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Galvanized and Aluminized Pipe Durability Field Review and Evaluation

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The findings support previous results that indicated increased deterioration rates following the 1974 policy change and showed reduced deterioration rates since the 1989 study. Furthermore, the 2001 policy allowing Aluminized Type 2 CMP under specific site conditions showed deterioration rates similar to those before the 1974 study. A pilot study was also conducted to investigate an alternative method for estimating deterioration rates using a soil leachate analysis.

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Abstract

Two studies were conducted by KDOT in the 1980s to evaluate the performance of corrugated metal pipe (CMP) after a 1974 pipe policy change. This report is a follow-up study to evaluate the impact of the study initiated in 1989 and another pipe policy change in 2001.

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Chapter 1: Introduction

There are a significant number of corrugated metal pipe (CMP) drainage structures throughout the state of Kansas; over 2,990 CMPs managed by KDOT are listed in Districts One and Four alone. As such, KDOT has conducted studies to determine CMP durability and service life, specifically related to deterioration from corrosion (Stratton, 1989; Stratton, Frantzen, & Meggers, 1990). The findings of these studies have resulted in several changes to KDOT pipe policy. One of the largest studies investigated the deterioration of 819 galvanized CMPs. Stratton et al. (1990) determined that CMPs were drastically underperforming following a KDOT pipe policy change in 1974 that allowed for a higher gauge (i.e., thinner CMP). KDOT reverted to the pre-1974 pipe policy following the Stratton et al. (1990) study. In 2001, after additional reviews of reports, materials, and field conditions, KDOT policy was changed again to allow the use of Aluminized Type 2 steel CMP in place of galvanized CMP when soil and runoff conditions were suitable for installation and traffic was below 3,000 vehicles per day. The objective of this study was to evaluate the impact of KDOT pipe policy changes in 1974 and 2001 and the impact of the recommendations from the last comprehensive study (Stratton et al., 1990) on CMP deterioration rates.

This study includes a survey of 81 CMP within KDOT Districts One, Three, and Four. The field survey followed the same procedure as Stratton et al. (1990), including a visual inspection and qualitative rating of the CMP crown, side, exterior, and invert along with a general rating and field resistivity measurements. Approximately half of these CMPs (41) were also surveyed by Stratton et al.; the remaining CMPs were installed after 1990. An additional pilot study on the electrochemical analysis of soil porewater (leachate analysis) was conducted on a subset of six CMP with variable deterioration rates. The objectives of the pilot study were to determine if a simplified methodology can be utilized to predict CMP service life and to support a follow-up study to further develop this methodology. This study is significant because it highlights the impact of the changes in KDOT pipe policy over the past 44 years and it indicates the potential for an alternative methodology to directly determine CMP deterioration rates. A literature review that includes the fundamentals of corrosion, common methods to assess corrosion potential, previous studies conducted in Kansas on CMP conditions, and a summary of previous studies conducted by others follows this introduction. The research methodology, results, and analysis are then presented, followed by the conclusions and recommendations of this study.

Chapter 2: Literature Review

2.1 Corrosion

Corrosion is the degradation of metals through electrochemical reactions and is the process of metal returning to a natural state. There are four requirements to induce the electrochemical process of corrosion: an anode, cathode, electric pathway, and an electrolytic pathway. The anode, or the location of metal dissolution, acts as a reducing agent generating electrons that travel to the cathode via an electrical pathway. Simultaneously, positively charged ions are produced which travel back to the anode by way of electrolytic pathway, thus functioning as an electrical circuit. The metal becomes corroded due to the loss of metal ions to the electrolyte (Elias, Fishman, Christopher, & Berg, 2009).

The phenomenon of preferential galvanic corrosion is widely used to protect metals and alloys from corrosion. The severity of galvanic corrosion depends on the difference in voltage potential, which is illustrated as the order of metals and alloys on the galvanic series in Figure 2.1 (Cicek, 2014). For example, Revie (2011) clamped two 1.5-inch-diameter, $^{1}/_{16}$-inch-thick zinc and iron disks together so that only the edges were exposed. The disks were exposed to a marine environment for seven years and weighed. The weight loss associated with iron coupled with zinc was more than three times less than iron coupled with iron; it was also less than zinc coupled with zinc. Iron is a more noble metal than zinc, as shown in Figure 2.1, therefore the zinc was susceptible to preferential galvanic corrosion. By providing a surface layer of a more anodic material, the underlying metal gains protection from corrosion. The anodic surface acts as a sacrificial layer, even providing protection in locations where discontinuities occur in the coating.

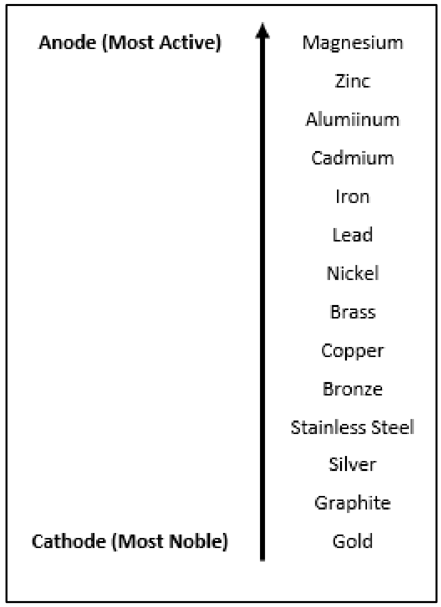

Figure 2.1: Galvanic Series

Material passivity is the process in which a metal or alloy exhibits a much higher corrosion resistance than its electrochemical potential indicates (Cicek, 2014). Figure 2.2 details how an ideal passive metal reacts to electrochemical potential. As the electrochemical potential of an anode increases, so does the current density, which correlates to an increased rate of corrosion. The anode actively corrodes until the critical density (i_c) is reached. A passive film is formed at the passivation potential (E_p) at which point the current density drops to a passive current density (i_p), thus a decreased rate of corrosion. All metal and alloys, except gold, form a thin protective layer on the surface after reacting with the environment. Some of these films have special characteristics that enable them to provide superior corrosion resistant surfaces. These passive films that develop are critical in controlling the corrosion process by preventing the spontaneous reaction of reverting metals to ores (Revie, 2011).

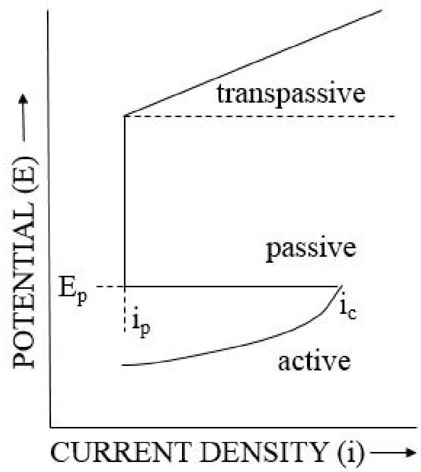

Figure 2.2: Idealized Anodic Polarization Curve for a Passive Metal
Source: Revie (2011)

Conditions for which passivity occur are illustrated in Pourbaix diagrams. Pourbaix diagrams graphically represent electrochemical equilibria of metals in different aqueous solutions based on pH and electrochemical potential. Pourbaix diagrams are used to establish theoretical domains of passivity, immunity, and corrosion. The dashed line A in Figure 2.3 represents the reversible oxygen line and the dashed line B represents the reversible hydrogen line. Water is thermodynamically stable between dashed lines A and B. Outside of these boundaries, water either decomposes to form hydrogen gas (H_2), or is oxidized to form oxygen gas (O_2). Only the region between the reversible oxygen line and reversible hydrogen line is considered when analyzing the corrosion and passivity of a metal or alloy in water (Kelly, Scully, Shoesmith, & Buchheit, 2003).

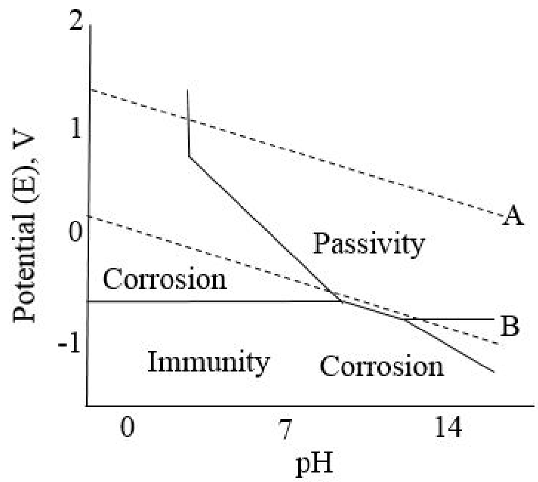

Figure 2.3: Simplified Pourbaix Diagram for Iron-Water
Source: Revie and Uhlig (2008)

2.2 Contributing Factors of Corrosion

Temperature, humidity level, hydrogen ion concentration (pH), concentrations of dissolved oxygen, pore fluid electrolytes, presence of aggressive ions, flow rate, and metal impurities all are factors that contribute to a metals susceptibility to corrosion (Cicek, 2014). The impact of these factors on corrosion processes are interrelated and many are functions of the location, such as temperature and humidity. The rate of corrosion increases with increasing temperature. Regions with humid climate, such as eastern Kansas in this study, have an increased risk of acidic soil due to the leaching of alkaline salts. An increased flow rate increases corrosion because the protective films can be removed by liquid turbulence or abrasive sediments. In this study the flow rate was noted in the field; however, the implications on the corrosion level were beyond the scope as were any unidentifiable metal impurities. Experiments on galvanized steel have indicated that the main factors that affect corrosion are the surrounding material's electrical resistivity, pH, and the concentration of dissolved sulfate and chloride ions (Bourgeois, Corfdir, & Chau, 2013). These factors were investigated in this research and are discussed below.

2.2.1 Hydrogen Ion Concentration (pH)

Hydrogen ion concentration (pH) is widely used to determine the risk a certain area poses in facilitating aggressive corrosion. The Pourbaix diagram in Figure 2.4 illustrates how the pH can change the chemical equilibria for a pure aluminum, affecting the corrosion. This is similar to Aluminized Type 2 culverts that have a layer of aluminum coating on the surface. At pH ranges of approximately 5 to 9, the reaction is passive. This means a protective aluminum oxide coating is produced, further strengthening the metal's resiliency to corrosion. When the surrounding environment is outside of the 3.5 to 8.5 pF range, soluble products such as Al^{3+} and AlO_2^- are formed, allowing for the corrosion of the underlying metal.

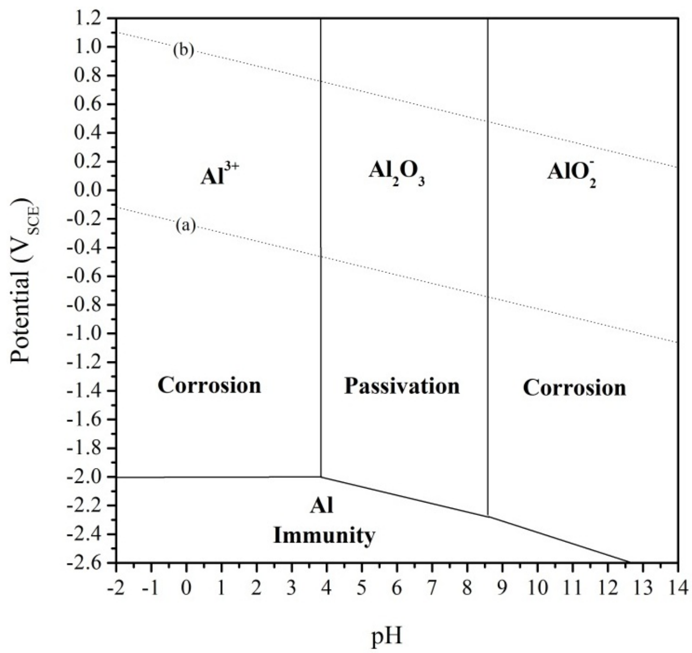

Figure 2.4: Pourbaix Diagram of Pure Aluminum at 25°C in Aqueous Solution
Source: Sukiman et al. (2012)

2.2.2 Electrical Resistivity

The minimum electrical resistivity of a material is believed to be the most accurate indicator of corrosion potential (Elias et al., 2009; King, 1977). Electrical resistivity is an intrinsic material property that quantifies the ability of a given material to resist the flow of current (Tucker-Kulesza, Snapp, & Koehn, 2016). The greater the electrical resistivity for a material, the less capable the material is at providing an electrical pathway for an electrochemical corrosion reaction; thus, the greater the electrical resistivity of a material, the lower the corrosion potential (Snapp, Tucker-Kulesza, & Koehn, 2017; AASHTO T 288-12, 2012). The electrical resistivity of soils and rocks depends on the degree of saturation, water content, porosity, shape and size of particles, mineralogy, clay content, temperature, and conductivity of the pore fluid (Fukue, Minato, Horibe, & Taya, 1999; Zonge, Wynn, & Urquhart, 2005). Typical resistivity values associated with soil and rock are shown in Table 2.1.

