THE WATER QUALITY IMPLICATIONS OF PIPE REHABILITATION TECHNOLOGY

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ABSTRACT

Cured-in-place pipe (CIPP) rehabilitation is among the most commonly used trenchless pipe repair technologies, used for repairing damaged sewer, drinking water, and storm and surface water pipes across the U.S. In typical CIPP applications, a lining tube saturated with a styrene-based thermosetting resin is installed into the damaged pipe. Subsequent curing with a heat source results in a pipe-within-a-pipe.

In this study, seven styrene-based CIPP installations in surface water and stormwater conveyances maintained by the Virginia Department of Transportation (VDOT) were identified and observed over the course of one year. Water samples collected from pipe outlets at five of the seven projects showed detectable levels of styrene. The maximum duration that styrene was detected at any site was 88 days following the CIPP installation. Styrene levels at five of the sites were higher than the U.S. Environmental Protection Agency's maximum contaminant level for drinking water of 0.1 mg/L. Certain measurements were also found to exceed tolerable concentrations for several freshwater aquatic indicator species.

The findings suggest that the elevated styrene levels could have resulted from one or a combination of the following: (1) installation practices that did not capture condensate containing styrene, (2) uncured resin that escaped from the liner during installation, (3) insufficient curing of the resin, and (4) some degree of permeability in the lining material. A summary of the actions taken by the VDOT in response to the preliminary findings of this study is provided in this report.

INTRODUCTION

Because many pipes and culverts were placed more than 20 years ago, repair or replacement of damaged or worn pipes is becoming a large maintenance concern in the United States. Cured-in-place pipe (CIPP) rehabilitation is one of several "trenchless" pipe repair technologies that allow users to repair existing underground pipes in place rather than using the conventional method of unearthing and replacing sections of damaged pipe. Trenchless technologies were first developed about 25 years ago and were used primarily in western Europe until about 15 years ago, when departments of transportation and construction outfits in North America began to use them (Lueke and Ariaratnam 2001). In the mid-1990s when the city of Houston, Texas, undertook a major overhaul of its sewer system, contractors used trenchless methods for 87 percent of the repairs, involving millions of feet of pipe line. Of the many trenchless methods available, contractors used CIPP technology significantly more than any other in situ pipe rehabilitation method (Wright 1995). CIPP repair dominates the underground pipe rehabilitation industry (Hoffstadt 2000), and both under- and above-ground CIPP rehabilitation is common worldwide. The CIPP business was pioneered by Insituform Technologies, Inc., which now performs projects for industries and municipalities in 40 countries and for transportation agencies in 36 U.S. states (Insituform 2007).

Despite its widespread and frequent use, little has been investigated regarding the environmental impact of CIPP technology on surface water or aquatic habitat. Although literature on the mechanisms involved in CIPP rehabilitation is readily available, studies have not been published regarding the potential environmental impacts if effluent is leaked or discharged downstream or if chemicals leach from the cured pipe after the installation is completed. Of particular concern are the potential effects of styrene, which is commonly used as a main component of the resin that saturates the lining tube. Styrene is classified by the U.S. Environmental Protection Agency (EPA) as a mutagen and is thus potentially carcinogenic (EPA 2007). In certain concentrations, styrene is toxic to aquatic species (Qureshi *et al*. 1992, Machado 1995, Cushman *et al*. 1997, Baer *et al*. 2002).

The Virginia Department of Transportation (VDOT) uses CIPP repair technology for many of its pipes that convey streams or stormwater beneath or along roads. VDOT uses CIPP rehabilitation more than any other pipe repair method and issues contracts to several companies to perform this work (Stanley L. Hite, unpublished data).

