Updated Environmental Limits for Aluminized Steel Type 2 Pipe Application

L. BEDNAR

The limits of environmental conditions over which aluminized steel Type 2 drainage pipe exhibits good long-term service life have been defined more clearly owing to the results of continuing field inspections. As a result, the strengths of the material compared with galvanized steel and its behavior under severe exposure can now be illustrated with increased clarity.

The advantageous durability of aluminized steel Type 2 pipe demonstrated in field tests and in actual service (*1–3*) provides an effective means to address the statistically more important limitations in corrosion behavior of galvanized steel in drainage pipe environments. Aluminized steel complements galvanized steel in drainage pipe applications in a fashion that results in expansion of the limits of environmental conditions over which corrugated steel pipe can be effectively used. However, for best results it is important to specify the limits of environmental tolerance for both materials reasonably well. The California Department of Transportation (Caltrans) chart has filled this need for galvanized steel pipe for many years, although it has proven to be unreliable under some environmental conditions. To help ensure that galvanized steel is used within the limits of its capabilities, Armco Research spent considerable time in field studies to develop a more realistic modified Caltrans-type graph to guide galvanized steel application. The results were introduced a few years ago (*4,5*). Recently, cumulative studies on aluminized steel pipe field performance became sufficiently comprehensive to permit construction of a new graph for reasonable conservative estimation of product durability under a range of conditions, including those approaching and exceeding the limits of environmental tolerance.

BACKGROUND

Initially, aluminized steel application was guided mainly by the results of a series of inspections of 30-year-old riveted pipe installed at numerous culvert sites in 14 states in the United States (*1*). The ranges of environmental conditions existing among these sites did not establish the limits of environmental tolerance but were sufficiently comprehensive to justify stipulation of general water and soil limits of a pH range of 5–9 and a resistivity above 1500 ohm·cm. Some of the data suggested the resistivity limit could be as low as 1000 ohm·cm under some conditions, but Armco preferred to use a conservative 1500 ohm·cm general limit until the field data became sufficiently comprehensive to determine the conditions under which a lower resistivity limit would apply. As is the case with any new product, during the years following the introduction of aluminized steel, occasionally the product was exposed under corrosive conditions too severe for expected service life to be realized. Such cases emphasized the need to determine the limits of environmental tolerance.

Sufficient field performance data now exist on newer lock seam and weld seam aluminized steel pipe exposed over a range of conditions in service for a sufficient length of time (up to about 12 years) to begin to estimate better the limits of environmental tolerance. For pipe water environments, these limits have now been estimated with reasonable confidence, and behavioral trends have been determined using simple water alkalinity and hardness measurements in addition to the normal resistivity and pH measurements. Water data are believed to be sufficiently accurate and comprehensive to permit a realistic comparison with galvanized steel pipe, for which there is a good deal of Armco data. This is fortunate because, for the nation as a whole, water chemistry is the primary factor controlling galvanized pipe durability. Generally, therefore, water chemistry is the only environmental factor requiring testing and usually it is the only factor aluminized steel must address.

Armco data for aluminized and galvanized steel performance in soil environments are less comprehensive than the data for water environments, and soil corrosivity is inherently difficult to investigate. Fortunately, soilside corrosion problems for corrugated steel pipe are unlikely (*6*) except under well-defined conditions found in certain geographical areas. Such areas include those with saline soils found mainly in arid regions (*4,5*) and those with highly acidic soils found in parts of certain wet regions (*7,8*). In these areas, adverse soil conditions associated with low resistivity or low pH can control durability, and soil guidelines based on minimum resistivity (water-saturated resistivity) and pH are quite useful.

