MD-14-SP109B4D

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Anthony G. Brown, *Lt. Governor*

State Highway Administration
Maryland Department of Transportation

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# STATE HIGHWAY ADMINISTRATION RESEARCH REPORT

# IDENTIFICATION OF TECHNIQUES TO MEET PH STANDARD DURING IN-STREAM CONSTRUCTION

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## MORGAN STATE UNIVERSITY

**Project Number SP109B4D**
**FINAL REPORT**

**March 2014**

*Technical Report Documentation Page*

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|---|---|---|
| 1. Report No.<br>MD-14-SP109B4D | 2. Government Accession No. | 3. Recipient's Catalog No. |
| 4. Title and Subtitle<br>Identification of Techniques to Meet pH Standard During In-stream Construction | | 5. Report Date<br>March 2014 |
| | | 6. Performing Organization Code |
| 7. Author/s<br>James G. Hunter Jr., Dong Hee Kang, Mark M. Bundy | | 8. Performing Organization Report No. |
| 9. Performing Organization Name and Address<br>Morgan State University<br>School of Engineering<br>1700 E. Cold Spring Lane<br>Baltimore, MD 21251 | | 10. Work Unit No. (TRAIS) |
| 12. Sponsoring Organization Name and Address<br>Office of Policy and Research<br>Maryland State Highway Administration<br>707 N. Calvert St.<br>Baltimore, MD 21202<br><br>National Transportation Center<br>Morgan State University<br>1700 E. Cold Spring Lane<br>Baltimore, MD 21251 | | 11. Contract or Grant No.<br>SP109B4D<br>13. Type of Report and Period Covered<br>Final Report<br>14. Sponsoring Agency Code |
| 15. Supplementary Notes | | |

16. Abstract

Many of Maryland’s tributaries traverse highway infrastructure via culverts that are managed and maintained by SHA. These culverts are often made of galvanized steel and over time are subjected to scour. Concrete grout is often used as a repair material when these issues are identified. However, once water is allowed to inundate the freshly paved culvert, the grout surface can produce a dissolution effect in which elevated pH can impact downstream waters. The occurrence of this pH spike from grout has been reported in past projects, and has resulted in concerns as the pH of water may reach above the regulatory limit of 8.5. The goal of this project was to ensure that SHA has a proper specification and remedial actions for addressing the pH concern. The overall objectives of this research were to (1) review the current specification for using grout for culvert maintenance, (2) determine the various parameters that control pH spikes for effluent waters, (3) determine applicable remedial applications, and (4) revise the current specification and provide a guidance document/tool for SHA and contractors. Laboratory and field studies were used to investigate and test these objectives.

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|---|---|---|---|
| 17. Key Words:<br>culvert, grout, invert paving, maintenance, pH, water quality | 18. Distribution Statement: No restrictions<br>This document is available from the Research Division upon request. | | |
| 19. Security Classification (of this report)<br>None | 20. Security Classification (of this page)<br>None | 21. No. of Pages<br>99 | 22. Price |

**Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized.**

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# ACKNOWLEDGEMENTS

This work was supported and directed by the Maryland State Highway Administration's Office of Environmental Design and Office of Policy and Research. We would like to thank Cheryl Jordan, Veronica Piskor, Hua (Remy) Xiang, and Alison Hardt, along with those SHA units and personnel who assisted us with their comments, input, and logistical support.

We would also like to thank Morgan State's National Transportation Center (NTC) and Dr. Andrew Farkas for additional grant and administrative support, with special thanks to Anita Jones for assistance with administrative duties regarding the NTC budget related. We would also like to acknowledge Morgan State's Estuarine Research Center (ERC), led by Dr. Kelton Clark. ERC staff members Jody Gregory, J. Hixon, and William Yates were very helpful in supporting many of the research activities and acquisition of supplies.

The authors are indebted to the following Morgan State University students and their sponsoring programs for providing support for this research:

**Jalil Abdul,** sophomore, Department of Civil Engineering
Scholars in Engineering awardee; *SEM student researcher* (NSF Sponsored Programs) *and Minority Access Role Models 2012 Conference awardee*
**Amon Dow**, senior, Department of Civil Engineering
*MBRS RISE student researcher* (NSF Sponsored Programs) *and ABRCMS 2012 awardee*
**Olumayokun Odukale,** junior, Department of Civil Engineering
*SEM student researcher and Chesapeake Bay Trust 2013 Honorable Arthur Dorman Scholarship recipient*
**S. Brittany Daniels,** junior, Department of Civil Engineering
**Akin Oni,** doctoral student, Bio-Environmental Science

We are proud of the knowledge these students obtained and the recognition they gained in Maryland and at the national level for their exceptional work and insightful presentations made on the research.

# EXECUTIVE SUMMARY


Many of Maryland's tributaries traverse highway infrastructure via culverts that are managed and maintained by SHA. These culverts are often made of galvanized steel and over time are subjected to scour. Concrete grout is often used as a repair material when these issues are identified. However, once water is allowed to inundate the freshly paved culvert, the grout surface can produce a dissolution effect in which elevated pH can impact downstream waters. The occurrence of this pH spike from grout has been reported in past projects, and has resulted in concerns as the pH of water may reach above the regulatory limit of 8.5.

The goal of this project was to ensure that SHA has a proper specification and remedial actions for addressing the pH concern. The overall objectives of this research were to 1) review the current specification for using grout for culvert maintenance, (2) determine the various parameters that control pH spikes for effluent waters, (3) determine applicable remedial applications, and (4) revise the current specification and provide a guidance document/tool for SHA and contractors.

Laboratory and field studies were used to investigate and test the project's objectives. Results indicate that the primary cause of the pH spike is based on the extent of the contact time and flow rate the water has with the paved grout surface, while other parameters, such as surface washing and temperature, may have a subtle impact on the extent of the pH monitored. A remedial application was developed using wetted peat as a buffering agent for high pH water. The research also indicates that contractors should be more cognizant of the procedures and the quality of work performed in the field.

# 1 BACKGROUND AND RESEACH OBJECTIVES

## 1.1 Project background

Culverts, constructed from a variety of materials and available in many different shapes and configurations, are hydraulically short conduits necessary to convey stream flow through a roadway embankment or past some other type of flow obstruction. The service life of a culvert is subject to field conditions and the durability of the culvert material. Environmental conditions over time will deteriorate all culvert materials due to abrasion, corrosion, and removal of bedding materials (Norman et al., 2005). As water travels through the deteriorating culvert, water may also begin to travel outside of the culvert, eroding the soil bed and weakening the entire structure. The loss of soil and bedding beneath the road will eventually create voids, making the roadway unstable and the road pavement above may also fail. Therefore, proper attention must be given to this deterioration and periodic maintenance is required to increase the service life of a culvert.

Cementitious grout is often used in the repair and maintenance of culverts. However, consideration must be taken to ensure that grout paving materials used to reline the culvert do not adversely impact local water quality, particularly by spiking the pH due to hydrolysis of calcium oxide (CaO), which can increase pH to as high as 12.4 (Gupta et al., 2009). Consequently, the inundation of water over this reactive surface could produce caustic alkalinity and increases in pH that can raise the toxicity of other pollutants, impacting aquatic organisms. For example, the toxicity of ammonia is 10 times more severe to fish at a pH of 8.5 than it is at a pH of 7.5 (Turston et al., 1981).

Few studies have been conducted to ascertain the impact of grout materials used during field application (Reiner, 2008). One previous study of note, a 2003 Virginia Department of Transportation (VDOT) study by G. Michael Fitch, illustrated that the use of grout materials can result in spikes to pH depending on the combination of stream flow and grout application rates. For newly paved culverts, proper precautions and actions (such as diversion and treatment) may be needed for waters that exceed Maryland’s pH upper limit of 8.5. Thus, there is a concern that the Maryland State Highway Administration’s (SHA) routine maintenance activities using grout paving may cause waters to exceed the state’s pH limit.

Each year, hundreds of SHA remedial structural activities require waterway permits from the Maryland Department of the Environment (MDE) and the U.S Army Corps of Engineers (USACE). The regulatory agencies are becoming increasingly concerned with water quality standards, particularly with Maryland’s High Quality (Tier II) waters, and have indicated the possibility of, as a first step in holding SHA accountable to state water quality standards, conditioning SHA permits to require pH monitoring. This is significant because if impacts to a waterway are unavoidable and cannot be justified, MDE and USACE will deny permits or approvals.

With the safety of SHA’s structures at stake, this research sets to identify maintenance construction techniques that allow SHA to comply with current state and federal water quality standards and remedial action(s) that are low-cost and dependable. Proposed for this study are field and laboratory tests of typical grout paving applications under various conditions to provide recommendations and a decision-making flowchart to meet Maryland's pH limit of 8.5. In addition, this study will also identify potential remedial techniques for high pH waters contained within the work area and first flush of the grouted work surface so that they meet Maryland's acceptable pH range of 6.5 to 8.5.

### 1.1.1 Culvert

All culverts can be classified based on their different structural loads and the interrelationship between the culvert structure and the surrounding soil. Culvert types are also often described by their shape and material. Culverts have various shapes, such as circular, arch, elliptical, box, and multiple barrel. Materials may also vary and may be made of concrete, corrugated steel, corrugated aluminum, masonry, vitrified clay (or terra cotta), wood, iron cast, and plastic.

The culvert may experience a wide variety of problems over its service life: scour and erosion of streambed and embankments, inadequate flow capacity, corrosion and abrasion of metal culverts, abrasion and deterioration of concrete and masonry culverts, sedimentation and blockage by debris, separation and/or drop off of sections of modular culverts and inadequate length, cracking of rigid culverts, undermining and loss of structural support, loss of the invert due to corrosion or abrasion, over-deflection and shape deformation of flexible culverts, and stress cracking of plastic culverts.

Culvert problems caused by factors such as, high flow velocity, turbulence, weathering, over loads, and age, require routine maintenance to keep the culvert functioning. However, replacement of unserviceable culverts requires significant construction costs and causes severe traffic disruptions. These circumstances require viable methods for the repair and rehabilitation of unpractical culverts.

The corrugated steel culvert has been widely used throughout the country for many years due to its cheaper cost, transportability, and ease of assembly in comparison to other culvert pipes. Corrugated steel culverts can be made of aluminum coated steel, galvanized steel, and bituminous-coated galvanized steel. Paint, polyethylene, bituminous, or epoxy coatings may also be used to protect corrugated steel culverts. The coating provides a barrier against corrosive agents, moisture, oxygen, and electrical currents. The most serious fundamental problem with a corrugated steel culvert is deterioration of the invert due to a combination of abrasion and corrosion. A coated corrugated steel culvert with an asphaltic or other type of protective coating has limited durability against abrasion from sand and rocks. Eventually, the coating abrades or breaks away. Corrosion due to chemicals in the surrounding soil and in the water that passes through the culvert may reduce the thickness of the pipe wall and, therefore, reduce its strength. Continuation of abrasion and corrosion frequently results in almost total loss of the invert and the creation of deep scour holes under the culvert.

Many types of repairs and rehabilitation action may be taken to restore corrugated steel culverts. One of the most effective ways to rehabilitate the corroded and severely deteriorated invert of a corrugated steel culvert is paving. The inverts of corrugated steel culverts are frequently paved to extend the life of the culvert by protecting the invert against corrosion and abrasion. The paving smoothes the inside of the culvert, and in turn improves its hydraulic capacity. The invert of culverts may be paved with plain or reinforced Portland cement concrete to provide additional thickness that will resist abrasion and corrosion and may be either conventional ready-mix type concrete or shortcrete. Sufficient steel reinforcement should be installed and securely anchored to restore the culvert's structural capacity and resist circumferential thrust loads.

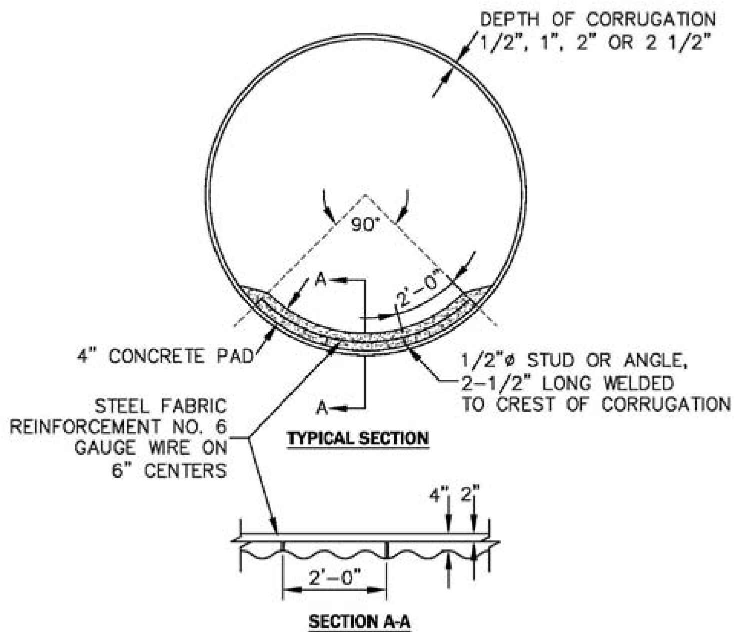



**Figure 1.1: In-place installation of a concrete invert** (U.S. DOT, FHWA, 1995)

### 1.1.2 Characteristics of concrete/grout paving

Concrete is a mixture of two components: aggregate and binder. The aggregate provides the basic structure of the material and is typically either sand or gravel. The binder, or mortar, consists of hydrated cement and is responsible for binding the aggregate together and, thus, provides the cohesive properties of the material. Dry, powdered cement is produced by calcinating calcareous (calcium-containing) and argillaceous (clay-containing) rocks with either silica or alumina (AWWARF and DVGW-TZW, 1996). The cement produced by this process contains a number of silicates and oxides of calcium, aluminum, and iron.

The Portland cement commonly employed in water treatment and distribution primarily consists of tricalcium silicate ($Ca_3SiO_5$, abbreviated as $C_3S$), dicalcium silicate ($Ca_2SiO_4$, $C_2S$), calcium aluminate ($Ca_3Al_2O_6$, $C_3A$), iron calcium aluminate ($Ca_4Fe_2Al_2O_{10}$, $C_4AF$), and gypsum ($CaSO_4{\bullet}2H_2O$). When Portland cement is wetted, these phases undergo a series of hydrolysis, hydration, and ultimately precipitation reactions that produce a hardened material. This process results in the formation of calcium hydroxide ($Ca(OH)_2$.

### 1.1.3 Water quality issue

Contaminant leaching and pH changes in the surrounding soil and water are environmental considerations for the grout mixture of sand and cement used in culvert maintenances. Cement primarily consists of calcium sulfate, calcium and magnesium oxide, heavy metals, potassium and compounds of sodium sulfate, chromium, and nickel, all of which can result in heavy metals leaching.

Concrete washout wastewater produced during culvert maintenance is caustic and considered corrosive due to the presence of calcium hydroxide, with a high pH over 12, that could have an adverse effect on the surrounding environment (Mulligan, 2002). The high pH may also increase the toxicity of ammonia, as an elevated pH may amplify ammonia toxicity severely to ten-fold at a pH of 8 than at a pH of 7. Additionally, high pH from concrete wash water also reduces the amount of oxygen and smothers aquatic habitats, impairs the feeding ability of fish and other aquatic organisms, and permanently damages fragile ecosystems.

### 1.1.4 Free lime leaching into solution

Once a culvert paving project is completed, tributary water comes in contact with the cured grout, which is freshly exposed, and the residual free lime content (CaO or CaOH) rapidly produces alkalinity and the pH spike related to rise in hydroxide ($OH^-$) ions in the water. This alkaline environment and related water temperature may further enable the interstitial material of the exposed grout materials to be dissolved, contributing to the elevated pH.

As the surface water emerges from the culvert and is exposed to the atmosphere, streambed, vegetation, and ground surface, the water will go through a complex series of pseudo-stable phases. In a rare instance, ponded water in contact with grout materials continues to exhibit an extended release of hydroxide ions. More typically, carbon dioxide from the atmosphere or microbial active zones will buffer the pH of the leachate as the water continues to travel through the tributary.

Saturation and/or evaporation of the leachate facilitates the precipitation of calcium carbonate ($CaCO_3$), a naturally occurring compound commonly referred to as tufa (Banks et al., 2006). Calcium carbonate, hydrolyzes to produce calcium hydroxide ($Ca(OH)_2$), or slaked lime . Tufa occurs in nature, is usually found in water bodies, and can clog soil and drains. Cured grout can exhibit a level of chemical reactivity that moderates and stabilizes after a short period of dissolution with the flow of tributary water.

High concentrations of slaked lime, in turn precipitates $CaCO_3$ in the presence of the atmospheric $CO_{2(g)}$. Lime, $CaO_{(lime)}$, initially reacts with water to generate calcium and hydroxide ions and a solution with a pH of 9 to 12.

### 1.1.5 Why is pH important?

Aquatic organisms need the pH of their water body to be within a certain range for optimal growth and survival. Although each organism has an ideal pH, most aquatic organisms prefer pH of 6.5 to 8.0. Outside of this range, organisms become physiologically stressed resulting in suppressed reproduction and even death.

In addition to directly affecting the physiology of aquatic organisms, low pH may increase the solubility of heavy metals and other toxic compounds, releasing them from sediments where they may be absorbed by aquatic animals or plants. Changes in pH also influence the availability of plant nutrients, such as phosphate, ammonia, iron, and other trace metals in the water (Addy et al., 2004).

### 1.1.6 Reducing water pH

Organic materials are expected to yield lower pH due to the presence of humic/organic acids due to microbial decomposition that produces carbon dioxide (gas) and carbonate species (Lindsay, 1979; Roadcap et al., 2005). Portland cement primarily consists of tricalcium silicate ($Ca_3SiO_5$), dicalcium silicate ($Ca_2SiO_4$), calcium aluminate ($Ca_3Al_2O_6$), iron calcium aluminate ($Ca_4Fe_2Al_2O_{10}$), and gypsum ($CaSO_4 \bullet 2H_2O$). When Portland cement is wetted, these phases undergo a series of hydrolysis, hydration, and ultimately precipitation reactions that produce a hardened material. This process results in the formation of calcium hydroxide ($Ca(OH)_2$) and poorly crystalline calcium silicate hydrate (C-S-H) gel. Tricalcium silicates on hydration would produce 61 percent $C_3S_2H_3$ (C-S-H gel) and 39 percent portlandite ($Ca(OH)_2$),while dicalcium silicates produces 82 percent $C_3S_2H_3$ (C-S-H gel) and 18 percent $Ca(OH)_2$ (Mehta and Monteiro, 2006).

The most common source of acidity in water is dissolved carbon dioxide. The calcium hydroxide in concrete interacts with carbon dioxide from the atmosphere, the biological processes of organic carbon digestion, and photosynthesis to form calcium carbonate. Carbonation, the neutralization of alkalis in concrete pore water to yield carbonic acid ($H_2CO_3$) exists in equilibrium with hydronium, $H_3O^+$ and bicarbonate, $HCO_3^-$. This chemical behavior explains why water, which normally has a neutral pH of 7, can have an acidic pH when it has been exposed to air.

## 1.2 Research objectives

The main purpose of this research is to provide guidance to SHA for routine maintenance of culverts requiring grout paving and to assist SHA in meeting Maryland's water quality standard for pH. The primary objectives of this research are to:

1. Identify the magnitude of the anticipated fluctuation in water pH during in-stream grout paving through field and laboratory observations.
2. Identify suitable procedures/techniques (such as use of anti-washout admixtures) during the paving process to limit pH spikes above the allowable limit.
3. Test possible remedial actions for the high pH effluent trapped in the work area and/or generated by first flushes.

To satisfy these objectives, this project assessed elevated pH, along with other related water quality measures of conductivity, total dissolved solids (TDS), temperature, and alkalinity from grout paving activities. This project included field monitoring at construction locations in Maryland and laboratory studies.

The research included the following six tasks:

1. Identify the current technologies, methods, and materials used in culvert rehabilitation and maintenance, and determine what methods and materials can be used to mitigate water quality impacts. Interviews with appropriate industry groups and SHA personnel were utilized to gain further insight.

2. Coordinate with SHA to identify field sites that represent a variety of environmental conditions and flow regimes. The Morgan research team then evaluated four identified field sites to ascertain the current construction techniques' ability to meet state water quality pH standards.

3. Concurrent tank leaching and flow-through laboratory testing were done. Laboratory leaching tests were performed to measure pH variations under various experimental conditions. Laboratory tests of proposed construction/mitigation techniques were done for consideration in future maintenance contracts.

4. Based on the methods found in literature reviews and practical experience, laboratory examination of remedial techniques for high pH effluent waters from within the culvert were tested to identify practicable and low-cost pH mitigation methods.

5. Using the knowledge gained from laboratory studies, additional field sites were evaluated using the recommended mitigation techniques.

6. Develop a construction technique flowchart and best management practices for in-stream grout paving work to be incorporated into future SHA projects and then share them with regulatory agencies.

# 2 LABORATORY METHODOLOGY

## 2.1 Mixing method

The tilting drum mixer (Scaffolding Factory Co., Hong Kong) used for all grout mixings has a container with a cross section (Figure 2.1). The blades are attached to the inside of the movable drum. The blades' main purpose is to lift the material as the drum rotates. The angle of the rotation axis is the only controlled parameter. The mixing speed was kept at the same speed for all mixings. Type I/II Portland Cement (Saylor's, Essroc Cement Corp., Nazareth, PA), sand, and tap water were added into the drum mixer and mixed until a workable consistency was obtained. Mixed grout was used for further experiments.

**Figure 2.1: Grout mixing by tilting drum mixer.**

The mixing ratio was adopted from the concrete mix design tested by the Concrete Technology Division in SHA's Office of Materials Technology. The proportion of mixed grout was 1 of cement to 1 of sand to .492 of water. The mixed grout was placed into cube molds for leaching experiments or PVC section bottom for flow-through experiments, and cured for two days or four days prior to the each experiment. All mixings and curing processes were performed at room temperature 20 to 23$^o$C (68 to 73.4$^o$F).

## 2.2 Tank-leaching experiment

The tank-leaching test assesses the potential and speed of pH change of the grout paving material over the long term. The Environmental Protection Agency (EPA) preliminary version of method 1315—semi-dynamic tank leaching procedure (USEPA, 2009)—was used to measure the pH change of precast monolithic specimens made of the grout paving materials under normal conditions of exposure. The monolithic specimens (an estimated 5 cm x 5 cm x 5 cm) were prepared by mixing water and cement in a ratio per the manufacturer's specification and placed in molds. All test specimens were stored in the laboratory at 22$^o$C (71.6 $\pm$1$^o$F). On the day following the casting, the specimens were de-molded and placed in curing condition, namely standard 20$^o$C (68$^o$F) air cure for a specified duration (two and four days). This method consists of continuously water-saturated grout paving material in a water-filled tank with periodic renewal of the leaching solution (Figure 2.2). The de-ionized water used in the tank experiment was collected in a cleaned 5-gallon bucket and then placed into a temperature-controlled room for at least 48 hours to make equilibrium with the temperature in the control room. For each test, a monolithic specimen made of the grout paving materials was put into eluent, and leachate samples were collected after a specified time. A control without monolithic specimens was also positioned for comparison. The LS ratio, which is the ratio of the total liquid volume used in the leaching interval to the external geometric surface area of the solid material, was maintained at 9±1 ml/cm$^2$. The monolithic specimens were positioned at the bottom of the leaching vessel with a minimum 2 cm distance between the solid-liquid interfaces. A monolithic specimen stand was made with a PVC pipe (3.8 cm in diameter, 2.5 cm in height) that had four holes for holders. Nylon string was used for the monolithic specimen holder. Air-tight containers (10 cm in diameter and 20 cm in height, made of high density polyethylene) were used. All experiments were run with duplicates under three different temperatures 4$^o$C (39.2$^o$F), 12$^o$C (53.6$^o$F), and 22$^o$C (71.6$^o$F). At timed intervals, the leachate was collected and the pH, turbidity, alkalinity, conductivity, and total dissolved solids (TDS) of each solution were determined. The eluent was renewed after 1 and 22 hours and 2, 6, 13, and 22 days.

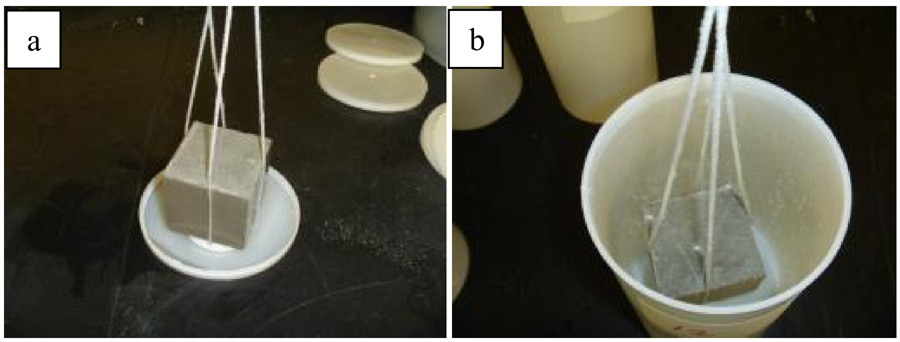



**Figure 2.2: Tank leaching experiment.**

### 2.3 Flow-through experiment

The in-pipe grout paving was prepared by mixing water and Portland cement per the SHA-specified ratio. The laboratory leaching tests were evaluated using several physical parameters: curing time, volumetric flow rate (Q), admixture, pipe shape, washing procedure, topical treatment, temperature, and paved section length. Selected parameters, according to the greatest probability of impact on pH, could represent the different field conditions (Figure 2.3). The water supply system for the flow-through experiments was assembled with a 5-cm diameter PVC pipe for the main water supply system. A 2.54-cm diameter PVC pipe was used to branch the water supply system, and the flow rate controller was used to maintain steady flow to each flow-through experiment. The inlet of the main water reservoir (200 liters) was connected to a faucet of tap water with a water level sensor to maintain equal water volume. The outlet of the main water reservoir was connected to the main water supply system. A 15 cm diameter and 3.66 meter long PVC pipes were horizontally cut, and three different lengths of the PVC pipe were prepared: 91.4 cm, 183cm, and 366cm. Different amounts of grout were poured into the PVC pipes: 6.1 kg into the 91.4 cm pipe, 12.2 kg into the 183 cm pipe, and 24.4 kg into the 366 cm pipe (Figure 2.4).

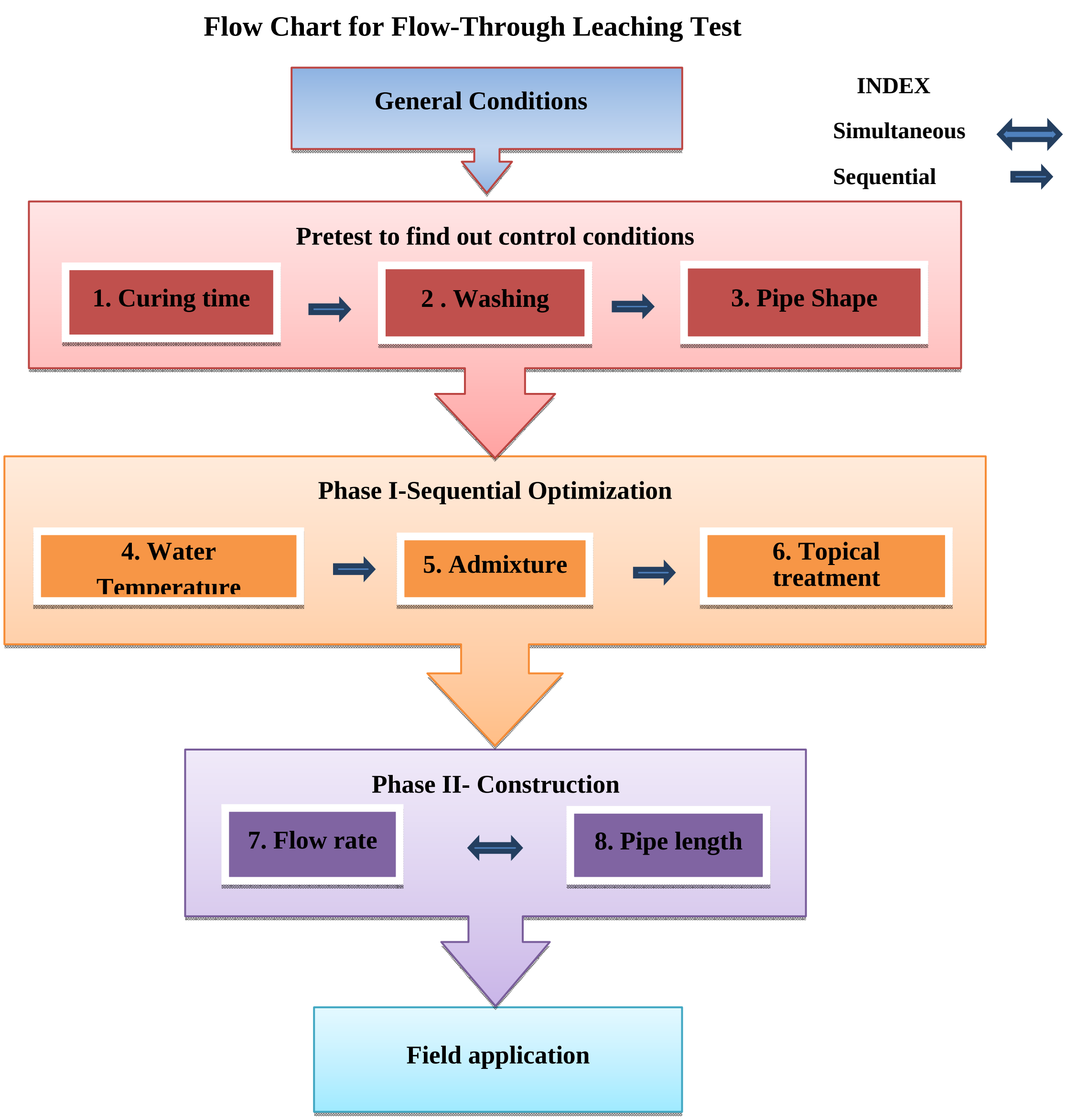



**Figure 2.3: Flowchart for flow-through leaching test.**

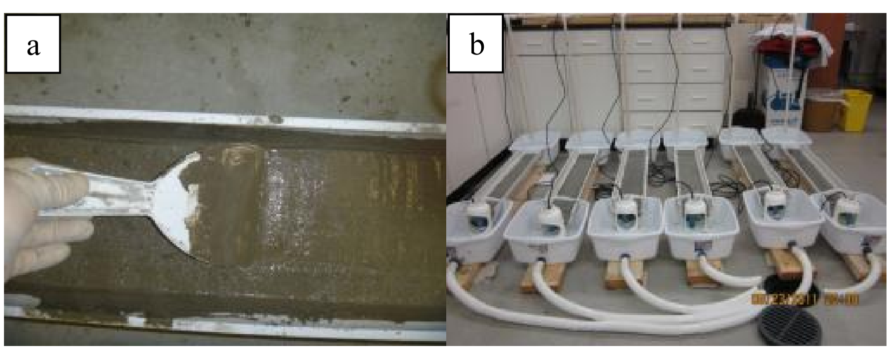



**Figure 2.4: Flow-through leaching test.**

Tap water was used at room temperature. All experiments were performed in duplicate for about 24 hours. Several conditions were assessed to evaluate the change of pH value. Different volumetric flow rates were controlled by the degree of dilution. Admixture was tested to assess if its ability to affect the air entraining capability or workability could impact water pH. The surface washing procedure after curing removed the high impact of the initial runoff through the grout-paved surface. Water continuously inundated the sections of pipe lined with grout paving under a range of flow rates. The flow-through experiments were performed under the following conditions to get appropriate culvert maintenance procedures that meet the state and federal pH regulations. The pH meters (OMEGA NOMAD pH & temperature reader, OMEGA Engineering, INC., Stamford, CT) were positioned in the water reservoir tank and the PVC pipe outlet. The pH meter in the water reservoir tank measured initial tap water pH and temperature as a control condition. The pH meter at the outlet of the PVC pipe assessed pH change after the supplied water contacted the grout surface.

### 2.3.1 Curing time

Two curing times were tested to evaluate the effect on pH change. Curing periods of 48 hours and 96 hours were applied after grout was placed into each pipe. A basic flow rate (930±20 ml/min) was adopted for both curing times. The length of the semicircular PVC pipe was 91.4 cm and the diameter was 15 cm. Six kilograms of grout mixture was placed into the PVC pipe. The surface area was 1097 $cm^2$ (12 cm wide and 91.4 cm long).

### 2.3.2 Surface washing and brushing

The surface washing and brushing procedure was applied after the two-day grout curing process. The grout surface was gently brushed to remove debris and then the surface washing procedure (1.6 $ml/cm^2$) was applied to it. A power washer (Black & Decker, 1900 PSI electric power washer) was used to clean the grout surface and remove debris (Figure 2.5). Five water volumes were tested: 0.0 $ml/cm^2$, 0.4 $ml/cm^2$, 1.6 $ml/cm^2$, 3.2 $ml/cm^2$, and 4.7 $ml/cm^2$. The basic flow rate (930±20 ml/min) was adopted after the washing process. The length of PVC pipe was 91.4 cm.

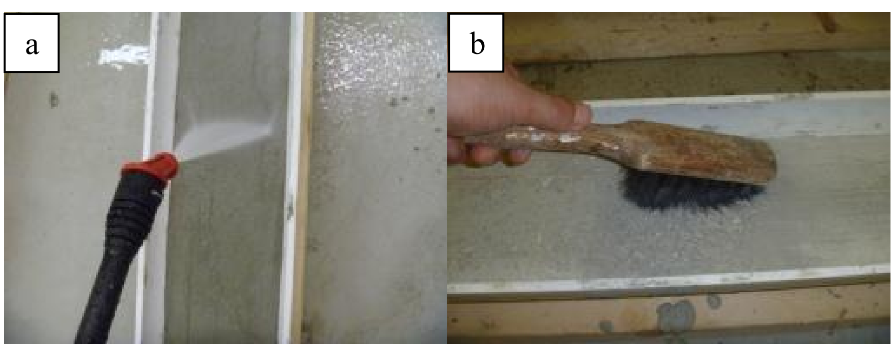



**Figure 2.5: Surface washing by power washer and surface cleaning by brush.**

### 2.3.3 Pipe shape

Pipe shape's effect was evaluated with two shapes of pipe. The first shape was semicircular. The second shape was rectangular. The grout surface was 12 cm wide and 91.4 cm long for the semicircular pipe, and 15 cm wide and 91.4 cm long for the rectangular pipe. The surface washing procedure (1.6 ml/$cm^2$) was applied after the two-day curing process finished. A basic flow rate (930±20 ml/min) was adopted after the washing process (Figure 2.6).

**Figure 2.6: Pipe shape effect.**

### 2.3.4 Water temperature

Two water temperatures were applied to the flow-through experiment to evaluate water temperature's effect on pH change. The surface washing procedure (1.6 ml/$cm^2$) was done after the two-day grout curing process finished. The basic flow rate (930 ±20 ml/min) was adopted. The length of the semicircular PVC pipe was 91.4 cm and the diameter was 15 cm. The surface area was 1097 $cm^2$ (12 cm wide and 91.4 cm long).

### 2.3.5 Admixture

Three anti-washing admixtures were added to the grout mixture to evaluate their effect on pH change. EUCOM-AWA (The Euclid Chemical Company, Cleveland, OH), which reduces cement washout and fine aggregates when concrete is placed underwater, was tested. It is recommended by the manufacturer that 0.65 to 2.1 L of EUCOM-AWA be used per 100 kg of cement. FX-Segnot (Fox Industries, Baltimore, MD), was used at a ratio of 0.06 to 0.22 L of admixture per 100 kg of cement to resist washout of cement and segregation. Lastly, V-MAR was used to increase viscosity (W. R. Grace & Co-Conn. Cambridge, MA), and was tested at a ratio of 0.096 to 0.16 L of admixture per 100 kg of cement. The surface washing procedure (1.6 ml/$cm^2$) was applied after the two-day grout curing process finished. The basic flow rate (930 ±20 ml/min) was adopted. The length of the semicircular PVC pipe was 91.4 cm and the diameter was 15 cm. The surface area was 1097 $cm^2$ (12 cm wide and 91.4 cm long). EUCOMA-AWA was added to the first two pipes, FX-Segnot was added to the next two pipes, and V-MAR was added to the last two pipes (Figure 2.7).