Procedures and Materials for CIPP Installations

Typical CIPP operations begin with the project setup, which includes measures to prevent water flow through the damaged host pipe. ASTM standards for CIPP procedures specify that bypassing or diverting the flow should be done by pumping the flow to a downstream point (ASTM International 2003, ASTM International 2007). Rocks and debris are then removed from the pipe. The next phase of the operation is liner insertion. The resin-saturated liner, which has been transported from the factory via a refrigerated truck, is inserted into the host pipe. Depending on the company, the liner is either pulled or inverted through the host pipe. Inversion is accomplished by forcing air into one end of the liner, causing the liner to turn inside-out as it travels the length of the host pipe. The liner is expanded to conform to the inner dimensions of the host pipe and is subsequently cured to form a pipe-within-a-pipe. Typical curing is achieved by circulating heated water or steam through the pipe to polymerize the resin material. The curing process takes up to several hours, depending on the size of the pipe. The curing process and subsequent cool-down period generate spent process water or steam condensate. ASTM standards (ASTM International 2003, ASTM International 2007) specify that during the cool-down period, hot water or steam effluent should be drained through a small hole in the downstream end of the pipe and replaced with the introduction of cool water. Following the cool-down period, the closed ends of the cured liner are cut open, and generally a video camera is inserted into the pipe for a final inspection. A more detailed explanation of CIPP procedures is provided in ASTM F1743-96(2003) (ASTM International 2003), ASTM F1216-07b (ASTM International 2007), and ASTM D5813-04 (ASTM International 2004). These standards contain a caveat that "it is the responsibility of the user to establish appropriate safety and health practices and determine applicability of regulatory limitations prior to use" (ASTM International 2003, ASTM International 2004, ASTM International 2007).

The pipe lining material used in CIPP operations is composed of absorbent non-woven felt fabric that is pre-saturated (at the manufacturing facility) with a thermosetting resin. Typically, the liner tube has a membrane coating to protect and contain the resin; the membrane is generally a flexible thermoplastic, such as polyethylene or polyurethane (Hoffstadt 2000). This coating is normally only on the inner surface of the finished product. This allows the resin to migrate into any voids in the host pipe such as joints or cracks prior to curing. Three types of resins are typically used in CIPP applications: unsaturated polyester resins, vinyl ester resins, and epoxies (Hoffstadt 2000). Unsaturated polyester resin and vinyl ester resins are the most common and contain styrene; epoxies do not.

The styrene content of polyester and vinyl ester resins is generally on the order of 30 to 50 percent (by weight). A Material Safety Data Sheet (MSDS) obtained from one vendor shows the styrene content of the resin to be 44 percent (by weight), with the remaining components composed of unspecified polymers (50% to 54%) and colloidal silica (1% to 5%) (Ashland 2005).

Standards and Toxicity Studies on Styrene Concentrations in Water

The EPA drinking water standard lists the maximum contaminant level (MCL) for styrene as 0.1 mg/L (0.1 parts per million [ppm]) (EPA 2007). The EPA does not have established regulatory standards for ecological toxicity specifically for styrene concentrations in water. In Canada, however, a section of the British Columbia Environmental Management Act sets limits for toxins in discharged effluent (Environmental Management Act 1999). Under the act's Municipal Sewerage Regulation (which includes regulations for surface water), effluent must not be discharged unless any toxins in the effluent are below the lethal limit for rainbow trout (*Oncorhynchus mykiss*) as determined by Environment Canada's 96-hr LC_{50} bioassay test method (i.e., the concentration required to kill 50% of the test population after 96 hours of exposure to that concentration) for this species (Environment Canada 1990).

Numerous acute toxicity studies have documented the impacts of styrene on aquatic organisms (Qureshi *et al*. 1992, Machado 1995, Cushman *et al*. 1997, Baer *et al*. 2002). Table 1 provides a summary of published values for acute styrene toxicity studies for several aquatic indicator species that are found in freshwater habitats throughout the United States. Indicator species are sensitive to pollutants, and their disappearance from a body of water can be indicative of contamination.

The literature reveals that spills of uncured resin from CIPP installations can cause large fish kills. Three to four gallons of uncured resin were released during a CIPP installation (the location of which was not disclosed in the report) on a stormwater drain (Lockheed Martin Energy Systems 2007). The residual uncured resins were carried to a creek, resulting in the death of more than 5,500 fish of various species. Water samples indicated a 100 ppm (100 mg/L) concentration of styrene in the downstream manhole at the project site (Lockheed Martin Energy Systems 2007). Except in the immediate vicinity of a spill, typical environmental exposures of styrene are not deemed to cause deleterious effects on natural communities of organisms (Alexander 1997). Styrene volatilizes rapidly and has not been shown to bioaccumulate in organisms to any measurable extent (Alexander 1997). Rates of volatilization are dependent on many factors, including styrene concentration, water temperature, and oxygen availability. Styrene compounds degrade more rapidly once microorganisms adapt to their presence (Alexander 1997, Bogacka *et al*. 1997). Bogacka et al. found that the styrene (and other aromatic hydrocarbons) introduced to river water in concentrations up to 37 mg/L was reduced by 99 percent after 20 days (1997). Fu and Alexander found that 50 percent of 2 to 10 mg/L was lost by volatilization in 1 to 3 hours in lake water samples (1992).

