Contaminant Release from Storm Water Culvert Rehabilitation Technologies: Environmental & Long-Term Material Integrity Impacts

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Stormwater culverts and repairs in the U.S.

12 million+ linear feet of culvert in place (FHWA 2005)

1 million+ existing culverts require rehabilitation (FHWA 2010)

Mechanical failures can be catastrophic (traffic disruption, public safety)
Factors that can affect concrete and metal pipe service life are well understood.
Instead of replacing the damaged culvert, often trenchless culvert rehabilitation approaches can be applied

<table>
<thead>
<tr>
<th>Trenchless Technology Options</th>
<th>Potential Challenges for Some Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slip lining</td>
<td>• Water flow diversion</td>
</tr>
<tr>
<td>Spiral wound pipe</td>
<td>• Grouting necessary</td>
</tr>
<tr>
<td>Close fit pipe</td>
<td>• Reduction in cross-sectional area</td>
</tr>
<tr>
<td>Thermoformed pipe</td>
<td>• Structural integrity not improved</td>
</tr>
<tr>
<td>Fold-and-form pipe</td>
<td>• Host pipe must be completely dry</td>
</tr>
<tr>
<td>Spray-on coating</td>
<td>• Cost</td>
</tr>
<tr>
<td>Cured-in-place-pipe (CIPP)</td>
<td></td>
</tr>
<tr>
<td>50% of all water, sewer, and stormwater pipes</td>
<td></td>
</tr>
</tbody>
</table>
Several culvert repair technologies chemically manufacture
the product at the culvert site – Inside the Asset

\[
\begin{align*}
\text{Isocyanate} & \quad + \quad \text{Polyol} & \quad \Rightarrow & \quad \text{Polyurethane} \\
\text{Isocyanate} & \quad + \quad \text{Polyamine} & \quad \Rightarrow & \quad \text{Polyurea}
\end{align*}
\]
Many State DOTs have conducted studies to understand what culvert rehabilitation trenchless technologies are available. Few focus on identifying or monitoring environmental impacts.
<table>
<thead>
<tr>
<th>Location (date)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GEORGIA (2016)</td>
<td>Contractors released chemicals and entered waterway causing odor on University campus.</td>
</tr>
<tr>
<td>ALABAMA (2014)</td>
<td>7.4 ppm styrene downstream of culvert; steam-cured CIPP waste dissolved test organisms within 24 hr; A variety of non-styrene compounds found leaching from CIPP for 30 days</td>
</tr>
<tr>
<td>OREGON (2013)</td>
<td>CIPP was installed in a stormwater culvert using steam curing, 174 ppm styrene reported</td>
</tr>
<tr>
<td>OREGON (2012)</td>
<td>Contractor discharged steam cured CIPP waste to Willamette River; “Styrene levels were so high that the responder had to wear a respirator to collect samples.”</td>
</tr>
<tr>
<td>MINNESOTA (2011)</td>
<td>Odor caused by resin spill prompted building evacuations; residual remained for five months.</td>
</tr>
<tr>
<td>CANADA (2011)</td>
<td>Moratorium instituted; fish kill investigated due to CIPP activity</td>
</tr>
<tr>
<td>ALABAMA (2010)</td>
<td>&gt; 70,000 gal of CIPP wastewater dumped into creek bed along with concentrated styrene from CIPP stormwater culvert relining. Found 143 ppm styrene in water. Residents complained drinking water from a local well had odor. Vapors originating from faucets made residents ill, 4ppm styrene levels at the faucets. “Apparently, they (contractors) have been doing this on a lot of culverts, this was just the first time they got caught.”</td>
</tr>
<tr>
<td>VIRGINIA (2009)</td>
<td>&gt; 77 mg/L styrene in stormwater &gt; 77 mg/L after CIPP installation complete.</td>
</tr>
<tr>
<td>FLORIDA (2009)</td>
<td>Fish kill because of uncured resin released into a stormwater drain</td>
</tr>
<tr>
<td>NEW YORK (2008)</td>
<td>Hot water discharged into a creek by CIPP stormwater culvert installation, 130 ppm styrene reported</td>
</tr>
<tr>
<td>Unknown (2007)</td>
<td>3 gal to 4 gal of uncured resin released during a CIPP installation into a storm-water drain; Residual uncured resins were carried to a creek, resulting in the death of more than 5,500 fish of various species. Water sampling at a manhole downstream of the spill showed styrene present. Styrene estimated at 100 ppm in water.</td>
</tr>
<tr>
<td>CANADA (2007)</td>
<td>Fish kill because of process water discharged into tributary. 2 to 85 ppm styrene found</td>
</tr>
<tr>
<td>CONNECTICUT (2004)</td>
<td>40 lbs to 161 lbs of process water and resin released to storm-water pipe and retention pond; water able to be captured was discharged to sanitary sewer; after 12 days, 0.0291 ppm concentration detected; remediation required by state</td>
</tr>
</tbody>
</table>
There are several factors that contributed to past incidents