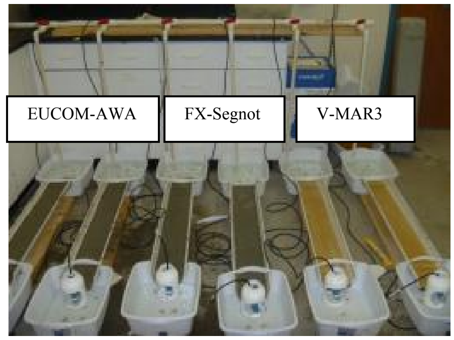



**Figure 2.7: Admixture effect experiment.**

### 2.3.6 Topical treatment

A topical treatment was tested to evaluate the effect on pH change. Kaufman's Thin Film Exterior Curing Compound (Kaufman Products Inc., Baltimore, MD) was used with the flow-through experiment setup. The Kaufman Thin Film Exterior Curing Compound was carefully painted by sponge to cover the grout surface after the two-day grout curing process finished. The flow-through experiment was performed after the Kaufman Thin Film Exterior Curing Compound completely dried. The basic flow rate (930 ±20 ml/min) was adopted. Two lengths of semicircular PVC pipe with a 15 cm diameter—91.4 cm and 366 cm —were tested. The surface areas were 1097 $cm^2$ and 4388 $cm^2$.

### 2.3.7 Flow rate

Three flow rates were applied to evaluate pH change after the two-day grout curing process finished. Low flow rate (930 ±20 ml/min), mid flow rate (1820 ±20 ml/min), and high flow rate (2700 ±20 ml/min) were assessed with tap water. The semicircular pipe was 91.4 cm long and had a 15 cm diameter. The surface area was 1097 $cm^2$ (12 cm wide and 91.4 cm long).

### 2.3.8 Pipe length

Three lengths of semicircular PVC pipe were evaluated to estimate pipe length's effect on pH change. Three flow rates were applied to evaluate pH change after the two-day grout curing process finished. Low flow rate (930 ±20 ml/min), mid flow rate (1820 ±20 ml/min), and high flow rate (2700 ±20 ml/min) were assessed with tap water. All pipes of the pipes had a 15 cm diameter, and the following lengths were used: 91.4 cm, 192 cm, and 366 cm. The surface areas were 1097 $cm^{2,}$ 2194 $cm^2$, 4388 $cm^2$ (Figure 2.8).

**Figure 2.8: Pipe length effect experiment in the laboratory.**

## 2.4 Remedial methods for high pH water

Experiments were designed to test remedial methods for treating the high pH waters contained within repaved culverts. These methods would be under consideration use as part of the specification to meet the state's pH requirements. Remedial actions such as the potential use of a $CO_2$ system and organic materials are similar to the ones used to treat high pH slag leachate (Banks et al., 2006; Boyer, 1994). Neutralization of alkaline waters can be achieved by adding sulfuric or hydrochloric acids; however, these strong acids may pose difficulties in handling and process control (Elkanzi, 2006). Acid dosing may initially allow pH to remain fairly constant; however, the pH can drop significantly at the neutral point after small additions of acid. As an alternative neutralizing agent, $CO_2$ (by sparging) was tested in an experiment with water that exceeded the Maryland water quality standard. The remedial methods were tested based on influent and effluent samples of pH, conductivity, TDS, temperature, chloride, and alkalinity.

### 2.4.1 Sediment bag use with organic materials

Sediment-laden water from culvert repair projects are typically collected during the construction activity and pumped through a geotextile bag (sediment bag) to filter sediment-laden water prior to possible re-entering downstream (Figure 2.9). The filter bag is placed in a location that allows for easy collection of the trapped sediment and has minimal interference with construction activities. As a remedial action, the sediment bag can potentially be used with suitable base materials to reduce water pH.

For this experiment, a wooden frame (1.30 m x 1.30 m) was made to guide the filtrated water. The hole to drain the filtrated water was located in the bottom of the wooden frame. A green vinyl tarp (2 m x 2 m) covered the wooden frame to prevent water leakage. A nestable plastic pallet made of recyclable material (1.1 m x 1.1 m) was placed on top of the vinyl tarp to drain filtrated water by maintaining the space between the sediment bag and the wooden frame. Two plastic meshes (0.6 m x 1.2 m) were placed above the pallet to support the filter paper. The guide wooden frame was placed on the top of the plastic mesh to guide the sediment bag. Filter paper covered the plastic mesh to prevent clogging debris, and the sediment bag was placed on top.

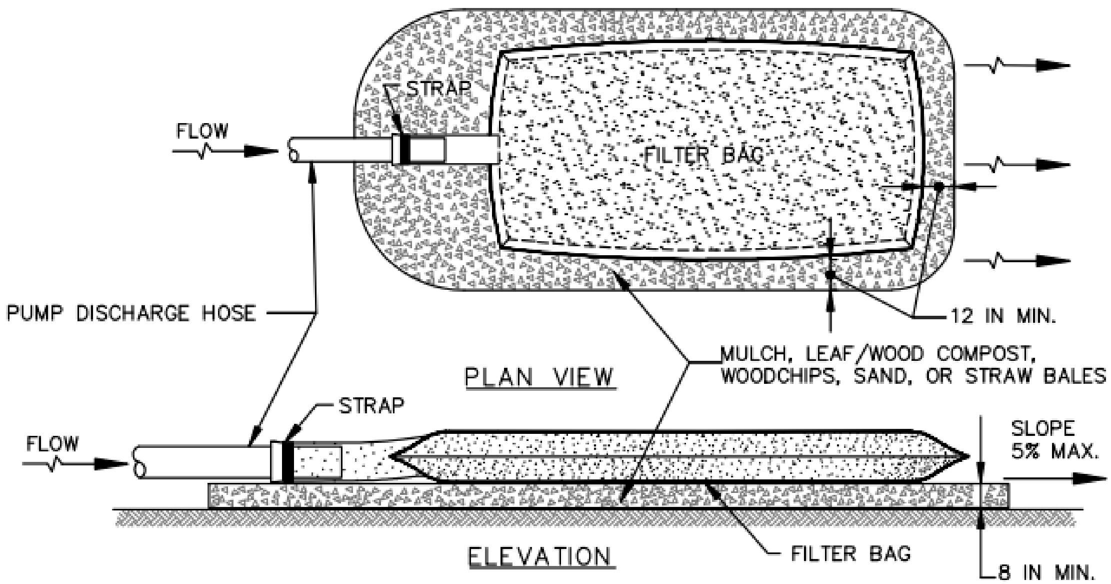



**Figure 2.9: Schematic design of sediment bag detail (MDE, 2011).**

A T-shaped PVC pipe, with a 2.5 cm diameter and 0.2 cm drain holes per 3 cm distance, was placed in the sediment bag to equally distribute the effluent water. The sediment bag (1.22 m x 1.22 m, woven geotextile) was purchased from Grainger. It is important to keep the connection between the pump hose and the sediment bag watertight during operation. The guided flow water was tested for pH and temperature. Water samples collected at the outlet were periodically analyzed for alkalinity, ORP, conductivity, TDS, nitrate, and phosphorus.

A 294-gallon galvanized sheet metal tank was filled with tap water and then 1 kg of Type I/II Portland cement was added to get approximately pH 11. A submersible sump pump (Indoor/Outdoor model # 5-MSP-18, Little Giant Pump Company, Oklahoma City, OK) delivered water into the sediment bags. Two flow rates were managed by the pump controller (Sotera Systems Model 825, Tuthill Corp, Fort Wayne, IN). The slow flow rate was 2.7 L/min, and the fast flow rate was 6.0 L/min. Organic matter such as straw, mixed mulch (Garden Pro Pine Bark Mulch and Garden Pro Shredded Hardwood Mulch, Harvest Garden Pro, LLC, Milford, DE), and peat moss (Garden Pro Sphagnum Peat Moss, Coastal Supply Company, Milford, DE) were placed on top of the filter paper and then a sediment bag was positioned on top of the organic matter. In layers, 10 cm of straw (Figure 2.10), 10 cm of mulch (Figure 2.11), 10 cm of dry peat (Figure 2.12), and 6.5 cm of wetted peat (Figure 2.13) were placed in the guide wooden frame.

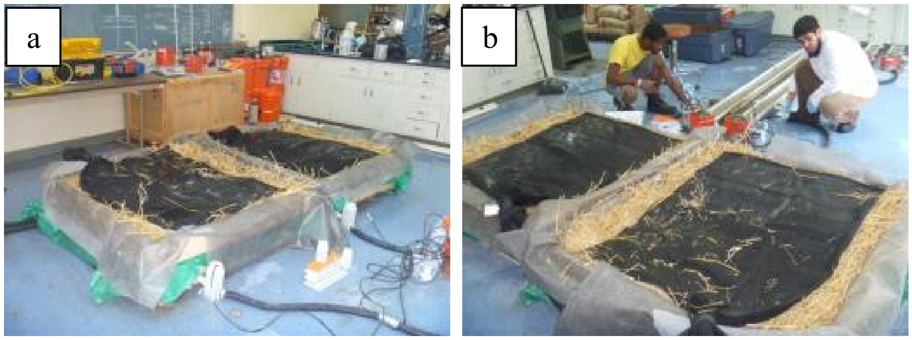



**Figure 2.10: Remedial experiment of sediment bag with straw**


**Figure 2.11: Remedial experiment of sediment bag with 10 cm of mulch**

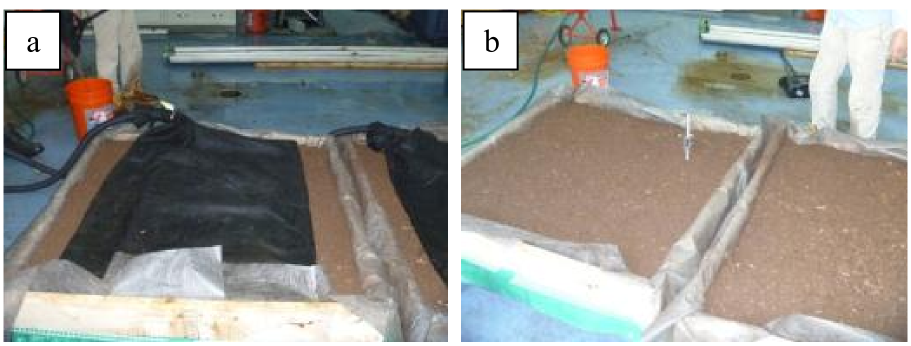



**Figure 2.12: Remedial experiment of sediment bag with 10 cm dry peat**

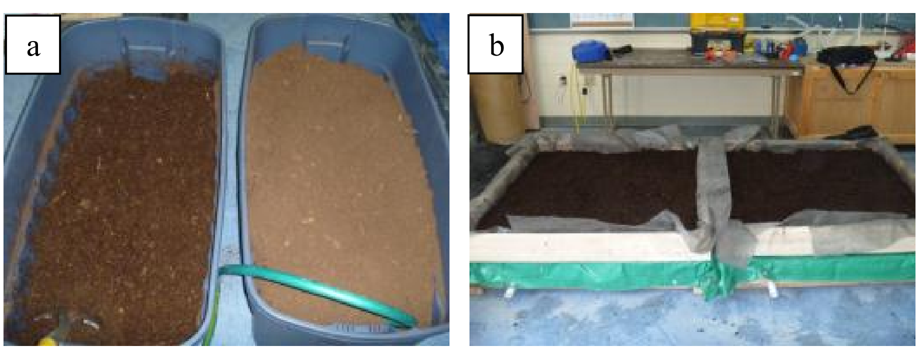



**Figure 2.13: Remedial experiment of sediment bag with 6.5 cm wetted peat.**

### 2.4.2 Optimization of remedial action (mixing ratio)

It was determined that a viable option for reducing high pH water was to drain the water through a readily available, acidic natural material such as bales of sphagnum peat moss. The peat is water absorbent, has a low pH value (Table 2.1). As the water drains through the peat provides limited capacity for buffering the high pH water. Also, the combination of the atmospheric effect of buffering the water returning to the receiving stream would allow the water to return to a pH range of 6.5 to 8.5.

**Table 2.1: Characteristics of sphagnum peat (Lucas et al., 1965).**

| Type of Peat | Nitrogen (%) | Absorbing Capacity (%) | Ash Content (%) | pH | Vol. Weights (lbs./ft.$^3$) |
|---|---|---|---|---|---|
| Sphagnum moss peat | 0.6-1.4 | 1,500-3,000 | 1.0-5.0 | 3.0-4.0 | 4.5-7.0 |

Small-scale tests were done using tap water to determine the peat to straw ratios in the column studies. The column study setup is shown in Figure 2.14. The water is allowed to drain through the column and then tested using the Omega data loggers to determine the buffering capacity of each setup. Each setup was done in duplicate in the laboratory at Morgan State University.

Three ratios were tested in the lab:

- 1:1 ratio of straw to wet peat, comprising 4 inches of straw and 4 inches of wet peat
- 2:1 ratio of straw to wet peat, comprising 6 inches of straw and 3 inches of wet peat
- 3:1 ratio of wet peat to straw, comprising 6 inches of straw and 2 inches of wet peat

Completely mixed replicates of wet peat and straw at a depth of 8 inches were also tested with the columns. Tap water with a pH of 7 served as the control for the various ratios to see the efficiency of the ratios and the acidic capacity of the materials. Upon completion of the test with the tap water, the setups were tested using high pH water in a worst-case scenario experiment.

To make the high pH water, Portland type II cement was mixed with sodium hydroxide (NaOH), which resulted in a pH about 12. Two 25-liter containers were filled with the solution, connected, and slowly fed the solution into the water tank to maintain the high pH flowing through the columns. The tests were run in duplicate to ensure precision of the results. The results for this study can be found in Appendix B.

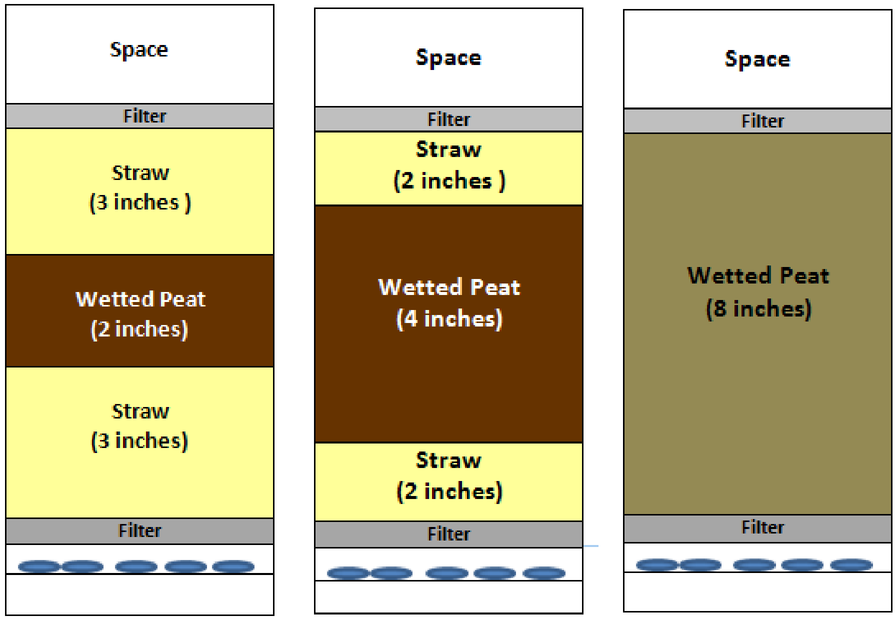



**Figure 2.14: Schematic of column study setup using organic materials to buffer high pH water**

### 2.4.3 Carbon dioxide sparging

The potential use of introducing carbon dioxide to high pH water is based on a previous SHA study by Boyer (1994) treating high pH slag leachate. Sparging is the process of introducing a gas as fine bubbles to a liquid in order to increase the rate of reaction. Carbon dioxide can be used in sparging applications for pH control. Carbon dioxide was introduced into the high pH water using three sizes of air stones, 19.4 $cm^2$, 51.6 $cm^2$, and 741.9 $cm^2$ (3 $in^2$, 8 $in^2$, and 115 $in^2$), installed in the middle of vessels that contained the high pH water. Small carbon dioxide bubbles were then released by the diffusers into the high pH water. A pH probe was installed and measured the pH change. Two high pH waters (pH 9.2±1 and pH 11.2±1) were prepared for the carbon dioxide reaction. Three carbon dioxide gas flow rates (1520 ml, 7600 ml, and 22,800 ml of carbon dioxide per minute), modulated by a flow controller, were applied to the two high pH waters, and 19 liters and 120 liters of high pH water were tested. All experiments were performed in duplicate. A carbon dioxide sparging was maintained until the pH value stabilized around 6.

# 3 LABORATORY FINDINGS & DISCUSSION

## 3.1 Tank leaching test

This method was designed to provide the mass transfer rates (release rates) of diffusion-controlled release conditions as a function of leaching time. Cumulative conductivity, TDS, ORP, and alkalinity are listed in Table 3.1. For all conditions, including curing and temperature variability, a pH over 11 was detected. Conductivity is a measure of the ability of water to pass an electrical current affected by the presence of inorganic dissolved solids. The changes in conductivity could then be an indicator that a discharge of pollution has entered water. Four-day-cured monolithic cubes released less inorganic dissolved solids than the two-day cured cubes did for all temperatures. Conductivity results showed that inorganic dissolved solids may release at an average 75 ±6 (μS/m) per hour from the beginning of the test to hour 20, and around 6 ±1 (μS/m) per hour from hour 500 to 1000. The initial discharge was higher (81±1 μS/m) at a high temperature (22$^{o}$C).

**Table 3.1: Tank leaching experiment result at variable temperatures**

(a) Temperature 7$^{o}$C

| 7 | Time (hr) | pH | CONDUCTIVITY ( μS/m) | TDS (mg/L) | ORP (mV) | Alkalinity (mg/L) |
|---|---|---|---|---|---|---|
| Control | 20 | 5.04 | 1.67 | 1.05 | 229.00 | 0.57 |
| | 68 | 5.10 | 8.77 | 3.06 | 456.00 | 1.57 |
| | 214 | 5.25 | 16.30 | 4.40 | 704.67 | 3.07 |
| | 498 | 5.01 | 25.00 | 5.91.4 | 931.67 | 4.07 |
| | 1026 | 5.19 | 33.67 | 7.45 | 1122.67 | 5.07 |
| 2-Day Curing | 20 | 11.87 | 1383.33 | 1021.67 | -13.33 | 297.67 |
| | 68 | 11.43 | 2259.00 | 1748.67 | 10.33 | 519.00 |
| | 214 | 11.43 | 3446.67 | 2652.33 | 49.67 | 806.67 |
| | 498 | 11.45 | 4500.67 | 3391.4.00 | 103.67 | 1031.33 |
| | 1026 | 11.35 | 5254.33 | 3984.67 | 161.00 | 1239.33 |
| 4-Day Curing | 20 | 11.86 | 1331.33 | 978.00 | -2.67 | 280.67 |
| | 68 | 11.28 | 191.48.00 | 1463.67 | 25.00 | 430.67 |
| | 214 | 11.48 | 3204.00 | 2530.67 | 47.00 | 752.00 |
| | 498 | 11.43 | 4244.33 | 3356.00 | 91.4.33 | 974.67 |
| | 1026 | 11.35 | 4956.00 | 3930.67 | 132.00 | 1173.87 |

(b) Temperature 14$^oC$

| 14 | Time (hr) | pH | CONDUCTIVITY ( µS/m) | TDS (mg/L) | ORP (mV) | Alkalinity (mg/L) |
|---|---|---|---|---|---|---|
| Control | 20 | 5.62 | 1.67 | 1.05 | 229.00 | 0.57 |
| | 68 | 5.12 | 11.67 | 3.25 | 479.33 | 1.23 |
| | 214 | 5.35 | 34.87 | 4.67 | 707.00 | 2.73 |
| | 498 | 5.15 | 43.84 | 5.87 | 1168.67 | 3.73 |
| | 1026 | 4.95 | 96.84 | 7.72 | 1380.33 | 4.73 |
| 2-Day Cure | 20 | 11.94 | 1582.67 | 1170.33 | -17.67 | 337.17 |
| | 68 | 11.43 | 4434.33 | 1889.67 | 9.67 | 552.83 |
| | 214 | 11.44 | 5756.67 | 3022.33 | 52.00 | 871.83 |
| | 498 | 11.47 | 6825.33 | 3774.33 | 135.67 | 1095.17 |
| | 1026 | 11.11 | 7333.33 | 4197.67 | 210.00 | 1256.50 |
| 4-Day Cure | 20 | 11.92 | 1495.33 | 1103.77 | -3.33 | 324.67 |
| | 68 | 11.47 | 2255.00 | 1874.77 | 23.33 | 556.67 |
| | 214 | 11.40 | 3556.33 | 2792.77 | 52.00 | 824.37 |
| | 498 | 11.46 | 4868.00 | 3511.77 | 103.00 | 1041.03 |
| | 1026 | 11.41 | 5470.00 | 3970.77 | 151.67 | 1219.70 |

(c) Temperature 22$^oC$

| 22 | Time (hr) | pH | CONDUCTIVITY ( µS/m) | TDS (mg/L) | ORP (mV) | Alkalinity (mg/L) |
|---|---|---|---|---|---|---|
| Control | 20 | 5.28 | 2.80 | 1.04 | 203.67 | 0.57 |
| | 68 | 5.12 | 7.53 | 1.90 | 406.67 | 1.23 |
| | 214 | 5.35 | 22.39 | 3.33 | 584.67 | 2.40 |
| | 498 | 5.15 | 44.02 | 4.10 | 795.33 | 3.40 |
| | 1026 | 4.95 | 97.02 | 5.60 | 1001.33 | 7.40 |
| 2-Day Cure | 20 | 11.94 | 1655.33 | 1230.67 | 25.67 | 340.50 |
| | 68 | 11.43 | 2623.33 | 2055.00 | 93.00 | 589.17 |
| | 214 | 11.44 | 3638.33 | 3209.67 | 173.00 | 833.17 |
| | 498 | 11.47 | 4580.67 | 3858.87 | 293.00 | 1027.83 |
| | 1026 | 11.11 | 5410.33 | 4199.87 | 408.67 | 1148.83 |
| 4-Day Cure | 20 | 11.92 | 1590.67 | 1156.00 | -12.67 | 341.83 |
| | 68 | 11.47 | 2301.00 | 1754.33 | 13.33 | 522.83 |
| | 214 | 11.40 | 3392.33 | 2653.33 | 49.33 | 786.83 |
| | 498 | 11.46 | 4148.67 | 3179.33 | 107.00 | 946.83 |
| | 1026 | 11.41 | 4523.00 | 3434.33 | 160.33 | 1059.17 |

TDS are a measure of the combined content of all inorganic and organic substances in water. TDS are made up of inorganic salts as well as a small amount of organic matter. As with the conductivity results, the two-day curing conditions showed higher TDS than the four-day curing conditions for all temperatures. TDS were 55 ±6 (mg/L) per hour until the test's beginning to hour 20, and around 3.7 ±0.4 (mg/L) per hour from hour 500 to hour 1000. The initial discharge was higher (61.5 mg/L) at a high temperature (22°C) with the two-day curing.

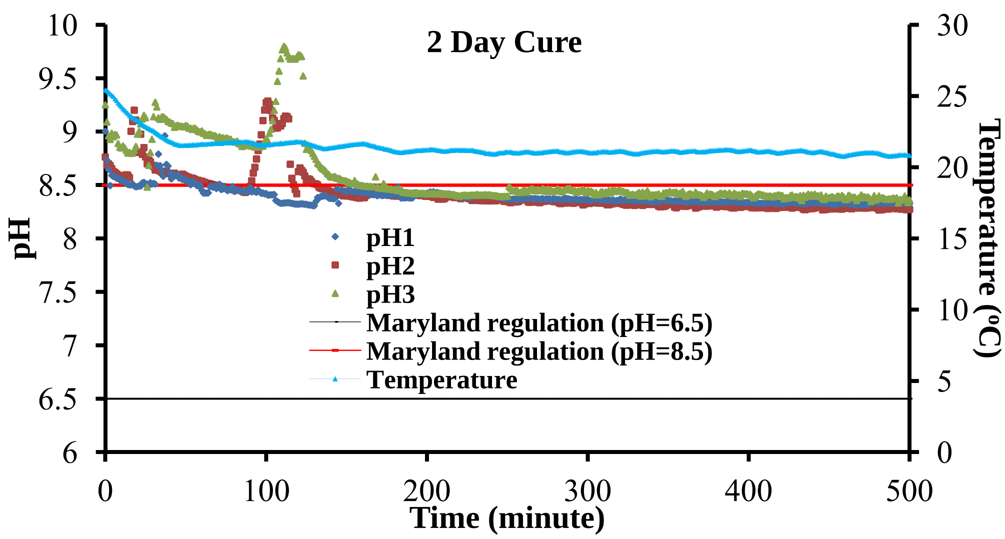
Oxidation/reduction potential (ORP) is a measure of the potential of a chemical species to accept electrons and thereby be reduced. A higher ORP means there is a higher potential for reduction to occur, while a lower one means there is a greater tendency for oxidation to occur. ORP values were lower than the control results. High pH water (pH over 11) has more reducing agents (low ORP) and low pH water, such as the control condition (pH around 5), has more oxidizing agents (high ORP). Alkalinity measures the ability of a solution to neutralize acids to the equivalent point of carbonate or bicarbonate. Two-day curing conditions showed higher alkalinity than the four-day curing for all temperatures. Alkalinity was 16±1 (mg/L) per hour until the test's beginning to hour 20, and around 1.1 ±0.1 (mg/L) per hour from hour 500 to hour 1000. The initial discharge was higher (17 mg/L) at a high temperature (22°C) than at a low temperature.

## 3.2 Flow-through leaching test

### 3.2.1 Curing time

The results for the different curing times are in Figure 3.1. Each figure contained the result of triplicate for each curing condition. The high pH ranges were 9 to 9.8 under two-day curing conditions, and 8.9 to 9.9 under four-day curing conditions. The pH exceeded the Maryland regulation (pH=8.5) for 56 to 157 minutes (average 93 minutes) with the two-day curing condition, and 11 to 145 minutes (average 89 minutes) for the four-day curing condition (Table 3.2). The two-day and four-day curing conditions were not significantly different for pH and time. Therefore, the two-day curing condition was applied to further experiments.

a)



b)

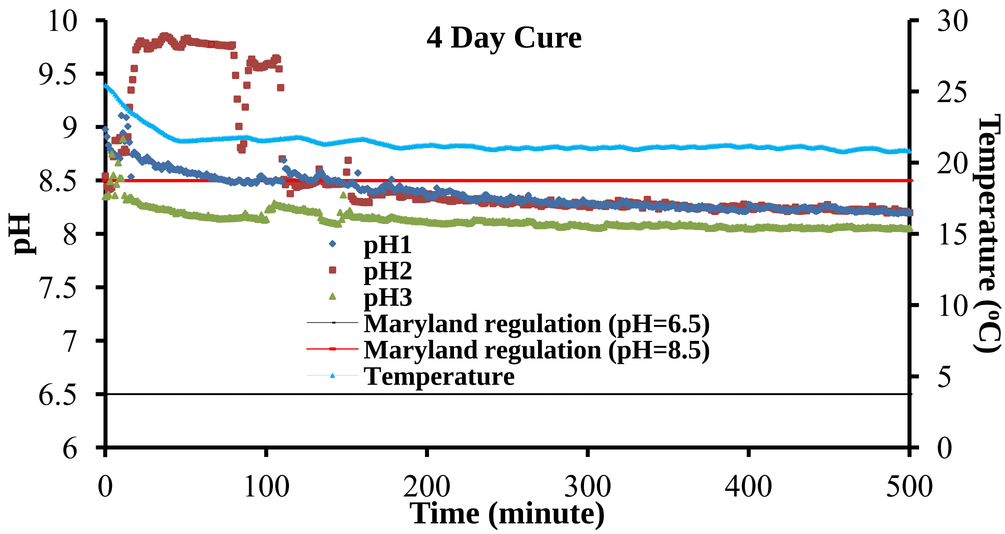



**Figure 3.1: Flow-through leaching test with different curing durations.**

**Table 3.2: Duration of water pH over pH 8.5 for variable cure times**

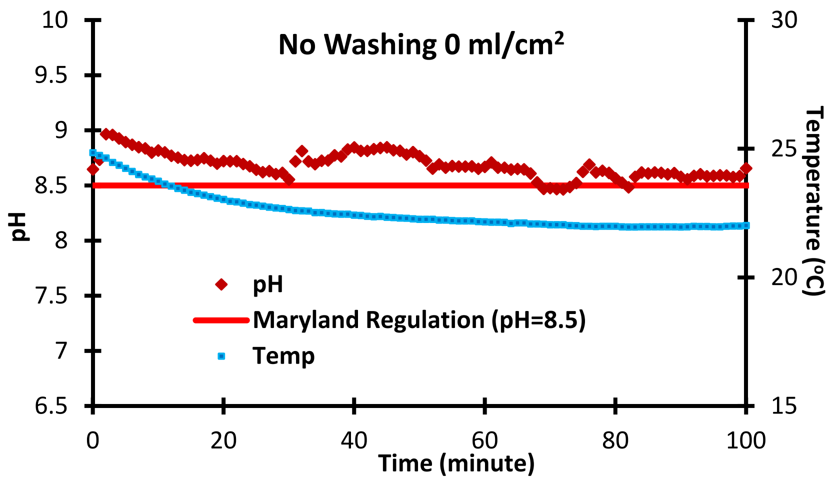
| | 2-Day curing | | 4-Day curing | |
|---|---|---|---|---|
| | High pH | Time (min) | High pH | Time (min) |
| 1st | 9.00 | 56 | 9.43 | 145 |
| 2nd | 9.80 | 157 | 9.85 | 111 |
| 3rd | 9.29 | 67 | 8.89 | 11 |

### 3.2.2 Surface washing and brushing

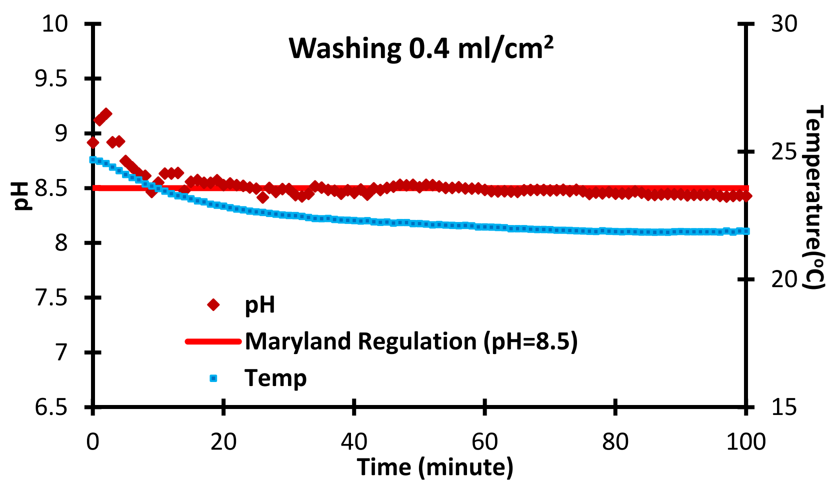
The results for the surface washing are in Figure 3.2. The high pH was 9.0 and the pH exceeded the Maryland regulation for 128 minutes in the no-surface-washing experiment. The high pH was 9.1 and the pH exceeded the Maryland regulation (pH=8.5) for 56 minutes after 0.4 ml/cm$^2$ surface washing. The high pH was 9.1 and the pH exceeded the Maryland regulation (pH=8.5) for 14 minutes after 1.6 ml/cm$^2$ surface washing.

The high pH was 8.7 and the pH exceeded the Maryland regulation (pH=8.5) for 11 minutes after 3.2 ml/cm$^2$ surface washing. The high pH was 8.6 and the pH exceeded the Maryland regulation (pH=8.5) for 4 minutes after 4.8 ml/cm$^2$ surface washing. The 1.6 ml/cm$^2$ surface washing condition was selected for further experiments.

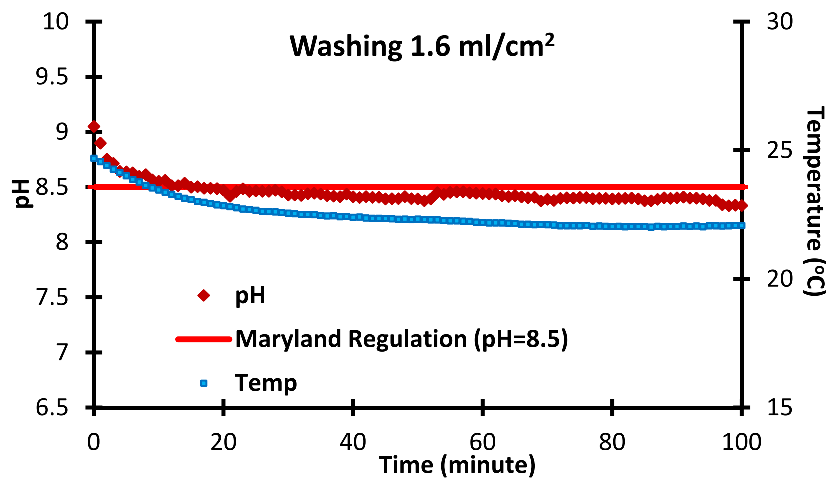
a)


No Washing 0 ml/cm²
pH
Temperature (°C)
Time (minute)
pH
Maryland Regulation (pH=8.5)
Temp
10
9.5
9
8.5
8
7.5
7
6.5
30
25
20
15
0
20
40
60
80
100

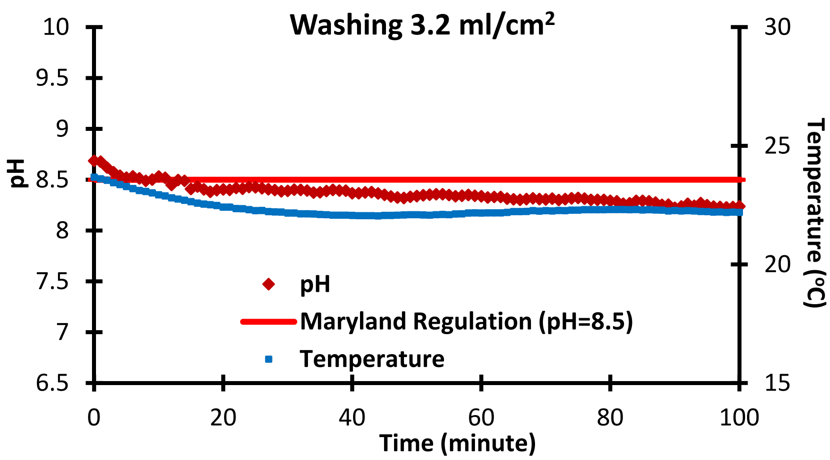
b)


Washing 0.4 ml/cm²
pH
Temperature(°C)
Time (minute)
pH
Maryland Regulation (pH=8.5)
Temp
10
9.5
9
8.5
8
7.5
7
6.5
30
25
20
15
0
20
40
60
80
100

c)




d)




e)

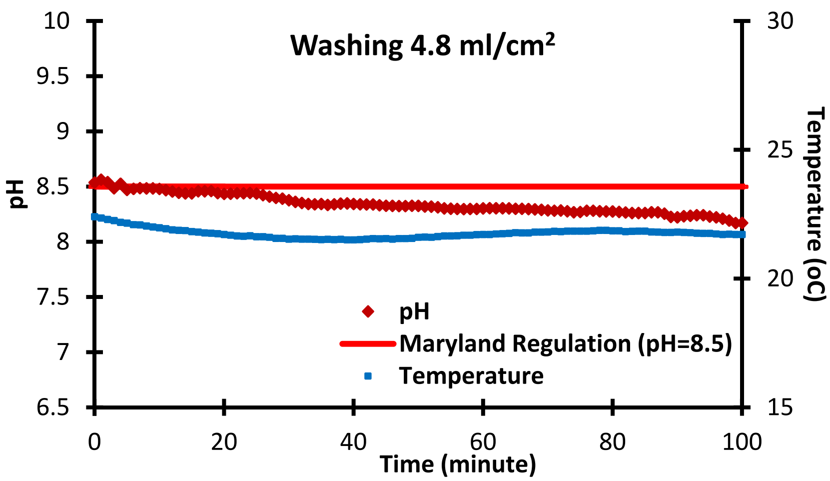



**Figure 3.2: Flow-through leaching test with applied surface washing**

### 3.2.3 Pipe shape

The results for the rectangular pipe are in Figure 3.3. The results for the semicircular pipe are in Figure 3.7 c. The high pH was 9.1 and the pH exceeded the Maryland regulation (pH=8.5) for 14 minutes after 1.6 ml/cm$^2$ surface washing. In the case of the rectangular pipe, the high pH was 9.0 and the pH exceeded the Maryland regulation (pH=8.5) for 51 minutes after 1.6 ml/cm$^2$ surface washing. The rectangular pipe showed a longer time exceeding the Maryland regulation (pH=8.5). The surface area of the rectangular pipe was 1371 cm$^2$, which was larger than the semicircular pipe's surface area (1097 cm$^2$), and this likely accounts for the extended pH spike.

