SERVICE LIFE EVALUATION OF CORRUGATED STEEL PIPE

Storm Water Detention Systems in the Metropolitan Washington, DC Area
INTRODUCTION

Corrugated steel pipe (CSP) storm water detention systems (plain galvanized, aluminized, or bituminous coated) have been in use in the metropolitan Washington, DC area since the early 1970s. A qualitative condition survey to assess the overall performance of 17 of these systems was conducted by Parsons Brinkerhoff of Baltimore, MD on behalf of the National Corrugated Steel Pipe Association (NCSPA) in early 1998. The overall conclusion of the survey was that the systems were performing extremely well. Most systems still had the zinc layer intact after about 25 years of service. There were no signs of visible deflection and most joints appeared to be soil tight.

In May of 2000 the NCSPA retained Corrpro Companies Inc. to perform a more detailed and quantitative evaluation of the corrugated steel pipe storm water detention systems evaluated previously. This work includes determining coating or metal loss and using available methodology to predict service life. This report presents the findings of the study undertaken by Corrpro.

EVALUATION PROCEDURES

Fifteen of the 17 sites were selected for evaluation. Sites 15 and 20 are sand filter systems and were not evaluated because access to the invert would require removal of sand filter media. During the field inspection it was found that one of the systems (Site No. 12) had been removed during redevelopment. In addition, it was not possible to gain access to two of the systems, sites 1 and 18. Thus testing was performed at 15 of the 17 sites.

Figure 1. Average Coating Rating

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-95</td>
<td>galvanizing intact</td>
</tr>
<tr>
<td>90</td>
<td>galvanizing partly gone, some rust</td>
</tr>
<tr>
<td>80-75</td>
<td>galvanizing gone, significant metal loss</td>
</tr>
<tr>
<td>75</td>
<td>deep pits, heavy metal loss, perforation</td>
</tr>
<tr>
<td>65-55</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td></td>
</tr>
<tr>
<td>45-40</td>
<td></td>
</tr>
<tr>
<td>35-30</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>20-15</td>
<td></td>
</tr>
<tr>
<td>10-5</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>major metal loss</td>
</tr>
</tbody>
</table>

formed on 12 sites. Table 1 presents an overview of the systems including the numbering, location, land use, system size, age, and sampling performed at each of the sites.

**Field Testing**

Field-testing consisted of performing visual observations, in-situ measurements of soil resistivity, soil pH, and redox potential at each site. Disk coupons (1½ inch in diameter) were obtained from the top and invert at each location for subsequent determination of the remaining zinc layer thickness. A total of 25 coupons were collected. Soil and water samples were also collected from each site for laboratory analysis. Wherever possible, photographic documentation of the detention systems was made.

**Laboratory Work**

Samples collected from the field testing were evaluated in the laboratory. Corrugated steel pipe coupons were polished metallographically along their thickness to reveal the zinc layer. The zinc layer thickness was measured at ten locations with the help of a low-powered optical microscope and an average thickness was calculated. Soil samples were also collected from each site for laboratory analysis.

**Table 1. Stormwater Detention System Overview**

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Location</th>
<th>Pipe Diameter (inches)</th>
<th>Coating</th>
<th>Corrugation</th>
<th>Pipe Age (years)</th>
<th>Soil Depth to Top of Pipe (feet)</th>
<th>Number of Samples Collected</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Industrial, Montgomery County, MD</td>
<td>48</td>
<td>Galvanized</td>
<td>1x3&quot; Helical</td>
<td>26</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>Industrial, Montgomery County, MD</td>
<td>48</td>
<td>Galvanized</td>
<td>1x5&quot; Helical</td>
<td>26</td>
<td>4.25</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Industrial, Montgomery County, MD</td>
<td>60</td>
<td>Galvanized</td>
<td>1x5&quot; Helical</td>
<td>21</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>6</td>
<td>Commercial, Montgomery County, MD</td>
<td>96</td>
<td>Galvanized</td>
<td>1x5&quot; Helical</td>
<td>21</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>Commercial, Montgomery County, MD</td>
<td>96</td>
<td>Galvanized</td>
<td>1x5&quot; Helical</td>
<td>21</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>8</td>
<td>Commercial, Montgomery County, MD</td>
<td>72</td>
<td>Fully Bituminous Coated</td>
<td>1x5&quot; Helical</td>
<td>21</td>
<td>2.5</td>
<td>2</td>
</tr>
<tr>
<td>9</td>
<td>Commercial, Montgomery County, MD</td>
<td>72</td>
<td>Galvanized</td>
<td>1x5&quot; Helical</td>
<td>21</td>
<td>13</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>Commercial, Montgomery County, MD</td>
<td>108</td>
<td>Aluminum Coated Type 2</td>
<td>1x5&quot; Helical</td>
<td>11</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>11</td>
<td>Residential, Fairfax County, VA</td>
<td>67x104</td>
<td>Fully Bituminous Coated</td>
<td>1x5&quot; Helical</td>
<td>6</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>12</td>
<td>Residential, Alexandria, VA</td>
<td>144</td>
<td>Galvanized</td>
<td>1x5&quot; Helical</td>
<td>6</td>
<td>6</td>
<td>1</td>
</tr>
</tbody>
</table>