**SPECIFICATION** did not articulate how to and when contractors should prevent environmental contamination

**SPECIFICATION WRITER** did not understand the type and magnitude of chemical emissions from the technology

**CONSTRUCTION INSPECTOR** did not understand the type and magnitude of chemical emissions or when they can occur

**ENGINEERING FIRM** did not understand the type, magnitude of chemical emissions, or when they can occur

**CONTRACTORS** did not understand the type and magnitude of chemical emissions from the technology

**CONTRACTORS** did not follow the construction specifications

**Q:** What actions are needed to appropriately consider prevent a trenchless technology project from causing public and environmental impacts?
Examples of Chemical Air Emissions
Examples of Chemical Water Emissions
Questions to ask about potential environmental impacts.....

Is a water quality standard exceeded.....?
  During site setup
  During installation
  After installation

Does liquid or solid waste disposal violate state, county regulations for waterways (NPDES) or land?

Is a nuisance caused (i.e., odor)?

Are aquatic organisms harmed (i.e., daphnia magna, minnows, salmonid, others, etc.)?
Prior water impact study - Sampling for 2 culverts rehabilitated by polyurea and cement mortar coatings

<table>
<thead>
<tr>
<th>Tests Conducted</th>
<th>Water Sample Analyses and Sampling Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Polyurea</strong></td>
</tr>
<tr>
<td>Flowing water test</td>
<td>Analyses: methylene diphenyl diisocyanate (MDI), methylenedianiline (MDA), volatile organic compounds, total nitrogen, chemical oxygen demand, total organic carbon, pH</td>
</tr>
<tr>
<td><em>Open system</em></td>
<td>Sampling frequency: Days 2, 6, 10</td>
</tr>
<tr>
<td>Immersion test</td>
<td>Analyses: same constituents and water quality indicators as above</td>
</tr>
<tr>
<td><em>Open system</em></td>
<td>Sampling frequency: Day 3</td>
</tr>
<tr>
<td>Leaching test</td>
<td>Analyses: alkalinity, biochemical oxygen demand, chemical oxygen demand, total nitrogen, total organic carbon, pH</td>
</tr>
<tr>
<td><em>Closed system</em></td>
<td>Sampling frequency: Days 3, 6, 9, 12, 15</td>
</tr>
</tbody>
</table>
In the LAB LEACHING TEST each coating impacted stormwater differently
While lab-scale leaching test indicated water impacts were possible, the field test indicated there was little impact.

**Results: 1 Cement Coating**
- Lab leaching test
  - Elevated pH (11) and alkalinity
- Field sampling
  - pH slightly elevated
  - No elevated levels for the other water quality indicators

**Results: 1 Polyurea Coating**
- Lab leaching test
  - pH reduced 1 unit
  - Elevated water quality indicators (TOC, BOD, COD, and total N)
- Field sampling
  - No elevated levels for the water quality indicators tested

*Air emission (overspray) observed during both spray installations*
Cement Mortar Coating

- Install temporary curtain at the outlet and inlet to prevent overspray during installation.
- Reinstate flow NO SOONER THAN 24 hours following installation
- Prevent escape of rinse water and capture it, monitor pH. When below pH 9, can be released, otherwise transport for off-site disposal.

Polyurea Coating

- Qualified independent environmental services laboratory or environmental consultant to collect water samples
- Sample within 3 ft of the pipe ends: Before rehabilitation, and within 1 week after the pipe liner has cured
- If water is not available to sample, samples of rinse water shall be used for the analyses
- Analyzed for total methylene diphenyl diisocyanate (MDI), methylenedianiline (MDA), and total cyanide. MDI and MDA in water samples shall not exceed 1,000 mg/L and 39 mg/L, respectively
- Analyze for chemical oxygen demand (COD) and total nitrogen (TN)
- Submit a completed within 4 weeks after completion of rehabilitation
- Contractor’s responsibility to report and take appropriate corrective actions to remediate any water quality alteration resulting from the lining materials in accordance with applicable local, state or federal regulations. The cost for such remediation shall be at the Contractor’s expense.
Today, Cured-in-Place-Pipe (CIPP) is used to repair 50% of all water pipes in the USA

