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# Standardized Test Method to Quantify Environmental Impacts of Stormwater Pipe Rehabilitation Materials

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Final Report VCTIR 15-R11

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**FINAL REPORT**

**STANDARDIZED TEST METHOD TO QUANTIFY ENVIRONMENTAL IMPACTS  
OF STORMWATER PIPE REHABILITATION MATERIALS**

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## ABSTRACT

The purpose of this study was to develop a standardized test method that the Virginia Department of Transportation (VDOT) can apply to evaluate the environmental impact of stormwater infrastructure materials. Three laboratory stormwater infrastructure material leaching protocols named static, stirbar, and modified Toxicity Characteristic Leaching Procedure (mTCLP) were developed. These protocols were evaluated for their ability to predict field stormwater quality and aquatic toxicity caused by a pipe rehabilitation material. Cured-in-place pipe (CIPP) was used in this study as a model rehabilitation material because there was prior evidence this technology could cause environmental damage. The study objective was achieved, and during this project it was discovered that the material installation process itself was the main cause of environmental pollution, more than the material. Additional materials and installation processes should be examined in future work.

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As shown by the results of this study, chemicals other than styrene were released by CIPP into stormwater. Any further CIPP testing should not be limited to a few contaminants, but be expanded to include other contaminants of environmental and human health concern. Further work is necessary to determine the ability of the mTCLP method to predict field stormwater levels at multiple installation sites, for broader range of materials, and evaluate additional water quality and toxicity indicators. Additional materials that should be examined with this method include at least those that are created in-situ by chemical reactions such as spray-on coatings and liners. Further testing with additional model systems and individual compounds and at field sites is recommended.

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## **INTRODUCTION**

One million miles of stormwater culverts currently require repair (Hunt et al., 2010; Thornton et al., 2005), and departments of transportation (DOTs) across the United States are seeking inexpensive and reliable methods for their rehabilitation. Trenchless technology rehabilitation materials such as cured-in-place-pipe (CIPP), slip-liners, spray-on coatings, and composites are becoming popular among DOTs because of their versatility and ease of installation (P. Davies and S. Penders, personal communication; Torres and Ruiz, 2011; U.S. Environmental Protection Agency [EPA], 1992). However, anecdotal reports and a few state-funded DOT studies have demonstrated that some CIPP installation activities have released chemicals into the environment during and following installation causing damage (Donaldson and Baker, 2008; O'Reilly, 2008; Whelton et al., 2013). Spray-on coatings can also alter stormwater quality (Donaldson, 2012; Whelton et al., 2013).

To reduce the potential that DOTs will approve infrastructure rehabilitation technologies that cause environmental damage, a pre-approval water quality impact test method is needed. At present, no standard protocol exists though the Virginia Department of Transportation (VDOT) has taken great strides toward understanding the complexity of infrastructure rehabilitation and environmental impacts. The water quality impact protocol to be developed must be versatile to include the wide array of rehabilitation materials in-use that include, but are not limited to, cured-in-place pipe (CIPP), slip-liners, coatings, composites (EPA, 1992), and those that enter the marketplace in the future.

A literature review revealed that several material leaching protocols have been applied in the drinking water, hazardous waste, and wastewater industries. The National Sanitation Foundation International (NSFI) Standard 61 is a procedure for characterizing chemical release from drinking water contact materials in the United States (NSFI, 2007). As Table 1 indicates, the NSFI Standard 61 method is a static leaching test, carried-out for up to 14 days, and includes analysis for a wide range of inorganic and organic drinking water chemicals (NSFI, 2007). The Toxicity Leaching Characterization Procedure (TCLP) is another material leaching test, but has historically been applied to characterize solid wastes (EPA, 1992).

Toxicity Characteristic Leaching Procedure (TCLP) uses a mechanical mixing process and can include one or a mixture of acids, or bases at room temperature (i.e., NaOH and CH<sub>3</sub>COOH). Several of the TCLP extraction liquids are not typical of stormwater environments. The leaching potential of solid wastes can also be examined by application of the Synthetic Precipitation Leaching Procedure (SPLP). SPLP is identical to the TCLP except different extraction liquids are applied such as H<sub>2</sub>SO<sub>4</sub> and deionized water (EPA, 1994). None of those material-leaching procedures, however, incorporates aquatic toxicity testing. The most widely used aquatic toxicity test for wastewater quality is the Whole Effluent Toxicity (WET) test (EPA, 2002a). This test is applied to determine the ecotoxicity of wastewater effluent that is discharged to receiving waters (Sarakinos and Rasmussen, 1998; Carigan and Villard, 2001). The WET test encompasses many toxicity indicator organisms that are selected based on the specific traits of the ecosystem the effluent is being released and *Daphnia magna* are one indicator organism for freshwater (Carigan and Villard, 2001; EPA, 2002a; Sarakinos and Rasmussen, 1998).

An adequate material-leaching protocol should predict the amount of contaminants that could be released from a material in the field based on laboratory simulation testing. There are generally two methods of chemical extraction: static extraction and dynamic extraction (Harwell, 1999). The static extraction method uses a specified volume of fluid throughout the entire test and dynamic extraction method renews the leaching liquid throughout the test during specified time intervals (Harwell, 1999). These tests use a concentration gradient to extract chemical compounds through permeation from the host matrix (EPA, 2002b). It is well known that immersion of polymer material into fresh leaching liquid that lacks contaminants will drive residual contaminants out of the host polymer matrix into the fluid (i.e., uncured resin, and unreacted catalysts) down the concentration gradient (Harwell, 1999; EPA, 2002b). Frequent solution replacement resets the equilibrium process, thereby increasing the extraction rate, as simulated by the dynamic extraction approach. Comparing the laboratory leaching experiments with field data will elucidate the accuracy of the developed leaching protocol.

**Table 1. Experimental Condition Comparison for NSFI, EPA 1311, EPA 1312, and EPA 821 Water Quality Impact Protocols**

Parameter	Protocol Name & Mode of Contact			
	NSFI Standard 61 Static	EPA 1311 (TCLP) Dynamic	EPA 1312 (SPLP) Dynamic	EPA 821 (WET) Static
SA/V ratio Importance	Yes	Yes	Yes	N/A <sup>1</sup>
Temperature	23 + 2°C (Cold); 60 + 2°C (Hot)	Not specified (assumed room temperature, 23°C)	Not specified (assumed room temperature, 23°C)	Organism dependent: 20°C or 25°C
Duration of Contact	24 + 1 hr for 14 days; up to 90 days special circumstance	18 + 2 hr for single test period	18 + 2 hr for single test period	24 or 48 hr for single test period
Solution Types	Mimic potable water (1) With disinfectant (2) Without disinfectant	(1) Acetic acid & sodium hydroxide (2) Acetic acid	(1) 60/40 sulfuric & nitric acids & deionized water (pH 4.20) (2) 60/40 sulfuric nitric & deionized water (pH 5.00) (3) Deionized water	Mimic natural water with hardness and alkalinity
Water pH	Material dependent: 6.5 or 10	Extraction fluid dependent: 2.88 to 4.93	Extraction fluid dependent: 4.20 to 5.50	Organism dependent: 6.4 to 8.4
Metals	EPA regulated metals: Sb, As, Ba, Be, Cd, Cr, Cu, Pb, Mn, Hg, Mo, Ni, Se, Tl, V and Zn	EPA regulated (Not specified)	EPA regulated (Not specified)	N/A <sup>a</sup>
VOCs	EPA method 8260	EPA method 8260	EPA method 8260	N/A <sup>a</sup>
GC-MS (Other)	EPA Methods 625, 525.2, and 420.2	Not specified	Not specified	N/A <sup>a</sup>
Toxicity	Indirect assessment <sup>b</sup>	Indirect assessment <sup>c</sup>	Indirect assessment <sup>c</sup>	Direct assessment: Indicator organisms mortality

<sup>a</sup> Not applicable because organisms are placed in the extraction solution and solid material is not present.

<sup>b</sup> Based on concentration of found compounds and published toxicological data.

<sup>c</sup> Presence of EPA regulated compounds: Benzene, carbon tetrachloride, chlorobenzene, chloroform, 1,2-dichloroethane, 1,1-dichloroethylene, methyl ethyl ketone, tetrachloroethylene, and vinyl chloride.