**Table 2. Field Test Data**

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Location</th>
<th>Soil Resistivity*</th>
<th>Potential, mV vs. CSE**</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bottom (%)</td>
<td>Top (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom (%)</td>
<td>Top (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom (%)</td>
<td>Top (%)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Location</th>
<th>Soil Resistivity*</th>
<th>Potential, mV vs. CSE**</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Bottom (%)</td>
<td>Top (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom (%)</td>
<td>Top (%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Surface (%)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Bottom (%)</td>
<td>Top (%)</td>
<td></td>
</tr>
</tbody>
</table>

**Galvanized Systems**

2 Industrial, Montgomery County, MD
3 Industrial, Montgomery County, MD
5 Industrial, Montgomery County, MD
6 Commercial, Montgomery County, MD
7 Commercial, Montgomery County, MD
9 Commercial, Montgomery County, MD
21 Residential, Alexandria, VA

**Fully Bituminous Coated Systems**

8 Commercial, Montgomery County, MD
14 Residential, Fairfax County, VA
17 Residential, Fairfax City, VA

**Aluminum Coated Type 2 Systems**

13 Commercial, Montgomery County, MD
16 Residential, Fairfax City, VA

*Soil resistivity determined with a Collins Rod
**CSE = copper sulfate electrode
NM - Not Measured
evaluated to identify the soil type and physical character-istics, determine resistivity, pH, moisture content, chlorides and sulfides. Water samples were evaluated to determine pH, resistivity, chlorides, and sulfides.

Utilizing the soil and water analysis data, the predicted service life of the detention system was calculated using a variety of methods:

- Software previously developed by Corrpro Companies² for the NCSPA.
- California Method for Estimating Years to Perforation of Steel Culverts
- AISI Method for Service Life Prediction
- The procedures used by Potter in FHWA-FLP-91-006.

**FINDINGS**

Field Tests Table 2 summarizes the results of the soil resistivity, pH and potential measurements made at each site. Over 80% of the potential readings were found to be in the range of -617 mV to -946 mV with respect to a copper-copper sulfate electrode. Potential readings in this range indicate that the galvanized layer has not corroded away and exposed the bare steel.

**ANALYSIS AND DISCUSSION**

Table 3 summarizes the laboratory analysis data for the soil samples. These parameters were utilized to calculate the remaining life of the galvanized layer using the software program previously developed by Corrpro for NCSPA². That study of culvert and storm sewer installations concluded indicated that "93.2% of the plain galvanized installations have a soil side service life in excess of 75 years, while 81.5% have a soil side service life in excess of 100 years."

Perforation of Steel Culverts The software generates service life predictions from a statistical model developed to accurately predict the bare steel.