Table 1. Styrene toxicities for various freshwater indicator species.

Aquatic Species	**LC_{50} or EC_{50}[a] (mg/L)**	**NOEC[b] (mg/L)**	**Reference**
Water flea (*Daphnia magna*)	48-hr EC_{50}: 4.7 48-hr EC_{50}: 1.3	1.9 0.81	(Cushman *et al*. 1997) (Baer *et al*. 1995)
Amphipod (*Hyalella azteca*)	96-hr LC_{50}: 9.5	4.1	(Cushman *et al*. 1997)
Fathead minnow (*Pimephales promelas*)	96-hr LC_{50}: 5.2 96-hr LC_{50}: 10	2.6 4	(Baer *et al*. 2002) (Machado 1995)
Rainbow trout (*Oncorhynchus mykiss*)	96-hr LC_{50}: 2.5	NA	(Qureshi *et al.* 1982)
Freshwater green algae (*Selenastrum capricornutum*)	96-hr EC_{50}: 0.72 72-hr EC_{50}: 2.3	0.063 0.53	(Cushman *et al.* 1997) (Baer *et al.* 1995)

[a] Lethal concentration (LC_{50}) and effective concentration (EC_{50}), or the concentration required to kill (LC_{50}) or have a defined effect on (EC_{50}) 50% of the test population after a given number of hours of exposure in that concentration.

[b] No Observable Effect Concentration or the highest limit at which no mortalities or abnormalities were observed.

Styrene has a high degree of adsorption onto soils, and although styrene will mineralize to carbon dioxide under aerobic conditions (Fu and Alexander 1992), some is readily desorbed from soil and can enter groundwater. It is not expected to be transported considerable distances through soil, however, because of its high biodegradability (Fu and Alexander 1992).

PURPOSE AND SCOPE

The purpose of this study was to evaluate the potential for impacts on water quality from use of the steam-cured CIPP process. Of the thermosetting resins used in CIPP applications, styrene-based resins are the most common. Thus, this research focused on styrene-based CIPP products.

To gather information on the methods used in VDOT's CIPP installations and to analyze the impacts that the process might have on water quality, seven steam-cured CIPP installations in Virginia were identified and observed over the course of a 1-year study. Water samples were collected from each project site and analyzed for styrene. The results were then evaluated for compliance with established regulatory standards and published aquatic toxicity criteria.

METHODS

Seven CIPP installations were identified within the Piedmont and Blue Ridge Physiographic Provinces of Virginia, and water samples were collected over the course of this 1-year study (see Table 2). The installations were conducted by three primary companies that perform CIPP rehabilitation in Virginia. All project sites were surface water conveyances where the pipe inlet and outlet were exposed with the exception of Site 4, which was an entirely subsurface stormwater conveyance. None of these sites directly links to a source of drinking water.

Table 2. Project descriptions for seven CIPP installations in Virginia

			Pipe Size		
Site	**County**	**Route No.**	**Diameter (in)**	**Length (ft)**	**Conveyance Description**
1	Spotsylvania	1316	36	71	Conveys an unnamed tributary drainage to Massaponax Creek. Drains into concrete-lined ditch. Continual flow.
2	Prince Edward	15	18	60	Conveys an unnamed tributary drainage to Briery Creek. Drains into earthen ditch. Intermittent flow.
3	Prince Edward	628	30	100	Conveys an unnamed tributary drainage to Dickenson branch of Briery Creek. Drains into stream bed. Continual flow.
4	Albemarle	1722	24	121	Conveys stormwater entirely below ground. Drains into stormwater pond. Intermittent flow.
5	Nottoway	460	15	112	Conveys an unnamed tributary drainage to Lazaretto Creek. Drains into stream bed. Continual flow.
6	Nottoway	460 (Business)	18	64	Conveys an unnamed tributary drainage to Jacks Branch. Drains into stream bed. Intermittent flow.
7	Nottoway	613	30	60	Conveys an unnamed tributary drainage to Deep Creek. Drains into stream bed. Continual flow.