## PURPOSE AND SCOPE

The purpose of this study was to develop a dynamic leaching protocol for the environmental impact evaluation of stormwater infrastructure materials. CIPP specimens were used during testing because of their regional availability and the willingness of the Alabama Department of Transportation (ALDOT) to provide the project team access to stormwater infrastructure rehabilitation field sites. Specific objectives of this study included (1) characterization of aquatic toxicity and water quality after immersion of CIPP material into a synthetic stormwater leaching solution using three different agitation methods (static, stirbar, and modified TCLP [mTCLP]); (2) identification of contaminants released from cured CIPP material over three separate 18-h exposure periods; and (3) comparison of laboratory results to field testing conducted by the project team.

## MATERIALS AND METHODS

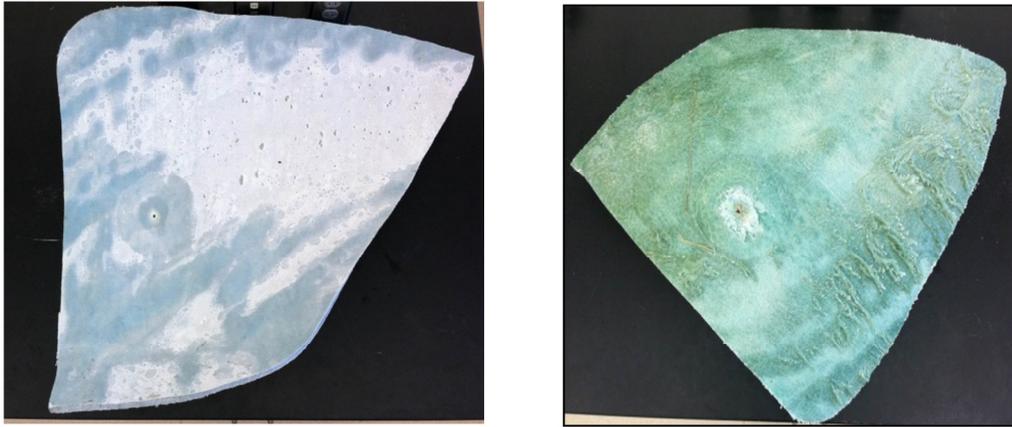
### Field Sites and Extraction Testing

CIPP material samples were collected from one of the two installation sites in central Alabama one day after the material was cured in place. Appendices B, C, D, and E show the locations and some sampling activity. Installation practices applied compared to those specified by VDOT as shown in Table 2. Before rehabilitation, the existing culvert was a corroded, asphalt-coated corrugated metal pipe. Material safety data sheets (MSDS) from the CIPP manufacturer stated that an unsaturated polyester or vinyl ester and a styrene-based resin were the primary ingredients (LMK, 2002). However, the specific ingredients used in the resin systems were not specified. The dimensions of the installed CIPP liner were 121 cm diameter x 482 cm length x 1.9 cm thick. The liner was steam-cured for six hours. Three large sections of cured CIPP were removed from the field with 1.9 cm wall thickness, 9.1 cm length and 121 cm width (Figure 1). CIPP interior and exterior surfaces were blistered from the steam curing.

**Table 2. Comparison of DOT Construction Specifications for CIPP Installation in Alabama and Virginia**

Category	ALDOT	VDOT
Installation Specification	According to manufacturer	Dry installation
Allowable CIPP Curing Methods	Water, steam, and UV-Light	Water, steam, and UV-light
Containment Methods	Clean-up all material not used in the installation. Site should be left in the same condition or better.	Impermeable sheeting immediately upstream and downstream of installation to capture any spillage of raw resin into the environment to be disposed of properly after installation is completed
Discharge Regulations	Not specified	Contractor to comply with all discharge permits, including air, water and wastewater (i.e., Publicly Owned Treatment Works or “POTW”)
Curing Water Capture	Required	Required
Rinse After Curing	Not Specified	Specified and requirement to dispose of properly
Environmental Monitoring	Not Specified	Specified pre and post construction soil and water testing from third party environmental consultant

Samples were cut using a diamond tipped saw to be approximately 5.08 cm length x 5.08 cm width x 1.9 cm height. The effects of CIPP specimen age on water quality impacts were also tested, as a subset of CIPP samples were also stored for 70 days and compared to the results of mTCLP testing of freshly cured CIPP.



**Figure 1. Interior (left) and Exterior (right) Views of Cured CIPP Specimen Exhumed From Alabama Field Site 2**

Field stormwater samples were collected at the culvert inlet, outlet, and downstream of the installation site 1, 7, 28, and 35 days after CIPP curing. Water samples collected were 2 L volume. Excess cured CIPP was also removed from the field after curing and underwent laboratory testing. When the CIPP end pieces were removed, a limited volume of stormwater was observed flowing through the culvert; the majority of the pipe circumference was not in contact with flowing water. The volume was calculated by examining the CIPP surface area (0.03 m width x 48.2 m length) that was exposed to approximately 0.64 cm of running water. The field site surface area to volume ratio (SA/V) was 1.57 cm<sup>2</sup>/mL for the CIPP surface observed in contact with the stormwater during the site investigation.

For all extraction methods, approximately 100 grams of CIPP sample (five 5.08 cm length x 5.08 cm width x 1.9 cm height CIPP pieces) were placed in each extraction vessel along with 2 L of synthetic stormwater (EPA, 2002a). The approximate surface area of CIPP in each vessel exposed to the water during extraction testing was 451.61 cm<sup>2</sup>/L. The CIPP SA/V ratio for each vessel was 0.23 cm<sup>2</sup>/mL (14% of the field SA/V).

## **Protocols**

Three methods were evaluated during laboratory experimentation (Figure 2). A previous study used a static extraction method to document the leaching behavior of stormwater polyurea coatings and cement mortar liners (Whelton et al., 2013). The same approach was applied in the present study. Synthetic water was created using deionized water and minerals shown in Appendix A. CIPP samples were cut and immersed in static vessels. Water was periodically removed for characterization and replaced with freshly prepared water. The second procedure evaluated was the mTCLP method. The mTCLP method used a dynamic agitation similar to the TCLP or SPLP method in which a 2 L bottle is rotated for 18 hr with the sample and the

extraction fluid (EPA 1992; EPA 1994). The mTCLP used the same protocol (rotation speed, volume to sample mass ratio, and duration) as EPA methods 1311 and 1312, but instead used a leaching fluid appropriate for *Daphnia magna* toxicity testing and referred to herein as synthetic “stormwater” (Appendix A). The third method examined was a hybrid between the static and mTCLP method. This procedure involved dynamic conditions, but instead of the TCLP apparatus, used a Polytetrafluoroethylene (PTFE) coated stirbar (and magnetic stirrer) to simulate water movement.



**Figure 2. Experimental Setup for Each Extraction Method Examined in Study: (Left) Static Testing Apparatus; (Center) Stirbar Testing Apparatus; (Right) TCLP Testing Apparatus**

The ability of the three extraction methods to remove chemical contaminants from the CIPP material was examined. The role of water type and exposure duration was also examined in this work. Two different water types (synthetic stormwater and deionized water) were applied. The synthetic stormwater consisted of water that contained hardness and alkalinity levels suitable for *Daphnia magna* survival as a means to determine toxicity of CIPP after contact with this water (EPA, 1987). Three consecutive 18 hr exposure periods were also applied to determine the influence that these factors extract chemicals from the host material.

### **Sample Measurements**

CIPP specimens were weighed using a Mettler Toledo XS204 (max 220g capacity) balance. The water volume applied within each TCLP vessel (in mL) was 20 times the sample weight (g) (EPA, 1992). Each sample weight was approximately 100 grams based on the TCLP weight to volume calculation. Based on the cut CIPP material size, the five CIPP pieces inserted into each glass vessel weighed approximately 100 grams in total.

### **Water Quality Analysis**

Several analyses were carried out on field and lab water samples to determine the degree with which the CIPP altered water quality. Alkalinity was determined in accordance with Standard Method (SM) 2320B (APHA et al., 1995). Sulfuric acid (0.025 N) was used for endpoint titration. Water pH was measured using a Fisher Scientific Accumet® basic AB15 plus pH meter. Calcium and magnesium ion concentrations were determined by titration using

ethylenediaminetetraacetic acid in accordance with SM 2340C. HACH<sup>®</sup> digestion reagent vials were used to facilitate the closed reflux, calorimetric method for quantifying chemical oxygen demand (COD) in accordance with the U.S. EPA reaction digestion method 8000 and SM 5220D. Digestion reagent vials were heated per method instructions (150°C/2 h) in a HACH<sup>®</sup> DRB 200<sup>™</sup> digital reactor block and the COD calorimetric determinations were made using a HACH<sup>®</sup> DR 5000<sup>™</sup> UV-VIS Spectrophotometer. COD describes the biodegradable and non-biodegradable components of the water. Aromatic organic constituent concentrations were analyzed by ultraviolet (UV) absorbance at 254 nm with a HACH<sup>®</sup> DR 5000<sup>™</sup> UV-VIS spectrophotometer. Prior to UV<sub>254</sub> characterization, all field water samples were filtered according to SM 5910B due to the turbidity of the samples that affected the accuracy of the spectrophotometer. Total organic carbon (TOC) concentration was characterized using a Shimadzu TOC-L analyzer following SM 5310A. A 1,000 ppm TOC standard solution (Aqua Solutions, Deer Park, TX) was diluted in deionized water to produce 0 ppm, 2 ppm, 4 ppm, and 5 ppm calibration standards.