Table 2.1: Typical Electrical Resistivity Values of Different Geo-Materials

Material	Resistivity (Ω−m)
Clay	5-100
Saturated Sand and Gravel	<50
Dry Sand and Gravel	>200
Shale	5-50
Sandstone	50-1,000
Conglomerates	1,000-10,000
Limestone and Dolomite	>1,000
Igneous Rocks	>1,000
Metamorphic Rocks	>1,000

Source: Knight and Endres (2005); Lucius, Langer, and Ellefsen (2007)

AASHTO has developed a standard method (AASHTO T 288-12, 2012) to measure the apparent electrical resistivity of soil using a two-electrode soil box. The soil box is constructed from chemically fused polycarbonate sheets and has two stainless steel electrode plates connected to opposite, interior sides. These plates are connected to exterior stainless steel posts that connect to a resistivity meter. Electric current is passed from one electrode through the soil sample to the other electrode, and the resulting voltage difference between the two electrodes is measured. Currently, AASHTO method T 288 is the only laboratory test used to determine corrosion potential of soil in Kansas, typically for mechanically stabilized earth backfill. Table 2.2 outlines ranges of electrical resistivity and the corresponding corrosion potential. Table 2.2 is also used by KDOT for determining CMP use in the field and for developing CMP use plans.

Table 2.2: Correlation Between Resistivity Values and Corrosion Potential

Aggressiveness	Resistivity (Ω−m)
Very corrosive	< 700
Corrosive	700 to 2,000
Moderately corrosive	2,000 to 5,000
Mildly corrosive	5,000 to 10,000
Noncorrosive	> 10,000

Source: Elias et al. (2009)

2.2.3 Pore Fluid Electrolytes

The bulk electrical resistivity of soil is primarily controlled by electrolytes in the pore fluid (such as sulfates and chlorides). This is because soil particles are generally less conductive than the pore fluid that carries the charge throughout the soil matrix. The exception to this is clay soils which are naturally conductive. Figure 2.5 compares the resistivity of the solid soil matrix to the resistivity of pore water electrolyte for clays and sands. Salinity is the measurement of the amount of soluble ionic salts in water. The greater the salinity of the pore water fluid, the greater amount of dissociated ions able to carry an electric current, thus a lesser resistivity. The major dissolved anions in soil pore fluid electrolytes are chloride, sulfate, phosphate, and bicarbonate. Chloride and sulfate are the most active anionic constituents in the corrosion process (Elias et al., 2009).

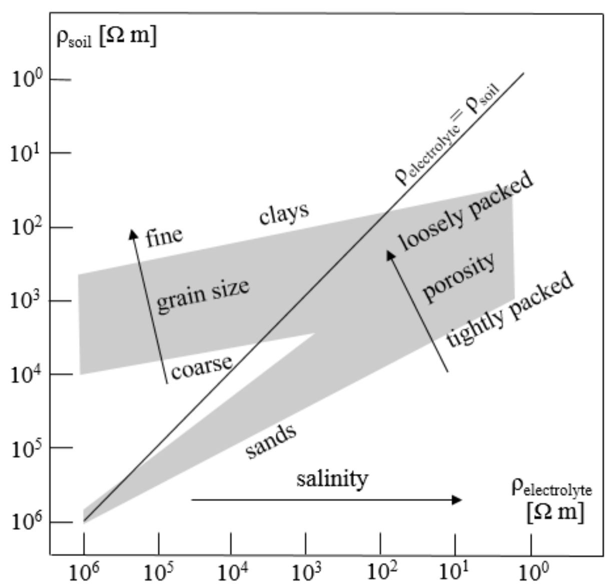

Figure 2.5: Electrical Conductivity of Saturated Soils
Source: Santamarina et al. (2005)

2.2.4 Chloride and Sulfate Concentrations

Chloride salts are a known strong electrolyte that completely dissociate into charge carrying ions. Unlike coastal regions where atmospheric chloride deposition is high, Kansas' potential sources of chloride result from man-made applications. Fertilizers such as muriate of potash (KCl), ammonium chloride (NH_4Cl), calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$), and sodium chloride (NaCl) are all used in agriculture; some fertilizers contain up to 74% chlorine (Ruiz Diaz, 2019). Another source of chloride in soil pore fluid is from the leaching of sodium chloride (NaCl) from roadway deicers. To prevent snow and ice from binding to the roadway creating hazardous conditions, it is common to apply salt brine to effectively lower the freezing temperature of water. KDOT has used salt brine for roadway deicing since 1998 (KDOT, 2007). Sulfate pockets in soil can occur naturally and as the result of man-made activity. Along with providing an electrolytic medium for current, sulfates may combine with free oxygen to form sulfuric acid that can lower pH at high concentrations. The most notable occurrence of sulfate is from mining waste deposits. There are also coal veins that naturally occur in northeastern Kansas. Elevated levels of these aggressive anions lead to increased corrosion rates.

2.3 Field Measurements of Resistivity and pH

The service life of steel culverts is typically predicted using field measurements of pH and electrical resistivity. California Test 643 (Caltrans, 2007) is commonly used to determine the pH of a sample in the field. California Test 643 recommends a standardized pH meter calibrated to a three-point buffer curve using pH values of 4.0, 7.0, and 10.0 for both soil and water samples. A pH meter takes readings of 1 g of soil per 1 mL of deionized water slurry to determine the pH of soil samples. The soil in the slurry uses material that passes the No. 8 (2.36 mm) sieve. The ASTM method for measuring soil pH, however, does not recommend adding water (ASTM G51-95, 2012). ASTM notes that some soils are so poorly buffered that adding water could change the pH.

AASHTO T 288 or ASTM G57 are used for measuring the electrical resistivity of soil samples in the laboratory as described in Section 2.2 (AASHTO T 288-12, 2012; ASTM G57-06, 2012; Edlebeck & Beske, 2014). Field resistivity measurements can be determined several ways. Vilda (2009) evaluated three methods for measuring soil resistivity in the field: the Wenner 4-pin method, single probe method, and electromagnetic induction. Vilda identified the Wenner 4-pin method as the most representative of in-situ conditions. The 4-pin Wenner array (ASTM D6431-99, 2010) measures resistivity similar to laboratory measured resistivity when water contents are similar (Vilda, 2009). The electrical resistivity of soil can also be measured using multi-electrode systems. The electrical resistivity of in situ aggregate backfill was measured using multi-electrode systems in a previously funded KDOT study (Tucker-Kulesza et al., 2016; Snapp et al., 2017).

Similar to the 4-pin Wenner, simplified soil probes with electrodes mounted on them can be used to measure resistivity at a point in situ (Wilmott et al., 1995; Pidlisecky, Knight, & Haber, 2006). The soil probe can be of variable length and is pushed by hand or a mechanical rig into the ground. These rods are similar to cones used for cone penetration tests and can be equipped with additional sensors to measure other electrochemical properties such as pH. Soil probes are advantageous because they can be pushed into small spaces, next to CMP for example, to measure the resistivity of the surrounding soil. The limitations of soil probes are that they can be difficult to drive into the ground. Also, they can only measure the resistivity and pH of the soil/water surrounding the probe so variability of the material may not be captured. Vilda (2009) also investigated the application of electromagnetic induction to measure electrical resistivity. While this method is advantageous because it does not require electrodes to be pushed in the subsurface, the equipment is costly (approximately $20,000) and data processing can be complicated.

2.4 CMP Service Life Estimation

In Kansas, the method of estimating CMP service life is based on the Florida Department of Transportation's (FDOT) policy. FDOT adopted the California method which uses pH and electrical resistivity measurement collected from soil and water samples to estimate the service life of a 16-gauge aluminized CMP (FDOT, 2014). The California method allows for additional performance credit for aluminized steel in non-abrasive environments (Caltrans, 2014). The FDOT method does not incorporate other site-specific factors that are known to affect the corrosive deterioration of CMP, such as frequency of flow, abrasion, organismic activity, silting, and standing water. A ±12 years of service life accuracy is used to account for these other factors. Aluminized CMP sites in Kansas that require soil and water testing must meet a minimum design life of 50 years. California Test 643 (Caltrans, 2007) is the standard for galvanized CMP, but all the counties in Kansas that allow for galvanized CMP installation do not require on site testing. Therefore, the California Method of estimating the service life is not directly used.

2.5 Durability of CMP in Kansas

A previous study conducted under the KDOT Bureau of Materials and Research determined the performance of galvanized CMP throughout Kansas. Stratton (1989) made observations from KDOT projects located in 10 counties across the state to represent all six KDOT districts (Figure 2.6). The objective of this study was to evaluate the performance of galvanized CMP installed since 1974 when a change in KDOT's pipe policy allowed the use of lighter gauge of CMP. Stratton sought to determine if this policy change contributed to the accelerated deterioration of galvanized CMP using a visual inspection of the CMP.

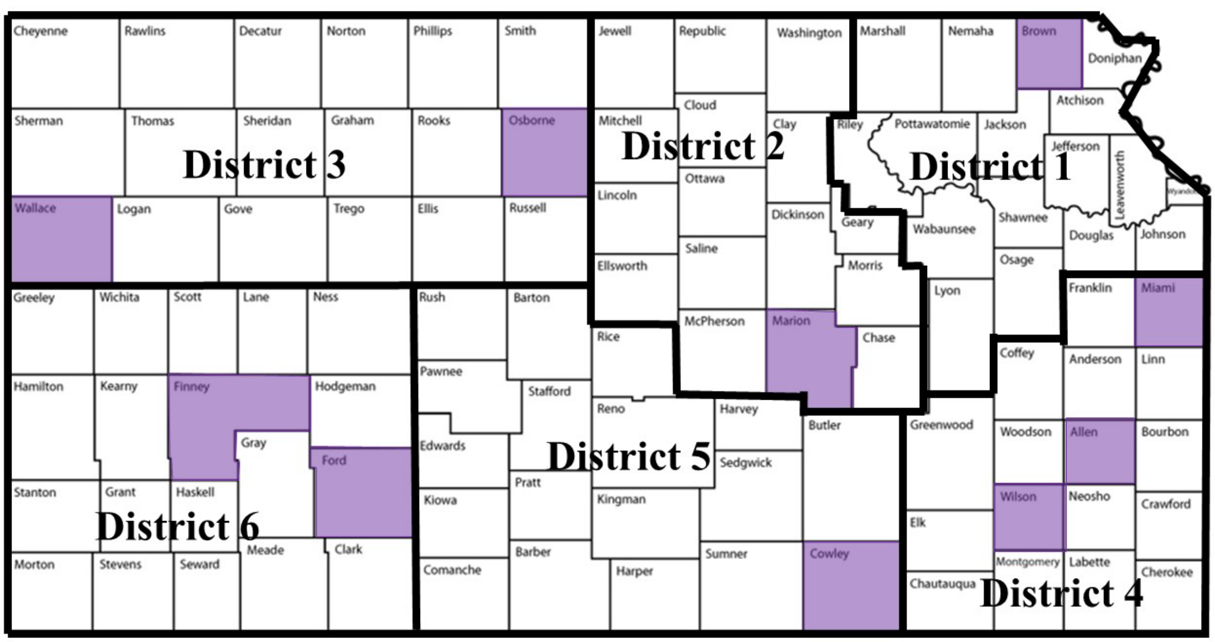

Figure 2.6: KDOT Districts

Stratton (1989) created a rating system to qualitatively compare the inspected CMPs (Table 2.3). Figure 2.7 shows a CMP inspected using the Stratton (1989) rating system. Four areas of the CMP were rated using this system: the invert or bottom, the interior side, the interior crown or top, and the soil side exterior. Only the visible portions of the exterior were rated (i.e., no soil was removed). The CMP shown in Figure 2.7 was given a rating of 1, or excellent condition. The thickness of the zinc coating and overall CMP thickness were also recorded.

Figure 2.7: Example of a Culvert with a 1 Rating
Source: Stratton (1989)

Table 2.3: 1989 Report Rating System

1	Pipe in excellent condition.
1+	Pipe in excellent condition. Minor inlet or outlet damage or erosion. Light silt and/or oxidation.
2	Pipe in good shape. Heavy oxide film. 0−40% silting and/or minor to moderate inlet or outlet damage.
2+	Pipe in reasonably good shape. Heavy oxide film. May have 40−50% silting. May have moderate to heavy inlet and/or outlet damage. Minor settling or distortion.
3	Pipe rusting. No distortion or settling. May have silting.
3+	Pipe rusting. Distortion and/or settling. May have silting.
4	Pipe heavily rusted with distortion and/or settling. May have silting.
5	Pipe failed. Because of distortion, collapse, rusting, or complete silting.

