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\(^1\) was that the systems were performing extremely well. Figure 1 shows the average condition rating (crown, sides, invert) based on a visual rating scale developed by Corrpro, 1991.\(^2\) 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 per-

Figure 1. Average Coating Rating

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
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</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>70-60</td>
<td>deep pits, heavy metal loss, perforation</td>
</tr>
<tr>
<td>50-40</td>
<td>minor metal loss</td>
</tr>
<tr>
<td>35-30</td>
<td>major metal loss</td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>20-15</td>
<td></td>
</tr>
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<td>10-5</td>
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<tr>
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</tr>
</tbody>
</table>

formed on 12 sites. Table 1 presents an overview of
each site 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 resis-
tivity, soil pH, and redox potential at each site. Disk
coupons (1/2 inch in diameter) were obtained from the
top and invert at each location for subsequent determi-
nation of the remaining zinc layer thickness. A total of
25 coupons were collected. Soil and water samples were
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
analyzed for pH and redox potential.

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>
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<tr>
<td>2</td>
<td>Industrial, Montgomery County, MD</td>
<td>48</td>
<td>Galvanized</td>
<td>1x3' Helical</td>
<td>26</td>
<td>2</td>
<td>2</td>
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<td>3</td>
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<td>1x5' Helical</td>
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<td>4.25</td>
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<td>60</td>
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<td>1x5' 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' Helical</td>
<td>21</td>
<td>4</td>
<td>2</td>
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<td>7</td>
<td>Commercial, Montgomery County, MD</td>
<td>96</td>
<td>Galvanized</td>
<td>1x5' Helical</td>
<td>21</td>
<td>2</td>
<td>2</td>
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<tr>
<td>8</td>
<td>Commercial, Montgomery County, MD</td>
<td>72</td>
<td>Fully Bituminous Coated</td>
<td>1x5' Helical</td>
<td>21</td>
<td>2.5</td>
<td>2</td>
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<tr>
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<td>1x5' Helical</td>
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<td>108</td>
<td>Aluminum Coated Type 2</td>
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<td>12</td>
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<table>
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<tr>
<th>Site No.</th>
<th>Location</th>
<th>Soil Resistivity*</th>
<th>Potential, mV vs. CSE**</th>
<th>pH</th>
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<td>-644</td>
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<td>NM</td>
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<tr>
<td>21</td>
<td>Residential, Alexandria, VA</td>
<td>1900</td>
<td>-629</td>
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<tr>
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<td>NM</td>
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<td>Residential, Fairfax City, VA</td>
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<td>-926</td>
<td>7.16</td>
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<td>13</td>
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<td>10.4</td>
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<tr>
<td>16</td>
<td>Residential, Fairfax City, VA</td>
<td>28000</td>
<td>-617</td>
<td>7.81</td>
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</table>

*Soil resistivity measured with a Collins Rod
**CSE = copper sulfate electrode
NM - Not Measured
evaluated to identify the soil type and physical characteristics, 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:

- The procedures used by Potter in FHWA-FLP-91-006.
- Software previously developed by Corrpro Companies 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.
- 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.

The software generates service life predictions from a statistical model developed to accurately predict service life for 16 gage galvanized pipe using software previously developed by Corrpro Companies, Inc for NCSPA.

### 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.

#### Table 3. Laboratory Soil Analysis Data and Soil Side Life Prediction*

<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>
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<td>Top</td>
<td>sandy clay loam</td>
<td>gray</td>
<td>23.72</td>
<td>7.4</td>
<td>16</td>
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<td>1.0</td>
<td>91.5</td>
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<td>20</td>
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<td>27</td>
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<td>0</td>
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*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 that pitting of the steel substrate could begin, the predicts the condition of the protective galvanized model uses black steel corrosion data from 23,000 coating over time plus the life of 16 gage black steel. black steel underground storage tank sites to analyze induces significant conservatism also, because, it is

According to the author: overall durability vs. time. The black steel used in the based on steel not previously galvanized, and there-

<table>
<thead>
<tr>
<th>Site No.</th>
<th>Sample Location</th>
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<th>Gage</th>
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<th>Minimum California</th>
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<td>85</td>
<td>64</td>
<td>30</td>
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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.
3. This water smelled of antifreeze. It was considered an aberrant condition for service life prediction.
4. **This water** was saturated organic matter.
fore, does not recognize the effects of residual galvanizing and the alloy layer formed during the galvanizing 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 life estimates.

