RECLAMATION

Managing Water in the West

Technical Memorandum No. 8140-CC-2004-1

Corrosion Considerations for Buried Metallic Water Pipe

United States Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

July 2004

Mission Statements

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The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

BUREAU OF RECLAMATION

Technical Memorandum No. 8140-CC-2004-1

Date: July 2004

Region: Reclamation

Project: N/A

Feature: N/A

To: Director of Operations

From: TSC Director

Subject: Corrosion Considerations for Buried Metallic Water Pipe

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1.0 EXECUTIVE SUMMARY

Because of corrosion concerns raised relative to the use of cathodic protection and polyethylene (PE) encasement on ductile iron pipe, Reclamation conducted an extensive evaluation of the corrosion mitigation alternatives listed in the April 23, 2003, Corrosion Prevention Criteria and Requirements table (table 1). This study was based on Reclamation's experience, the experience of other professionals in the corrosion and pipe industries, a review of pertinent national standards, and a review of relevant literature.

While much of the review completed during the preparation of this report focused on steel and ductile iron pipe, the findings resulting from this review have also proven valuable in evaluating Reclamation's corrosion protection criteria for concrete pipe with steel reinforcement. Therefore, the updates to Reclamation's Corrosion Prevention Criteria and Requirements table include revised criteria for steel and ductile iron pipe as well as revised criteria for concrete pipe with steel reinforcement. Other more general changes to the table reflect a move to a more unified means of corrosion prevention designs for all Reclamation pipelines regardless of the type of water system.

The study results and the information contained in this report resulted in an updated Corrosion Prevention Criteria and Requirements table, dated July 2004 (table 2). Application of the table's criteria and requirements shall be in accordance with the Reclamation Manual Policy "Performing Design and Construction Activities" (FAC P03).

The updates to Reclamation's Corrosion Prevention Criteria and Requirements table are as follows:

1. The table title has been changed to reflect that these are minimum corrosion requirements.

2. The distinction between irrigation pipelines vs. municipal and industrial pipelines has been removed. The same corrosion prevention criteria and requirements now apply to all Reclamation pipelines.

3. The pipe size and weight restrictions for the use of PE encasement on ductile iron pipe have been removed from the table.

4. The soil resistivity values for the minimum required corrosion protection measures for pipelines have been revised:

    - For steel and ductile iron pipe, a bonded dielectric coating and cathodic protection is required for soil resistivities ≤ 2,000 ohm-cm, an unbonded coating (PE encasement for ductile iron pipe and cement mortar with coal tar epoxy for steel pipe) and cathodic protection is the minimum requirement for soil resistivities between 2,000 and 3,000 ohm-cm, and an unbonded coating (PE encasement for ductile iron pipe and cement mortar for steel pipe) and corrosion monitoring is the minimum requirement for soil resistivities ≥ 3,000 ohm-cm.

- For pretensioned concrete pipe, mortar coating with coal tar epoxy and cathodic protection is required for soil resistivities < 3,000 ohm-cm, and mortar coating and corrosion monitoring is the minimum requirement for resistivities ≥ 3,000 ohm-cm.

- For reinforced concrete pipe, concrete coating with coal tar epoxy and cathodic protection is required for soil resistivities < 3,000 ohm-cm, and concrete coating and corrosion monitoring on pipe with steel joint rings is the minimum requirement for resistivities ≥ 3,000 ohm-cm.

5. The cutoff point for increased corrosion protection for pretensioned and reinforced concrete pipe was reduced from 4,000 ohm-cm to 3,000 ohm-cm.

6. Prestressed concrete pipe has been removed from the table. Reclamation has had a moratorium on the use of this type of pipe since 1990. If and when this changes, corrosion mitigation measures for prestressed concrete pipe will be added to this table.

Based upon the information gathered during the preparation of this report, Reclamation has not found sufficient cause to conclude there is a significant difference in the performance expectations for repairs or anticipated service lives of steel or ductile iron pipelines.

The report includes a method of applying an adjustment to the bid prices for buried metallic pipes based upon operation, maintenance, replacement, and energy (OMR&E) costs for cathodic protection (CP). Metallic pipe is defined as steel, ductile iron, or any concrete pipe containing ferrous elements.

2.0 INTRODUCTION

When Reclamation designs or reviews designs for corrosion protection of pipelines, many factors are considered, including the guidelines in the Corrosion Prevention Criteria and Requirements table. These guidelines are updated occasionally to reflect the most current and applicable corrosion design parameters.

Recent questions regarding Reclamation's corrosion mitigation practices prompted an evaluation of the corrosion mitigation alternatives listed in the April 23, 2003, table entitled "Corrosion Prevention Criteria and Requirements" (See table 1). This report analyzes corrosion protection measures for buried metallic pipes currently used by Reclamation, with special focus on steel and ductile iron pipe.

Reclamation has had good experience with both steel and ductile iron pipe performance when the pipes are properly designed, manufactured, and installed. Consequently, Reclamation commonly specifies multiple pipe options, including steel and ductile iron pipe, for pipeline projects.

Table 1

Corrosion Prevention Criteria and Requirements					Updated April 23, 2003
Pipe Alternative	External Protection (Primary/Supplemental)	Soil Resistivity – 10% Probability Value (Σ-m) Irrigation	Soil Resistivity – 10% Probability Value (Σ-m) M&I	Corrosion Monitoring System	Cathodic Protection System
Ductile Iron	Polyethylene encasement[1]	>15	>30	x	
		≤15	≤30	x	x
	Bonded dielectric[2]	>10	>20	x	
		≤10	≤20	x	x
Prestressed Concrete[3]	Mortar/coal-tar epoxy	>25	>50	x	
		≤25	≤50	x	x
Pretensioned Concrete	Mortar	>20	>40	x	
		≤20	≤40	x	x
	Mortar/coal-tar epoxy	>15	>30	x	
		≤15	≤30	x	x
Reinforced Concrete	Concrete	>20	>40	x	
		≤20	≤40	x	x
	Concrete/coal-tar epoxy	>15	>30	x	
		≤15	≤30	x	x
Steel	Mortar	>20	>40	x	
		≤20	≤40	x	x
	Mortar/coal-tar epoxy	>15	>30	x	
		≤15	≤30	x	x
	Bonded dielectric[2]	>10	>20	x	
		≤10	≤20	x	X

[1] Applicable to pipe with corrosion allowance, 24-inch inside diameter maximum, and 150 lb/ft maximum.
(NOTE: Given recent pipe industry experience with ductile iron pipe, Reclamation plans to re-examine this provision.)

[2] Bonded directly to metal to be protected.

[3] Reclamation currently has a moratorium on this pipe alternative.

The results of this study are incorporated into the latest update to Reclamation's Corrosion Prevention Criteria and Requirements table, dated July 2004 (see table 2).

2.1 Background

Reclamation first considered using ductile iron pipe on projects in the mid 1960s. At that time, Reclamation's position from a corrosion standpoint was that ductile iron pipe would be treated the same as steel pipe, except that steel pipe could be coated with either cement mortar or a bonded dielectric coating (depending on soil conditions), while ductile iron pipe could only be coated with a bonded dielectric coating.

In the 1970s, Reclamation added PE encasement as an alternative corrosion mitigation method for ductile iron pipe.

In 1980, Reclamation determined that different corrosion prevention criteria should be applied to pipelines carrying water for municipal and industrial use versus pipelines used only for irrigation. The reason for this distinction or "Use Factor" was based upon the fact that irrigation pipelines were available for maintenance annually, as opposed to municipal and industrial pipelines which were required to provide uninterrupted service.

In the mid-1980s, a table was developed which outlined corrosion protection criteria for various types of metallic pipe.

In the early 1990s, Reclamation revised the table for both steel and ductile iron pipe. For steel pipe, a coating option for mortar encased with coal tar epoxy was added. For ductile iron pipe, a footnote was added limiting the use of PE encasement on ductile iron pipe to diameters of 24 inches or smaller and weights of 150 pounds per foot or lighter. This limitation was based on concerns that damage may occur to the PE encasement during the handling and installation of larger diameter and heavier pipe. The limitation was not based on the inability for larger pipes to be adequately protected by intact PE encasement. In 2003, Reclamation revised the footnote adding the following: "NOTE: Given recent pipe industry experience with ductile iron pipe, Reclamation plans to re-examine this provision."

Reclamation's use of ductile iron pipe is somewhat limited. Approximately 30 miles of ductile iron pipe have been installed on Reclamation-designed projects. The ductile iron pipelines on Reclamation designed projects were installed beginning in the late 1970s and are 24 inches in diameter or less.

Additionally, over 300 miles of ductile iron pipe have been installed on non-Reclamation projects where Reclamation has had oversight responsibilities (projects not designed by Reclamation). Ductile iron pipelines installed with Reclamation oversight typically have been

Table 2

Corrosion Prevention Criteria and Minimum Requirements[1]				July 2004
Pipe Alternative	Soil Resistivity – 10% Probability Value (ohm-cm)	Minimum External Protection (Primary/Supplemental)	Corrosion Monitoring	Cathodic Protection[2]
Ductile Iron	≤2,000 ohm-cm	Bonded dielectric[3]	YES	YES
	>2,000 ohm-cm <3,000 ohm-cm	Polyethylene encasement	YES	YES
	≥3,000 ohm-cm	Polyethylene encasement	YES	NO
Pretensioned Concrete	<3,000 ohm-cm	Mortar / coal-tar epoxy	YES	YES
	≥3,000 ohm-cm	Mortar	YES	NO
Reinforced Concrete	<3,000 ohm-cm	Concrete / coal-tar epoxy	YES	YES
	≥3,000 ohm-cm	Concrete	YES[4]	NO
Steel	≤2,000 ohm-cm	Bonded dielectric[3]	YES	YES
	>2,000 ohm-cm <3,000 ohm-cm	Mortar / coal-tar epoxy	YES	YES
	≥3,000 ohm-cm	Mortar	YES	NO

[1] This table should be considered to be the minimum corrosion prevention requirements for a pipeline corrosion design. Additional soil conditions and risk assessment factors should be considered on a case-by-case basis for each specific project.
[2] OMR&E costs for cathodic protection for each pipe type should be evaluated.
[3] Bonded directly to metal to be protected.
[4] Corrosion monitoring is required for concrete pipe with steel joint rings, but not for concrete pipe with concrete joints.

installed with PE encasement and CP. To date, Reclamation is unaware of any failure of ductile iron pipe on a Reclamation-designed project or on a project for which Reclamation has had an oversight responsibility.

Reclamation's historical experience with steel pipe is much more extensive than that for ductile iron pipe. One of the first steel pipe specifications was the construction of a 90-inch diameter above-ground steel plate siphon for St. Marys River Crossing and a 78-inch diameter above-ground siphon for Halls Coulee on the St. Marys Storage Unit of the Milk River Project, Montana (Specification No. 361-D, October 20, 1924). Additionally, Reclamation designed 4- to 20-inch diameter buried steel pipes for the South Ogden Distribution System on the Ogden River Project in Utah (Specification 1420-D, September 11, 1940). Since the 1960s, Reclamation has designed and installed approximately 320 miles of buried steel pipe. To date, Reclamation is unaware of any corrosion failures for steel pipe on Reclamation-designed projects when cathodic protection has been used.

Reclamation's historical experience with concrete pipe is extensive. Reclamation has designed concrete pipe diameters ranging from 12 inches up to 252 inches. Reclamation has designed various types of concrete pipes including, but not limited to, unreinforced drainage, cast in place reinforced, cylinder, reinforced, pretensioned, lined cylinder prestressed, and prestressed concrete pipes. One of Reclamation's earliest uses of concrete pipe was a 10.5-foot-diameter buried concrete siphon pipe for Stiver Canyon on the North Platte Project issued in 1923 as Specification No. 419.

This report summarizes Reclamation's review of these issues and presents the results of Reclamation's evaluation of the technical considerations related to corrosion mitigation for buried metallic pipelines.

2.2 Scope of Review

National standards and corrosion engineering practices were reviewed to compare with current Reclamation criteria for determining pipeline corrosion protection measures.

Major water utilities were surveyed to determine their experience with steel and ductile iron pipe, including what current corrosion criteria they use to protect their pipelines.

Historical performance data was reviewed for steel and ductile iron pipe where possible to see if a failure rate trend for either type of pipe could be predicted.

In 2003, Reclamation's corrosion engineer completed an extensive literature review of over 150 available industry references related to the effectiveness of PE encasement used as part of a corrosion control system for ductile iron pipe (see appendix B). The effectiveness of this system has been the subject of debate within the pipeline and corrosion industries for years and results of engineering studies on the subject differ widely. Reclamation also reviewed available data regarding the possible use of PE encasement for steel pipe.

Reclamation also executed contracts with two private sector corrosion engineers (CH_2M Hill and Schiff and Associates) as well as a materials scientist with the National Institute of Standards and Technology (NIST) to conduct an independent technical peer review of the findings of Reclamation's corrosion engineer. In addition, a contract was issued with two additional materials scientists with NIST to serve as independent "referees" to evaluate the three reviewers' conclusions as well as the preliminary conclusions of Reclamation's corrosion engineer.

3.0 CORROSION DESIGN

3.1 Corrosion by Soils

Soil is an essentially neutral, aqueous electrolyte; thus, corrosion of ferrous alloys in soil is a special case of aqueous corrosion. The general cause of corrosion in neutral soil is attributable to cathodic depolarization or depassivation by the activity of oxygen. In oxygen concentration-promoted corrosion, the combined effect of oxygen and moisture causes corrosion. The driving voltage for the corrosion cell is caused by differences in oxygen available to all surfaces. The conductivity of the soil controls both the intensity and extent of attack. Oxygen concentrations in the soil are attributable to differences in aeration, salt concentrations, and their effect on oxygen solubility, soil permeability, and ground-water flow. However, when the oxygen or moisture is depleted, corrosion will stop. Appendix B of this report includes a detailed explanation of the corrosion process.

3.2 Soil Corrosivity Parameters

Soil burial is one of the most aggressive exposures encountered by metallic pipelines. The common corrosion cells experienced underground are pseudogalvanic (oxygen and pH concentration effects) and electrolysis (stray current corrosion). Soil conductivity governs the intensity and extent of attack of both electrolytic and pseudogalvanic corrosion. When iron and steel are exposed to a highly alkaline environment (coated with mortar or encased in concrete), the potential corrosive effects of the soil are reduced.

Installation of a buried pipeline requires excavation of a trench, preparation of the invert bedding, installing the pipe, backfilling with special material to support the pipe, and filling the remainder of the trench to original ground surface. This sequence ensures an abundant supply of both oxygen and water in the pipe trench. The trench intercepts, collects, and conveys ground water which may contain dissolved salts. The water level within the pipe trench will fluctuate with the ground-water supply, which is related to atmospheric precipitation. Oxygen enrichment and cyclic wetting and drying concentrate the ground-water salts within the backfill. Backfilling with select, free-draining material (e.g., sand and gravel) compounds this effect by creating a "French drain."

Thus, soil corrosivity may be increased relative to virgin conditions by virtue of digging a trench, installing a pipeline, and backfilling. A supply of both water and oxygen is provided for pseudogalvanic corrosion and, with time, the conductivity increases because of the elevated salt concentration.

Stray currents are also a common cause of underground pipeline corrosion. For stray current corrosion, current from a foreign source such as a nearby CP system, electrified railway, or improperly grounded equipment is required. Current is collected at some surfaces (cathodes) of the pipeline and discharged from other surfaces (anodes) as the current returns to the originating source. The metal corrodes at the anodic sites. The extent and intensity of stray current corrosion are related to the driving voltage of the foreign power supply, the circuit resistance, the geometrical relationship between the source of earth currents and the pipeline, the axial resistance of the pipeline, the dielectric properties and continuity of the pipe coating, and the soil conductivity.

A source of earth currents is required for stray current corrosion. Although the existing sources of earth currents can be identified by performing route surveys during design data collection, additional sources could be installed before or after pipe installation. For this reason, stray current corrosion is always a consideration for buried pipelines. Rubber gasketed, bell and spigot joints are often used on pipelines in the water industry and often result in a pipeline which is not electrically continuous, which is a factor to consider for corrosion mitigation. The electrical continuity across the joint is dependent on the physical contact between the bell and spigot ends of a joint. If physical contact exists electrical continuity can occur, although without installation of electrical continuity joint bonds positive continuity is not obtained. An electrically discontinuous pipeline collects less stay current than an electrically continuous pipeline which results in less stray current corrosion (Bonds, 1997). However, any current that is collected on an electrically discontinuous pipeline can cause stray current corrosion when the current leaves the pipe surface to get around an electrically discontinuous pipe joint.