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sample Location</th>
<th>Soil Type</th>
<th>Sample Color</th>
<th>Moisture (%)</th>
<th>pH</th>
<th>Chloride (ppm)</th>
<th>Sulfide (ppm)</th>
<th>Resistivity (ohm-cm)</th>
<th>16 gage galvanized pipe life (yrs)*</th>
<th>Gage Multiplier</th>
<th>Predicted Pipe Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Top sandy clay loam</td>
<td>gray</td>
<td>23.72</td>
<td>4.7</td>
<td>16</td>
<td>0.3</td>
<td>722</td>
<td>91.5</td>
<td>1.0</td>
<td>91.5</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Top clay</td>
<td>gray</td>
<td>29.14</td>
<td>7.9</td>
<td>32</td>
<td>0</td>
<td>2538</td>
<td>100.1</td>
<td>1.0</td>
<td>100.1</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Top silty clay loam</td>
<td>gray-brown</td>
<td>23.83</td>
<td>7.9</td>
<td>20</td>
<td>0</td>
<td>8696</td>
<td>141.4</td>
<td>1.3</td>
<td>183.8</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Top silty clay loam</td>
<td>gray-brown</td>
<td>26.51</td>
<td>7.4</td>
<td>27</td>
<td>0</td>
<td>3663</td>
<td>91.7</td>
<td>1.3</td>
<td>119.2</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Top silty clay loam</td>
<td>light brown</td>
<td>27.52</td>
<td>6.4</td>
<td>37</td>
<td>0</td>
<td>4630</td>
<td>57.4</td>
<td>1.3</td>
<td>74.6</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Top silty clay loam</td>
<td>light brown</td>
<td>29.18</td>
<td>6.8</td>
<td>28</td>
<td>0.3</td>
<td>5051</td>
<td>67.7</td>
<td>1.3</td>
<td>80.0</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Top silty clay loam</td>
<td>light brown</td>
<td>30.21</td>
<td>6.6</td>
<td>9</td>
<td>0</td>
<td>11765</td>
<td>122.9</td>
<td>1.3</td>
<td>159.8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Invert clay</td>
<td>gray-red brown</td>
<td>34.00</td>
<td>7.6</td>
<td>10</td>
<td>0</td>
<td>2899</td>
<td>139.7</td>
<td>2.3</td>
<td>321.3</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Top silty clay</td>
<td>light red gray</td>
<td>24.17</td>
<td>6.0</td>
<td>34</td>
<td>0</td>
<td>1992</td>
<td>45.4</td>
<td>1.8</td>
<td>81.7</td>
<td></td>
</tr>
</tbody>
</table>

**Fully Bituminous Coated Systems**

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sample Location</th>
<th>Soil Type</th>
<th>Sample Color</th>
<th>Moisture (%)</th>
<th>pH</th>
<th>Chloride (ppm)</th>
<th>Sulfide (ppm)</th>
<th>Resistivity (ohm-cm)</th>
<th>16 gage galvanized pipe life (yrs)*</th>
<th>Gage Multiplier</th>
<th>Predicted Pipe Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>Top silty clay Light clay</td>
<td>yellow gray</td>
<td>25.58</td>
<td>7.7</td>
<td>32</td>
<td>0</td>
<td>2899</td>
<td>94.9</td>
<td>1.3</td>
<td>123.4</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Top silty clay Light clay</td>
<td>yellow gray</td>
<td>27.48</td>
<td>7.6</td>
<td>30</td>
<td>0</td>
<td>3846</td>
<td>96.8</td>
<td>1.3</td>
<td>125.8</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Side silty clay Light clay</td>
<td>light brown</td>
<td>23.07</td>
<td>5.7</td>
<td>10</td>
<td>0</td>
<td>7813</td>
<td>79.9</td>
<td>1.8</td>
<td>143.8</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Side silty clay Light clay</td>
<td>light brown</td>
<td>32.38</td>
<td>6.6</td>
<td>10</td>
<td>0</td>
<td>10417</td>
<td>115.9</td>
<td>1.8</td>
<td>208.6</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Invert silty clay Light brown</td>
<td>27.95</td>
<td>5.1</td>
<td>12</td>
<td>0</td>
<td>6993</td>
<td>59.3</td>
<td>1.8</td>
<td>106.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Aluminum Coated Type 2 Systems**