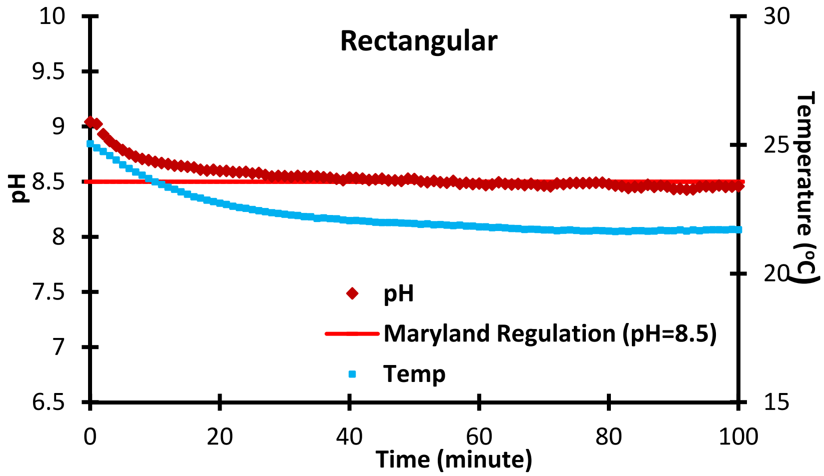



**Figure 3.3: Flow-through leaching test with water volume for surface washing at 1.6 ml/cm$^2$, rectangular pipe PVC pipe.**

### 3.2.4 Water temperature

The results for the water temperature effect are shown in Figure 3.4. The high pH was 9.4 and the pH exceeded the Maryland regulation (pH=8.5) for 319 minutes after 1.6 ml/cm$^2$ surface washing with high water temperature. There is a delayed effect of lower temperature on the pH as there is a slight increase. This could be due to the fact that the solubility of portlandite ($Ca(OH)_2$) goes up as temperature decreases.

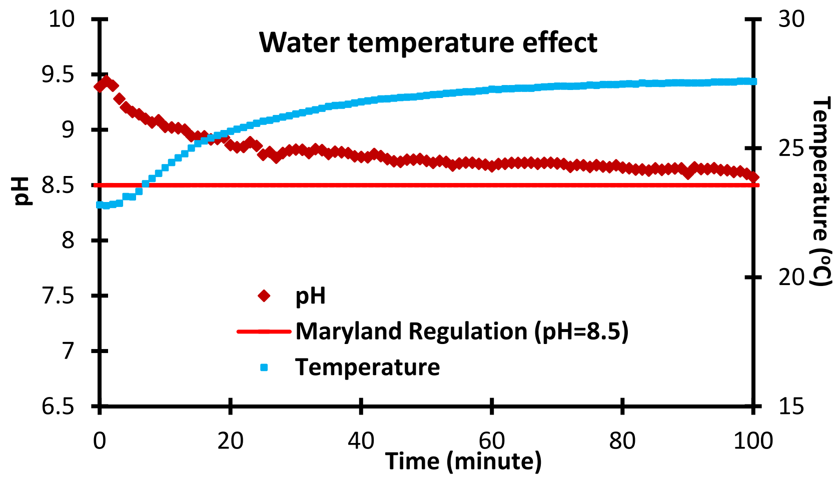



**Figure 3.4: Flow-through leaching test with high temperature (approximately 33°C)**

### 3.2.5 Admixture

The results of the different admixture types are in Figure 3.5. The high pH range for the EUCOM-AWA admixture was 9.2 to 9.8 and the pH exceeded the Maryland regulation (pH=8.5) for 14 minutes after 1.6 ml/cm$^2$ surface washing. The high pH range for the FX-Segnot admixture was 9.5 to 9.6 and the pH exceeded the Maryland regulation (pH=8.5) for 18 to 21 minutes. The high pH range for the V-MAR admixture was 9.0 to 9.1 and the pH exceeded the Maryland regulation (pH=8.5) for 15 to 19 minutes. The high pH without admixture was 9.1 and the pH exceeded the Maryland regulation (pH=8.5) for 14 minutes (Figure 3.5). The admixtures used in the experiments did not show the capability to diminish water pH.

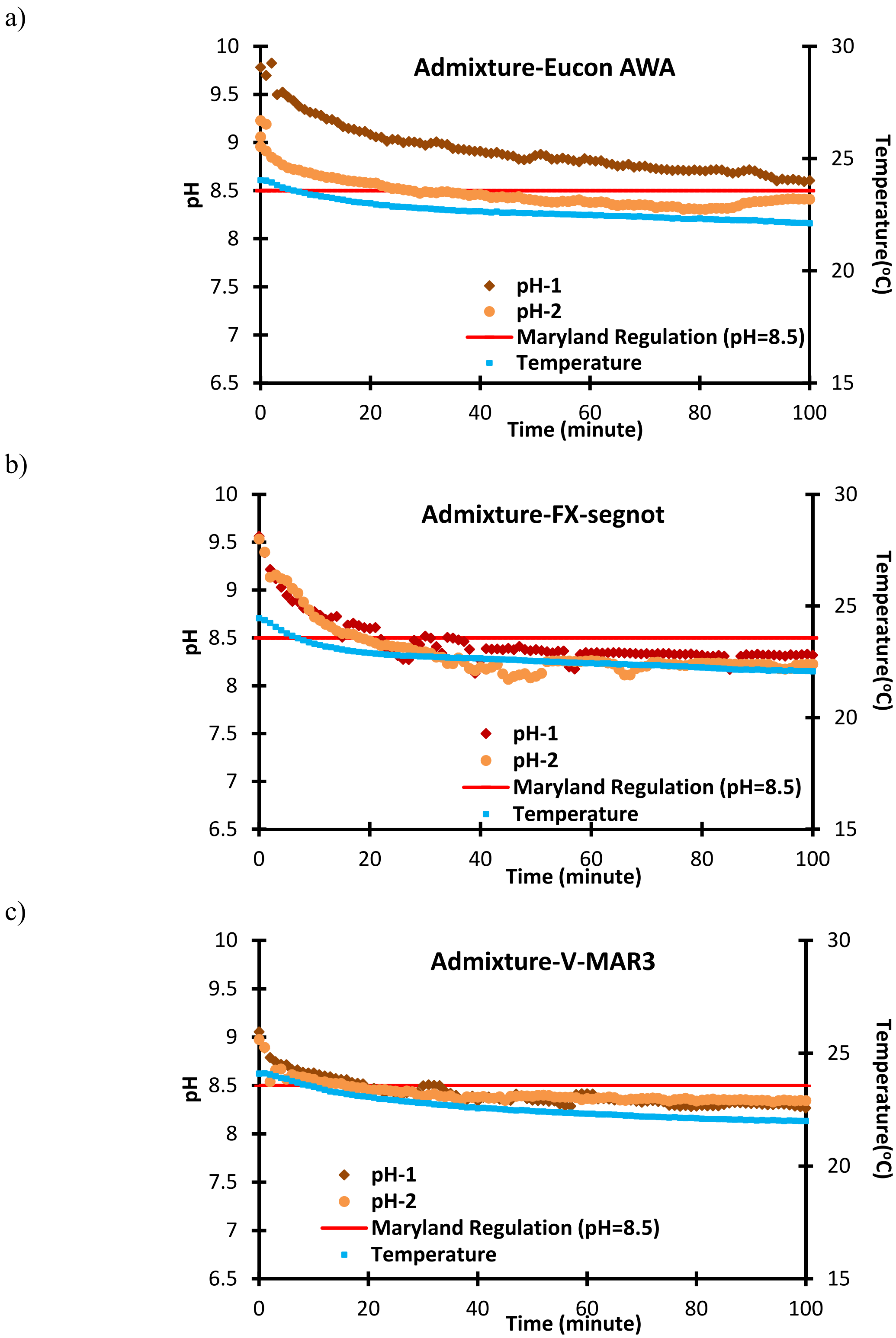
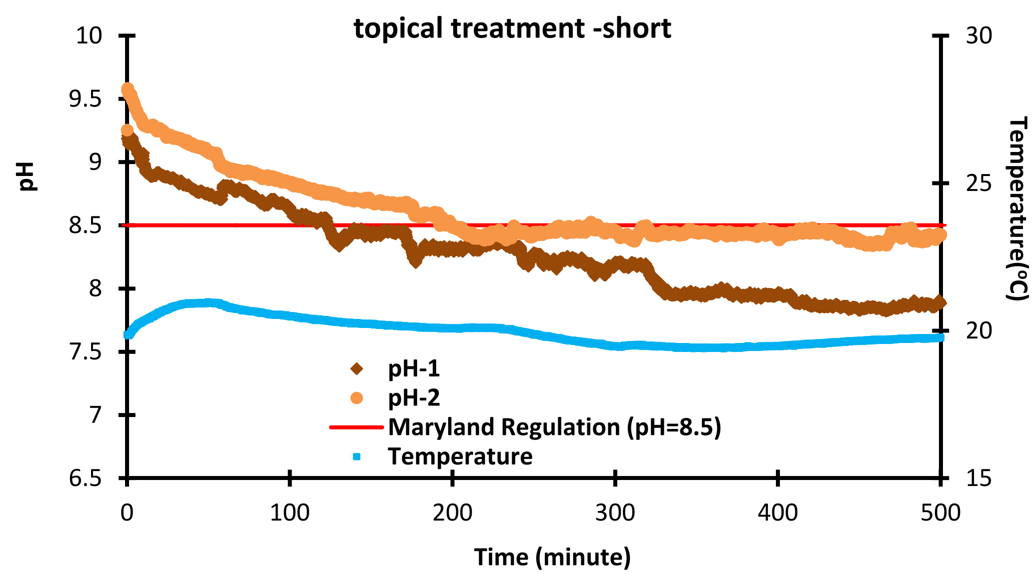



**Figure 3.5: Flow-through leaching test with different admixtures: (a) EUCOM-AWA, (b) FX-Segnot, (c) V-MAR**

### 3.2.6 Topical treatment

The results of the different PVC pipe lengths (91.4 cm and 365.6 cm) are in Figure 3.6. The pH over 8.5 continued for 161.1 minutes with the short PVC pipe (91.4 cm) and for 1340 minutes with the long PVC pipe (365.6 cm). The time that the pH was over 8.5 with the topical treatment for the flow-through experiment was longer than the control condition (without topical treatment). In the control condition, pH over 8.5 lasted for 72.5 minutes with the short PVC pipe and for 1334 minutes with the long pipe length. Based on the results, the topical treatment using Kaufman Thin Film Exterior Curing Compound is ineffective to reduce water pH.

a)




b)

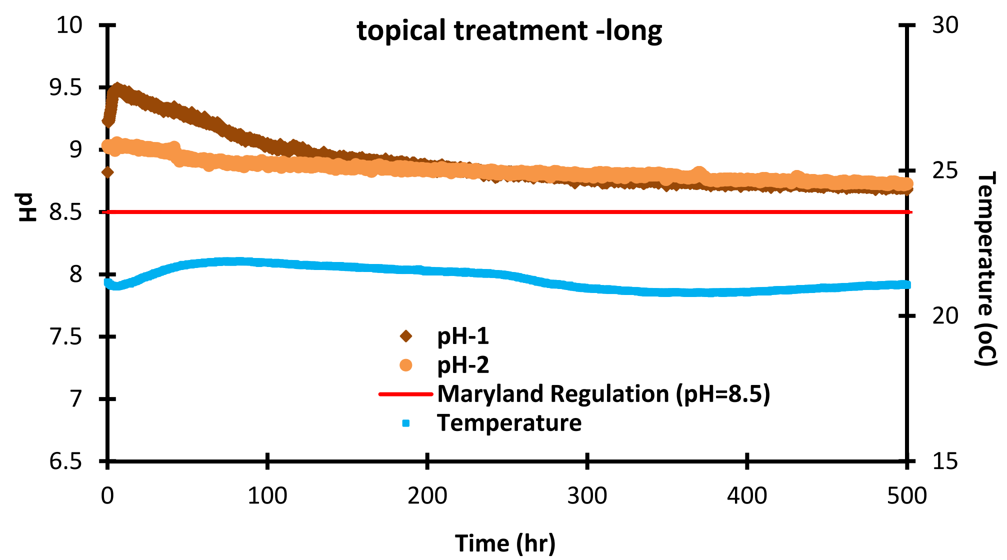
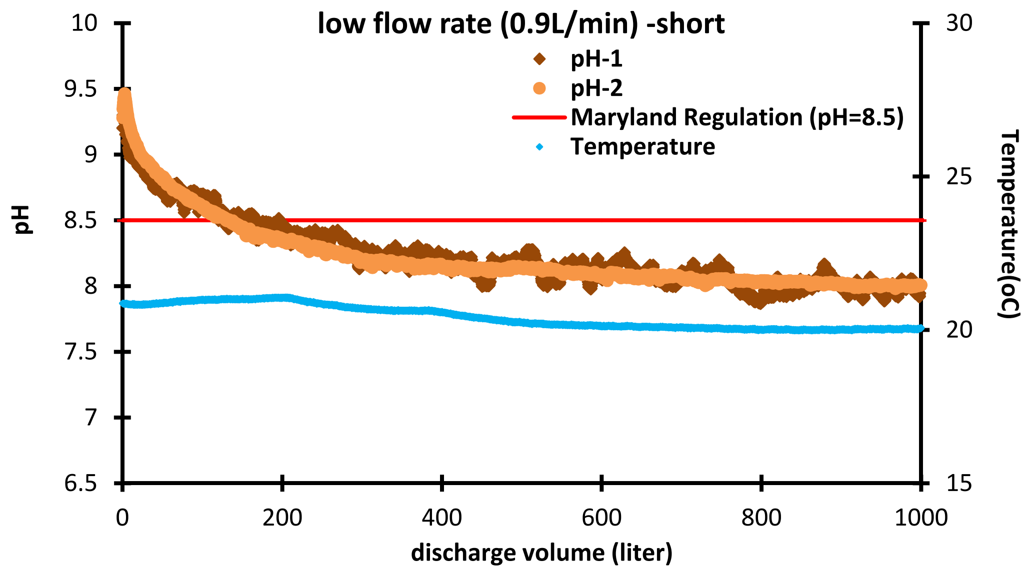



**Figure 3.6: Topical treatment effect (Kaufman Thin Film Exterior Curing Compound)**

### 3.2.7 Flow rate and pipe length

The flow rate and pipe length experiments were performed simultaneously. Three flow rates—low (0.9 L/min), medium (1.8 L/min), and high (3.5 L/min)—and two PVC pipe lengths—short (91.4 cm) and long (365.6 cm)—were used to find the relationship between discharge volume and grout surface as well as discharge volume and flow rate. The results with the different pipe lengths (91.4 cm and 365.6 cm) and flow rates are in Figure 3.7 to 3.9. An average 99.7 liters and 1270 liters of water were needed to make the pH fall below 8.5 at low flow rate with the short and long PVC pipe, respectively (Figure 3.7). At the medium flow rate, an average 83 liters and 1051.1 liters of water were needed to make pH fall below 8.5 at medium flow rate with the short and long PVC pipe, respectively (Figure 3.8). At the high flow rate, an average 25.5 liters and 155.9 liters of water were needed to make pH fall below 8.5 at high flow rate with the short and long PVC pipe, respectively (Figure 3.9).

a)




b)

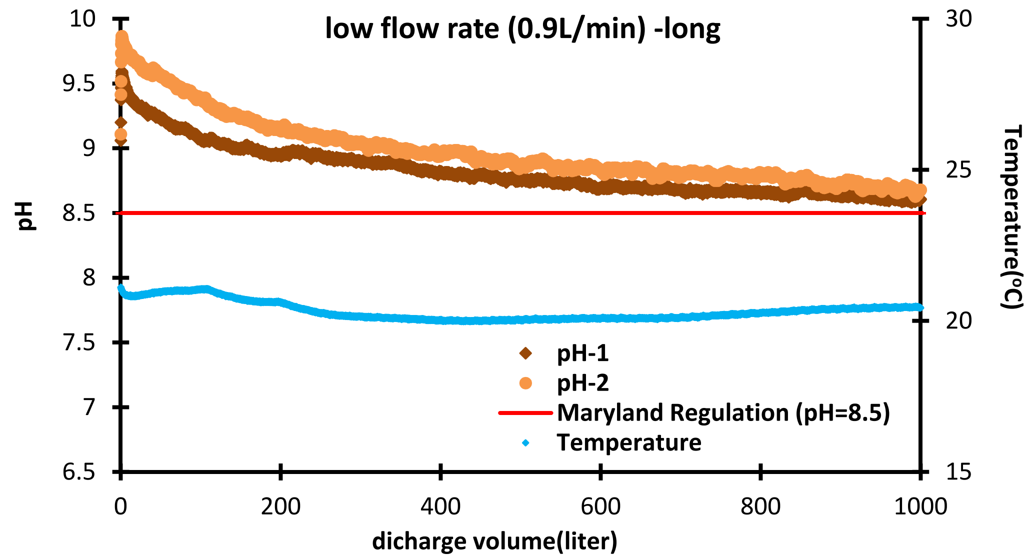



**Figure 3.7: Low flow rate at two lengths of PVC pipe, (a) short (91.4 cm) and (b) long (365.6 cm).**

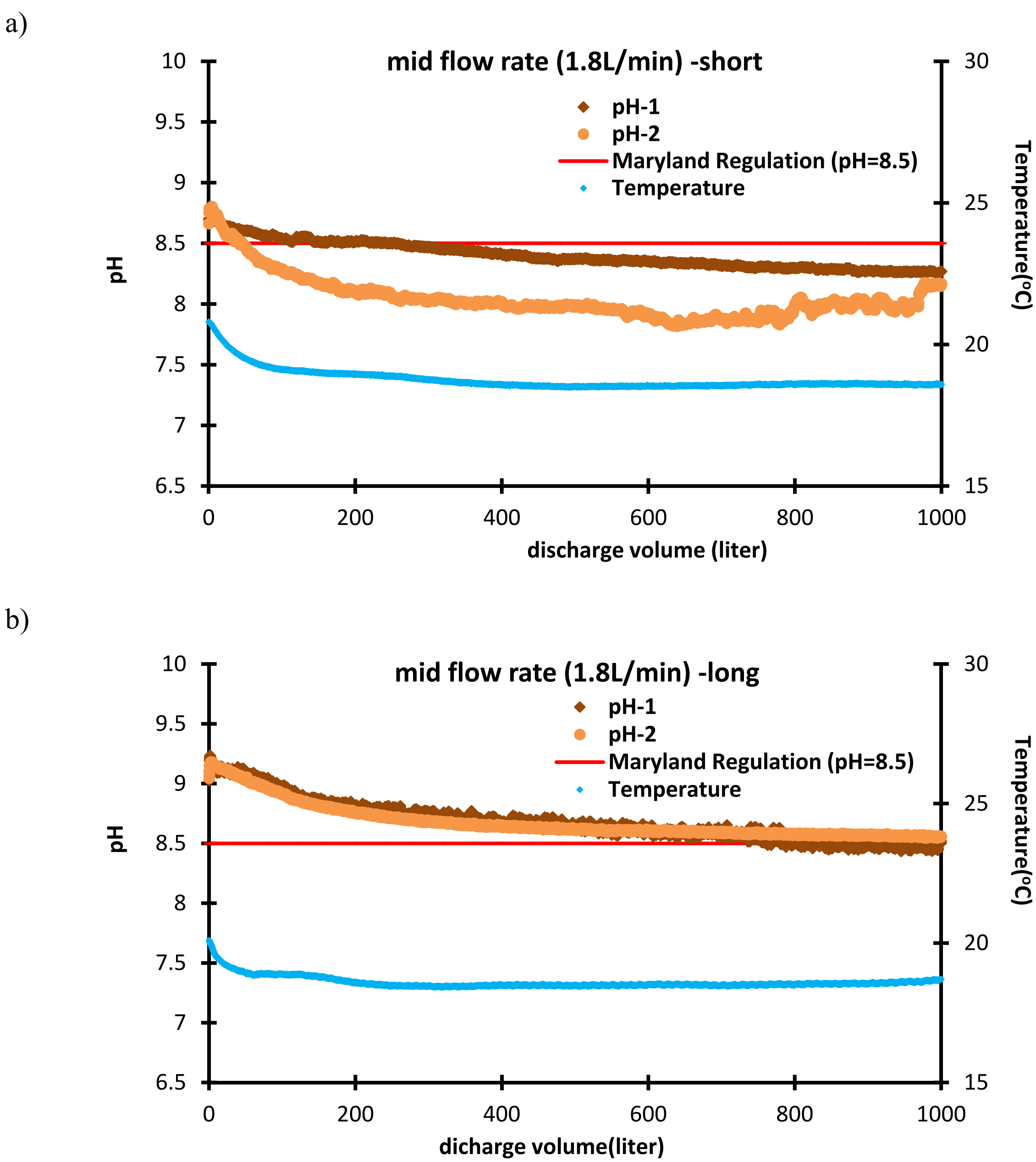
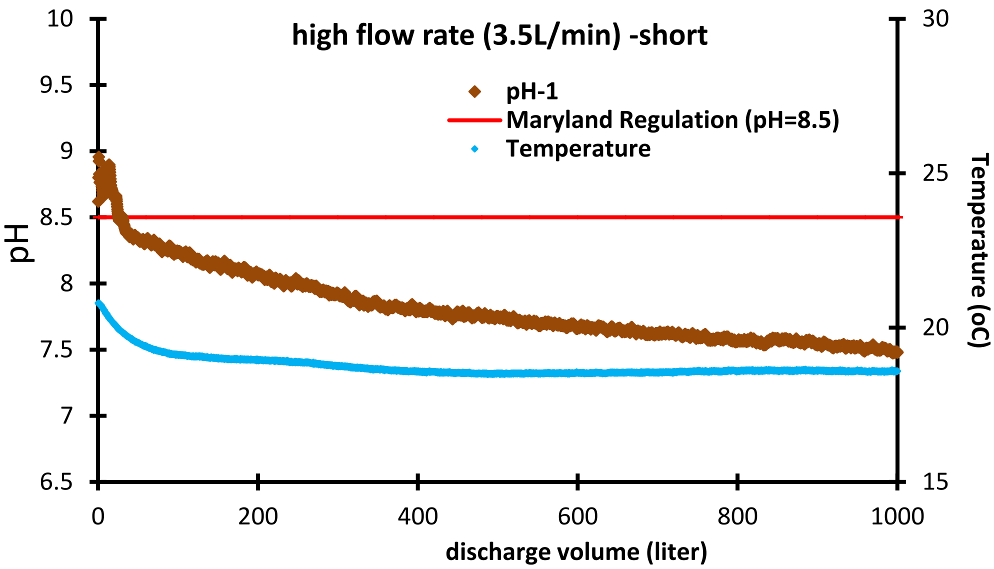



**Figure 3.8: Mid flow rate at two lengths of PVC pipe, (a) short (91.4 cm) and (b) long (365.6 cm).**

a)




b)

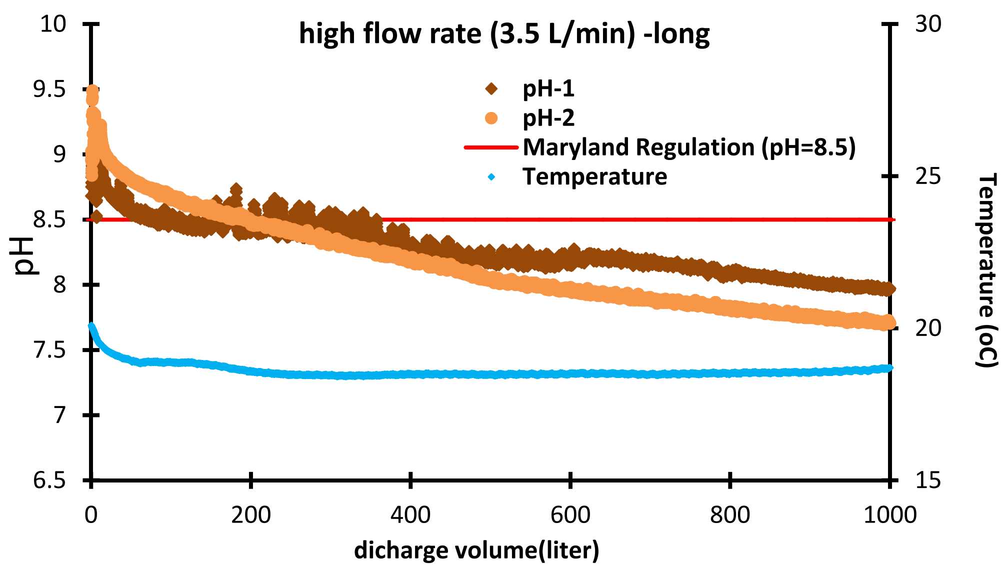
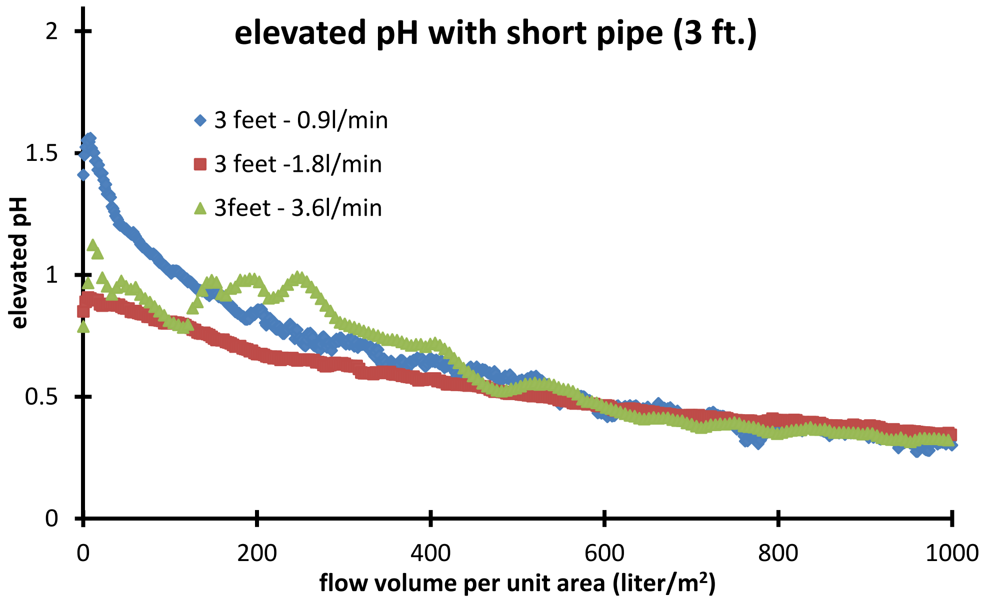



**Figure 3.9: High flow rate at two lengths of PVC pipe, (a) short (91.4 cm) and (b) long (365.6 cm).**

### 3.2.8 Interpolated relationship between elevated pH and flow rate per unit area

A generalized relationship was determined based on laboratory data. This correlation could be applied providing that either SHA or the contractor obtains the initial measurement of the parameters needed to determine elevated pH using the interpolated relationship from Figure 3.10.

a)




b)

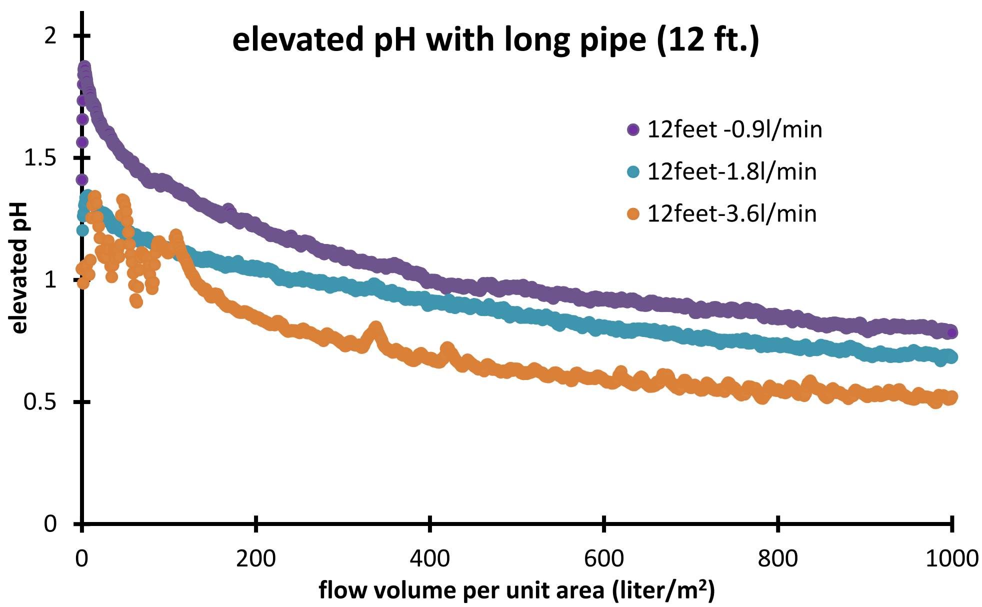



**Figure 3.10: Flow-through experiment depending on the different lengths and flow rates**

The elevated pH means that outlet water pH is greater than the pH of inlet water. The pH is raised after the water contact with grout surface. The results for short pipes with different flow rates exhibited similar elevated pH values, but elevated pH values varied significantly at different flow rates for long pipes. Based on the laboratory results for the different lengths and flow rates, the general relation between elevated pH (y) could be calculated using flow volume per unit area (Figure 3.11).   In case of Fredrick, 13.7 L/sec of flow rate and 61.5 $m^2$ of contact area (41.0m of length and 1.5 m of stream width) were measured.  Flow volume per unit area is 13.37L/$m^2$ (X value). Therefore, 1.07 of elevated pH (y) is calculated after 1 minute of a contact time between the stream water and the grout surface.  The pH buffer of Fredrick field site was pH 0.5 ( pH 8.5 : Maryland regualtion and stream initial pH =8.0). 580 L/$m^2$ of flow volume per unit area required to reach pH =8.5. It will takes 43.4 minutes (required water volume =580L/$m^2$ *41m*1.5m =35,670L, elapsed time =35,670L/13.7L/sec*60sec/minute =43.4 minute). Therefore, 43.4 minutes will be over stream pH 8.5. That was similar to the field result (41 minute). The calculation is only applicable within the work area (near culvert outlet).  The high pH water outside the work area may mix with downstream water and contact streambed such as soil, rock, grass, and organic matter (falling leaf). These reactions, called dilution and buffer affects, will reduce and stabilize pH in a short distance. Therefore, pH data collected from outside work area were not exceeded pH=8.5.  In case of Owings Mills, the relation is not applicalbe due to the fact that the data contain unknown effects such as rainfall events. In the case of Crofton, 176 minutes are required to comply with the Maryland regulation, while the measured time was 312 minute. This was caused by grout bags used at the site to prevent erosion at the culvert outlet. To verify the laboratory results, more field data is needed.

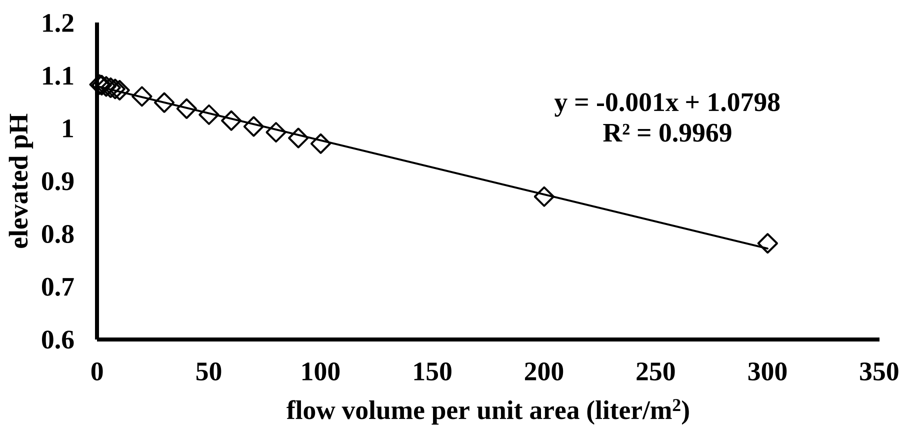



**Figure 3.11: The relationship between elevated pH and flow volume per unit area.**

## 3.3 Remedial action

### 3.3.1 Sediment bag

The experiment was an effort to assess the general pH neutralizing ability of different organic materials, with results shown in Figures 3.12 to 3.15. It should be noted that the results show instances where measured pH of the treated water was higher than the influent.  This may indicate sensitivity in the pH electrode's response to changes in solubility of lime created by changes in temperature (NLA, 2012).

The average pH at the control was 11.4 for straw material (four-inch depth). After control water (pH=11.4) passed through the sediment bag at different flow rates, the average pH at the outlet was 11.4 and 10.8 using fast (6.0 L/min) and slow (2.7 L/min) flow rates, respectively (Figure 3.12). These results mean that straw material is ineffective to reduce water pH.

The average pH of the control water was 10.7 for the mulch material. After the control water (pH=10.7) passed through a sediment bag, the average pH at the outlet was 10.1 and 9.8 for fast (6.0 L/min) and slow (2.7 L/min) flow rates, respectively (Figure 3.13). The pH for a remedial action through the sediment bag with slow flow rate reduced more than the fast flow rate with mulch (four-inch depth) because of more contact time. However, the pH results under both flow rates were still higher than the Maryland regulation (pH=8.5). This means the mulch material is also ineffective to reduce water pH.

The average pH of the control water was 11.1 for the dry peat material. After control water (pH=11.1) passed through a sediment bag at different flow rates, the average pH at the outlet was 11.4 and 11.3 using fast (6.0 L/min) and slow (2.7 L/min) flow rates, respectively (Figure 3.14). The pH with dry peat (four-inch depth) was higher than the control water pH. This indicates preferential flow and filtering of the water through the dry peat. Dry peat material was ineffective at significantly reducing water pH.