The vulnerability of metallic pipes to stray current corrosion is dependent on metal surface area, dielectric properties of the coating, and pipeline continuity.

Another source of corrosion is the lack of isolation between two different types of pipe materials. This commonly occurs when copper pipes are directly attached to steel or ductile iron pipes without any isolation. The potential difference between the two materials will lead to corrosion.

Because the requirement for both oxygen and pH concentration cells are provided in the pipe trench, and stray current sources are, or may be, installed, the only remaining major uncontrolled corrosivity parameter is soil electrical resistivity, which is a measure of the conductivity of the soil.

Soil resistivity is one of the most influential parameters affecting corrosion. The importance of soil resistivity to corrosion activity has long been recognized by corrosion engineers. Pseudogalvanic and stray current exposures provide the driving force (voltage difference) for the corrosion reaction. The resistance of the chemical portion of the circuit (i.e. the soil) including the ionic resistance of the electrolyte and the metal/electrolyte contact resistances at both the anode and cathode surfaces controls the magnitude of current flow. These resistances are directly related to the resistivity of the electrolyte. Soil resistivity is a measure of the soil's moisture content and dissolved salts.

The corrosion experienced on buried metallic pipelines is more dependent on the environmental characteristics than the compositional variations (amount and types of metal) within a specific type of pipe. It is widely accepted that both steel and ductile iron corrode at similar rates in similar soils (FHWA, 2001; Fitzgerald, 1968; Romanoff, 1968).

Although they corrode at approximately the same nominal rate, there is a very important difference between the corrosion characteristics of steel versus ductile iron. Ductile iron pipe typically corrodes by graphitization, pitting corrosion, or microbiologically influenced corrosion (MIC). Graphitization does not occur with steel, which typically corrodes by pitting. Graphitic corrosion is a type of dealloying in which the iron within the iron/carbon matrix of ductile iron is preferentially corroded due to the galvanic couple between the iron and graphite. Iron is anodic to graphite and when galvanically coupled with graphite the iron will experience accelerated corrosion. As the iron corrodes, the iron/carbon matrix transforms to a porous iron oxide/carbon matrix with an accompanying reduction of mechanical properties (e.g. ductility and tensile strength). The graphitized material tightly adheres to the metal substrate. There is generally no visible evidence of graphitic corrosion; the original pipe surface remains the same including contour, texture, and color (there may be a very slight color change). Pitting corrosion is usually easily identified and is visually evident by surface cavities and/or color variation due to the presence of corrosion by-products. In either case, graphitization or pitting, the end result is the same; a cavity will develop in the pipe wall.

Because of the tightly adhering nature of graphitic corrosion products, graphitized pipe is capable of containing significant pressure even when corrosion has fully penetrated the pipe wall (Romanoff, 1957; Smith, 1963). Although this is a desirable property, it cannot be relied upon as an engineering property. The brittle nature of graphitic corrosion products result in the graphitized pipe being susceptible to failures from stress caused by such factors as surges, freeze/thaw, expansive soils, temperature changes, and vehicular loading. Reclamation is not aware of any graphitization failures on any ductile iron pipe designed by Reclamation.

Microbiologically influenced corrosion occurs due to the presence and activity of bacteria in anaerobic conditions. This type of corrosion generally occurs under disbonded coatings at pipe surface locations that are blocked from adequate cathodic protection current, and could be a concern under PE encasement, especially in high sulfate soils. Reclamation is not aware of any MIC failures on any Reclamation-designed projects.

In summary, both steel and ductile iron pipes are vulnerable to corrosion when buried. They corrode at approximately the same rate when exposed to the same conditions, and the corrosion experienced is highly dependent on the corrosion characteristics of the soil and/or stray currents.

3.3 Corrosive Soil Determination

The corrosion of metal pipe buried in soil is an electrochemical process. The more easily electricity is conducted in the soil, the more corrosive the soil will be. Stated conversely, soils with high resistivity are less corrosive. Therefore, the potential of soils to provide a ready path for corrosion can be determined by field measurements to evaluate the soil resistivities. However, field measurements will only give an indication of corrosion characteristics for in situ soil conditions at the time the readings were taken. The worst case for determining the corrosion characteristics of any soil would involve a laboratory test with the soil sample saturated. Therefore, when using field measurements to determine the minimum corrosion requirements for a pipeline, one should understand that these readings may not be the absolute worst corrosion conditions for a given soil, but they are representative of in situ conditions. Also, low resistivities can be an indication of high chloride or sulfate concentrations. The relative corrosion rate at differing soil resistivities has been studied over the years by many organizations and many criteria have been developed to portray the amount of corrosion that can be expected to occur over the life of a project based on soil resistivity. Examples of the different evaluations of the relationship between soil resistivity and corrosivity are shown in table 3. Reclamation has chosen to use the in situ field measurements because we believe these readings more accurately reflect the conditions the pipeline will encounter.

One of the correlations that can be made from the criteria in table 3 is that soils with resistivities less than 1,000 ohm-cm are classified as very corrosive conditions and that most users classify soil resistivities less than 2,000 ohm-cm as severe corrosion conditions. The fact that some organizations believe 3,000 ohm-cm or less indicate corrosive conditions illustrates there is still debate in the industry as to what soil conditions constitute a severely corrosive environment.

In the 1970s, Reclamation developed the idea of using the soil resistivity with a 10 percent probability of occurring along the pipeline alignment as the design resistivity. This prevents a few erroneous test results from requiring an entire pipeline to meet more stringent corrosion requirements and also assumes that in a worst-case scenario, only 10 percent of the pipeline would be subject to a higher corrosion rate than expected.

The Ductile-Iron Pipe Research Association's (DIPRA) original 10 point system (circa 1970s) is an example of how some criteria for corrosion rates have been developed to take into account other environmental factors in addition to soil resistivity. The 10 point system also evaluates pH, reduced oxygen (redox) potential (aerobic or anaerobic), sulfides and moisture content. Each

Table 3.—Corrosivity Related to Soil Resistivity

Source	Soil Resistivity Range (ohm-cm)	Corrosivity
NACE Publication 10A292 Technical Committee Report, NACE Task Group T-10A-21	Below 500 500-1,000 1,000-2,000 2,000-10,000 Above 10,000	Very corrosive Corrosive Moderately corrosive Mildly corrosive Progressively less corrosive
RUSTNOT[1] (Consultant)	0-1,000 1,000-3,000 3,000-5,000 5,000-10,000 Over 10,000	Extremely Corrosive Very Corrosive Corrosive Moderately Corrosive Mildly Corrosive
Bureau of Reclamation (Paint Manual)	0-1,000 1,000-5,000 5,000-10,000 Over 10,000	Very Corrosive Moderately Corrosive Mildly Corrosive Slightly Corrosive
American Water Works Association (AWWA) AWWA - M11 Steel Pipe Manual	0-2,000 2,000-4,500 4,500-6,000 6,000-10,000	Bad Fair Good Excellent
Department of Defense (DOD) Unified Facilities Criteria (UFC 3-570-06) (Army, Navy, Air Force)	0-10,000 Over 10,000	Corrosive Less Corrosive

[1] Spickelmire, B., July 2002. "Corrosion Considerations for Ductile Iron Pipe," *Materials Performance,* pp. 16 – 23.

factor is given a numerical rating and if the total adds up to 10 or greater, some form of corrosion protection is required. The AWWA has adopted the DIPRA 10 point system, and the AWWA C105 table outlining the 10 point system is shown in table 4.

**Table 4.—AWWA C105 Appendix A
Soil Test Evaluation**

Source	Soil Characteristics	Points[1]
Resistivity – ohm-cm (based on a single probe at pipe depth or water saturated soil box)	0-700 700-1,000 1,000-1,200 1,200-1,500 1,500-2,000 Over 2,000	10 8 5 2 1 0
pH	0-2 2-4 4-6.5 6.5-7.5 7.5-8.5 Over 8.5	5 3 0 0[2] 0 3
Redox potential	Over +100mV +50 to +100 mV 0 to +50 mV Negative	0 3.5 4 5
Sulfides	Positive Trace Negative	3.5 2 0
Moisture	Poor drainage, continuously wet Fair drainage, generally moist Good drainage, generally dry	2 1 0

[1] Ten points means that the soil is corrosive to gray or ductile iron pipe; protection is required.
[2] If sulfides are present and low or negative redox potential results are obtained, three points shall be given for this range.

The theory behind the DIPRA 10 point system is that even if the soil resistivities are relatively low, there will be no corrosion if the soil properties are not corrosive to metal, although soils with resistivities less than 700 ohm-cm would automatically require corrosion protection. The moisture conditions around the pipe should also be considered. If the soil stays dry all of the time, there will be no pipe corrosion. However, any pipeline can leak, and soil moisture conditions can change over time. So the assumption of a dry soil condition around the pipe is usually not valid.

The DIPRA 10 point system was developed in the early 1970s. Since that time, expanded tables have been developed to cover even more soil properties (e.g., chlorides) as well as stray current potential, service life, type of system (transmission or distribution), pipe size, and hydraulic transient pressures. While all of these factors are important in the development of a pipeline corrosion strategy, these tests can be cost intensive for long pipe alignments and very much subject to judgment or interpretation as to which point values should be assigned. Also, collecting and testing individual soil samples along a long pipeline alignment will likely miss some of the soils that have corrosive characteristics. For these reasons it seems logical to use soil resistivities as the basis for corrosion design of a pipeline. These surveys cover the entire alignment and provide specific information as to the potential for corrosion.

After reviewing the above assessments of soil corrosivity, Reclamation has concluded that even in the absence of other corrosion factors, any pipeline installed in environments with soil resistivities less than 2,000 ohm-cm should be protected with the most comprehensive corrosion protection system available for each pipe option. Reclamation has also concluded that other corrosion factors (e.g. stray currents, soil pH, soil or groundwater chlorides or sulfides, and redox potential) warrant consideration in designing the corrosion protection system for all pipelines, including those installed in less corrosive soils (e.g. soil resistivities greater than 3,000 ohm-cm).

3.4 Typical Corrosion Mitigation Methods

3.4.1 Bare Pipes

Buried metallic pipelines have the potential to corrode and typically require corrosion protection. Without a protective coating the remaining corrosion protection alternative is CP. A bare pipe can be adequately protected with a CP system; however, the amount of current required to protect a bare pipeline is significantly greater than the amount of current required to protect a well-coated pipeline. The larger current requirement results in a larger number of CP ground beds (locations at which the protective current is injected into the ground) which increases the design, installation, operation and maintenance, and power requirement costs associated with the CP system. Bare pipes may provide the lowest initial capital costs, but could also have the highest maintenance costs. Keeping the CP system functioning properly for bare pipes is absolutely essential due to the lack of protective coating.

Because of the inherent potential for metal pipes to corrode, Reclamation practice is to use some form of encasement or bonded coating, as well as corrosion monitoring, on all metallic pipe, even in high resistivity soils.

3.4.2 Polyethylene Encasement

Polyethylene encasement is a dielectric coating which is not bonded to the underlying metallic surface. Because this type of coating is not bonded to the exterior surface of the pipe, it is considered to be an encasement rather than a true coating. Any damaged area or discontinuity in a coating or encasement that exposes the underlying metallic surface to the corrosive environment is called a holiday.

Polyethylene encasement provides better protection than bare pipe, and is relatively inexpensive when compared to bonded dielectric coatings.

No PE encasement will be holiday free. Holidays within the PE encasement can occur during manufacturing, installation, and/or deterioration with time. At holidays, the pipe wall is exposed to the soil, and in the presence of moisture, corrosion will occur as governed by the corrosion characteristics of the soil. As the number of holidays increases, a correspondingly larger amount of current is required for CP.

Cathodic protection on PE encased ductile iron pipe is a controversial issue. The concern is that CP will not be able to protect, and monitoring will not be able to detect, areas of corrosion away from the holidays.

The Department of Transportation does not allow PE encasement on petroleum pipelines, and has required bonded dielectric coatings since 1970 for all soil resistivities[2]. Opinions on the use and effectiveness of PE encasement within the water industry vary.

3.4.3 Bonded Dielectric Coatings

A bonded dielectric coating tightly adheres to the surface on which it is applied. Common bonded dielectric coatings are epoxies, tape wraps, and polyurethanes. Bonded dielectric coatings can be and have been successfully applied to both steel and ductile iron pipe (Szeliga et al., 1993; Garrity et al., 1989; Pimentel, 2001; Brander, 2001; Lieu and Szeliga, 2002; Fogata, 2003). AWWA M41 – Ductile Iron Pipe and Fittings (1996, revised 2003), lists bonded dielectric coatings as an alternative corrosion mitigation method for ductile iron pipe. Coatings similar to those applied to steel pipe can be applied to ductile iron pipe; however, surface preparation guidelines for steel pipe generally cannot be used for ductile iron pipe. In 2000 the National Association of Pipe Fabricators, Inc (NAPF) published a standard for surface preparation for ductile iron pipe and fittings (NAPF 500-03, 2000). Prior to the NAPF standard there were no national standards for the surface preparation of ductile iron pipe and most organizations had to write their own surface preparation and coating specifications. Installed

[2] 49 CFR Part 192.1.

bonded dielectric coatings are not holiday-free; however the number of holidays is usually limited when compared to PE encasement, and will result in lower power costs than PE encasement if CP is required. Bonded dielectric coatings are relatively expensive, but most corrosion engineers believe they provide better corrosion protection than other coatings.

3.4.4 Cement Mortar Coatings

Cement mortar prevents corrosion by providing a passivated environment for the underlying metal. The cement mortar is not always bonded completely with the metal or the coating can crack or experience damage during handling, installing, or backfilling, which may lead to corrosion. However, the use of a coal tar epoxy seal coat on the outside of the mortar creates a coating bonded to the mortar and substantially reduces the number of holidays which penetrate to the underlying metal, thus decreasing the power required for a CP system.

3.4.5 Corrosion Monitoring Systems

Irrespective of the amount of environmental testing that is conducted prior to pipeline design, there is always a potential for a buried pipeline to have corrosion-related problems. If a corrosion-related problem is identified, the corrosion monitoring system allows a means to investigate and address the problem. Without a corrosion monitoring system the options available to identify, investigate, and address corrosion-related problems are limited.

A corrosion monitoring system requires the pipeline to be electrically continuous. Providing this positive electrical continuity on a pipeline will increase the probability of corrosion resulting from stray currents. However, the corrosion monitoring system can be used to investigate, identify, and mitigate long line and stray current corrosion. Reclamation believes the benefits of a corrosion monitoring system far exceed the risks. Reclamation’s position has been and continues to be that all buried metallic pipelines be installed with corrosion monitoring systems.

3.4.6 Cathodic Protection Systems

Cathodic protection is a proven method of mitigating corrosion and is the only corrosion control method which can potentially halt ongoing corrosion of a buried pipeline. Cathodic protection uses a corrosion cell to the benefit of the protected pipeline. With CP the pipeline that is to be protected is made the cathode of the corrosion cell (corrosion does not occur at the cathode). Because there is an operating corrosion cell there must be an anode. Therefore, an anode material must be installed which will be sacrificed for the sake of the pipeline to be protected. It should be noted that corrosion is not stopped, but is transferred from the pipeline that is to be protected to sacrificial material which is installed to be consumed.

Since CP is a corrosion cell, current must flow. As with the corrosion cell, current flows from the anode to the cathode within the electrolyte, and from the cathode to the anode within the metallic path. For pipeline installations the electrolyte is the moisture in the surrounding soil. The metallic path is along the pipeline and the joint bonding cables for the CP system. A pipeline must be electrically continuous for the successful application of CP.

There are two types of CP systems, galvanic anode and impressed current. Both systems require the installation of a sacrificial material as the anode. Galvanic anode CP requires the installation of galvanic anodes. A galvanic anode is a material which is more electro-chemically active than the pipeline to be protected. Galvanic anodes use the natural potential difference between the anode material and the pipeline to cause current to flow. For soil applications zinc and magnesium are typically used as the galvanic anode material. Galvanic anodes are typically installed some distance from a pipeline and connected to the pipeline through cables.