Although an increasingly strong case can be made for extending the soil minimum resistivity limit of aluminized steel to about 1000 ohm·cm with a reduced pH range (~6.0–8.5) below 1500 ohm·cm, Armco is still uncertain of the actual limit of tolerance and prefers to retain a conservative general nationwide lower limit of 1500 ohm·cm for the present. However, because of the results of a recent field inspection survey in western states, Armco has enough field data from arid climates to recognize a considerably lower soil minimum resistivity limit for regions with arid climates. This special limit applies because waterflow in such climates is generally too infrequent to influence durability considerations, and soils are usually dry enough that the effect of salt content is greatly

Armco Steel Co., Research & Technology, 703 Curtis Street, Middletown, Ohio 45044-3999.

reduced (in situ resistivity controls corrosion). Of course, a condition of infrequent waterflow means that, in general, soil minimum resistivity and pH will be the only criteria governing materials selection in arid climates.

DISCUSSION ON MECHANICS OF THE METHOD

Water Environments

The graph for behavior of aluminized and galvanized steel in waters shown in Figure 1 includes the effect of water alkalinity and hardness as well as pH and resistivity because this effect is important in determining the reaction of both materials to the water. For galvanized steel, alkalinity and hardness are important in determining the tendency toward protective mineral scaling necessary for good long-term service life (*4*). For both materials, the determination of alkalinity and hardness reveals the proportion of corrosive Cl^- and SO_4^{-2} salts contributing to the resistivity. The total dissolved salt content indicated by the resistivity generally consists mainly of beneficial or nonharmful alkalinity or hardness salts instead of corrosive salts such as SO_4^{-2} and Cl^-, and it is necessary to determine the proportions of the two types of salts to characterize the effect of resistivity on behavior. At any level of hardness and alkalinity, decreasing resistivity corresponds to increasing Cl^- and SO_4^{-2} and decreasing service life. It is also important to determine free carbonic acid (CO_2) (calculated from pH and alkalinity) because free CO_2 is the only form of free acidity present in most pipe waters.

CO_2 has a direct adverse effect on galvanized steel and can enhance the adverse effect of Cl^- and SO_4^{-2} on galvanized and aluminized steel. At any given level of hardness and alkalinity, increasing free CO_2 corresponds to decreasing service life to a degree determined by Cl^-, SO_4^{-2}, and resistivity. To express the corrosive influence of free acidity, the free CO_2 concentration is more realistic than the pH alone (*4*). Figure 1 does not deal with acidity other than CO_2 because water containing other free acidity would necessarily be below pH 4.5. Water below pH 4.5 is likely to contain other free acidity. The result of having pipe water containing such free acidity would be a condition too severe for most common pipe materials (*4*). Thus, the graph cannot be used for waters with pH values below 4.5, and a negative sum on the graph vertical axis refers only to water relatively low in hardness and alkalinity and relatively high in free CO_2. The graph also cannot be used at pH values above 9.0, where normally beneficial alkalinity becomes partially detrimental because of an adverse effect on the aluminum layer of the bilayer aluminized coating.

The 50-year and 20-year lines in the graph of Figure 1 represent the lower water chemistry limits at which at least 50-year or 20-year service life is realized for each material. Any chemistry falling below these lines will tend to give lower service life because such a low reading indicates higher proportions of Cl^- and SO_4^{-2} or free CO_2, or both, at a given resistivity. Service life is defined as the time in service before pipe maintenance at certain minimum gauges is likely to be needed. The minimum gauges representing the two materials in the graph are different because the data were from two different studies using baseline materials of 2.0-mm (14-gauge) galvanized steel and 1.62-mm (16-gauge) aluminized steel. The limit lines for galvanized steel were developed from earlier field studies (*4*). The limit lines for aluminized steel were developed from later field studies; the data are presented in Figure 2. Thus Figure 1 is a composite of Figure 2 and the earlier figure for galvanized steel. The aluminized steel data are from random field inspections except for the five problem waters (less than 20-year life), which are from three problem