### **Headspace Solid Phase Micro-Extraction Gas Chromatography-Mass Spectrometry (Headspace SPME GC-MS)**

Headspace Solid Phase Micro-Extraction Gas Chromatography-Mass Spectrometry (SPME GC-MS) was applied to characterize volatile organic compound (VOC) concentration in sample waters. The applied protocol was similar to the method developed by Silva et al. (2000). An Agilent Technologies 7890A GC system with a 5975C inert mass selective detector (MSD) multi-purpose sampler was used. The GC column was an Agilent Technologies HP-5ms (length-30 m, diam.-0.250 mm, film-0.25 µm). The extraction process used a Supelco<sup>™</sup> SPME fiber assembly (85 µm polyacrylate, 23-ga) that was conditioned at 220°C for 1 h., per manufacturer recommendation. The GC-MS oven program used helium as a carrier gas at a rate of 0.65 mL/min. The GC was ramped from 50°C to 100°C at 10°C/min. and then to 150°C at 5°C/min. Temperature was held for 25 min. The injector was in splitless mode and held at 220°C. GC vials (20 mL) were filled with 10 mL of sample water. Then the SPME fiber was held in the headspace for an adsorption time of 10 min at 55°C. The fiber was placed into the GC injector where it was thermally desorbed of analytes at 220°C for 2 min. A styrene standard solution of 200 ppb concentration in methanol was diluted with deionized water to produce 0 ppb, 25 ppb, 50 ppb, 75 ppb, and 100 ppb styrene concentrations for a calibration curve. The calibration curve's correlation coefficient ( $r^2$ ) was 0.9734.

### **Liquid-Liquid Extraction Gas Chromatography-Mass Spectrometry (LLE GC-MS)**

Two hundred milliliters of field water samples were extracted using 20 mL dichloromethane (DCM) following methods optimized by Koch (2004). Each extraction was performed thrice and dried over anhydrous sodium sulfate. Rotary evaporation (rotovap) at 300 mbar pressure and room temperature was applied to reduce the extracted sample size from approximately 60 mL to 0.5 mL. Each 0.5 mL sample was then directly injected into the GC-MS port. The GC-MS oven program used helium as a carrier gas at a rate of 2 mL/min. The GC oven temperature was held at 40°C for 4 min. and ramped to 300°C at a rate of 12°C per min. Temperature was held at 300°C for 10 min. The injector was in splitless mode and held at

280°C. A percent recovery of toluene, naphthalene, and phenanthrene for the LLE method was determined with three replicates to be 93.0 + 19.4%, 73.2 + 15.5%, and 84.1 + 14.5%, respectively.

### ***Daphnia magna* Toxicity Testing**

*Daphnia magna* served as the aquatic toxicity bioindicator. *Daphnia magna* cultures were raised in laboratory prepared stormwater based on EPA protocol 600/8-87/011 (EPA, 1987). *Daphnia magna*, trout food, and algae were purchased from Aquatic Biosystems, Inc (Fort Collins, Colorado). Between 20 and 25 adult daphnids (6 to 10 d old) were placed in 2-liter beakers containing 1.6 L of laboratory prepared stormwater. Only broods less than 24 h old and from generations 2 through 6 were used for the toxicity testing. Water changes and feeding occurred 3 times a week. *Daphnia* were maintained at  $20 \pm 2$  °C and were exposed to 16 h:8 h light:dark cycle.

Standard protocols were applied for daphnid testing (EPA, 1987). Synthetic stormwater and deionized water blanks were used as controls. All tests had three replicates due to field water sample limitations, which differed from the EPA Protocol requirement of four replicate beakers. Daphnids were examined to count the number of dead organisms after 24 h and 48 h exposure periods.

### **Statistical Analysis**

Mean and standard deviation values were calculated for each water quality result. Water quality results were statistically analyzed using a three-way ANOVA to determine statistical significance of independent variables and interactions between independent variables. A posthoc Tukey-Kramer multiple comparison test was also conducted. Type I error was applied for all statistics ( $\alpha = 0.05$ ) for null hypothesis rejection.

## **RESULTS AND DISCUSSION**

### **Five-Week Water Quality Monitoring Effort at Rehabilitation Installation Sites**

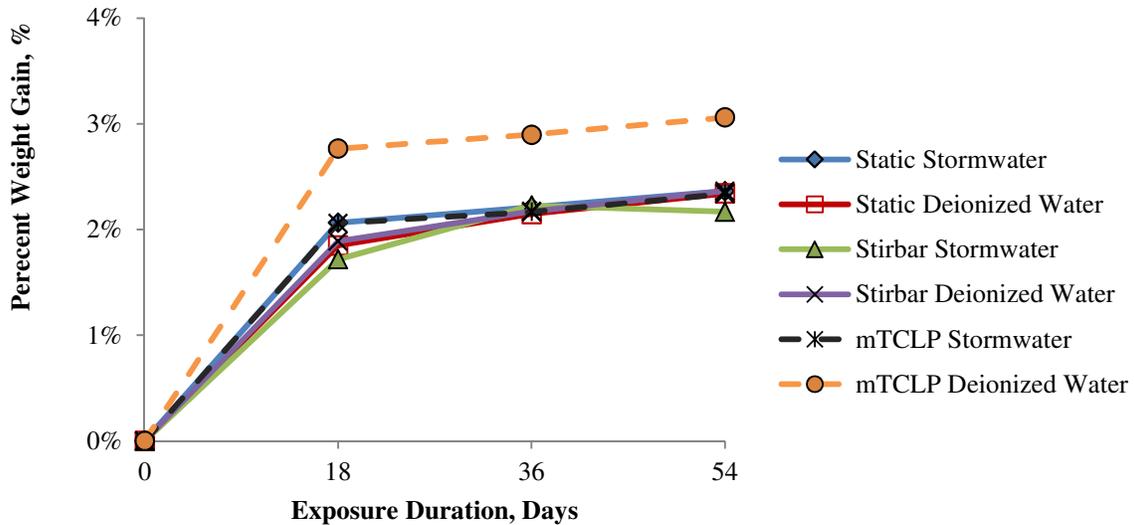
Stormwater quality monitoring conducted at two CIPP sites demonstrated that CIPP installation activities resulted in contaminated stormwater at and downstream of both stormwater culverts during the five week monitoring period. This involved water sampling immediately one day after CIPP curing and 7, 28, and 35 days after material installation. Outlet and downstream COD levels ranged from 100 ppm to 375 ppm and styrene concentration was 0.01 ppm to 7.4 ppm. Styrene results were similar to other studies reported in the literature of 0.596 ppm to 174 ppm in the stormwater (Donaldson and Baker, 2008; O'Reilly, 2008; Whelton et al., 2013). No prior investigators have reported COD levels near CIPP sites. Contaminant levels generally decreased with time; however the greatest COD and styrene concentrations were detected 15.2 m downstream of each installation site the day following material installation, not at the culvert outlets (Tabor et al., 2014). Materials released by the installation process included raw uncured

resin, CIPP cut shavings the project team observed downstream, or mist observed at the entry and exit to the culvert during installation. Because COD levels of unpolluted waters are less than 20 ppm and styrene is not present, it can be concluded that the CIPP installation process polluted the environment at these locations.

Another important finding is that CIPP process liquid waste generated by the installation contractor was not discharged into waterways, but collected for appropriate process and disposal off site. During past CIPP incidents in several other states, process liquid has been discharged directly into the environment and sanitary sewer systems, compromising water quality (Whelton et al., 2013). A combined sample of CIPP condensate waste for these two Alabama sites had a pH of 6.2, 36,000 ppm COD, and an elevated styrene level. This liquid, once cooled to room temperature, totally dissolved *Daphnia magna* during the toxicity test within 24 h; no organisms remained for mortality counting. When condensate was diluted by a factor of 10,000, 100% mortality of the *Daphnia magna* occurred. This finding was significant because the aqueous styrene concentration of this dilution was less than the *Daphnia magna* LC<sub>50</sub>, indicating that non-styrene contaminants or a mix of contaminants were likely responsible for *Daphnia magna* mortality. A laboratory leaching test that predicts field stormwater quality impacts must consider these factors.

