9 160727 CONC	9	7/27/2016	CONC	165.6	6.85	0.41867766	1.151753	0.48602	2.77483	33.88348	0.00087
NRF10 160729 CONC	10	7/29/2016	CONC	69.7	6.99	0.35647678	0.549325	0.38734	0.6357	12.83604	0.0119
NRF11 160730 CONC	11	7/30/2016	CONC	64.8	7.03	0.25257811	0.487979	0.15243	0.46494	12.34996	0.00537
NRF12 160805 CONC	12	8/5/2016	CONC	67.5	6.87	0.27827084	0.525361	0.17109	0.58384	11.20241	0.01098
NRF14 160808 CONC	14	8/8/2016	CONC	46.4	6.80	0.25468823	0.418949	0.15914	0.56813	4.81829	0.00297
NRF15 160809 CONC	15	8/9/2016	CONC	75.4	6.84	0.35202631	0.600419	0.21864	1.13982	10.84072	0.00391
NRF16 160816 CONC	16	8/16/2016	CONC	43.4	6.73	0.18170075	0.334	0.11906	0.58404	7.28097	0.0036
NRF17 160818 CONC	17	8/18/2016	CONC	42.5	6.85	0.22703598	0.46701	0.18153	0.43056	10.0873	0.01525
NRF18 160822 CONC	18	8/22/2016	CONC	82.4	6.91	0.33736327	0.845291	0.58134	0.82641	22.93531	0.0022
NRF19 160902 CONC	19	9/2/2016	CONC	106.9	6.88	0.36232761	0.982449	2.05929	3.34523	30.80017	0.00745
NRF20 160919 CONC-a	20	9/19/2016	CONC	66.9	6.99	0.35279334	0.824727	0.86123	0.80688	15.9823	
NRF22 161121 CONC	22	11/21/2016	CONC	199.3	7.62	1.65090501	2.036432	131.392	30.8089	138.273	
NRF23 161130 CONC	23	11/30/2016	CONC	93.2	7.01	0.78091013	2.43029	0.22672	0.24154	19.301	
NRF24 161204 CONC	24	12/4/2016	CONC	10.8	6.15	0.03180186	0.254188	0.0342	0.0516	4.65104	
NRF25 161206 CONC	25	12/6/2016	CONC	7.5	5.95	0.01346609	0.071456	0.03489	0.05351	1.83138	
NRF26 161212 CONC	26	12/12/2016	CONC	36.9	6.71	0.20322406	0.493775	0.23505	0.36193	6.97396	
			GRASS = soil/vegetation								
NRF1 160621 GRASS-b	1	6/21/2016	GRASS	2360	6.20		9.638282	87.55716	90.82285		
NRF2 160624 GRASS-b	2	6/24/2016	GRASS	1232.43237	6.48			46.57309	39.81029	56.44726	16.31211
NRF3 160627 GRASS-b	3	6/27/2016	GRASS	709.189209	5.86			29.20129	40.67187	59.335	
NRF4 160628 GRASS-b	4	6/28/2016	GRASS	1676.75671	6.24			58.80179	82.41462	76.79998	3.42756

								Acid Anions			
Analysis Name 1	Storm Number	Date Collected	Sample/ Tray	Conductivity (uS/cm)	pH units	ANC - meas (meq/L)	ANC - calc (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)
			GRASS = soil/vegetation								
---	5	7/5/2016									
NRF6 160707 GRASS	6	7/7/2016	GRASS	1224.1344	5.02		-1.425642	78.8146	93.7397	89.052	0.0007
NRF7 160709 GRASS	7	7/9/2016	GRASS	731.111084	5.93		-6.949228	193.4379	220.3916	302.5941	0.0008
NRF8 160715 GRASS	8	7/15/2016	GRASS	801.268738	6.58	0.65793085	-0.898155	88.956	116.3458	88.9548	0.1011
NRF9 160727 GRASS	9	7/27/2016	GRASS	423.875427	6.42	0.59244955	1.370314	28.2718	21.4401	66.6938	0.0027
NRF10 160729 GRASS	10	7/29/2016	GRASS	334.371399	5.66	0.00556682	0.34462	26.0852	57.4008	59.4146	0.016
NRF11 160730 GRASS	11	7/30/2016	GRASS	446.435638	5.20	-0.0179877	-0.458007	33.5069	79.692	50.3464	0.0496
NRF12 160805 GRASS	12	8/5/2016	GRASS	358.316833	5.63	0.00449146	-17.53196	219.1913	420.4243	351.7899	3.9964
NRF14 160808 GRASS	14	8/8/2016	GRASS	269.207916	5.45	-0.0136938	0.234067	15.9438	44.1896	44.4574	0.0469
NRF15 160809 GRASS	15	8/9/2016	GRASS	420.693054	4.96	-0.0296566	0.536082	20.8648	56.0223	91.8962	0.0261
NRF16 160816 GRASS	16	8/16/2016	GRASS	180.693069	5.44	-0.0112255	0.379939	6.1176	24.3264	35.6084	0.0296
NRF17 160818 GRASS	17	8/18/2016	GRASS	159.007523	4.90	-0.0095564	0.43417	9.0644	36.5964	49.0334	0.2971
NRF18 160822 GRASS	18	8/22/2016	GRASS	243.218048	4.80	-0.0140315	1.417363	12.3728	49.3509	89.1059	0.5239
NRF19 160902 GRASS	19	9/2/2016	GRASS	215.548874	5.25	-0.0071012	0.957684	9.1706	23.0188	85.7362	0.0871
NRF20 160919 GRASS-a	20	9/19/2016	GRASS	144.571426	4.80	-0.0213955	0.548806	6.1426	23.6651	66.265	
NRF22 161121 GRASS	22	11/21/2016	GRASS	432.691742	6.38	0.14599395	0.179933	68.7467	14.6023	275.07	
NRF23 161130 GRASS	23	11/30/2016	GRASS	117.744362	5.55	0.00182235	0.689625	4.0369	15.8494	37.3785	
NRF24 161204 GRASS	24	12/4/2016	GRASS	117.503761	6.14	0.0293068	0.613787	4.70511	15.5742	46.6571	
NRF25 161206 GRASS	25	12/6/2016	GRASS	138.556396	4.71	-0.0169368	0.318336	5.04314	15.5928	87.877	
NRF26 161212 GRASS	26	12/12/2016	GRASS	115.759399	4.80	-0.0159086	0.421292	2.52683	7.53436	71.832	
			LINER = geoliner								
NRF1 160621 LINER-b	1	6/21/2016	LINER	55.2999992	6.81		0.269335	3.69073	4.17241	9.64101	
NRF2 160624 LINER-b	2	6/24/2016	LINER	22.7027035	6.75			0.43018	1.64106	1.15883	
NRF3 160627 LINER-b	3	6/27/2016	LINER	7.39157057	5.24			0.1001	0.75365	0.66976	
NRF4 160628 LINER-b	4	6/28/2016	LINER	10.6658525	6.15			0.18857	1.78368	0.69017	
NRF5 160705 LINER	5	7/5/2016	LINER	14.8486462	6.37		0.101643	0.42212	1.29586	1.39462	
NRF6 160707 LINER	6	7/7/2016	LINER	8.40148735	6.37		0.044051	0.36263	0.79737	0.98213	
NRF7 160709 LINER	7	7/9/2016	LINER	8.48645878	5.82		0.060248	0.2268	0.83015	0.58729	
NRF8 160715 LINER	8	7/15/2016	LINER	43.8062286	7.00	0.36237893	0.38402	0.45899	1.61066	1.66212	0.01536
NRF9 160727 LINER	9	7/27/2016	LINER	27.2895031	6.38	0.15202095	0.234865	0.28858	2.12727	1.04778	0.00093
NRF10 160729 LINER	10	7/29/2016	LINER	0.75609863	6.41	0.0441035	0.068868	0.1848	0.4037	0.3611	0.00034
NRF11 160730 LINER	11	7/30/2016	LINER	5.97864485	6.11	0.02475905	0.052683	0.0755	0.49398	0.41	0.00967