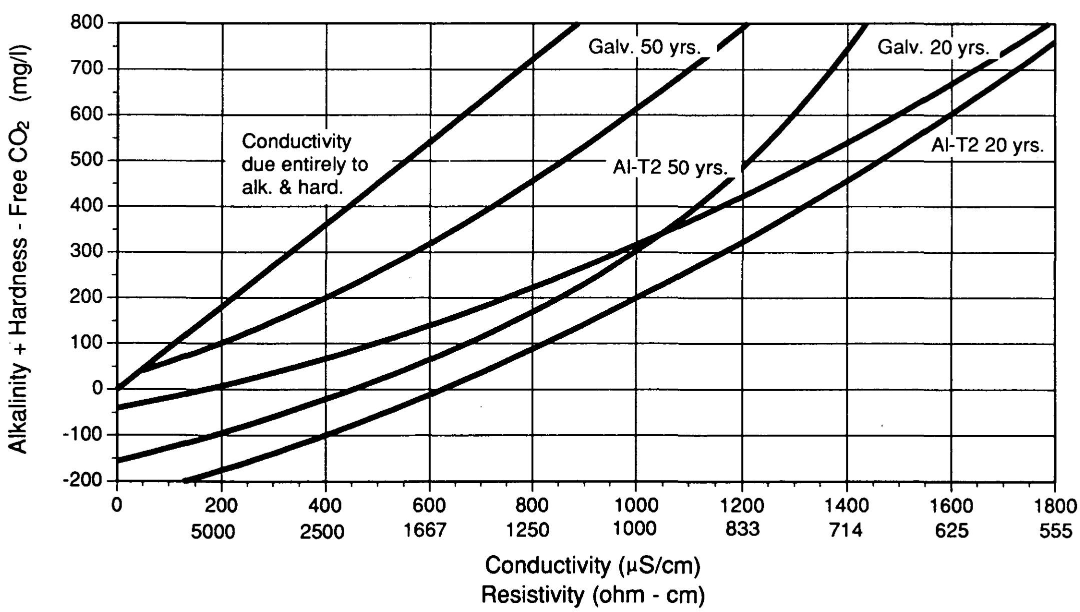

FIGURE 1 Comparative minimum service life for 1.62-mm-thick Type 2 aluminized steel and 2.0-mm-thick galvanized steel as a function of water chemistry (µS/cm = umho/cm, mg/l = ppm, 1.62 mm = 16 gauge, 2 mm = 14 gauge).