Resin impregnated tube hardened in a damaged pipe
Polyvinylester, vinyl ester, epoxy resins
Curing method: Hot water, Steam, UV light
Deliberate curing time: Hours to many days
Video: Uncured Resin Tube Installation & Curing for Sewer Pipe
Uncured resin tubes emit chemicals even when they are not being cured

...because you are chemically manufacturing a pipe in the field....not in a manufacturing facility

1,361 ppmv
Site preparation

- Inspect culvert condition
- Redirect flow and clean culvert
- Fill fabric with raw chemicals (resin, catalyst)
- Transport uncured resin tube to site and inspect

Product installation

- Insert uncured resin tube into culvert
- Setup equipment for curing (hoses, boiler, lamps, etc.)
- Conduct curing of tube (hot water, steam, UV light)
- Remove wastewater, condensate for disposal
- Cut ends of CIPP
- Package CIPP samples for testing by 3rd party lab

Site cleanup

- Disconnect equipment from curing process and pack up
- Clean water rinse CIPP
- Transport waste to appropriate disposal site
- Reinstate flow

After contractors leave site

- Uncured resin tube chemical emission into the air
- Uncured resin tube chemical emission into the air and on the ground before and during insertion
- Chemical emission during curing into the air
- Chemical emission during cooldown into the air
- Wastewater, condensate can escape into the environment
- Shavings can escape the CIPP into the environment
- Chemical emission into the air from the new CIPP
- Chemical emission into air from materials cut from CIPP
- Chemical emission into reinstated water flow from CIPP
- Shavings, wastewater, condensate, materials cut from CIPP left behind will leach chemicals into the environment
- Chemical emission into the air from the new CIPP
- Chemical emission into reinstated water flow from CIPP
Current Knowledge about CIPP Culvert Repair Water Impacts

**Virginia Transportation Research Council**

Understanding the Environmental Implications of Cured-in-Place Pipe Rehabilitation Technology

Donaldson & Baker (2008)

[Link to full report](https://www.virginia.dot.org/vtrc/main/online_reports/pdf/08-s64.pdf)

**O’Reilly NYSDOT (2009)**

Summary of Water Sampling CIPP for 4 Culverts

**Preliminary Investigation**

Caltrans Division of Research and Innovation

Produced by CTC & Associates LLC

Environmental Effects of Cured-in-Place Pipe Repairs

Requested by
Sean Penders, Design
David Melendrez, North Region Environmental Engineering

August 6, 2012

Water Quality Implications of Culvert Repair Options: Vinyl Ester Based and Ultraviolet Cured-in-Place Pipe Liners

Donaldson (2013)


**Stormwater Chemical Contamination Caused by Cured-in-Place Pipe (CIPP) Infrastructure Rehabilitation Activities**

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1 Department of Civil Engineering, University of South Alabama, Mobile, Alabama 36688, United States
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Publication Date (Web): August 15, 2014

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

Whelton et al. (2015)


**FINAL REPORT**

February 2017

Prepared for
California Department of Transportation
by CSUS

WATER QUALITY OF FLOW THROUGH CURED-IN-PLACE PIPE (CIPP)
Very Brief Overview of Existing CIPP Studies—Some CIPP activities have caused environmental damage

- VDOT and CALTRANS previously suspended CIPP use, but followed up with field studies to improve their specifications
- 2009, NYSDOT conducted field studies to understand CIPP styrene leaching
- 2013, VDOT supported field studies to understanding CIPP leaching
- 2015, VDOT supported field and lab studies to understand CIPP leaching and condensate characteristics and toxicity, and develop predictive lab test
- 2017, CALTRANS supported field studies to understand CIPP leaching

Main Findings

1. Chemical leaching from CIPP sites was detected 30 days after installation
2. Styrene was not the only chemical emitted
3. CIPP condensate was extremely toxic, should not enter the environment
4. Styrene was not responsible for aquatic life toxicity when condensate diluted, other unidentified chemicals were responsible
Research prompted changes to CIPP DOT specifications in AL, CA, NY, and VA