External power is required to supply the current for an impressed current CP system. Any DC type power supply can be used for CP, although a rectifier is typically used. A rectifier converts AC power into DC power. Impressed current requires the installation of anodes and a power supply; the power supply is connected between the pipeline and anodes. Because external power provides the driving force for the CP current (which allows a higher potential to be reached) a wide range of anode materials can be used. Some commonly used impressed current anode materials include high silicon cast iron, graphite, mixed metal oxides, and platinum.

The CP system must be capable of supplying sufficient current to provide adequate corrosion protection. Galvanic anode CP systems are limited in the current which they can provide and therefore are typically used in situations with small current requirements (e.g. smaller pipelines or pipelines with bonded dielectric coatings). Impressed current CP systems can provide a large and variable amount of current and can be used in situations requiring small or large current requirements (e.g. larger pipelines or poorly coated pipelines).

4.0 BURIED STEEL AND DUCTILE IRON PIPE

This section focuses on steel and ductile iron pipe, and includes information on corrosion mitigation and prevention criteria, historical performance, expected service life, and life cycle costs.

4.1 Corrosion Mitigation for Ductile Iron Pipe

Corrosion mitigation methods typically used for ductile iron pipe include PE encasement, bonded dielectric coatings, and/or CP. Ductile iron pipe designs have historically added a service allowance in the pipe design wall thickness as an added factor of safety against corrosion. The wall thickness designs for ductile iron pipe were originally based on the designs for cast iron pipe. Both steel and ductile iron will corrode at approximately the same rate in the same environment. Since ductile iron pipe has a thicker wall than a comparable steel pipe, it will take longer for corrosion to penetrate the wall of a ductile iron pipe than a comparable steel pipe. This phenomenon is one reason pipeline designers have allowed ductile iron pipe to be installed with PE encasement in locations where a comparable steel pipe required the more robust bonded dielectric coating.[3] In recent years, the ductile iron pipe industry has reduced the wall thickness of the pipe based on the superior structural performance characteristics of ductile iron compared to cast iron. So, while the designed service allowance for ductile iron pipe has remained the same for many years, the overall ductile iron pipe wall thickness (when adding wall thicknesses for structural strength and the service allowance) is thinner than the cast or ductile iron pipes previously produced. This reduction in ductile iron pipe wall thickness has raised concerns within the water industry over the longevity of the pipe in corrosive environments.

Ductile iron pipe has also been installed by some water utilities without coatings of any kind (see table 5). This pipe is considered to be "bare."

Various corrosion control method philosophies are currently used by ductile iron pipe users within the U.S. (water utilities), DIPRA, NACE (National Association of Corrosion Engineers), and water utilities outside the U.S. to control corrosion. A brief discussion of the various corrosion control method philosophies are listed below:

- ***U.S. Water Utilities*** – In some instances, water utilities are using corrosion control methods recommended by sources such as DIPRA, NACE, other water utilities and other countries. Other water utilities are creating or adjusting their own corrosion control method philosophies based on historical data and experience from their installed pipelines.

- ***DIPRA*** – The association recommends the use of PE encasement for ductile iron based on extensive historical performance. DIPRA points out that "since 1958, PE encasement has been used to protect millions of feet of cast and ductile iron in thousands of installations across the U.S."[4] Additionally, DIPRA points out that "There has been no instance where the soil evaluation procedure has proved inadequate or faulty in predicting where corrosion protection is needed."[4] DIPRA strongly disagrees with the recent tendency of corrosion engineers who advocate the universal application of joint bonding and the installation of test leads on all pipe systems regardless of soil corrosivity or potential for stray current corrosion. DIPRA asserts that CP is very expensive to install compared to PE encasement. DIPRA asserts that CP can be applied to ductile iron pipe and can be successful under certain circumstances, but is seldom cost effective. In most cases, DIPRA asserts that CP is also unnecessary due to the availability of alternative methods of corrosion control that are equally reliable and less expensive. Additionally, the American Water Works Association (AWWA) has adopted the DIPRA 10 point system for soil assessment for ductile iron pipe in AWWA's C105 publication. In August of 2002 DIPRA announced that the eight leading manufacturers in North America

[3] 49 CFR Part 192.1.
[4] Stroud, T.F., 1988. "Polyethylene Encasement versus Cathodic Protection: A View on Corrosion Protection."

will no longer honor a warranty for ductile iron pipe with any exterior dielectric coating other than polyethylene encasement.[5] In cooperation with DIPRA, Corrpro Companies Inc., prepared a document in 2004, which proposes an updated "Design Decision Model" for corrosion protection of ductile iron pipe. Their report concludes that "Bonded, dielectric coatings are not a cost-effective solution for corrosion protection of ductile iron pipe. . .".[6]

- ***NACE*** – The National Association of Corrosion Engineers (NACE) corrosion control method recommends the use of bonded dielectric coating and, if required, CP for all metallic pipe systems. Individual pipes are joint bonded for electrical continuity to facilitate corrosion monitoring via pipe to soil measurements of electrical potential and, if required, CP. NACE has expressed concern about the performance of polyethylene wrap on ductile iron pipe. For example, NACE International's RP0169-2002 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," requires a bonded dielectric coating for buried pipeline applications and expresses concern that unbonded coatings (PE is considered an unbonded coating) can create electrical shielding of the pipeline that could jeopardize the effectiveness of the CP system.

- ***Water Utilities Outside the U.S.*** – Some countries (European and Japan) employ a combination of coating systems and, if required, CP, for ductile iron pipe. The coating systems can involve a combination of PE wrap, coal tar enamel for outside protection, and zinc coatings. In a corrosive environment, these utilities recommend that both a bonded dielectric coating and CP be used.

4.1.1 Effectiveness of Polyethylene Encasement on Ductile Iron Pipe

Polyethylene encasement was first used on a buried pipeline in the early 1960s. The use of PE encasement within the water industry is controversial. The major controversies related to ductile iron pipe involve the effectiveness of PE encasement as a corrosion mitigation method and the compatibility of PE encasement and CP. It is widely accepted that corrosion on the pipe wall opposite from PE encasement holidays can be mitigated by CP. The technical disagreements generally are focused on the occurrence of corrosion under intact PE encasement and the mitigation of that corrosion by the use of CP.

Below are the more prominent issues that are generally presented by the proponents and opponents of PE encasement.

Proponents of the use of PE encasement indicate that in most corrosive soils, PE encasement alone is the recommended corrosion mitigation technique (AWWA M41, 2003; Kroon et al.,

[5] Infrastructure Preservation News, Vol. 1, No. 2, June 2003. "Assessing DIPRA's New Corrosion Protection Standards."

[6] Kroon, David H., Dale Lindemuth, Sheri Sampson, and Terry Vincenzo, Corrpro Companies Inc., 2004. NACE International, Paper No. 04046, "Corrosion Protection of Ductile Iron Pipe."

2004). However, in uniquely severe environments other corrosion mitigation techniques, such as bonded dielectric coating and/or CP, should be considered (Stroud, 1989). This also includes the use of CP with polyethylene encased ductile iron pipe, where the PE encasement reduces the amount of CP current required (Smith, 1970; Clark, 1972; Stroud, 1989; Lisk, 1997). American Water Works Association (AWWA) C105 "Polyethylene Encasement For Ductile-Iron Pipe Systems" is a national standard which is often referenced as supporting documentation for PE. AWWA C105 covers materials and installation procedures for PE encasement on ductile iron pipe. A non-mandatory appendix in AWWA C105 covers how to determine if corrosive soils are present.

Proponents of the use of PE encasement generally agree with the following:

1. The mechanism of corrosion protection provided by PE encasement is that of placing a dielectric barrier between the pipe wall and soil that causes oxygen starvation within the corrosion cell.

2. Intact PE encasement prevents direct contact between the pipe and soil.

3. The PE encasement is not bonded to the pipe surface and can therefore allow moisture within the annular space between the pipe and PE. The moisture, when present, and its dissolved oxygen will initially result in corrosion on the pipe surface, but once the dissolved oxygen is consumed by the initial corrosion reaction, further corrosion activity will be stifled. The moisture within the annular space, after being devoid of dissolved oxygen, then provides a non corrosive, uniform environment to the pipe surface.

4. The PE encasement retards the transport of dissolved oxygen to and corrosion products away from the pipe surface.

5. Significant exchange of moisture within the annulus is prevented by the weight and compaction of the backfill, which presses the PE encasement against the pipe.

6. Stray current corrosion from external sources is reduced by the dielectric barrier of the PE encasement.

7. Although CP may not be required, polyethylene encased pipe can be successfully cathodically protected.

DIPRA has an inspection program under which they have conducted a number of inspections on operating pipelines with PE encasement. The inspection program indicates that ductile iron pipe is protected with the use of PE encasement (Stroud, 1989). Others have reported that corrosion under undamaged PE encasement is very low (Schiff and McCollom, 1993). A continuation of Schiff and McCollom work indicates that corrosion under undamaged PE encasement has remained low, that the corrosion rate under undamaged polyethylene is an order of magnitude less than that experienced outside the polyethylene within sand backfill, and that CP is effective under undamaged polyethylene (Bell, 2003).

Opponents to the use of PE encasement indicate that the pipe surface opposite holidays in the PE encasement experiences corrosion, pipe surfaces under intact PE encasement experience corrosion between the holidays in the PE encasement, and corrosion occurring under these areas cannot be mitigated by CP (Fitzgerald, 1968; Garrity et. al., 1989; Noonan, 1996; Szeliga and Simpson, 2001; Spickelmire, 2002). The opponents further indicate that corrosion under areas of intact PE encasement cannot be detected by above- ground corrosion monitoring methods (e.g., pipe-to-soil potential surveys) and corrosion under intact polyethylene will go undetected until failure (Szeliga and Simpson, 2003).

Opponents to the use of PE encasement often reference the following three national documents as supporting documentation of their position:

- The NACE International's Recommended Practice RP0169-2002 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems."

- The Code of Federal Regulations (CFR) Title 49 parts 192 and 195 (October 1, 2002) as enforced by the U. S. Department of Transportation's Office of Pipeline Safety.

- The Docket No. OPS-5A (Federal Register Vol. 36, No. 166 – Thursday, August 26, 1971).

Although the three documents noted above were primarily developed for the oil and gas industry, the information contained in them is relevant to this discussion. In fact, RP0169-2002 includes water systems in its recommendations.

The NACE Document RP0169 requires a bonded dielectric coating for buried pipeline applications and indicates that unbonded coatings such as PE encasement can create electrical shielding of the pipeline that could jeopardize the effectiveness of the CP system.

49 CFR 192 and 195 do not allow unbonded coatings as an acceptable corrosion mitigation technique for federally regulated pipelines. Federally regulated pipelines include pipelines which transport natural gas or hazardous liquids (water pipelines are not federally regulated).

In Docket No. OPS-5A, the Office of Pipeline Safety specifically denied a petition to permit the use of PE encasement for cast and ductile iron pipes as an alternative method of corrosion control, and as indicated by 49 CFR 192 and 195, this is the Office of Pipeline Safety's current position.

Pipe corrosion under areas of intact PE encasement has been reported (Szeliga and Simpson, 2003; Spicklemire, 2002; Fogata, 2003). The ductile and cast iron pipelines inspected in San Diego during the CIPRA 1968 and DIPRA 1981 excavations have experienced corrosion-related failures (Fogata, 2003). The San Diego cast iron pipeline was one of the initial installations of PE, installed in 1961, and the soil in which the pipelines were buried is considered very corrosive (DIPRA, 1981). Corrosion and the mitigation of corrosion under disbonded coatings has been a concern within the corrosion industry for a number of years.

In summary, proponents of and opponents to the use of PE encasement agree that corrosion can occur at locations where holidays in the PE encasement expose the pipe wall to the soil and that the resulting corrosion can be mitigated by CP. Proponents and opponents agree that corrosion can take place under areas of intact PE encasement between holidays; however, they do not agree on the severity of corrosion that can take place. The proponents indicate that under most situations the corrosion reaction occurring under intact PE encasement will be reduced over time and significant corrosion does not occur. The opponents argue that 100 percent intact PE encasement is not feasible, that the corrosion reaction under intact PE encasement is not reduced over time, that significant corrosion can occur, and that CP can not be used to mitigate the corrosion.

Backfill aggregate size and type can be very important in determining the effectiveness of PE encasement with regard to reducing corrosion and CP costs. The use of large diameter angular gravel as backfill can lead to perforations in the PE encasement and should be avoided. See appendix F.

Both successful and unsuccessful applications of PE encasement on ductile pipe without CP have been reported, although most installations with both PE encasement and CP seem to be performing satisfactorily. It should be noted, however, that the nature of the corrosion experienced on cast and ductile iron pipe is such that the recognition of corrosion related failures is not readily apparent, creating the possibility that corrosion failures may not be fully accounted for. After 40 years of use, there are still basic issues regarding the use of PE encasement for corrosion protection of ductile iron pipe that are unresolved.

4.1.2 Peer Review of Reclamation's Evaluation of PE Encasement for Ductile Iron Pipe

A Review Panel was convened by Reclamation in March of 2004 to peer review Reclamation's evaluation of the effectiveness of unbonded coatings on metallic pipe. The Panel consisted of two private sector corrosion engineers (G.E.C. Bell, M.J. Schiff & Associates, Claremont, CA; and R.Z. Jackson, CH2M Hill, Sacramento, CA) and a materials scientist from the National Institute of Standards and Technology (NIST). (Y. Cheng, Materials Reliability Division, Boulder, CO). Also included by contract was an independent Panel chair and technical assistant to serve as a referee to incorporate the panelists' comments into a peer-reviewed document (NIST: (C.N. McCowan (Panel Chair) – Boulder; and R.E. Ricker, Metallurgy Division, Gaithersburg, MD)).

The panel peer reviewed a February 2004 draft of an evaluation of corrosion mitigation issues related to ductile iron pipe prepared by Tom Johnson (Reclamation's corrosion engineer until leaving for a position with another agency in February of 2004). A copy of this evaluation which has been updated to include the panel's comments is included in appendix B. The peer review comments were considered and incorporated into Section 8 (Recommendations). The panel was also asked to respond to a series of six questions regarding corrosion protection practices. The six questions and the panel's conclusions are included in appendix D. Reclamation's responses to the panel's input are included in appendix A.

4.2 Corrosion Mitigation for Steel Pipe

Corrosion mitigation measures typically used for steel pipe differ from those used on ductile iron pipe in recognition of the differing material properties of the two materials. The different material properties of steel allow steel pipes to be designed with much thinner walls than comparable ductile iron pipes. When a service allowance is added to the ductile iron pipe wall thickness (which has not historically been added to the steel pipe wall thickness), the difference in wall thicknesses between the two pipe options becomes even larger. Because both steel and ductile iron corrode at similar rates in similar soil conditions, corrosion will penetrate the thinner walls of a steel pipe more quickly than the thicker wall of a ductile iron pipe. This has led Reclamation and other water utilities, as well as corrosion consultants, to adopt more aggressive corrosion protection measures for steel pipe.

Steel pipes have been installed with dielectric coatings such as, epoxies, tapes, and polyurethane. Bonded dielectric coatings adhere to the metallic pipe surface and have a high resistance to electric current flow.

Cement mortar has also been used as a coating for corrosion protection on steel pipe. According to AWWA C205 (Cement mortar Protective Lining and Coating for Steel Water Pipe - 4 in. and Larger - Shop Applied), "bond or adhesion" exists between the cement mortar coating and the steel cylinder.

For the purposes of corrosion protection, the cement mortar coating provides a reservoir of alkalinity, thus passivating the steel provided intimate contact exists between the mortar and the steel. Without a coal tar epoxy seal coat, the cement mortar coating is porous, thereby allowing the ingress of moisture and dissolved salts during wetting and drying cycles. If the cement mortar coating does not have a coal tar epoxy seal coat, it is considered to be no more or no less effective than PE encasement on ductile iron pipe in reducing corrosion.