								Acid Anions			
Analysis Name 1	Storm Number	Date Collected	Sample/ Tray	Conductivity (uS/cm)	pH units	ANC - meas (meq/L)	ANC - calc (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)
			LINER = geoliner								
NRF12 160805 LINER	12	8/5/2016	LINER	6.93966961	6.27	0.02995178	0.071735	0.11088	0.51561	0.30175	0.05404
NRF14 160808 LINER	14	8/8/2016	LINER	3.57608199	5.92	0.00951593	0.037548	0.05868	0.48399	0.13965	0.04145
NRF15 160809 LINER	15	8/9/2016	LINER	5.8248806	6.02	0.02212968	0.041995	0.0792	1.03403	0.15748	0.00422
NRF16 160816 LINER	16	8/16/2016	LINER	5.59423447	6.17	0.02727201	0.04763	0.07547	0.63149	0.19962	0.09296
NRF17 160818 LINER	17	8/18/2016	LINER	6.32334375	6.15	0.01781111	0.038084	0.09746	0.45007	0.31573	0.02845
NRF18 160822 LINER	18	8/22/2016	LINER	9.62853622	6.30		0.050836	0.187	0.76781	0.6564	0.00192
NRF19 160902 LINER	19	9/2/2016	LINER	51.6390991	6.89	0.36874601	0.298262	1.87603	3.53607	2.11808	0.00358
NRF20 160919 LINER-a	20	9/19/2016	LINER	15.0916004	6.68	0.11000025	0.183599	0.20406	0.0405	0.5106	
NRF22 161121 LINER	22	11/21/2016	LINER				2.525085	27.0008	0.99235	7.61023	
NRF23 161130 LINER	23	11/30/2016	LINER	11.2089491	6.51		0.028663	0.58175	0.39569	3.46033	
NRF24 161204 LINER	24	12/4/2016	LINER	2.81300211	5.99	0.00899264	0.015534	0.16345	0.1229	0.46509	
NRF25 161206 LINER	25	12/6/2016	LINER	4.15027523	6.15	0.01435639	-0.008121	0.19913	0.08424	0.34022	
NRF26 161212 LINER	26	12/12/2016	LINER	7.44786882	6.24	0.02352318	0.026324	0.23099	0.37657	1.02077	
			ROCK = pyrite rock								
NRF1 160621 ROCK-b	1	6/21/2016	ROCK	1740	3.24		12.91692	5.40746	6.05609		
NRF2 160624 ROCK-b	2	6/24/2016	ROCK	1436.75671	3.20			1.7924	2.30808		
NRF3 160627 ROCK-b	3	6/27/2016	ROCK	294.054047	3.55			0.27409	0.92238	48.97087	
NRF4 160628 ROCK-b	4	6/28/2016	ROCK	1232.43237	3.18			1.02902	2.24559		1.13383
---	5	7/5/2016									
NRF6 160707 ROCK	6	7/7/2016	ROCK	1206.56335	3.16		-0.676464	0.9496	1.8093	392.072	0.2295
NRF7 160709 ROCK	7	7/9/2016	ROCK	857.20929	3.24		3.994018	0.7792	1.5677	287.9695	0.0277
NRF8 160715 ROCK	8	7/15/2016	ROCK	1138.06226	3.74	-0.075	6.67759	0.9286	1.7369	446.6091	0.1043
NRF9 160727 ROCK	9	7/27/2016	ROCK	1233.10266	3.20	-0.325	-1.625891	0.5363	1.788	428.915	0.099
NRF10 160729 ROCK	10	7/29/2016	ROCK	866.781982	3.31	-0.2	0.734006	0.3895	0.6843	333.7801	0.0753
NRF11 160730 ROCK	11	7/30/2016	ROCK	819.702942	3.30	-0.21	3.345513	0.4089	1.0897	258.0309	0.053
NRF12 160805 ROCK	12	8/5/2016	ROCK	790.990112	3.31	-0.2	1.254134	4.0558	6.269	307.091	0.7741
NRF14 160808 ROCK	14	8/8/2016	ROCK	583.069336	3.43	-0.16	1.109857	0.6467	0.8456	207.0121	0.2642
NRF15 160809 ROCK-a	15	8/9/2016	ROCK	886.039612	3.29	-0.22	0.232261	1.1371	1.837	295.5458	0.1727
NRF16 160816 ROCK	16	8/16/2016	ROCK	554.356445	3.44	-0.155	0.034275	0.2708	1.447	191.374	0.3136
NRF17 160818 ROCK	17	8/18/2016	ROCK	663.067688	3.21	-0.2966151	2.122315	20.6841	0.7936	355.518	0.0849
NRF18 160822 ROCK	18	8/22/2016	ROCK	1280.21057	3.00	-0.6	12.24955	0.4609	0.9827	550.5404	0.0753
NRF19 160902 ROCK	19	9/2/2016	ROCK	854.345886	3.13	-0.35	4.247233	1.8874	2.0826	386.4143	0.1152

								Acid Anions			
Analysis Name 1	Storm Number	Date Collected	Sample/ Tray	Conductivity (uS/cm)	pH units	ANC - meas (meq/L)	ANC - calc (meq/L)	Cl- (mg/L)	SO4^2- (mg/L)	NO3- (mg/L)	PO4^3- (mg/L)
			ROCK = pyrite rock								
NRF20 160919 ROCK-a	20	9/19/2016	ROCK	163.218048	3.58	-0.1498004	-0.346117	0.10377	0.19101	94.069	
NRF22 161121 ROCK	22	11/21/2016	ROCK	1713.29321	3.00	-0.55	-18.80789	2.25927	6.85548	1580.574	
NRF23 161130 ROCK	23	11/30/2016	ROCK	1005.3233	3.09	-0.42	-2.476343	0.78822	1.48687	950.288	
NRF24 161204 ROCK	24	12/4/2016	ROCK	532.541382	3.29	-0.3072091	2.125978	0.16087	0.78336	402.541	
NRF25 161206 ROCK	25	12/6/2016	ROCK	347.8797	3.38	-0.1780055	0.773986	0.27452	0.56808	232.634	
NRF26 161212 ROCK-b	26	12/12/2016	ROCK	303.96991	3.39	-0.1675125	0.64671	0.29228	0.50108	165.217	
			RAIN = rainwater								
---	1	6/21/2016									
---	2	6/24/2016									
---	3	6/27/2016									
---	4	6/28/2016									
---	5	7/5/2016									
---	6	7/7/2016									
---	7	7/9/2016									
---	8	7/15/2016									
NRF9 160727 RAIN	9	7/27/2016	RAIN	53.125721	6.66	0.23607969	0.434432	1.85503	2.91275	4.93489	0.00095
NRF10 160729 RAIN	10	7/29/2016	RAIN	1.23170841	6.12	0.02955578	0.101294	0.1269	0.50466	1.18243	0.00069
NRF11 160730 RAIN	11	7/30/2016	RAIN	14.483716	6.43	0.07475274	0.147367	0.04687	0.63215	0.83645	0.01753
NRF12 160805 RAIN	12	8/5/2016	RAIN	10.9951954	6.27	0.03120972	0.082372	0.02607	0.78366	0.63925	0.01565
NRF14 160808 RAIN	14	8/8/2016	RAIN	11.8312874	6.43	0.04772752	0.138872	0.05528	0.52884	0.23147	0.01866
NRF15 160809 RAIN	15	8/9/2016	RAIN	15.2237053	6.42	0.06021989	0.120993	0.03565	1.15239	0.25884	0.01237
NRF16 160816 RAIN	16	8/16/2016	RAIN	9.37106323	6.23	0.03168127	0.128653	0.06106	0.58057	0.51088	0.01336
NRF17 160818 RAIN	17	8/18/2016	RAIN	13.6707478	6.23	0.03961918	0.127352	0.0691	0.67779	1.42658	0.055
NRF18 160822 RAIN	18	8/22/2016	RAIN	21.5639095	6.33	0.05724778	0.120231	0.22743	1.68284	1.54781	0.01925
NRF19 160902 RAIN	19	9/2/2016	RAIN	75.4586487	6.96	0.41198784	1.210281	2.9456	14.09757	11.85447	0.00408
NRF20 160919 RAIN-a	20	9/19/2016	RAIN				0.248023	0.14428	1.39996	1.25647	
NRF22 161121 RAIN	22	11/21/2016	RAIN	24.0902252	6.79	0.14582506	3.494509	12.1473	88.7762	47.6	
---	23	11/30/2016									
NRF24 161204 RAIN	24	12/4/2016	RAIN	3.68678856	5.89	0.00363026	-0.003659	0.05744	0.37581	0.49922	
NRF25 161206 RAIN	25	12/6/2016	RAIN	5.19122076	5.92	0.00767107	-0.005784	0.39371	0.241	0.66911	
NRF26 161212 RAIN	26	12/12/2016	RAIN	4.34022903	6.06	12.0880893	0.039117	0.13173	0.21036	0.41256	