Source: Stratton (1989)

Stratton (1989) observed 103 galvanized CMPs. No invert rusting due to water was found west of Osbourne County. The worst performing CMPs were located in KDOT Districts One and Four. Stratton also observed that silting was a major problem in CMPs throughout the state. Silting is the buildup of sediment in the invert of the CMP which contributes to the loss of overall flow capacity. This may contribute to unanticipated corrosion from trapped moisture remaining in contact with the CMP. Standing water or the presence of silt was estimated to be the primary cause of damage for 50% of the heavily rusted CMPs. In addition to silting, it was suggested that an abundance of agriculture chemicals used in areas adjacent to CMP locations contributed to an accelerated deterioration by etching away the zinc coating. Stratton concluded that over 50% of the CMPs examined would be perforated due to rust within 15 years.

The results from Stratton (1989) indicated that galvanized CMPs installed since 1974 were failing at a much faster rate than the anticipated design life; this prompted a follow up study. Stratton et al. (1990) included 819 CMPs surveyed via visual inspection. A new rating system was designed to better represent CMP conditions by including a larger range of numerical ratings as shown in Table 2.4. Observations of side, crown, exterior, and invert were recorded along with the CMP diameter, hydraulic adequacy, backfill material, watershed description, alignment, slope, and joint condition where applicable. A subset of 86 CMPs were selected for further testing. A 1.5-inch-diameter sample was taken with a hole saw, along with field measurements of pH and resistivity of the backfill soil through the hole cut in the CMP. The CMP samples were used to measure wall thickness and zinc coating by means of a micro test gauge.

Table 2.4: Updated CMP Rating System

Rating	Description
95-90	Spelter like new to very dull
87.5	Pinpoint rest
85.0	Spelter gone
80.0	Light rust film
70.0	Shallow pitting
60.0	Scaley rust or pits not halfway through metal
45.0	Heavy rust or pits halfway through metal
30.0	Heavy rust or pits 3/4 through metal
15.0	Heavy rust or holes through metal
0.0	Large areas of metal gone

Source: Stratton et al. (1990)

Stratton et al. (1990) determined that KDOT Districts One and Four exhibited the most rapid deterioration, while CMPs in Districts Three and Six showed much longer service life. Stratton et al. determined that CMPs installed since 1974 were deteriorating at rate substantially faster than those installed prior to the 1974 policy change in Districts One and Four. This supported the findings of Stratton (1989). Reasons for rapid deterioration included the 1974 policy change that allowed lighter gauge CMP and deeper corrugation; a lighter gauge meant thinner sacrificial zinc coatings. Deep corrugation resulted in a larger depth for water to pond and silt to settle.

Stratton et al. (1990) concluded that changes in construction of CMP beginning in 1974 contributed to accelerated CMP damage due to corrosion. Using the California Test 643 with the measurements of soil pH and resistivity, it was determined that most CMP in the study would have more than 25 years of remaining life based on steel thickness of invert. Stratton et al. noted that service life predictions are very site specific with readings of pH not always reflecting conditions in the field. Finally, the report concluded that on average, the CMP had performed well over the previous 50 years, but site conditions and material properties must be carefully considered in future projects if an adequate service life is to be achieved.

In 1952 and 1953, the Kansas Highway Commission installed four experimental aluminized CMP in connection with galvanized CMP. Three were inspected during the spring of 1999, approximately 46−47 years after installation. Inspections included taking soil and water pH if applicable and providing any observations of the condition of the CMP. For two of the three CMP inspected, it was observed that minimal deterioration of the aluminum coating had occurred, whereas the galvanized portions had heavy invert rusting with the galvanized coating etched away. Noticeable rusting had also occurred on the soil side of one of the galvanized CMPs.

2.6 Similar Studies by Departments of Transportation

Several Departments of Transportation have conducted studies similar to KDOT's regarding service life of cross road drainage structures, specifically regarding corrosion, and how different culvert materials interact with corrosive agents within the environment. Each study considered soil and water properties with varied success as described below.

Missouri, which shares the same humid climate as the eastern half of Kansas, has conducted various studies since the 1930s to monitor and evaluate the performance of different culvert materials used in construction (Lemongelli, 2000). For example, a Missouri Department of Transportation (MoDOT) culvert study report determined the life expectancy of galvanized steel CMP by performing field and laboratory testing on 153 CMPs (Gift & Smith, 2000). The results of the study indicated that the CMPs would need to be replaced due to deterioration approximately 44 years after installation. The study neglected the influence of soil parameters (e.g., moisture content, pH, chloride content, sulfide content, total hardness) on CMP deterioration. MoDOT has continually evaluated the performance of all pipe culverts to monitor corrosion damage, erosion, or abrasion with ongoing changes in policy (Wenzlick & Albarran-Garcia, 2008). Ultimately, Wenzlick and Albarran-Garcia noted that corrosion is the leading cause of damage in certain areas of Missouri and, based on the previous studies, recommended that only concrete or plastic pipe be used in these areas.

The Minnesota Department of Transportation sponsored a study using the Natural Resources Conservation Service (NRCS) Web Soil Survey (NRCS, 2017). The NRCS Web Soil Survey was used to gather pH and soil resistivity data to predict the service life of steel pipe culverts via the California method. Taylor and Marr (2012) postulated that collecting soil and water samples throughout the state was not practical and assumed that water pH and soil resistivity collected in the invert was greatly affected by adjacent soil characteristics. Therefore, they used online soil type information to identify areas at risk for increased corrosion potential. By comparing the Web Soil Survey pH to the known pH of specific locations in Minnesota, it was determined that the Web Soil Survey on average estimates a lower pH and, consequently, a conservative service life estimation. It was concluded that a further study should be developed to map the projected service life for steel pipe culverts based on available geographic soil characteristic data.

The Arkansas State Highway and Transportation Department compared the durability of different CMP materials with water pH, soil resistivity, soil potential, and CMP age (Boyd, Gattis, Myers, & Selvam, 1999). The dataset included 19 galvanized and two aluminized CMPs. Galvanized CMPs performed well under "dry stream" conditions, but when the invert was continuously exposed to aqueous corrosion, deterioration accelerated. The two aluminized CMP sites were observed to be in fair condition. One of the aluminized CMPs was connected with a galvanized CMP. The aluminized section was in fair condition and only slightly discolored. The galvanized section showed evidence of corrosion damage. No statistically significant measurable soil/water properties were identified to predict corrosion potential in this study.

The Ohio Department of Transportation conducted a comprehensive field study to investigate the relationship between resistivity and pH of soil and water samples taken in the pipe invert and the corrosion potential in the field. Meacham, Hurd, and Shisler (1982) investigated 1,616 culverts, including galvanized steel CMPs and reinforced concrete pipe. Soil and water results were compared with land use and geological data to make inferences of how the states mining industry and peat rich deposits influence the corrosion potential of the soil. Meacham et al. found that water pH measurements were generally more acidic in areas where mining had occurred. Chemical testing of water taken from the pipe invert indicated that in areas of low pH, high pyrite coal was present. Pyrite was identified by the existence of iron and sulfate ions in the water sample. Although land use patterns and soil characteristics, such as ion concentration, were considered, the only parameters that indicated a significant effect on pipe durability was water pH and abrasion potential. Abrasion is the wearing of the pipe surface due to shearing of suspended materials flowing through the pipe, usually occurring in the invert. Flow velocities ranging from 12 ft/s to 15 ft/s carrying a bed load (suspended materials) are considered very abrasive (Caltrans, 2014).

At the national level, Ault and Ellor (2000) investigated 32 pipe culverts, 21 of which were Aluminized Type 2 CMP in three states. The sites were selected from three different field investigations representing different areas of the country. Ten pipes from Oregon, six pipes from Alabama, and five pipes in Maine were sampled. The depth of the deepest pit of the invert measured with a micrometer was compared to the initial manufactured thickness to determine the percent perforation in each pipe. The percent of perforation was compared to the linear estimation of perforation predicted by the California method for determining the service life of galvanized pipe. Ault and Ellor concluded that in the absence of abrasion, Aluminized Type 2 CMP may have a service life 8 times longer than that of galvanized, and 3.5 times longer if water side (invert) corrosion is only considered.

2.7 Current State Policy and Summary

The current Kansas pipe policy details guidelines of the appropriate use of different crossroad drainage materials (KDOT, 2016). The policy is used when state or federal aid is applied toward a transportation project in Kansas. The policy outlines the acceptable pipe material by county and if site specific soil and water testing are required. Counties are deemed acceptable, or unacceptable, for galvanized or aluminized CMP installation based on a comprehensive soil survey conducted by KDOT. Currently Cherokee, Crawford, and Labette are the only counties where the risks of accelerated corrosion are considered too high, prohibiting all use of galvanized and aluminized CMP. Many of the remaining counties require soil and water resistivity and pH testing at the site of the proposed galvanized and aluminized CMP installation. In 2001, KDOT shifted policy allowing for an increased use of aluminized steel CMP in projects where annual average daily traffic does not exceed 3,000 vehicles per day. The decision to adopt a policy where aluminized CMP would be preferred over galvanized arose from several publications highlighting the increased durability of Aluminized Type 2 CMP.

Chapter 3: Methodology

3.1 Field Observations

The objectives of this study were to evaluate the impact of KDOT pipe policy changes in 1974 and 2001, as well as the impact of the recommendations from the last comprehensive KDOT study on CMP deterioration (i.e., Stratton et al., 1990). The inspection methodology for each CMP included visual inspection, general notes on flow conditions in and around the CMP, any observations of structural compromise, GPS coordinates, and photographs of the CMP. Visual inspections included assessing the CMP at the crown, invert, interior sides, and exterior on both ends. The ends were denoted in the Appendix either as Side A, for the northernmost and easternmost end of a CMP, and Side B for the southernmost and westernmost end of a CMP. A numerical rating between 0 and 100 was assigned to each of the inspected locations following the KDOT rating system defined by Stratton et al. (1990); see Table 3.1. A zero rating was used for CMPs where large areas of metal were gone due to corrosion, and the efficiency of the CMP to transport water was likely reduced. The highest rating, 100, was reserved for CMPs installed during inspection (2018); however, no 2018 CMP were inspected in this study.

Table 3.1: Rating Description

Rating	Description
95	Spelter like new
92	Spelter dull
90	Spelter very dull
88	Pin-point rust spots
85	Spelter entirely gone
80	Light rust film
70	Shallow pitting
60	Scaley rust or pits not 1/2 through metal
45	Heavy rust or pits 1/2 through metal
30	Heavy rust or pits 3/4 through metal
15	Few holes through metal
0	Large areas of metal gone

Source: Stratton et al. (1990)

The goal of data collection in the field was to find an even distribution of CMPs representing different ages and locations in KDOT Districts One and Four. Table 3.2 illustrates the population spread of metal CMPs in Districts One and Four using information provided by KDOT. Note that Table 3.2 does not include all culverts in active use, but rather a list of known projects where galvanized or aluminized CMP culverts were listed in the plans for bidding. CMPs installed before 1989 were located using reference marker and stationing information from Stratton et al. (1990). Culverts installed after 1989 were identified using construction as-built plan sheets from the KDOT ProjectWise database (Version 08.11.11.590, 2014, Bentley Systems).

Table 3.2: Populations of Recorded CMP Installations

All CMP (District One & Four)

Age	Galvanized	Aluminized
80+	40	0
75-79	35	0
70-74	23	0
65-69	62	0
60-64	54	3
55-59	66	0
50-54	10	0
45-49	4	0
40-44	0	0
35-39	42	0
30-34	11	0
25-29	0	0
20-24	1024	0
15-19	1227	0
10-14	337	12
5-9	0	40

Many attempts to locate older CMPs in the field were unsuccessful due to the reconstruction of highways which replaced the existing CMP. This especially held true for projects along major traffic US highways where any significant road improvements likely replaced older cross road CMPs. Silting was observed in many CMPs. Enough silt was removed with a shovel to allow for observations of the invert. All silting was documented in the description of each surveyed CMP included in the ARCGIS database. Data collected at each site were recorded using the ARCGIS Collector application and stored online through the K-State Geographic Information Systems Spatial Analysis Laboratory's online ArcGIS account. Using this application allowed for rapid collection and interpretation of spatial data. The open access database can be reviewed at http://arcg.is/81Xiz. The raw data are also included in the Appendix of this report.