The calculations show the average predicted life of a 16 gage galvanized pipe in these environments is about 86 years. Table 3 also attempts to adjust the service life prediction by using a gage multiplier as recommended by the AISI Method. This shows that the average predicted life of the systems is about 130 years. The minimum predicted service life for any of the systems is 65 years. Taking all of the above factors into consideration, the total service life of the structures would be in excess of 100 years. Method predicted service life (first perforation). Yet the systems are all in quite good condition, with most of the galvanized coating still in tact. There would certainly need to be extreme corrosion to occur if they are about 86 years. Table 3 also attempts to adjust the service life prediction by using a gage multiplier as (also developed by Stratful) is based on the Caltrans Method but is used to predict average invert service life. 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.

Table 4 shows the predicted service life of each system using both the California and AISI methods. The California Method was developed by Stratful to predict time to fist perforation, which is not considered the end of service life. The AISI Method was developed by Stratful, and is based on 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.

Figure 2. Percent Metal Perforation vs. California Prediction

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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 metallographically determined to be intact at nominally the original thickness.

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

<table>
<thead>
<tr>
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<tr>
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<td></td>
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<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>
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<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>
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<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>
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<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>
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<tr>
<td>7</td>
<td>0.071</td>
<td>0.068</td>
<td>4.2%</td>
<td>27</td>
<td>21</td>
<td>77.6%</td>
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<tr>
<td>9</td>
<td>0.128</td>
<td>0.126</td>
<td>1.6%</td>
<td>94</td>
<td>21</td>
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<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>
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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>
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<td>0.124</td>
<td>0.120</td>
<td>3.2%</td>
<td>47</td>
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<td>23.4%</td>
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<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

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 supports the conclusion that the galvanized detention systems will last more than twice as long as the California Method might predict. Figure 2 shows the data plotted in a manner similar to that used by Potter. Best-fit lines were regressed through all of the data for galvanized and asphalt coated pipes. No plot was made for aluminum coated pipes due to a lack of sufficient number of data points.
Corrugated steel pipe storm detention Systems (galvanized, aluminized, or bituminous coated) are performing satisfactorily in service.

2. The service life of detention systems appears to be driven by soil-side corrosion.

3. There is no significant water-side invert deterioration. 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.

4. 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.

5. 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.

6. 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.

7. Corrugated steel pipe manufacturers provide a range of coatings and material thicknesses that make it possible to design a detentions 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**

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<tr>
<th>Parameter</th>
<th>Value</th>
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<td>Chloride, ppm</td>
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<tr>
<td>Sulfide, ppm</td>
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<td>Resistivity, ohm-cm</td>
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**Soil Data**

<table>
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<tr>
<th>Parameter</th>
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<tr>
<td>pH</td>
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<tr>
<td>Chloride, ppm</td>
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<tr>
<td>Sulfide, ppm</td>
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<td>Resistivity, ohm-cm</td>
<td>722</td>
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<tr>
<td></td>
<td>1,684</td>
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**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
- pH: 6.2
- Chloride, ppm: 16
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 5,181

Soil Data
- Moisture %: 27.52% 29.18%
- pH: 6.4 6.8
- Chloride, ppm: 37 28
- Sulfide, ppm: 0 0.3
- Resistivity, ohm-cm: 4,630 5,051

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

Water Data

- pH: 7.3
- Chloride, ppm: 7
- Sulfide, ppm: 0
- Resistivity, ohm-cm: 4,016

Soil Data

- Moisture %: 26.73, 34.33%
- pH: 6.6, 7.2
- Chloride, ppm: 30, 18
- Sulfide, ppm: 0, 0
- Resistivity, ohm-cm: 1,961, 3,745

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

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<td>Sulfide, ppm</td>
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<td>Resistivity, ohm-cm</td>
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Soil Data

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<td>Sulfide, ppm</td>
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<tr>
<td>Resistivity, ohm-cm</td>
<td>10,417</td>
</tr>
</tbody>
</table>

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