PYRITE GEOLOGY WATER CHEMSITRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Natural Rainfall

		Base Cations				Dissolved Metals							
Storm Number	Sample/ Tray	Na+ (mg/L)	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
	CONC = shotcrete												
1	CONC	15.72088	0	31.38889	34.12115	0.009509	0.023101	0.215777	20.48914	2.700447	0.238044	0	0.270473
2	CONC												
3	CONC												
4	CONC												
5	CONC	4.898996	21.52615	2.174228	6.930186	0.035651	0.009909	1.036291	1.260868	1.451485	0.037598	0	0.016956
6	CONC	3.221873	15.16268	0.564958	6.057281	0.023081	0.00079	0.069126	0.075381	1.615303	0.001814	0	0
7	CONC	3.165586	14.18828	0.493065	3.162581	0.016125	0.001796	0.191363	0.023219	1.618355	0.011764	0	0
8	CONC	3.713123	18.95069	3.391527	16.33287	0.05091	0.002737	0.991888	0.659184	1.715445	0.023285	0	0.010609
9	CONC	3.195936	17.32621	5.215954	11.42787	0.048787	0.005432	0.797717	1.636726	1.273702	0.024096	0	0.022001
10	CONC	2.08446	11.15346	1.166769	3.893586	0.043852	0.001468	0.241411	0.163691	1.318654	0.005899	0	0
11	CONC	1.728099	8.279103	1.15228	4.835548	0.024413	0	0.372789	0.113805	0.798895	0.005496	0	0.001205
12	CONC	1.611595	8.27167	1.445968	4.270448	0.021153	0	0.328161	0.264117	1.189893	0.007085	0	0.001066
14	CONC	1.120158	5.176594	0.782455	3.994914	0.008496	0	0.080173	0.060908	0.862466	0.002208	0	0
15	CONC	2.110602	10.62188	1.233149	4.071116	0.009193	0	0.082096	0.147219	1.779727	0.003492	0	0
16	CONC	0.975919	3.985544	0.904254	3.559475	0.029341	0	0.578558	0.108632	0.590194	0.003199	0	1.67E-05
17	CONC	1.719171	7.437165	1.190899	3.340348	0.014256	0.000244	0.108306	0.14334	1.447138	0.002809	0	0
18	CONC	4.083491	15.68618	2.580605	5.146742	0.026169	0	0.142114	0.309491	2.52823	0.005348	0	0
19	CONC	2.473443	11.89132	6.099423	10.59939	0.036591	0.001922	0.261045	1.329341	1.400303	0.028135	0	0.013692
20	CONC	1.969252	11.47963	1.495515	8.405355	0.006676	0.001478	0.108411	0.000781	2.745999	0.002872	0.00101	0
22	CONC	7.357275	44.89482	22.28647	95.90387	0.044948	0.038503	0.133933	0.020514	7.046947	0.171138	0.00127	0.025848
23	CONC	0.901368	5.167059	1.306379	44.6791	0.005311	0.002166	0.021526	0.003216	3.340193	0.01673	4.3E-06	0
24	CONC	0.009738	0.166786	0.12823	3.706826	0.054635	0.002934	0.159715	0.061114	1.635978	0.001888	0	0
25	CONC	0	0.106934	0.036867	0.877841	0.010041	0.00092	0.032187	0.01757	0.709093	0	0.000105	0
26	CONC	0.852326	4.317944	0.83926	5.890432	0.00643	0.00102	0.044819	0.059365	1.467658	0.001867	0	0
	GRASS = soil/vegetation												
1	GRASS	21.01778	0	61.19947	148.2746	0.261468	0.114233	0.792869	6.432137	4.440685	0.624764	8.76E-05	0.256886
2	GRASS												
3	GRASS												
4	GRASS												

		Base Cations				Dissolved Metals							
Storm Number	Sample/ Tray	Na+ (mg/L)	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
	GRASS = soil/vegetation												
5													
6	GRASS	3.602826	0	16.5114	45.22322	0.530084	0.03311	1.57829	2.886354	2.564445	0.234921	9.36E-07	0.055556
7	GRASS	0.37662	0	30.42187	95.02048	0.712493	0.017941	0.995266	5.825212	5.204078	0.451261	3.83E-05	0.120622
8	GRASS	3.595699	0	30.03564	51.72167	0.315682	0.012827	1.78661	2.492453	0.946842	0.09258	0	0.046598
9	GRASS	1.659312	0	17.7077	37.11443	0.541473	0.023997	2.287678	2.544536	0.937611	0.08506	0	0.03645
10	GRASS	1.467126	29.433	11.89268	21.95454	0.574386	0.016169	2.779861	1.730215	1.549174	0.087099	0	0.036189
11	GRASS	1.740045	0	14.47915	25.47504	0.700483	0.014622	3.314411	1.862057	2.145391	0.07987	5.64E-05	0.036257
12	GRASS	1.509819	32.93925	11.75141	20.43672	0.497857	0.013213	2.101985	1.655298	1.768665	0.054336	0	0.023123
14	GRASS	1.334271	24.46524	7.554697	15.53839	0.409087	0.010868	1.478694	1.163106	1.34053	0.06316	0	0.031524
15	GRASS	1.345855	31.95973	13.06613	26.35989	1.295741	0.016056	2.112918	2.382411	2.680119	0.130544	0	0.071784
16	GRASS	0.74664	15.28473	5.196923	10.83817	0.454208	0.008357	1.461027	1.193587	1.29311	0.045663	0	0.023185
17	GRASS	0.85682	17.85581	7.587294	16.25197	0.702863	0.011088	1.615348	1.379339	1.834013	0.074939	0	0.037991
18	GRASS	1.193193	26.10311	15.16008	28.50389	1.583872	0.037089	8.705655	2.73089	3.635618	0.143217	0	0.0857
19	GRASS	1.252626	15.33344	11.4099	28.19563	0.136186	0.008779	1.682352	4.012694	0.857272	0.049496	0	0.032259
20	GRASS	0.69923	18.57127	5.899938	18.13271	0.792469	0.027959	2.008613	1.206407	2.473192	0.099387	0.001153	0.038845
22	GRASS	1.361279	11.32183	13.38531	97.06975	0.069365	0.012344	0.49392	10.77767	1.735991	0.35757	0.001073	0.15905
23	GRASS	0.487062	10.71568	3.985364	15.82889	0.306448	0.017715	2.548751	1.402221	1.994977	0.054835	0	0.019512
24	GRASS	0.361381	9.82729	4.624319	14.29247	0.758205	0.024883	4.494646	1.587779	2.144117	0.091423	0	0.042847
25	GRASS	0.384303	11.09831	5.796223	16.51045	0.935017	0.031263	6.298912	2.33819	2.477126	0.153813	0	0.071323
26	GRASS	0.265116	7.992422	5.046116	14.88684	1.032351	0.027717	4.284002	1.586974	1.374705	0.160221	0	0.072177
	LINER = geoliner												
1	LINER	2.645564	1.584029	0.791175	7.453133	0.026978	0.023643	0.080097	0.060801	0.135348	0.13425	0	0.001053
2	LINER												
3	LINER												
4	LINER												
5	LINER	0.256762	0.540639	0.181311	2.276844	0.00503	0.012691	0.034126	0.016881	0.079072	0.02745	0	7.39E-05
6	LINER	0.257395	0.417818	0.11064	0.965119	0.002339	0.000804	0.023847	0.046672	0.061823	0.007466	0	0.00036
7	LINER	0.166298	0.092203	0.135821	0.932326	0.061061	0.000863	0.399963	0.044075	0.036592	0.019329	0	0.002652
8	LINER	0.542256	0.551745	0.240688	7.830054	0.015245	0.001962	0.002966	0.001905	0.094589	0.004294	0	0
9	LINER	0.466088	0.424038	0.31893	4.530475	0.038837	0.002987	0.211974	0.036465	0.092319	0.013327	0	0.001208
10	LINER	0.401366	0.203287	0.074709	1.099532	0.006657	0.001266	0.032832	0.009607	0.029369	0.004844	0	0
11	LINER	0.326115	0.152002	0.093854	0.85378	0.003957	0.000975	0.02126	0.004877	0.026738	0.007249	0	0