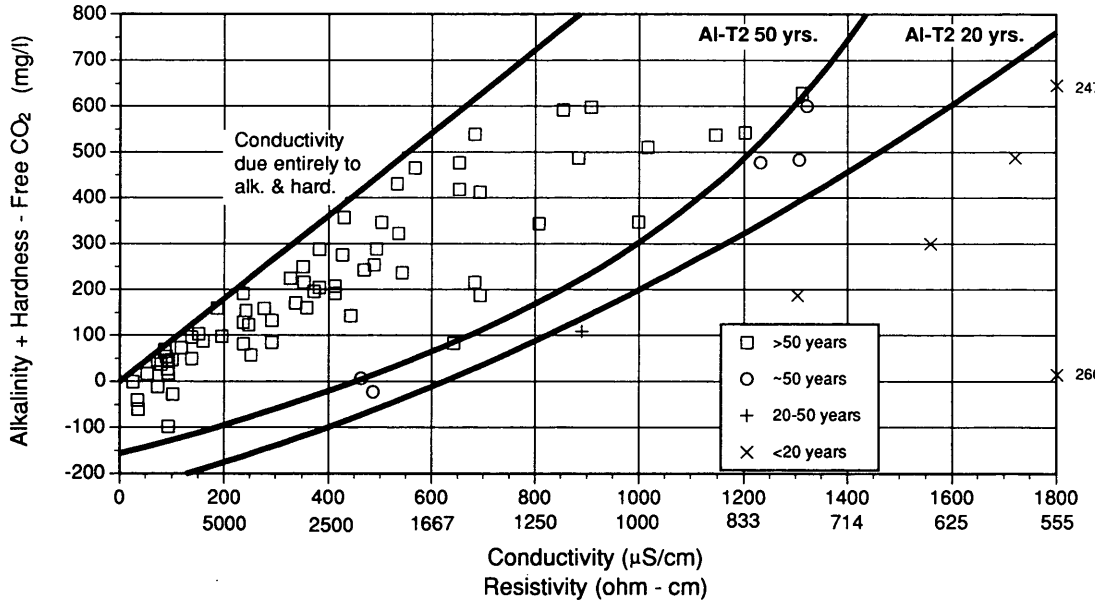

FIGURE 2 Estimated service life of 1.62-mm-thick Type 2 aluminized steel as a function of water chemistry (μS/cm = umho/cm, mg/l = ppm, 1.62 mm = 16 gauge).

sites specifically chosen for study. Two of these sites had multiple waterflow sources (lateral intercept flow as well as main invert flow), thus affording the opportunity to investigate the effect of more than one water at one site. Because the problem sites were not chosen randomly, their number with regard to the total number studied obviously has no statistical significance, but inclusion of data from these sites is helpful in establishing the limits of environmental tolerance.

Figure 1 is intended for groundwater evaluation at sites where the groundwater table is high enough to produce at least some slight dry weather groundwater seepage and flow at the depth of pipe burial. At aluminized sites that are dry during nonrainfall periods, there is normally no need for a water evaluation because the material is generally not substantially affected by rainwater surface runoff. Likewise there is normally no significant effect of surface runoff in the high-water zone above the groundwater level. Surface runoff is usually relatively soft and near-neutral in pH because of dilution or aeration effects, and aluminized steel has optimum resistance to such water (*1*). The higher velocity of surface runoff is no problem because of the enhanced resistance of aluminized steel to erosion corrosion and abrasion by turbulent rapid flow (*1*).

Because groundwater is normally the only pipe effluent of any concern, water testing should be accomplished in dry weather at least 2 days after the last rainfall, when dissolved mineral concentration is maximal. In arid climates, only sites with significantly prolonged flow or standing water resulting from a local high water table are of concern. The degree of accuracy required in water analysis is not high enough to justify use of standardized methods of analysis. For hardness and alkalinity testing, simplistic digital titration kits employing prequantified encapsulated reagents are adequate. Alkalinity and hardness data are commonly expressed in ppm as $CaCO_3$. These data must be converted to ionic concentration form before use in Figure 1 by multiplication of the alkalinity by 1.22 and of the hardness by 0.4.

Soil Environments

The graph for behavior in soil environments is shown in Figure 3. This graph is more simplistic and less specific for three reasons. First, for practical purposes it is limited to the parameters of pH and resistivity. Second, because of the limited data available, the limits of environmental tolerance have not yet been estimated, and it is necessary to use conservative limits adequately supported by the available data. Third, the data limitations prevent a reliable soilside comparison of the two materials. The present form of the soilside graph in Figure 3 serves only to illustrate the soilside conditions necessary to ensure a minimum 50-year service life for aluminized steel at 1.62 mm thickness (16 gauge) according to present knowledge.

One potential problem in detecting low soil pH values that must be recognized is the possibility that in a nonselect heterogeneous backfill there may be a highly acidic phase that directly contacts the pipe but is not detected because of the normal practice of mixing soil for pH measurement. A dark or light gray, blue, or olive-colored clay phase in a native-soil fill may be acidic and should be isolated for a pH measurement. Highly acidic clays of such color are found in certain geographical areas and arise from conditions chemically comparable to those that produce environments of acid minewater. When extensively distributed in a pipe watershed soil, such clays may give rise to groundwater seepage of temporary high acidity during prolonged dry weather when the volume of groundwater flow is minimal.