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sample Location</th>
<th>Soil Type</th>
<th>Sample Color</th>
<th>Moisture (%)</th>
<th>pH</th>
<th>Chloride (ppm)</th>
<th>Sulfide (ppm)</th>
<th>Resistivity (ohm-cm)</th>
<th>16 gage galvanized pipe life (yrs)*</th>
<th>Gage Multiplier</th>
<th>Predicted Pipe Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>Top silty clay</td>
<td>light brown</td>
<td>26.73</td>
<td>6.6</td>
<td>30</td>
<td>0</td>
<td>1961</td>
<td>60.6</td>
<td>2.3</td>
<td>139.4</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Top silty clay</td>
<td>light brown</td>
<td>34.33</td>
<td>7.2</td>
<td>18</td>
<td>0</td>
<td>3745</td>
<td>100.1</td>
<td>2.3</td>
<td>230.2</td>
<td></td>
</tr>
</tbody>
</table>

*Service life for 16 gage galvanized pipe using software previously developed by Corrpro Companies, Inc for NCSPA
dict service life of galvanized CSP for sites where durability is limited by soil side corrosion. The model predicts the condition of the protective galvanized coating over time plus the life of 16 gage black steel. According to the author:

> "When the galvanized coating reaches the point that pitting of the steel substrate could begin, the model uses black steel corrosion data from 23,000 black steel underground storage tank sites to analyze overall durability vs. time. The black steel used in the model was 16 gage. Therefore the model does not accommodate added life projections due to the increased thickness of the pipe wall. Use of this data induces significant conservatism also, because it is based on steel not previously galvanized, and there-

| Table 4. Service Life Predictions in Accordance with the California Method and AISI Method |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Site No. | Sample Location | pH | Resistivity (ohm-cm) | Gage | California Pred. Life (yrs) | AISI Pred. Life (yrs) | Minimum California | Minimum AISI | 
| Galvanized Systems | | | | | | | | |
| 2 | Crown Soil Invert Soil Water* | 7.4 | 722 | 16 | 28 | 57 | 57 | 28 | 57 |
| 3 | Crown Soil Invert Soil Water** | 7.9 | 2538 | 16 | 48 | 95 | 62 | 31 | 62 |
| 5 | Crown Soil Invert Soil Water | 7.9 | 8696 | 14 | 97 | 205 | 73 | 34 | 73 |
| 6 | Crown Soil Invert Soil Water | 6.4 | 4630 | 14 | 33 | 69 | 67 | 32 | 67 |
| 7 | Crown Soil Invert Soil Water | 6.3 | 2941 | 14 | 27 | 53 | 67 | 27 | 58 |
| 9 | Invert Soil Water | 7.6 | 2899 | 10 | 108 | 231 | 135 | 94 | 201 |
| 21 | Crown Soil Water | 6.0 | 1992 | 12 | 29 | 61 | 106 | 29 | 61 |
| Fully Bituminous Coated Systems | | | | | | | | |
| 8 | Crown Soil Invert Soil Water | 7.7 | 2899 | 14 | 62 | 130 | 135 | 62 | 130 |
| 14 | Side Soil Invert Soil Water | 5.7 | 7813 | 12 | 44 | 94 | 114 | 44 | 94 |
| 17 | Invert Soil Water | 5.1 | 6993 | 12 | 38 | 80 | 130 | 38 | 80 |
| Aluminum Coated Type 2 Systems | | | | | | | | |
| 13 | Side Soil Invert Soil Water | 6.6 | 1961 | 10 | 47 | 100 | 214 | 47 | 100 |
| 16 | Crown Soil Water | 4.9 | 10417 | 14 | 30 | 64 | 85 | 30 | 64 |

Notes: 1. The above resistivity and pH data was obtained from laboratory analysis of field samples. 2. All predictions are for galvanized pipe of the designated gage. No multiplier or “add-on” for additional coating has been used. *This water smelled of antifreeze. It was considered an aberrant condition for service life prediction. **This “water” was saturated organic matter.
fore, does not recognize the effects of residual galva-
ning and the alloy layer formed during the galva-
nizing in slowing the corrosion process. Additionally,
the slowing of the corrosion pitting rate with time for
thicker gages cannot be accommodated. However,
these shortcomings add conservatism to the service
detention system using both the California and AISI
life estimates.*

The calculations show the average predicted life of
a 16 gage galvanized pipe in these environments is
considered the end of service life. The AISI Method
about 86 years. Table 3 also attempts to adjust the
(also developed by Stratful) is based on the Caltrans
service life prediction by using a gage multiplier as
Method but is used to predict average invert service
recommended by the AISI Method. This shows that the
average predicted life of the systems is about 130
using each of the environmental samples (soil and

Table 4 shows the predicted service life of each
systems are all in quite good condition, with most of
the galvanized coating still in tact. There would cer-
tainly need to be extreme corrosion to occur if they are
have penetrations at the age predicted by the
California Method. This suggests that the AISI Method
provides a more accurate service life prediction than
the California Method for detention systems, however
both methods provide very conservative predictions
for these environments.