### **Laboratory Material Leaching Protocols: Water Uptake**

It is well known that polar polymers such as polyester can sorb water (Lee and Rockett, 1992), although water sorption by CIPP has not previously been examined. All CIPP specimens examined in this work sorbed water during the 54 hr contact period during all leaching procedures (Figure 3). The greatest amount of weight gain occurred during the first contact period of all leaching procedures, which corresponded to the greatest mass of organic chemical released during all leaching procedures. CIPP likely sorbed water because it consisted of the polar and unsaturated polyester polymer. Researchers who have examined similar unsaturated polyester composites have also reported a weight gain between 1% and 12% based on the amount of polyester resin in the composite at room temperature while submerged in deionized water over a 30 h exposure (Dhakal et al., 2006; Ferracane, 1994). With the exception of the mTCLP deionized water agitation, all other leaching procedures caused CIPP samples to gain 1.6% to 2.1% weight (Figure 3). CIPP samples that underwent mTCLP testing with deionized water gained 3.0% weight after 54 hr. This finding indicated that the mTCLP deionized water method may have provided conditions whereby a greater quantity of contaminants was extracted from CIPP specimens than the other procedures. Contaminants likely extracted included uncured resin, initiators, and ingredient degradation byproducts.



**Figure 3. All CIPP Specimens Sorbed Water As Demonstrated by Weight Gain Measurement at Room Temperature**

### Comparison of Contaminant Levels Across the Three Leaching Methods

By comparing COD, UV<sub>254</sub> absorbance, and styrene levels the impact of agitation, water type and exposure time on water quality was determined. UV<sub>254</sub> absorbance has not been considered as a water quality impact leaching parameter by other stormwater infrastructure material leaching researchers because it is an indicator of aromatic compound concentration in contact waters. However, for this study, since little was known about what aromatic contaminants were released by CIPP operations, UV<sub>254</sub> absorbance measurement was applied.

Tables 3 through 6 and Figure 4 show that the mTCLP testing method resulted in the greatest COD, UV<sub>254</sub> absorbance, and styrene levels. Appendix G also describes these results but shows contaminant flux calculations based on CIPP sample surface area and water volume ratio per laboratory experiment. Water type had no effect on either COD or UV<sub>254</sub> absorbance levels, but deionized water was found to facilitate styrene release more than synthetic stormwater. Interestingly, CIPP specimens that underwent mTCLP testing with deionized water gained the most weight and released the greatest amount of styrene into water. Both COD and UV<sub>254</sub> absorbance results demonstrate that there is a significant quantity of organic contaminants released other than styrene.

For all methods, the greatest amount of chemicals imparted into the water occurred during the initial exposure period. Styrene was released by the CIPP examined in this work and this finding is supported by field CIPP water quality impact efforts by other investigators (Donaldson and Baker, 2008; O'Reilly, 2008; Tabor et al., 2014). Unique to this study, however, was that a number of other chemical contaminants detailed in subsequent sections were also found in extraction waters. Alkalinity, pH, and hardness were unchanged throughout the entire 54 hr exposure period. None of the extraction waters caused *Daphnia magna* mortality, and styrene levels in those extraction waters did not exceed LC<sub>50</sub> values.

**Table 3. Statistical Significance of Agitation Method, Water Type, and Exposure Time That Affected Water Quality**

Factor	Parameter <sup>a</sup>		
	COD	UV <sub>254</sub>	Styrene
Agitation	Yes (0.007)	Yes (<0.001)	Yes (<0.001)
Water Type	No (0.087)	No (0.589)	Yes (<0.001)
Exposure Time	No (0.881)	Yes (<0.001)	Yes (0.010)
<i>Interactions</i>			
Agitation x Water Type	No (0.085)	Yes (<0.001)	Yes (0.036)
Agitation x Exposure Time	Yes (<0.001)	Yes (<0.001)	No (0.484)
Water Type x Exposure Time	No (0.815)	No (0.270)	No (0.746)

<sup>a</sup> Experimentally determined *p* values shown. Agitation refers to the stir bar and mTCLP testing only. The table shows which factors were found to influence COD, UV<sub>254</sub>, and styrene levels in contact water.

**Table 4. Chemical Oxygen Demand Comparison Across Static, Stirbar, and mTCLP Methods with Mean and Standard Deviation**

Agitation Method and Water Type	Concentration (ppm) and Exposure Period <sup>a</sup>			Total Mass of COD Released (mg) <sup>b</sup>
	1	2	3	
Static				
Stormwater	5.67 + 0.15	6.17 + 0.81	11.40 + 1.30	23.23
Deionized water	4.23 + 0.40	4.53 + 0.23	8.17 + 0.91	16.93
Stirbar				
Stormwater	6.50 + 0.36	7.70 + 1.39	13.77 + 0.71	27.97
Deionized water	4.83 + 0.49	5.20 + 1.31	8.70 + 0.40	18.73
mTCLP				
Stormwater	30.00 + 4.38	24.53 + 0.12	19.97 + 1.42	74.50
Deionized water	28.67 + 7.55	27.27 + 5.87	23.03 + 0.60	78.97

<sup>a</sup> Mean and standard deviation values shown.

<sup>b</sup> Total mass of COD calculated by the addition of mean concentration for each exposure period.

**Table 5. Ultraviolet 254 nm Absorbance Comparison Across Static, Stirbar, and mTCLP Methods**

Agitation Method and Water Type	Absorbance (cm <sup>-1</sup> ) and Exposure Period <sup>a</sup>		
	1	2	3
Static			
Stormwater	0.010 + 0.001	0.000 + 0.000	0.007 + 0.001
Deionized water	0.006 + 0.001	0.000 + 0.000	0.006 + 0.001
Stirbar			
Stormwater	0.011 + 0.002	0.004 + 0.007	0.011 + 0.000
Deionized water	0.009 + 0.002	0.000 + 0.000	0.007 + 0.000
mTCLP			
Stormwater	0.080 + 0.001	0.010 + 0.004	0.021 + 0.000
Deionized water	0.086 + 0.001	0.009 + 0.004	0.026 + 0.000

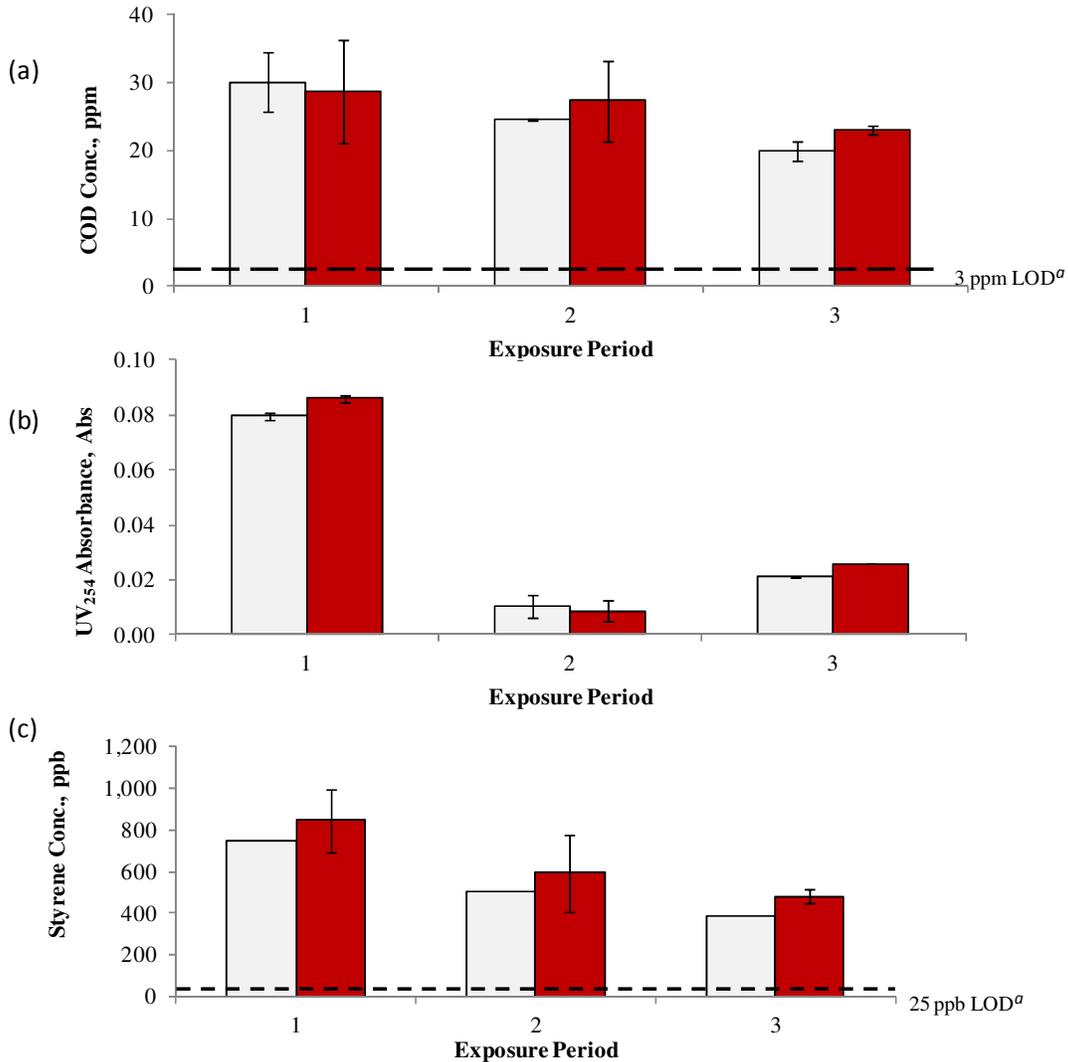
<sup>a</sup> Mean and standard deviation values shown.