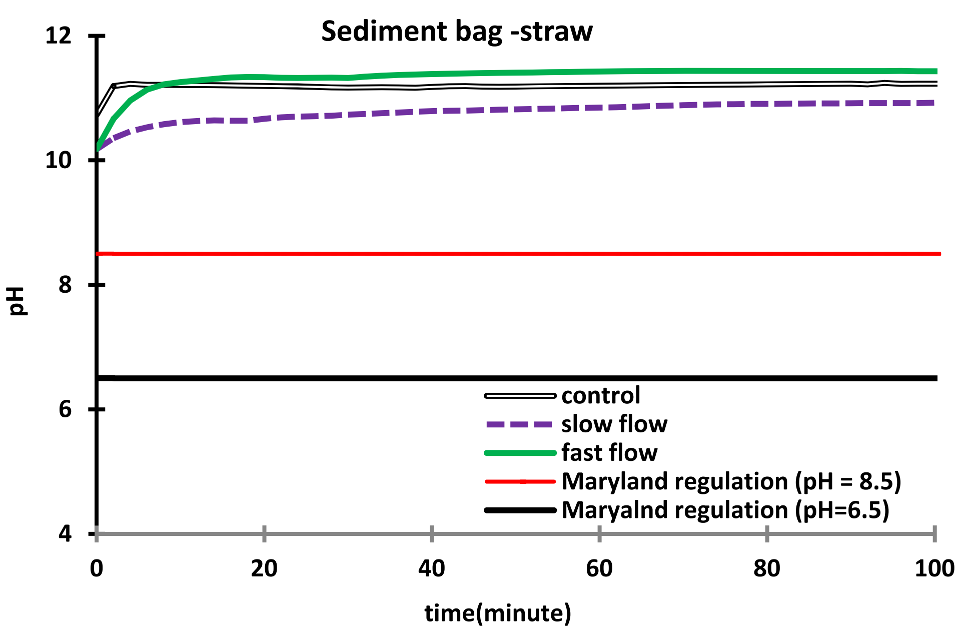



**Figure 3.12: Experiment of sediment bag with straw at slow flow rate (2.7 L/min) and fast flow rate (6.0 L/min).**

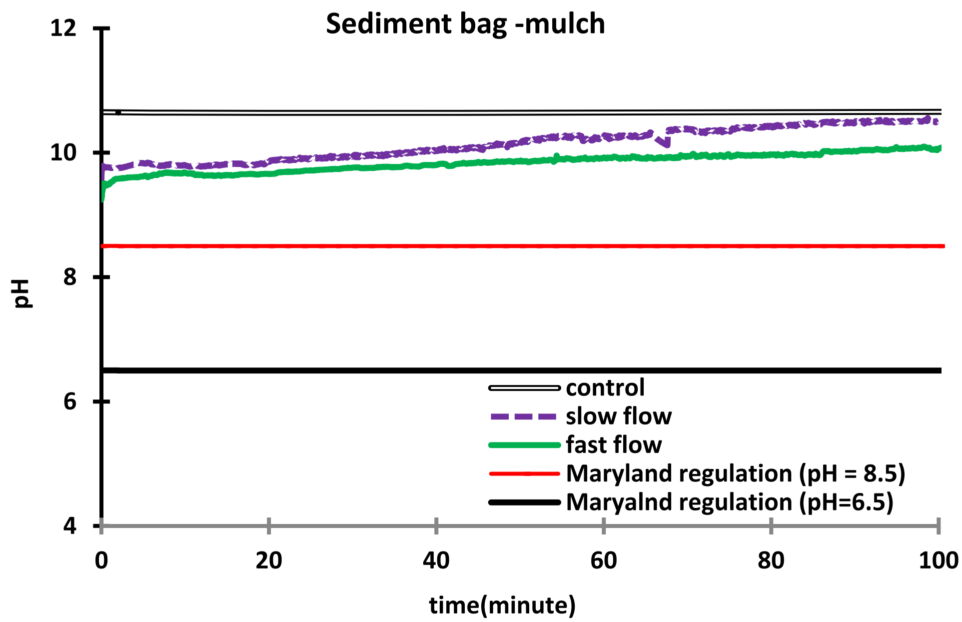



**Figure 3.13: Experiment of sediment bag with mulch at slow flow rate (2.7 L/min) and fast flow rate (6.0 L/min).**

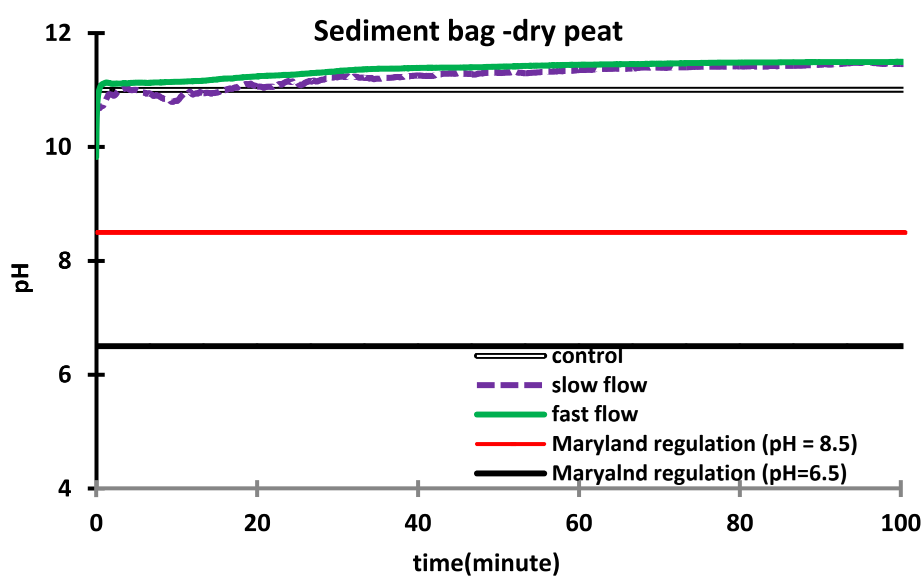



**Figure 3.14: Experiment of sediment bag with dry peat at slow flow rate (2.7 L/min) and fast flow rate (6.0 L/min).**

The average pH of the control water was 11.1 for wet peat material. After control water passed through a sediment bag, the average pH at the outlet was 4.9 for both fast (6.0 L/min) and slow (2.7 L/min) flow rates (Figure 3.15). Due to the presence of humic/organic acids of the peat, the pH immediately decreased, but gradually increased over time. This indicates that the peat has an effective, yet finite capacity to reduce high pH water. The pH results under both flow rates were lower than the Maryland regulation (pH=8.5) and resulted in lower than suitable stream water pH (6 to 8.5).

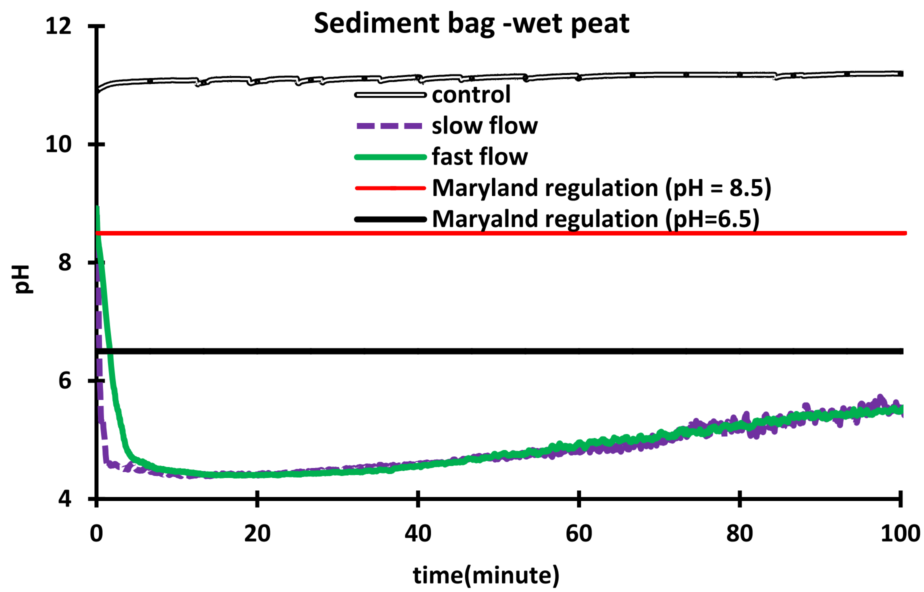



**Figure 3.15: Experiment of sediment bag with wetted peat at slow flow rate (2.7 L/min) and fast flow rate (6.0 L/min).**

Applied in the field, the sediment bag with wet peat base filter would be placed at adequate distance from the stream to allow for sheet flow and pH buffering of water re-entering downstream. It is anticipated that a greater flow rate would be supplied by the pump in the field in comparison to the flow applied in the laboratory experiment. This may result in a higher initial pH after immediate filtering and earlier exhaustion of the peat's pH neutralizing capacity. The pH of the water passing through a wet peat barrier may be affected by contact time, the quantity of wet peat, and flow rate.

The results of ORP, which measures the tendency for chemical species to acquire electrons and thereby be reduced in aqueous solutions with the different organic materials, are shown in Figure 3.16. The ORP of dry peat is shown to be higher than wet peat and mulch, and lower than straw. Mulch and wet peat showed similar ORP values. ORP values were not affected by flow rates. Straw showed higher ORP values than the other organic materials. The water from straw has a higher tendency to gain electrons than the other organic materials, and mulch and wet peat have a tendency to lose electrons. ORP was not affected by flow rate.

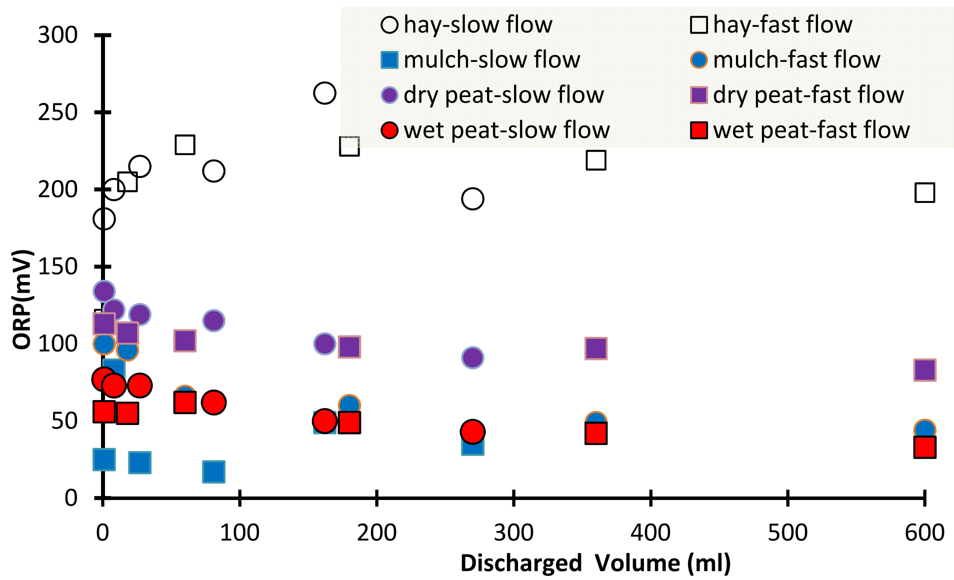



**Figure 3.16: ORP (mV) measured in collected leachate samples from the sediment bag experiments at different flow rates (slow - 2.7 L/min, fast - 6.0 L/min).**

The results for conductivity, which measures the ability of water to pass an electrical current, are shown in Figure 3.17. Conductivity in water is affected by the presence of inorganic dissolved solids. The straw showed a lower conductivity value than the other organic materials. This is because straw is composed of more inert materials that do not dissolve and ionize. The initial conductivity of dry peat and mulch were elevated before decreasing with discharge volume over time.

The conductivity of wet peat showed a low initial value and then continuously increased with discharge volume. This means the released amounts of ionic components from wet peat were increasing with discharge volume. The high pH water running through the wet peat and mulch tends to have higher conductivity due to dissolved organic components. Conductivity was not affected by flow rate.

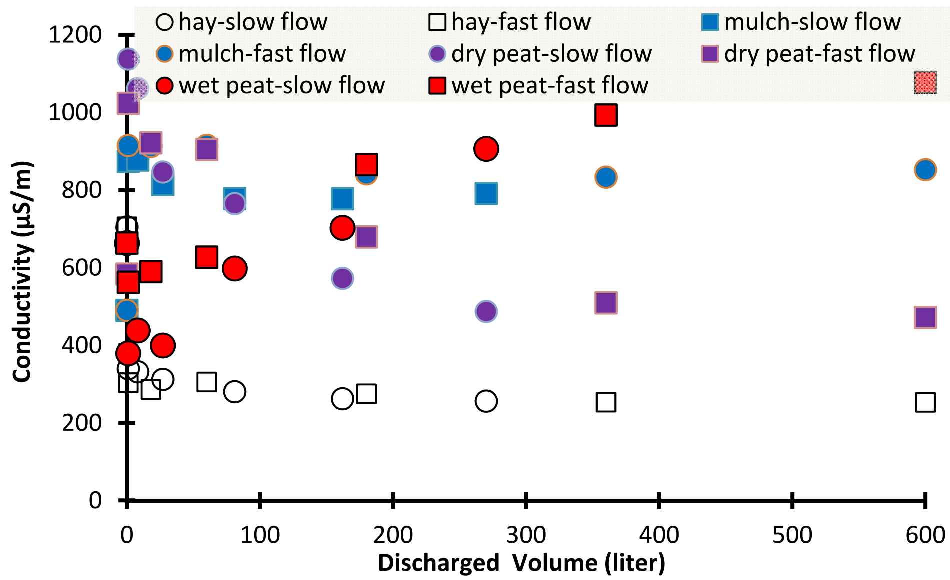



**Figure 3.17: Conductivity (µS/m) measured in collected leachate samples from the sediment bag experiments at different flow rates (slow - 2.7 L/min, fast - 6.0 L/min).**

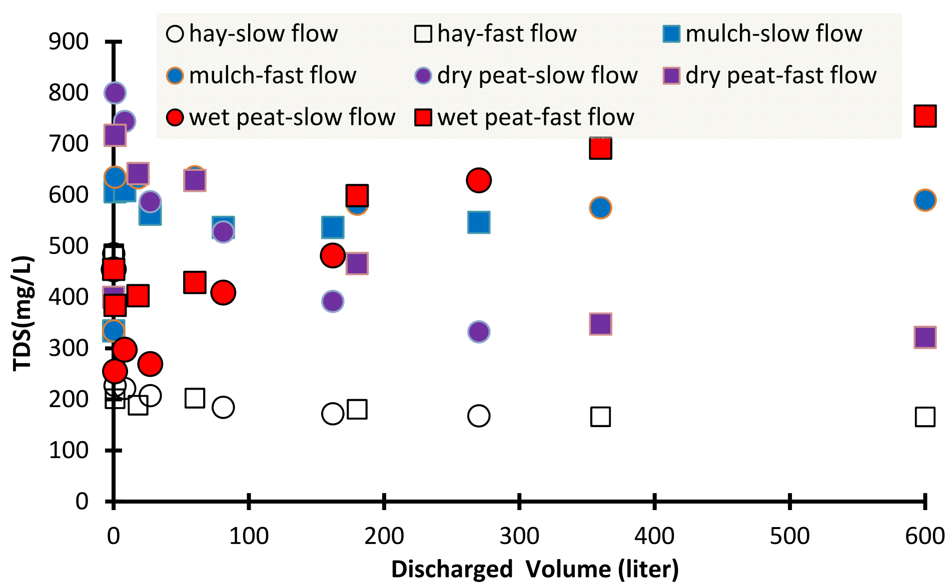



**Figure 3.18: TDS (mg/L) measured in collected leachate samples from the sediment bag experiments at different flow rates (slow flow rate of 2.7 L/min, fast flow rate of 6.0 L/min).**

The results for TDS, which measures the combined content, inorganic and organic, and dissolved substances contained in the water, are shown in Figure 3.18. The TDS results showed a trend similar to conductivity. Straw showed a lower value than the other organic materials. The high pH water running through straw tends to have a lower TDS because the straw is composed of more inert materials that do not dissolve. The initial TDS of dry peat and mulch appeared high and then TDS decreased with discharge volume. The TDS of wet peat showed a low initial value and then continuously increased with discharge volume. This result means that the released amounts of inorganic and organic substances from wet peat were increasing with the discharge volume. The United States has established TDS of 500 mg/l as a secondary water quality standard to provide for the palatability of drinking water. The TDS in the collected water samples after they have run through mulch and wet peat materials were higher than the secondary water quality standard. TDS was not affected by flow rate.

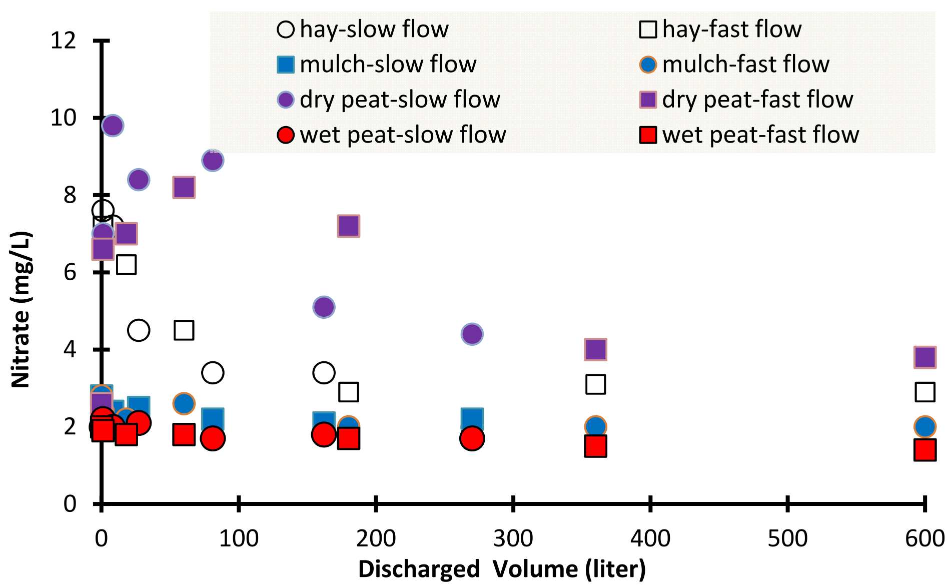



**Figure 3.19: Nitrate (mg/L) measured in collected leachate samples from the sediment bag experiments at different flow rates (slow - 2.7 L/min, fast - 6.0 L/min).**

Nitrate concentrations in the collected water samples are shown in Figure 3.19. Nitrate concentrations with dry peat and straw showed higher values than the other organic materials and the nitrate concentrations decreased with discharge volume. Nitrate concentrations with mulch and wet peat showed a low initial value and the concentrations were not changed by discharge volume. The Environmental Protection Agency (EPA) has set nitrate concentrations to prevent potential health problems in drinking water. All nitrate concentrations in the collected water samples have lower than a water quality standard (The EPA maximum contaminant level for nitrate is 10 mg/L.) after they have run through the organic materials. The nitrate concentration was not affected by flow rate.

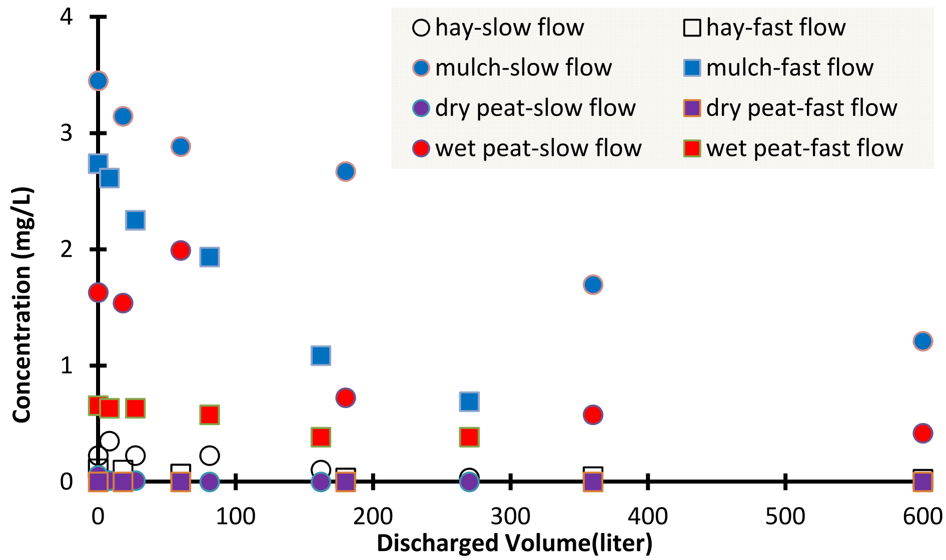



**Figure 3.20: Phosphate concentrations (mg/L) measured in collected leachate samples from the sediment bag experiments at different flow rates (slow - 2.7 L/min, fast - 6.0 L/min).**

The phosphate concentration in the collected water samples is shown in Figure 3.20. Phosphate with mulch showed a higher value than the other organic materials, and the phosphate concentration decreased with discharge volume. The phosphate concentration with wet peat showed a lower initial value than mulch, but was higher than straw and dry peat. The phosphate concentration in the collected water samples was affected by flow rate. More phosphate was released at the slow flow rate.

The orthophosphate concentration in the collected water samples is shown in Figure 3.21. Wet peat showed a higher orthophosphate value than the other organic materials, and the orthophosphate concentrations decreased with discharge volume. The orthophosphate concentration with mulch showed a lower initial value than wet peat, but the concentration was not affected by discharge volume. Wet peat and mulch released more orthophosphate than straw and dry peat. The orthophosphate concentration in the collected water samples was not affected by the two flow rates.

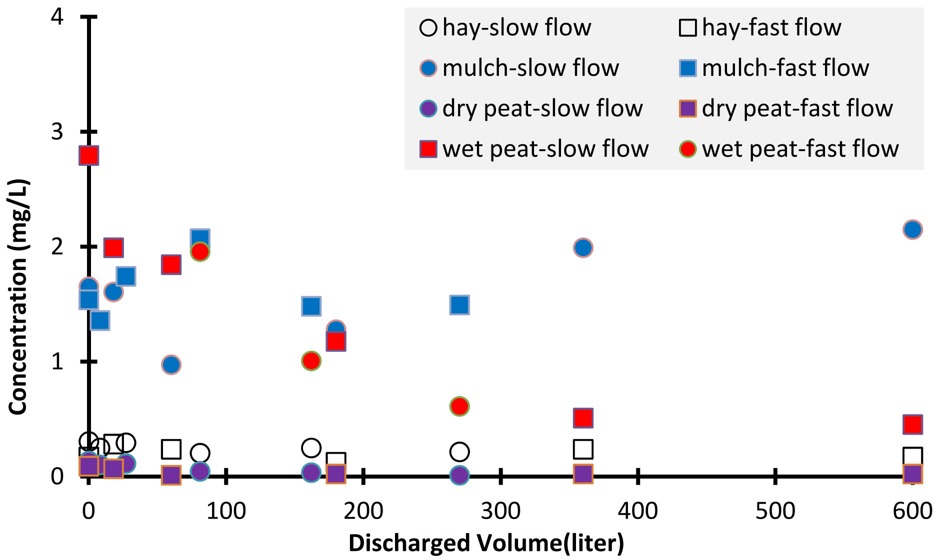



**Figure 3.21: Orthophosphate (mg/L) measured in collected leachate samples from the sediment bag experiments at different flow rates (slow - 2.7 L/min, fast - 6.0 L/min).**

### 3.3.2 Optimization of remedial action

A small-scale study to determine the ratio of peat to straw was conducted to determine the acceptable ratio to be tested with the column study and tested in the field. Table 3.3 is a summary of the small-scale study. Based on these results, 2:1 and 3:1 peat to water (by volume) ratios were used in the column study. The findings showed that the remedial action of layering 2 inches of straw with 4 inches of wetted peat provided the best reduction of pH value for high pH water. It was observed that clogging and separation of the peat could be an issue depending on the flow rate from the sediment bag.

**Table 3.3: Data from peat mixing ratio experiment.**

| Peat:Water:Straw Ratio | pH | TDS |
|---|---|---|
| 1:1:2 | 7.8 | 534.6 |
| 2:1:2 | 7.6 | 613.0 |
| 3:1:2 | 6.9 | 566.5 |
| 4:1:2 | 6.2 | 984.9 |

### 3.3.3 Carbon dioxide sparging

The results for neutralizing pH with different carbon dioxide flow rates are shown in Figures 3.22 and 23. The average times to reduce 5 gallons of pH from 9.5 to 8.5 were 5.3, 13, and 16.7 seconds for slow (1520 ml of $CO_2$/minute), medium (7600 ml of $CO_2$/minute), and fast (22800 ml of $CO_2$/minute), respectively. The average times to reduce 5 gallons of pH from 11 to 8.5 were 20, 31.7, and 119 seconds for small, medium, and large volumes of carbon dioxide flow rate, respectively. The medium and fast volumes showed a similar trend, but the slow flow rate needed more time to reduce the high pH (Figure 3.22).

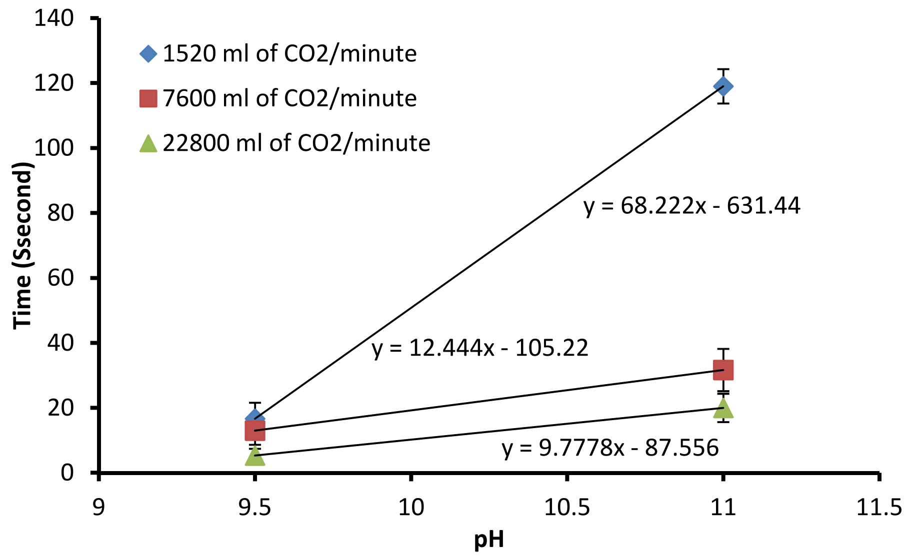



**Figure 3.22: Remedial experiment through carbon dioxide into high pH water.**

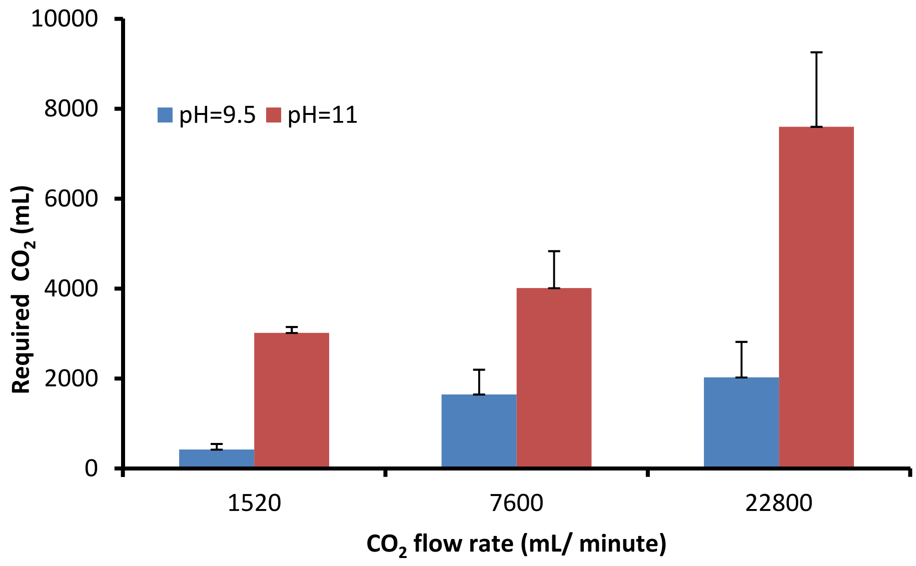



**Figure 3.23: Volume of $CO_2$ required to reduce high pH waters to regulatory limit of 8.5.**

The average carbon dioxide volumes to reduce pH from 9.5 to 8.5 were 442, 552, and 2026 ml for slow, medium, and fast carbon dioxide flow rate, respectively. The average carbon dioxide volumes to reduce pH from 11 to 8.5 were 3014, 4011, and 7600 ml for the small, medium, and large volumes carbon dioxide flow rates, respectively (Figure 3.23). Detail results for each condition are listed in appendix B (Figure B3 to B10).

# 4 FIELD MONITORING

Five SHA culvert paving projects that represented various stream environments were selected for monitoring. Of those projects, three sites were monitored to understand the extent of any water quality impairments. Monitoring activities were limited to the Maryland water quality standard for pH. SHA assisted in the selection of the site that best represented a variety of construction techniques and environmental conditions. Site selection was determined by the location, ease of access, and schedule of maintenance activities.

Two SHA culvert paving projects were visited before the start of the field study: Structure #03277 (I-83/I-695 over a branch of Roland Run, Baltimore County, MD) and Structure #03388XO (I-83 north of the Ruxton Road exit/overpass, Baltimore County, MD) (Figure 4.1).


**Figure 4.1: Culvert paving field visit of Structure #03277 (Baltimore County, MD).**

The continuous pH monitoring devices were installed at the water quality monitoring points. Water quality measurements were taken at appropriate downstream points from construction sites to ensure that the collected data represented the stream water's pH (Table 4.1). Four continuous monitoring systems were set downstream of the construction site. One probe was located at the estimated complete mixing point that produces a uniform, final concentration in the stream. Three field sites, including four culvert paving activities, were monitored to understand the extent of any water quality impairments. Data loggers were deployed at the following sites:

- Structure #03322X0—located beneath I-795, just east of the intersection with Painters Mill Road in Baltimore County. November 28, 2011, 55 Music Fair Road, Owings Mills, MD 21117 (Figure 4.2).

- Structure #02029X0—located on MD 450, quarter mile east of the intersection with MD 424 in Anne Arundel County. November 18, 2011, 2301 Davidsonville Road, Gambrills, MD 21054 (Figure 4.3).

- Structure #10058X0—located on MD 550, just north of Dublin Road/Steiner Smith Road in Frederick County. November 15-16, 2011, 11700 Woodsboro Creagerstown Road, Woodsboro, MD (Figure 4.4)

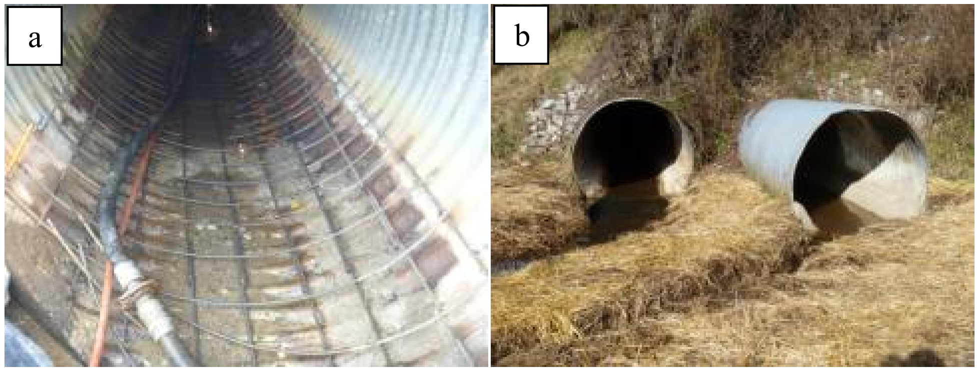



**Figure 4.2: Structure #03322X0 (55 Music Fair Rd., Owings Mills, MD 21117)**


**Figure 4.3: Structure #02029X0 (2301 Davidsonville Rd., Crofton, MD 21054)**

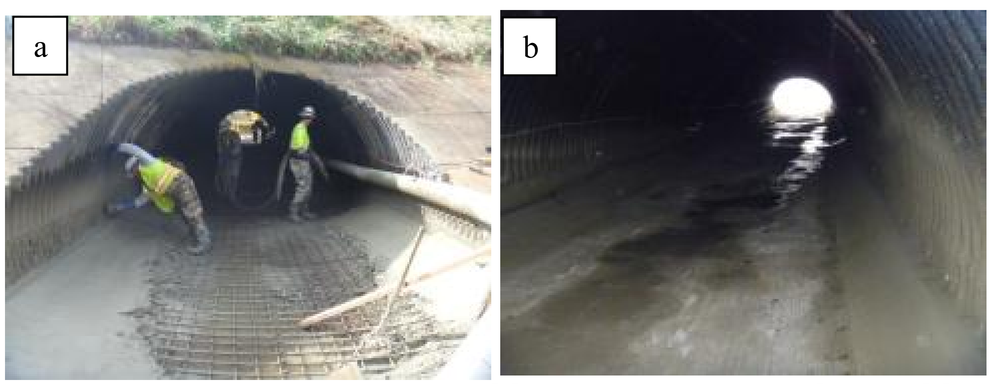



**Figure 4.4: Structure #10058X0 (11700 Woodsboro Creagerstown Rd., Woodsboro, MD)**

**Table 4.1: Field information for culvert maintenance activity**

| Field Location (Maryland) | | Owings Mills | | Crofton | Frederick |
|---|---|---|---|---|---|
| Structure No. | | 03322X0 | | 02029X0 | 10058X0 |
| Max Culvert Diameter (m) | | 1.8 | | 1.5 | 3.7 |
| Culvert Length (m) | | 121.9 | | 24.4 | 41.0 |
| Invert Grout Width (m) | | 0.7(0.5)*** | | 0.5(0.2) | 2.5(1.5) |
| Monitoring Probe Install Date | | 11/28/2011 | 12/7/2011 | 11/18/2011 | 11/15/2011 |
| Stream velocity (m/sec) | | 0.12 | | 0.17 | 0.201(1.59*) |
| Monitoring Probe Location (meter from outlet) | 1 | upstream | upstream | upstream | upstream |
| | 2 | 0 | 0** | 0** | 0** |
| | 3 | 10 | 0.1** | 10** | 10 |
| | 4 | 30 | 10 | 20 | 20 |
| | 5 | 50 | 30 | 40 | 50 |
| Barrier Location (meter from outlet) | | N/A | N/A | 10-20 | 0-10 |

* Rainfall event
** pH logger was placed in the work area
*** Actual contract width of grout and water

After consultation with SHA, the mitigation method identified as the most practical and useful was the sediment bag and optimization experiments were selected for field application. Two projects similar environmental conditions were selected based on the previous water quality criteria for pH, conductivity, TDS, temperature, oxidation reduction potential (ORP), and alkalinity. Upstream and downstream measurements that indicate water quality were taken. The initial condition of the water before it entered the culvert and the effluent from rehabbed culverts were continuously measured for flow rate and water quality using a multi-parameter measurement system. Continuous monitoring devices were installed at predetermined water quality monitoring points. Monitoring of waters impacted "in pipe" and remedial actions were also performed.

### 4.1 Analysis

The pH and temperature during the flow-through test were measured by an OMEGA NOMAD pH & temperature reader (OMEGA Engineering, Inc., Stamford, CT). The flow rates of streams were gauged by a Lab Navigator 1.0 with NavFlo, which is a flow rate sensor (Forston Labs, Fort Collins, CO). Conductivity, TDS, temperature, and ORP were analyzed with the Myron Ultrameter II (Myron Company, Carlsbad, CA).

# 5 FIELD FINDINGS & DISCUSSION

## 5.1 Field results

Three selected field locations were monitored from mid-September to early November, 2011. Five pH and temperature loggers were installed before grout was poured into the culvert. Collected stream water samples were analyzed for initial pH, temperature, flow rate, conductivity, TDS, and ORP. The results are summarized in Table 5.1. Initial pH was 7.52 at Owings Mills, for both inlet and outlet water samples. Crofton water samples were pH 6.9 at the inlet and pH 7.6± 0.2 at the outlet. The Frederick water samples' pH values (7.9 to 8.5) were higher than the others' (6.9 to 7.5). Occasionally, an outlet water sample's pH value was above the Maryland regulation (pH 8.5). Water temperatures were lower than 15$^{o}$C for all three sites, lower than the laboratory condition (22$^{o}$C). The flow rate of Crofton was 0.5 liter/sec, lower than the others (12 to 14 liter/sec). Conductivity, which is affected by the presence of inorganic dissolved solids, was around 340 to 800. TDS, which measures the combined content of all inorganic and organic substances, ranged from 230 to 560 mg/liter. ORP, which is a measure of the tendency of a chemical species to acquire electrons and thereby measures oxidation/reduction, ranged from 35 to 99. The stream water of Crofton had higher inorganic and organic substances than that of Owings Mills and Frederick, based on the conductivity and TDS results. Crofton's ORP was lower than the others (Table 5.1).