Cathodic protection has been applied to steel pipe in corrosive environments with bonded dielectric or mortar coatings. Standards for cement mortar coatings and bonded coatings on steel pipe are covered by AWWA. To the best of Reclamation's knowledge, the use of PE encasement as a corrosion protection system over bare steel pipe is not recommended by any national standard. Reclamation has not used this approach for corrosion protection of its buried steel pipe, and none of the water utilities surveyed indicate that they have used this method.

4.3 Corrosion Prevention Criteria

4.3.1 Previous Reclamation Guidelines

The corrosion criteria and requirements updated on April 23, 2003 are shown in table 1. Table 1 contains recommended corrosion mitigation measures for various pipe alternatives and various soil conditions. The table's recommended methods of protection include some measure of protection for all metallic pipe and more aggressive protection measures for more corrosive environments.

Within Reclamation, the type of coating and CP requirements for buried pipelines are based on the material properties of the pipe and soil resistivity. The corrosion prevention criteria and requirements are guidelines used by Reclamation when making corrosion prevention recommendations for buried pipeline alternatives. The design recommendations in the table are based only on the 10-percent probability value of soil resistivity. It should be noted that other parameters such as performance history and stray current exposure for a given route, criticality of the pipeline, conservatism employed in the design, and specific client requests should be considered when determining corrosion prevention requirements for a specific pipeline.

Reclamation's standard practice was to use the criteria and requirements to determine the appropriate methods of corrosion protection of buried pipelines designed by Reclamation which remain in Federal ownership. The criteria and requirements were not intended to be a rigid requirement, but rather a tool used in formulating the corrosion protection scheme on a particular pipeline. The specified corrosion prevention requirements for a particular pipeline should be developed by a corrosion engineer working directly with the pipeline designer.

For ductile iron pipe, the table includes options to use PE encasement or bonded dielectric coating. In more corrosive soils, a CP system was recommended to supplement the protection provided by the protective encasement or coating. A footnote was added to the table in the early 1990s which added a recommendation to limit the use of PE encasement to ductile iron pipe 24 inches in diameter or smaller (and 150 lb/ft or lighter). This provision was based on a concern about potential damage to the encasement during installation of larger and heavier pipe.

For steel pipe, the table includes options to use bonded dielectric coating, mortar coating with coal-tar epoxy, or mortar coating alone. As with ductile iron pipe, a CP system was recommended in more corrosive soils to supplement the protection provided by the protective coating.

4.3.2 National Industry Standards

Widely recognized water and corrosion industry standards, such as NACE, AWWA, and the Department of Transportation, are similar in their corrosion prevention recommendations for steel pipe. However, the standards differ widely in the recommended practice for corrosion prevention of ductile iron pipe, mainly with regard to the use of PE.

American Water Works Association (AWWA):

- AWWA M41, "Manual of Water Supply Practices, Ductile-Iron Pipe and Fittings," was issued in 1996 and revised in 2003 and recommends PE encasement for corrosion protection of ductile iron pipe, but acknowledges that alternate methods such as bonded dielectric coatings, among others, may be appropriate in certain circumstances. The standard discusses the use of CP as an economic alternative for corrosion protection. No limitations are placed on the use of PE encasement based on pipe diameter.

- AWWA C105, "Polyethylene Encasement for Ductile-Iron Pipe Systems," was first issued in 1972 and the most current version was issued in 1999. The standard covers materials and installation procedures for PE encasement for ductile iron pipe. A non-mandatory appendix to the standard outlines a 10 point system to be used to determine the need for corrosion protection. The standard does not identify a restriction for the use of PE encasement relative to pipe diameter. The standard states that cuts, tears, punctures, or other damage to the PE encasement shall be repaired, and that care should be taken to prevent damage to the PE encasement when placing backfill.

- AWWA M11, "Manual of Water Supply Practices, Steel Pipe – A Guide for Design and Installation," was first issued in 1964 with the current version issued in 2004. The chapter on coatings and linings recommends bonded dielectric coatings or cement mortar coating for steel pipe. The manual states that the addition of a corrosion allowance to the steel pipe wall thickness is not an ". . .applicable solution. . .where standards for coating and lining materials and procedures exist." The manual suggests that cathodic protection is widely used by water utilities for corrosion control, and that a coating with high adhesion is required.

National Association of Corrosion Engineers (NACE):

- NACE Publication 10A292 Technical Committee Report, NACE Task Group T-10A-21, "Corrosion Control of Ductile and Cast Iron Pipe", 1992. This publication states that "…polyethylene sleeves are protective *when undamaged*, as are other coatings when undamaged", and does not mention any limitation on the use of PE encasement based on pipe diameter. It also states that "joint bonding is necessary for electrical continuity if CP is considered."

- RP0169 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems" manual is a recommended practice first issued in 1969 with the most current revision issued in 2002. This manual states that "Pipeline external coating systems shall be properly selected and applied to ensure that adequate bonding is obtained. Unbonded coatings can create electrical shielding of the pipeline that could jeopardize the effectiveness of the cathodic protection system."

American Society for Testing and Materials (ASTM):

- A674-00 "Standard Practice for Polyethylene Encasement for Ductile Iron Pipe for Water and Other Liquids." This document has an appendix similar to AWWA C105 discussing the 10 point system. The standard does not identify a restriction for PE encasement relative to pipe diameter. The standard states that any rips, punctures, or other damage to the PE encasement should be repaired with adhesive tape or with a short length of PE tubing cut open, wrapped around the pipe, and secured in place. The standard also states that special care should be taken to prevent damage to the PE wrapping when placing backfill.

4.3.3 Water Utilities Criteria

Reclamation conducted an informal survey of several water utilities to determine the criteria they use for corrosion protection of their steel and ductile iron pipelines. Approximately 10 water utilities across the United States were interviewed including the City of Aurora (Colorado), City of Houston (Texas), City of San Diego (California), Denver Water (Colorado), East Bay Municipal Utility District (Oakland, California), Huntsville Utilities Water Department (Alabama), Los Angles Department of Water and Power (California), Newport News Waterworks (Virginia), Seattle Public Utilities (Washington), and Washington Suburban Sanitary Commission (Maryland). Of major interest was the relationship of soil resistivities or other criteria for pipe corrosion protection measures such as PE encasement, tight bonded coating systems including dielectric coatings, and/or cathodic protection. If available, the water utilities' corrosion criteria for steel and ductile iron pipe was requested during the survey. In some instances, the water utilities employed general procedures rather than specific corrosion guidelines. For example, some water utilities based their corrosion criteria on the purpose of the pipeline, such as whether the pipeline is used for transmission or distribution of water.

According to some water utilities' philosophies, transmission pipelines are more critical than distribution pipelines. Generally, a transmission pipeline provides water to one or more distribution pipelines and typically serves a greater number of water users. The distinction between transmission and distribution pipelines was characteristically based on pipe diameter and the number of water users serviced. Distribution pipelines were smaller pipe diameters, usually less than 24 inches, which served a limited number of water users. According to some water utilities, transmission pipelines required greater consideration and study with respect to corrosion during the design phase given the number of water users serviced.

Additionally, the Department of Defense Unified Facilities Criteria (UFC 3-570-06) dated January 31, 2003 are used jointly by the Departments of the Army, Navy and Air Force. The Unified Facilities Criteria (UFC) system is prescribed by MIL-STD 3007 and provides planning, design, construction, sustainment, restoration and modernization criteria. The UFC applies to the Military Departments, the Defense Agencies and the Department of Defense Field Activities. U.S. Army Corps of Engineers (USACE), Naval Facilities Engineering Command (NAVFAC) and Air Force Civil Engineer Support Agency (AFCESA) are responsible for administration of the UFC system.

A summary of the survey results is shown in table 5.

4.3.3.1 Survey Results

The survey results indicated varying philosophies for corrosion protection of ductile iron pipelines by water utilities. The corrosion protection philosophies were based on individual historical experience, DIPRA and NACE philosophies or a combination of all three.

4.3.3.2 Ductile Iron Pipe Survey Results

A true consensus was not evident with respect to ductile iron corrosion protection measures for the various water utilities surveyed. Water utilities' ductile iron pipeline corrosion protection criteria included the following range of positions:

- Use of DIPRA's / AWWA's 10 point system for evaluation of corrosion, including the use of PE encasement if required.

- Use of DIPRA's / AWWA's 10 point system with restrictions. For example, the use of DIPRA's / AWWA's 10 point system for distribution pipelines only, and the use of a NACE philosophy (tight bonded coating system and/or cathodic protection) for transmission pipelines.

- Use of a NACE philosophy (tight bonded coating system and/or cathodic protection) for the evaluation of corrosion for all pipelines. The use of PE encasement is not recommended.

- Development and use of a corrosion protection measure based on a combination of individual historical experience, pipeline purpose (transmission or distribution pipeline), and DIPRA and NACE philosophies.

Table 5.—Survey Summary of Water Utilities

Utility	Corrosion Criteria – Ductile Iron	Polyethylene Encasement (PE) – Ductile Iron	Tight Bonded Coating – Ductile Iron	Cathodic Protection (CP) – Ductile Iron	Corrosion Criteria – Steel	Tight Bonded Coating – Steel	Cathodic Protection (CP) – Steel
DOD – Unified Facilities Criteria (UFC 3-570-06) (Army, Navy, Air Force)	Yes for soils < 10,000 ohm-cm; NACE RP0169 is cited; When soil resistivities are above 10,000 ohm-cm bonded joints only	No discussion on PE encasement	Yes, NACE RP0169 is cited	Yes for soils < 10,000 ohm-cm; NACE RP0169 is cited; When soil resistivities are above 10,000 ohm-cm bonded joints only	Corrosion control by coating supplemented with cathodic protection or by some other proven method. Unless investigations indicate corrosion control is not required	Yes, NACE RP0169 is cited	Yes
City of Aurora	Uses AWWA/DIPRA 10 pt system; Ductile iron may be used in soils > 1,000 ohm-cm; For soils < 1,000 ohm-cm, PVC is used; > 10 pts uses PVC	Yes, all ductile iron; 8 mils; Satisfied with PE encasement	No	Yes, based on the size of the pipe and type of soil in which it is laid. CP for > 12" with PE	Performs actual NACE design	Three layer tapecoat 80 mil Polyken YG-III	Yes, impressed current
City of Houston	Project-by-project corrosion assessment; CORRPRO; NACE approach	Yes, unless CP is provided	Yes, polyurethane 25 mils; Bonded epoxy for fittings	Yes, unless PE is used	Project by project corrosion assessment; CORRPRO; NACE approach	Yes, tape coating 80 mils; Cement mortar, poly-urethane 25 mils	Yes, impressed current
City of San Diego	Cathodic protection on every pipeline.	NO PE. DIPRA test site (24-inch, installed in 1967) has had failures and is no longer listed in DIPRA literature. The PE has deteriorated in some places. DIPRA had no explanation. They have had several failures under intact PE encasement	Yes, 24 mil coal tar or wax tape system. According to 1999 Spec - Polyurethane 25 mils; Fusion bonded epoxy 14 mils; Coal tar enamel	All lines are cathodically protected. Impressed current and sacrificial anodes	Cathodic protection on every pipeline	Tape wrap since 1990; Coal tar enamel; Fusion bonded epoxy; Polyurethane 25 mils; Same for fittings	Yes, impressed current and sacrificial anodes
Denver Water	Soils < 1,000 ohm-cm use plastics unless local water district requires ductile (if below 1,000 ohm-cm require cathodic protection on polyethylene encased ductile iron)	Yes, standard on all DI; Satisfied, no problems since 1980 so far	No	Yes if below 1,000 ohm-cm; Sacrificial anodes; Since late 1980s to early 1990s; No corrosion problem	Tight bonded coating and CP always	Yes - always; Polyken YG-III; Satisfied; Fittings Polyken YG-III and wax tape	CP - always; Required for steel; Since mid 1960s; No problems; Limited leakage
East Bay Municipal Utility District	None. Uses steel pipe with tight bonded coating and cathodic protection now	Yes, for ductile iron pipelines—the pipe, valves, fittings, and appurtenances shall have PE encasement. Primarily at test site; No followup	Would consider it if ever specified ductile iron	Yes for one ductile iron line (12"); Since 1980; No problems noted	Soils < 1,000 ohm-cm highly corrosive; Soils > 2,000 ohm-cm although supporting corrosion are relatively slower acting as resistivity increases	Yes, cement mortar with PE encasement special cases (Stray current, pH, etc.), extruded plastic, tape wrapped plastic, coal tar enamel	Yes, benefit to cost of 24 to 1 for CP on steel pipeline; CP on PE encased mortar coated steel
Huntsville Utilities Water Department	DIPRA Soil Testing Program; Asphaltic coated ductile iron; Polyethylene where necessary; Polyethylene encasement if in corrosive or low pH soils	Polyethylene encasement if in low pH soils (< 5). Asphaltic DI for most part	No	No	None	No tight bonded coating on old steel line—line is being replaced	No

Table 5.—Survey Summary of Water Utilities

Utility	Corrosion Criteria – Ductile Iron	Polyethylene Encasement (PE) – Ductile Iron	Tight Bonded Coating – Ductile Iron	Cathodic Protection (CP) – Ductile Iron		Corrosion Criteria – Steel	Tight Bonded Coating – Steel	Cathodic Protection (CP) – Steel
Los Angles Department of Water and Power	Developed a water service map based on corrosion test sites and survey	Yes, standard practice. From a practical standpoint, it is hard to install PE on ductile iron without damage	One case of ductile iron with dielectric coating near a subway	One case of cathodic protection		Tight bonded coating and CP required on all steel pipes	Yes, use steel with dielectric coating with cement mortar rock shield and CP for hilly and high pressure areas. Coal tar enamel and extruded polyolefin coatings	Yes, standard for steel pipe with dielectric coating. Also used in hilly and high pressure areas. Use both impressed and sacrificial anodes. Satisfied with CP
Newport News Waterworks	General procedures: Distribution main < 16" exclusive DI; Use 10 pt DIPRA system. PE and forget it (passive corrosion protection PE encasement). Transmission lines > 16" NACE process is followed and an active corrosion protection system is used	Yes, since 1972	Tight bonded coatings on ductile iron depending on route corrosivity; High quality bonded dielectric coating - Polyken's 80 mil YGIII coating. In the ground 10 to 15 yrs limited inspection; Craftsmanship key; Weather sensitivity an issue	Yes on large transmission lines ≥36"		Stopped using steel 10 yrs ago	Epoxy	Yes
Seattle Public Utilities	Old criteria were to use corrosion protection multilayer polyethylene tape coating for DI in soils < 2,500 ohm-cm. 80 mils according to standard specifications; New criteria require thermoplastic coated ductile iron with fusion bonded coated fittings 25 to 30 mils; Also uses polyurethane coating now. As soil resistivities increase, 8 mil PE encasement is used in conjunction with bonded joints and sand backfill.	As soil resistivities increase, 8 mil PE encasement is used in conjunction with bonded joints and sand backfill. This combination is used as an intermediate point for corrosion prevention.	New criteria require thermoplastic coated ductile iron with fusion bonded coated fittings 25 to 30 mils; Also uses polyurethane coating now; Old criteria required multilayer poly-ethylene tape coat 50 to 80 mils; Fittings coatings - tape wrap and epoxy coating	Yes		Not available	Yes - tape wrap coating; In ground approximately 10 yrs	Yes; Some pipelines are just monitored; CP in the ground approximately 10 yrs. The frequency of leaks has diminished (becoming lower as CP was applied)
Washington Suburban	Yes, own point system based on pH, chlorides, redox potential, soil description, soil resistivity; if >15.5 pts., severe corrosion	Yes for ductile iron <30"; Project by project	Ductile iron >30"; Bonded dielectric (epoxy, tape) liquid epoxy, polyurethane	Yes, sacrificial		Tight bonded coating and CP always	Dielectric coated steel, coal tar enamel; Polyken YG-III; Same for fittings	Yes, always use CP for steel

Soil resistivity data is being used by some utilities to evaluate corrosion potential. Soil resistivity limits for specific corrosion protection measures for ductile iron pipelines varied considerably between water utilities. Examples of the criteria used are shown below:

- If soil resistivity is below 10,000 ohm-cm, protective coatings and cathodic protection are recommended.
- If soil resistivity is below 2,500 ohm-cm a tight bonded coating system is recommended. As soil resistivities increase, 8 mil PE encasement is used in conjunction with bonded joints and sand backfill. This combination is used as an intermediate point for corrosion prevention.
- If soil resistivity is below 1,000 ohm-cm, the use of PVC instead of ductile iron pipe is recommended.
- If soil resistivity is below 1,000 ohm-cm, PE encasement and CP is recommended.
- A tight bonded coating and CP are required for every pipeline as a standard practice regardless of soil resistivity.
- Every pipeline is required to have PE encasement as a standard practice.
- Specific corrosion protection measures are performed on a project-by-project basis using NACE philosophy.
- Ductile iron pipe is not used, regardless of soil conditions.