**Table 6. Styrene Concentration Comparison Across Static, Stirbar, and mTCLP Methods**

Agitation Method and Water Type	Concentration (ppb) and Exposure Period <sup>a</sup>			Total Styrene Released (mg) <sup>b</sup>
	1	2	3	
Static				
Stormwater	674.71 + 221.13	728.06 + 26.69	626.46 + 252.95	2.03
Deionized water	708.79 + 46.20	647.82 + 24.07	354.97 + 92.98	1.71
Stirbar				
Stormwater	823.36 + 125.54	928.59 + 290.66	533.61 + 66.36	2.29
Deionized water	580.19 + 199.63	606.54 + 226.28	243.36 + 59.19	1.43
mTCLP				
Stormwater	1594.46 + 1002.16	2241.13 + 131.03	1363.68 + 772.03	5.20
Deionized water	896.45 + 558.00	1200.83 + 370.88	888.06 + 358.24	2.99

<sup>a</sup> Mean and standard deviation values shown.

<sup>b</sup> Total mass of styrene calculated by the addition of mean concentration for each exposure period.



**Figure 4. Mean And Standard Deviations of mTCLP Laboratory Results: (a) COD Concentration; (b) UV<sub>254</sub> Absorbance; (c) Styrene Concentration for Three Consecutive 18-hr Exposure Periods. Standard deviation for several periods was zero. Light bars represent tests using synthetic water and dark bars represent tests using deionized water. *Daphnia magna* toxicity thresholds are shown for styrene. Thresholds do not exist for COD and UV<sub>254</sub> absorbance. <sup>a</sup> LOD-Limit of detection for the GC-MS method.**

COD is routinely applied to describe wastewater quality, but has been sparingly applied to monitor chemical release from polymer materials in contact with water (Bae et al., 2002; Whelton et al., 2013). No regulatory standard exists for COD in stormwater, but typical unpolluted waterways have COD levels below 20 ppm. Changes observed for COD, UV<sub>254</sub> absorbance, and styrene levels were statistically different for subsequent 18 hr leaching periods. The variation within the COD levels was not statistically different between periods during this experiment ( $p > 0.05$ ). COD levels observed during the three sampling periods of this study ranged from 5.7 ppm to 30.0 ppm (stormwater) and 4.2 ppm to 28.7 ppm (deionized water). COD levels observed during the leaching tests were substantially less than those reported for a static leaching test on polyurea stormwater culvert coating removed from a Virginia site. In the Virginia study, a 100 ppm COD level was observed during the first 3-day static exposure period (Donaldson and Baker, 2008; Whelton et al., 2013).

Like COD, no UV<sub>254</sub> absorbance regulatory standard exists but UV<sub>254</sub> absorbance can be applied as a surrogate parameter to provide insight into aromatic contaminant release from materials. A substantial reduction in UV<sub>254</sub> absorbance for all leaching methods was detected after the first exposure period. This finding indicated that the greatest amount of aromatic organic material was released during the initial exposure period. Interestingly, UV<sub>254</sub> absorbance levels were slightly greater during the third exposure period compared to the second exposure period, but remained far less than those observed during the first exposure period.

There are no regulatory standards for styrene levels in the environment, but because styrene is an aromatic contaminant it can be detected by two of the analytical methods applied: UV spectroscopy and GC-MS methods. A statistically significant reduction in styrene level was detected during the experiment for all leaching methods ( $p = 0.010$ ). Because the UV absorbance results do not demonstrate a similar trend, it can be concluded that non-styrene contaminants were present and also contributed to UV absorbance results. The application of multiple water quality parameters (COD, UV<sub>254</sub> absorbance, and styrene) to infrastructure rehabilitation material leaching assessments helped describe CIPP chemical release.

### **Role of Specimen Storage in CIPP Water Quality Impacts**

The leaching behavior of newly cured CIPP material was compared to the leaching behavior of the same CIPP material stored in a room temperature laboratory for 70 days. Similar to the new CIPP specimen, the 70-day-old specimen underwent mTCLP testing. COD and styrene results demonstrated that the aged CIPP sample imparted less mass of organic material into the water ( $p < 0.001$ ). The difference between UV<sub>254</sub> absorbance for water that contacted 70 day old CIPP and new CIPP was not statistically significant. Similar to new CIPP material, water type did not affect COD or UV absorbance levels, but deionized water extracted more styrene than stormwater (Table 7). Deionized water extracted more aromatic compounds from the aged sample than the synthetic stormwater. The aged CIPP sample leachate water was not acutely toxic to *Daphnia magna*. The differences may be due to volatilization of some of the compounds found in cured CIPP during holding.

**Table 7. Comparison Between mTCLP Testing Results for New and 70-Day Stored CIPP Specimens**

Parameter <sup>a</sup>	Percent Difference Between Aged CIPP and New CIPP Materials	
	Stormwater mTCLP	Deionized water mTCLP
COD, ppm	-27.5%	-26.9%
UV <sub>254</sub> , cm <sup>-1</sup>	0%	0%
Styrene, ppm	-48.0%	+6.0%

<sup>a</sup> Stormwater mTCLP contact water was not found to be toxic to *Daphnia magna* after 48 hr testing; The toxicity of deionized water mTCLP contact water was not evaluated because deionized water cannot sustain *Daphnia magna* life.

### Comparison of Laboratory Leaching Results to Field Stormwater Quality Data

Laboratory extraction water results were compared to field stormwater collected at the CIPP installation site. Field stormwater was collected entering, exiting, and 50 feet downstream of the culvert one day after installation and was monitored for five weeks. Stormwater samples were characterized for organic contaminants because prior work demonstrated that CIPP process wastewater contained limited metal loadings (Tabor et al., 2014). Only zinc (1.01 ppm) and copper (0.030 ppm) were detected above background levels in the wastewater (EPA, 1983). These metals are estimated to be used for CIPP coloring and catalysts (Vernardakis, 2006). Based on these low metal concentrations, metal contaminant levels were not monitored during laboratory material leaching experiments.

Of the three protocols evaluated, the mTCLP method most closely predicted field water quality (COD, UV<sub>254</sub>, and styrene) levels, while the static and stirbar laboratory leaching methods poorly predicted COD and UV<sub>254</sub> absorbance levels (Table 8). The mTCLP method resulted in nearly 95% of the field styrene concentration after 54-hr exposure.

**Table 8. Comparison Between Stormwater Quality at CIPP Culvert Outlet and Laboratory Stormwater Leaching Methods**

Parameter	Field Culvert Outlet 1 Day After Install	Percent Field Levels Predicted Laboratory Stormwater Leaching Result					
		First Exposure Period			Σ All Exposure Periods		
		Static	Stirbar	mTCLP	Static	Stirbar	mTCLP
COD, ppm	361.67	1.6%	1.8%	8.3%	6.4%	7.7%	20.6%
UV <sub>254</sub> , Abs	3.50	0.2%	0.2%	2.3%	-	-	-
Styrene, ppm	5.48	12.3%	15.0%	29.1%	37.0%	41.8%	94.9%
<i>Daphnia magna</i> 48 hr Toxicity	No	No	No	No	-	-	-
TICs <sup>a</sup> found by LLE <sup>b</sup> GC-MS <sup>c</sup>	22	1	1	4	-	-	-
TICs <sup>a</sup> found by SPME <sup>d</sup> GC-MS <sup>c</sup>	3	3	3	3	-	-	-
TICs <sup>a</sup> found in both field and lab analysis	2	1	1	4	-	-	-

<sup>a</sup> TIC = tentatively identified compound with greater than a 90% National Institute for Standards and Technology (NIST) library match.