**Table 5.1: Water sample analysis collected from the field**

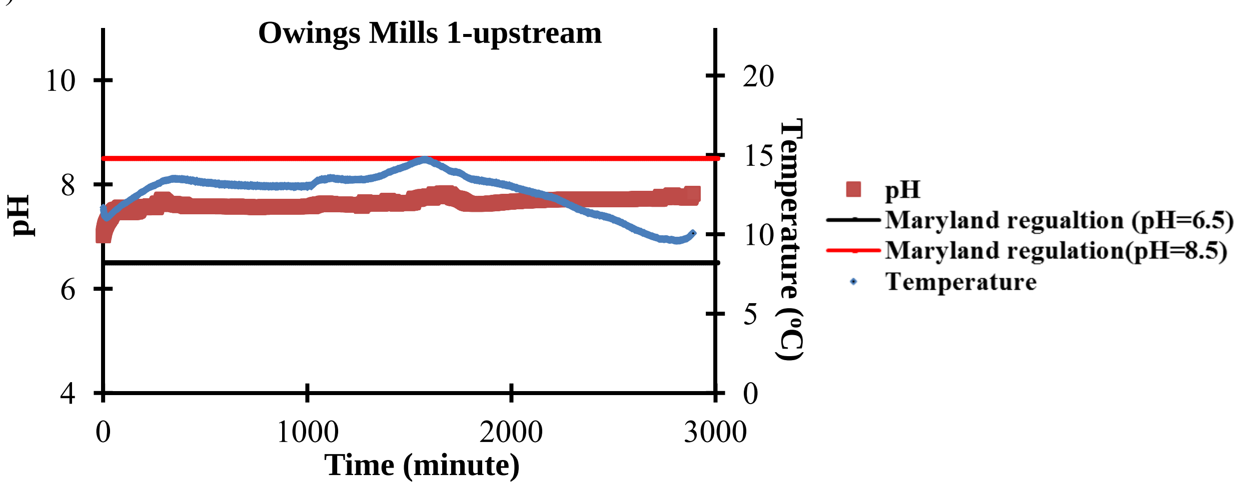
| Field Location (Maryland) | Inlet pH | Outlet pH | Flow rate (liter/sec) | Temp (C$^{\circ}$) | Conductivity (µS/cm) | TDS (mg/liter) | ORP (mV) |
|---|---|---|---|---|---|---|---|
| Owings Mills | 7.5 | 7.5 | 12.2 | 12.5 | 516 | 359 | 99 |
| Crofton | 6.9-7.0 | 7.4-7.8 | 0.5 | 8.7 | 491-800 | 343-563 | 35-38 |
| Frederick | 7.9-8.2 | 8.3-8.5 | 13.7 | 12.5-14 | 343-376 | 233.2-257.3 | 84-91 |

The field location in Owings Mills has two culverts (1.8 meters in diameter, and 120 meters in length). The estimated invert paving area is 72 m$^2$. During construction, the culvert that was not under construction was used to divert the stream from the work area. At the completion of the work, the stream diversion was then shifted to the completed and cured culvert. The first monitoring probes for pH and temperature were operated on November 28, 2011. The stream velocity was 0.12 m/sec. Water flowed through the culvert for 2 hours before the start of data logging, which may be enough time to wash out the grout surface. Therefore, pH data collected from Owings Mills 1 did not exceeded pH 8.5. The average, minimum, and maximum data for pH and temperature collected from Owings Mills 1 are listed in Table 5.2. The data loggers were placed upstream (inlet) and 0 m (at the outlet of the culvert), 10 m, 30 m, and 50 m from the end of culvert. Water temperature was recorded as high as 17.0$^{o}$C and as low as 9.6$^{o}$C. The highest pH was 8.1, and the lowest pH was 7.0. The logger data for Owings Mills 1, which includes pH and temperature, and Maryland pH regulation (8.5) as compared to the Maryland regulation shown in Figure 5.1.

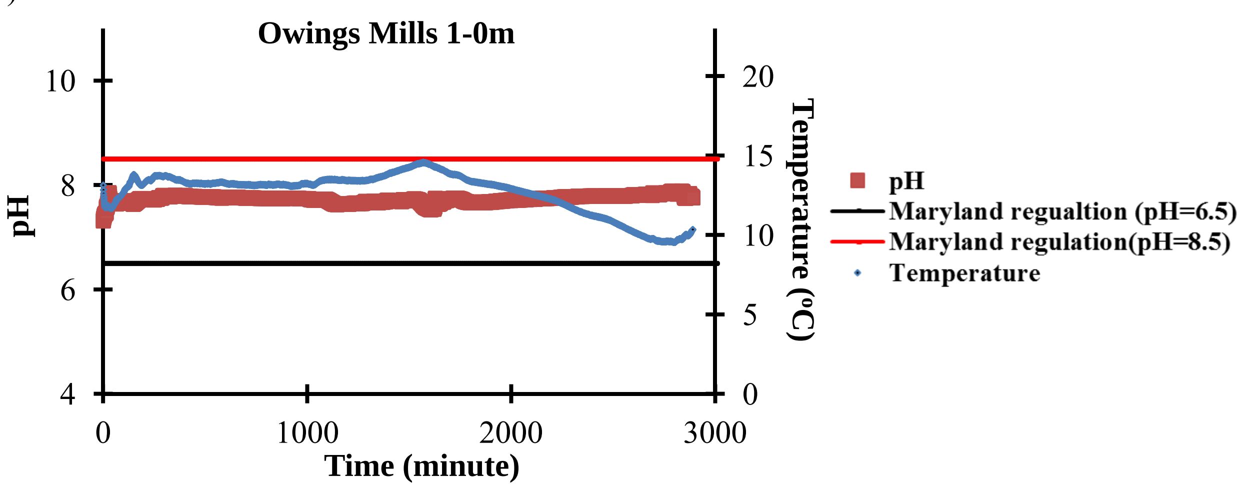
**Table 5.2: pH and temperature of Owings Mills 1**

| Owings Mills 1, MD | | upstream | | 0m | | 10m | | 30m | | 50m | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH |
| | Average | 12.7 | 7.7 | 12.7 | 7.3 | 12.8 | 7.5 | 12.8 | 7.6 | 12.2 | 7.9 |
| | Minimum | 9.6 | 7.0 | 9.5 | 7.3 | 10.1 | 7.1 | 10.0 | 7.1 | 9.2 | 7.6 |
| | Maximum | 14.7 | 7.8 | 14.6 | 7.9 | 14.4 | 7.7 | 14.7 | 7.8 | 17.1 | 8.1 |

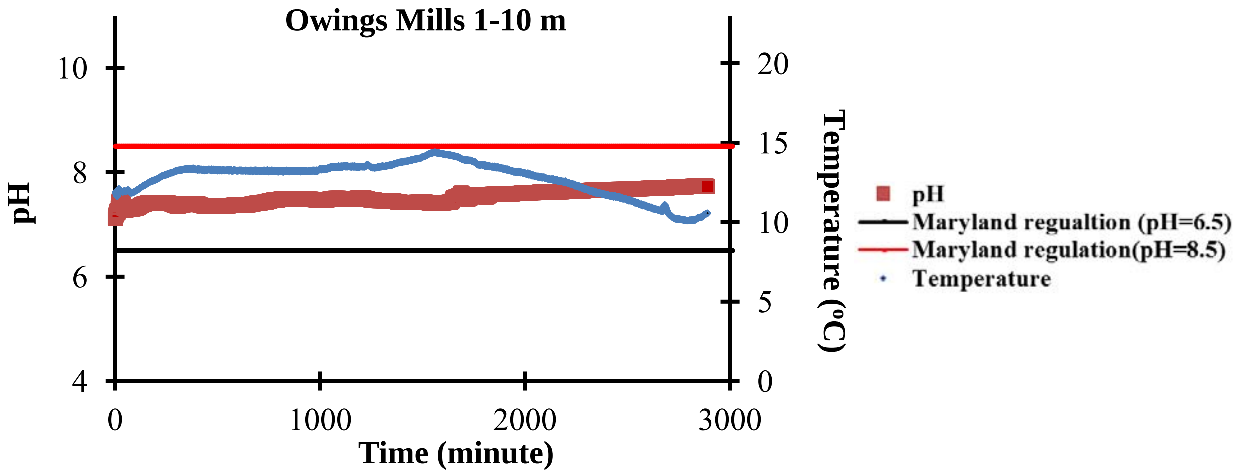
a)



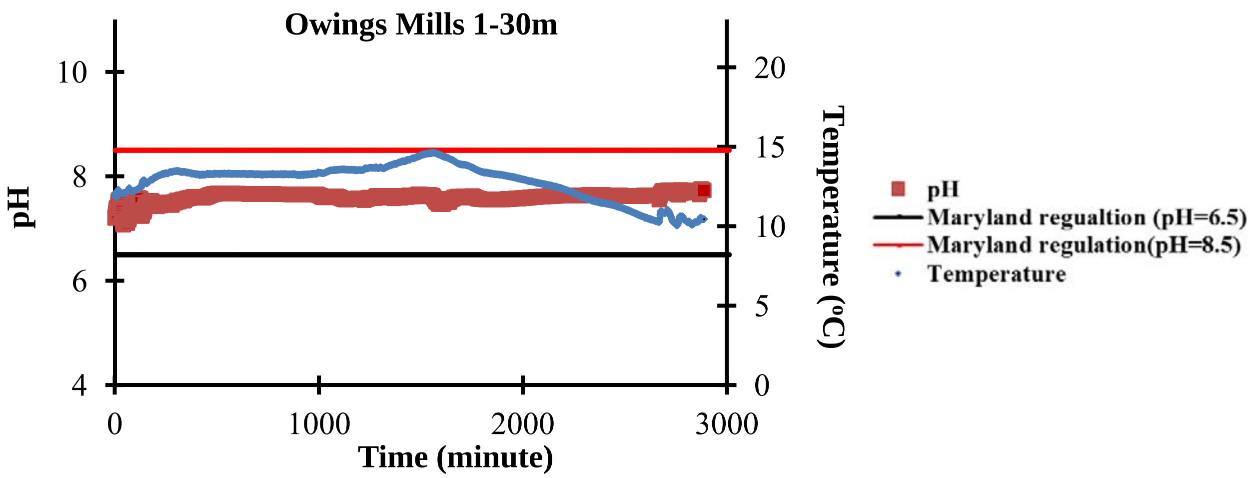

b)



c)




d)




e)

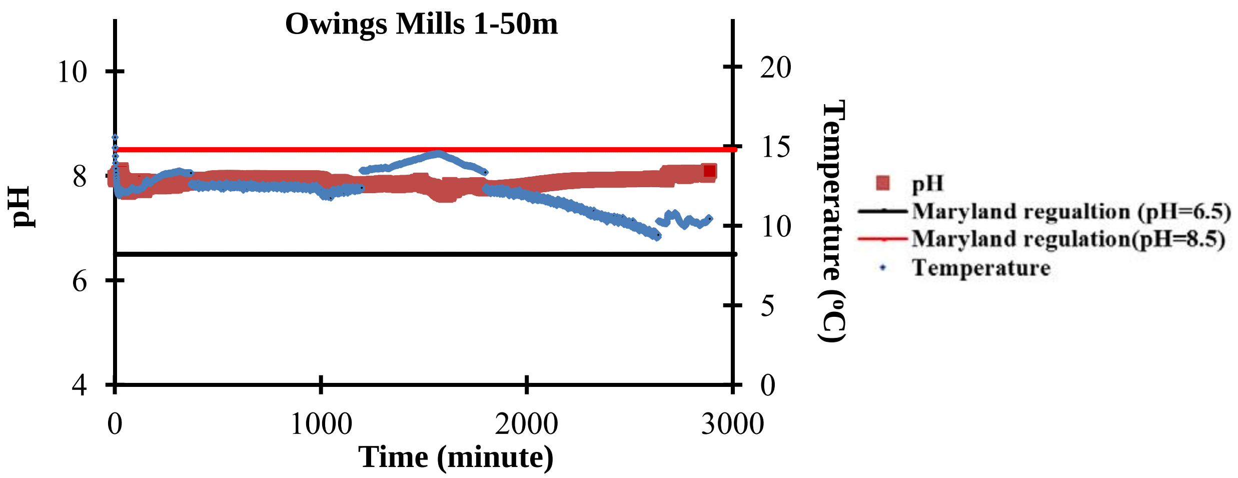



**Figure 5.1: Monitoring of Owings Mills 1 culvert for pH and temperature upstream and at locations downstream**

The monitoring probes for the second culvert at Owings Mills 2 were operated on December 7, 2011. The stream velocity was 0.12 m/sec, the same as the previous monitoring. The average, minimum, and maximum data for pH and temperature collected from the second culvert are listed in Table 5.3. One data logger was placed at the upstream (inlet) and two were placed at the effluent points of the two culverts, as well as 10 and 30 meters from the end of culvert. The water temperature was recorded as high as 15.2°C and as low as 3.3°C. The highest pH, 10.9, was recorded during the curing process from the probe located at 0 meters. The lowest pH, 7.3, was recorded at the same location after water flowed out the culvert. The logger data for Owings Mills 2, including pH and temperature, and compared to the Maryland pH regulation (8.5) are shown in Figure 5.3.

**Table 5.3: pH and temperature of Owings Mills 2**

| | | upstream | | 0meters | | 0.1meters | | 10meters | | 30meters | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH |
| Owings Mills 2, MD | Average | 7.1 | 7.7 | 9.2 | 8.5 | 8.5 | 8.0 | 6.8 | 7.9 | 6.8 | 7.8 |
| | Minimum | 4.5 | 7.6 | 5.5 | 7.9 | 4.1 | 7.3 | 3.2 | 7.5 | 3.3 | 7.5 |
| | Maximum | 14.0 | 8.2 | 14.7 | 10.9 | 14.8 | 10.3 | 15.2 | 8.1 | 14.8 | 8.2 |

a) Owings Mills 1 and 2 culvert


b) water filled inside culvert

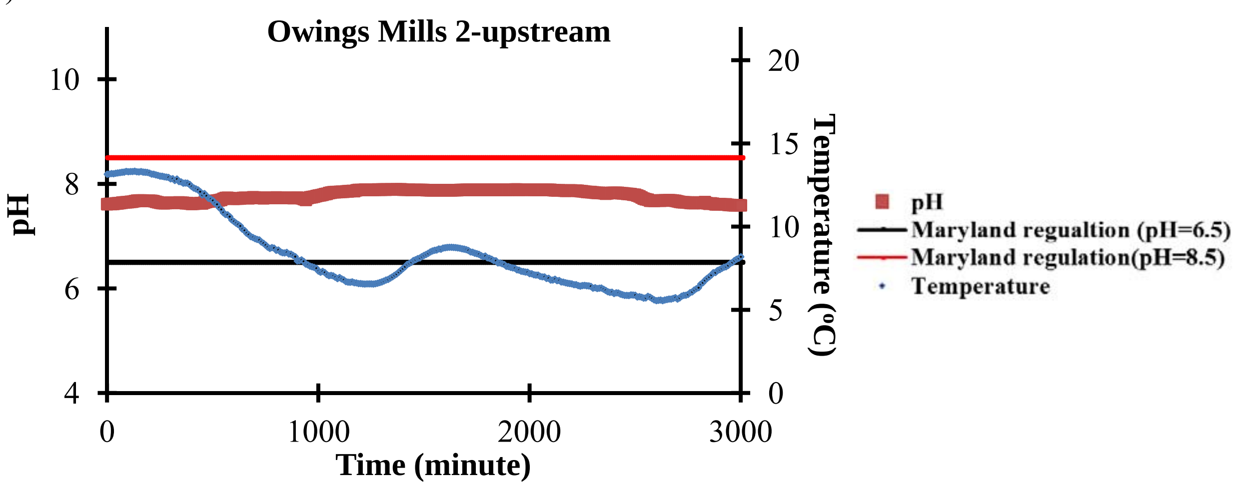

c) water leaking inside culvert


d) remove grout slurry

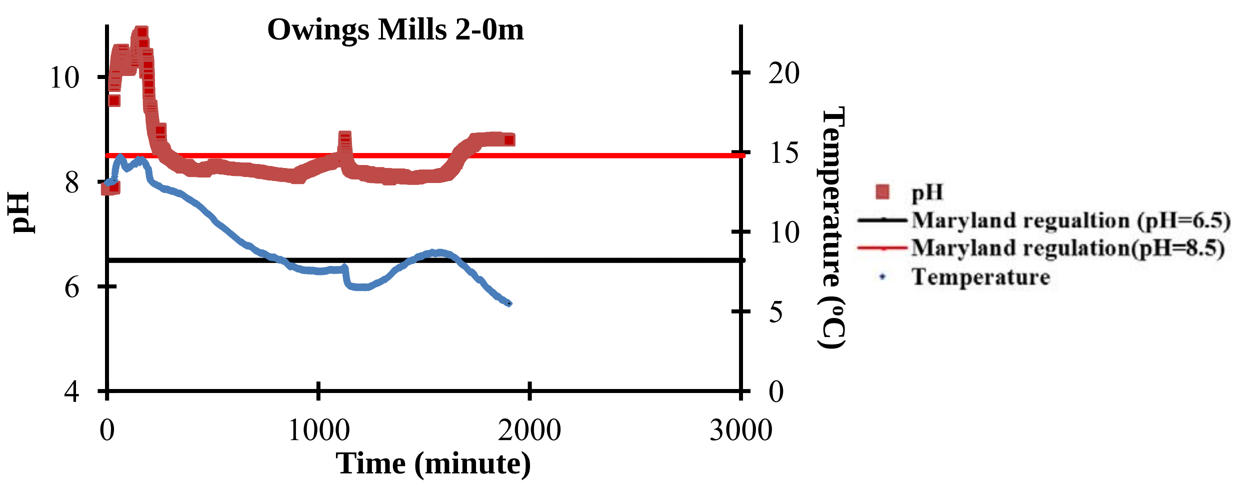

**Figure 5.2: Curing process seen at site in Owings Mills, MD.**

Data logger 2 (0 meters from culvert outlet) and 3 (0.1 meters from culvert outlet) were located in the work area near the culvert outlet. At data logger 2, the pH was over 10.3 for 220 minutes. A rainfall event started after the grout paving and continued during the curing process, causing runoff and leaking groundwater (Figure 5.2c) to fill the inside of the culvert. The water leaking inside the culvert after the grout paving may have increased water content that altered the grout paving curing process. The grout paving mixture with high water content turned into a slurry (Figure 5.2 d). There was no further activity at Owings Mills 2 to remove the water that had entered the culvert (Figure 5.2 b), which is why the water pH was high for a long time.

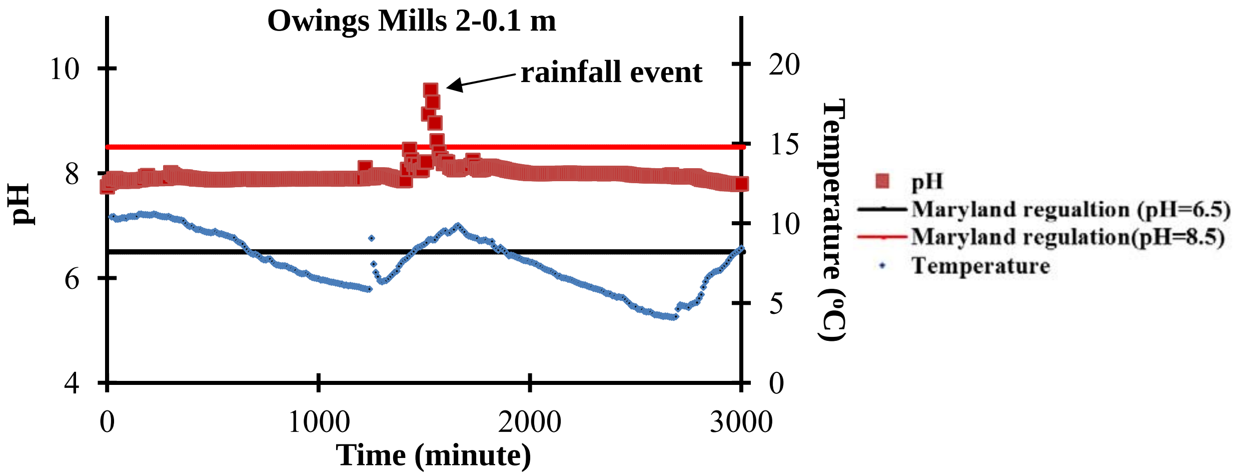
a)



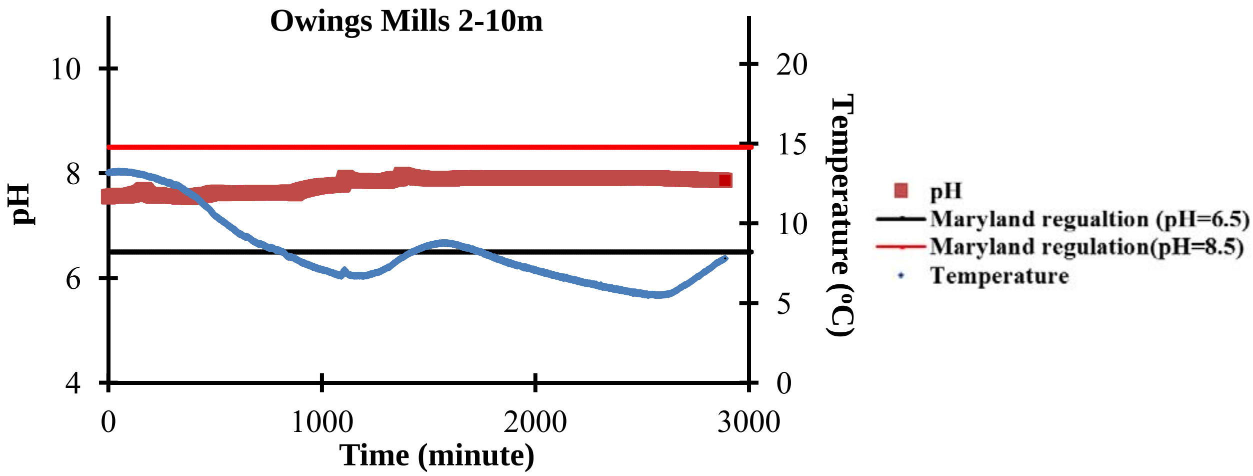

b)



c)




d)




e)

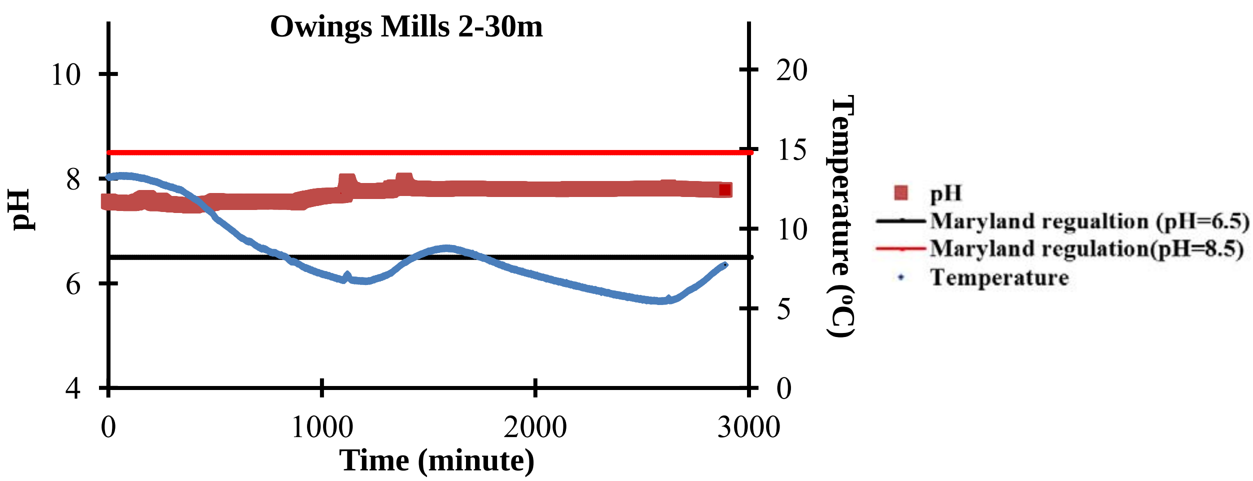



**Figure 5.3: Monitoring of Owings Mills 2 culvert for pH and temperature upstream and at locations downstream**

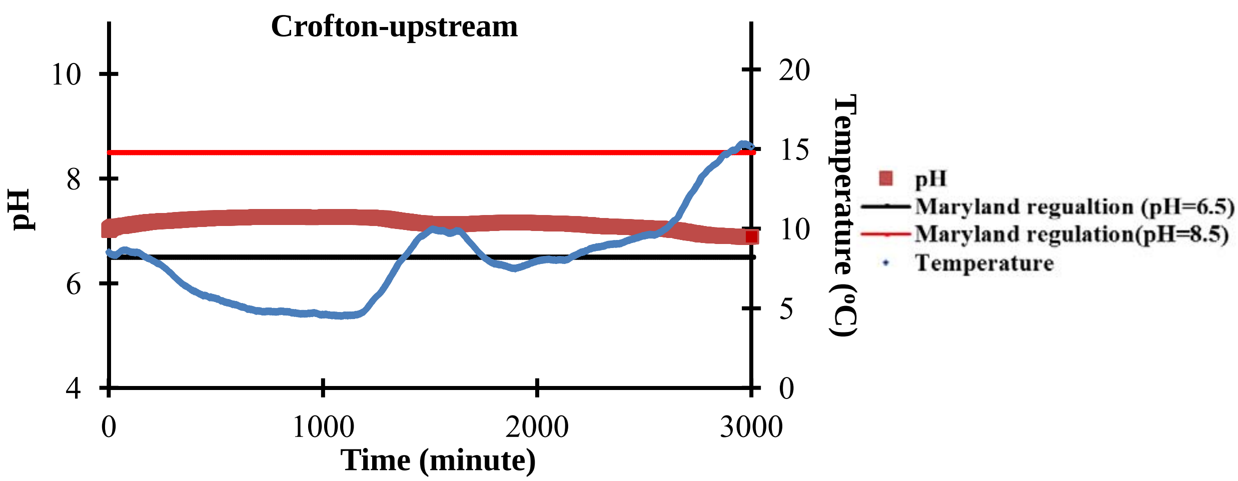
The monitoring probes at Crofton were operated on November 12, 2011. The stream velocity was 0.17 m/sec. The average, minimum, and maximum data for pH and temperature collected from the second culvert are listed in Table 5.4. The data loggers were placed upstream (inlet) and 0 meters (outlet of the culvert), 10 meters, 20 meters, and 40 meters from the end of culvert. The water temperature was recorded as high as 17.7$^{o}$C and as low as 4.5$^{o}$C. The highest pH, 12.5, came from the probe located at 0 meters (outlet of culvert), and lowest reading of pH 6.5 came from the probe at 20 meters. The logger data for Crofton includes the pH and temperature data and is compared to the Maryland pH regulation (pH=8.5) in Figure 5.4.

The Crofton site used grout bags at the culvert outlet area to prevent erosion. The stream bottom is approximately 1 meter below the culvert outlet (Figure 5.4); therefore, the grout bags produced a high concentration of grout leachate for the curing process. The water was pumped to the sediment bag to remove sediment and grout leachate. Data logger 2 was placed between the grout bags and water; however, no water was pumped out during the curing process. The pump connected to the sediment bag was stopped after the grout was poured. Before data logger 1 was moved, it was located where there was a ponded area of grout leachate; therefore, the pH had not dropped under pH 12. After data logger 1 was moved to a location where water was flowing near the original location, pH quickly dropped below 8.5 in 12 minutes. Data logger 3 was also located inside the water flow barrier (within work area), which is why the data logger 3 pH value reached 9.9. After water flow started, pH dropped below 8.5 in 318 minutes.

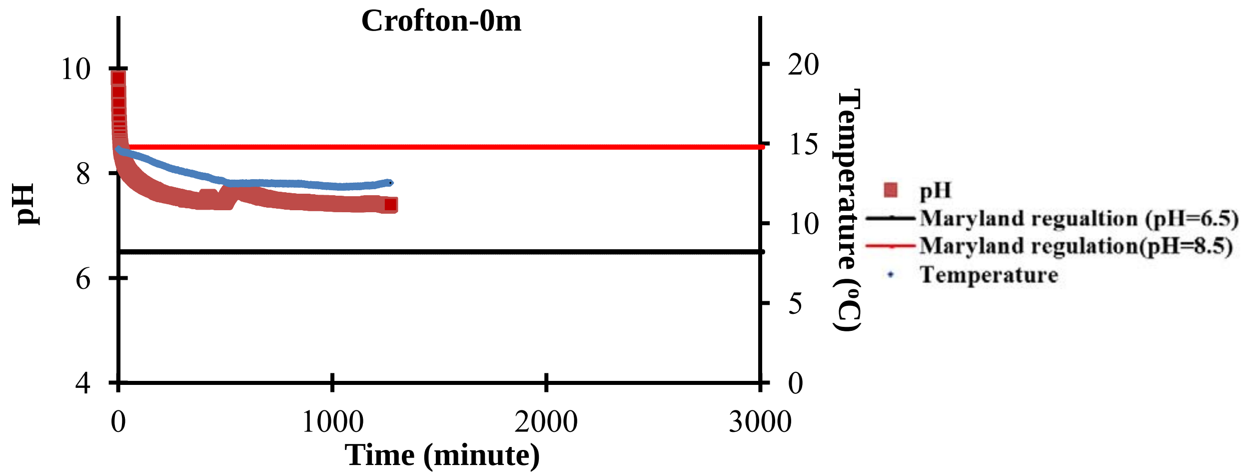
**Table 5.4: pH and temperature of Crofton, MD**

| | | upstream | | 0 meters | | 10 meters | | 20 meters | | 40 meters | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp ($^{o}$C) | pH | Temp ($^{o}$C) | pH | Temp ($^{o}$C) | pH | Temp ($^{o}$C) | pH | Temp ($^{o}$C) | pH |
| Crofton, MD | Average | 10.37 | 7.12 | 15.59 | 11.17 | 12.25 | 7.97 | 11.17 | 7.19 | 11.07 | 7.10 |
| | Minimum | 4.51 | 6.89 | 12.17 | 7.38 | 8.17 | 6.47 | 6.15 | 6.81 | 6.23 | 6.88 |
| | Maximum | 15.33 | 7.86 | 17.71 | 12.45 | 15.26 | 9.87 | 15.22 | 7.76 | 14.95 | 7.28 |

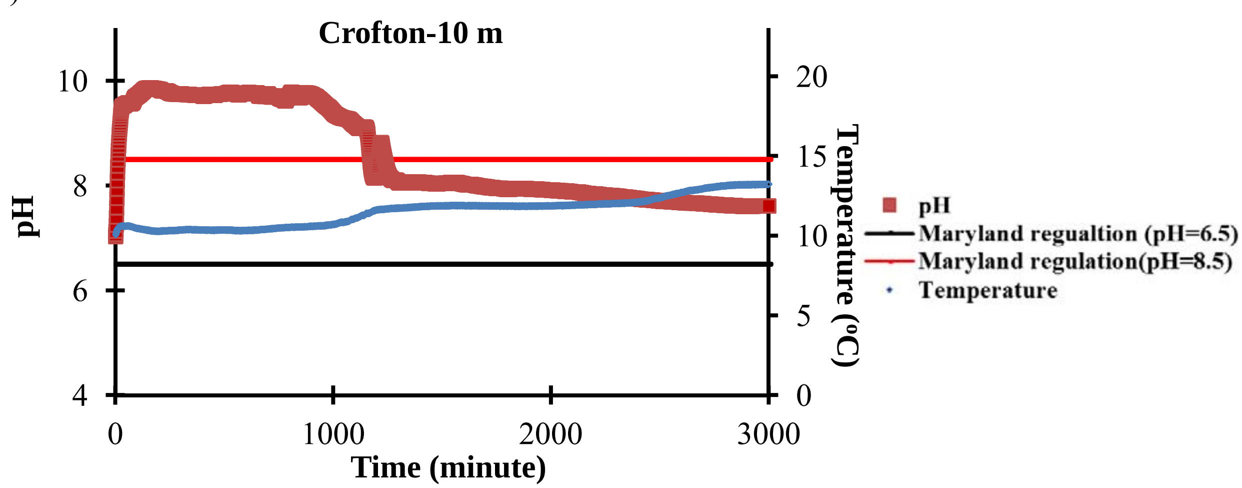
a)



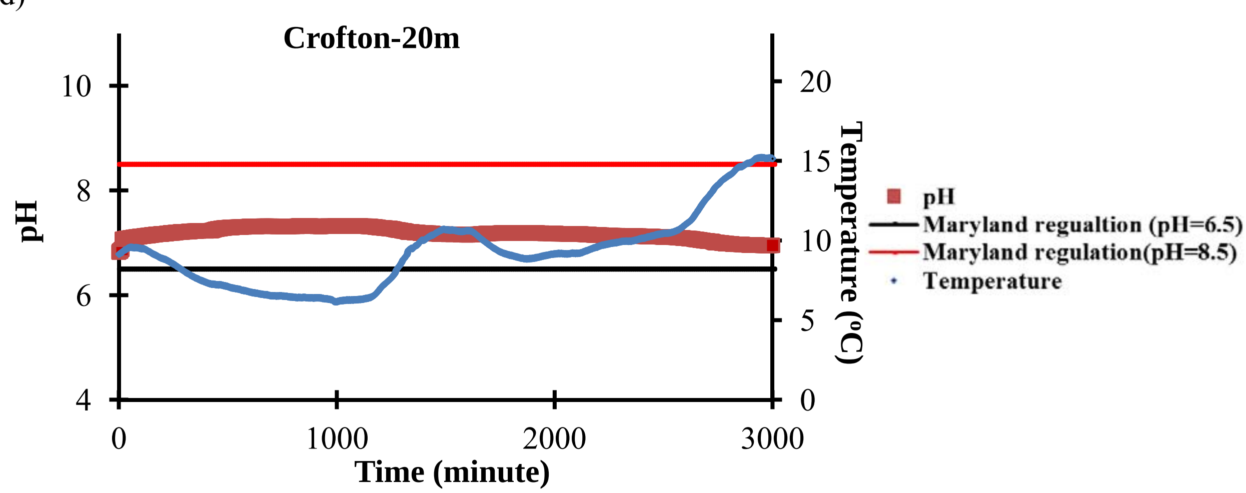
b)


Crofton-0m
pH
Temperature (ºC)
Time (minute)
pH
Maryland regualtion (pH=6.5)
Maryland regulation(pH=8.5)
Temperature

c)


Crofton-10 m
pH
Temperature (ºC)
Time (minute)
pH
Maryland regualtion (pH=6.5)
Maryland regulation(pH=8.5)
Temperature

d)


Crofton-20m
pH
Temperature (ºC)
Time (minute)
pH
Maryland regualtion (pH=6.5)
Maryland regulation(pH=8.5)
Temperature

e)

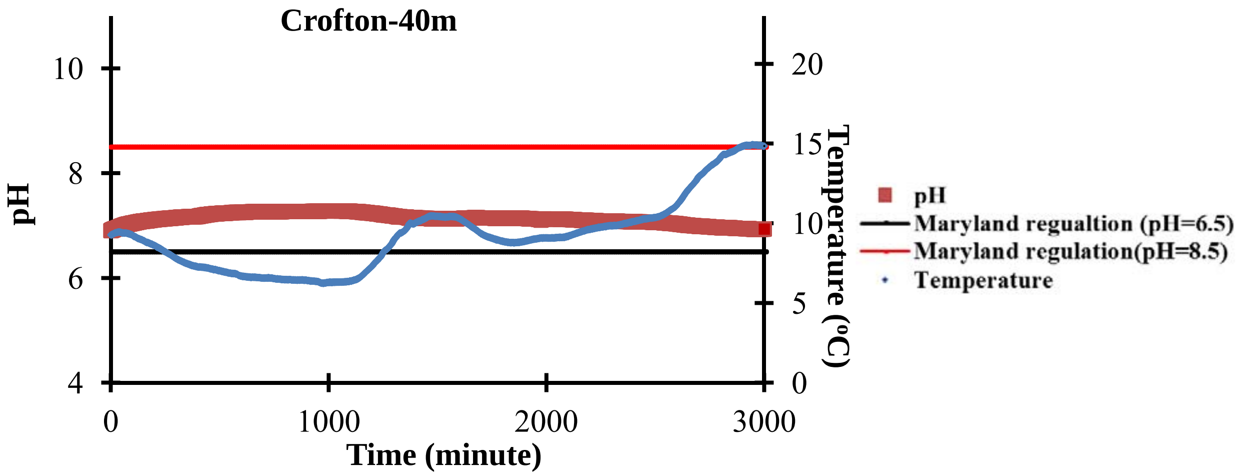



**Figure 5.4: Monitoring of Crofton, MD culvert for pH and temperature upstream and at locations downstream**

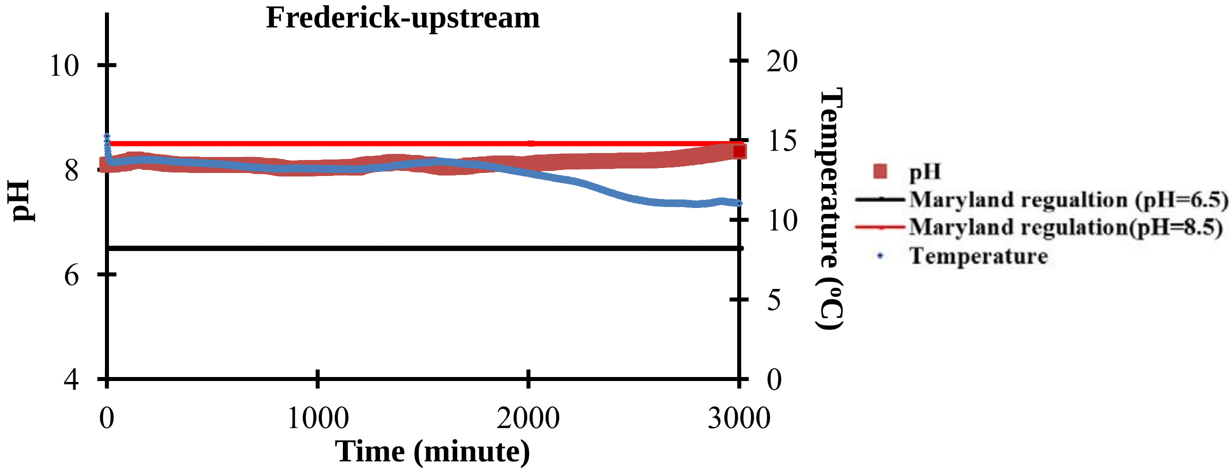
The monitoring probes at Frederick were operated on November 15, 2011. The stream velocity was 0.20 m/sec. The average, minimum, and maximum data for pH and temperature collected from the second culvert were listed in Table 5.5. The data loggers were placed upstream (inlet) and 0 meters (outlet of culvert), 10 meters, 30 meters, and 50 meters from the end of culvert. Water temperature was recorded as high as 15.3°C and as low as 7.2°C. The high pH was 8.4 from the probe located at 0 meters (outlet of culvert) and pH 7.9 was at the probe located at 10 m. The grout was placed by shortcrete at the Frederick site. The pH spikes depicted in the graph 5.5b where the pH rapidly spiked 8.9 is when the neighboring property owner disturbed the probe. When water was allowed to flow over the paved invert, the pH rapidly spiked to 9.7 for 41 minutes at pH logger 2 (0 meters) and to 9.4 for 11 minutes at pH logger 3 (10 meters). The flow rate was estimated as 13.7 liter/sec, higher than other sites. The stream velocity was also higher (1.6 m/s) due to a rainfall event.