Field Observations

Project sites were observed during CIPP installations and at various periods after the installations were complete. Because the CIPP installations observed continued up to 30 consecutive hours and because of the distance between the project sites, the authors could not be present to collect samples at consistent intervals during and after all installations. Observations of incidents that could potentially result in adverse impacts to water quality were documented.

Water Samples

A control sample was collected from the water within 1 m of the pipe outlet at Sites 1, 3, and 4 immediately prior to CIPP installations. At sites that were not monitored until the installation was underway (Site 2) or until 15 to 16 days after installation (Sites 5-7), a control sample was collected after installation at least 10 m upstream from the pipe inlet. Water samples were collected at various intervals during installation at Sites 1, 2, and 3 and at various intervals after installation at all seven sites. During each sampling period, a sample was taken from the water within 1 m of the pipe outlet. During some sampling periods at five of the six surface water sites (Sites 1, 2, 3, 5, and 7), samples were also taken from the water 5 to 40 m downstream. At Sites 2 and 3, a sample was taken from the stream water within 1 m of the outlet during steam condensate release. Water samples were collected at all sites for a maximum of 30 to 116 days, depending on the site, after CIPP installation until the styrene concentration at the site was below the reporting limit (0.005 mg/L) of the primary laboratory (Microbac) used in this study.

The subsurface stormwater pipe at Site 4 conveyed water only during rain events. Because it was difficult to time sample collections with rain events, a rain event was simulated for each sampling period by pouring 1 gal of distilled water into the inlet of the repaired section of pipe and capturing the water as it flowed out of the outlet of the pipe section.

All samples were collected into 40-ml volatile organic analysis (VOA) vials with HCl preservative. The samples were packed on ice and sent to the laboratory via an overnight courier service. All samples were analyzed for styrene in accordance with the EPA’s SW-846 Method 8260B (EPA 1996) by Microbac Laboratories in Baltimore, Maryland. Samples collected at the last one to two sampling periods from Sites 1, 4, 5, 6, and 7 were also sent to Air, Water, and Soil Laboratories, Inc., in Richmond, Virginia. These samples were also packed on ice and sent to the laboratory via an overnight courier service. Sample analyses were “blind” in that locations and project descriptions were not disclosed to either laboratory.

RESULTS

Field Observations

Table 3 lists observations during and following CIPP operations at Sites 1 through 4.

The authors observed effluent from the steam condensate being discharged downstream by workers at Sites 2 and 3. At Sites 1, 3, and 4, the authors observed uncured resin residue waste immediately outside the pipe outlet or inlet. A sample of the uncured resin left in the stream bed at Site 1 (collected 1 day after installation) had a styrene concentration of 580 mg/L.

At Sites 1, 2, and 3, algal blooms were apparent within 6 to 8 days after installation (Aaron L. Mills, unpublished data); algae were not visible at any of these sites when visited before the CIPP installation and were not present upstream of the installation. (The other three surface water sites in this study were not monitored until 15 and 16 days after installation; algal blooms were not visible at these sites.) Algae appeared most dense at the pipe outlet (occurring up to 8 in below the water surface), and the density decreased further downstream; the algae were present in clusters up to 50 m downstream from the repaired pipe section. Although the density of algal blooms appeared to decrease over time, blooms were observed 50 to 55 days after installation. Blooms were no longer visible 78 to 88 days after installation.

Table 3. Environmental observations for four CIPP installations for surface water conveyances

Site	Stream Flow Management	Curing Method	Effluent (Steam Condensate) Disposal Method	Post-project Conditions
1	Temporary dam	Steam	Not observed (authors not present at this stage of installation)	Extruded resin in stream (Figure 1A); algal blooms present at pipe outlet (0 to 10 m downstream, Figure 1A); residue present at pipe outlet (present at each sampling period up to study's end)
2	None necessary (dry pipe at time of installation)	Steam	Discharged by workers in stream (see associated water sample results in Figure 2)	Algal blooms present at pipe outlet (0 to 5 m downstream); residue present at pipe outlet (present at each sampling period up to study's end)
3	Temporary dam	Steam	Discharged by workers in stream (see associated water sample results in Figure 2)	Extruded resin in stream (Figure 1B); algal blooms present at pipe outlet (0 to 50 m downstream); residue present at pipe outlet (present at each sampling period up to study's end)
4	None necessary (dry pipe at time of installation)	Steam	Not observed (authors not present at this stage of installation)	Extruded resin just outside of pipe inlet (present at each sampling period up to study's end)