Specific corrosion prevention measures for ductile iron pipelines used by the surveyed water utilities included but were not limited to:

- Ductile iron pipe with asphaltic coating provided by the manufacturer only.
- Ductile iron pipe with PE encasement.
- Ductile iron pipe with PE encasement and CP.
- Ductile iron pipe with tight bonded coating system.
- Ductile iron pipe with tight bonded coating system and CP.

4.3.3.3 Steel Pipe Survey Results

For steel pipelines a general consensus was readily apparent and was primarily based on the NACE philosophy. The NACE philosophy is based on the use of tight bonded coating systems and cathodic protection. For example, water utilities' steel pipeline corrosion protection philosophies were:

- Use of a NACE philosophy (tight bonded coating system and/or CP) for corrosion prevention measures.

- Use of a cement mortar coating system and PE encasement, with CP, for corrosion prevention measures.

Soil resistivity data is being used by some utilities to evaluate soils. Soil resistivity limits for specific corrosion protection measures for steel pipelines varied from water utility to water utility, as demonstrated by the example criteria shown below.

- Corrosion control using coating supplemented with CP unless investigations indicate corrosion control is not required.

- Every steel pipeline is subjected to tight bonded coating and CP as a standard practice regardless of soil resistivity.

- Soil resistivity < 1,000 ohm-cm is considered highly corrosive. Tight bonded coating and CP is recommended.

- Specific corrosion protection measures are performed on a project-by-project basis using NACE philosophy (tight bonded coating system and/or CP).

Specific corrosion prevention measures for steel pipelines used by the surveyed water utilities included but were not limited to:

- Steel pipe with tight bonded coating system.

- Steel pipe with tight bonded coating system and CP.

- Steel pipe with cement mortar coating and PE encasement, with CP.

- No water utilities surveyed allowed PE encasement on bare steel pipe.

- Steel pipe is not used, regardless of soil conditions.

4.4 Historical Performance

A technical review of available reports and data was performed on historical performance (i.e. breaks/mile/year) of steel and ductile iron pipes. Reclamation, American Water Works Association Research Foundation (AWWARF) and other sources were investigated for available reports and data.

4.4.1 Summary of Reports and Data Reviewed

The following reports and data were examined:

- *Bureau of Reclamation Report Number: R-94-12 - Historical Performance of Buried Water Pipe Lines by Kurt von Fay and Michael Peabody; September 1994.*

  The results of Reclamation's report No: R-94-12 are shown in table 6. Reclamation and AWWARF steel and ductile pipe data were examined through a formal survey. A detailed breakdown of Reclamation and AWWARF data is also included in table 6. Historical performance of a particular pipe type is quantified by the number of failures/mile/year. Failures are defined as corrosion, external damage, fish mouth, installation damage, or other or undetermined, which required some type of action after installation to correct a pipe deficiency – namely repair, replacement or both.

  Reclamation's data for steel and ductile iron pipe were 0.0545 and 0.000 failures per mile per year, respectively. AWWARF's data for steel and ductile iron pipe were 0.0064 and 0.0179 failures per mile per year, respectively. The combined data for Reclamation and AWWARF for steel and ductile iron pipe were 0.0340 and 0.0175 failures per mile per year, respectively.

- *National Research Council of Canada – A-7019.1 Final Water Mains Breaks Data on Different Pipe Materials for 1992 and 1993, by B. Rajani, S. McDonald, G. Felio; 1995.*

  The results of this report are shown in table 6. This report presents data collected on water main breaks during 1992 and 1993 from 21 Canadian cities. The results of the 1995 National Research Council of Canada Report indicated ductile iron has an average 0.15 breaks/mile/year (9.5 breaks/100 km/year), asbestos-cement pipe average break 0.093 breaks/mile/year (5.8 breaks/100km/year) and PVC average 0.01 breaks/mile/year (0.7 breaks/100km/year). Steel pipe was not studied in this report. The age of the water mains and the cause of the breaks were not included in this study.

- *AWWARF No. 90677 – Distribution System Performance Evaluation by A. Deb, Y. Hasit, F. Grablutz; October 1995.*

  The results of this report are shown in table 6. The objectives of this report were to identify and define distribution system performance criteria and measures, develop procedures to evaluate distribution systems performance using performance measures, and develop guidelines for utility managers to (1) evaluate the overall condition of their distribution systems, (2) establish target levels of performance and (3) identify system improvements needed to achieve these target levels. Based on the analysis of data from various water systems, the following goals for water main breaks and leakage are recommended:

  - Main breaks – no more than 0.25 to 0.30 breaks/mi/year (0.16 to 0.19 breaks/km/year).

  - Water leakage – no more than 4,000 to 6,000 gal/d/mi (9.6 to 14.4 m^3/d/km)

  Water main breaks are defined as water transmission or distribution pipeline breaks. Typically, service connections to the water user from the water main are not considered to be water mains.

  When the performance measures for water main breaks are exceeded, possible action scenarios would include rehabilitation of the water main, replacement of the water main, a leak repair program, an external corrosion control program, and/or an internal corrosion control program.

  The main break recommendation of 0.25 to 0.30 breaks/mi/year (0.16 to 0.19 breaks/km/year) in the study was for all pipe types, both metallic and non-metallic. The various pipe materials such as steel and ductile iron were not specifically identified in this report.

- *EPA 600/R-02/029 Decision-Support Tools for Predicting the Performance of Water Distribution and Wastewater Collection Systems; 2002.*

  This report summarizes the Environmental Protection Agency's efforts to identify and describe European practices that managers are using to make rehabilitation decisions (performance indicators) and the non-hydraulic models for predicting failures and managing and optimizing the operation and maintenance of water distribution and wastewater collection systems. Additionally, this report recommends a conceptual framework for developing a standardized national database that could maintain performance indicators related to pipe failures, their causes, repair costs and other important factors. The proposed modeling efforts would require performance indicators such as pipe material, pipe age, section length, number of breaks or bursts, and diameter.

4.4.2 Interpretation of Historical Performance Data Reviewed

The historical performance data for steel and ductile iron pipe is at best fragmentary as noted by EPA's document described above and as shown in table 6. Reclamation's failures/mile/yr for both steel and ductile iron pipes are shown below as well as the AWWARF guidelines and the National Research Council of Canada values for ductile iron pipe.

The data is somewhat limited in the Reclamation study. For example, Reclamation's ductile iron data is limited to a total length of 15,794 feet (about 3.0 miles). Reclamation began using ductile iron pipe in the late 1970s. Conversely, Reclamation has used steel pipe in above-ground installations since the mid 1920s (Specification No. 361, dated October 20, 1924) and in buried installations since 1940 (Specification, Number 1420-D, dated September 11, 1940).

The 1995 National Research Council of Canada study did not examine steel pipe. Ductile iron pipe, as well as other pipe types, was examined and ductile iron had the highest number of breaks per mile per year of the pipe materials examined in their study. However, this study did not collect age data or the cause of the breaks for the pipes examined, so the results may not provide the full performance picture of each pipe type over time.

The 2002 AWWARF No. 90677 report did not provide a distinction between pipe materials in their study. The value cited by AWWARF is a guideline or a benchmark for assessing the performance of a water utility.

4.4.3 Historical Performance Conclusions

Data on the historical performance of steel and ductile iron pipe is somewhat limited. As pointed out in EPA 600/R-02/029, "Decision-Support Tools for Predicting the Performance of Water Distribution and Wastewater Collection Systems," a framework is needed for developing a standardized national database for performance indicators related to pipe failures, their causes, repair costs and other important factors.

Ductile iron pipe has a thicker wall than steel pipe for a given pressure rating. Therefore, the results of the 1994 Reclamation study showing a lower failure rate for ductile iron pipe appears reasonable based on the pipe wall thickness and the age of the installed ductile iron pipelines versus the age of the installed steel pipelines.

Given the limited and somewhat fragmented nature of the available data on failure rates noted above, Reclamation does not believe there is sufficient cause to conclude there is a significant difference in the performance expectations of steel and ductile iron pipe.

Table 6.—Summary of Collected Reports and Data				
Item	Number of Failures	Length (Feet)	Composite Age = Length x Age / Sum (Length)	Failures Per Mile Per Year
Bureau of Reclamation Report Number: R-94-12 Historical Performance of Buried Water Pipelines				
Reclamation Data				
Ductile Iron Pipe	0	15,794	11.0	0.0000
Steel Pipe	277	626,844	42.8	0.0545
AWWARF Data				
Ductile Iron Pipe	23	667,917	10.2	0.0179
Steel Pipe	24	873,374	22.8	0.0064
Combined Reclamation and AWWARF Data				
Ductile Iron Pipe	23	683,711	10.2	0.0175
Steel Pipe	301	1,500,218	31.2	0.0340
National Research Council of Canada - A-7019.1 Final Water Mains Breaks Data on Different Pipe Materials for 1992 and 1993				
Ductile Iron Pipe				0.15 breaks/mile/year (0.095 breaks/km/year)
Other Considerations				
AWWARF Report No. 90677 – Distribution System Performance Evaluation				AWWARF recommends a goal for limits on water main breaks to 0.25 to 0.30 breaks/mile/year (0.16 to 0.19 breaks/km/year) for pipe. Separate goals for water main breaks by pipe material were not discussed in the study.

4.5 Expected Service Life

During the design process the selection of materials or products is generally based on engineering material properties and life cycle expectations. Typically, life cycle design involves the identification of project service life and product service life. However, expected service life of a product should not be confused with economic life. For example, Reclamation typically uses 40 years for economic life, which represents the time for repayment of the project's loans, and at least 50 years for the expected service life of a pipe. This section summarizes Reclamation's findings regarding expected service lives of steel and ductile iron pipe.

4.5.1 Reclamation Information on Expected Service Life

The following Reclamation reports and data were examined:

- *Replacements: Units, Service Lives, Factors, Prepared for U.S. Department of the Interior Bureau of Reclamation and U.S Department of Energy Western Area Power Administration, May 1989.*

  This document summarizes services lives for 13 different types of pipe material when designing pipelines for water conveyance. Steel and ductile iron pipes are included in the 13 different types of pipe. According to this report, steel and ductile iron pipes will have similar service lives. The report also concludes that pipes of all types will give satisfactory service for a period exceeding 50 years if properly installed and protected. Generally, CP is provided on steel and ductile iron pipelines where a corrosive environment is present.

4.5.2 Literature Review on Expected Service Life

The following reports and data were examined:

- *EM-1110-2-2902 U.S Army Corps of Engineers Engineering and Design Conduits, Culverts and Pipes; October 31, 1997.*

  The engineering manual provides discussion on project, economic, and product service lives. The economic service life is typically projected for 50 to 75 years. The product service life for corrugated steel pipe is at least 50 years provided the coating is applied properly.

- *"Ductile Iron Corrosion Factors to Consider and Why," by William Spickelmire; ASCE 2003 Proceedings of the ASCE International Conference on Pipeline Engineering and Construction.*

  This paper provides a discussion of an analysis using a 60-year service life cycle cost for 24-inch steel and ductile iron pipes. The document provides a discussion on the typical forecasted life cycle costs for steel and ductile iron pipelines with corrosion costs factored for a 60-year period.

  Additionally, according to the document, "The life-cycle cost analyses and our experience indicates that ductile iron's heavier wall allows it to outlast steel, given equal corrosion measures in aggressive soils. Conversely, in the most aggressive soils, coated steel with CP will provide a longer life than polyethylene encased ductile iron with or without CP. In aggressive soils, ductile iron with only PE encasement will have a shorter life than cathodically protected ductile iron with either PE encasement or bonded dielectric coating."

- *Toronto Staff Report to Works Committee; Dated September 28, 2001.*

  This document was created to report on the Water and Wastewater Services long-term sewer and water main infrastructure renewal needs. According to this document, "Cast iron water mains were assumed to have life expectancies in a range from about 60 to 100 years, while ductile iron water mains were assumed to have life expectancies in a range from about 50 to 70 years."

- *E-Mail messages from Mike Woodcock (Washington Suburban) to James Keith (Reclamation) 3/11/04.*

  Mike Woodcock works for Washington Suburban as a metallurgist. Several e-mail messages from Mr. Woodcock were received, and excerpts from them are included in appendix C. His comments generally indicated that service life predictions are theoretical in nature because their oldest ductile iron pipe has not been in the ground long enough to establish a service life. He also stated that he expects to see increasing corrosion problems on ductile iron pipe from this time forward.

4.5.3 Conclusions on Expected Service Life

Reclamation has been able to establish statistically-based service life expectations for a wide variety of equipment and pipelines and concluded that steel and ductile iron pipes will give satisfactory service for a period exceeding 50 years. It is likely with the use of CP on steel and ductile iron pipes, the service life will be extended beyond that of pipes with coatings only. The

City of Toronto's Water and Wastewater Services are assumed to have life expectancies in a range from 50 to 70 years for ductile iron water mains. However, it should be noted that according to available documents, ductile iron pipe has only been used in the United States since the 1960s for water transmission and distribution systems.

Based on all of the information obtained, it is reasonable to assume that a minimum anticipated service life for steel and ductile iron pipes of 50 to 70 years is achievable (see table 7).

4.6 Life Cycle Costs

4.6.1 General

Life cycle costs for a pipeline project include initial capital costs as well as periodic operation, maintenance, replacement and energy (OMR&E) costs incurred throughout the economic life of the project. This section of the report provides guidance for Reclamation designers on how to evaluate key OMR&E costs for a pipeline project and how to incorporate differences in those costs for various pipe options into a construction contract through a bid adjustment or other means.

Key components of the OMR&E costs for a pipeline system are costs associated with pumping and cathodic protection systems, the major component being the cost of power required for pumping. Due to differences in manufacturing, ductile iron pipe is typically supplied in slightly larger inside diameters than steel pipe for the same nominal diameter. This larger diameter allows the water within the pipe to flow at a lower velocity reducing hydraulic pressure losses which, in turn, allows the same flow of water to be supplied using less energy to pump the water.

Reclamation designs pipelines to meet the hydraulic performance requirements of each project in the most economical manner practicable. During the design phase of a project, Reclamation evaluates pipe diameters, pumping plant configurations, and hydraulic transient control features to meet the hydraulic performance requirements of the project. Initial capital costs for these features are compared to major operational costs such as energy costs for pumping to obtain the lowest life cycle cost of the pipeline system. This process leads to the most economic combination of pipe diameters along the pipeline's alignment which are included in the construction specifications.

Reclamation's construction contracts contain a provision under which a bidder may substitute other combinations of actual inside pipe diameters (which match the manufacturing techniques of the pipe-type being bid) as long as the proposed combination of pipe diameters meets the hydraulic performance requirements of the project. This contract provision effectively removes any difference in pumping costs between pipe options. Therefore, differences in pumping costs

Table 7.—Service Life Recommendations

Item	Years
Project Service Life	
Reclamation's economic life	40
Army Corps economical analysis	50 to 75
Army Corps major infrastructure projects	100
Product Service Life	
Steel Pipe	
Steel pipe service life exceeds 50 yrs ("Replacements units, service lives, factors", Bureau of Reclamation, FIST)	50
Steel at least 50 yrs for most environments with coatings (USACE)	50
Washington Suburban (Mike Woodcock metallurgist)	
Oldest 30 inch no cathodic protection and coal tar enamel	50 to 60
Oil and gas steel pipes	50 to 100
Ductile Iron Pipe	
Ductile iron pipe service life exceeds 50 yrs ("Replacements units, service lives, factors," USBR, FIST)	50
Toronto Water and Wastewater Division (September 28, 2001)	50 to 70
Life cycle cost from 2003 ASCE Pipe Conference - "Ductile Iron Corrosion Factors to Consider and Why" by William Spickelmire	60
Washington Suburban (Mike Woodcock metallurgist)	
Unwrapped	35
Polyethylene encased pipe	40 to 45
European practices (zinc/aluminum spray coat, epoxy top coat plus polyethylene encasement)	100
Blast clean off magnetite coating and coat with either fusion bond epoxy or coat with extruded polyethylene coating and then add CP	100
Recommendations	
Both products contain approximately the same amount of iron (roughly 95-percent) iron (FE). Therefore, it is expected that both materials will react similarly to corrosive environments.	
Steel	50 to 70
Ductile iron	50 to 70

between pipe options with different inside diameters are not included in this life cycle cost analysis. This section does provide an example of how to estimate costs associated with a cathodic protection system in a construction contract.