At the Frederick field site, the duration of the pH spike over 8.5 was less than those at other two field sites (Owings Mills and Crofton, MD). The detected pH value from data loggers 4 and 5 was not over 8.5. The data loggers placed in the work area; Owings Mills 1(0m), Owings Mills (0 and 0.1m), Crofton (0 and 10m), and Fredrick (0m), shown higher pH values than Maryland regulation pH=8.5. However, the high pH water, by flowing downstream, will go through carbonate/bicarbonate buffering and contact materials such as soil, rock, grass, and organic matter. These reactions reduce and stabilize the pH. Therefore, pH monitored downstream and outside the work area did not exceed pH of 8.5.

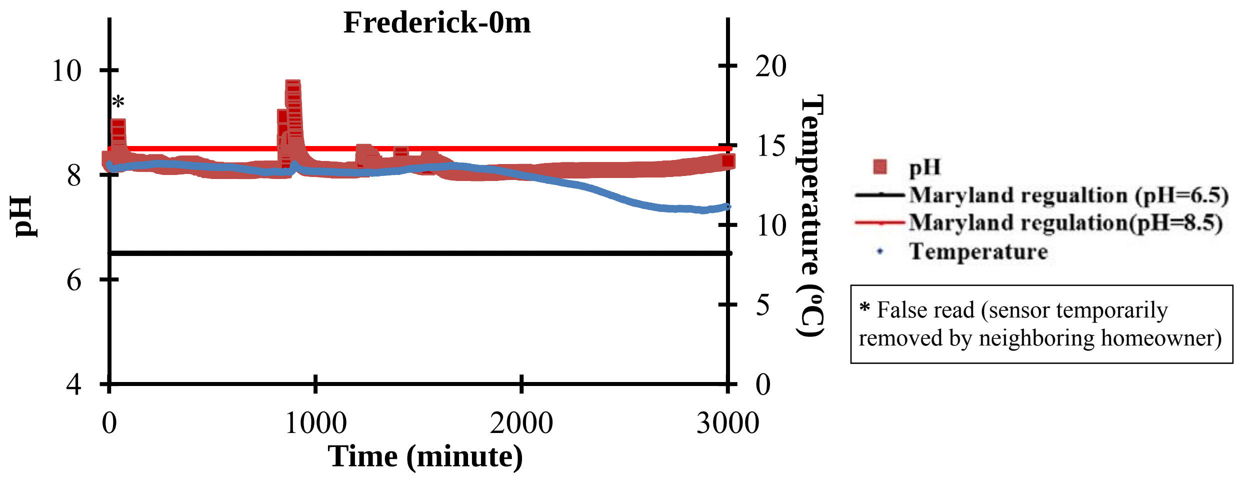
**Table 5.5: pH and temperature of Frederick, MD**

| | | upstream | | 0 m | | 10 m | | 30 m | | 50 m | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH | Temp (°C) | pH |
| Frederick, MD | Average | 11.72 | 8.17 | 10.96 | 8.15 | 10.88 | 8.05 | 13.72 | 8.05 | 13.68 | 8.14 |
| | Minimum | 7.15 | 8.03 | 6.97 | 8.03 | 6.92 | 7.92 | 13.56 | 7.96 | 13.52 | 8.04 |
| | Maximum | 15.26 | 8.35 | 13.73 | 9.67 | 13.64 | 9.4 | 14.98 | 8.08 | 14.98 | 8.16 |

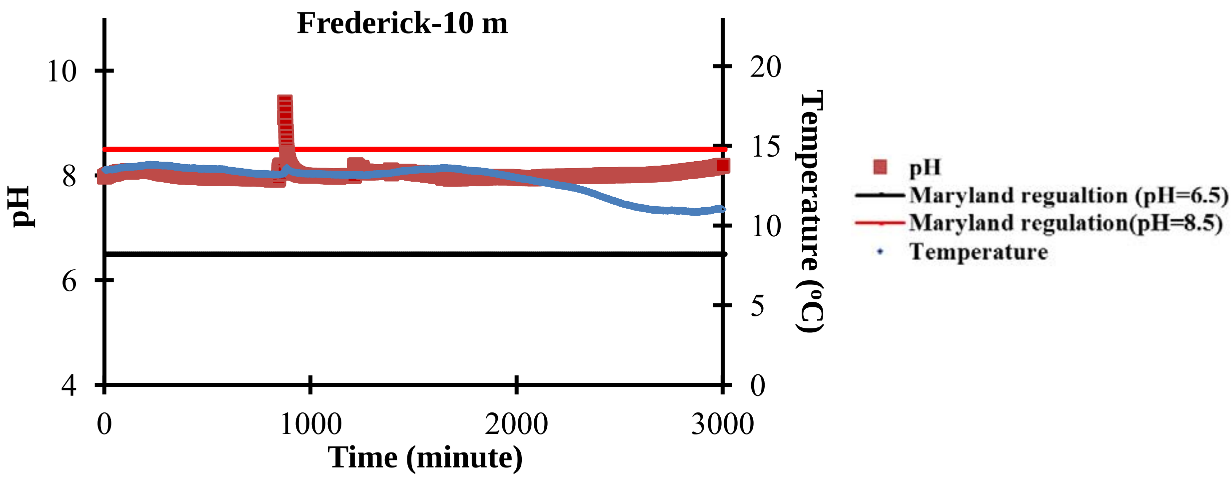
a)


Frederick-upstream
10
8
6
4
pH
20
15
10
5
0
Temperature (°C)
0
1000
2000
3000
Time (minute)
pH
Maryland regualtion (pH=6.5)
Maryland regulation(pH=8.5)
Temperature

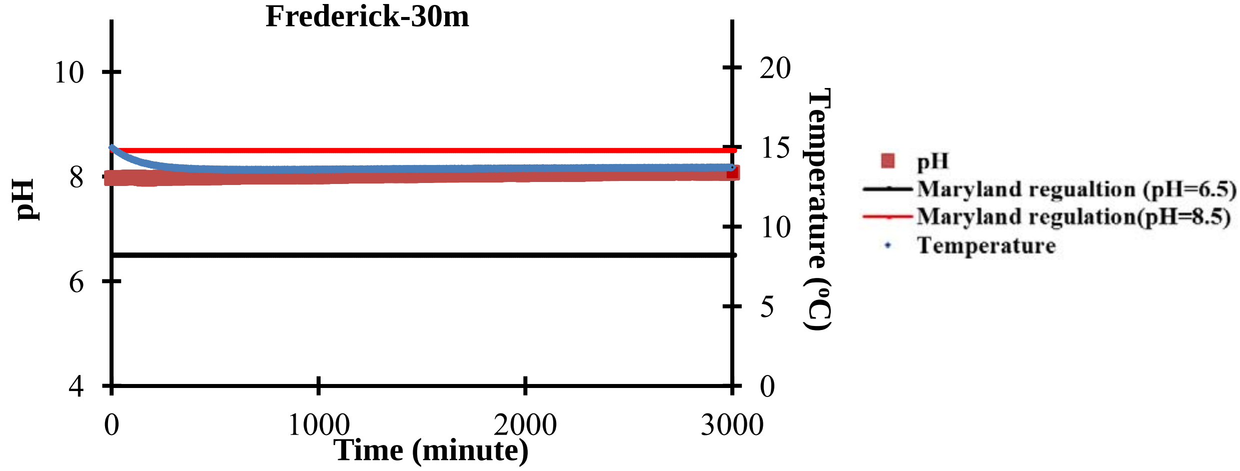
b)


Frederick-0m
*
10
8
6
4
pH
20
15
10
5
0
Temperature (°C)
0
1000
2000
3000
Time (minute)
pH
Maryland regualtion (pH=6.5)
Maryland regulation(pH=8.5)
Temperature
* False read (sensor temporarily removed by neighboring homeowner)

c)


Frederick-10 m
10
8
6
4
pH
20
15
10
5
0
Temperature (°C)
0
1000
2000
3000
Time (minute)
pH
Maryland regualtion (pH=6.5)
Maryland regulation(pH=8.5)
Temperature

d)




e)

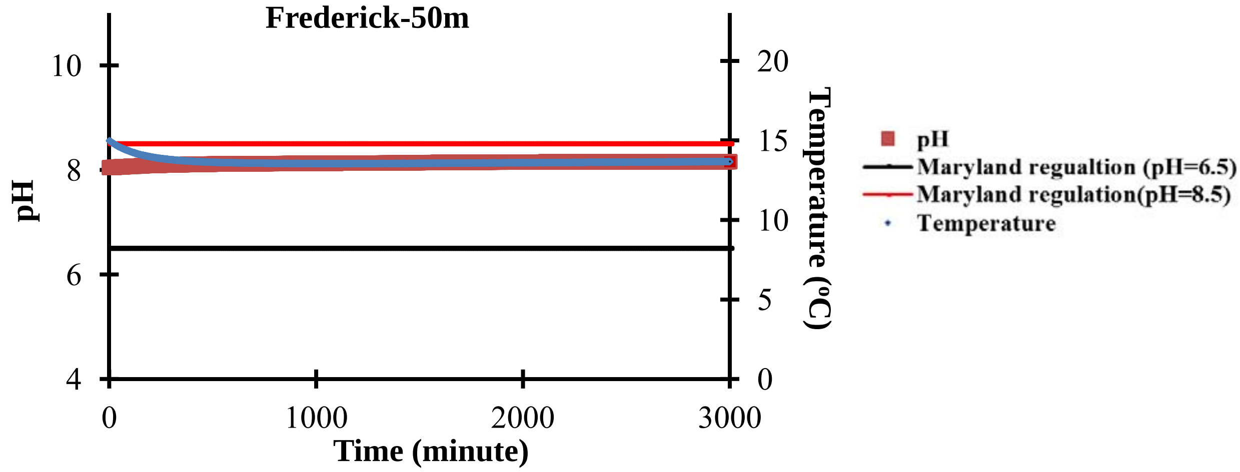



**Figure 5.5: Monitoring of Frederick, MD culvert for pH and temperature upstream and at locations downstream**

## 5.2 Field result for remedial action trials

Two field sites were used to test two remedial options. The first site (Figure 5.6) was a single paved culvert in Savage, MD, (Structure 13131X0) and the site utilized a straw-only remedial application. The second site (Structure 03078X0), in Catonsville, MD, had two paved culverts and utilized a well-constructed catchment area which was fed for 3 hours as a sediment bag was underlain by peat and straw layers. The results may indicate that the pH realized was due more to the workmanship of the contractors than to the execution of the remedial action.

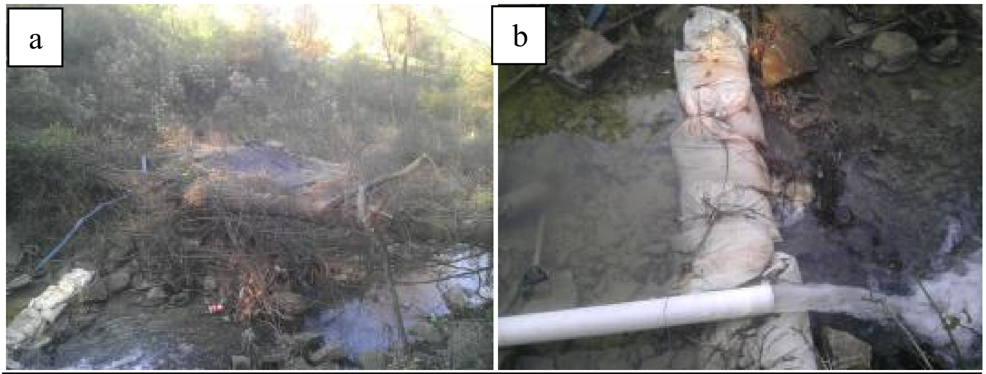
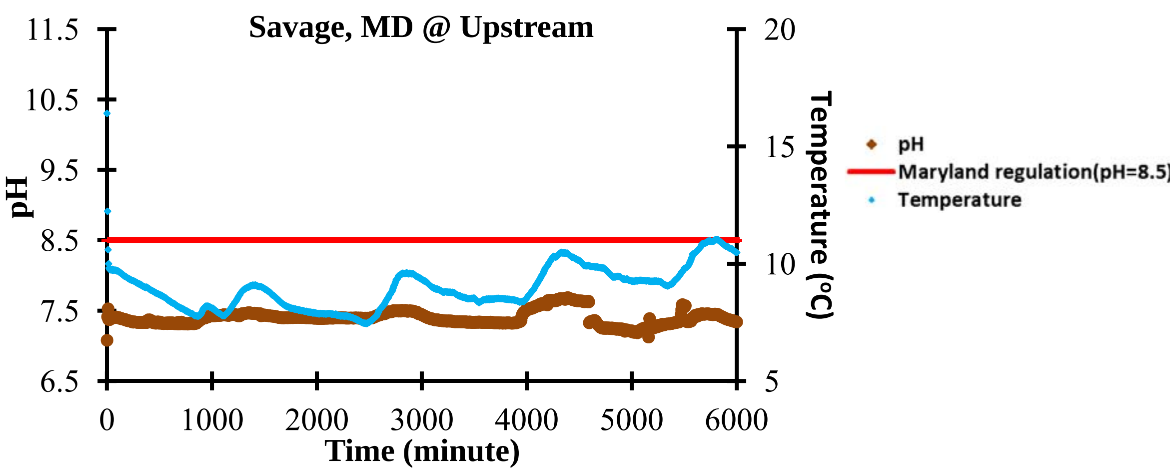
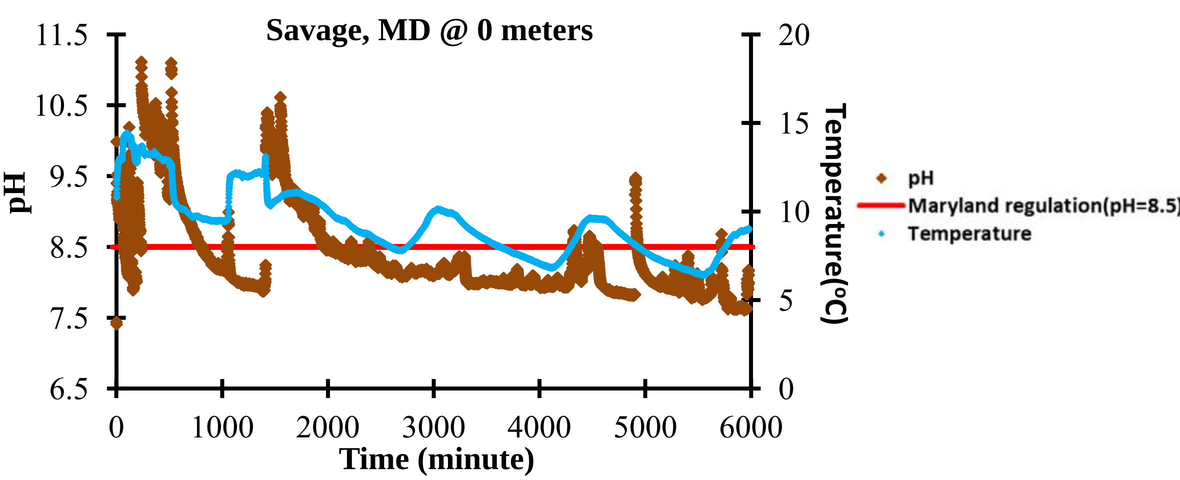



**Figure 5.6: Field site in Savage, MD adjacent to I-95, (a) sediment bag underlain by straw, (b) pump ceased to work and water overflowed sandbag dike into stream.**

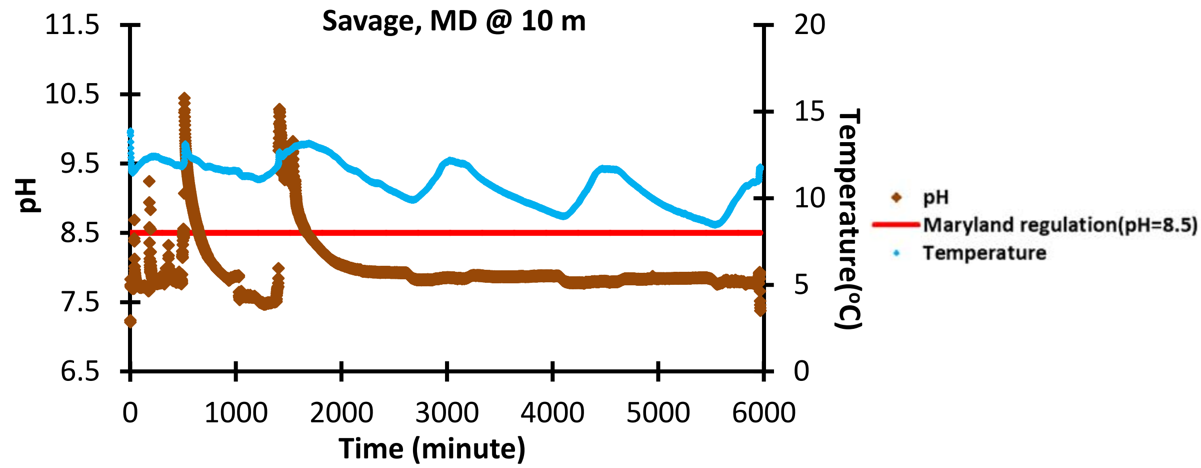
a)




b)



c)




d)

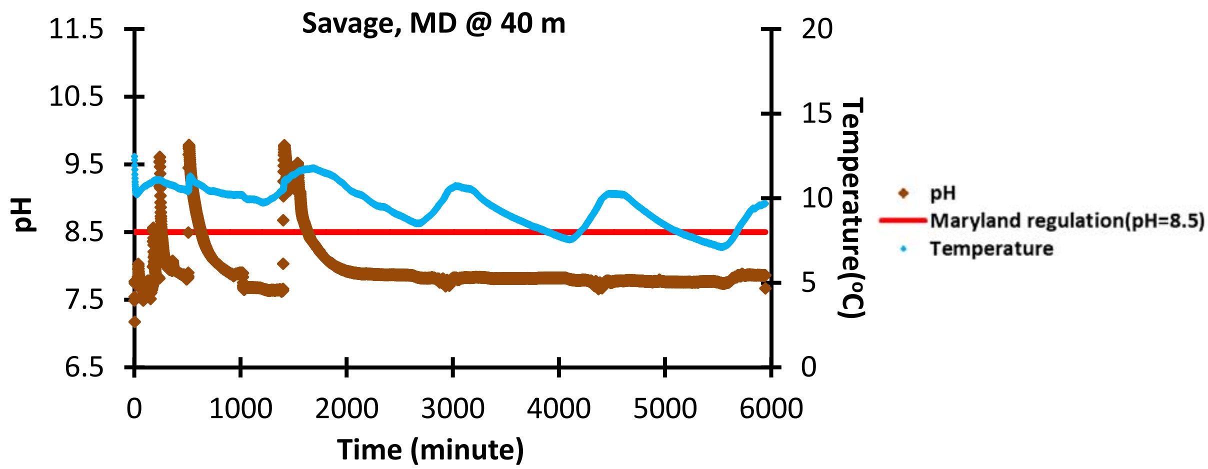



**Figure 5.7: pH and temperature monitoring of the culvert in Savage, MD.**

The Savage site did have pH spikes over 8.5 (Figure 5.7) during the paving activity and after the stream diversion was removed. These spikes were logged up to 40 meters from the effluent point of the culvert. The devised sandbag dike was likely set at an inadequate height at the effluent end may have resulted in the pH spikes. Also observed was that the pump at the effluent end feeding the sediment had stopped functioning. The remedial action in this case was not effective. The use of straw alone had been determined in the laboratory tests as the least effective measure for reducing high pH water.

The site in Catonsville provided what could be considered an ideal setup by the contractor and resulted in ideal field result. A well-conceived catchment area provided adequate containment of any waters at the effluent end of the double culverts (Figure 5.8). Once the stream diversion was removed, a minor spike in pH was logged downstream. The peat remedial option was used at this site; however, the use of peat (shown in Figure 5.9) required additional work, and the peat was not well contained once water from the sediment bag began to drain. Peat should be wetted and mixed prior to placement. Peat would be best kept in place contained in burlap bags or unbagged surrounded by a run of straw bales. The results (Figure 5.10 and 5.11) indicated no pH spike of significant duration downstream.

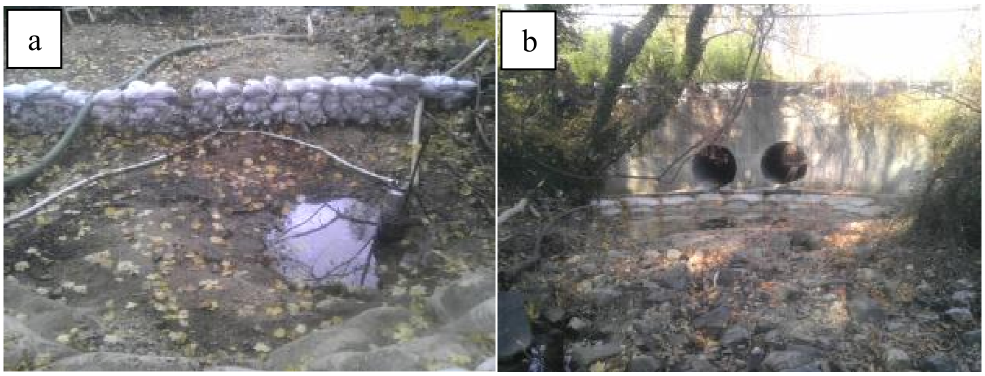



**Figure 5.8: Scene at Catonsville, MD, culvert site on Rt. 144**


**Figure 5.9: Remedial attempt at the culvert site in Catonsville, MD.**

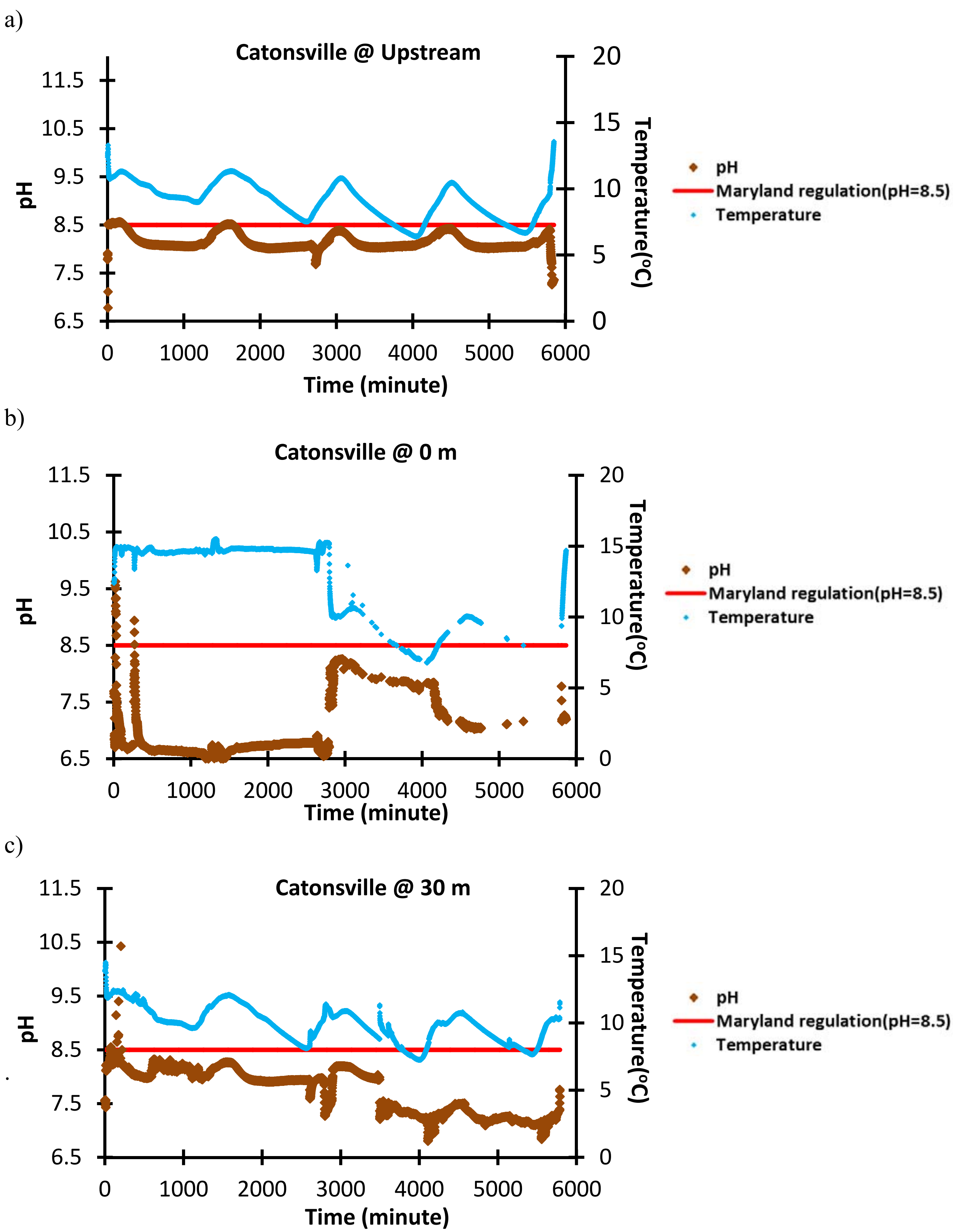
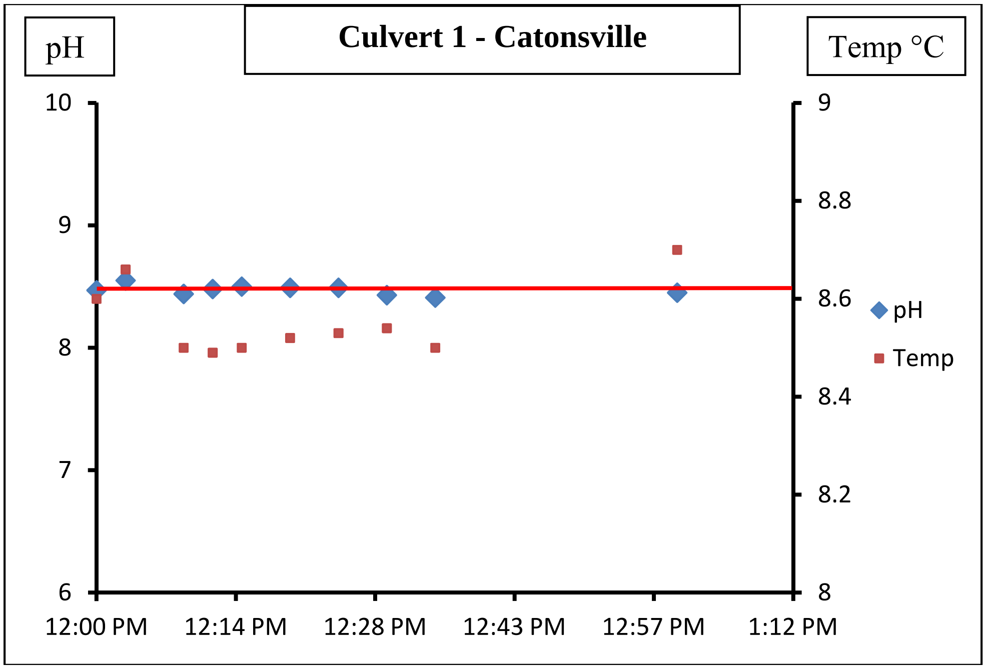



**Figure 5.10: pH and temperature monitoring of culvert in Catonsville, MD**



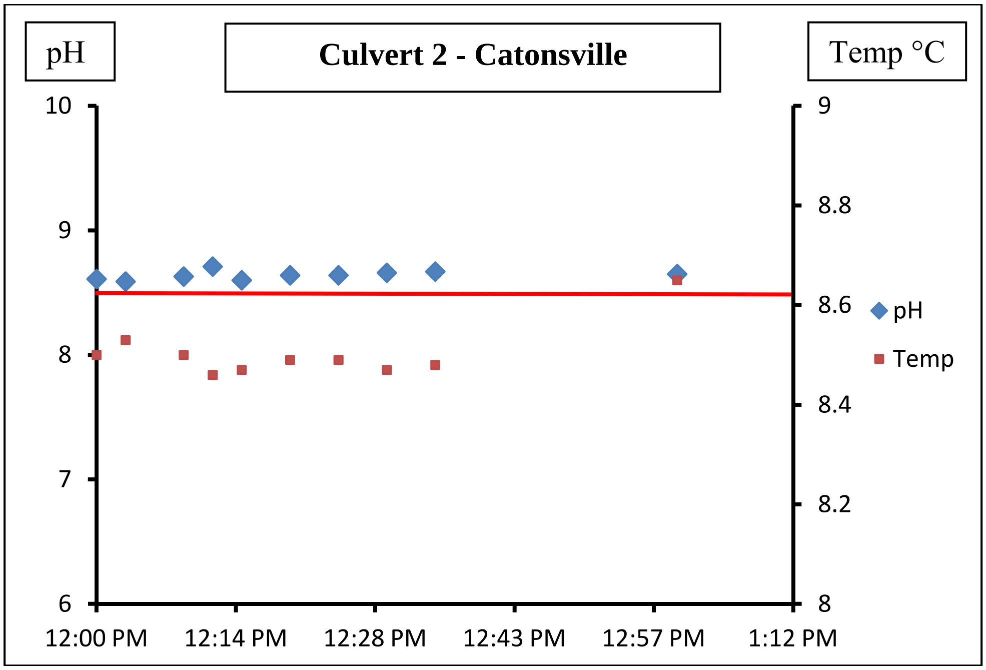




**Figure 5.11: pH measurements for Catonsville culverts 1 & 2 at immediate effluent points taken after water was released over the invert surface**

# 6 CONCLUSIONS

The in-stream maintenance of culverts using grout paving is a standard practice commonly used by SHA. This practice is applied when normal base flows can be pumped and handled practically via a pipe or other devised conduit. It is intended for situations where the temporary stream diversion is needed during the late-spring/summer/fall months of low stream flow. This is a time when construction can be minimized and the site can be stabilized before winter. These projects vary based on size, length, number of culverts maintained, and initial conditions of the stream (base flow and pH), and initial pH of the stream. Due to the varying characteristics of stream and contractor workmanship observed, engineering judgment must be used in evaluating the necessary site controls and remedial actions.

This research effort endeavored to establish approaches that will help improve the decisions made in the field, with the goals of enhancing the quality of work and environmental performance seen with this practice. Of particular concern is limiting instances when "unfiltered" (or untreated) discharge from the culvert area reaches surface water downstream, impacting the stream's pH with possible rise above the regulatory limit of 8.5. The sediment and high pH water must first be treated via sediment bag. In most cases, the pH of the water downstream will be below 8.5 if attention is paid to the following areas: handling of the "first-flush"; allowance for passive treatment; and contractor workmanship.

**<u>Properly handle the "first-flush"</u>**

Dewatering the culvert work area occurs in two distinct phases: the removal of the collected water within the excavation; and the treatment of collected water. The removal of water from the excavated area can be accomplished by various methods. The most common one is mechanical pumping.

Towards the end of construction, when the grout paving has cured, the "first-flush" of water allowed to flow over the paved culvert invert should be prevented from immediately entering downstream. The full or partial removal of the upstream dike will result in the release of stream water to "wash" over the invert surface. This water should be collected behind a well-constructed sandbag dike at a short distance beyond the outlet end of the culvert, and continuously pumped into the sediment bag. The duration of this treatment can be determined based on site conditions and culvert length (see Page 34).

It is important that the contractor have adequate flow and sediment controls to prevent environmental degradation of a stream during construction. The contractor should provide for proper inspection and monitoring of site conditions throughout the project period to ensure that protective measures are properly implemented and maintained. This "impacted" water should be collected behind an impervious sandbag dike and pumped to a sediment bag underlain by organic materials, with adequate distance from the stream.

**<u>Allowance for Passive Treatment</u>**

**Passive Treatment -** The discharge from the bag will pass through various media (straw, peat moss) and grass/vegetative buffer to neutralize the pH of dewatered effluent and the "first-flush."

The contractor should confirm the ability to dewater the work area and transfer the collected water to a predetermined location where it will eventually percolate to the groundwater or re-enter downstream. Sediment laden and high pH water from the in-stream work area must be filtered before the water is allowed to re-enter downstream. The remedial measure with the sediment bag setup used should be located such that the water drains back into the stream below the downstream sandbag dike.

For optimal treatment of “first-flush”, it is recommended that the water collected from the effluent side of the culvert be pumped to a filter bag underlain by a combination of straw and wetted peat. Based on the field results, this “pump and treat” practice should last for a few hours depending on the culvert length or until it has been determined that the pH has stabilized under 8.5. Ideally, this effluent is converted to sheet flow to travel through the grass buffer between the filter bag and the stream prior to re-entry downstream. Additional run of straw bales can be used to trap or contain unbagged peat (if used) and also provide cover for poorly grassed areas.