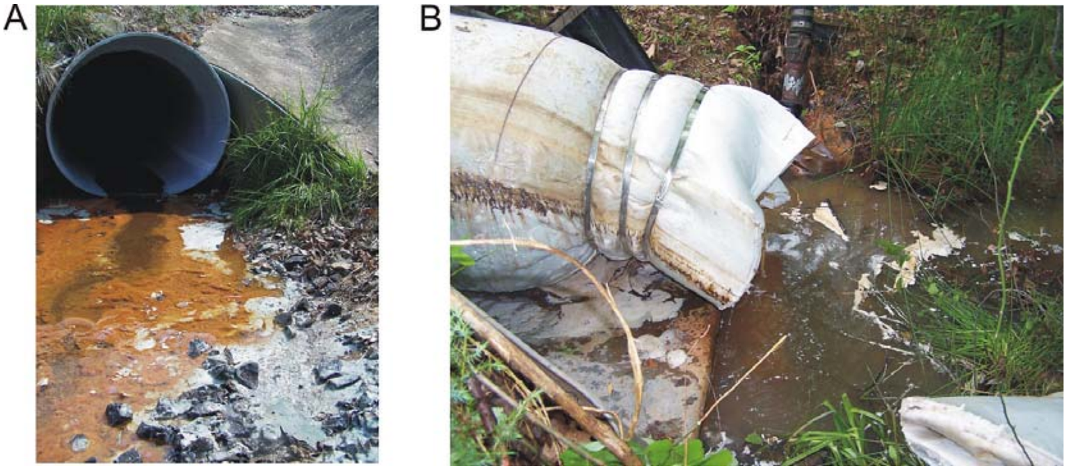

Figure 1. ***A:*** **Uncured resin waste (gray substance adjacent to outlet and along rocks on right side of image) at Site 1, 1 week after installation; algal blooms (brown cloudy substance in water) also visible.** ***B:*** **Uncured resin waste (white substance adjacent to pipe liner and in water) extruded during installation, just before pipe end was cut.**

Water Sampling Results

Styrene concentrations in all control samples were below the reporting limit (0.005 mg/L) of the primary laboratory used in this study. Samples were collected until styrene concentrations were below the reporting limit at all sites. Samples collected at the pipe outlet often contained residue that was visible on the water surface after installation.

Figure 2 provides styrene concentrations at all sites as compared with the MCL and with the EC_{50} or LC_{50} values for two species (as detailed in Table 1). Samples for three sites were taken during installation, and samples for all sites were taken at various intervals after installation. No compounds other than styrene were detected in the laboratory analyses.

The results indicate that styrene concentrations were generally highest in water samples collected during installation, although comparable levels were detected at some sites several days after installation. The highest concentration (77 mg/L) was recorded at Site 3 at the outlet while steam condensate was discharged during the installation process.

Styrene concentrations and the duration of its detectable presence were highly variable among sites. Samples from some sites did not show a consistent decrease in concentration, particularly at sites with low or intermittent water flow. Although none of the sites was directly linked to a source of drinking water, styrene concentrations exceeding the MCL for drinking water were measured at five of the seven study sites. The concentrations at Sites 1, 2, 3, and 6 exceeded the MCL for drinking water (0.1 mg/L) at sampling periods of 5 to 50 days after installation, and at Site 4, the concentration exceeded the MCL 71 days after installation during a period of very low flow. The maximum styrene concentrations at four sites (Sites 1, 2, 3, and 6) exceeded published EC_{50} or LC_{50} values (Table 1) for various aquatic species. At Site 2, the concentration exceeded these values for the water flea and the rainbow trout at the sampling period of 24 days.