		Base Cations				Dissolved Metals							
Storm Number	Sample/ Tray	Na+ (mg/L)	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
	LINER = geoliner												
12	LINER	0.371597	0.220222	0.122897	1.008865	0.011602	0.000378	0.177542	0.002386	0.025828	0.007042	0	0.000583
14	LINER	0.331983	0.067654	0.075835	0.532092	0.003867	0.000651	0.066472	0.003422	0.008586	0.008725	0	2.82E-05
15	LINER	0.344846	0.170638	0.125071	0.700015	0.003961	4.39E-05	0.003928	0.005236	0.039699	0.006037	0	0
16	LINER	0.372377	0.188078	0.080725	0.778106	0.001943	0.00038	0.002049	0.004253	0.026363	0.005809	0	0
17	LINER	0.350956	0.128147	0.082536	0.567466	0.001433	0	0.00227	0.001669	0.029246	0.003595	0	0
18	LINER	0.360567	0.081294	0.169532	0.941379	0.006159	0.000435	0.036027	0.005261	0.022647	0.005852	0	0.000215
19	LINER	0.347854	0.667149	0.459798	7.513653	0.019792	0.002172	0.013416	0.010277	0.109905	0.081591	0	0
20	LINER	0.146949	0.099756	0.287088	3.098123	0.010133	0.001334	0.050554	0.00304	0.10444	0.012424	0.0013	0.000923
22	LINER	0.727401	5.028546	1.586033	62.10518	0.013011	0.005999	0.033135	0.004291	0.406981	0.094137	0.001147	0.000712
23	LINER	0.058322	0.012101	0.090045	1.973911	0	0.000393	0	0.001774		0.003988	0	0
24	LINER	0.059717	0.085253	0.009477	0.46166	0.003971	0.002655	0.017319	0.002726		0.009356	0	0.001075
25	LINER	0.083614	0	0		0.002762	0.002044	0.015268	0.001368		0.004192	0	0.000444
26	LINER	0.042969	0.002011	0.067935	0.97682	0.000989	0.001441	0.011783	0.002478		0.004538	0	0
	ROCK = pyrite rock												
1	ROCK	3.839908	3.968077	35.66902	52.71912	46.32671	1.398215		45.40168	3.077125	6.297525	0	2.81132
2	ROCK												
3	ROCK												
4	ROCK												
5													
6	ROCK	0.314746	0.6121	17.79009	12.85554	24.5471	0.645928		17.1065	1.292949	2.374941	0	1.334167
7	ROCK		0.544492	11.21477	6.43542	13.75159	0.381491	148.4558	12.47733	0.670452	1.541893	0	0.838491
8	ROCK	3.260131	0.692026	27.2145	48.03558	20.25336	0.455586	172.9658	14.25658	1.04708	1.603623	0	1.234955
9	ROCK	3.089653	0.199151	9.751806	14.7933	8.434192	0.195214	70.34808	3.982088	0.285119	0.613547	0	0.54289
10	ROCK	3.006577	0.136893	12.2039	10.99358	12.53932	0.237065	77.55281	5.734315	0.386081	0.666502	0	0.617715
11	ROCK	0.359602	0.160296	15.8737	13.38341	13.0977	0.26907	104.6397	7.044023	0.480208	0.775254	0	0.620965
12	ROCK	3.14313	0.809213	14.38856	9.66663	12.95615	0.267781	80.8625	6.163183	0.608876	0.62589	0	0.586138
14	ROCK	3.296538	0.782166	9.809672	5.784525	10.12979	0.155798	52.76719	4.269786	0.405144	0.457319	0	0.401821
15	ROCK	3.013274	0.398691	11.15768	5.87459	10.66494	0.193995	62.09984	6.420899	0.50709	0.618295	0	0.497285
16	ROCK	3.071201	0.150875	7.075079	4.155928	6.817229	0.137614	37.26577	2.779691	0.321695	0.334884	0	0.28858
17	ROCK	2.945831	0.246112	19.65834	7.251543	19.06898	0.333947	106.0607	8.727159	0.655154	0.880168	0	0.720146
18	ROCK	3.054048	0.523546	45.73868	14.63228	47.29316	0.997017	284.269	22.41891	1.424479	2.394405	0	1.799145
19	ROCK	2.944074	0.443991	27.34733	24.55974	19.75775	0.462097	117.4688	11.59705	0.742434	1.207312	0	0.92432