A minimum 30-foot grass buffer should be maintained adjacent to the stream from the filter bag (with peat). Preferably, the maximum extent practical should be utilized for the placement and location of the filter bag and filter materials. For placement within steeper slopes or where a straw base is used alone to filter pumped water, additional length from the stream should be available in order for such methods to be feasible. Regardless, the runoff from the filter bag must not cause a water quality violation where water re-enters the stream. Concentrated flow from the filter bag should be avoided, as this can cause erosion.

**Contractor Workmanship**

The goal of SHA and its contractors is to achieve the timely construction and maintenance of the culvert, with no detrimental water quality impacts. The quality management of these paved culvert projects succeeds through the partnership between a contractor and SHA. The contractor is responsible for the daily quality control (QC) of the construction work. While SHA, through quality assurance (QA), ensures the contractor's QC is effective. The research effort indicates that close examination of the contractors’ workmanship and practices is necessary. Particular attention to use of grout bags on the downstream side, where ponding and extended contact of the water with grout should be avoided. The functioning of pumps, placement of filter bags, integrity of materials, and construction of sandbag dikes also needs attention. This will help minimize any unintended impacts to receiving waters.

QC measures should be implemented to ensure that the remedial and construction procedures are performed in compliance with the specifications and recommendation made in this report.

**Inspection and maintenance:** This practice may require ongoing maintenance during the construction period and work should proceed in a cautious manner. Sandbag dikes, used particularly at the effluent end of the culvert, should be monitored to ensure that any collected water is not entering the stream. Caution and additional controls should be used when stream flow increases subsequent to rainfall events. Periodic inspection must also be performed to ensure that the sediment bag is maintained and not damaged. Maintenance shall be performed immediately, as needed, to ensure that the practices related to this construction activity complies with the standards and specifications.

To ensure that all construction and remedial activities comply with the project specifications, site inspections for future work should include the following:

- Inspecting the project throughout to ensure the desired quality of the diversion structure and practices. Follow-up inspections performed daily as work progresses to ensure continuing compliance with contract requirements. Physical examination of materials and equipment may be needed to assure that they conform to approved contract requirements.

- Workmanship that does not meet the specified level of quality should be properly documented, including the nature of any non-conformance. Construction deficiencies should be tracked to ensure timely corrective action.

- Examine the work area to ascertain any damage or leaks to the sandbag dikes and filter bags. Repair any damage or replace as needed.

- Inspect bypass pump and temporary piping daily to ensure proper operation, ensuring flow is adequately diverted through pipe.

- If grouted surface is washed, use only a pressure low flow spray and sweeping the surface with water can aid the wash. The "wash" water must be fully collected behind a sandbag dike and pumped appropriately to the properly placed sediment bag.

- Provisions should be adequate ensure that surface water within the construction area does not have prolong contact with paved grout surfaces or materials and that this water does not enter the downstream source.

- The culvert effluent pump and remedial setup (filter bag and media) should remain in use until it has been determined that the pH of the water over the paved culvert has stabilized. The inspecting authority approves the removal.

- **Storm Events:** If a major storm is predicted, measures should be taken to minimize any overflow and downstream impacts.

- Based on field conditions or suspicion of inadequate controls by the contractor, determine if verification monitoring of pH is needed to assess to water quality during the construction period.

In summary, based on the field and laboratory work, the following points can be made:

- The resulting spikes in pH were dependent upon site conditions: initial pH value of the stream, contractor's establishment of continuous flow, flow volume, and contact time or ponding with any grout materials.

- When water flows over the paved grout surface, its pH value will rise until the free lime content of the paved surface dissolves and decreases over time. This reaction occurs the strongest in the first few hours.

- If pH spikes were seen in the field they were short in duration (minutes up to hours) when flow was re-established over the paved culvert invert. The high pH water passes within the streambed contacts soil, rocks, grass, and other organic matter. These reactions, considered having a buffering effect, will reduce and stabilize pH within a short distance. Therefore, pH data collected from outside work area typically does not exceed pH of 8.5 downstream.

- The coupled dissolution reaction occurs when considering atmospheric carbon dioxide. The carbon dioxide in the air readily dissolves in the water and provides a buffering effect. This buffering may not be enough to reduce the pH below 8.5 in locations closest to the effluent point of the culvert. However, time and distance will allow for additional carbon dioxide dissolution into the water and reduce the pH downstream.

- Longer held pH spikes in the field can occur with prolonged contact of water with the paved invert. This extended contact time can be due to culvert length, slow flow, and ponding where grout bags are utilized. Grout bags were used at the Crofton site resulting in ponding and a pH spike downstream measured for 19 hours. Monitoring at the Savage field site showed that the pH of downstream water did not stabilize below 8.5 until almost 28 hours after monitoring began.

- Higher stream flow may result in the shorter duration of pH spikes as observed in the field and laboratory results.

- The remedial application using peat as a buffering agent can be applied when the peat is wetted and mixed at a 3:1 ratio (peat to water by volume), placed in large burlap bags, and set to a minimum depth of four inches (Figure 4.1). Figure 3.32 shows that uncontained peat was difficult to handle and mix. The addition of water at a high rate will also move the peat from its resting position. This may be a concern if the peat is placed too close to the stream or resting on steep slopes.

**Discretionary Interventions**

The following actions were proven in the laboratory to reduce the pH spike. These actions were not tested in the field, but can be readily tested by SHA and applied during construction activity for further consideration.

- **Washing the invert surface** – Used in combination with the dewatering of collected water to the sediment bag, the contractor could wash the paved invert surface with a power washer set at "low pressure" and/or brush (sweep) the invert surface with water (perhaps partial inflow from the stream) to agitate and remove the dissolvable alkali. This water would be collected with the "first-flush" and would pass through a sediment bag, underlain with straw and peat, placed at adequate distance from the stream.

- **Use of antiwashout admixture –** It was determined during laboratory trials that out of the admixtures tested, V-MAR showed the greatest propensity to reduce the duration and magnitude of pH spike. This antiwashout concrete admixture lessens the pH spike which would translate to reduced time in the field to treat any high pH water. Additional verification would be needed to ascertain the proper mix design and performance characteristics associated with using V-MAR for grout paving projects.

- **$CO_2$ sparge** – This method uses $CO_2$ to sparge gas into the collected water to neutralize the pH, either within the diversion combined with a big wash or in the dirt bag combined with the first flush techniques. The $CO_2$ is dispersed in the high pH water through an air stone – a weighted object with multiple holes so that the $CO_2$ comes bubbling out of multiple locations. This may be the most challenging method to implement as it requires a $CO_2$ canister(s), air stones, as well as a pH meter to monitor the water pH. The bubbling $CO_2$ remains in place until the water is within regulatory limits. This method would be relatively inexpensive, with a low likelihood of overdosing if properly controlled and monitored with continuous flow.

Based on the research, the following recommendations are made:

- If possible, it is recommended that pH be minimally monitored from the influent and effluent sides of the culvert during the construction period. The interpolation can be used if flow rate is obtained along with the dimensions of the culvert. The monitoring ensures that the water quality regulation is being met. Time can be saved by the contractor if the pH has proven to be stabilized and falls within 6.5-8.5.

- At the effluent side, a catchment area devised by sandbags (at adequate height) should be used to capture the "first flush" from the culvert effluent side. This flush should then be pumped to the sediment bag which can be underlain with peat and straw at sufficient distance from the stream.

- Following grout placement and cure, any loose pieces of dried grout or dust should be removed from within the culvert. Washing the surface with water and treating this wash water with the "first flush" over the paved invert can reduce the time of an anticipated pH spike.

- The water should be pumped from the culvert effluent area into the sediment bag on a bed of wetted peat contained in burlap bags at a minimum depth of 4 inches peat should be wetted and mixed in a 3:1 ratio (peat to water by volume). This setup should be placed, at a minimum 30 feet from the stream.

- If grout bags are used to secure the inlet or effluent ends of the culvert, it should be constructed in such a way to ensure water is not allowed to pond on these materials. The extended contact time could result in a possible high pH reading.

- Contractor accountability and adherence to these specifications are necessary to ensure that the pH standard is met. The workmanship of individuals can impact the water quality, and onsite personnel should be mindful of potential liability. Examples of deficiencies seen in the field can be found in Appendix C.

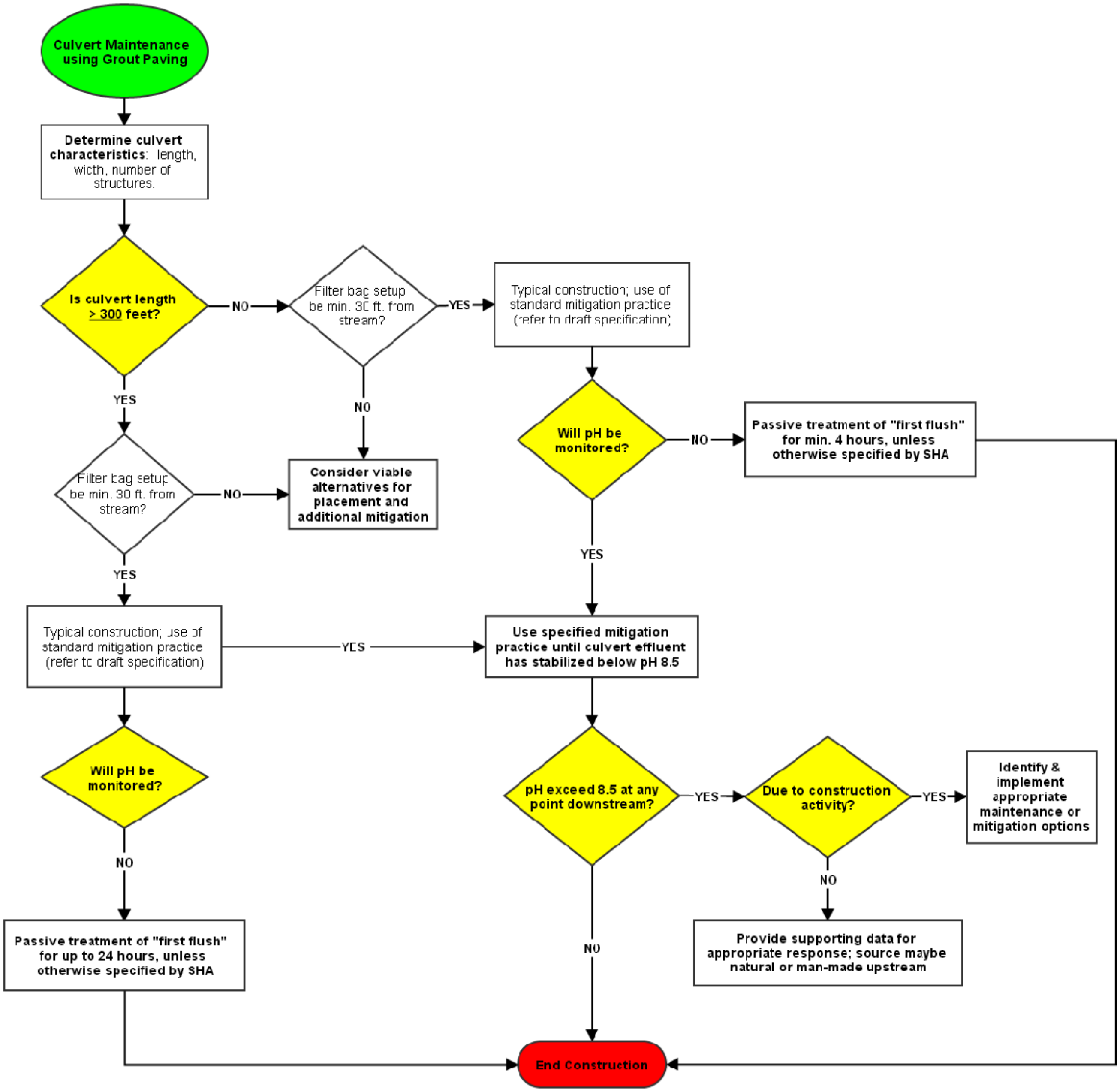



**Figure 6.1: Decision tree for mitigation action during in-stream culvert construction using grout paving.**

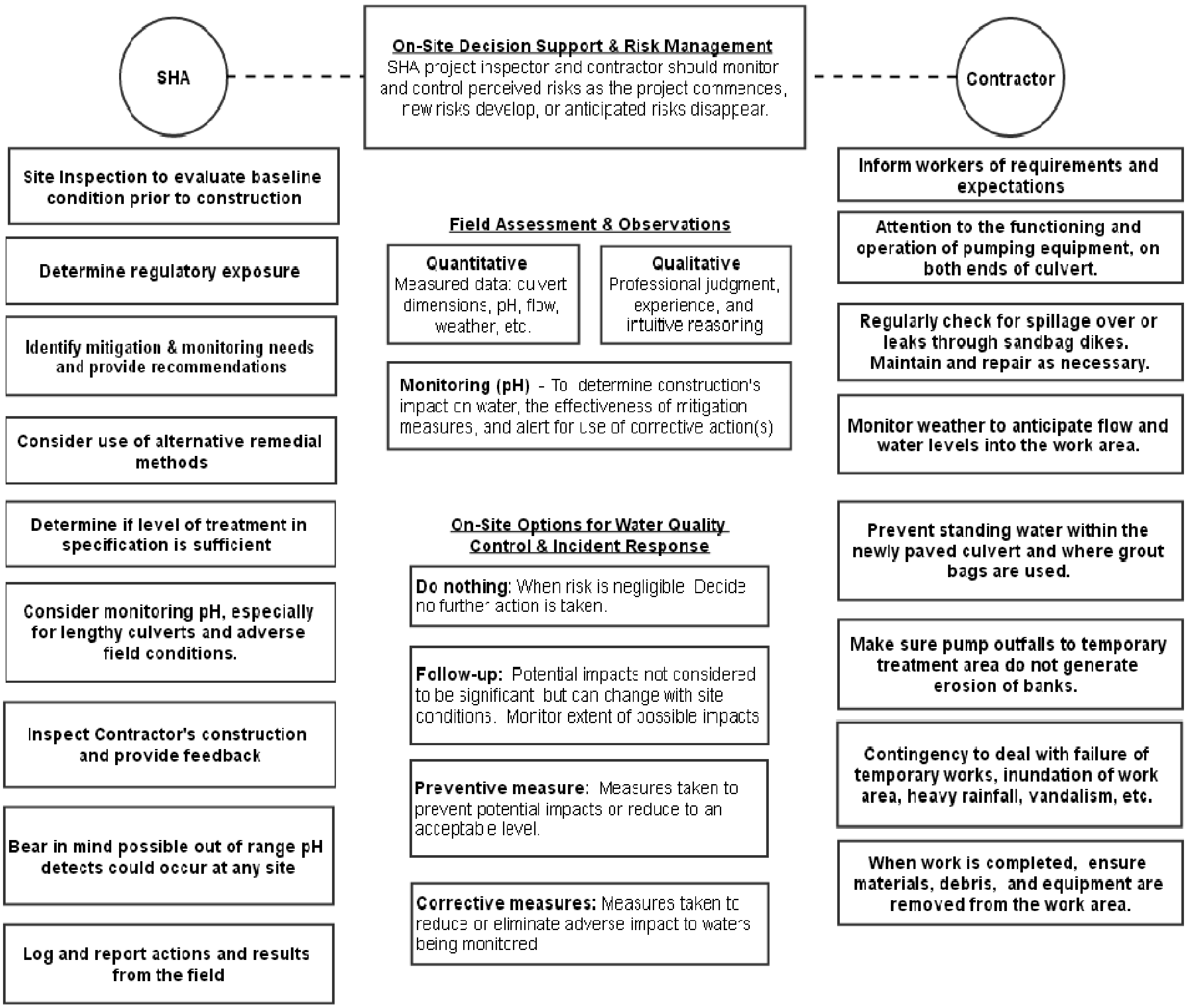



**Figure 12.2: On-site Decision Support & Risk Management.** Chart depicts agency and contractor responsibilities and provides general guidance for on-site decision making.

# REFERENCES


AWWARF and DVGW-TZW.1996. Internal Corrosion of Water Distribution Systems. AWWARF: Denver, CO.

Addy, K., Green, L., and Herron, E. (2004). pH and Alkalinity. URI WATERSHED WATCH, Cooperative Extension. URIWW-3, July 2004

Banks, M.K., A.P. Schwab, J.E. Alleman, J.G. Hunter, and J.C. Hickey**.** (2006). "Constructed Wetlands for the Remediation of Blast Furnace Slag Leachates**"**. U.S. Department of Transportation / Federal Highway Administration FHWA/IN/JTRP-2006/3, 2006.

Boyer, B.W. (1994). Alkaline leachate and calcareous tufa originating from slag in a highway embankment near Baltimore, Maryland. *Transportation Research Record* 1434, 3-7.

Cassidy, M. (2003). "Waterwatch Tasmania Reference Manual: A guide for community water quality monitoring groups in Tasmania". Waterwatch Australia

Culvert Repair Practices Manual Volumes 1 and 2, Report Nos. FHWA-RD-94-096/FHWA-RD-95-089, U.S. DOT, FHWA, May 1995

Elkanzi, E.M. (2006). "Using Carbon Dioxide for Alkaline Wastewater Treatment". First Regional Symposium on Carbon Management: Carbon Management Challenges and Opportunities for the Petroleum Industry. Dhahran, Saudi Arabia. May 22-24, 2006.

Fitch, G.M. (2003).Virginia Transportation Research Council "Final Report: Minimizing the Impact on Water Quality of Placing Grout Underwater to Repair Bridge Scour Damage". U.S. Department of Transportation / Federal Highway Administration, VTRC 03-R16, 2003.

Gupta, S.C., D.H. Kang, and A. Z. Ranaivoson. (2009). Hydraulic and mechanical properties of recycled materials. Local Road research Board, MnDOT 2009-32. http://www.lrrb.org/pdf/200932.pdf

Kashyap, A. (2008). Effects of water chemistry, temperature, gaseous cavitation & phosphate inhibitors on concrete corrosion

Lucas, Robert E, P E. Rieke, and Rouse S. Farnham. *Peats for Soil Improvement and Soil Mixes*. E. Lansing, Mich: Cooperative Extension Service, Michigan State University, (1965). Internet resource.

Maryland Department of the Environment, Water Management Administration. (2011). 2011 Maryland Standards and Specifications for Soil Erosion and Sediment Control.

Mehta, P.K., and Monteiro, J.M.P. 2006. *Concrete; Microstructure, Properties and Materials*, 3rd Edition. McGraw-Hill: New York.

National Lime Association. “Lime fact sheet: Properties of typical commercial lime products”. URL http://www.lime.org/documents/lime_basics/lime-physical-chemical.pdf [access 05.15.2013].

Norman, J. M., Houghtalen, R. J., and Johnston, W. J. (2005). Hydraulic Design of Highway Culverts. Hydraulic Design Series No. 5 (HDS-5), U.S. Federal Highway Administration, Publication No. FHWA-NHI-01-020.

Reiner, Mark (2008). Evaluation of Potential pH Environmental Hazards and Mitigation Measures When Utilizing Recycled Concrete Aggregate in the Field. Symbiotic Engineering. Boulder, Colorado. January 2008.

Thurston, R.V., R.C. Russo, and G.A. Vinogradov. (1981). Ammonia toxicity to fishes. The effect of pH on the toxicity of the un-ionized ammonia species. Environ. Sci. Technol. 15: 837-840.

UNEP and WHO. (1996). “Water Quality Monitoring - A Practical Guide to the Design and Implementation of Freshwater Quality Studies and Monitoring Programs”.

U.S. Environmental Protection Agency. (2009). Mass Transfer Rates of Constituents in Monolith or Compacted Granular Materials Using a Semi-Dynamic Tank Leaching Test, Draft Method 1315.

# APPENDIX A

# SPECIFICATION FOR FILTER BAG & PEAT BAG (DRAFT)

## SPECIFICATION FOR FILTER BAG & PEAT BAG (CULVERT MAINTENANCE)

Definition

A filter bag is geotextile bag through which sediment-laden and potentially high pH water is pumped. The peat bag layer is wetted sphagnum peat moss placed in burlap bags that aid in reducing high pH from culvert flush water.

Purpose

To filter sediment-laden waters and treat high pH water prior to downstream discharge

Conditions Where Practice Applies

When dewatering, the sediment bag and peat is needed in association with culvert maintenance and when waters come in contact with paved grout. This practice will be used in accordance with grout placement within culverts and meeting the pH regulation for waters of the state. This setup is to be used on the effluent side during the dewatering and eventual first-flush (up to first 24 hours) of the culvert.

Design Criteria

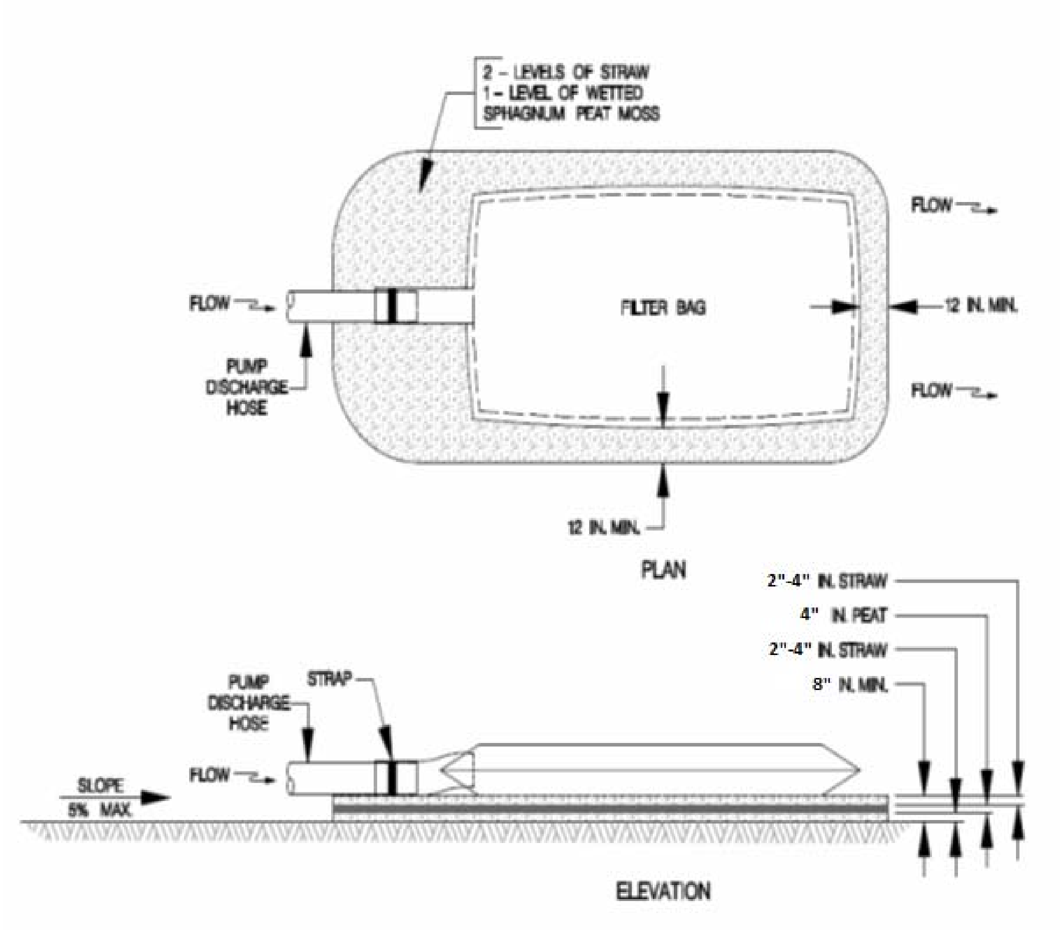
Dewatering of surface water from within the culvert work area by mechanical pumping, as needed, to perform the required construction in accordance with the specifications.

Filtration bags shall be attached to pump discharges and surrounded with a secondary containment or on a stabilized area. Filter bags shall not be placed, whole or partially, within aquatic areas (streams, wetlands, etc.). The filter bag should be placed in a location that allows for ease of disposal of waters and provides sufficient distance from water bodies (30 feet, if possible) to allow for adequate pH adjustment/buffering. Filter and peat bag setup is also intended to remove sediment and provide minimal interference with construction activities.

Sphagnum Peat Moss should be wetted mixed with water (3:1, Peat: water ratio) and placed within a burlap bags. Mixing of peat and water can be done in a large mixing trough, tub, or stock tank and manually mixed using shovels or by attempting to use a hand-held paddle mixer.

Maintenance

If the filter bag clogs, it needs to be replaced. Rips, tears, and punctures also necessitate replacement of the filter bag. The connection between the pump hose and filter bag needs to be kept watertight during operation. If the bedding becomes displaced, it must be replaced.




## CONSTRUCTION SPECIFICATIONS

1. TIGHTLY SEAL SLEEVE AROUND THE PUMP DISCHARGE HOSE WITH A STRAP OR SIMILAR DEVICE.
2. PLACE FILTER BAG ON SUITABLE BASE (E.G., PEAT AND STRAW BALES) LOCATED ON A LEVEL OR 5% MAXIMUM SLOPING SURFACE. DISCHARGE TO A STABILIZED AREA. EXTEND BASE A MINIMUM OF 12 INCHES FROM EDGES OF BAG.
3. CONTROL PUMPING RATE TO PREVENT EXCESSIVE PRESSURE WITHIN THE FILTER BAG IN ACCORDANCE WITH THE MANUFACTURER RECOMMENDATIONS. AS THE BAG FILLS WITH SEDIMENT, REDUCE PUMPING RATE.
4. REMOVE AND PROPERLY DISPOSE OF FILTER BAG UPON COMPLETION OF PUMPING OPERATIONS OR AFTER BAG HAS REACHED CAPACITY, WHICHEVER OCCURS FIRST. SPREAD THE DEWATERED SEDIMENT FROM THE BAG IN AN APPROVED UPLAND AREA AND STABILIZE WITH SEED AND MULCH BY THE END OF THE WORK DAY. RESTORE THE SURFACE AREA BENEATH THE BAG TO ORIGINAL CONDITION UPON REMOVAL OF THE DEVICE.
5. USE NONWOVEN GEOTEXTILE WITH DOUBLE STITCHED SEAMS USING HIGH STRENGTH THREAD. SIZE SLEEVE TO ACCOMMODATE A MAXIMUM 4 INCH DIAMETER PUMP DISCHARGE HOSE. THE BAG MUST BE MANUFACTURED FROM A NONWOVEN GEOTEXTILE THAT MEETS OR EXCEEDS MINIMUM AVERAGE ROLL VALUES (MARV) FOR THE FOLLOWING:

| | | |
|---|---|---|
| GRAB TENSILE | 250 LB | ASTM D-4632 |
| PUNCTURE | 150 LB | ASTM D-4833 |
| FLOW RATE | 70 GAL/MIN/FT$^2$ | ASTM D-4491 |
| PERMITTIVITY (SEC$^{-1}$) | 1.2 SEC$^{-1}$ | ASTM D-4491 |
| UV RESISTANCE | 70% STRENGTH @ 500 HOURS | ASTM D-4355 |
| APPARENT OPENING SIZE (AOS) | 0.15-0.18 MM | ASTM D-4751 |
| SEAM STRENGTH | 90% | ASTM D-4632 |

6. REPLACE FILTER BAG IF BAG CLOGS OR HAS RIPS, TEARS, OR PUNCTURES. DURING OPERATION KEEP CONNECTION BETWEEN PUMP HOSE AND FILTER BAG WATER TIGHT. REPLACE BEDDING IF IT BECOMES DISPLACED.

# APPENDIX B

# LABORATORY RESULTS

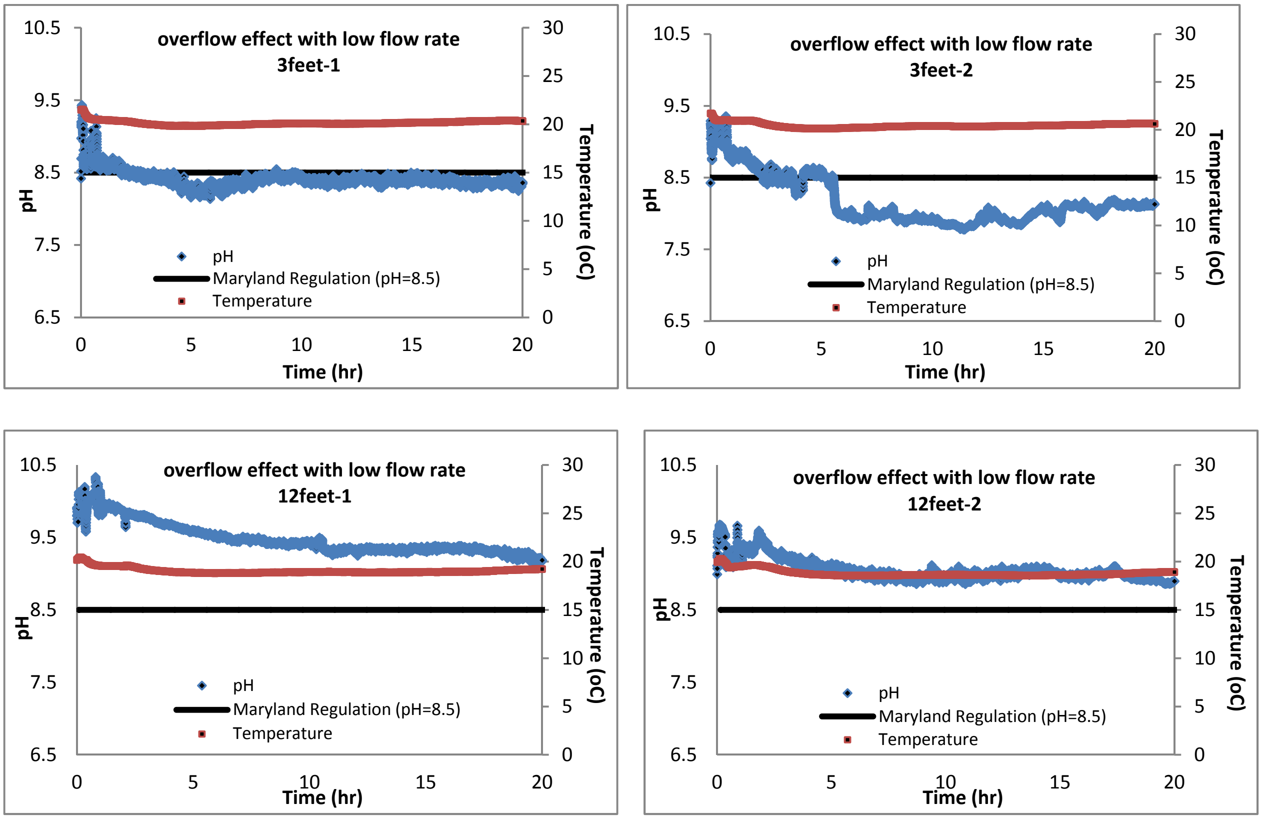
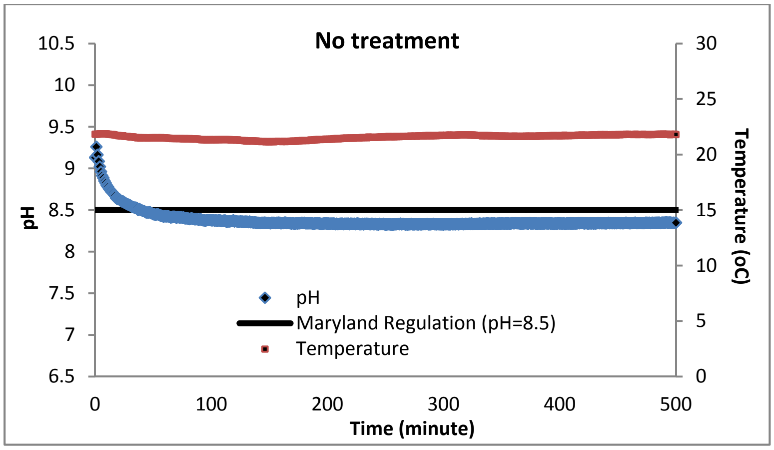
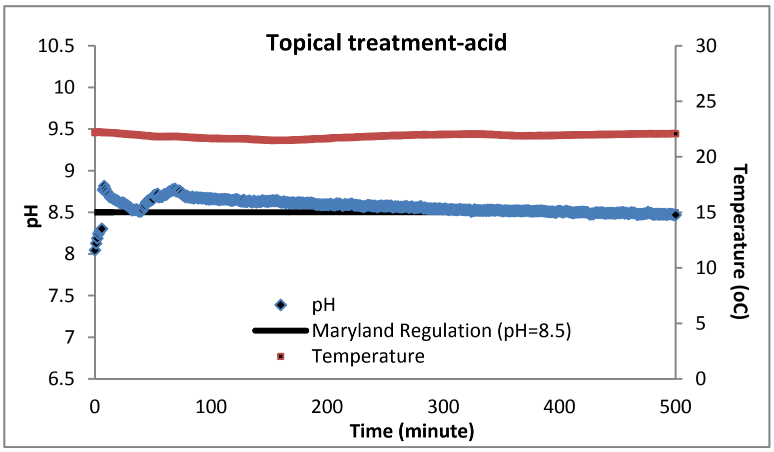



Figure B1: Flow-through leaching test of the overflow effect with different culvert lengths (3 feet and 12 feet), low flow rate (0.9 L/min), and increasing contact time



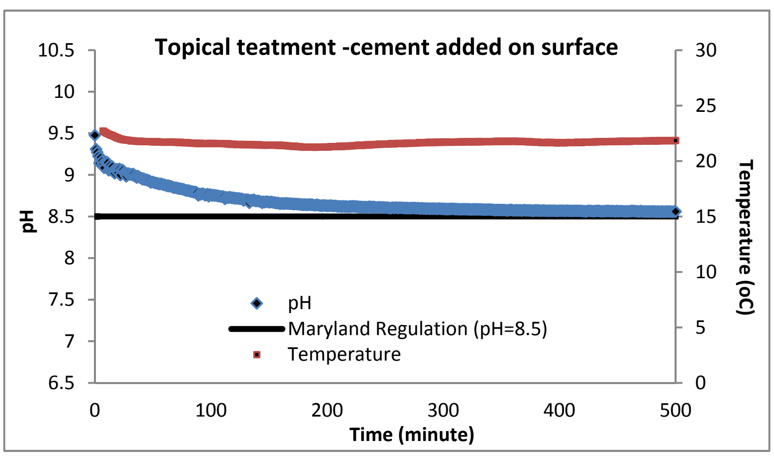




Figure B2: Flow-through leaching test of the topical treatment. Acid topical treatment: the surface was brushed after two-day curing and then 250 ml of acid solution (1:10 ratio of concentrated HCl and deionized water) was poured onto the surface for 5 minutes and then washed (4 ml/cm$^2$).