Another component of a pipeline project's OMR&E costs relates to the periodic cost of repairs of the pipe over the life of a project. As noted in section 4.4.3 of this report, Reclamation has not found sufficient cause to conclude there is a significant difference in the performance expectations of steel or ductile iron pipe. Since these costs would be very similar for both pipe options, the estimated costs of expected repairs are not included in this life cycle cost analysis.

Another component of a pipeline project's OMR&E costs relates to the replacement of the pipeline itself. As noted in section 4.5.3 of this report, Reclamation has not found compelling data to conclude any significant difference in the anticipated service lives of properly designed, manufactured, installed, and maintained steel or ductile iron pipelines. Since pipeline replacement costs for either pipe option would not be incurred during the economic life of the project, these costs are not included in this life cycle cost analysis.

Cathodic protection OMR&E costs include the costs of energy, replacement costs for the anode beds, and operation and maintenance costs. These costs vary by pipe type, coatings, and other factors. These costs are not normally included in the bid documents.

4.6.2 Impact on Bid Prices

The Federal Acquisition Regulations (FAR) promote full and open competition or maximum practicable competition and "only includes restrictive provisions or conditions to the extent necessary to satisfy the needs of the agency or as authorized by law".[7]

All technically acceptable pipe options are evaluated for use on Reclamation projects. Any practice that eliminates competition has the ability to raise capital costs for a given project. When comparing two material types, one would expect competition among the different pipe material types as well as competition between similar pipe material types. Many factors other than competition will also affect the bid price to the owner and the supplier's price to each contractor. Factors affecting prices include but are not limited to the following: quantity, location, current supply and demand, market fluctuations in raw materials, business overhead and profit, etc. Quantifying the true effects of eliminating a material type from competition would be difficult, but it would be fair to conclude that over time, costs could be expected to increase if only one type of material is allowed to compete for the work.

[7] FAR 2001-15 August 25, 2003 11.002 Policy. (a)(1)(ii).

4.6.3 Life Cycle Cathodic Protection Costs

A comparative project present worth analysis was performed to evaluate annual costs between steel and ductile iron pipe options for a generic pipe system. The initial costs of furnishing and installing pipe and CP systems are usually not included in the life cycle cost study. The time period or service life evaluated was 50 years. The costs included in this evaluation were the following: 20 and 40 year replacement costs of the CP system, annual operation of the CP system, and annual maintenance costs of the CP system.

This study utilized assumptions that would be consistent with typical Reclamation projects. The comparison shown in table 8 is not intended to cover all possible scenarios, but instead to give the reader some indication of the order of magnitude of the costs, and a meaningful comparison for a generic project.

Table 8 - Bid Adjustment Worksheet

Note: This is an example only. Costs will vary greatly depending on the actual requirements of an individual system and appropriate factors applied by the designers.

Pipe System		Units	Factors:		Units
Diameter	36	Inches	Life Cycle	50	Years
Distance	10.00	Miles	Real Interest Rate *	3.50%	Percent
Soil Resistivity	1,500	ohm-cm	Cost of Power	$0.06	/kWh
Average Pressure	150	PSI			

						Pipe Option Bid					
						Ductile Iron Pipe With PE Encasement			Steel Pipe With Dielectric Coating		
Estimated Cathodic Protection Cost/Bed	$	$35,000	/Anode Bed		Beds	2	Beds	$70,000 **	1	Beds	$35,000 **
Present Worth Replacement			PWF		Duration	20	Year	$35,180	20	Year	$17,590
Present Worth Replacement			PWF		Duration	40	Year	$17,680	40	Year	$8,840
Annual Cathodic Protection O&M			Annual	Labor	$20	80	Hours/Yr	$1,600	40	Hours/Yr	$800
				Non Labor				$400			$200
				Total				$2,000			$1,000
			PWA					$46,911			$23,456
Annual Power Requirements			Annual			1835	kWh	$110.10	33	kWh	$1.98
			PWA					$2,582			$46
			Total adjustment			**Totals**		$102,353			$49,932

* OMB Circular #A-94

** Because these costs are included in the bid documents, they are not included in bid adjustment

Table 8 shows an example of how Reclamation might utilize life cycle costs as performance evaluation criteria to award a technically acceptable pipe option. This would result in the best value to the Government over the life of the project, and not just the best value at the time of award.

An economic analysis would need to be performed for each project to see if a bid adjustment was warranted. There are many technical factors that go into the design of a cathodic protection system which in turn affect expected life cycle costs. If warranted, a bid adjustment would take into account the OMR&E costs associated with the cathodic protection system and coatings required for different pipe options used in the specifications.

The costs required for CP depend on the type of pipe and coating selected. A pipe type with a larger surface area of metal will require more current to polarize the metal and provide sufficient corrosion protection. When comparing coatings on steel and ductile iron pipe, the ductile iron pipe with PE encasement requires much more current than steel pipe with a tape wrap coating. Therefore, the ductile iron pipe will usually require additional anode beds to be placed along the alignment as compared to the number of beds required for steel pipe. The costs for the original ground beds will be reflected in the capital cost bid for each pipe alternative. However, the power, maintenance and replacement costs (every 20 yrs) are not currently reflected in the original capital cost of the project.

If warranted, the differences in the identifiable OMR&E costs between steel and ductile iron pipe should be reflected in the contract award decision. This can be accomplished by using OMR&E life cycle costs as performance evaluation criteria when awarding a contract. Appropriate OMR&E present worth costs associated with the pipe type chosen by each bidder would be added to that bidder's "Total for Schedule" to evaluate the 50-year cost of the project. This process would not eliminate competition, but would allow Reclamation to utilize life cycle costs as performance evaluation criteria in awarding contracts. The contract would then be awarded to the bidder which represented the best overall value to Reclamation.

4.7 Peer Review of Reclamation Corrosion Protection Strategy

The review panel that was convened by Reclamation in March of 2004 was also asked to peer review Reclamation's updated Corrosion Prevention Criteria and Requirements. Their specific input on this issue is included in appendix D. On April 6, 2004, Reclamation and the panel developed a consensus on the following key points regarding the corrosion prevention criteria and requirements:

- Steel and ductile iron pipe should be installed with some form of coating. No bare pipe should be allowed.

- All metallic pipe installed should be electrically continuous.

- Soil resistivities are a good indicator of a soil's corrosion potential.
- Other factors in addition to soil resistivities should be evaluated when designing a corrosion protection system. These factors include, but are not limited to, performance history, stray current exposure, pH, sulfates, chlorides, criticality of the pipeline, design conservatism, and specific client requests.
- Polyethylene encasement is not a true coating.
- Polyethylene encasement can be used on ductile iron in less corrosive environments.
- Bedding and backfill can be critical to the successful use of PE encasement.
- The panel has no knowledge of corrosion failures where PE encasement was used in conjunction with CP.
- The panel believes the table suggested by Reclamation may be slightly conservative, but they feel an agency should use whatever corrosion mitigation methods with which it is comfortable.
- The panel believes Reclamation has little choice other than to rely on past experience and establish a conservative guideline that the bureau can consistently follow.
- The panel supports a conservative approach by Reclamation for the design, construction, and monitoring of public sector water projects.
- A bid adjustment for CP should be considered during design.
- The performance of PE encasement on ductile iron pipe is not adversely affected by the diameter of the pipe.

5.0 Buried Concrete Pipe with Steel Reinforcement

The data reviewed for steel and ductile iron pipe during the preparation of this report indicated a need to review the corrosion prevention criteria for concrete pipe with steel reinforcement. Concrete pipe relies on the alkalinity present in concrete or mortar coating to encapsulate the steel in a passivated environment that will prevent corrosion. Intimate contact is required between the steel and the concrete or mortar coating.

Mortar coatings are used to protect the steel rod in pretensioned concrete cylinder pipe and to protect the steel wire in prestressed concrete pipe. Mortar is applied pneumatically to the outside of the pipe as it is spun. Reclamation has required that mortar coated pipe be cathodically protected in corrosive soil conditions since 1990.

Reclamation has experienced corrosion- and cathodic protection-related problems on two major prestressed concrete pipe projects. As a result, Reclamation placed a moratorium on the use of prestressed concrete pipe for Reclamation projects in 1990. This pipe option has therefore been removed from the corrosion table until the issues related to the moratorium have been addressed.

Corrosion problems have also been noted around the country with the use of pretensioned concrete cylinder pipe in corrosive soils. However, the corrosion can easily be controlled with the proper application of CP.

Steel reinforcement encased in high-quality dense concrete (as is the case in reinforced concrete pipe) has long been considered to be well protected from corrosion. In recent years, concerns about concrete's vulnerability to penetration by dissolved salts (chlorides and sulfates) to the depth of the reinforcement led Reclamation to recommend additional corrosion protection measures for reinforced concrete pipe installed in severely corrosive soils.

As noted earlier in this report, there is no definitive threshold level of soil resistivities where soil conditions go from mildly corrosive to severely corrosive. Based on the previous discussion in this report, Reclamation has decided to be consistent with the type of protection provided for all types of buried metallic pipe. Therefore, 3,000 ohm-cm soil resistivity was selected as the dividing line between mildly corrosive and severely corrosive conditions for concrete pipe with steel reinforcement.

Therefore, concrete pipe installed in soils with resistivities less than 3,000 ohm-cm require a dielectric coating over the concrete or mortar coating in conjunction with CP. Concrete pipe installed in soils with resistivities greater than or equal to 3,000 ohm-cm do not require a dielectric coating over the concrete or mortar but, except as noted below*, will require a corrosion monitoring system.

> * ***Note***: Reinforced concrete pipe can be manufactured with or without steel joint rings. It is difficult, but not impossible, to electrically connect pipe units without steel joint rings. This characteristic severely limits the ability to construct an electrically continuous pipeline out of such pipe units. Given Reclamation's good historical experience with reinforced concrete pipe installed in mildly corrosive soils, the requirement for corrosion monitoring (and the resulting need to construct an electrically continuous pipeline) in soils with resistivities above 3,000 ohm-cm is waived for reinforced concrete pipe manufactured without steel joint rings.

As for all buried metallic pipe, evaluation of all soil conditions should be considered in the final corrosion prevention design. Corrosion prevention measures may vary on a given project based on differing conditions along the alignment.

6.0 RECOMMENDATIONS

6.1 Corrosion Provisions

The updated Corrosion Prevention Criteria and Minimum Requirements are outlined in table 2.

These criteria are designed to provide minimum requirements to determine a corrosion design for a pipeline based on soil resistivities along the pipeline alignment. The criteria are not intended to replace good engineering judgment. As an example, the 25-point table, as recommended by corrosion engineer Bill Spickelmire in the Lewis and Clark Rural Water System Draft Report, considers many other factors, such as required service life, pipe size, hydraulic transient pressures, and pipe location when determining the amount of corrosion protection required for a pipeline. All these factors can be examined on a case-by-case basis, but table 2 will provide a good starting point from which to begin the corrosion design process for a specific pipeline application.

Previous versions of Reclamation's Corrosion Prevention Criteria and Requirements (see table 1) reflected differing levels of conservatism in the design of corrosion mitigation for a given pipeline installation depending on the type of deliveries serviced by the pipeline. For a given set of soil resistivities, more conservative corrosion measures were required for a municipal and industrial (M&I) system than for an irrigation system. This approach was intended to reflect a higher level of consequences of failure for an M&I system vs. an irrigation system.

Given the shifting focus of Reclamation's water delivery projects from purely irrigation systems towards more M&I systems, and the reallocation of water from irrigation to M&I, this distinction no longer seems prudent. Also, a reduction in future OMR&E costs needs to be considered no matter what type of system is being built. Therefore, Reclamation's update of its Corrosion Prevention Criteria and Minimum Requirements will adopt a single set of corrosion mitigation recommendations based on pipe materials and soil conditions regardless of the type of system being designed.

Other updates to the Corrosion Prevention Criteria and Minimum Requirements table, as shown in table 2, are discussed below:

Bonded coating and CP are required for ductile and steel pipes that pass through soils with lower than 2,000 ohm-cm resistivities. The rationale for using a resistivity of 2,000 ohm-cm as the cutoff is based in part on the 10-point system used to determine the possibility of pipeline corrosion. This system appears in DIPRA literature as well as the appendices of ASTM A888 and AWWA C105. The tables indicate that soils with lower than 2,000 ohm-cm resistivities are more likely to cause corrosion than higher resistivity soils. These tables use the lowest resistivity found during testing and award points from 0 to 10 based on the precise resistivity. NACE classifies soils with resistivities from 1,000 - 2,000 ohm-cm as moderately corrosive, and the AWWA M11 Steel Pipe Manual classifies soils with resistivities from 0 – 2000 ohm-cm as bad.

These corrosive conditions dictate the use of a conservative design for the pipe protection in these soils to provide a minimum 50-year life.

Because there is conflicting information as to the effectiveness of CP on ductile iron pipe with PE encasement, it seems prudent to not allow the use of PE encasement under severe corrosion situations. Therefore, for these soil conditions, the use of pipe with a bonded coating and CP will be required. This coating system will also reduce the annual cost of power associated with protecting a pipeline in this environment. Exterior mortar or concrete coatings on steel pipe should be used in these environments only with a coal tar epoxy seal coat. The epoxy coating is assumed to provide a bonded coating to the mortar or concrete.

The use of 2,000 ohm-cm in table 2, based on field measurements, is a good break point for the cutoff from soils with definite severe corrosion risks as opposed to more benign soils with greater resistivities. By assuming that the soils less than 2,000 ohm-cm are definitely corrosive and will require the best protection possible (bonded dielectric coating and CP), there is very little need for any further soil analysis of the pipeline alignment. Conversely, where the soil resistivities are greater than 2,000 ohm-cm, the soils are often less aggressive, and the minimum level of corrosion protection required for the pipeline could be lower than that required in the more corrosive soils. Because bonded dielectric coatings are not automatically required for these soils, more soil tests should be performed to ensure that there are not any other conditions which could cause severe corrosion.

Soil resistivity ranges from 2,000-3,000 ohm-cm are generally classified as moderately corrosive. Because the data and information about the exact cutoff point from severe corrosion conditions to mild corrosion conditions are not perfect, it seems prudent to provide some form of dielectric coating on the pipe (bonded or unbonded), and CP to ensure the longevity and lower maintenance costs over the life of the project. Based on the data reviewed during the preparation of this report, Reclamation believes PE encasement for ductile iron pipe and coal tar epoxy seal coat on mortar coated steel or concrete pipe should be satisfactory to reduce long-term CP power costs.

For soil resistivities greater than 3,000 ohm-cm, the chance of corrosion diminishes, and bonded coatings and CP are normally not required. Corrosion monitoring and joint bonding should be provided in case corrosion becomes an issue and CP is required later.

The above discussion about soil resistivities does not address the need for the evaluation of soils for other corrosion factors such as the presence of pH, sulfates, chlorides and stray current interference from adjacent pipelines or other features. In addition, an evaluation of the use, ease of access, pressure requirements, and other pertinent information, similar to the 25-point system used by some water utilities, should be considered. These factors should always be included in the determination of a corrosion protection design, regardless of soil resistivity.

While the overall corrosion prevention methods for a pipeline are based, in part, on a 10 percent probability of encountering soils with a given resistivity, each project should be evaluated to determine if greatly differing soil conditions occur along the alignment. If certain locations differ greatly from others, the corrosion prevention methods should be adjusted accordingly.