		Base Cations				Dissolved Metals							
Storm Number	Sample/ Tray	Na+ (mg/L)	K + (mg/L)	Mg ^2+ (mg/L)	Ca ^2+ (mg/L)	Al (mg/L)	Cu (mg/L)	Fe (mg/L)	Mn (mg/L)	Si (mg/L)	Zn (mg/L)	Cd (mg/L)	Ni (mg/L)
	ROCK = pyrite rock												
20	ROCK	0.158501	0.129737	2.772098	3.917612	2.687545	0.070936	10.4099	1.233184	0.203304	0.188959	0.000936	0.138948
22	ROCK	0.504326	0.799184		101.3095		2.560751		35.9686	1.49032	5.130391	0	3.845403
23	ROCK	0.349126	0.144248	51.32655	23.30369	59.21431	1.592778		17.49483	1.032532	2.725746	0	1.982335
24	ROCK	0.01586	0.001323	18.77498	11.04354	20.72401	0.655818	103.3565	10.2953	0.992004	1.366541	0	0.80723
25	ROCK	0.151851	0.042656	9.594442	7.10817	9.113009	0.255727	57.05916	6.613928	0.740303	0.696683	0	0.391666
26	ROCK	0.117812	0.052994	7.35809	5.681438	6.127255	0.250974	42.00211	5.037224	0.413363	0.552389	0	0.319786
	RAIN = rainwater												
1													
2													
3													
4													
5													
6													
7													
8													
9	RAIN	1.440875	0.821527	0.942017	8.045391	0.110978	0.055931	0.993071	0.081916	0.145034	0.012654		0.007841
10	RAIN	0.29173	0.070591	0.222089	1.014446	0.129416	0.009072	0.870628	0.062435	0.033668	0.009789		0.004856
11	RAIN	0.331128	0.07507	0.203683	2.694166	0.013742	0.001688	0.087958	0.009861	0.04076	0.003781		9.19E-05
12	RAIN	0.32825	0.061846	0.14762	1.533492	0.00484	0.000487	0.022199	0.010354	0.051621	0.005009		8.9E-05
14	RAIN	0.305912	0.07288	0.094566	2.610109	0.004526	0.00118	0.007111	0.00241	0.018574	0.003628		
15	RAIN	0.287812	0.054855	0.143092	2.426111	0.004932		0.020695	0.003053	0.028379	0.004879		
16	RAIN	0.327961	0.03827	0.183092	2.127724	0.026379	0.001217	0.222885	0.022406	0.03454	0.005338		0.001382
17	RAIN	0.317877	0.034259	0.25103	1.943892	0.086119	0.002099	0.587255	0.059592	0.033752	0.007137		0.004471
18	RAIN	0.400698	0.194189	0.262899	2.691584	0.010616	0.001424	0.033928	0.007995	0.081504	0.004417		
19	RAIN	0.474291	5.405494	2.169304	27.48096	0.124082	0.034679	0.451934	0.079458	0.444757	0.032353		0.002399
20	RAIN	0.233869	0.236458	0.394589	4.930591	0.00462	0.001938	0.003314	0.000848	0.072182	0.013074	0.000957	0.000362
22	RAIN	3.202364	5.514781	5.579394	110.627	0.023299	0.025315	0.008031	0.000924	2.510287	0.040334	0.001045	0.000296
23													
24	RAIN		0.026354	0.01866	0.212922	0.000774	0.001173	0.011499	0.003109	0	0.010853		0.000214
25	RAIN	0.239919	0.134501	0.011581	0.104914	0.002411	0.002252	0.00931	0.001687	0	0.010562	1.02E-05	0.000442
26	RAIN	0.027054	0.481731	0.057722	0.699416		0.000708	0.010306	0.004262	0	0.002535	6.22E-05	3.08E-06

PYRITE GEOLOGY WATER CHEMSITRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Natural Rainfall

			Acid Anions					Base Cations				
Storm Number	Sample/ Tray	Pb (m/L)	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)
	CONC = shotcrete											
1	CONC	0.002999	0.191106	0.131835	0	0	0.322942	0.683517	0	2.583447	1.706058	4.973022
2	CONC											
3	CONC											
4	CONC											
5	CONC	3.91E-05	0.024815	0.022642	0.51497	0	0.562427	0.213	0.551953	0.178949	0.346509	1.290411
6	CONC	0	0.019254	0.016237	0.243833	0	0.279323	0.140081	0.388787	0.046499	0.302864	0.878231
7	CONC	0	0.01792	0.016836	0.18538	0	0.220136	0.137634	0.363802	0.040581	0.158129	0.700147
8	CONC	0.001554	0.023606	0.052601	0.468988	0.000096	0.545291	0.16144	0.485915	0.279138	0.816643	1.743137
9	CONC	0.001261	0.013729	0.057809	0.546508	2.75E-05	0.618074	0.138954	0.444262	0.429297	0.571394	1.583906
10	CONC	0.001249	0.010942	0.013244	0.207033	0.000376	0.231594	0.090629	0.285986	0.09603	0.194679	0.667324
11	CONC	0.001765	0.004306	0.009686	0.199193	0.00017	0.213355	0.075135	0.212285	0.094838	0.241777	0.624035
12	CONC	0.000784	0.004833	0.012163	0.180684	0.000347	0.198027	0.070069	0.212094	0.11901	0.213522	0.614696
14	CONC	0.001509	0.004495	0.011836	0.077714	9.38E-05	0.09414	0.048703	0.132733	0.0644	0.199746	0.445581
15	CONC	0.001349	0.006176	0.023746	0.17485	0.000123	0.204896	0.091765	0.272356	0.101494	0.203556	0.669171
16	CONC	0.000389	0.003363	0.012168	0.117435	0.000114	0.133079	0.042431	0.102193	0.074424	0.177974	0.397023
17	CONC	0.001348	0.005128	0.00897	0.162698	0.000482	0.177278	0.074747	0.190697	0.098016	0.167017	0.530477
18	CONC	0.000961	0.016422	0.017217	0.369924	6.95E-05	0.403633	0.177543	0.40221	0.212395	0.257337	1.049485
19	CONC	0	0.058172	0.069692	0.496777	0.000235	0.624877	0.107541	0.304906	0.50201	0.52997	1.444427
20	CONC	0.00153	0.024329	0.01681	0.257779	0	0.298918	0.08562	0.29435	0.123088	0.420268	0.923324
22	CONC	0.004215	3.711638	0.641852	2.23021	0	6.5837	0.319882	1.151149	1.834277	4.795193	8.100501
23	CONC	0	0.006405	0.005032	0.311306	0	0.322743	0.03919	0.132489	0.107521	2.233955	2.513154
24	CONC	0	0.000966	0.001075	0.075017	0	0.077058	0.000423	0.004277	0.010554	0.185341	0.200595
25	CONC	0	0.000986	0.001115	0.029538	0	0.031639	0	0.002742	0.003034	0.043892	0.049668
26	CONC	0	0.00664	0.00754	0.112483	0	0.126663	0.037058	0.110717	0.069075	0.294522	0.511371
	GRASS = soil/vegetation											
1	GRASS	0.004872	2.473366	1.892143	0	0	4.365509	0.913816	0	5.036994	7.41373	13.36454
2	GRASS											
3	GRASS											
4	GRASS											

			Acid Anions					Base Cations				
Storm Number	Sample/ Tray	Pb (m/L)	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)
	GRASS = soil/vegetation											
5												
6	GRASS	0.001871	2.226401	1.95291	1.436323	2.21E-05	5.615656	0.156645	0	1.358963	2.261161	3.776769
7	GRASS	0.004826	5.464347	4.591492	4.88055	2.53E-05	14.93641	0.016375	0	2.503858	4.751024	7.271257
8	GRASS	0.002191	2.512881	2.423871	1.434755	0.003193	6.3747	0.156335	0	2.472069	2.586083	5.214487
9	GRASS	0.003359	0.798638	0.446669	1.075706	8.53E-05	2.321099	0.072144	0	1.457424	1.855721	3.385289
10	GRASS	0.001469	0.73687	1.19585	0.9583	0.000505	2.891525	0.063788	0.754692	0.978822	1.097727	2.895029
11	GRASS	0.001176	0.946523	1.66025	0.812039	0.001566	3.420378	0.075654	0	1.191699	1.273752	2.541106
12	GRASS	0.001281	6.191845	8.75884	5.674031	0.126202	20.75092	0.065644	0.844596	0.967194	1.021836	2.899271
14	GRASS	0.000979	0.45039	0.920617	0.717055	0.001481	2.089542	0.058012	0.627314	0.621786	0.776919	2.084031
15	GRASS	0.001805	0.589401	1.167131	1.482197	0.000824	3.239553	0.058515	0.81948	1.075402	1.317994	3.271391
16	GRASS	0.000515	0.172814	0.5068	0.574329	0.000935	1.254877	0.032463	0.391916	0.42773	0.541909	1.394018
17	GRASS	0.000712	0.256056	0.762425	0.790861	0.009382	1.818725	0.037253	0.457841	0.624469	0.812598	1.932162
18	GRASS	0.001346	0.349514	1.028144	1.437192	0.016544	2.831394	0.051878	0.66931	1.247743	1.425194	3.394126
19	GRASS	0.001883	0.259056	0.479558	1.382842	0.002751	2.124207	0.054462	0.393165	0.939087	1.409782	2.796495
20	GRASS	0.001834	0.17352	0.493023	1.06879	0	1.735333	0.030401	0.476187	0.485592	0.906636	1.898815
22	GRASS	0.003965	1.941997	0.304215	4.436613	0	6.682825	0.059186	0.290303	1.101672	4.853488	6.304649
23	GRASS	0	0.114037	0.330196	0.602879	0	1.047112	0.021177	0.274761	0.328013	0.791445	1.415396
24	GRASS	0	0.132913	0.324463	0.752534	0	1.209909	0.015712	0.251982	0.380602	0.714623	1.36292
25	GRASS	0	0.142462	0.32485	1.417371	0	1.884683	0.016709	0.284572	0.477055	0.825523	1.603859
26	GRASS	0	0.071379	0.156966	1.158581	0	1.386926	0.011527	0.204934	0.415318	0.744342	1.376121
	LINER = geoliner											
1	LINER	0.000335	0.104258	0.086925	0.1555	0	0.346683	0.115025	0.040616	0.065117	0.372657	0.593415
2	LINER											
3	LINER											
4	LINER											
5	LINER	0.002246	0.011924	0.026997	0.022494	0	0.061415	0.011164	0.013863	0.014923	0.113842	0.153791
6	LINER	0.002624	0.010244	0.016612	0.015841	0	0.042696	0.011191	0.010713	0.009106	0.048256	0.079266
7	LINER	0.00125	0.006407	0.017295	0.009472	0	0.033174	0.00723	0.002364	0.011179	0.046616	0.06739
8	LINER	0.000591	0.012966	0.033555	0.026808	0.000485	0.073815	0.023576	0.014147	0.01981	0.391503	0.449036
9	LINER	0.001333	0.008152	0.044318	0.0169	2.94E-05	0.069399	0.020265	0.010873	0.026249	0.226524	0.283911
10	LINER	0.001321	0.00522	0.00841	0.005824	1.07E-05	0.019466	0.017451	0.005212	0.006149	0.054977	0.083789
11	LINER	0.001054	0.002133	0.010291	0.006613	0.000305	0.019342	0.014179	0.003897	0.007725	0.042689	0.06849