One potential problem in resistivity measurements arises because of the influence of chloride deicing salts. These salts induce snow and ice melting that produces a trickle flow of salty moisture that percolates through the soil and may attack the pipe if the salt content is high enough. The advent of spring weather brings rains that leach the soil to remove this temporal salt, and measurement of resistivities afterward gives misleading high values. In sandy or other granular soils, drain-

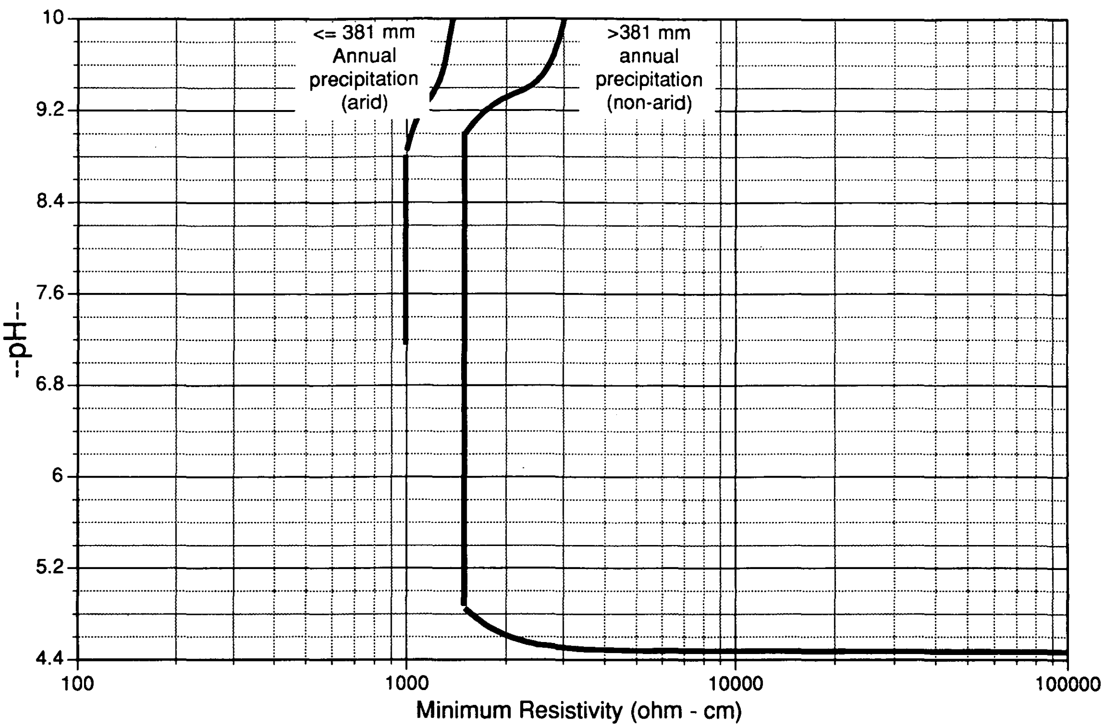

FIGURE 3 pH/resistivity soilside tolerance limits of Type 2 aluminized steel for good long-term durability approaching 50 years minimum in nonarid and arid regions (1 in. = 25.4 mm).

age and leaching occur quickly after the first rainfall, and even in arid climates, all traces of chloride from deicing salt are removed after the first appreciable rainfall.

Other Comments

The estimation of pipe service life in waters and soils is derived by extrapolation of field performance under a variety of exposure conditions and has been described previously (*9*). The method is based on the results of inspections of 30-year-old culvert sites in which the progress of coating and substrate attack at 20- and 30-year intervals was studied. Extrapolation of performance from 30 to 50 years involved little uncertainty. Actually, the inspection results showed that the long-term behavior of aluminized steel is predictable early in the exposure period. This is so largely because a passive metal such as aluminum that exhibits normal good passive behavior during the first several years in service continues to do so over the long term, and the existence of any troublesome conditions becomes evident early.