• Impermeable sheet, impermeable device upstream and downstream of the host pipe
• Remove and dispose of waste materials
  • Discharge-related permits, including air, water, and wastewater treatment (i.e. POTW).
  • Written approval from the POTW before repair work can start, provide engineer documentation
• Capture and dispose of cure water or steam condensate
• Rinse the CIPP with clean water, dispose of rinse water prior to re-introducing flow.
• Temporarily divert creek for 4 days to assure the CIPP is cured prior to having re-introducing flow.
• Styrene-based CIPP and vinyl ester-based CIPP water sampling needed
  • Sample within 3 ft of the pipe ends: Before rehabilitation, and within 1 week after the pipe liner has cured
  • Analyze for total organic carbon (TOC), chemical oxygen demand (COD), temperature, and pH.
  • For styrene-based liners, water samples shall also be analyzed for styrene. Styrene concentrations shall not exceed 2.5 mg/L.
  • For vinyl ester-based liners, analyze for diallyl phthalate (DAP), which shall not exceed 0.4 mg/L.
• Contractor’s responsible to report and remediate any water quality alteration.
Determine:

(1) The scope of the problem across departments of transportation (DOTs) (i.e., the extent of use of these technologies and the scale of their impacts to water quality);

(2) The effectiveness of existing construction specifications at minimizing contaminant release from rehabilitated culverts; and

(3) The degree to which the structural integrity and longevity of rehabilitated culverts are compromised by chemical leaching.

*Focusing on CIPP, most commonly used across partner DOTs*
Task 1 (in progress): Evaluate the scope of the problem across departments of transportation (DOTs) (i.e., the extent of use of these technologies and the scale of their impacts to water quality);

* CIPP was found to be the most popular culvert repair technology for partner DOTs. It is focus of this pooled fund project.

Task 2 (in progress): To understand how to prevent environmental impacts we need to understand what chemicals can be released, their magnitudes and when during the CIPP installation activity those releases can occur
### In the Field, We Collected Uncured Resin Tube and CIPP from 5 Installations

<table>
<thead>
<tr>
<th>Installation Number</th>
<th>Host Pipe</th>
<th>Used Preliner? No. Used</th>
<th>Resin Brand</th>
<th>Resin Type</th>
<th>Cooldown Method</th>
<th>Liner Insertion Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CSP</td>
<td>Yes, 1</td>
<td>AOC</td>
<td>Polyester styrene</td>
<td>Ambient Air</td>
<td>Air inversion</td>
</tr>
<tr>
<td>2</td>
<td>CSP</td>
<td>No</td>
<td>Ecotek</td>
<td>Vinyl ester low VOC</td>
<td>None</td>
<td>Air inversion</td>
</tr>
<tr>
<td>3</td>
<td>CSP</td>
<td>Yes, 2</td>
<td>AOC</td>
<td>Polyester styrene</td>
<td>Hot Air</td>
<td>Air inversion</td>
</tr>
<tr>
<td>4</td>
<td>RCP</td>
<td>Yes, 1</td>
<td>AOC</td>
<td>Polyester styrene</td>
<td>None</td>
<td>Air inversion</td>
</tr>
<tr>
<td>5</td>
<td>CSP</td>
<td>No</td>
<td>AOC</td>
<td>Polyester styrene</td>
<td>None</td>
<td>Pull-in</td>
</tr>
</tbody>
</table>

EcoTek Low VOC resin: “Does not contain any styrene monomers or hazardous air pollutants, vinyl ester resin”

AOC resin: 1% Di-(4-tert-butyl-cyclohexyl) peroxycarbonate and 0.5% Trigonox® KSM; Polyester resin, Styrene 32 wt.%.

### Contractor Estimated Curing Conditions

<table>
<thead>
<tr>
<th>Installation Number</th>
<th>Cure Time (min)</th>
<th>Interface Temp. (°F)</th>
<th>Steam Temp. (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>130</td>
<td>58-200</td>
<td>240-250</td>
</tr>
<tr>
<td>2</td>
<td>150</td>
<td>58-177</td>
<td>240</td>
</tr>
<tr>
<td>3</td>
<td>165</td>
<td>65-244</td>
<td>230-250</td>
</tr>
<tr>
<td>4</td>
<td>175</td>
<td>60-170</td>
<td>230-250</td>
</tr>
<tr>
<td>5</td>
<td>155</td>
<td>60-280</td>
<td>248-250</td>
</tr>
</tbody>
</table>
We chemically extracted the uncured resin tube and CIPP for each installation.

Glass vials with PTFE caps
At least 3 replicates used for each CIPP + blanks (no CIPP)

Vials were filled with either methylene chloride or hexane solvents
CIPP specimens soaked at room temperature
Preliminary: Some compounds were created by the contractors during installation, not present on SDS, and if at high enough concentration can be acutely toxic.