<sup>b</sup> LLE = Liquid-Liquid Extraction.

<sup>c</sup> GC-MS = Gas Chromatography-Mass Spectrometry.

<sup>d</sup> SPME = Solid Phase Microextraction; The SA/V ratio used for laboratory leaching result scaling was 6.82.

The UV<sub>254</sub> absorbance observed by the mTCLP testing was significantly less than the field parameter at the installation site (<10%). Moreover, stormwater is known to contain natural organic matter (NOM) and this can affect UV<sub>254</sub> absorbance values. The laboratory prepared synthetic stormwater did not contain NOM (Badin et al., 2008). The NOM, however, would not be a source of tentatively identified compounds found in this study. It is known, however, that NOM could influence organic chemical fate and resulting toxicity.

Of all testing methods, the field stormwater styrene concentration was best predicted by mTCLP. The literature reports styrene concentrations ranging from 0.596 ppm to 174 ppm the water (Donaldson and Baker, 2008; O'Reilly, 2008; Whelton et al., 2012). The mTCLP method resulted in almost 95% (5.20 ppm) of the total field stormwater styrene concentration after 54 hr exposure. These contact waters had 1.5, 2.2, and 1.3 ppm concentrations of styrene, below the 4.7 ppm *Daphnia magna* LC<sub>50</sub> values summarized by others (Donaldson and Baker 2008). None of the lab extraction waters was found to cause *Daphnia magna* mortality over a 48 h period, and this finding agreed with the field data.

Of the 22 stormwater compounds found exiting the CIPP culvert in the field, only five were detected in mTCLP extraction waters. These tentatively identified chemicals included a known CIPP ingredient (styrene), a likely formulation solvent (benzene), a known degradation byproduct of the CIPP initiator Perkadox (4-(1,1-dimethylethyl)-cyclohexanol) and one compound of unknown origin (*N*-Butyl-benzenesulfonamide) (AzkoNobel, 2013). The 17 compounds not found in laboratory extraction waters but were present in the stormwater exiting the CIPP culvert represented known plasticizers (diisooctyl phthalate and dibutyl phthalate) and many compounds of unknown origin (Table 9). Additional work should be focused on confirming and quantifying these contaminants in stormwater and within the CIPP material. Extraction, detection, confirmation, and quantification of these compounds will be difficult and time intensive as there are few readily available chemical standards. It is likely that volatile compounds in Table 9 that have high octanol/water coefficients (styrene and benzene) can become dissolved in the water during the steam curing process or may readily sorb to organic matter or volatilize (Siskin and Katritzky, 2000).

The literature review showed that some of the compounds found at the CIPP installation site are known carcinogens (benzene and styrene), endocrine disrupting chemicals (diisooctyl phthalate and dibutyl phthalate) and degradation byproducts (4-(1,1-dimethylethyl)-cyclohexanol) (AzkoNobel, 2008, 2013; Crisp et al., 1997). All of these compounds were also found in the waters that contacted CIPP samples in mTCLP testing, except those endocrine disrupting chemicals. However, diethyl phthalate (84-66-2) is an endocrine disrupting chemical found in the mTCLP that has smaller molecular weight and could possibly be a degradation byproduct of the above chemicals. These chemicals were extracted from the contact water using LLE with DCM as the extraction solvent.

**Table 9. Comparison Between Tentatively Identified Compounds Detected at Field Site and mTCLP Laboratory Protocol**

Compound Name (CAS #) <sup>a</sup>	RT <sup>b</sup> , min.	Water Sample and Percent NIST Library Match (Signal Intensity, Abundance)		
		Field <sup>c</sup> : Culvert Outlet	Field <sup>c</sup> : Downstream	Lab: mTCLP <sup>d</sup> Period 1
<b>Detected at Field CIPP Site and mTCLP Extraction Waters</b>				
Styrene (100-42-5)	6.5	96% (20,464,217)	96% (27,414,633)	90% (14,929,977)
Benzene (71-43-2)	9.6	91% (749,259)	97% (460,648)	94% (1,265,726)
4-(1,1-dimethylethyl)-Cyclohexanol <sup>f</sup> (98-52-2)	11.6	90% (7,591,072)	95% (625,427)	83% (518,992)
N-Butyl-benzenesulfonamide (3622-84-2)	17.7	94% (148,133)	ND <sup>e</sup>	64% (323,037)
<b>Detected Only at Field CIPP Site</b>				
Cyclohexanone, 4-(1,1-dimethylethyl)- <sup>f</sup> (98-53-3)	11.8	93% (432,879)	94% (681,091)	ND <sup>e</sup>
4,7-Methano-1H-indenol, hexahydro (37275-49-3)	12.5	97% (801,334)	97% (176,753)	ND <sup>e</sup>
1-Hydroxymethyl-2-methyl-1-cyclohexene (29474-11-1)	13.3	91% (1,202,082)	93% (105,648)	ND <sup>e</sup>
2(3H)-Benzothiazolone (934-34-9)	16.6	94% (334,384)	94% (1,302,273)	ND <sup>e</sup>
n-Hexadecanoic acid (57-10-3)	19.1	96% (912,733)	96% (1,213,783)	ND <sup>e</sup>
Octadecanoic acid (57-11-4)	20.6	99% (1,040,354)	99% (1,312,631)	ND <sup>e</sup>
Phthalic acid, di(oct-3-yl) ester (1000377-72-3)	23.4	86% (386,808)	80% (660,056)	ND <sup>e</sup>

<sup>a</sup> Chemical properties were obtained from the U.S. EPA's EPIWEB database.

<sup>b</sup> RT = retention time.

<sup>c</sup> Field results shown represent stormwater.

<sup>d</sup> mTCLP results shown represent laboratory prepared stormwater.

<sup>e</sup> Not detected.

<sup>f</sup> Known degradation byproducts of Perkadox.

### Findings Related to Implementing a Standardized Test Method

The mTCLP method identified in this work shows promise for predicting water quality impacts of one stormwater infrastructure rehabilitation material, specifically for styrene release. This method should be further tested against other materials for validation purposes. Testing should consider mTCLP testing and a comparison to field stormwater quality levels. Future work should focus on evaluating the ability of the mTLCP method to predict chemical levels observed in the field at multiple stormwater culvert rehabilitation sites. More investigation is also needed to identify construction specifications that minimize the environmental impacts of infrastructure rehabilitation materials.

None of the laboratory leaching protocols was designed to predict environmental impacts due to the installation process itself, such as moving the resin impregnated fabric into place, curing, cutting CIPP pipe, cleanup, etc. Laboratory leaching protocols were designed to determine the environmental impacts caused by the material removed from the field after the installation. All leaching protocols examined under predicted chemical levels observed in the field. Evidence from this testing revealed that the act of installing the stormwater culvert rehabilitation material posed a greater environmental risk than the material itself.

Laboratory leaching protocols examined in this study are limited in that (1) the CIPP specimen only represented one curing condition and formulation. The GC-MS analytical and DCM extraction methods applied may also not have extracted and detected all contaminants present. These methods were optimized for nonpolar organic contaminant extraction, not polar organic chemicals. To understand better the environmental impact of rehabilitation methods, a broad suit of environmental characterization methods should be applied.

### **Non-Styrene Contaminants Released at Field Installation Sites**

Contractors followed condensate collection practices as outlined in ALDOT contract specifications. Despite their compliance, their in-situ stormwater culvert rehabilitation activity caused environmental contamination and contaminants were present in the environment for at least 30 days. Moreover, past investigators outside Alabama (as summarized in the literature review) have only tested for styrene levels and not other contaminants released by CIPP materials during and following installation. Thus, with the exception of this effort, there are no data that describe environmental contamination caused by CIPP sites for non-styrene compounds. Styrene is highly volatile and other more persistent contaminants released during and following material installation may be more of an environmental concern.