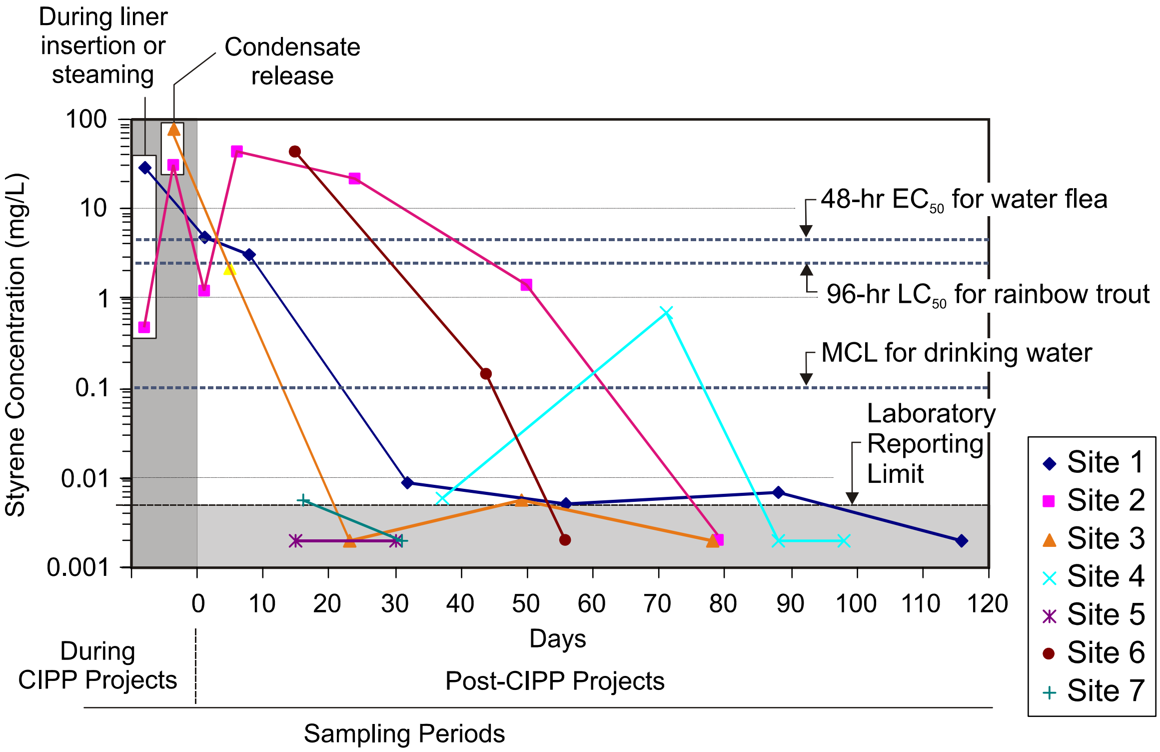

Figure 2. Styrene concentrations in water samples collected at pipe outlet during installation and at sampling periods up to 116 days after installation. Horizontal lines indicate the maximum contaminant level (MCL) of

drinking water (0.1 mg/L), the EC_{50} or LC_{50} styrene concentrations for two aquatic species (as detailed in Table 2), and the laboratory reporting limit (0.005 mg/L). For styrene concentrations below the laboratory reporting limit, the data points shown merely indicate that sampling occurred and that the results were below the limit of 0.005 mg/L; they do not indicate the true concentration value.

DISCUSSION

At certain times after CIPP installation, styrene concentrations exceeded the MCL for drinking water at five of the seven study sites and exceeded the EC_{50} or LC_{50} values of common indicator species (the water flea [Cushman *et al*. 1997] and the rainbow trout [Qureshi *et al*. 1982]) at four of the monitored project sites. As compared with samples collected from sites with continual water flow, samples from sites with intermittent flow contained relatively higher styrene concentrations for a greater length of time after CIPP installation. This suggests that flow volume and regularity are important factors in diluting styrene concentrations.

At the two sites where styrene was not detected, the initial sample was not collected until 15 and 16 days, respectively, after installation; therefore, it cannot be known whether these installations had any effect on water quality or whether styrene, if indeed present, had decreased to concentrations below detection. At sites where styrene was detected, styrene was above the laboratory reporting limit (0.005 mg/L) at sampling periods 44 to 88 days after installation.

Styrene concentrations reached as high as two orders of magnitude greater than the MCL for drinking water. Concentrations exceeded the MCL for drinking water for at least 5 days after installation at five sites and for at least 44 to 71 days at three of these sites. Concentrations above the MCL were detected up to 40 m downstream. Although the sites in this study do not directly link to a drinking water supply, roadway conveyances often convey water upon which a variety of aquatic species depend. The sample results from five of seven sites exceeded one or more aquatic toxicity criterion (EC_{50} or LC_{50} values, Table 2) for styrene, and concentrations exceeding these values were detected as far as 10 m downstream. Styrene concentrations at one site exceeded the EC_{50} value for the water flea and the LC_{50} value for the rainbow trout at the sampling period of 24 days following installation.