3.2 Field Measurements

Field tests included a measurement of soil pH, soil resistivity, water pH, and water resistivity (if applicable). Field pH tests were performed in accordance with California Test 643 (Caltrans, 2007). California Test 643 recommends a 12-volt single probe system for measuring the electrical resistivity in the field. A Collins Rod was utilized in this study to collect field resistivity measurements because it was rapid, inexpensive, and verified using a calibrated electrical resistivity meter. The Collins Rod is a 40-inch-long hollow rod with a steel tip separated by a 0.25-inch insulating spacer (Figure 3.1). A wire connects the steel tip and hollow body to an AC bridge. The rod is pushed into the soil, making sure to maintain contact between the tip and soil. The resistivity is read by listening to a speaker connected to the hand-held meter and adjusting the resistivity dial until the circuit is balanced, or the sound of the speaker is nullified. Electrical resistivity and soil samples were collected near the CMP. The exact locations varied depending on the accessibility of the area and with the hardness of the soil to minimize the risk of damage to the Collins Rod.

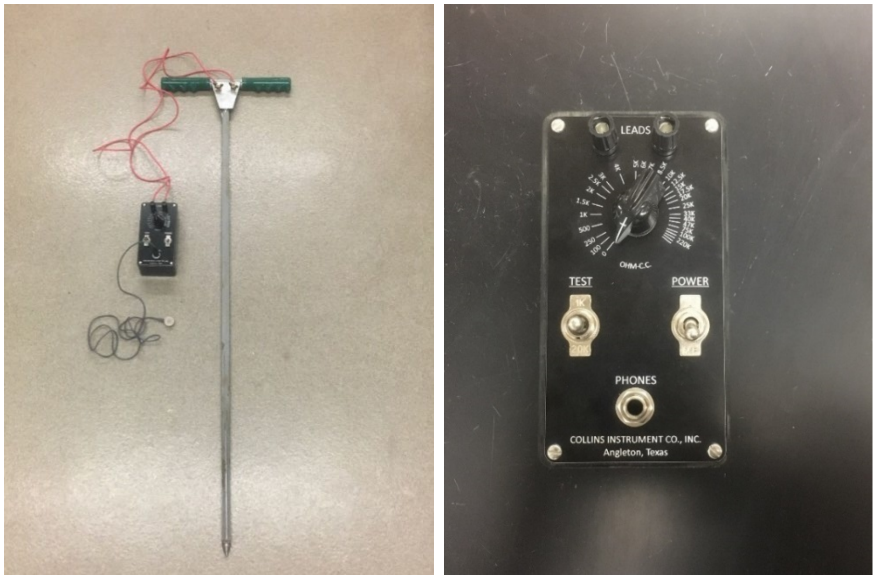

Figure 3.1: Collins Model 54-A Single Rod Soil Apparatus

The accuracy of the Collins Rod was verified by comparing the results to a known resistivity of a site. A 56-electrode survey was collected using the Advanced Geosciences, Inc., SuperSting R8 meter. The raw field data were collected such that the Collins Rod reading was located in the middle of the profile. The data were inverted following the procedure outlined in Tucker-Kulesza et al. (2016) to determine the true resistivity of the subsurface (Figure 3.2). The Collins Rod indicated the electrical resistivity of the soil at 1.5 ft was 2,300 Ohm-cm (23 Ohm-m). The bulk electrical resistivity as measured using the SuperSting at the same location was approximately 21 Ohm-m.

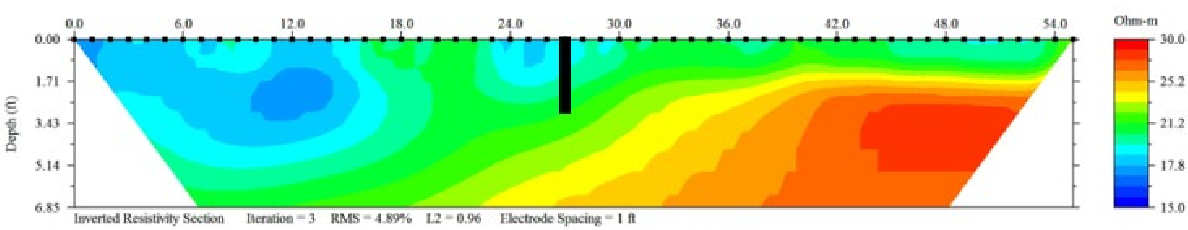

Figure 3.2: Electrical Resistivity Tomography for Collins Rod Validation

3.3 Laboratory Testing

The field observations in this study were collected during the summer of 2018. CMPs under dry conditions did not show signs of standing water in the invert which could lead to substantial corrosive damage. Soil samples were collected in 2016 from four CMPs and were used as a subset for field and laboratory testing. The goal of the field and laboratory testing was to identify corrosive agents in the soil, and how they were activated when saturated. The selected subsample of CMPs were determined by selecting CMPs that were observed to have varying degrees of corrosion deterioration.

Approximately 30 g of the grab soil sample was measured and passed through a #8 sieve, then added to a 50 mL conical centrifuge tube containing 30 mL of deionized water. The soil and water were mixed until a slurry formed and the pH was measured using a sympHony™ B10P benchtop pH meter. This method of determining soil pH was in accordance with California Test 643 which estimates the service life of galvanized steel culverts (Caltrans, 2007). To verify the accuracy of the sympHony™ B10P benchtop pH meter, pH measurements of the four sample soils were collected using four different pH reading probes as shown in Figure 3.3.

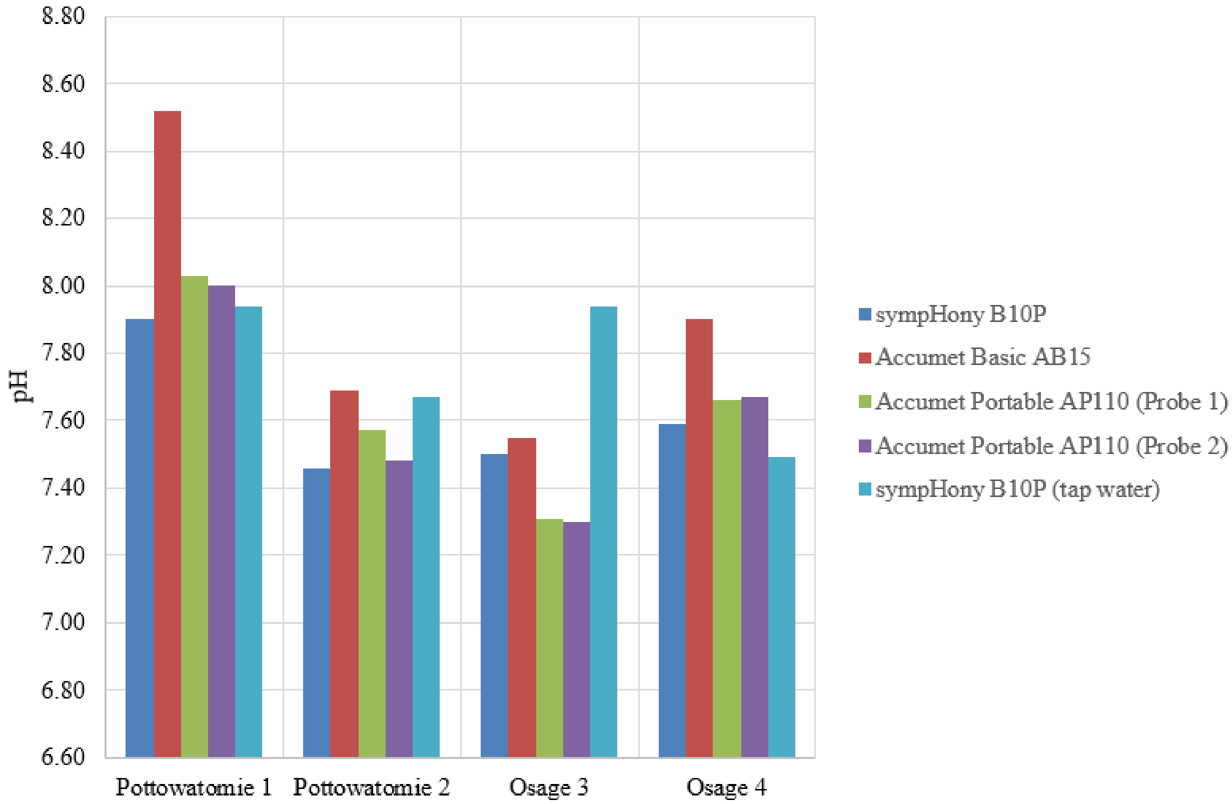

Figure 3.3: Accuracy Testing of sympHony™ B10P Benchtop pH Meter

Another set of soil samples were prepared in tap water to provide another means of comparison. Other than a single outlier using the Accumet Basic AB15 meter, the pH measurements at each site were shown to have an average precision of ±.2 pH, which was deemed acceptable.

An initial measurement of ion content was found to understand the nature of electrolytes contributing to the corrosive process in the pore fluid. To obtain the pore water ion content, 1 mL of the soil slurry was filtered through a 0.2-micrometer filter and into 1.5-ml vials. These samples were then analyzed via ion chromatography by the Kansas State University Soil Testing Laboratory for concentrations of chlorides, sulfates, nitrates, and cations. A leachate test was conducted to simulate soil conditions in the field; 100 grams of soil sample was weighed, placed in an Erlenmeyer flask, and submerged in one liter of deionized water. The soil-water solution was vigorously shaken to suspend soil particles. The sample was then left to settle for 24 hours. Filtered samples were taken from the soil-water slurry for ion concentration testing. Samples were also taken for pH testing. Water was removed from the Erlenmeyer flask and one liter of new deionized water was reintroduced. Again, the solution was vigorously shaken to suspend the soil particles and left for 24 hours before collecting water samples for testing. The purpose of bathing the soil in water was to determine what anions were easily mobilized when introduced to water in the field. The ions that are freely mobilized within the pore water fluid may have a greater charge carrying potential, thus leading to corrosion. The pH of the leachate water was also measured to determine the effects of saturation.

Chapter 4: Results and Analysis

4.1 CMP Inspections in 2018

A total of 80 CMPs were surveyed in KDOT Districts One and Four. One of the aluminized CMPs installed in 1952 (described in Section 2.5) was surveyed in District Three. All of the 81 surveyed CMP locations are shown in Figure 4.1. The inspection report for each CMP contains data to help locate the CMP (i.e., project or route number, county, age), the manufactured specifications of the CMP (i.e., material, diameter, pitch, depth), and field measurements (i.e., condition ratings, resistivity, description, photos). Thickness was not measured in this study because the manufactured thickness could not be found for all CMP. A sample CMP is shown below to illustrate the information included in each data point in Figure 4.1. The data of this CMP, retrieved from the ArcGIS database, can be examined in Table 4.1; the photos of the CMP can be seen in Figure 4.2.

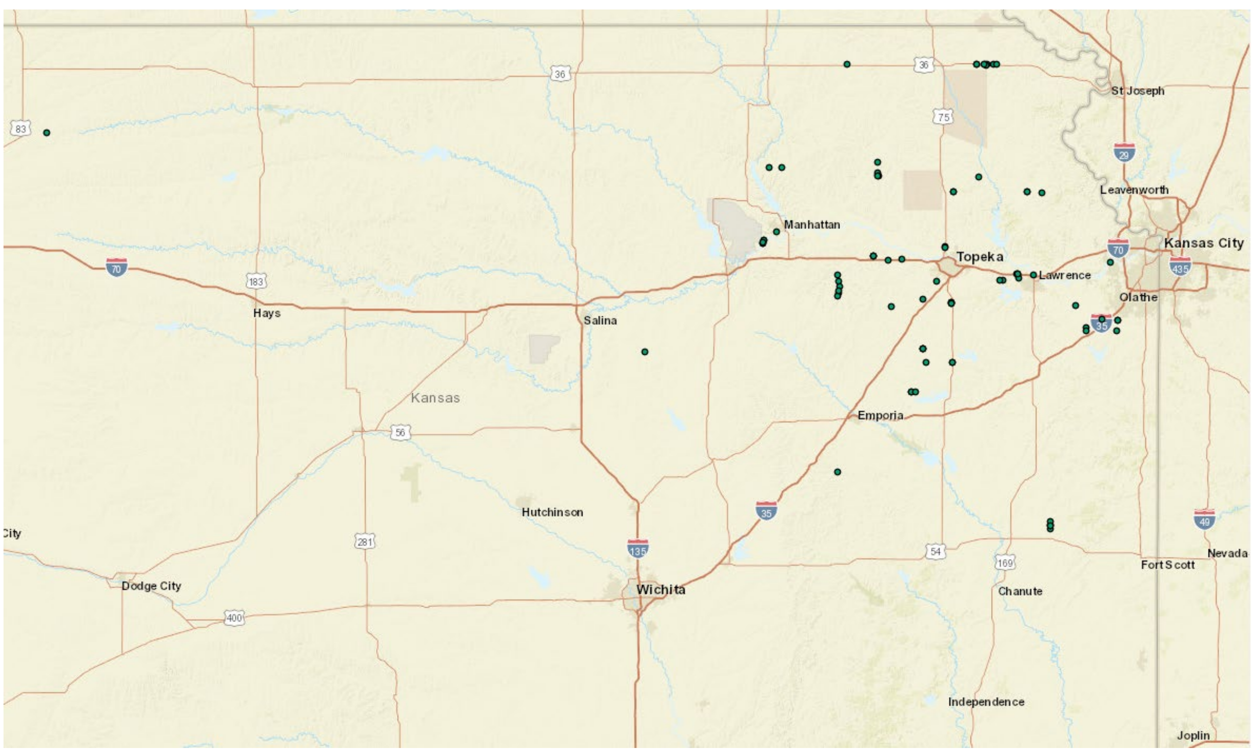

Figure 4.1: ARCGIS Map with All Data

Table 4.1: Sample Data Collected for Each CMP that are Available in the ARCGIS Database