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To better understand the relationship between the California Method predictions and existing conditions, Potter correlated percent penetration with percent of California predicted service life expended. While there has been extensive debate over the validity of the technique, it is used as another method to compare service life predictions. Table 5 presents the minimum thickness measured on coupons from each system. That value is compared with the “original” thickness. The original thickness was determined in most cases by measuring overall thickness on the crown of the pipe where the galvanizing was metallurgically determined to be intact. Using all data points, the analysis suggests that the galvanized systems are performing 2.8 times as well as the California Method would predict while the fully bituminous coated systems are performing 4.6 times as well as the California Method would predict for galvanized material. It should be noted that this multiplier increases to 7.3 times for galvanized systems if Site #6 is ignored. The inspection of the systems support the conclusion that the galvanized detention systems will last more than twice as long as the California Method might predict.

**Table 5. Service Life Analysis Using the Technique Developed by Potter**

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Original (est)</th>
<th>Min</th>
<th>Percent Perforation</th>
<th>Min. Calif Pred. Years*</th>
<th>Years</th>
<th>Percent of Calif. Pred.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Galvanized Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.058</td>
<td>0.048</td>
<td>17.2%</td>
<td>28</td>
<td>26</td>
<td>92.9%</td>
</tr>
<tr>
<td>3</td>
<td>0.058</td>
<td>0.056</td>
<td>3.4%</td>
<td>31</td>
<td>26</td>
<td>83.9%</td>
</tr>
<tr>
<td>5</td>
<td>0.072</td>
<td>0.069</td>
<td>4.2%</td>
<td>34</td>
<td>21</td>
<td>61.8%</td>
</tr>
<tr>
<td>6</td>
<td>0.071</td>
<td>0.044</td>
<td>38.0%</td>
<td>32</td>
<td>21</td>
<td>65.6%</td>
</tr>
<tr>
<td>7</td>
<td>0.071</td>
<td>0.068</td>
<td>4.2%</td>
<td>27</td>
<td>21</td>
<td>77.8%</td>
</tr>
<tr>
<td>9</td>
<td>0.128</td>
<td>0.126</td>
<td>1.6%</td>
<td>94</td>
<td>21</td>
<td>22.3%</td>
</tr>
<tr>
<td>21</td>
<td>0.099</td>
<td>0.097</td>
<td>2.0%</td>
<td>29</td>
<td>6</td>
<td>20.7%</td>
</tr>
<tr>
<td><strong>Fully Bituminous Coated Systems</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>0.075</td>
<td>0.071</td>
<td>5.3%</td>
<td>62</td>
<td>21</td>
<td>33.9%</td>
</tr>
<tr>
<td>14</td>
<td>0.098</td>
<td>0.096</td>
<td>2.0%</td>
<td>44</td>
<td>6</td>
<td>13.6%</td>
</tr>
<tr>
<td>17</td>
<td>0.105</td>
<td>0.099</td>
<td>5.7%</td>
<td>38</td>
<td>6</td>
<td>15.8%</td>
</tr>
<tr>
<td><strong>Aluminum Coated Type 2 Systems</strong></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>13</td>
<td>0.124</td>
<td>0.120</td>
<td>3.2%</td>
<td>47</td>
<td>11</td>
<td>23.4%</td>
</tr>
<tr>
<td>16</td>
<td>0.070</td>
<td>0.053</td>
<td>24.3%</td>
<td>30</td>
<td>11</td>
<td>36.7%</td>
</tr>
</tbody>
</table>

*Data from Table 4 of this report*
Corrugated steel pipe storm detention systems (galvanized, aluminized, or bituminous coated) are performing satisfactorily in service. The service life of detention systems appears to be driven by soil-side corrosion. As a result, it is expected that the service life would be longer for detention systems than for culverts or storm sewers. This may be due in part to an absence of abrasion in the invert of detention systems.