In August of 2002 DIPRA announced that the eight leading manufacturers in North America will no longer honor a warranty for ductile iron pipe with any exterior dielectric coating other than polyethylene encasement.[8] In corrosive soil conditions, this could result in decreased competition, as the number of available pipe options will decrease. This in turn could result in higher capital costs, because project bids are usually more competitive when there is more than one pipe type option. But not every pipe type will work on every project, due to size limitations or pressure requirements, so it is not unusual to have a pipe type eliminated from consideration because it cannot meet the needs of the user.

With regard to life cycle costs, Dr. Graham Bell proposed in the April 6, 2004 review panel discussion with Reclamation that more than $\$3.00/ft^2$ should never be spent for a coating, as this will become uneconomic when compared to the power costs required to protect a bare pipeline with CP. He explained that this is why PE encasement is so popular with ductile iron pipe installers. A typical dielectric coating can easily cost more than $\$3.00/ft^2$ for larger diameter pipes. Bonded dielectric coatings for smaller pipes (24-inch diameter and less) typically have costs less than $\$3.00/ft^2$. Because a larger pipe carries more flow then a smaller pipe, the consequences of failure are greater to the user when there is a pipe failure. Repair costs are greater, and more people will probably be affected by the shutdown. Because smaller diameter pipes have lower coating costs and larger diameter pipes are more critical to keep in service, Reclamation feels that in a corrosive environment, the use of both CP and a bonded dielectric coating should be used for all diameters of pipe. Typical costs for exterior coatings are listed in appendix E.

The review panel also suggested the use of rounded or small aggregate size backfill about the pipe, such as sand or 1/4-inch minus material. This would help prevent damage to the PE encasement during placement of the backfill material. Determination of available materials for a project is site-specific. Importation of sand or 1/4 -inch minus material may be expensive and uneconomic for a specific project. The installation design of the pipe may not allow the use of sand due to high ground water and possible migration of materials over time. Therefore, the type of backfill should be considered where PE encasement is being used, but should not be an overwhelming driver in the corrosion design. CP can always be added later if the monitoring shows that corrosion is occurring from damage to the PE encasement.

6.2 Bid Adjustments

Some water utilities have utilized bid adjustments to account for economic differences as a result of various pipe types and coatings necessary in corrosive soils. Utilizing localized historical data gathered on various pipe and coating options, costs have been developed to account for OMR&E differences as a result of the various pipe and coating combinations. A capital cost adjustment is applied during the procurement process to account for the OMR&E historical differences.

[8] Infrastructure Preservation News, Vol. 1, No. 2, June 2003. “Assessing DIPRA’s New Corrosion Protection Standards.”

Reclamation does not have specific data relevant to the life (repairs) of the pipe that represents the many locations in the western United States where one might find the need to require a CP system, and therefore uses a more conservative approach to corrosion design. Expected life cycle costs associated with the OMR&E of the CP system can, however be analyzed and addressed using a bid adjustment.

If warranted, a bid adjustment will allow Reclamation to obtain the lowest life cycle costs and not just the lowest capital cost. Specifications would include criteria utilized to evaluate contractor's proposals not only for capital costs but also for life cycle costs associated with a CP system. The contract would be awarded to the offeror that represented the best overall value to Reclamation and its stakeholders.

6.3 Updates to the Corrosion Prevention Criteria and Requirements Table

Table 2 outlines Reclamation's current (July 2004) corrosion prevention criteria and minimum requirements.[9] Application of the table's criteria and requirements shall be in accordance with the Reclamation Manual Policy "Performing Design and Construction Activities" (FAC P03). The updates to the table are as follows:

1. The table title has been changed to reflect that these are minimum corrosion requirements.

2. The distinction between irrigation pipelines vs. M&I pipelines has been removed. The same corrosion prevention criteria and requirements now apply to all Reclamation pipelines.

3. The pipe size and weight restrictions for the use of PE encasement on ductile iron pipe have been removed from the table.

4. The soil resistivity values for the minimum required corrosion protection measures for pipelines have been revised:

    - For steel and ductile iron pipe, a bonded dielectric coating and cathodic protection is required for soil resistivities ≤ 2,000 ohm-cm, an unbonded coating (PE encasement for ductile iron pipe and cement mortar with coal tar epoxy for steel pipe) and cathodic protection is the minimum requirement for soil resistivities between 2,000 and 3,000 ohm-cm; and an unbonded coating (PE encasement for ductile iron pipe and cement mortar for steel pipe) and corrosion monitoring is the minimum requirement for soil resistivities ≥ 3,000 ohm-cm.

[9] Table 1 outlines the corrosion prevention criteria and requirements updated on April 23, 2003.

- For pretensioned concrete pipe, mortar coating with coal tar epoxy and cathodic protection is required for soil resistivities < 3,000 ohm-cm, and mortar coating and corrosion monitoring is the minimum requirement for resistivities ≥ 3,000 ohm-cm.

- For reinforced concrete pipe, concrete coating with coal tar epoxy and cathodic protection is required for soil resistivities < 3,000 ohm-cm, and concrete coating and corrosion monitoring on pipe with steel joint rings is the minimum requirement for resistivities ≥ 3,000 ohm-cm.

5. The cutoff point for increased corrosion protection for pretensioned and reinforced concrete pipe was reduced from 4,000 ohm-cm to 3,000 ohm-cm.

6. Prestressed concrete pipe has been removed from the table. Reclamation has had a moratorium on the use of this type of pipe since 1990. If and when this changes, corrosion mitigation measures for prestressed concrete pipe will be added to this table.

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Table 1

Corrosion Prevention Criteria and Requirements					Updated April 23, 2003
Pipe Alternative	External Protection (Primary/Supplemental)	Soil Resistivity – 10% Probability Value (Σ-m) Irrigation	Soil Resistivity – 10% Probability Value (Σ-m) M&I	Corrosion Monitoring System	Cathodic Protection System
Ductile Iron	Polyethylene encasement[1]	>15	>30	x	
		≤15	≤30	x	x
	Bonded dielectric[2]	>10	>20	x	
		≤10	≤20	x	x
Prestressed Concrete[3]	Mortar/coal-tar epoxy	>25	>50	x	
		≤25	≤50	x	x
Pretensioned Concrete	Mortar	>20	>40	x	
		≤20	≤40	x	x
	Mortar/coal-tar epoxy	>15	>30	x	
		≤15	≤30	x	x
Reinforced Concrete	Concrete	>20	>40	x	
		≤20	≤40	x	x
	Concrete/coal-tar epoxy	>15	>30	x	
		≤15	≤30	x	x
Steel	Mortar	>20	>40	x	
		≤20	≤40	x	x
	Mortar/coal-tar epoxy	>15	>30	x	
		≤15	≤30	x	x
	Bonded dielectric[2]	>10	>20	x	
		≤10	≤20	x	X

[1] Applicable to pipe with corrosion allowance, 24-inch inside diameter maximum, and 150 lb/ft maximum.
(NOTE: Given recent pipe industry experience with ductile iron pipe, Reclamation plans to re-examine this provision.)
[2] Bonded directly to metal to be protected.
[3] Reclamation currently has a moratorium on this pipe alternative.

Table 2

Corrosion Prevention Criteria and Minimum Requirements[1] **July 2004**

Pipe Alternative	Soil Resistivity – 10% Probability Value (ohm-cm)	Minimum External Protection (Primary/Supplemental)	Corrosion Monitoring	Cathodic Protection[2]
Ductile Iron	≤ 2,000 ohm-cm	Bonded dielectric[3]	YES	YES
	> 2,000 ohm-cm < 3,000 ohm-cm	Polyethylene encasement	YES	YES
	≥3,000 ohm-cm	Polyethylene encasement	YES	NO
Pretensioned Concrete	<3,000 ohm-cm	Mortar / coal-tar epoxy	YES	YES
	≥3,000 ohm-cm	Mortar	YES	NO
Reinforced Concrete	< 3,000 ohm-cm	Concrete / coal-tar epoxy	YES	YES
	≥3,000 ohm-cm	Concrete	YES[4]	NO
Steel	≤ 2,000 ohm-cm	Bonded dielectric[3]	YES	YES
	> 2,000 ohm-cm < 3,000 ohm-cm	Mortar / coal-tar epoxy	YES	YES
	≥3,000 ohm-cm	Mortar	YES	NO

1 This table should be considered to be the minimum corrosion prevention requirements for a pipeline corrosion design. Additional soil conditions and risk assessment factors should be considered on a case-by-case basis for each specific project.
2 OMR&E costs for cathodic protection for each pipe type should be evaluated.
3 Bonded directly to metal to be protected.
4 Corrosion monitoring is required for concrete pipe with steel joint rings, but not for concrete pipe with concrete joints.

Appendix A

Responses to Review Panel Input

In 2003, Reclamation's corrosion engineer completed an extensive literature review of over 150 available industry references related to the effectiveness of PE encasement used as part of a corrosion control system for DIP. The review of this material was documented in a draft report originally entitled "Corrosion Considerations for Ductile Iron Pipe."

A Review Panel was convened by Reclamation in March of 2004 to peer review Reclamation's evaluation of the effectiveness of unbonded coatings on metallic pipe. The Panel consisted of two private sector corrosion engineers (G.E.C. Bell, M.J. Schiff & Associates, Claremont, CA; and R.Z. Jackson, CH2M Hill, Sacramento, CA) and a materials scientist from the National Institute of Standards and Technology (NIST). (Y. Cheng, Materials Reliability Division, Boulder, CO). Also included by contract was an independent Panel chair and technical assistant to serve as a referee to incorporate the panelists' comments into a peer-reviewed document (NIST: (C.N. McCowan (Panel Chair) – Boulder; and R.E. Ricker, Metallurgy Division, Gaithersburg, MD)). The Panel peer reviewed the above draft report, prepared by Tom Johnson (Reclamation's corrosion engineer until leaving for a position with another agency in February of 2004). A copy of the draft report, which includes the panel's comments, is included in appendix B. In addition, the Review Panel was asked to provide conclusions to a series of six questions with regard to corrosion protection practices. The questions and conclusions are included in appendix D.

The Review Panel provided Reclamation with the following three products:

1. A summary of the discussions by the Review Panel of the Draft Document (included in appendix B)

2. Specific comments and recommendations on the draft report "Corrosion Considerations for Ductile Iron Pipe," (included in appendix B).

3. Panel responses on six questions posed by Reclamation regarding corrosion protection practices (included in appendix D).

This appendix provides Reclamation's responses to each of the products listed above.

Reclamation's Responses to the Summary of the Discussions by the Review Panel of the Draft Document

Panel Comment 1. "All of the specific additions suggested for the draft by the reviewers were agreed to be relevant and were incorporated into the draft in one form or another."

Reclamation Response: See the responses to the specific comments in the section below.

Panel Comment 2. "Although the draft was considered in detail and specific additions and changes were made, it is premature to consider that full consensus was reached concerning the specific language in the draft. (The reviewers did not see the final changes to the draft; there was not enough time to discuss all the details at the panel meeting)."

Reclamation Response: Reclamation acknowledges the Review Panel's review of the draft report. Reclamation has decided to incorporate the draft report into this Technical Memorandum rather than finalize the report.

Panel Comment 3: "There was general consensus that the technical details considered in the existing draft are reasonable and appropriate, but the scope of the document needed to be more clearly defined and followed. The draft primarily takes a material (iron versus steel technology) view of corrosion on ductile iron pipe and is virtually silent on other design aspects that can influence the corrosion of these materials (such as back fill)."

Reclamation Response: We agree that the draft report was focused on a material view of corrosion on ductile iron pipe. The Technical Memorandum deals with corrosion prevention considerations for all metallic pipe and covers additional design aspects.

Panel Comment 4. "Many of the specific comments have been incorporated. It was agreed that this draft needed significant expansion to cover the scope implied by the title. As the scope and text stand, it was estimated that the document was between 50 and 70 percent ready for submittal to a peer-reviewed journal."

Reclamation Response: As stated above, Reclamation has decided to incorporate the draft report into a Technical Memorandum rather than finalize the report.

Panel Comment 5. "Either the scope of the document (and title) needs to be clearly defined and limited, to better reflect the issues actually discussed in the document, or most of the comments in the draft should be developed and incorporated into the document to better address the various issues that are not covered in the current draft of 'Corrosion Considerations for Ductile Iron Pipe'".

Reclamation Response: As stated above, Reclamation has decided to incorporate the draft report into a Technical Memorandum rather than finalize the report. The Technical Memorandum deals with corrosion prevention considerations in a broader sense.

Panel Comment 6. "There was no disagreement on the first conclusion of the document, that the use of polyethylene encasement for corrosion protection of ductile iron pipe is a controversial subject. Because of this, it was generally agreed that Reclamation had little choice other than to carefully consider past experience and establish a conservative guideline that they will consistently follow."

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning the use of polyethylene encasement.

Panel Comment 7. "There was no disagreement concerning the first recommendation, use polyethylene encasement as per revised (2004) Table 1, presented for the Questions session with the panel. This appears to be a reasonable technical position, based on available knowledge and their past experience."

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning the use of polyethylene encasement.

Panel Comment 8. "The topics targeted for research in the recommendations were agreed to include the important and pressing issues."

Reclamation Response: The recommendations in the Technical Memorandum have incorporated additional research performed since the completion of the draft report. Reclamation will weigh the need for further research on this issue against other research needs of the agency.

Reclamation's Responses to Specific Comments and Recommendations on the Draft Report Made by the Review Panel

The Review Panel's comments, discussions, and recommendations were considered and incorporated into the body of the Technical Memorandum, including the revised Corrosion Prevention Criteria and Requirements Table (table 2), where deemed appropriate. Applicable portions of the draft report, "Corrosion Considerations for Ductile Iron Pipe," as well as information addressing the Review Panel's comments, were included in the body of the Technical Memorandum rather than finalizing the draft report.

Listed below are specific comments on the draft report from the Review Panel, followed by Reclamation's responses:

Panel Comment: "The original title of this draft report, as prepared by Tom Johnson (formerly Reclamation's corrosion engineer), was "Corrosion Considerations for Ductile Iron Pipe." (Appendix B, title page).

Reclamation Response: Portions of the draft report, as well as information addressing the Review Panel's comments, were included in the body of the Technical Memorandum rather than finalizing the draft report.

Panel Comment: "Was cathodic protection required also? If not, why not? If so, state it." (Appendix B, page B-1).

Reclamation Response: Requirements for cathodic protection would have been based on soil resistivities.

Panel Comment: "What was the reason for the change?" (Appendix B, page B-1).

Reclamation Response: The background for changes to the Corrosion Prevention Criteria and Requirements Table are discussed in Section 2.1 of the Technical Memorandum.

Panel Comment: "Why not electrically isolate the areas that need CP and not have to CP the entire length? In many cases, we have been able to segment alignments, provide CP where necessary and not burden the project with unnecessary corrosion requirements." (Appendix B, page B-2).

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis.

Panel Comment: "Either here or later on, there should be some mention of the other factors and issues related to corrosivity discussed by AWWA C105 or DIPRA…while resistivity is a major factor, there are other factors." (Appendix B, page B-2).

> *Reclamation Response*: Additional factors related to corrosivity are discussed in Section 6 of the Technical Memorandum.

Panel Comment: "Does Reclamation assume or require electrical isolation from appurtenances and other external factors?" (Appendix B, page B-2).

> *Reclamation Response*: Reclamation requires electrical isolation from appurtenances, structures, and between differing pipe types.

Panel Comment: "If to date there has not been a reported corrosion failure of any ductile iron pipeline on a Reclamation-designed project or on a project for which Reclamation has had an oversight responsibility, then what is the concern for corrosion damage? Something needs to be described here for justification for the concern." (Appendix B, page B-2).

> *Reclamation Response*: Reclamation periodically reviews its design standards and criteria to reflect recent agency and industry experience. This review was prompted by concerns within the pipe and corrosion industries regarding the effectiveness of polyethylene encasement.

Panel Comment: "It is my belief and practice that making pipelines electrically continuous is simply a matter of preserving options in the future. From a stray current standpoint, by making pipelines electrically continuous more stray current is collected, but only electrically continuous pipelines can be monitored for stray current and when identified, can be effectively mitigated using standard pipeline methods. Further, the application of cathodic protection at any time is simplified. Pipelines should be made intentionally electrically continuous using appropriately sized joint bonds as a matter of general practice." (Appendix B, page B-4).