RESULTS AND DISCUSSION

Characteristics of Graph for Water Environments

The most important factor limiting galvanized steel service life for the nation as a whole is softer higher-resistivity water containing significant free CO_2 and having little or no natural protective mineral scaling tendency (*10*). This condition is common in certain regions of the country, and the use of aluminized steel in such regions effectively addresses the problem, as shown in Figure 1. According to the figure, a minimum 50-year aluminized steel service life is realized under conditions of higher resistivity and free CO_2 encompassing even those severe enough to limit galvanized service life to somewhat less than 20 years. As a passive metal with passive oxide film protection, aluminum is highly resistant to soft high-resistivity water and to a weak acid like carbonic acid (*11*). Nonpassive zinc develops minimal film protection of any kind in such water and is subject to acceleration of corrosion by CO_2 in accordance with the free acidity concentration (*12*).

As resistivity decreases from high levels, the combined adverse effect of increasing Cl^-/SO_4^{-2} and any significant free CO_2 becomes increasingly potent. However, aluminized steel continues to maintain a minimum 50-year service life under conditions of moderately low resistivity, even those severe enough to limit galvanized steel to a service life of less than 20 years. This degree of advantage persists down to a resistivity level on the order of 950 ohm·cm. Thus, aluminized steel may be used effectively to address corrosion problems existing over the range of high to moderately low resistivity. This advantage is the result of the combined influence of superior resistance to free CO_2 and a modestly superior resistance to Cl^-/SO_4^{-2}. As resistivity decreases still further and Cl^- and SO_4^{-2} increase further, pitting corrosion accelerates notably and the advantage of aluminized steel over galvanized steel decreases more and more abruptly. At some point over the 950 to 600 ohm·cm range, pitting becomes severe enough that the advantage becomes minimal. Thus, aluminized cannot be used to address corrosion problems caused by low resistivity. If water resistivity is low enough and water chemistry coordinates on the graph fall far enough below the 50-year service life line, service life can be relatively short.

Characteristics of Graph for Soil Environments

In general, field experience indicates that soilside environments are less severe than waterside environments (*6*), and problems for aluminized or galvanized steel pipe are less likely, except for cases involving certain well-defined avoidable conditions. This is fortunate because soilside studies are inherently more difficult, and Armco soilside performance data are not yet sufficient to permit a reliable estimation of the limits of tolerance for either material. The most useful approach under these circumstances is to use for good long-term durability conservative limits that are supportable by comprehensive data, and to depict known behavioral trends near these limits.

As shown in Figure 2, for good long-term aluminized steel service life (approaching 50 years as a minimum), a 1500 ohm·cm general nationwide lower limit on soilside minimum resistivity and a 5–9 pH range will be retained until soilside data become sufficiently comprehensive to determine the conditions under which lower resistivity can be tolerated. For the present, the only exception sufficiently supportable by available data is a general 1000 ohm·cm minimum resistivity limit for arid climates with 381 mm/year (15 in./year) or less total annual precipitation. Armco's experience suggests the lower general limit in arid climates is as low as 800 ohm·cm and possibly even as low as 600 ohm·cm, but 1000 ohm·cm is better supported by the present data and will be used for the present. For arid climates Armco has no idea of resistivity tolerances at pH values below a level of about 7.2 because the company has never observed lower pH values than this at low resistivity levels in arid climates. Such conditions appear to be rare and may not exist at all. Of course, the special 1000 ohm·cm limit applies in recognition of the benefit of dry soil conditions and does not apply at installations where soil is wetted by groundwater. In arid or nonarid regions, the presence of groundwater seepage resulting from a groundwater table that reaches up to the pipe burial depth necessitates the use of Figure 1 for further guidance.