Data Field	User Input	Data Field	User Input
Project/Route Number	K-63	General Condition (A)	62.5
County	Pottawatomie	External (A)	80
Material	Galvanized	Crown (A)	85
Age (yr)	78	Side (A)	85
Diameter	24	Invert (A)	0
Pitch (in)	2.67	General Condition (B)	70
Depth (in)	0.5	External (B)	80
Resistivity (Ohm-cm)	700	Crown (B)	85
Description	na	Side (B)	85
Photos	Figure 4.2	Invert (B)	30

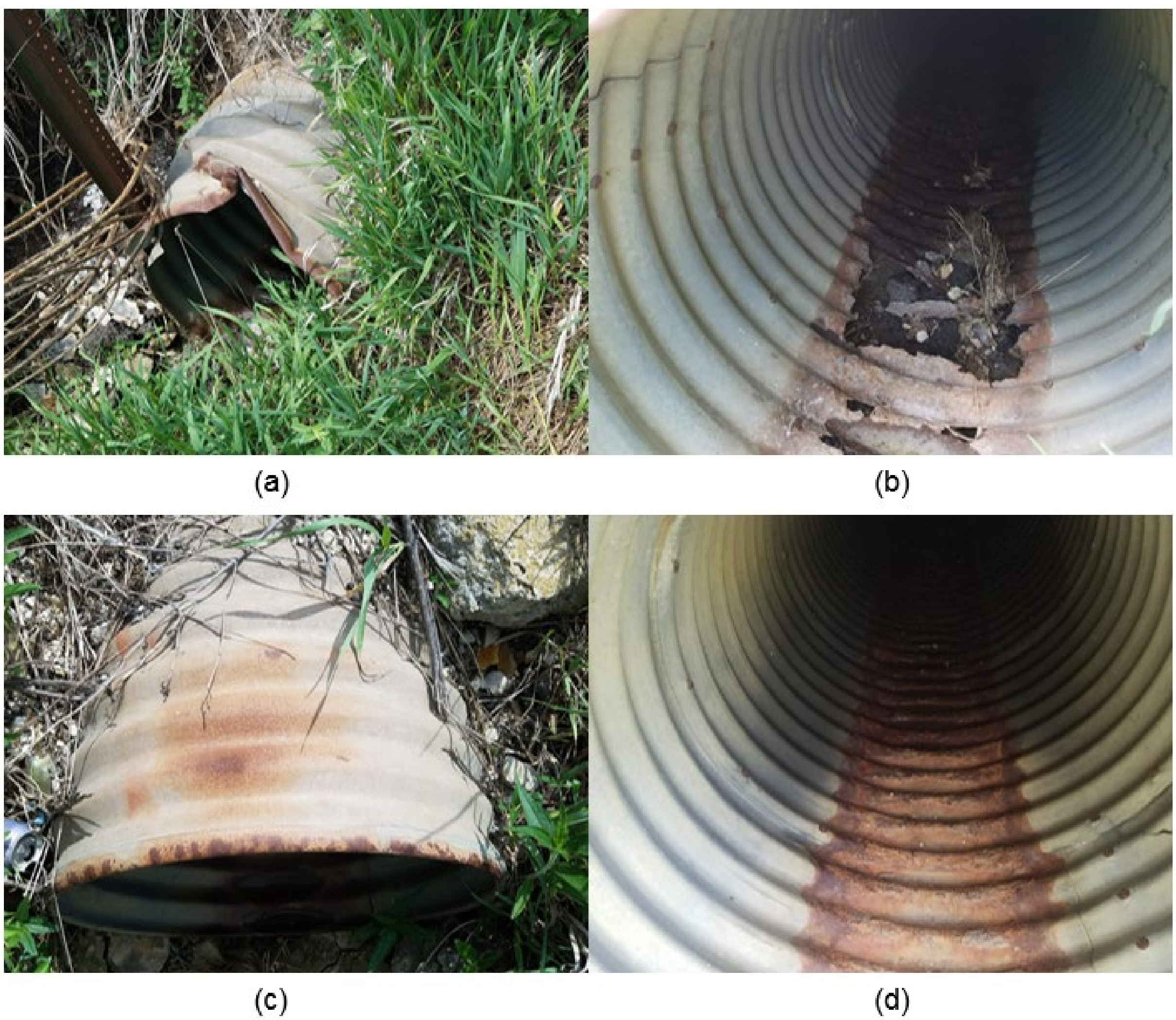

Figure 4.2: Field Photos Included in ARCGIS Database for Sample Data: (a) Side A External, (b) Side A Internal, (c) Side B External, (d) Side B Internal

Table 4.2 shows a summary of the rating condition statistics for the 81 surveyed CMPs (162 ends) that were included in the analysis of this study. When the deterioration rates and condition rating trends were assessed, only one end was used; the end used was the end with the lowest general condition rating. The general condition rating was found by averaging the ratings of the invert, crown, side, and external faces of the CMP. This may be used by KDOT to quickly identify CMP that have large areas of metal gone and have failed (rating of zero for the invert, crown, side, or external face) or were on the verge of failure at the inspection. For example, 56% of the CMPs with a general condition rating of 70 or below had at least one rating of 0.

If data were not complete on both ends, the end with a complete rating was used. For example, only one end could be located in 13 CMPs. Two CMPs had standing water, preventing invert and general condition ratings from being recorded. In both of these instances, the end with a complete rating set was used. One CMP in the database was not used for analysis because the age could not be determined. Of all 162 ends that were examined, the invert ratings showed the most deterioration; 64% (104 out of 162) of the inverts were noted as having rust (rating of 80.0 or less). Approximately 50% of the invert condition by Stratton et al. (1990) showed rust, so invert deterioration was anticipated as over half the surveyed CMP in 2018 were also surveyed by Stratton et al.

Table 4.2: Summary of CMP Ratings for 2018 Study

Rating	External		Crown		Side		Invert	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
95	9	5.6	7	4.3	6	3.7	0	0
92	28	17.3	33	20.4	27	16.7	5	3.1
90	35	21.6	68	42.0	58	35.8	24	14.8
88	15	9.3	4	2.5	12	7.4	11	6.8
85	12	7.4	25	15.4	19	11.7	0	0
80	19	11.7	1	0.6	6	3.7	10	6.3
70	9	5.6	4	2.5	8	4.9	14	8.6
60	9	5.6	5	3.1	10	6.3	18	11.1
45	7	4.3	0	0	3	1.9	27	16.7
30	0	0	1	.6	0	0	9	5.6
15	0	0	0	0	0	0	6	3.7
0	6	3.7	1	0.6	0	0	20	12.3
No Rating	13	8.0	13	8.0	13	8.0	18	9

Some CMP damage included in this study was likely not caused by the type and/or quality of the CMP. For example, a number of CMP appeared to have been run over, likely by tractor or lawnmower. These CMPs showed signs of corrosion where surfaces were damaged. Figure 4.3(a) and Figure 4.3(b) shows CMP with external damage to the side and invert likely not caused by corrosion, although these data are included in the overall summary. Some CMP were disconnected from their end section, as seen in Figure 4.3(c). Other CMP exhibited increased corrosion along welded seams, shown in Figure 4.3(d).

Figure 4.3: Non-Corrosion Induced Damage: a) Damage to the Top Face; b) Damage to the Side; c) Disjointed CMP; d) Corrosion Along Welded Seam

The crown and side ratings are summarized in Figure 4.4. Figure 4.4(a) and 4.4(c) are box and whisker plots of the observed ratings to show the distribution and observe trends in deterioration of all CMP surveyed in 2018. The upper and lower boxes are the first and third quartiles of the data and the line in the box is the second quartile (median). A horizontal line only (i.e., 25–34 years) indicates there was no variability in the data. There were no CMP surveyed in the 25–34 range and two were surveyed in the 44–55 range. The large distribution of data in the 65–74 year range highlight why the average ratings are lower in this age group than the oldest CMP. One 65-year-old CMP in Jefferson County has completely failed and three more have a zero rating on two or more surveyed locations (i.e., crown, side, invert, or exterior). Only seven CMP were surveyed in this age group, so the average rating is greatly influenced. Figure 4.4(b) and 4.4(d) show the average crown and side ratings for this study and for CMPs surveyed in this study that were also in Stratton et al. (1990). There is a general trend of deterioration with age in Figure 4.4(b) and 4.4(d), shown with a best-fit line. This was expected since these areas of the CMP are primarily exposed to atmospheric corrosion only. On average, no rusting was observed on the crown or side of CMPs less than 65 years old.

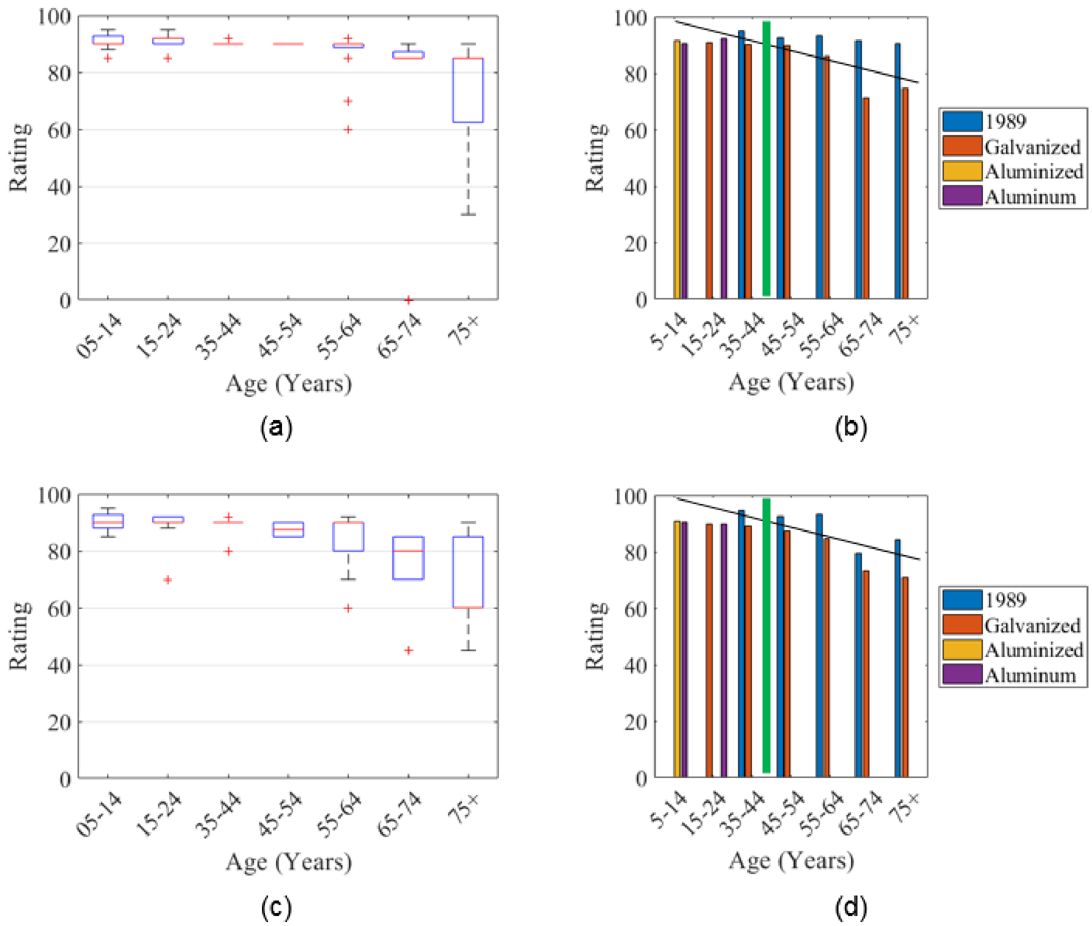

Figure 4.4: Crown and Side Observations: a) Crown Rating in 2018; b) Average Crown Rating in 2018 and 1989; c) Side Ratings in 2018; d) Average Side Rating in 2018 and 1989

Figure 4.5 shows the external and invert CMP ratings. Again, Figure 4.5(a) and 4.5(c) show the variability in the 2018 ratings; however, the external and invert appear to be influenced by more than just the age of CMP. The change in KDOT policy in 1974 was identified as a cause of accelerated deterioration by Stratton et al. (1990); the green line in Figure 4.5(b) represents CMP installed before/after this policy change. Although CMPs 41 years and older were part of the pre-1974 group, all surveyed CMP in the 35–44 year range were 39 years old. The difference in external rating in Figure 4.5(b) between 1989 and 2018 appears to be greater after the 1974 policy change, despite the fact that the CMP are younger. This indicates higher deterioration rates. This is also true in the 65−74 range, where the average rating in 2018 was the lowest, but again one of the six CMP in this subset completely failed and this affects the average rating for the small sample size. The rate of deterioration will be quantified and discussed later in this chapter.