### **Construction Specifications**

ALDOT CIPP specifications and those of many DOTs across the United States, including VDOT, are primarily based on limiting styrene release, and have not included the release of other contaminants into the environment. As a result, there remains a significant knowledge gap of what contaminants are released from infrastructure rehabilitation sites, at what levels, and for what duration. Should VDOT continue to permit specification of in-situ culvert rehabilitation methods, a large-scale environmental sampling activity should be considered. The scale and duration of environmental impacts caused by other culvert rehabilitation technologies and best construction practices that prevent contamination remain poorly understood. To avoid costly construction specification requirements that have little influence on protecting the environment, additional research is recommended.

## CONCLUSIONS

- *Of the three protocols evaluated, the mTCLP dynamic protocol most closely predicts field stormwater quality, whereas both static and stirbar methods demonstrate a poor ability to predict field water quality at the CIPP site.*
- *The mTCLP method predicts total stormwater styrene concentrations well, but underpredicts other water quality indicators evaluated. The application of this method resulted in nearly 95% (5.20 ppm) of the field styrene concentration after 54 hr exposure, but only 20.6% of the total field values of COD and 2.3% of UV absorbance.*
- *The comparison between chemical levels in the laboratory and field indicates that the act of installing the stormwater culvert rehabilitation material poses a greater risk to water quality than the material itself. Specifically, materials observed being released by the installation process included raw uncured resin, CIPP cut shavings the project team observed downstream, or mist observed at the entry and exit to the culvert during installation. This limitation must be recognized when the test method is adopted and efforts should be considered to better understand and limit installation practices from causing environmental contamination.*
- *CIPP samples gain weight when in contact with water, indicating that contaminants are released from the sample as the water is sorbed. The greatest change in sample weight occurred during the first 18 hr exposure period which correlated to the largest COD concentration, UV<sub>254</sub> absorbance and styrene concentration.*
- *Organic chemicals other than styrene are released by CIPP such as benzene, 4-(1,1-dimethylethyl)-cyclohexanol, 4-(1,1-dimethylethyl)-cyclohexanone, and several phthalates. This research effort contains the first report of non-styrene contaminants in CIPP condensate and released by installed CIPP into stormwater.*
- *CIPP samples stored for 70 days at room temperature release fewer chemicals into water when compared to freshly cured CIPP. This is likely due to chemical volatilization and continuation of the curing process.*

## RECOMMENDATIONS

1. *Based on the research findings that the CIPP material installation process and the material itself can introduce contaminants into the environment, VDOT's Materials, Construction, and Environmental Divisions should consider adding the following requirements to VDOT's CIPP specifications (VDOT, 2014):*
  - *Water samples should be tested for total organic carbon, chemical oxygen demand, pH and temperature in addition to the current testing requirements (VDOT, 2014). As stated in the current requirements, samples should be collected by a qualified independent*

environmental services laboratory or environmental consultant and should be collected in accordance with applicable ASTM standard procedures.

- *The Contractor shall complete and submit a water sample reporting form (to be referenced in the revised CIPP specifications to the VDOT Engineer and VCTIR within 4 weeks after completion of the rehabilitation. Sampling and reporting details will be provided in the form.*
2. *VCTIR should consider participating in a pooled fund effort or other national effort that investigates one or more of the following:*
- *the ability of the mTLCP method to predict to predict chemical levels observed in the field at multiple stormwater culvert rehabilitation sites and additional materials*
  - *the number, concentration, and toxicological significance of other (non-styrene) contaminants released at CIPP field installation sites*
  - *the ability of specific specification measures to limit contamination.*

## **BENEFITS AND IMPLEMENTATION PROSPECTS**

With millions of aging stormwater culverts installed across the United States, all DOTs will need to select cost-effective culvert rehabilitation practices and materials. As new infrastructure rehabilitation materials are introduced into the trenchless rehabilitation market, costs associated with evaluating the environmental impact of each installation site separately will grow exponentially. It is not sustainable for VDOT to fully characterize the environmental impacts of every technology that is proposed for use in the Commonwealth. This is a technology research and development expense that should be shouldered before the technology is presented to a state DOT. for this reason, an infrastructure rehabilitation material test method is very much needed so that the technology innovators can pre-test their processes and materials and demonstrate to DOTs that their approach does not harm the environment or nearby population. This project demonstrates that the mTCLP approach shows promise as an environmental impact testing approach.

The test method developed can quantify the water quality impacts of exhumed stormwater pipe rehabilitation materials, from a chemical and ecological standpoint. This method would enable VDOT to review the data to determine the degree and duration of water quality impacts caused by exhumed materials. Several water quality characterization methods demonstrated their value in this project. All DOTs should consider this approach for existing and future rehabilitation materials as an effort to identify any environmental issues with the infrastructure repair technologies.

This project has underscored that DOTs should not be constricted to testing for only chemicals the manufacturer reports to use in their formulations when investigating

environmental contamination. While there are main chemical ingredients manufacturers apply in their formulations, “minor” compounds and ingredient degradation products were detected in the present study in stormwater and during laboratory leaching testing. These compounds could be more environmentally persistent and toxic than the main formulation ingredients. Future DOT environmental impact projects should involve characterization for a broad array of contaminants, not just those reported by the material manufacturers.

A significant benefit of this project is that science based evidence now exists that demonstrates culvert rehabilitation processes can release a number of contaminants into the environment, even when waste is collected (per construction specifications) during and following culvert repair. All DOTs can now reevaluate their construction specifications for culvert rehabilitation materials and more closely scrutinize the technologies being used and proposed for culvert repair.

### ACKNOWLEDGMENTS

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## APPENDIX A

### SYNTHETIC STORMWATER RECIPE

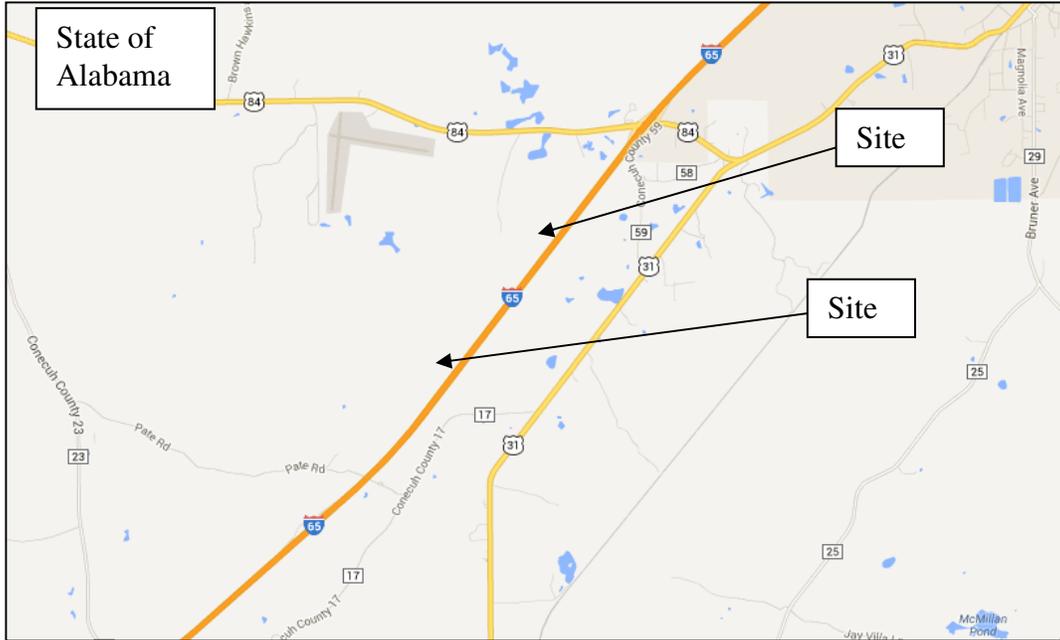
pH: 6.8-8.2  
Hardness: 160-180 ppm as  $\text{CaCO}_3$   
Alkalinity: 110-120 ppm as  $\text{CaCO}_3$

2.00 g  $\text{NaCO}_3$   
1.54 g  $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$   
1.84 g  $\text{MgSO}_4$   
5 drops of HCl to drop pH to approximately 7.3  
10 L of Deionized Water



## APPENDIX B

### CIPP INSTALLATION SITES IN EVERGREEN, ALABAMA



**Locations of CIPP Installation Sites 1 and 2 Along I-65. Site 1 was located 31.38° N, 87.04° W, and Site 2 was Located 31.30° N, 87.03° W.**