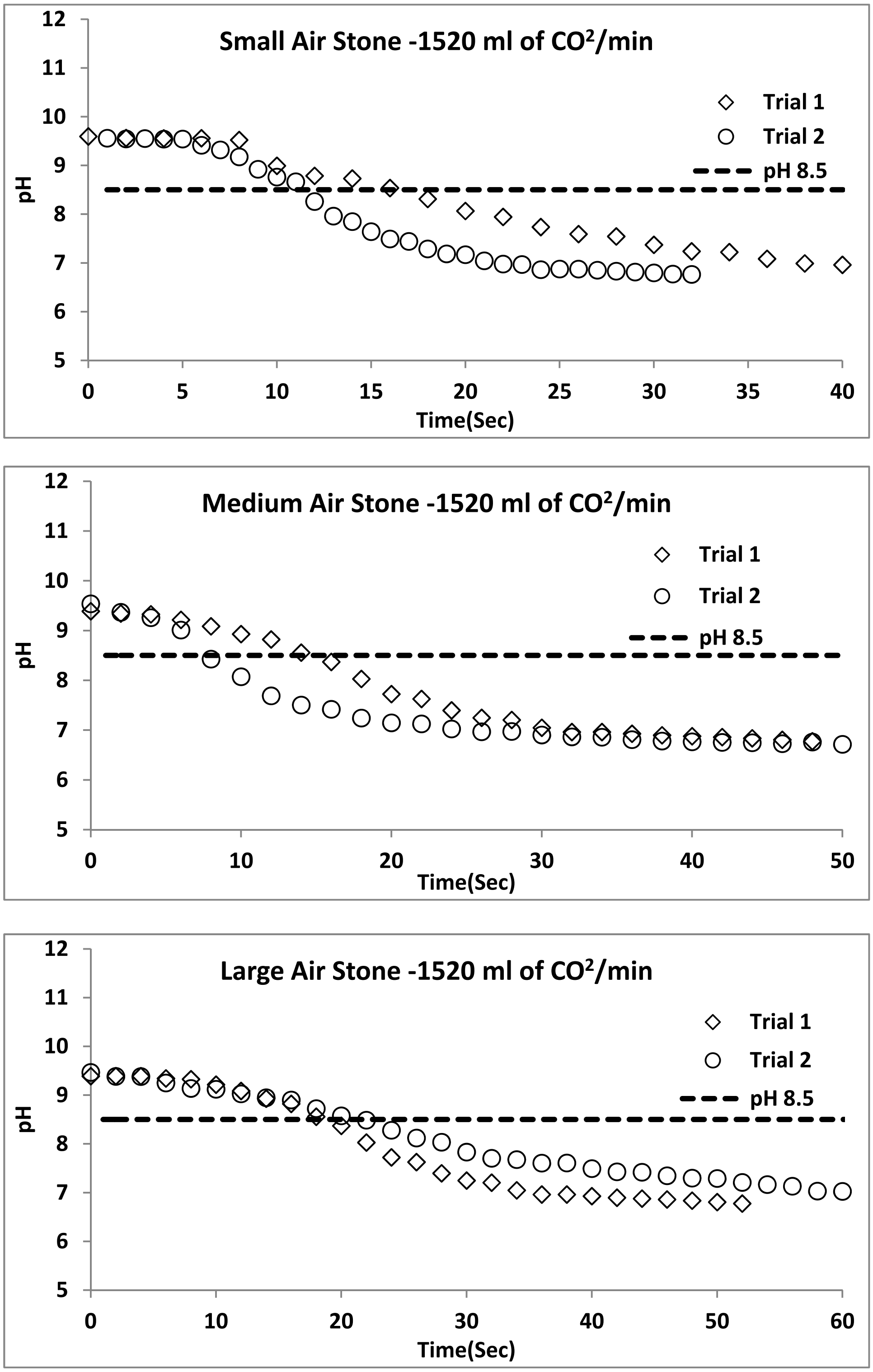



Figure B3: Remedial action experiment through carbon dioxide sparging into 5 gallons of "hot water (pH 9.5) with three different air stones (20 ml of carbon dioxide per minute.).

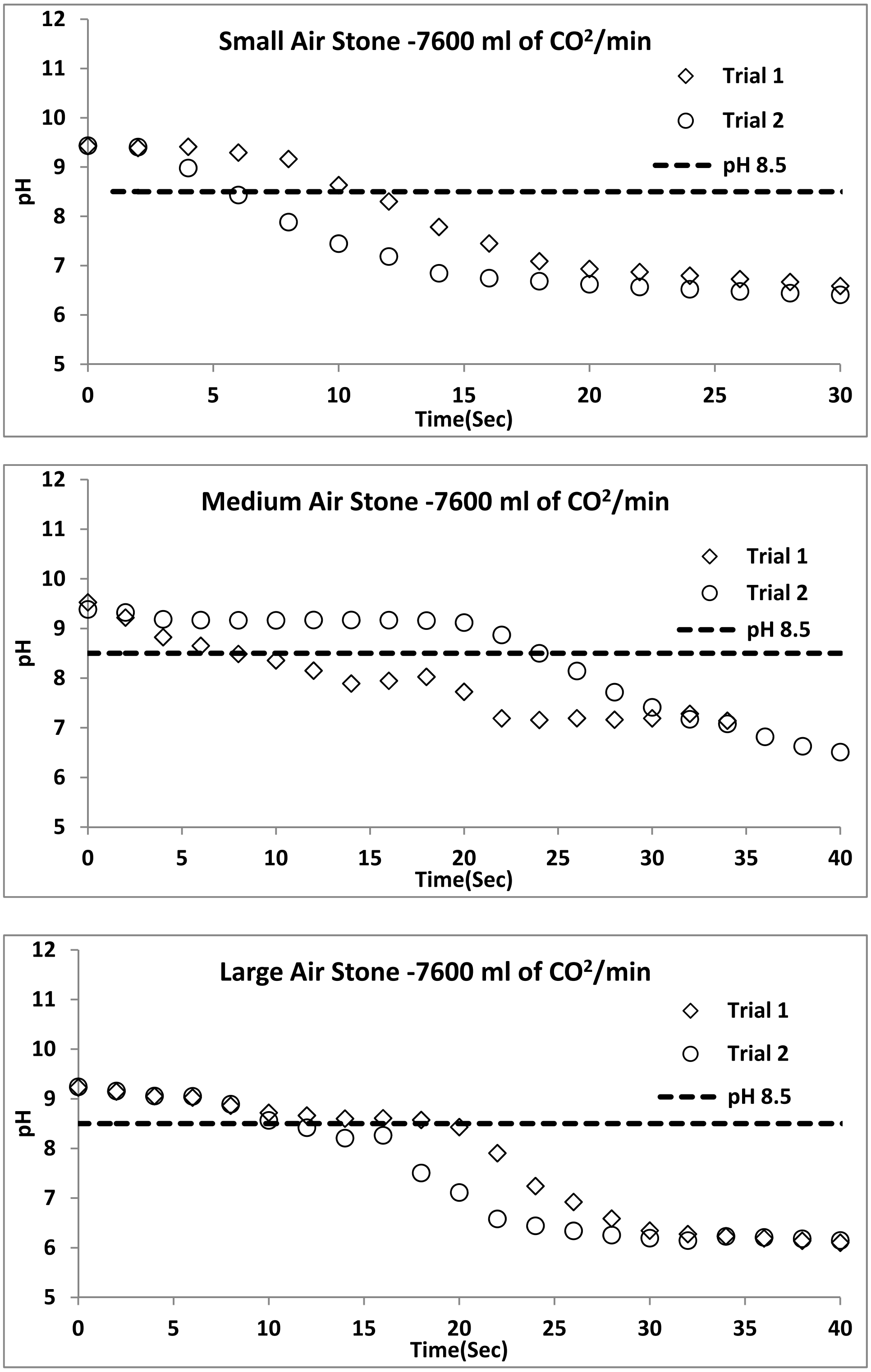



Figure B4: Remedial action experiment through carbon dioxide sparging into 5 gallons of hot water (pH 9.5) with three different air stones (7600 ml of carbon dioxide per minute into hot water).

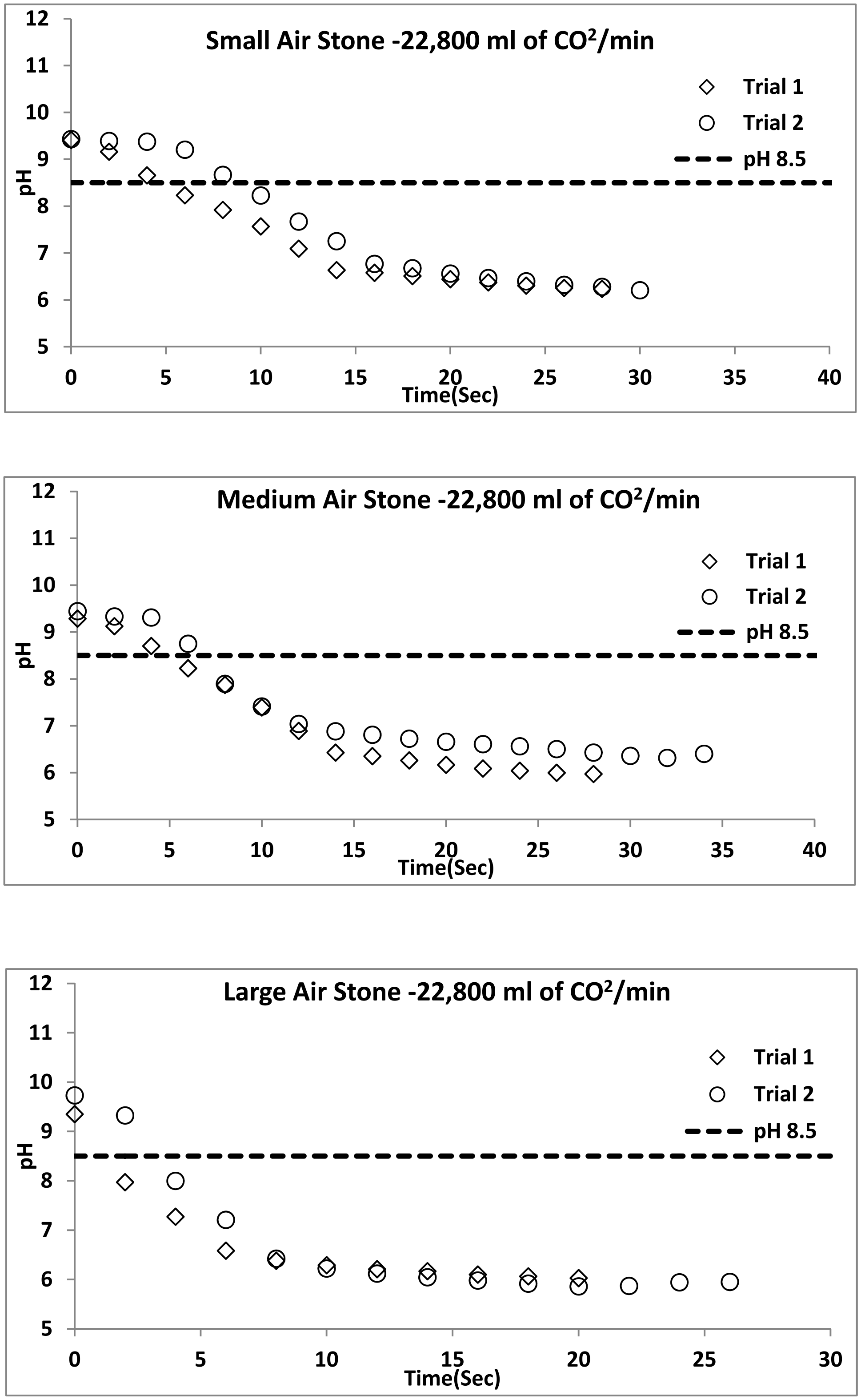
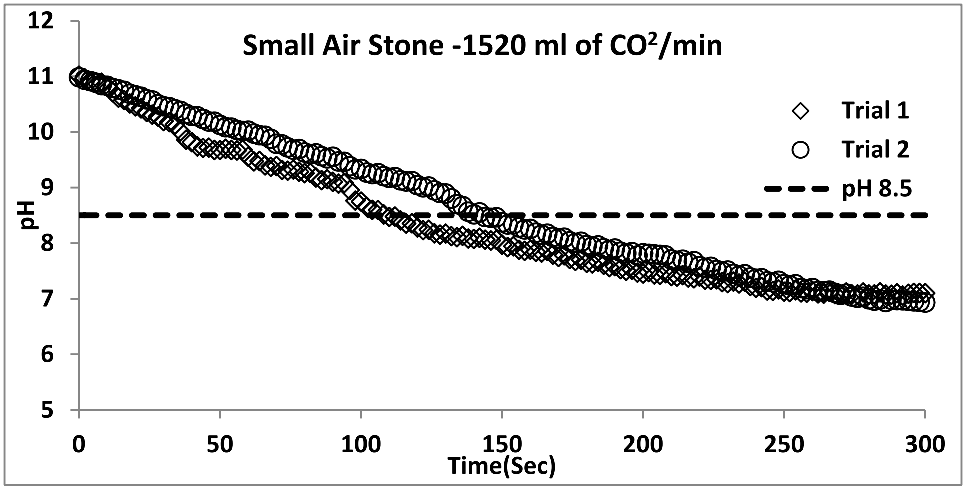
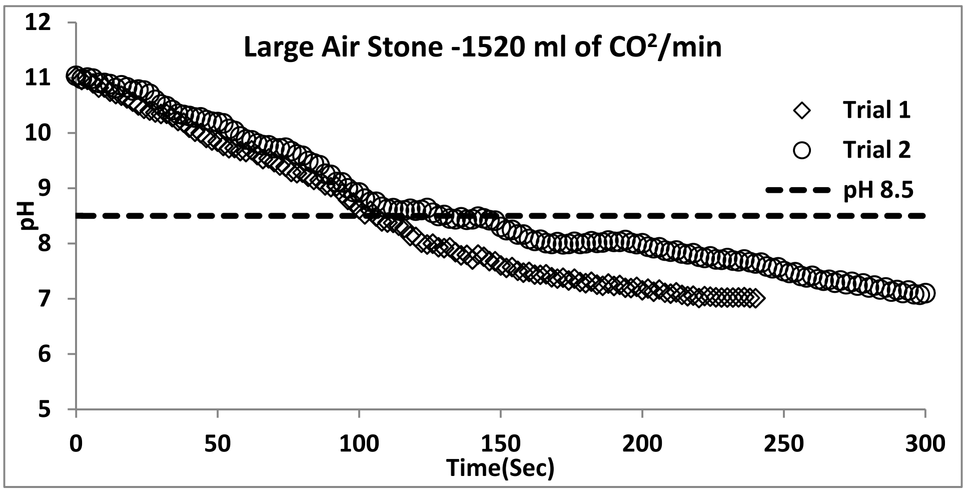



Figure B5: Remedial action experiment through carbon dioxide sparging into 5 gallons of "hot" water (pH 9.5) with three different air stones (22,800 ml of carbon dioxide per minute).



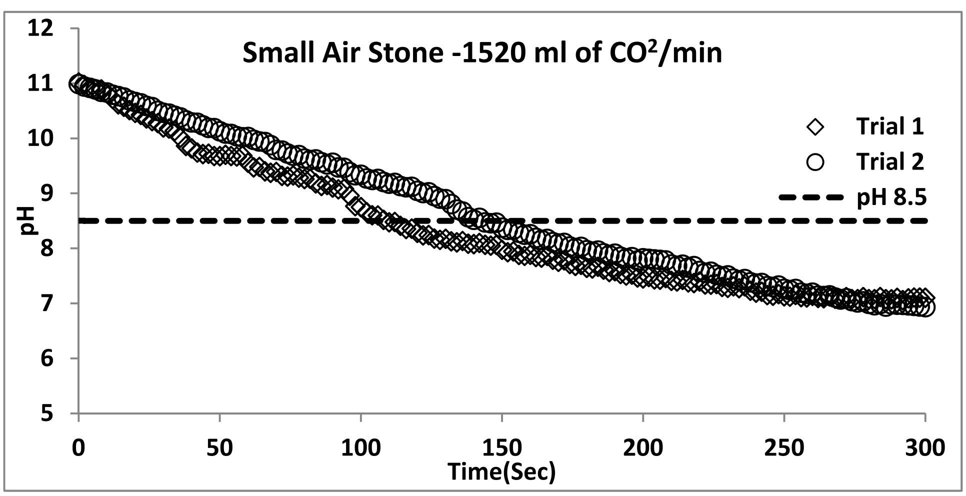




Figure B6: Remedial action experiment through carbon dioxide sparging into 5 gallons of "hot" water (pH 11) with three different air stones (1520 ml of carbon dioxide per minute).

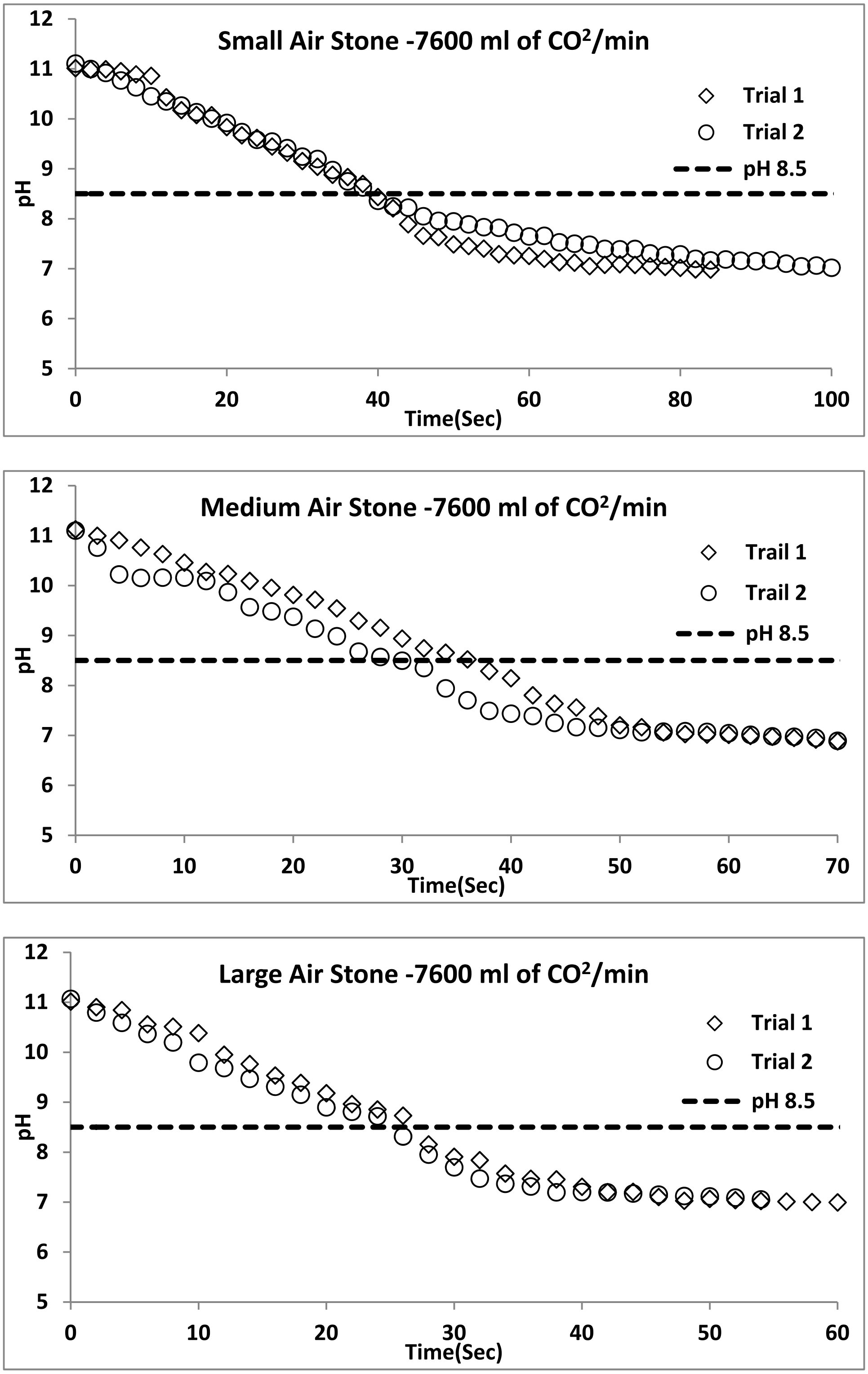



Figure B7: Remedial action experiment through carbon dioxide sparging into 5 gallons of "hot" water (pH 11) with three different air stones (7600 ml of carbon dioxide per minute into).

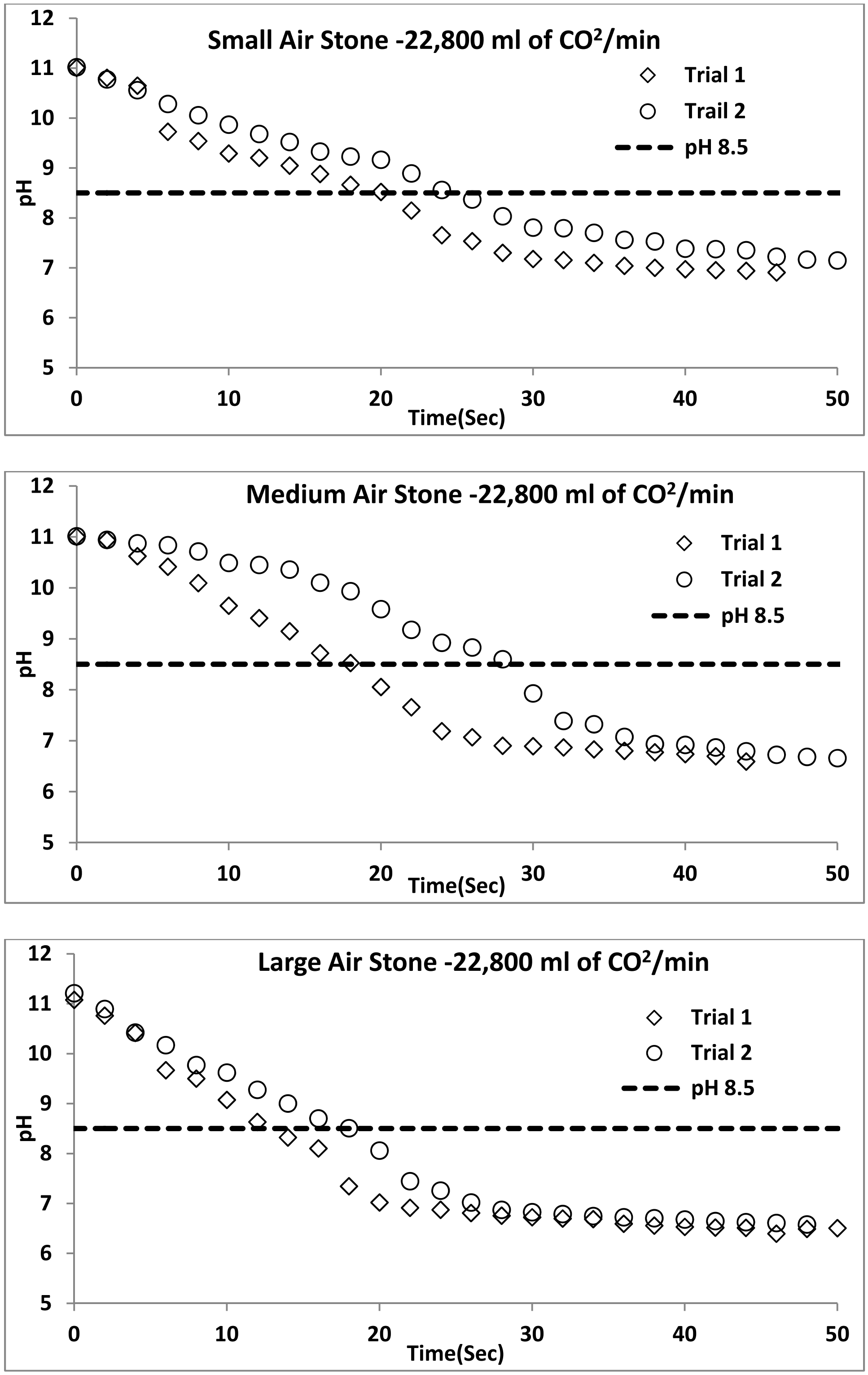



Figure B8: Remedial action experiment through carbon dioxide sparging into 5 gallons of "hot" water (pH 11) with three different air stones (22,800 ml of carbon dioxide per minute).

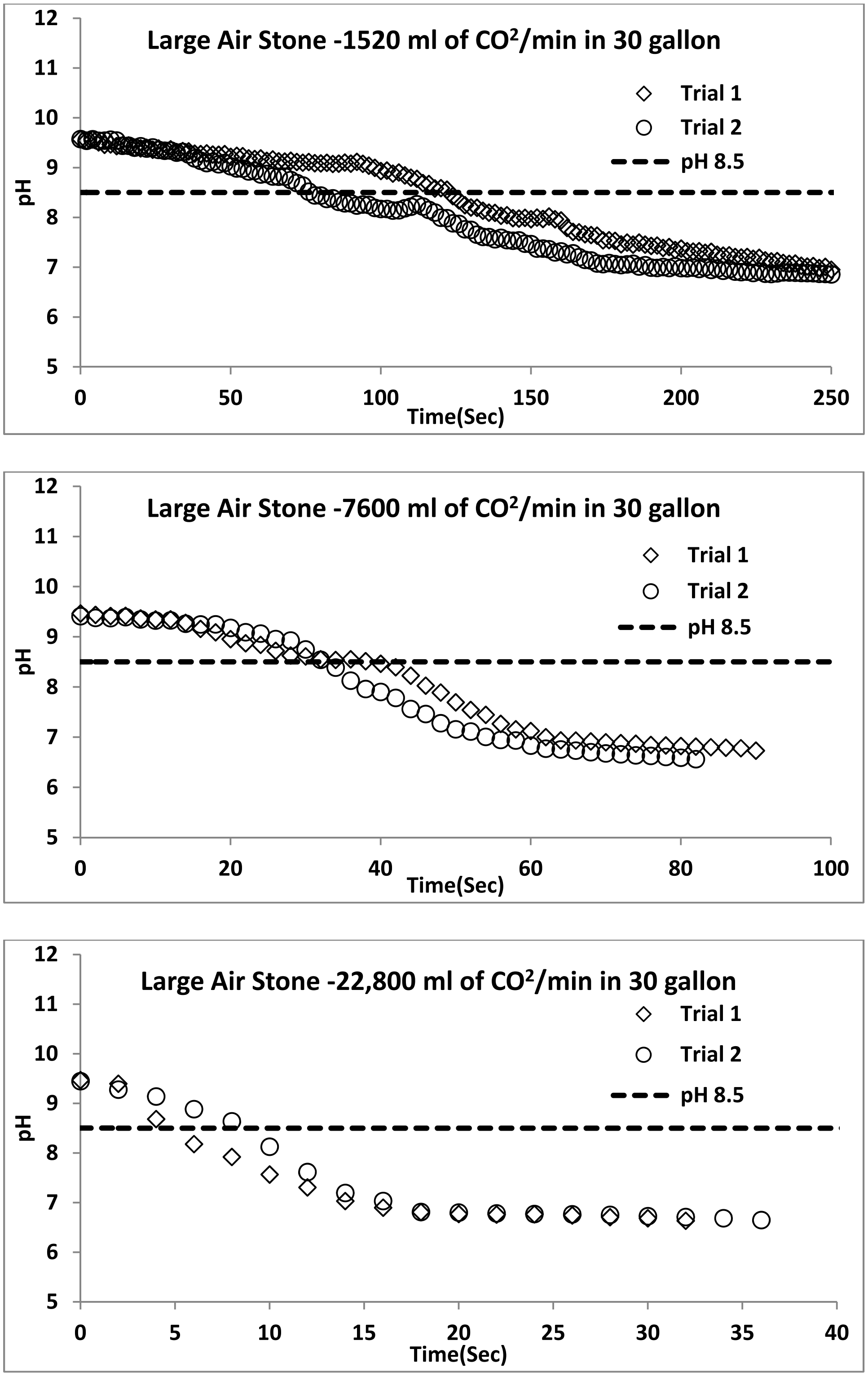
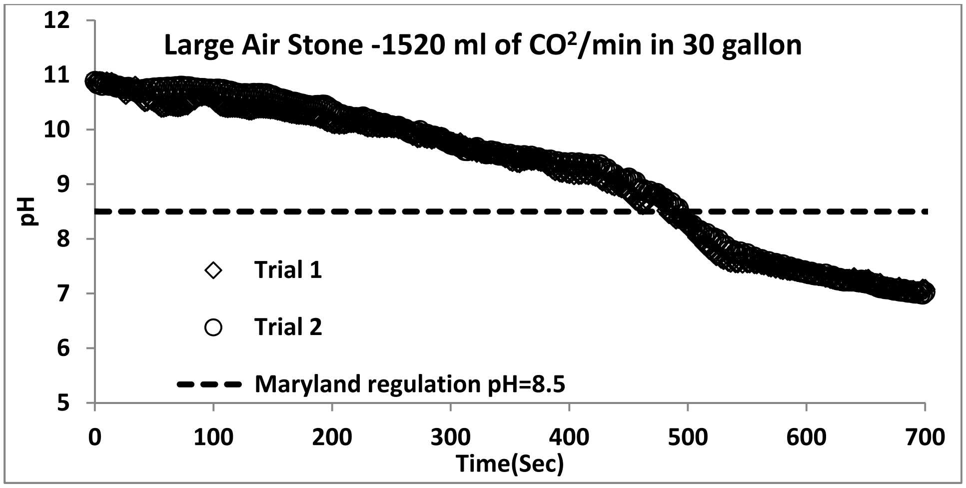
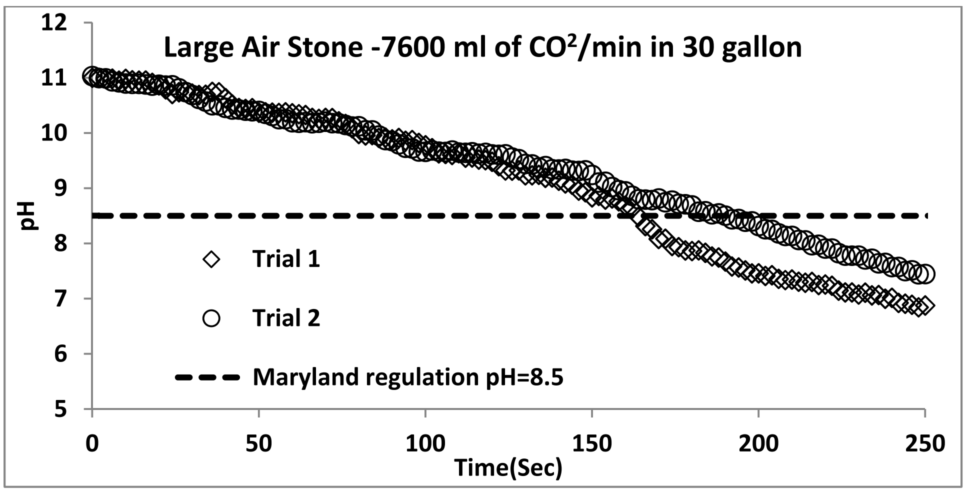



Figure B9: Remedial action experiment through carbon dioxide sparging into 30 gallons of “hot” water (pH 9.5) with large air stones (1520, 7600, and 22,800 ml of carbon dioxide per minute).



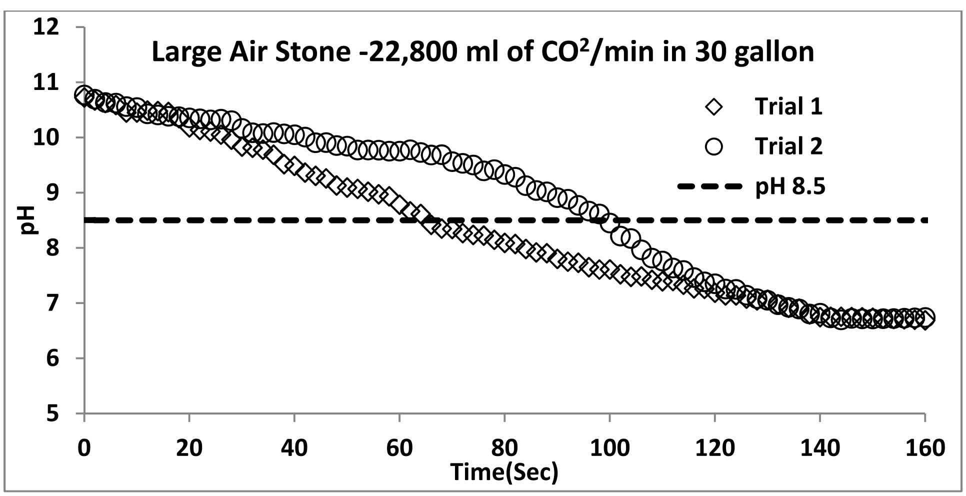




Figure B10: Remedial action experiment through carbon dioxide sparging into 30 gallons of "hot" water (pH 11) with large air stones (1520, 7600, and 22,800 ml of carbon dioxide per minute).

**Optimization of Peat Utilization**

**Table B.1: Data from peat: water: straw mix experiment.**

| | | Results | |
|---|---|---|---|
| **Ratio (vol.)** | **Material** | **pH** | **TDS** |
| 1:1:2 | Peat/Water/Straw | 7.12 | 522.8 |
| 1:1:2 | Peat/Water/Straw | 8.05 | 538.3 |
| 1:1:2 | Peat/Water/Straw | 8.13 | 542.6 |
| **Ratio** | **Material** | **pH** | **TDS** |
| 2:1:2 | Peat/Water/Straw | 7.40 | 567.3 |
| 2:1:2 | Peat/Water/Straw | 7.75 | 640.2 |
| 2:1:2 | Peat/Water/Straw | 7.65 | 631.6 |
| **Ratio** | **Material** | **pH** | **TDS** |
| 3:1:2 | Peat/Water/Straw | 6.92 | 417.0 |
| 3:1:2 | Peat/Water/Straw | 6.89 | 680.3 |
| 3:1:2 | Peat/Water/Straw | 6.74 | 602.3 |
| **Ratio** | **Material** | **pH** | **TDS** |
| 4:1:2 | Peat/Water/Straw | 6.09 | 987.8 |
| 4:1:2 | Peat/Water/Straw | 6.33 | 985.7 |
| 4:1:2 | Peat/Water/Straw | 6.29 | 981.2 |

# APPENDIX C

# FIELD PROJECT DEFICIENCIES

**Contractor workmanship**

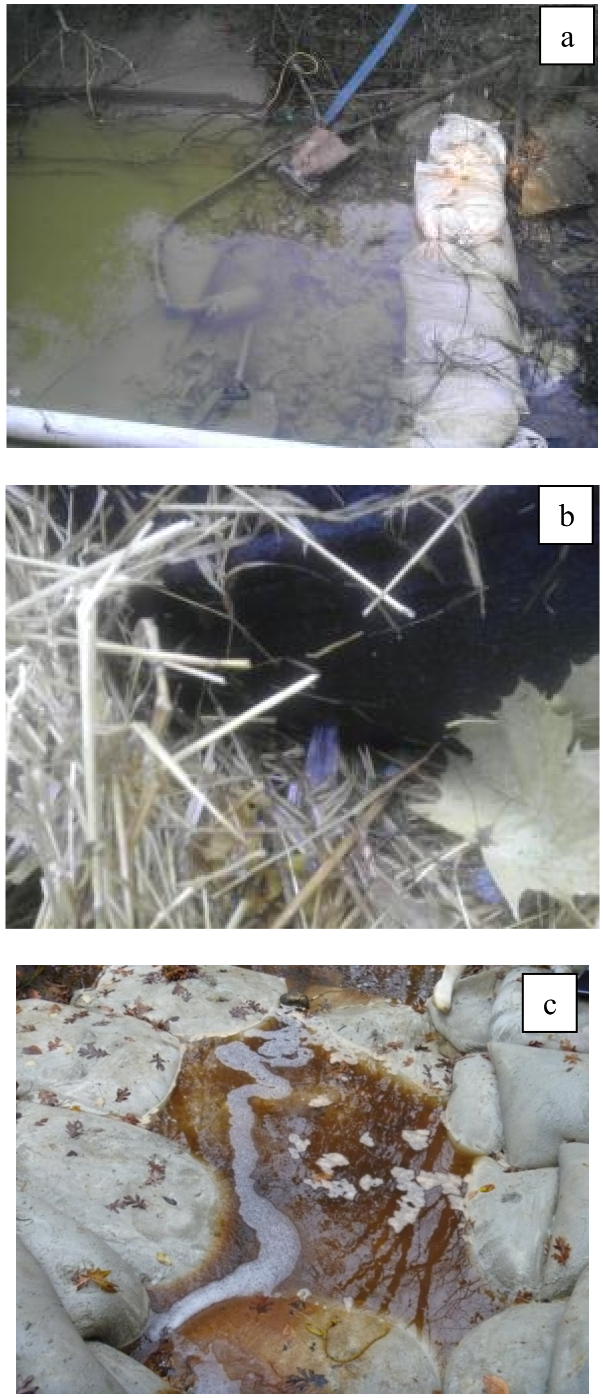



Figure C1: Workmanship of contractors may be a major determinant of pH monitored in-stream: (a) malfunctioning pump at Savage site, water re-enters downstream over inadequate sandbag dike; (b) punctured sediment bag at Catonsville site; (c) ponded water caused by lengthened contact time with grout bags and tufa formation, which resulted in high pH headway recorded at Crofton site.