The AISI Method appears more realistic in terms of predicting Detention System Service Life than the California Method, though both will provide conservative service life predictions for most environments. Visual observations and measurements of remaining galvanized layer thickness on coupons are in concurrence with theoretical calculations using previously developed software for remaining life prediction.

Physical inspection of these systems along with the analytical approach presented herein support the prediction of a functional service life for these galvanized detention systems in excess of 100 years. Corrugated steel pipe manufacturers provide a range of coatings and material thicknesses that make it possible to design a detention system in practically any environment that will last in excess of 100 years where corrosion is the life limiting factor.
SITE 2: 48" Detention System, Montgomery County

**Water Data**
- pH: 5.5
- Chloride, ppm: 139
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 613

**Soil Data**
- Moisture %: 23.72 - 27.32%
- pH: 7.4 - 7.7
- Chloride, ppm: 16 - 60
- Sulfide, ppm: 0.3 - 0
- Resistivity, ohm-cm: 722 - 1,684

**General Information**
- Age of Inspection: 26 years
- Coating Type: galvanized
- Diameter: 48"
- Corrugation: 1x5" helical
- Land Use: industrial
- Location: Montgomery County, Md.
## SITE 3: 48" Detention/Infiltration System, Montgomery County

### Water Data
- **pH**: 7.5
- **Chloride, ppm**: 66
- **Sulfide, ppm**: 0.3
- **Resistivity, ohm-cm**: 881

### Soil Data
- **Moisture %**: 29.14%
- **pH**: 7.9
- **Chloride, ppm**: 32
- **Sulfide, ppm**: 0
- **Resistivity, ohm-cm**: 2,538

### General Information
- **Age of Inspection**: 26 years
- **Coating Type**: galvanized
- **Diameter**: 48"
- **Corrugation**: 1x5" helical
- **Land Use**: industrial
- **Location**: Montgomery County, Md.
SITE 5: 60" Detention System, Montgomery County

**Water Data**
- pH: 7.4
- Chloride, ppm: 193
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 692

**Soil Data**
- Moisture %: 23.83, 26.51%
- pH: 7.4, 7.4
- Chloride, ppm: 20, 27
- Sulfide, ppm: 0, 0
- Resistivity, ohm-cm: 8,696, 3,663

**General Information**
- Age of Inspection: 21 years
- Coating Type: galvanized
- Diameter: 60"
- Corrugation: 1x5" helical
- Land Use: industrial
- Location: Montgomery County, Md.
### SITE 6: 96" Detention System, Montgomery County

**Water Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.2</td>
</tr>
<tr>
<td>Chloride, ppm</td>
<td>16</td>
</tr>
<tr>
<td>Sulfide, ppm</td>
<td>0</td>
</tr>
<tr>
<td>Resistivity, ohm-cm</td>
<td>5,181</td>
</tr>
</tbody>
</table>

**Soil Data**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture %</td>
<td>27.52%</td>
</tr>
<tr>
<td>pH</td>
<td>6.4</td>
</tr>
<tr>
<td>Chloride, ppm</td>
<td>37</td>
</tr>
<tr>
<td>Sulfide, ppm</td>
<td>0</td>
</tr>
<tr>
<td>Resistivity, ohm-cm</td>
<td>4,630</td>
</tr>
</tbody>
</table>

**General Information**

- **Age of Inspection:** 21 years
- **Coating Type:** galvanized
- **Diameter:** 96"
- **Corrugation:** 1x5" helical
- **Land Use:** commercial
- **Location:** Montgomery County, Md.
SITE 7: 96" Detention System, Montgomery County

Water Data
- pH: 7.3
- Chloride, ppm: 14
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 3,165

Soil Data
- Moisture %: 23.67, 30.21%
- pH: 6.3, 6.6
- Chloride, ppm: 42, 9
- Sulfide, ppm: 0, 0
- Resistivity, ohm-cm: 2,941, 11,765