			Acid Anions					Base Cations				
Storm Number	Sample/ Tray	Pb (m/L)	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)
	LINER = geoliner											
12	LINER	0.000499	0.003132	0.010742	0.004867	0.001707	0.020448	0.016156	0.005647	0.010115	0.050443	0.082361
14	LINER	0.000498	0.001658	0.010083	0.002252	0.001309	0.015302	0.014434	0.001735	0.006242	0.026605	0.049015
15	LINER	0.00014	0.002237	0.021542	0.00254	0.000133	0.026453	0.014993	0.004375	0.010294	0.035001	0.064663
16	LINER	0	0.002132	0.013156	0.00322	0.002936	0.021443	0.01619	0.004823	0.006644	0.038905	0.066562
17	LINER	0	0.002753	0.009376	0.005092	0.000898	0.01812	0.015259	0.003286	0.006793	0.028373	0.053711
18	LINER	0.000685	0.005282	0.015996	0.010587	6.06E-05	0.031926	0.015677	0.002084	0.013953	0.047069	0.078783
19	LINER	0.001145	0.052995	0.073668	0.034163	0.000113	0.160939	0.015124	0.017106	0.037843	0.375683	0.445757
20	LINER	0.001247	0.005764	0.000844	0.008235	0	0.014844	0.006389	0.002558	0.023629	0.154906	0.187482
22	LINER	0.001672	0.762734	0.020674	0.122746	0	0.906154	0.031626	0.128937	0.130538	3.105259	3.39636
23	LINER	0	0.016434	0.008244	0.055812	0	0.080489	0.002536	0.00031	0.007411	0.098696	0.108953
24	LINER	0	0.004617	0.00256	0.007501	0	0.014679	0.002596	0.002186	0.00078	0.023083	0.028645
25	LINER	0	0.005625	0.001755	0.005487	0	0.012868	0.003635	0	0	0	0.003635
26	LINER	0	0.006525	0.007845	0.016464	0	0.030834	0.001868	5.16E-05	0.005591	0.048841	0.056352
	ROCK = pyrite rock											
1	ROCK	0.039411	0.152753	0.126169	0	0	0.278922	0.166953	0.101746	2.935722	2.635956	5.840375
2	ROCK											
3	ROCK											
4	ROCK											
5												
6	ROCK	0.012466	0.026825	0.037694	6.323742	0.007247	6.395508	0.013685	0.015695	1.464205	0.642777	2.136361
7	ROCK	0.009122	0.022011	0.03266	4.644669	0.000875	4.700216	0	0.013961	0.923026	0.321771	1.258759
8	ROCK	0.010603	0.026232	0.036185	7.203373	0.003294	7.269083	0.141745	0.017744	2.239876	2.401779	4.801144
9	ROCK	0.02039	0.01515	0.03725	6.917984	0.003126	6.97351	0.134333	0.005106	0.802618	0.739665	1.681722
10	ROCK	0.00863	0.011003	0.014256	5.38355	0.002378	5.411187	0.130721	0.00351	1.004436	0.549679	1.688346
11	ROCK	0.005648	0.011551	0.022702	4.161789	0.001674	4.197715	0.015635	0.00411	1.306477	0.669171	1.995393
12	ROCK	0.013977	0.114571	0.130604	4.953081	0.024445	5.222701	0.136658	0.020749	1.184244	0.483332	1.824982
14	ROCK	0.01019	0.018268	0.017617	3.338905	0.008343	3.383133	0.143328	0.020056	0.80738	0.289226	1.25999
15	ROCK	0.012275	0.032121	0.038271	4.766868	0.005454	4.842714	0.131012	0.010223	0.918327	0.293729	1.353292
16	ROCK	0.002433	0.00765	0.030146	3.086677	0.009903	3.134376	0.13353	0.003869	0.582311	0.207796	0.927507
17	ROCK	0.001667	0.584297	0.016533	5.734161	0.002681	6.337672	0.12808	0.006311	1.617971	0.362577	2.114938
18	ROCK	0.017801	0.01302	0.020473	8.879684	0.002378	8.915554	0.132785	0.013424	3.7645	0.731614	4.642323
19	ROCK	0.021411	0.053316	0.043388	6.232489	0.003638	6.33283	0.128003	0.011384	2.250809	1.227987	3.618184