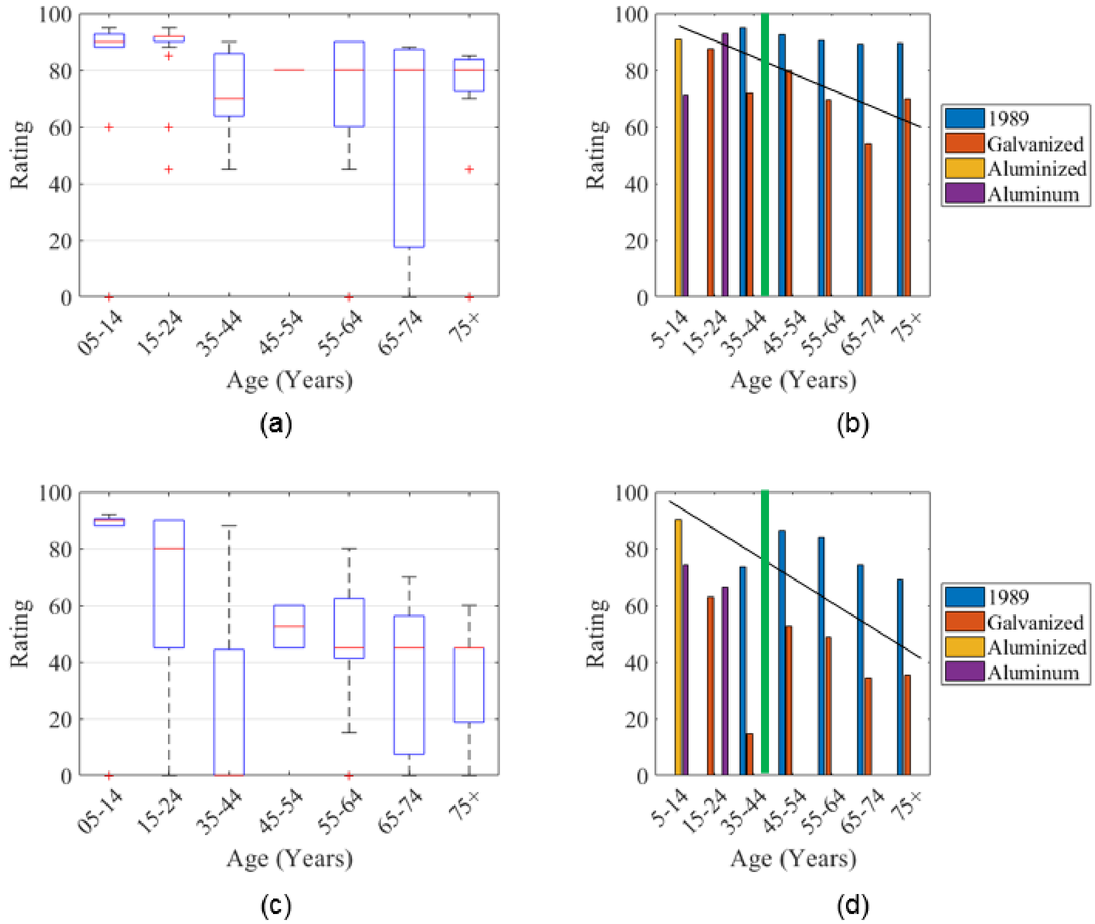

Figure 4.5: External and Invert Observations: a) External Rating in 2018; b) Average External Rating in 2018 and 1989; c) Invert Ratings in 2018; d) Average Invert Rating in 2018 and 1989

Figure 4.5(c) and 4.5(d) also indicate deterioration rates were not only attributable to age in the CMP inverts. The invert showed the most corrosion damage of all CMP locations and these data were also the most variable, as shown in Figure 4.5(c). Furthermore, unlike the average external, side, or crown ratings, the average invert rating indicated increased deterioration of CMP installed after 1989, or what would correspond to recommendations by Stratton et al. (1990).

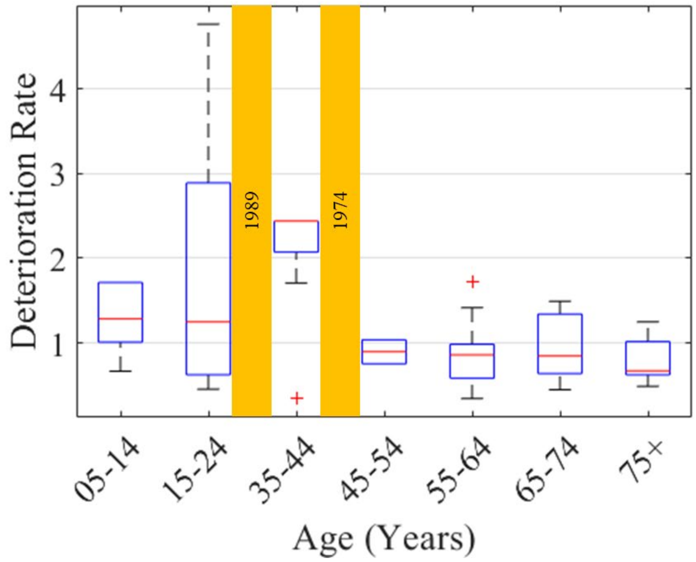

Figure 4.6: Invert Deterioration

Figure 4.6 shows the distribution of the CMP deterioration, where deterioration, D, was determined as:

$$D = (100 - I)/A \qquad \textbf{Equation 4.1}$$

Where *I* is the invert rating in 2018 and *A* is the CMP age.

Table 4.3 also includes the averages of these data. A larger number indicates a faster deterioration rate in the invert. The increased invert deterioration in Figure 4.5 for CMP installed since 1994 (youngest CMP surveyed in this study after the Stratton et al. [1990] recommendations) is also apparent in Figure 4.6, specifically for CMP that are 15–24 years old. The vertical lines indicate the 1974 change in policy to a thinner CMP installed and after the Stratton et al. recommendations.

Table 4.3 shows the average rate of deterioration of CMP. The higher the value, the faster the CMP deterioration rate. Since the 1974 policy change, the rate of deterioration increased relative to the pre-1974 rate. The rate of deterioration appears to have declined after the recommendations made by Stratton et al. (1990). Because of the small sample size and number of relatively new CMPs (less than five years), Equation 4.1 was modified to:

$$D_{mod} = (95 - I)/A \qquad \textbf{Equation 4.2}$$

Where all variables have previously been defined.

No CMP in the current study or Stratton et al. (1990) received a rating of 100, showing no deterioration. The deterioration rates of CMPs less than five years old do not appear to represent actual conditions. This trend should be interpreted with caution as the sample size of CMPs installed after the Stratton et al. project is relatively small (35 CMPs). Additionally, because only seven aluminized CMPs were surveyed and five of the seven were seven years old, the data were extremely skewed. The modified deterioration criteria indicate the aluminized CMP are deteriorating at a rate closer to the pre-1974 KDOT policy change galvanized CMP. Again, due to the small sample size these data should be interpreted with caution.

Table 4.3: Deterioration of Surveyed CMP Inverts

Installation year	Material	Average rate of deterioration*
Before 1975	Galvanized (0.5-inch corrugation depth)	.71(.38)
Before 1975	Galvanized (1-inch corrugation depth)	.57(.41)
1975−1989	Galvanized (0.5-inch corrugation depth)	2.07(1.79)
1975−1989	Galvanized (1-inch corrugation depth)	2.32(1.43)
1990−Present	Galvanized (0.5-inch corrugation depth)	1.05
2001−Present	Aluminized	.71
2001−Present	Aluminum	1.03

*(using Equation 4.2)

4.2 Leachate Analysis

A subset of CMPs were sampled to explore a new method for predicting CMP invert deterioration based on the corrosion potential of the soil and pore water in the soil through a leachate analysis. Four CMPs were selected and sampled to represent a wide range of invert deterioration. A summary of the subset is shown in Table 4.4. The invert deterioration was determined by:

$$D_{\text{invert}} = (R_{1989} - R_{2016})/27 \qquad \textbf{Equation 4.3}$$

Where R_{1989} is the invert rating from Stratton et al. (1990), R_{2016} is the invert rating from this study, and 27 is the number of years between the two studies.

Table 4.4: Summary of CMP Sampled for Soil Analysis

Sample	External 89/16	Crown 89/16	Side 89/16	Invert 89/16	pH	D_{invert}
1	70/45	70/70	70/15	70/15	7.9	2.04
2	87.5/15	92.5/87.5	92.5/90	80/15	7.46	2.41
3	92.5/88	92.5/85	92.5/85	92.5/80	7.39	0.46
4	92.5/60	92.5/60	92.5/60	70/60	7.59	0.37

An initial laboratory leachate test was conducted to determine the basic corrosion agents in the soil. Results of ion concentrations of soil slurry in deionized water are shown in Figure 4.7; the deterioration rates from Table 4.4 differentiate the samples. The initial study of anion presence in the soil suggests that chloride salts (purple bar) have the most significant influence on corrosion mechanisms in the soil pore fluid. Additionally, the pH of the leachate was measured over three days as described in the methodology. The leachate pH is shown in Figure 4.8.

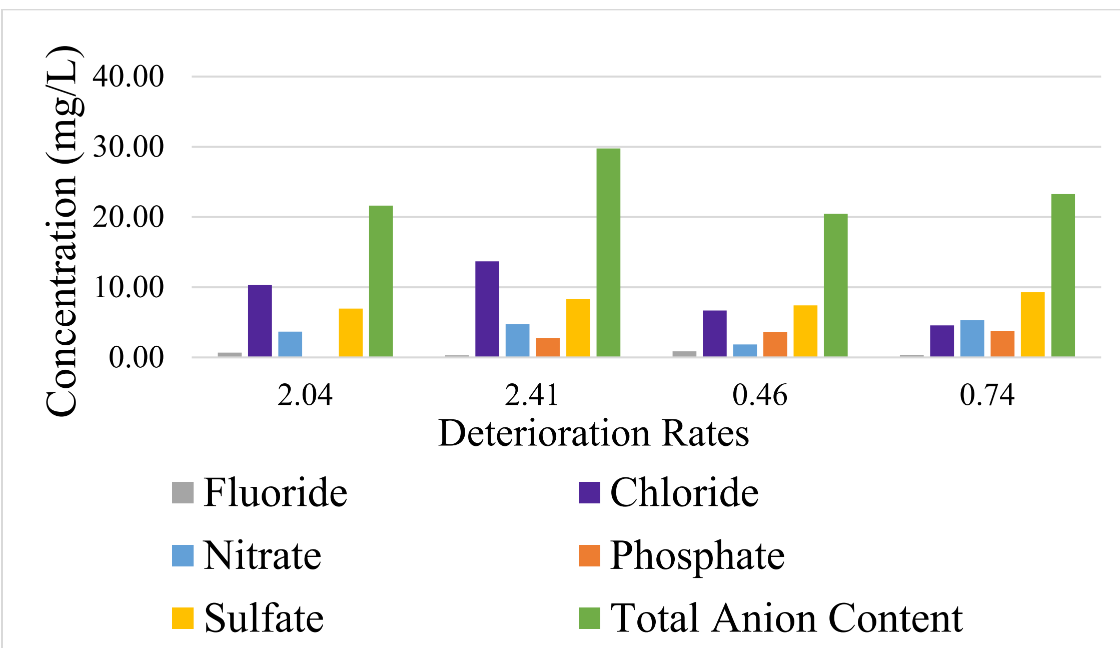

Figure 4.7: Laboratory Leachate Testing

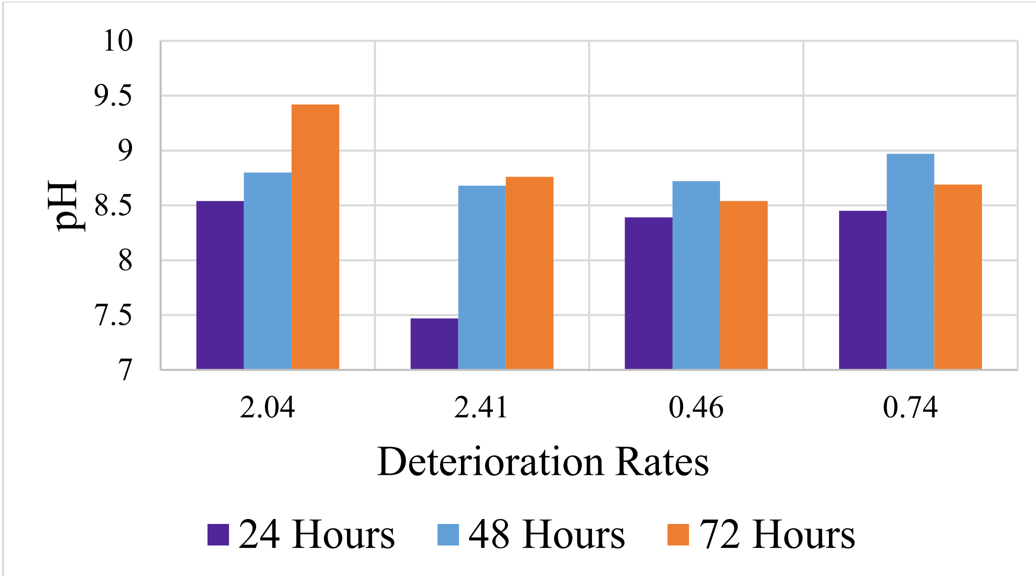

Figure 4.8: pH of Leachate

The pH measurements of the leachate samples were compared to the invert CMP deterioration per sample. The change of pH for each bath was compared by finding the standard deviation S_{pH} for each sample location. The standard deviation S is:

$$S_{pH} = \sqrt{\frac{\sum_i (y_i - \bar{y})^2}{n-1}} \quad \textbf{Equation 4.4}$$