General Information
- Age of Inspection: 21 years
- Coating Type: galvanized
- Diameter: 96"
- Corrugation: 1x5" helical
- Land Use: commercial
- Location: Montgomery County, Md.
SITE 8: 72" Detention System, Montgomery County

Water Data
pH: 7.6
Chloride, ppm: 40
Sulfide, ppm: 0
Resistivity, ohm-cm: 3,135

Soil Data
Moisture %: 25.58 27.48%
pH: 7.7 7.6
Chloride, ppm: 32 30
Sulfide, ppm: 0 0
Resistivity, ohm-cm: 2,899 3,846

General Information
Age of Inspection: 21 years
Coating Type: fully bituminous coated
Diameter: 72"
Corrugation: 1x5" helical
Land Use: industrial
Location: Montgomery County, Md.
SITE 9: 108" Detention System, Montgomery County

**Water Data**
- pH: 7.9
- Chloride, ppm: 34
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 2,066

**Soil Data**
- Moisture %: 34.00%
- pH: 7.6
- Chloride, ppm: 10
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 2,899

**General Information**
- Age of Inspection: 21 years
- Coating Type: galvanized
- Diameter: 108"
- Corrugation: 1x5' helical
- Land Use: commercial
- Location: Montgomery County, Md.
### SITE 13: 108" Detention System, Montgomery County

<table>
<thead>
<tr>
<th>Water Data</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>pH</strong></td>
<td>7.3</td>
<td></td>
</tr>
<tr>
<td>Chloride, ppm</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Sulfide, ppm</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Resistivity, ohm-cm</td>
<td>4,016</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Soil Data</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture %</td>
<td>26.73</td>
<td>34.33%</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>6.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Chloride, ppm</td>
<td>30</td>
<td>18</td>
</tr>
<tr>
<td>Sulfide, ppm</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Resistivity, ohm-cm</td>
<td>1,961</td>
<td>3,745</td>
</tr>
</tbody>
</table>

**General Information**
- Age of Inspection: 11 years
- Coating Type: aluminum coated type 2
- Diameter: 108"
- Corrugation: 1x5" helical
- Land Use: commercial
- Location: Montgomery County, Md.
SITE 14: 67"x104" Detention System, Fairfax City

**Water Data**
- pH: 6.9
- Chloride, ppm: 32
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 4,184

**Soil Data**
- Moisture %: 23.07, 32.38%
- pH: 5.7, 6.6
- Chloride, ppm: 10, 10
- Sulfide, ppm: 0, 0
- Resistivity, ohm-cm: 7,813, 10,417

**General Information**
- Age of Inspection: 6 years
- Coating Type: fully bituminous coated
- Diameter: 67"x104"
- Corrugation: 1x5" helical
- Land Use: residential
- Location: Fairfax City, Va.
SITE 16: 80" Detention System, Fairfax City

Water Data
- pH: 6.8
- Chloride, ppm: 133
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 5,814

Soil Data
- Moisture %: 20.40%
- pH: 4.9
- Chloride, ppm: 16
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 10,417

General Information
- Age of Inspection: 11 years
- Coating Type: aluminum coated type 2
- Diameter: 80"
- Corrugation: 1x5" helical
- Land Use: residential (SFH)
- Location: Fairfax City, Va.
SITE 17: 65"x107" Detention System, Fairfax City

**Water Data**
- pH: 6.6
- Chloride, ppm: 121
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 12,195

**Soil Data**
- Moisture %: 27.32%
- pH: 5.1
- Chloride, ppm: 12
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 6,993

**General Information**
- Age of Inspection: 6 years
- Coating Type: fully bituminous coated
- Diameter: 65"x107"
- Corrugation: 1x5" helical
- Land Use: residential
- Location: Fairfax City, Va.
SITE 21: 72" Detention System, Alexandria

**Water Data**
- pH: 6.2
- Chloride, ppm: 120
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 8,333

**Soil Data**
- Moisture %: 24.17%
- pH: 6.0
- Chloride, ppm: 34
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 1,992

**General Information**
- Age of Inspection: 6 years
- Coating Type: galvanized
- Diameter: 72"
- Corrugation: 1x5" helical
- Land Use: residential