<table>
<thead>
<tr>
<th>Compound</th>
<th>Site 1 (AOC)</th>
<th>Site 2 (EcoTek)</th>
<th>Site 3 (AOC)</th>
<th>Site 4 (AOC)</th>
<th>Site 5 (AOC)</th>
<th>D. Magna acute toxicity endpoint, mg/L</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resin</td>
<td>CIPP</td>
<td>Resin</td>
<td>CIPP</td>
<td>Resin</td>
<td>CIPP</td>
</tr>
<tr>
<td>Styrene</td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Phenol</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BHT</td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-Tetradecanol</td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Benzoic acid</td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>4-t-butylocylcyclohexanone</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4-t-butylocyclohexanol</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetophenone</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TPGDA</td>
<td></td>
<td></td>
<td>√</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CSUS (2017) found styrene leaching from non-styrene based CIPP (site 2).
Task 3 (in progress): To understand the degree to which CIPP structural integrity and longevity is compromised by chemical leaching

• In other fiber reinforced composite systems, leaching and aging has compromised structural integrity and longevity

• Structural Integrity
  Measured by mechanical and thermomechanical testing for strength and brittleness as resins are leached under various conditions
  Degree of cure will be investigated and related to actual and optimal cure conditions

• Longevity
  Measured by accelerated aging

Resins and CIPP will be cured in lab conditions to determine optimal schedules (time, temp and thickness) for full cure of materials and a post-hoc QC test. Fully curing CIPP is a primary way of reducing emissions as less are available.
CIPP is cured from the inside out. 

*Is the CIPP inner surface the same as its outer surface?*

For the field sites, steam was injected into the pipe to both heat and expand the tube. Contractors used a polypropylene preliner to limit resin bleeding from the uncured tube.
We have found in prior testing that the inner and outer CIPP surfaces were chemically different
(CIPP for sewer from Indiana)

- CIPP leached a variety of compounds
  - Components from uncured resin
    - Styrene
    - Ethylene glycol
    - 1,3,5-Trimethylbenzene
  - Products from degradation and curing
    - Styrene oligomers
    - 4-Tert-butyl-cyclohexanone
    - 4-Tert-butyl-cyclohexanol
    - Acetone

- Isopropyl benzene, N-propyl benzene, ethyl acetate also present, but only at the inner surface
  - Possibly due to higher heat causing more degradation

- Less water extractives on inner surface
  - Probably lost with steam during cure
The inner and outer CIPP surfaces were thermally different (CIPP for sewer from Indiana)

• Inner surface showed three steps decomposition while middle and outer layer showed only one step decomposition, showing the inner surface to be structurally different

• At 160 °C, 0.97-1.20% weight loss was due to the evaporation of volatile compounds, styrene monomer and oligomer as depicted by NMR

• Inner surface revealed a PP liner melting peak at ~160 °C

• Also an unknown second small melting peak was found at ~120 °C
Takeaways from the Prior Studies

1. When you chemically manufacture a product in the field you can release chemicals into the environment

2. Different rehabilitation materials impact water quality differently (pH vs. dissolve organisms vs. organic chemicals)

3. To prevent environmental contamination, contractors, inspectors, and engineering firms need to understand when chemical emissions can occur

4. Limited information exists about environmental impacts caused by culvert rehabilitation
   • CIPP: Chemical leaching occurred for 30+ days, sometimes more than styrene was emitted
   • CIPP: Condensate was extremely toxic, should not be emitted to the environment at all, and toxicity was caused by non-styrene chemicals
   • Inexpensive water tests are available to evaluate stormwater impacts

5. CALTRANS, VDOT, NYSDOT upgraded specifications to better prevent environmental impacts
1. Some chemicals found in installed CIPPs were not listed on MSDS’s, but were created by the curing process or likely unreported ingredients in resin, preliner, felt, coating of the uncured resin tube.

2. Styrene was not the only compound emitted into the environment.

3. Styrene found in the non-styrene CIPP likely due to contractor equipment / resin tube contamination while onsite.

4. Chemical and thermal characteristics differed through a single CIPP pipe wall.
Our Horizon

Develop methods to standardize CIPP site comparisons
- Methods for extracting uncured resin tube and water samples
- Methods for characterizing/extracting exhumed CIPP pipes
- Methods for evaluating the role of leaching on composite longevity

Conduct field monitoring at partner DOT sites

Analyze and compare existing DOT construction specifications to determine the upgrades needed

Seeking additional partners interested who can provide feedback on their experiences, lessons learned, questions
Thank You

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