One apparent ecological change during this study was the emergence of algal blooms, which appeared at three surface water sites within 6 to 8 days after CIPP installation and remained at these sites for at least 50 to 55 days post-installation. Algal blooms are often indicative of poor water quality (commonly from nitrogen or phosphorus pollution) and can have adverse ecological impacts (EPA 2007). The fact that algae blooms were not seen at project sites before CIPP installation could be seen to suggest that some aspect of the CIPP process could be a contributing factor for the blooms, but the specific cause (whether hot effluent discharge, styrene leaching, factors unrelated to the installations, etc.) is unknown.

As typical CIPP resins contain between 30 and 50 percent styrene, even a relatively small amount of uncured resin could potentially result in water samples with detectable styrene concentrations at the project site or downstream. Any resin that might be unintentionally released during installation would not have been subject to the same curing conditions as the resin contained within the liner. A sample of the uncured resin waste in the stream bed at Site 1 collected 1 day after installation had a styrene concentration of 580 mg/L. Styrene was detected at sites even where resin waste was either not released or had washed downstream; styrene was also detected at sites long after observed discharges of steam condensate had been flushed downstream. These observations, coupled with the length of time styrene was detected after installation, suggest that these installation practices (i.e., uncured extruded resin and discharge of the steam condensate effluent) were not solely accountable for the styrene concentrations in water. These findings suggest that the resin-saturated liner was not completely cured during the installation process and continued to leach styrene, perhaps through or around the inner membrane liner.

Although the scope of this study did not lend itself to definitive determination of the specific contribution of styrene from each aspect of the CIPP process, the styrene concentrations identified in the laboratory tests of water samples may have resulted from one or a combination of the following: (1) installation practices that did not capture condensate containing styrene, (2) uncured resin that escaped from the liner during installation, (3) insufficient curing of the resin, and (4) some degree of permeability of the lining material.

Standards and Regulations

Although CIPP technology dominates the underground pipe rehabilitation industry and is a common method for above-ground pipe rehabilitation, only 3 of 85 trenchless pipe rehabilitation standards pertain directly to CIPP methods and materials (Hoffstadt 2000). ASTM standards for CIPP rehabilitation (ASTM International 2003, ASTM International 2004, ASTM International 2007) do not separate surface water conveyance guidelines from those for sewer lines. They also do not address measures to ensure containment of the resin that saturates the lining material. Although ASTM standards (ASTM International 2003, ASTM International 2007) contain a caveat that it is the user’s responsibility to determine the applicability of regulatory limitations prior to use, the standards direct users to dispose of the curing water or condensed steam (effluent) by allowing it to drain from a hole made in the downstream end of the pipe. It is also important to note again that ASTM standards for CIPP procedures specify that the flow be bypassed or diverted before CIPP installation (ASTM International 2003, ASTM International 2007).

A culvert pipe liner guide (Federal Highway Administration 2005) published by the Federal Highway Administration lists existing specifications for pipe repair technologies and provides a decision analysis tool designed to help users choose an appropriate pipe repair method based on various factors. The guide lists some specific environmental limitations of CIPP rehabilitation, including (1) possible thermal pollution from the discharge of the curing water, (2) potential toxicity of styrene-based resins prior to completion of the curing process, and (3) possible hazards to an environmentally sensitive area. The decision analysis tool addresses such concerns for CIPP technology by assigning it the highest ranking for environmental risk (on a scale of *1* to *5*). Neither the guide nor the decision analysis tool, however, provides guidelines or additional specifications (beyond the referenced ASTM standards) to mitigate environmental risks.

The EPA does not have published standards for allowable levels of styrene for receiving streams; however, the discharge of pollutants (which includes chemical wastes) to waters of the United

States is regulated (EPA 2007b). The discharge of steam condensate or spent cure water into waters of the United States would require a permit under the National Pollution Discharge Elimination System (NPDES) or state equivalent (EPA 2007b, Virginia Department of Environmental Quality 2007a). The permit conditions may require pre-treatment and monitoring prior to any discharge. State environmental regulatory agencies also typically have additional statutory and/or regulatory authority to prevent or regulate the discharge of pollutants to state receiving waters, including groundwater (Virginia Department of Environmental Quality 2007b). Although the state and/or federal agencies could use published water quality standards such as the relevant MCL or published aquatic toxicity criteria to determine acceptable styrene levels, it is unclear what, if any, environmental regulation would govern the leaching of styrene from a finished CIPP product.