			Acid Anions					Base Cations				
Storm Number	Sample/ Tray	Pb (m/L)	Cl- (meq/L)	SO4^2- (meq/L)	NO3- (meq/L)	PO4^3- (meq/L)	Sum AA (meq/L)	Na+ (meq/L)	K + (meq/L)	Mg ^2+ (meq/L)	Ca ^2+ (meq/L)	Sum BC (meq/L)
	ROCK = pyrite rock											
20	ROCK	0.002647	0.002931	0.003979	1.517242	0	1.524153	0.006891	0.003327	0.228156	0.195881	0.434255
22	ROCK	0.038443	0.063821	0.142823	25.49313	0	25.69977	0.021927	0.020492	0	5.065474	5.107893
23	ROCK		0.022266	0.030976	15.32723	0	15.38047	0.015179	0.003699	4.224407	1.165184	5.40847
24	ROCK		0.004544	0.01632	6.492597	0	6.513461	0.00069	3.39E-05	1.545265	0.552177	2.098166
25	ROCK		0.007755	0.011835	3.752161	0	3.771751	0.006602	0.001094	0.789666	0.355408	1.15277
26	ROCK		0.008256	0.010439	2.66479	0	2.683486	0.005122	0.001359	0.605604	0.284072	0.896157
	RAIN = rainwater											
1												
2												
3												
4												
5												
6												
7												
8												
9	RAIN		0.052402	0.060682	0.079595	0.00003	0.192709	0.062647	0.021065	0.077532	0.40227	0.563513
10	RAIN	0.000665	0.003585	0.010514	0.019071	2.18E-05	0.033192	0.012684	0.00181	0.018279	0.050722	0.083495
11	RAIN	0.000995	0.001324	0.01317	0.013491	0.000554	0.028539	0.014397	0.001925	0.016764	0.134708	0.167794
12	RAIN	0.000501	0.000736	0.016326	0.01031	0.000494	0.027867	0.014272	0.001586	0.01215	0.076675	0.104682
14	RAIN		0.001562	0.011018	0.003733	0.000589	0.016902	0.013301	0.001869	0.007783	0.130505	0.153458
15	RAIN	0.000594	0.001007	0.024008	0.004175	0.000391	0.029581	0.012514	0.001407	0.011777	0.121306	0.147003
16	RAIN		0.001725	0.012095	0.00824	0.000422	0.022482	0.014259	0.000981	0.015069	0.106386	0.136696
17	RAIN	0.000882	0.001952	0.014121	0.023009	0.001737	0.040819	0.013821	0.000878	0.020661	0.097195	0.132555
18	RAIN	0.000704	0.006425	0.035059	0.024965	0.000608	0.067056	0.017422	0.004979	0.021638	0.134579	0.178618
19	RAIN	0.002155	0.083209	0.293699	0.191201	0.000129	0.568238	0.020621	0.138602	0.178544	1.374048	1.711815
20	RAIN	0.001452	0.004076	0.029166	0.020266	0	0.053507	0.010168	0.006063	0.032476	0.24653	0.295237
22	RAIN	0.002566	0.343144	1.849504	0.767742	0	2.96039	0.139233	0.141405	0.459209	5.531349	6.271197
23												
24	RAIN		0.001623	0.007829	0.008052	0	0.017504	0	0.000676	0.001536	0.010646	0.012858
25	RAIN		0.011122	0.005021	0.010792	0	0.026935	0.010431	0.003449	0.000953	0.005246	0.020079
26	RAIN		0.003721	0.004383	0.006654	0	0.014758	0.001176	0.012352	0.004751	0.034971	0.05325

PYRITE GEOLOGY WATER CHEMSITRY: SUMMARY SHEET MIDDLEBROOK PIKE EXPERIMENT

Natural Rainfall

		Dissolved Metals								
Storm Number	Sample/ Tray	Al^3+ (meq/L)	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Zn^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	Si^2+ (meq/L)	ANC (meq/L)
	CONC = shotcrete									
1	CONC	0.001057	0.007728	0.745873	0.00728	0.000727	0	0.009215	0.192271	5.614232
2	CONC									
3	CONC									
4	CONC									
5	CONC	0.003964	0.037113	0.0459	0.00115	0.000312	0	0.000578	0.103345	0.920345
6	CONC	0.002566	0.002476	0.002744	5.55E-05	2.49E-05	0	0	0.115009	0.721783
7	CONC	0.001793	0.006853	0.000845	0.00036	5.65E-05	0	0	0.115226	0.605145
8	CONC	0.005661	0.035523	0.023996	0.000712	8.61E-05	0	0.000361	0.122139	1.386325
9	CONC	0.005425	0.028569	0.059582	0.000737	0.000171	0	0.00075	0.090687	1.151753
10	CONC	0.004876	0.008646	0.005959	0.00018	4.62E-05	0	0	0.093888	0.549325
11	CONC	0.002715	0.013351	0.004143	0.000168	0	0	4.11E-05	0.056881	0.487979
12	CONC	0.002352	0.011753	0.009615	0.000217	0	0	3.63E-05	0.08472	0.525361
14	CONC	0.000945	0.002871	0.002217	6.75E-05	0	0	0	0.061407	0.418949
15	CONC	0.001022	0.00294	0.005359	0.000107	0	0	0	0.126716	0.600419
16	CONC	0.003262	0.02072	0.003955	9.78E-05	0	0	5.69E-07	0.042022	0.334
17	CONC	0.001585	0.003879	0.005218	8.59E-05	7.69E-06	0	0	0.103036	0.46701
18	CONC	0.00291	0.00509	0.011266	0.000164	0	0	0	0.180009	0.845291
19	CONC	0.004069	0.009349	0.048392	0.00086	6.05E-05	0	0.000467	0.099701	0.982449
20	CONC	0.000742	0.003883	2.84E-05	8.78E-05	4.65E-05	1.8E-05	0	0.195514	0.824727
22	CONC	0.004998	0.004797	0.000747	0.005234	0.001212	2.26E-05	0.000881	0.501741	2.036432
23	CONC	0.000591	0.000771	0.000117	0.000512	6.82E-05	7.65E-08	0	0.237821	2.43029
24	CONC	0.006075	0.00572	0.002225	5.77E-05	9.23E-05	0	0	0.116481	0.254188
25	CONC	0.001116	0.001153	0.00064	0	2.89E-05	1.86E-06	0	0.050487	0.071456
26	CONC	0.000715	0.001605	0.002161	5.71E-05	3.21E-05	0	0	0.104497	0.493775
	GRASS = soil/vegetation									
1	GRASS	0.029074	0.028395	0.234151	0.019106	0.003595	1.56E-06	0.008752	0.316175	9.638282
2	GRASS									
3	GRASS									
4	GRASS									

		Dissolved Metals								
Storm Number	Sample/ Tray	Al^3+ (meq/L)	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Zn^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	Si^2+ (meq/L)	ANC (meq/L)
	GRASS = soil/vegetation									
5										
6	GRASS	0.058942	0.056524	0.105073	0.007184	0.001042	1.67E-08	0.001893	0.182588	-1.42564
7	GRASS	0.079225	0.035644	0.212057	0.0138	0.000565	6.82E-07	0.00411	0.370529	-6.94923
8	GRASS	0.035102	0.063985	0.090734	0.002831	0.000404	0	0.001588	0.067415	-0.89816
9	GRASS	0.060208	0.08193	0.09263	0.002601	0.000755	0	0.001242	0.066758	1.370314
10	GRASS	0.063868	0.099556	0.062986	0.002664	0.000509	0	0.001233	0.110301	0.34462
11	GRASS	0.077889	0.1187	0.067785	0.002443	0.00046	1E-06	0.001235	0.152751	-0.45801
12	GRASS	0.055359	0.075279	0.060258	0.001662	0.000416	0	0.000788	0.125928	-17.532
14	GRASS	0.045488	0.052957	0.042341	0.001932	0.000342	0	0.001074	0.095445	0.234067
15	GRASS	0.144078	0.075671	0.086728	0.003992	0.000505	0	0.002446	0.190824	0.536082
16	GRASS	0.050505	0.052324	0.043451	0.001396	0.000263	0	0.00079	0.092069	0.379939
17	GRASS	0.078154	0.057851	0.050213	0.002292	0.000349	0	0.001294	0.130581	0.43417
18	GRASS	0.176116	0.311779	0.099414	0.00438	0.001167	0	0.00292	0.258855	1.417363
19	GRASS	0.015143	0.060251	0.146076	0.001514	0.000276	0	0.001099	0.061038	0.957684
20	GRASS	0.088117	0.071935	0.043917	0.003039	0.00088	2.05E-05	0.001324	0.176091	0.548806
22	GRASS	0.007713	0.017689	0.392343	0.010935	0.000388	1.91E-05	0.005419	0.123602	0.179933
23	GRASS	0.034075	0.091279	0.051046	0.001677	0.000558	0	0.000665	0.142042	0.689625
24	GRASS	0.084307	0.160969	0.0578	0.002796	0.000783	0	0.00146	0.152661	0.613787
25	GRASS	0.103968	0.225586	0.085118	0.004704	0.000984	0	0.00243	0.176371	0.318336
26	GRASS	0.114791	0.153425	0.057771	0.0049	0.000872	0	0.002459	0.097879	0.421292
	LINER = geoliner									
1	LINER	0.003	0.002869	0.002213	0.004106	0.000744	0	3.59E-05	0.009637	0.269335
2	LINER									
3	LINER									
4	LINER									
5	LINER	0.000559	0.001222	0.000615	0.000839	0.000399	0	2.52E-06	0.00563	0.101643
6	LINER	0.00026	0.000854	0.001699	0.000228	2.53E-05	0	1.23E-05	0.004402	0.044051
7	LINER	0.00679	0.014324	0.001604	0.000591	2.72E-05	0	9.03E-05	0.002605	0.060248
8	LINER	0.001695	0.000106	6.94E-05	0.000131	6.18E-05	0	0	0.006735	0.38402
9	LINER	0.004318	0.007592	0.001327	0.000408	9.4E-05	0	4.11E-05	0.006573	0.234865
10	LINER	0.00074	0.001176	0.00035	0.000148	3.98E-05	0	0	0.002091	0.068868
11	LINER	0.00044	0.000761	0.000178	0.000222	3.07E-05	0	0	0.001904	0.052683