Figure 3 also shows a mild adverse effect of soil alkalinity at pH values above 9.0 on aluminized behavior. This effect is mild because high alkalinity adversely affects only the aluminum layer of the coating. The Fe and Al alloy (intermetallic) layer of the coating is not attacked by excessive alkalinity, and the substrate performs better as pH increases. Data above pH 9.0 are limited but suggest that a mild adverse effect on total service life can be expected in the 9–10 soil pH range. As the pH approaches 10, long-term performance of the substrate and the Fe and Al alloy coating layer are expected to be quite good, so the long-term effect of loss of the coating aluminum layer will become insignificant in attaining 50-year minimum life.

Figure 3 further shows a pronounced accelerating adverse effect of acidity on performance below pH 4.8, and good long-term service life over the 4.8–4.5 pH range is attainable only at increasingly high resistivity. Although this is a bit conservative, it is nonetheless indicative of the trend of a pronounced adverse effect of acidity that begins at some pH value near the 4.5 level at which free acidity other than CO_2 is likely to be introduced. The effect of acidity throughout the 4.0–4.8 pH range actually varies considerably, being minimal in well-drained oxidizing soils and maximal in poorly drained reducing soils (similar to the effect on galvanized steel). In waterlogged reducing soils, the effect of acidity is sometimes controlled by water-soluble heavy metals, primarily iron, in certain geographical areas. In such soils, pH values may drop below 4.0. Armco studies on materials behavior in waterlogged soils are continuing, and behavioral characteristics will be discussed in future reports.

CONCLUSIONS

1. The use of aluminized steel Type 2 to complement galvanized steel by effectively addressing the more important limitations in galvanized corrosion resistance substantially expands the limits of environmental chemistry over which corrugated steel pipe can be used. However, the limits of corrosion resistance capabilities of aluminized as well as galvanized steel must be recognized. Recognizing these limits is readily and easily accomplished by using new updated field-derived application guidelines and by conducting simple groundwater hardness and alkalinity tests in addition to the normal pH and resistivity tests wherever groundwater is a factor.

2. Updated guidelines indicate 50-year minimum service life for aluminized steel over water conditions ranging from high resistivity and high free CO_2 to moderately low resistivity and significant free CO_2. Throughout this range, conditions encompassed include those severe enough to limit galvanized steel life to somewhat less than 20 years. This advantage for aluminized steel persists down to resistivity values on the order of 950 ohm·cm, but the degree of advantage diminishes increasingly abruptly at lower values and becomes minimal at a point somewhere over the 950–600 ohm·cm range. Thus, use of aluminized steel effectively addresses water problems existing over the high to moderately low resistivity range down to at least 950 ohm·cm but does not effectively address problems resulting from very low resistivity. The use of aluminized steel also effectively addresses problems associated with rainwater surface runoff.

3. Updated soil guidelines retain the pH and resistivity basis for evaluating soil corrosivity and retain the 1500 ohm·cm minimum resistivity and 5–9 pH limits for aluminized steel for the nation as a whole. However, in arid climates with 381 mm/year (15 in./year) or less annual precipitation and with generally dry pipe inverts and soils, a general minimum resistivity lower limit of 1000 ohm·cm over the 7.2–9.0 pH range is now recognized. Exceptions to the arid-region soil application guidelines exist at installations where the groundwater table reaches the pipe burial depth. In arid or nonarid regions, any groundwater seepage at the pipe burial depth necessitates the use of Figure 1 for further guidance.

4. Updated guidelines illustrate the effect of excessive soil acidity and alkalinity somewhat more specifically than has been done in the past. It is well known that pipe materials are not expected to give good service life beyond certain critical levels of acidity, and for aluminized steel this critical level can be exceeded somewhere near pH 5.0–4.8. Severe limitations in service life can occur at pH values below 4.5 where various types of free organic or inorganic acidity are likely to appear. Alkalinity at pH values above 9.0 has a rather mild adverse effect on service life because, although strong alkalinity attacks the aluminum layer of the aluminized steel

coating, it does not attack the Fe and Al alloy layer, and it helps protect the steel substrate.

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Publication of this paper sponsored by Committee on Culverts and Hydraulic Structures.