ACTIONS TAKEN BY THE VIRGINIA DEPARTMENT OF TRANSPORTATION IN RESPONSE TO PRELIMINARY RESEARCH FINDINGS

VDOT took several actions upon receiving the preliminary research findings of this study:

1. *VDOT's Chief Engineer immediately placed a stop work order on all styrene-based CIPP repair projects contracted by VDOT* (Winstead 2007a*).* VDOT subsequently elected to allow CIPP installations on sanitary sewer projects (under certain conditions) while continuing to review the use of styrene-based CIPP repair (Winstead 2007b).

2. *A VDOT task group led by VDOT's Environmental Division was formed to evaluate further the use of steam- and water-CIPP repair projects containing styrene.* Task group participants included members of VDOT's Scheduling & Contract, Administrative Services, Materials, and Asset Management Divisions, as well as scientists from the Virginia Transportation Research Council (VTRC). Information gained from this evaluation was to be used to provide VDOT with recommendations for further action regarding the use of styrene-based CIPP technology.

3. *The task group conducted the evaluation,* which included acquiring the services of an independent environmental consultant to provide third party verification of the preliminary study findings and to test additional CIPP sites, meeting with the Virginia Department of Environmental Quality for support and guidance, and holding two series of interviews with CIPP industry representatives.

4. *The task group issued their evaluation report to the Office of the Commonwealth Transportation Commissioner in November 2007.* The report (VDOT Task Group 2007) provided recommendations regarding the modification of VDOT's CIPP contracting specifications, project management considerations, and conditions for reinstatement of styrene-based rehabilitation. The recommendations were primarily designed to prevent the unintentional release of styrene-based resin during installation and the leaching of styrene from the finished product.

5. *The Office of the Commonwealth Transportation Commissioner charged VDOT's Scheduling & Contract Division with developing an action plan to implement the*

recommendations outlined in the task group report. In April 2008, these recommendations were implemented and are incorporated in a VDOT memorandum that includes revised CIPP specifications (Coburn 2008). These specifications include the following measures:

- a requirement that a VDOT project inspector (who has undergone a CIPP training program) provide oversight of CIPP installations for the duration of each installation
- the acquisition of discharge-related permits, including air, water, and wastewater treatment
- ASTM and other applicable standard compliance requirements
- a requirement that all CIPP installations be performed in the dry (i.e. no water is contained or conveyed in the pipe during installation)
- a requirement that the contractor submit preconstruction installation and cure specifications
- additional lining materials and measures to ensure the containment of resin and styrene
- procedures for monitoring the curing of the CIPP lining material
- thorough rinsing of the finished product
- proper disposal of cure water, cure condensate, and rinseate
- requirements for water and soil testing prior to and after installation.

Statewide VDOT CIPP installations using the new procedures and specifications (*29*) were reinstated in June 2008. These actions are part of VDOT's ongoing effort to prevent the risks associated with styrene-based CIPP technology and, in doing so, to ensure due diligence by VDOT for the protection of the public health and safety as well as the environment.

CONCLUSIONS

- *The use of styrene-based CIPP technologies may result in detectable levels of styrene at and near the work site of the CIPP installation.* In this study, styrene was detected in water samples collected from the pipe outlet during or after installation at five of the seven CIPP installations monitored in this study. Styrene concentrations in water samples ranged from <0.005 mg/L to 77 mg/L and were generally highest in samples collected during and shortly after installation. The maximum time styrene was detected at any site was 88 days following CIPP installation.

- *Although further research is needed to discern the contribution from each potential source of styrene, the findings suggest that the elevated styrene levels could have resulted from one or a combination of the following:* (1) installation practices that did not capture condensate containing styrene, (2) uncured resin that escaped from the liner during installation, (3) insufficient curing of the resin, and (4) some degree of permeability in the lining material. These factors appear to pose a risk of negative impacts from the use of styrene-based CIPP technologies.

- *Under the observed conditions, styrene concentrations could result in violations of state and/or federal environmental standards.* Although the EPA does not have published standards for allowable levels of styrene for receiving streams, the discharge of pollutants to waters of the United States is regulated under the NPDES permit program.

- *Research on the ecological and species effects of chronic styrene exposure in natural conditions would be useful in order to foster an understanding the potential impacts.* These studies should also look at the factors that would create conditions leading to algal blooms.

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