		Dissolved Metals								
Storm Number	Sample/ Tray	Al^3+ (meq/L)	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Zn^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	Si^2+ (meq/L)	ANC (meq/L)
	LINER = geoliner									
12	LINER	0.00129	0.006358	8.69E-05	0.000215	1.19E-05	0	1.98E-05	0.001839	0.071735
14	LINER	0.00043	0.002381	0.000125	0.000267	2.05E-05	0	9.62E-07	0.000611	0.037548
15	LINER	0.00044	0.000141	0.000191	0.000185	1.38E-06	0	0	0.002827	0.041995
16	LINER	0.000216	7.34E-05	0.000155	0.000178	1.19E-05	0	0	0.001877	0.04763
17	LINER	0.000159	8.13E-05	6.08E-05	0.00011	0	0	0	0.002082	0.038084
18	LINER	0.000685	0.00129	0.000192	0.000179	1.37E-05	0	7.32E-06	0.001612	0.050836
19	LINER	0.002201	0.00048	0.000374	0.002495	6.84E-05	0	0	0.007825	0.298262
20	LINER	0.001127	0.001811	0.000111	0.00038	4.2E-05	2.31E-05	3.14E-05	0.007436	0.183599
22	LINER	0.001447	0.001187	0.000156	0.002879	0.000189	2.04E-05	2.43E-05	0.028977	2.525085
23	LINER	0	0	6.46E-05	0.000122	1.24E-05	0	0	0	0.028663
24	LINER	0.000442	0.00062	9.92E-05	0.000286	8.35E-05	0	3.66E-05	0	0.015534
25	LINER	0.000307	0.000547	4.98E-05	0.000128	6.43E-05	0	1.51E-05	0	-0.00812
26	LINER	0.00011	0.000422	9.02E-05	0.000139	4.54E-05	0	0	0	0.026324
	ROCK = pyrite rock									
1	ROCK	5.151228	0	1.652773	0.192585	0.044004	0	0.095786	0.21909	12.91692
2	ROCK									
3	ROCK									
4	ROCK									
5										
6	ROCK	2.729478	0	0.622734	0.072628	0.020328	0	0.045457	0.092058	-0.67646
7	ROCK	1.529087	5.316708	0.454217	0.047153	0.012006	0	0.028569	0.047736	3.994018
8	ROCK	2.252042	6.194494	0.518987	0.04904	0.014338	0	0.042077	0.074552	6.67759
9	ROCK	0.937827	2.519405	0.144961	0.018763	0.006144	0	0.018497	0.0203	-1.62589
10	ROCK	1.39429	2.777431	0.208748	0.020382	0.007461	0	0.021047	0.027489	0.734006
11	ROCK	1.456379	3.747506	0.256426	0.023708	0.008468	0	0.021157	0.034191	3.345513
12	ROCK	1.44064	2.895962	0.22436	0.01914	0.008427	0	0.019971	0.043352	1.254134
14	ROCK	1.126367	1.889773	0.155435	0.013985	0.004903	0	0.013691	0.028846	1.109857
15	ROCK	1.185872	2.224007	0.233742	0.018908	0.006105	0	0.016943	0.036105	0.232261
16	ROCK	0.758031	1.334614	0.10119	0.010241	0.004331	0	0.009832	0.022905	0.034275
17	ROCK	2.120346	3.798396	0.317698	0.026916	0.01051	0	0.024536	0.046647	2.122315
18	ROCK	5.258691	10.18064	0.816123	0.073223	0.031377	0	0.0613	0.101422	12.24955
19	ROCK	2.196933	4.206957	0.422171	0.036921	0.014543	0	0.031493	0.052861	4.247233

		Dissolved Metals								
Storm Number	Sample/ Tray	Al^3+ (meq/L)	Fe^2+ (meq/L)	Mn^2+ (meq/L)	Zn^2+ (meq/L)	Cu^2+ (meq/L)	Cd^2+ (meq/L)	Ni^2+ (meq/L)	Si^2+ (meq/L)	ANC (meq/L)
	ROCK = pyrite rock									
20	ROCK	0.298837	0.372814	0.044892	0.005779	0.002232	1.67E-05	0.004734	0.014475	-0.34612
22	ROCK	0	0	1.309378	0.156893	0.08059	0	0.131019	0.10611	-18.8079
23	ROCK	6.584245	0	0.63687	0.083356	0.050127	0	0.067541	0.073516	-2.47634
24	ROCK	2.304375	3.701551	0.374783	0.04179	0.020639	0	0.027504	0.07063	2.125978
25	ROCK	1.013307	2.043483	0.240769	0.021305	0.008048	0	0.013345	0.052709	0.773986
26	ROCK	0.681311	1.504239	0.183372	0.016893	0.007898	0	0.010896	0.029431	0.64671
	RAIN = rainwater									
1										
2										
3										
4										
5										
6										
7										
8										
9	RAIN	0.01234	0.035565	0.002982	0.000387	0.00176	0	0.000267	0.010326	0.434432
10	RAIN	0.01439	0.03118	0.002273	0.000299	0.000286	0	0.000165	0.002397	0.101294
11	RAIN	0.001528	0.00315	0.000359	0.000116	5.31E-05	0	3.13E-06	0.002902	0.147367
12	RAIN	0.000538	0.000795	0.000377	0.000153	1.53E-05	0	3.03E-06	0.003675	0.082372
14	RAIN	0.000503	0.000255	8.77E-05	0.000111	3.71E-05	0	0	0.001322	0.138872
15	RAIN	0.000548	0.000741	0.000111	0.000149	0	0	0	0.002021	0.120993
16	RAIN	0.002933	0.007982	0.000816	0.000163	3.83E-05	0	4.71E-05	0.002459	0.128653
17	RAIN	0.009576	0.021032	0.002169	0.000218	6.61E-05	0	0.000152	0.002403	0.127352
18	RAIN	0.00118	0.001215	0.000291	0.000135	4.48E-05	0	0	0.005803	0.120231
19	RAIN	0.013797	0.016185	0.002893	0.000989	0.001091	0	8.17E-05	0.031667	1.210281
20	RAIN	0.000514	0.000119	3.09E-05	0.0004	6.1E-05	1.7E-05	1.23E-05	0.005139	0.248023
22	RAIN	0.002591	0.000288	3.36E-05	0.001233	0.000797	1.86E-05	1.01E-05	0.178732	3.494509
23										
24	RAIN	8.61E-05	0.000412	0.000113	0.000332	3.69E-05	0	7.29E-06	0	-0.00366
25	RAIN	0.000268	0.000333	6.14E-05	0.000323	7.09E-05	1.81E-07	1.51E-05	0	-0.00578
26	RAIN	0	0.000369	0.000155	7.75E-05	2.23E-05	1.11E-06	1.05E-07	0	0.039117