Where n is the number of pH samples for each location (3), y_i is the pH of each bath, and $\bar{y}$ is the mean average of pH of the samples.

A linear trend was noted after comparing observed deterioration per sample versus the calculated standard deviation of pH during leachate testing. For the sample population, CMPs that demonstrated the most deterioration also showed the most variance in the pH of leachate water during bathing tests. The correlation between invert deterioration and leachate pH variation in the lab, as well as the pH taken in the field, possibly indicate that the buffering capacity of the soil contacting the pore water had a greater influence on deterioration than the actual pH value itself. Thus, pH measurements taken in the field may not properly estimate the amount of corrosion possible at a given site location. A correlation was also identified between the cumulative concentration of chlorides that were mobilized during the leachate testing and the deterioration rate. The accuracy at which the cumulative chloride concentrations predicted the invert deterioration rate may prove to be a stronger indicator of deterioration than that of a typical resistivity test in the field.

Using the findings of the leachate analysis, an initial regression analysis was performed to create an equation to describe the rate of deterioration. The deterioration rate as found by the timed leachate bath testing described in Chapter 3 is:

$$D = 2.57\,S + .074\gamma_{Cl,Total} - .27 \qquad \textbf{Equation 4.5}$$

Where S is the standard deviation of the pH as described by Equation 4.4, and $\gamma_{Cl,Total}$ is the cumulative total of chloride concentrations of the leachate samples taken over 72 hours.

The coefficient of determination for the proposed formula is .92 based on the four samples. A t-test was conducted to confirm that the chosen four samples were representative of the deterioration rates found for sites sampled in this study and by Stratton et al. (1990). The four sites chosen for leachate analysis were representative of the greater population surveyed in both studies in the 95% confidence interval. The t-test results are summarized in Table 4.5.

Table 4.5: T-Test Summary

	Surveyed	**Sample Pop.**
Number	40	4
Mean	1.409	1.412
Standard Deviation	0.933	0.954
Variance	0.870	0.911

$t = .0065$, $df = 44$, $p<.05$

Two additional sites were sampled and the leachate analysis was conducted, specifically measuring the total chloride concentration and pH over 72 hours. Again, the samples were chosen to represent an invert with a high rate of deterioration using the 1989 and 2016 data. The invert rating of Sample 1 in 1989 was 92.5, and the CMP had failed in 2016 (0 rating). The invert rating of Sample 2 was 60 in 1989 and 45 in 2016. A summary of the pilot leachate analysis validation is shown in Table 4.6. The predicted deterioration rates of the two samples were lower than the actual deterioration. The prediction of Sample 1 was within 20% of the actual deterioration rate over the past 27 years. Sample 2 significantly underpredicted the deterioration with a variance of 70%. Note that these samples were chosen based on a wide range of deterioration; however, Sample 2 showed the most deterioration of all CMP surveyed between 1989 and 2016, and the CMP was failed in 2016. This point, therefore, may be an outlier.

Table 4.6: Summary of Validation Data

Sample	pH (24 hr)	pH (48 hr)	pH (72 hr)	s_{pH} (Eq 4.4)	γ_{cl} (mg/L)	D_{pred} (Eq 4.5)	D_{invert} (Eq 4.3)
1	9.1	8.89	8.72	0.19	3.13	0.45	0.56
2	8.93	8.71	8.39	0.27	7.99	1.02	3.43

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

This study evaluated the condition of 81 CMPs in KDOT Districts One and Four and one in District Three to determine the impact of KDOT pipe policy changes and recommendations from previous KDOT studies on in situ deterioration rates. The results of this study confirmed previous KDOT findings (Stratton, 1989; Stratton et al., 1990) that reported increased deterioration in CMP following the 1974 pipe policy change which allowed for a lighter gauge CMP and deeper corrugations. The results of this study also indicate a slight increase in deterioration rates, relative to the pre-1974 deterioration rates, over the past 28 years despite the recommendations of the last KDOT study (Stratton et al., 1990). The deterioration rates over the past 28 years, however, are closer to the pre-1974 deterioration rates than those found between 1975 and 1989. The observed increase in deterioration since Stratton et al. may have been skewed by the methodology. CMP deterioration rates were calculated assuming the CMP rating started as perfect (100), but no CMP received this rating. The methodology was modified by calculating the deterioration rate from a starting rating of 95. This modified deterioration rate still indicated increased deterioration following the 1974 policy change; however, it indicated that the average rate of deterioration following Stratton et al. (1990) decreased, relative to the 1975−1989 time period. Furthermore, the deterioration rates of aluminized CMPs installed after 2001 were compared to deterioration rates of galvanized and aluminum CMPs installed after 2001 and were found to be 32% lower. This supports the 2001 change to the KDOT pipe policy which allowed aluminized CMP for crossroad installations when design traffic levels are under 3,000 in specific counties. This study was limited to a smaller sample size of CMPs (approximately 10% of the Stratton et al. study) and additional data are needed to further substantiate recommendations.

5.2 Recommendations

This study established that the CMP policy change after the Stratton et al. (1990) study to revert back to CMP standards before the 1974 policy change has reduced deterioration rates. CMP deterioration may be further improved by requiring an additional increase in the gauge thickness. If changing the CMP policy is not feasible, increased maintenance may reduce the deterioration of the inverts. Silting was noted as a considerable problem in many of the inspected CMPs. The presence of silt in the invert allows water to be trapped and expose the pipe to prolonged moisture. Also, silted inverts containing large particles such as gravel and rock can wear on the CMP by the process of abrasion. In 2016, KDOT began implementing stricter and more thorough best management practices (BMP) as a result of a ruling by the Environmental Protection Agency (United States of America v Kansas Department of Transportation, 2016). These BMPs include training for engineers and inspectors at KDOT and more detailed inspection forms.

5.3 Future Work

An additional pilot study was conducted to evaluate a proposed new method for predicting CMP deterioration rates using an analysis of the leachate from soil around the pipe. This study indicated that an analysis of the leachate chloride concentration and pH over time may be a more accurate predictor of deterioration than the method currently used by KDOT that relies on pH and resistivity. This pilot study utilized only four samples for the initial analysis and should not be used for design purposes until it is verified. A follow up study with a larger sample size and more detailed analysis is recommended to validate the leachate analysis method. Once validated, the leachate analysis may be used to determine where a more conservative CMP design is needed to reduce invert deterioration; this may improve the service life of CMP in Kansas without requiring over-conservative requirements in all new pipes.

A study similar to this and Stratton et al. (1990) is recommended as more aluminum and aluminized CMP are installed in Kansas. Measuring the deterioration rates of these materials for CMP older than 20 years would help determine the expected lifespan of these materials in Kansas. In addition to analyzing more aluminum and aluminized CMPs, a selection of CMPs (in all materials) with corrugation depths of 1 inch would also aid in validating the findings of this study.

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Appendix

Table A.1: Summary of All CMPs Surveyed in 2018

ID	Project/ Route Number	County	Material	Age (2018)	Diameter (in)	Pitch (in)	Depth (in)	Description
3	K-18	Riley	Aluminized	7	18	2.67	0.5	5 inches of sediment
4	K-18	Riley	Aluminized	7	18	2.67	0.5	5 inches of sediment
5	K-18	Riley	Aluminized	7	18	2.67	0.5	3.5 inches of sediment
6	K-18	Riley	Aluminized	7	18	2.67	0.5	10 inches of sediment
7	K-18	Riley	Aluminized	7	18	2.67	0.5	10 inches of sediment
14	99 C-4549-01	Wabaunsee	Aluminum	7	18	2.67	0.5	10 in of sediment
59	US-75	Osage	Aluminum	7	30	2.67	0.5	
60	US-75	Osage	Aluminum	7	30	2.67	0.5	
35	C-143	Johnson	Aluminum	9	36	2.67	0.5	
32	US-56	Johnson	Aluminum	9	60	3.00	1	standing water
15	Hodges Rd	Shawnee	Aluminum	11	24	2.67	0.5	17 in of sediment; could not locate Side A
85	K-18	Riley	Aluminized	12	18	2.67	0.5	could not locate Side A
16	SW 53rd St	Shawnee	Aluminized	13	18	2.67	0.5	Side B overgrown
26	23 C-3472-01	Douglas	Galvanized	15	48	2.67	0.5	standing water
27	23 C-3472-01	Douglas	Galvanized	15	48	2.67	0.5	standing water
22	23 U-1749-01	Douglas	Galvanized	16	12	2.67	0.5	could not locate Side A
61	K-31	Osage	Galvanized	16	24	2.67	0.5	3 inches of sediment
70	43 C-3770-01	Jackson	Galvanized	16	24	2.67	0.5	could not locate Side B
71	43 C-3770-01	Jackson	Galvanized	16	24	2.67	0.5	could not locate Side A
40	I-70	Shawnee	Galvanized	16	30	2.67	0.5	could not locate Side A
34	C-199	Johnson	Aluminum	17	18	2.67	0.5	Side B overgrown
68	US-75	Shawnee	Aluminum	18	15	2.67	0.5	standing water; could not locate Side B
38	99 C-3459-01	Wabaunsee	Galvanized	18	18	2.67	0.5	
69	US-75	Shawnee	Aluminum	18	18	2.67	0.5	standing water; could not locate Side B
36	99 C-3459-01	Wabaunsee	Galvanized	18	24	2.67	0.5	
37	99 C-3459-01	Wabaunsee	Galvanized	18	24	2.67	0.5	
72	44 C-2271-01	Jefferson	Galvanized	19	18	2.67	0.5	
84	56 C-3586-01	Lyon	Galvanized	19	18	2.67	0.5	could not locate Side B
18	10-23 K-3359-04	Douglas	Galvanized	21	24	2.67	0.5	