**APPENDIX C**

**CIPP INSTALLATION ACTIVITIES AT SITE 2**



**Site 2 CIPP installation activities were observed on July 9, 2013.**



**APPENDIX D**

**SAMPLE COLLECTED BEFORE INSTALLATION ON SITE 2**



**Site 2 upstream water sample collection on July 18, 2013, prior to CIPP installation.**



**APPENDIX E**

**SITE 1 CULVERT INLET**

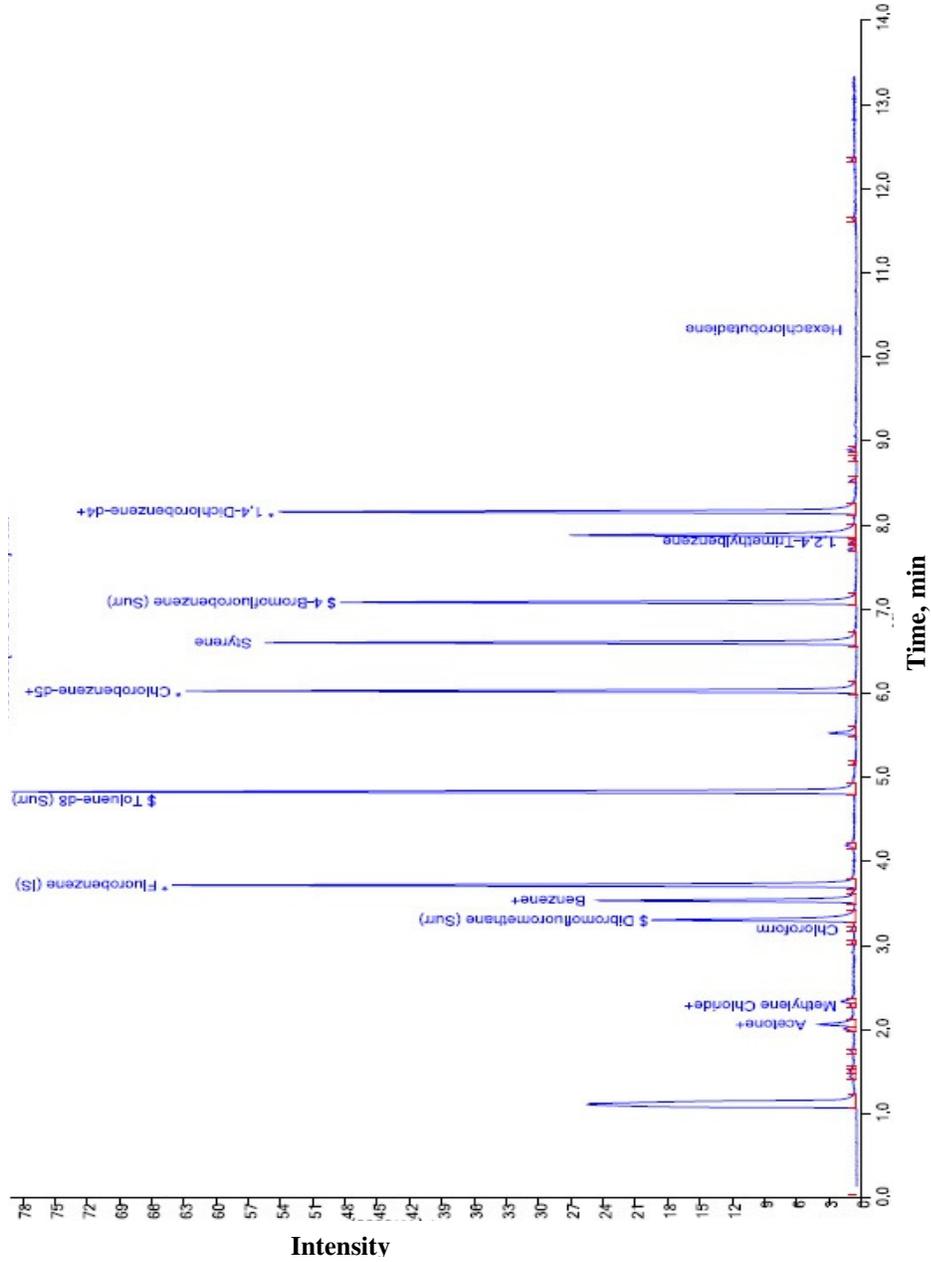


**CIPP culvert inlet at Site 1 had been cured for approximately 1 week when visited on July 2, 2012.**



# APPENDIX F

## GC-MS CHROMATOGRAM FOR CIPP CONDENSATE



GC-MS Chromatogram for CIPP Wastewater Diluted by a Factor of 100 After LLE With EPA 8260. The internal standards are shown as (Surr), (IS), d4 and d5: dibromofluoromethane, fluorobenzene, toluene, chlorobenzene, 4-bromofluorobenzene, and 1,4 dichlorobenzene.



## APPENDIX G

### CONTAMINANT FLUX RESULTS FOR LABORATORY EXPERIMENTS AND FIELD DATA

**Table A1. Chemical Oxygen Demand Flux Comparison Across Static, Stirbar, and mTCLP Methods**

Agitation Method and Water Type	Flux (mg/cm <sup>2</sup> -hr) per Exposure Period		
	1	2	3
Static			
Stormwater	0.0032 + 0.0001	0.0035 + 0.0005	0.0065 + 0.0007
Deionized water	0.0024 + 0.0002	0.0026 + 0.0001	0.0046 + 0.0005
Stirbar			
Stormwater	0.0037 + 0.0002	0.0044 + 0.0008	0.0078 + 0.0004
Deionized water	0.0027 + 0.0003	0.0029 + 0.0007	0.0049 + 0.0002
mTCLP			
Stormwater	0.0169 + 0.0024	0.1388 + 0.0001	0.0113 + 0.0008
Deionized water	0.0162 + 0.0043	0.0154 + 0.0033	0.0130 + 0.0003

**Table A2. Styrene Flux Comparison Across Static, Stirbar, and mTCLP Methods**

Agitation Method and Water Type	Flux (µg/cm <sup>2</sup> -hr) per Exposure Period		
	1	2	3
Static			
Stormwater	0.3820 + 0.1252	0.4122 + 0.0151	0.3547 + 0.1432
Deionized water	0.4008 + 0.0261	0.3663 + 0.0136	0.2007 + 0.0526
Stirbar			
Stormwater	0.4662 + 0.0711	0.5257 + 0.1646	0.3021 + 0.0376
Deionized water	0.3281 + 0.1129	0.3430 + 0.1280	0.1376 + 0.0335
mTCLP			
Stormwater	0.9027 + 0.5674	1.2688 + 0.0742	0.7721 + 0.4371
Deionized water	0.5069 + 0.3155	0.6790 + 0.2097	0.5022 + 0.2026

Flux was not calculated for UV absorbance results.

**Table A-3. Water Quality Monitoring Results From CIPP Installation Sites**

Days Following Material Installation	Parameter			
	COD, ppm	TOC, ppm	Styrene, ppm	UV <sub>254</sub> , Abs
<b>Day 0</b>				
Inlet	17.63 + 0.21	12.55 + 0.71	0.00 + 0.00	0.570 + 0.029
Outlet	361.67 + 3.06	150.80 + 18.56	5.48 + 0.25	3.500 + 0.000
Downstream	131.00 + 6.08	51.19 + 1.66	7.43 + 2.59	1.313 + 0.029
<b>Day 7</b>				
Inlet	2.67 + 1.53	12.55 + 1.62	0.48 + 0.34	0.213 + 0.005
Outlet	4.00 + 2.00	15.97 + 0.11	0.42 + 0.02	0.172 + 0.005
Downstream	26.00 + 5.57	20.43 + 0.27	7.76 + 2.30	0.393 + 0.027
<b>Day 28</b>				
Inlet	15.43 + 0.31	4.89 + 0.04	0.00 + 0.00	0.133 + 0.004
Outlet	26.03 + 0.81	7.03 + 0.09	1.27 + 0.02	0.291 + 0.002
Downstream	20.73 + 0.87	5.46 + 0.05	0.00 + 0.00	0.212 + 0.001
<b>Day 35</b>				
Inlet	6.53 + 3.39	1.88 + 0.01	0.00 + 0.00	0.063 + 0.001
Outlet	24.33 + 0.06	3.46 + 0.17	1.24 + 0.03	0.203 + 0.001
Downstream	15.43 + 3.57	3.25 + 0.08	0.00 + 0.00	0.133 + 0.001

Contaminant flux was not calculated for CIPP installation sites because of the many uncontrolled field variables (water contact time, fluctuations in water volume in the culverts, open-system permitting chemical volatilization, presence of NOM, etc.).