20	10-23 K-3359-04	Douglas	Galvanized	21	24	2.67	0.5	bituminous coating
21	10-23 K-3359-04	Douglas	Galvanized	21	24	2.67	0.5	
39	99 C-1982	Wabaunsee	Galvanized	22	24	2.67	0.5	5 in of sediment
23	10-23 K-3359-03	Douglas	Galvanized	22	48	2.67	0.5	24 in sediment; standing water - no invert rating
31	169-46K-5343-01	Johnson	Galvanized	23	24	2.67	0.5	Side A overgrown
25	10-23 K-3359-10	Douglas	Galvanized	23	36	2.67	0.5	
29	169-46K-5343-01	Johnson	Galvanized	23	48	2.67	0.5	standing water
30	169-46K-5354-01	Johnson	Galvanized	23	48	2.67	0.5	standing water
33	56-46 K-2643-01	Johnson	Galvanized	24	30	2.67	0.5	
28	K-7	Wyandotte	Galvanized	35	36	2.67	0.5	
53	US-36	Brown	Galvanized	41	42	2.67	0.5	
54	US-36	Brown	Galvanized	41	42	2.67	0.5	
50	US-36	Brown	Galvanized	41	48	2.67	0.5	
49	US-36	Brown	Galvanized	41	54	3.00	1	
52	US-36	Brown	Galvanized	41	60	3.00	1	
46	US-36	Brown	Galvanized	41	72	3.00	1	
47	US-36	Brown	Galvanized	41	72	3.00	1	invert covered in concrete
48	US-36	Brown	Galvanized	41	72	3.00	1	
1	K-16	Pottawatomie	Galvanized	53	36	2.67	0.5	7 inches of sediment
2	K-16	Potawattomie	Galvanized	53	36	2.67	0.5	7 inches of sediment
77	US-59	Allen	Galvanized	58	24	2.67	0.5	standing water
78	US-59	Allen	Galvanized	58	24	2.67	0.5	4 inches of sediment
79	US-59	Allen	Galvanized	58	24	2.67	0.5	
80	US-59	Allen	Galvanized	58	24	2.67	0.5	3 inches of sediment
81	US-59	Allen	Galvanized	58	24	2.67	0.5	4 inches of sediment
45	US-36	Nemaha	Galvanized	60	42	2.67	0.5	standing water
55	Old 75	Shawnee	Galvanized	61	24	2.67	0.5	14 in of sediment
8	K-99	Wabaunsee	Galvanized	64	24	2.67	0.5	
9	K-99	Wabaunsee	Galvanized	64	24	2.67	0.5	11 inches of sediment
10	K-99	Wabaunsee	Galvanized	64	30	2.67	0.5	6 in of sediment
12	K-99	Wabaunsee	Galvanized	64	30	2.67	0.5	16 in sediment
13	K-99	Wabaunsee	Galvanized	64	30	2.67	0.5	10 in of sediment
11	K-99	Wabaunsee	Galvanized	64	48	3.00	1	6 in of sediment

89	K-9	Sheridan	Aluminized	65	36	2.67	0.5	Long-term study, standing water
73	K-192	Jefferson	Galvanized	67	18	2.67	0.5	
74	K-192	Jefferson	Galvanized	67	18	2.67	0.5	
75	K-192	Jefferson	Galvanized	67	36	2.67	0.5	standing water
57	Old 75	Shawnee	Galvanized	69	18	2.67	0.5	
58	Old 75	Shawnee	Galvanized	69	24	2.67	0.5	4 in sediment
56	Old 75	Shawnee	Galvanized	69	30	2.67	0.5	
41	K-63	Pottawatomie	Galvanized	80	18	2.67	0.5	
42	K-63	Pottawatomie	Galvanized	80	24	2.67	0.5	
44	K-63	Pottawatomie	Galvanized	80	24	2.67	0.5	
86	K-63	Pottawatomie	Galvanized	80	24	2.67	0.5	
43	K-63	Pottawatomie	Galvanized	80	36	2.67	0.5	
62	K-170	Osage	Galvanized	82	24	2.67	0.5	6 inches of sediment
63	K-170	Osage	Galvanized	82	24	2.67	0.5	standing water
64	K-170	Osage	Galvanized	82	24	2.67	0.5	standing water; could not locate Side B
65	US-56	Osage	Galvanized	88	60	5.00	1	standing water
66	US-56	Osage	Galvanized	88	60	5.00	1	standing water
67	US-56	Osage	Galvanized	88	60	5.00	1	standing water
82	K-4				36	2.67	0.5	4 inches of sediment

Table A.2: Ratings of All CMPs Surveyed in 2018

ID	Gen. Con. A	External A	Crown A	Side A	Invert A	Gen. Con. B	External B	Crown B	Side B	Invert B	Resistivity	pH
3	88.5	88	90	88	88	88.5	88	90	88	88	1500	6.66
4	88.5	88	90	88	88	88.5	88	90	88	88	1500	
5	91	92	92	90	90	91	92	92	90	90	4800	6.97
6	92	92	92	92	92	92	92	92	92	92	4500	6.96
7	92	92	92	92	92	92	92	92	92	92	4500	6.96
14	82.5	60	90	90	90	82.5	60	90	90	90	1100	
59	88	88	88	88	88	88	88	88	88	88	600	
60	93.25	95	95	95	88	93.25	95	95	95	88	600	
35	93.75	95	95	95	90	93.75	95	95	95	90	1200	
32	42.5	0	85	85	0	93.75	95	95	95	90	500	
15		null	null	null	null	90	90	90	90	90	1000	
85		null	null	null	null	94.25	95	95	95	92	3000	
16	90.5	90	90	92	90		null	null	null	null	2500	
26	86.5	92	92	92	70	80.25	92	92	92	45	1400	
27	86	92	92	92	70	86	92	92	92	70	2500	
22		null	null	null	null	77.25	45	92	92	80	1800	
61	90	90	90	90	90	90	90	90	90	90	750	
70	90	90	90	90	90		null	null	null	null	2100	
71		null	null	null	null	91	92	92	90	90	2200	
40		null	null	null	null	84.5	85	85	88	80	900	
34	91.5	95	95	88	88		null	null	null	null	2200	
68	92	92	92	92	null		null	null	null	null	600	
38	90.5	92	90	90	90	90.5	92	90	90	90	2300	
69	79.25	92	90	90	45		null	null	null	null	900	
36	90	90	90	90	90	90	90	90	90	90	1800	
37	90	90	90	90	90	90	90	90	90	90	1800	
72	90	90	90	90	90	90	90	90	90	90	4200	
84	89	92	92	92	80		null	null	null	null	1800	
18	86.5	92	92	92	70	86.5	92	92	92	70	600	
20	82	88	90	90	60	82	88	90	90	60	800	
21	70.5	95	92	92	0	81.75	95	92	92	45	500	

39	90	90	90	90	90	90	90	90	90	90	1700	
23		92	92	70	null		92	92	70	null	2000	
31		null	null	null	null	69	92	92	92	0	900	
25	80.25	92	92	92	45	89	92	92	92	80	2500	
29	60	60	92	88	0	68	92	92	88	0	500	
30	69	92	92	92	0	69	92	92	92	0	500	
33	86.5	92	92	92	70	86.5	92	92	92	70	1300	
28	85.5	70	92	92	88	85.5	70	92	92	88	4900	
53	66.25	85	90	90	0	78.75	90	90	90	45	3900	
54	82	88	90	90	60	72.5	90	90	80	30	4000	
50	67.5	90	90	90	0	66.25	85	90	90	0	2800	
49	67.5	90	90	90	0	76.25	45	90	90	70	3400	
52	78.75	90	90	90	45	67.5	90	90	90	0	3800	
46	78.75	90	90	90	45	62.5	70	90	90	0	600	
47		90	90	90	null		45	90	90	null	600	
48	67.5	90	90	90	0	80	70	90	90	70	1100	
1	75	80	90	85	45	75	80	90	85	45	800	6.82
2	80	80	90	90	60	80	80	90	90	60	900	6.78
77	78.75	90	90	90	45	78.75	90	90	90	45	1250	
78	78.75	90	90	90	45	78.75	90	90	90	45	1100	
79	85	80	90	90	80	82.5	80	90	80	80	1400	
80	87.5	90	90	90	80	65	0	90	90	80	1250	
81	62.5	70	90	90	0	62.5	70	90	90	0	1600	
45	71.25	90	90	90	15	71.25	90	90	90	15	1200	
55	72.5	80	85	80	45	72.5	80	85	80	45	1500	
8	85	90	90	90	70	85	90	90	90	70	950	
9	87	88	90	90	80	78.25	88	90	90	45	1700	
10	60	60	60	60	60	60	60	60	60	60	1350	
12	67	60	90	88	30	67	60	90	88	30	800	
13	76	60	92	92	60	76	60	92	92	60	1600	
11	61.25	45	70	70	60	61.25	45	70	70	60	1700	
89	76.25	90	90	80	45	75.75	88	90	80	45	4000	
73	68.25	70	88	70	45	68.25	70	88	70	45	800	

74	77.5	85	85	70	70	35	0	0	70	70	800	
75	63.75	85	85	85	0	63.75	85	85	85	0	4000	
57	79.5	88	85	85	60	79.5	88	85	85	60	1300	
58	40	0	85	45	30	40	0	85	45	30	1100	
56	82.5	80	85	85	80	62.5	80	85	85	0	1600	
41	58.75	45	70	60	60	58.75	45	70	60	60	2800	
42	66.25	80	85	85	15	66.25	80	85	85	15	2300	
44	62.5	80	85	85	0	70	80	85	85	30	700	
86	68.75	80	90	90	15	68.75	80	90	90	15	4900	
43	72.5	80	90	90	30	90	90	90	90	90	2000	
62	72	88	85	85	30	36.25	0	30	85	30	600	
63	70	80	80	60	60	80	80	85	85	70	300	
64	58.75	70	60	60	45		null	null	null	null	500	
65	68.75	85	85	60	45	68.75	85	85	60	45	2000	
66	62.5	85	60	60	45	62.5	85	60	60	45	2000	
67	75	85	85	85	45	65	85	85	45	45	2000	
82	80	90	85	85	60	80	90	85	85	60	900	

Table A.3: Summary of CMPs Also Surveyed by Stratton (1989)

ID	Project/Route Number	County	Diameter	Material	Age (2018)	Age (1989)	External (1989)	Crown (1989)	Side (1989)	Invert (1989)
2	K-16	Pottawatomie	36	Galvanized	53	24	92.5	92.5	92.5	80
1	K-16	Pottawatomie	36	Galvanized	53	24	92.5	92.5	92.5	92.5
46	US-36	Brown	72	Galvanized	41	12	95	95	95	85
47	US-36	Brown	72	Galvanized	41	12	95	95	95	60
48	US-36	Brown	72	Galvanized	41	12	95	95	95	85
49	US-36	Brown	54	Galvanized	41	12	95	95	95	70
50	US-36	Brown	48	Galvanized	41	12	95	95	95	70
52	US-36	Brown	60	Galvanized	41	12	95	95	95	60
53	US-36	Brown	42	Galvanized	41	12	95	95	95	70
54	US-36	Brown	42	Galvanized	41	12	95	95	92.5	70
41	K-63	Pottawatomie	18	Galvanized	80	51	70	70	70	70
42	K-63	Pottawatomie	24	Galvanized	80	51	92.5	92.5	92.5	15
43	K-63	Pottawatomie	36	Galvanized	80	51	87.5	92.5	92.5	60
44	K-63	Pottawatomie	24	Galvanized	80	51	87.5	92.5	92.5	80
86	K-63	Pottawatomie	24	Galvanized	80	51	92.5	92.5	92.5	60
45	US-36	Nemaha	42	Galvanized	60	31	92.5	92.5	92.5	70
8	K-99	Wabaunsee	24	Galvanized	64	35	92.5	92.5	92.5	92.5
10	K-99	Wabaunsee	30	Galvanized	64	35	92.5	92.5	92.5	70
11	K-99	Wabaunsee	48	Galvanized	64	35	80	92.5	92.5	87.5
12	K-99	Wabaunsee	30	Galvanized	64	35	70	92.5	92.5	70
9	K-99	Wabaunsee	24	Galvanized	64	35	92.2	92.5	92.5	92.5
74	K-192	Jefferson	18	Galvanized	67	38	87.5	92.5	70	70
73	K-192	Jefferson	18	Galvanized	67	38	87.5	92.5	70	70
75	K-192	Jefferson	36	Galvanized	67	38	92.5	92.5	92.5	60
65	US-56	Osage	60	Galvanized	88	59	92.5	92.5	70	70
66	US-56	Osage	60	Galvanized	88	59	92.5	92.5	70	70
67	US-56	Osage	60	Galvanized	88	59	92.5	92.5	70	70
62	K-170	Osage	24	Galvanized	82	53	92.5	92.5	92.5	80
63	K-170	Osage	24	Galvanized	82	53	92.5	92.5	92.5	92.5
64	K-170	Osage	24	Galvanized	82	60	92.5	92.5	92.5	92.5
56	Old 75	Shawnee	30	Galvanized	69	40	87.5	92.5	92.5	92.5

57	Old 75	Shawnee	18	Galvanized	69	40	92.5	92.5	92.5	92.5
58	Old 75	Shawnee	24	Galvanized	69	40	87.5	87.5	60	60
55	Old 75	Shawnee	24	Galvanized	61	32	92.5	92.5	92.5	60
28	K-7	Wyandotte	36	Galvanized	35	46	95	95	95	92.5
77	US 59	Allen	24	Galvanized	58	29	95	95	95	92.5
78	US 59	Allen	24	Galvanized	58	29	95	95	95	92.5
79	US 59	Allen	24	Galvanized	58	29	95	95	95	92.5
80	US 59	Allen	24	Galvanized	58	29	95	95	95	92.5
81	US 59	Allen	24	Galvanized	58	29	92.5	92.5	92.5	92.5
13	K 99	Wabaunsee	30	Galvanized	64	35	92.5	92.5	92.5	87.5

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