> *Reclamation Response*: Discussions concerning electrical continuity are included in Section 3.4.5 of the Technical Memorandum.

Panel Comment: "What about the use of clean sand backfill?" (Appendix B, page B-4).

> *Reclamation Response*: The importance of backfill is discussed in several locations in the Technical Memorandum, including Sections 4.1.1 and 6.1.

Panel Comment: "You should discuss the 10 point system, its components and merits." (Appendix B, page B-5).

Reclamation Response: The 10 point system is discussed in Section 3.3 of the Technical Memorandum.

Panel Comment: "The 49 CFR 192 and 195 regulations are for oil and gas, it does not mean they are applicable. There are lots of other requirements in the CFRs that are also not followed in the water industry. Unless you are willing to accept the entirety of the requirements, you might want to tone down the use of these CFRs." (Appendix B, page B-6).

Reclamation Response: Section 4.1.1 of the Technical Memorandum states that these two documents were primarily developed for the oil and gas industry, but that the information contained in them is relevant to the discussion in that section.

Panel Comment: "Based on the cost of cathodic protection, you can show that from an economic standpoint you should never pay more than $3 per square foot for a coating because you can cathodically protect it for that amount. Reference: G.E.C. Bell, Value Engineering and Corrosion Control, AWWA Cal-Nevada Section, Spring Meeting, April 10, 1997, San Jose, CA." (Appendix B, page B-8).

Reclamation Response: This subject is discussed in Section 6.1 of the Technical Memorandum.

Panel Comment: "Suggest considering the positions of the Europeans and other international groups on the issue. He states that it is his understanding that polyethylene encasement has not been accepted as the sole form of protection for ductile iron in Europe. Also consider noting that in the U.S., the situation with respect to polyethylene encasement seems to have resulted in the evolution of 3 camps: (1) those outright rejecting polyethylene encasement and treating of ductile iron pipe the same as steel pipe, (2) those completely accepting polyethylene encasement, and (3) those somewhere between these two positions. This would seem to reinforce the conservative position recommended by Reclamation, namely, limiting the use of polyethylene encasement until research answers the fundamental questions posed in the Recommendations section." (Appendix B, page B-11).

Reclamation Response: European practices are discussed in Section 4.1, and listed in table 7 of the Technical Memorandum. Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning the use of polyethylene encasement.

Reclamation's Responses to the Panel's Conclusions on Six Questions Regarding Corrosion Protection Practices

Questions for the Panel and Panel Conclusions

1. **Reclamation currently requires protection on pipe alternatives (i.e., no bare pipe is installed) should problems be encountered in the future due to either environmental corrosion or stray current.**

Does the Panel concur with this practice?
Does the panel have comments with regard to this practice?

Jackson – Concurred

Bell – Concurred, but noted that cost is a consideration. He said coatings should be used for costs up to $3/ft^2, because cathodic protection can be applied for about this cost.

Reclamation Response: A discussion of this topic is included in Section 6.1 of the Technical Memorandum.

Cheng – Concurred

2. **Reclamation currently requires bonded joints and Corrosion Monitoring for all pipeline installations in order to monitor and assess pipe corrosion activity.***
******Note***: With the exception of reinforced concrete pipe without steel joint rings. (See section 5.0 for discussion.)**

Does the Panel concur with this practice?
Does the panel have comments with regard to this practice?

Jackson – Concurred; but said one should allow for exceptions.

He said that in special cases where there are stray currents one should consider isolation rather than conductivity. For example, he worked on a project where a pipeline paralleled a high voltage power line. In that situation, isolation from other structures is definitely needed, and can be achieved by reducing the continuous length of pipe that can draw a stray current.

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis.

Bell – Concurred that bonded joints and test stations are needed, and that isolation from other structures is important. He also stated that with a bonded coating, one may not be able to see changes in the potentials on the pipeline, meaning it may be difficult to detect if corrosion is occurring. He felt that newer technologies, such as electrical resistance coupons, may be better.

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis. Reclamation's position has been and continues to be that all buried metallic pipelines be installed with corrosion monitoring systems, with the exception of reinforced concrete pipe without steel joint rings. (See section 5.0 for discussion.)

Cheng – Concurred with the practice of corrosion monitoring. He also stated that one needs to monitor for unusual circumstances and changes in potential, and have a practice or written guideline to establish what changes to look for and what to do if changes are found.

Other comments:

Connections from sublaterals to main pipeline account for 90 percent of all corrosion problems on distribution systems. Isolation is the key.

Reclamation Response: Reclamation requires electrical isolation from appurtenances, structures, and between differing pipe types.

Cathodic protection is the last resort if there are problems.

Reclamation Response: We agree that installation of a corrosion monitoring system allows for testing and determination of precise requirements for implementation of a cathodic protection system, if necessary.

3. Reclamation currently uses soil resistivity and stray current as an indicator of need for CP. Additionally, in some cases Reclamation will examine chlorides and sulfates concentrations in the soil. This approach does not consider, or may be considered to assume, other parameters of soil chemistry, pH, Oxidation Reduction Potential (Redox), cyclic wetting and drying (moisture), etc. This parameter is quick, easy and cheap to measure in the field.

Does the Panel concur with this practice?
Does the panel have comments with regard to this practice?

Jackson – He stated that field resistivity is one part of the data gathering. CH2M Hill prefers the collection of additional information for major pipelines, e.g., pH, chlorides, and sulfates. Resistivity values are calculated in the laboratory (saturated) as well as in the field. He stated that the potential for stray currents needed to be evaluated, and that a conservative assumption would be that every project is likely to have stray current. The use of PE encasement to provide shielding from stray currents is a good idea.

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis. Section 6.1 of the Technical Memorandum discusses the importance of evaluation of a variety of factors that could influence corrosion.

Bell – He felt the best approach was to get the pipe in the ground and then determine what is needed. He stated that even hazardous pipelines are given 1 year of operation to allow for tweaking of CP to meet exact needs of a particular pipeline.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions. Reclamation concurs that initial operation of a CP system should be reviewed and adjusted as necessary.

He stated that resistivity is a good indicator of corrosion mitigation needs, but that the use of Electro-Magnetic Conductivity Surveys may be better. Measurements could be taken every 20 feet to 15 feet of depth. This method should be used to find where there are changes, and that data should be used to determine the field sampling locations. He stated that the anions–chlorides and sulfides—as well as the cations—calcium, magnesium, and sodium need to be measured. He felt that there is a small price difference between a full analysis and a partial analysis, and that this extra analysis helps determine where to put magnesium beds.

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis.

Other comments:

Bell – A conservative assumption would be to use good coatings and CP for lower resistivity soils.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions.

Bell – Stray current is difficult to assess. The conservative view is to assume projects are likely to have future potential for stray current.

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis.

4. PE effectiveness is a disputed issue both for its ability to protect pipe from corrosion, possible installation damage and potential shielding which impacts Corrosion Monitoring and CP. For example, NACE International's RPO 169-2002 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," requires a bonded dielectric coating for buried pipeline applications and indicates that unbonded coatings (PE encasement is considered an unbonded coating) can create electrical shielding of the pipeline that could jeopardize the effectiveness of the CP system. Reclamation is concerned by this dispute.

Does the panel have comments with regard to the effectiveness of PE encasement as a corrosion measure and/or its effect on the ability to monitor pipe corrosion and to apply effective CP?

Jackson – He felt that PE encasement is not a perfect answer, but there are locations in less corrosive environments where it can be used. He agreed that Reclamation has a legitimate concern and needs to take a conservative view, and should make changes to corrosion mitigation criteria if warranted.

Reclamation Response: This is a design approach that should be considered for each project on a case-by-case basis. Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions. Reclamation's corrosion provisions indicate agreement with Mr. Jackson's statement that PE encasement can be used in locations with less corrosive environments.

Jackson – He has used PE encasement with CP, and has not had any cases where he has been called to go back and inspect the pipe. This would indicate that there have been no specific problems for these cases.

Jackson – He said that two other aspects should be considered:

1. As the pressure class decreases, the pipe thickness decreases, making the thinner pipe more susceptible to penetration. The pipe thickness also decreases as the size decreases.

2. Bedding and backfill are critical and must be considered carefully. CH2M Hill likes to use sand as a bedding material for DIP with PE. A minus ¼" gravel may be reasonable. Dig-ups have shown damage to the PE, especially around the top of the pipe. Two layers of PE encasement could help eliminate this problem.

Reclamation Response: The importance of backfill is discussed in several locations in the Technical Memorandum, including Sections 4.1.1 and 6.1.

Jackson – CH2M Hill is more conservative with larger diameter pipe because the flows are larger, the implications of the failure are greater, and large diameters are more expensive to fix. With larger pipe, a more conservative approach is warranted. With 12-inch and smaller pipe, less conservatism may be needed.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions.

Bell – He stated that he leans towards the use of PE encasement with CP applied, because he has seen it work. He agreed that PE encasement cannot be considered to be a coating; it is an encasement only. He said that data has recently been published which indicates DIP with a select backfill can be protected with PE encasement to reduce corrosion, and that CP works under intact PE.

He noted that RP0169 (RP stands for Recommended Practice) recommends a tight bonded coating, but that it is not a requirement; it is only a recommended practice. He stated that he has never specified tight bonded coating with DIP.

He stated that he has had good experience with PE encasement and with the application of CP on polyethylene encased DIP. He stated that the costs of PE encasement are on the order of $0.05/diameter inch of pipe. He also stated that the cost of CP for DIP with PE encasement can be considered to be 28 times that of steel, but that it is still a small number when put in context of the entire project cost.

He advised Reclamation to look at its own experience. He stated that if Reclamation has not had failures with PE encasement, then it should keep doing what has been done. He said that he has never seen significant failures of DIP protected with PE encasement and CP.

He said that damage to the PE encasement is not due to the weight or size of the pipe, but the fact that the wrong type of PE encasement is used. He stated that the quality of PE encasement can vary greatly, and that lower-quality PE may not have enough thickness or tensile strength.

He felt that the size restriction on pipe with PE encasement should be eliminated. He agreed that the consequences of failure need to be considered. Larger diameter pipe generally does have higher consequences.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's current position concerning corrosion provisions.

Bell – He stated that the fittings on the pipe cause the most problems, because the pipe is manufactured in a controlled environment, whereas the fittings are a field installation and not controlled as well. He felt that close inspection during installation is the best investment.

Reclamation Response: Reclamation has inspectors in the field during construction.

Bell – Other comments:

The quality of the PE is important.

Inspections and cathodic system maintenance are important.

Reclamation Response: Reclamation routinely performs inspections and maintenance on its facilities and encourages the operators of the systems we build to do the same.

5. Reclamation is prepared to recommend an updated approach for pipe alternative coatings or encasements installed in various soil conditions. The newest recommendation is enclosed as Table 2.

Does the Panel concur with the Table?
Does the panel have comments with regard to the Table?

Bell – He stated that a bonded dielectric coating is more difficult to apply and more expensive for DIP than for steel pipe. With DIP, a thicker coating is needed due to the dimpling on the pipe, and that the larger the diameter, the greater the coating thickness becomes. Thick coatings can cause problems at the joints, making the pipe hard to assemble. Mortar and reinforced concrete need to be handled differently. Mortar coating in conditions with chlorides and sulfides is a problem. In wetting and drying conditions, the mortar can act like a sponge, and eventually lead to chlorides accumulating on the metal. Corrosion protection additives can be put into the coating. If coal tar epoxy is used, it should be used directly on the steel, with mortar on the outside for rock protection. He stated that three layers of tape with mortar coating are pretty much bullet proof. He said that a seal coat over mortar is not a good system, because it could cause shielding of CP and allow corrosion to occur under any disbonded mortar coating. The mortar should be used over the dielectric coating.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions.

Bell – He said that both coal tar epoxy and PE encasement can shield CP.

He said that for soil resistivities below 1,500 Ohm-cm, PE encasement with CP should be used.

He stated that the Reclamation table is geared towards conservatism, and that this makes sense if it agrees with a good history of installation.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions.

Bell – He stated that if CP systems are not always well maintained, one should never depend totally on CP to protect a pipeline.

Reclamation Response: Reclamation routinely performs inspections and maintenance on its facilities and encourages the operators of the systems we build to do the same.

Jackson – He stated that if a bonded dielectric coating is required, alternatives will probably be more limited, because pipe will probably not be obtainable from DIP manufacturers. He said that it is a good idea to make sure there is more than one pipe alternative available in order to keep capital costs down.

Reclamation Response: To the extent practical, Reclamation includes all technically viable pipe options in its specifications.

Jackson – He felt that there could be problems with corrosion in any soils with resistivities below 3,000 Ohm-cm. For resistivities below 2,000, he felt that corrosion protection designs should definitely be considered. For resistivities below 1,000, he felt that there could be really serious problems.

Reclamation Response: Discussions in Section 6.1 of the Technical Memorandum, as well as the revisions to the Corrosion Prevention Criteria and Requirements Table, reflect Reclamation's updated position concerning corrosion provisions.

Jackson – In the end, he felt that the user should adhere to the criteria with which they are the most comfortable.

Reclamation Response: The design approach for each project should be determined on a case-by-case basis.

Other comments:

Bell – Coal tar epoxy can be placed directly on the pipe with mortar over the epoxy for rock protection.

If the coal tar epoxy is on the outside of the mortar and the mortar becomes disbonded from the pipe, salty water can be a problem.

Reclamation Response: This is a design consideration that should be addressed on a case-by-case basis.

6. Pipe life cycle costs, or other economic considerations are important in the overall design and O&M budgeting and expenditures over the life of a project. Reclamation is prepared to use pipe life cycle costs as a bid correction item.

Does the Panel concur with this practice?
Does the panel have comments with regard to this practice?

Jackson – In general, he felt that life cycle costs are needed in specifications. He concurred with using bid adjustments in specifications for increased costs due to CP. As an example, CH2M Hill did use long-term costs for the Mni Wiconi Project, but it did not change the pipe option selected for the project. The lowest life cycle costs were for DIP with PE encasement and CP.

Reclamation Response: Life cycle costs are discussed in Section 4.6 of the Technical Memorandum.

Bell – He said he has never used life cycle costs, but he would have no problem with including it. He stated that it would be important to be definitive about how the calculation will be made.

He said that, in general, the cost of installation of CP is about $2,000 to $3,000 per installed amp. The current required for ductile iron is about 28 to 30 times that required for steel.

Reclamation Response: Life cycle costs are discussed in Section 4.6 of the Technical Memorandum.

He felt that the average service life for a pipe project should be assumed to be 40-60 years, so a good starting point would be 50 years. He has known clients that have asked for as high as 100 years.

Reclamation Response: Service life for pipe projects is discussed in Section 4.5 of the Technical Memorandum.

Appendix B

"Considerations in Using Polyethylene Encasement with Ductile Iron Pipe"

The Review Panel was asked to review a February 12, 2004, draft report prepared by Tom Johnson (formerly Reclamation's corrosion engineer). The title of the draft report was "Corrosion Considerations for Ductile Iron Pipe." The Panel's comments are included in the right margin of the draft report. The Panel's recommended additions are underlined, and their recommended deletions are shown as strikeout.

Summary of the Discussions by the Review Panel of the Draft Document

1. All of the specific additions suggested for the draft by the reviewers were agreed to be relevant and were incorporated into the draft in one form or another.

2. Although the draft was considered in detail and specific additions and changes were made, it is premature to consider that full consensus was reached concerning the specific language in the draft. (The reviewers did not see the final changes to the draft; there was not enough time to discuss all the details at the panel meeting).

3. There was general consensus that the technical details considered in the existing draft are reasonable and appropriate, but the scope of the document needed to be more clearly defined and followed. The draft primarily takes a material (iron versus steel technology) view of corrosion on ductile iron pipe and is virtually silent on other design aspects that can influence the corrosion of these materials (such as back fill).

4. Many of the specific comments have been incorporated. It was agreed that this draft needed significant expansion to cover the scope implied by the title. As the scope and text stand, it was estimated that the document was between 50 and 70 percent ready for submittal to a peer-reviewed journal.

5. Either the scope of the document (and title) needs to be clearly defined and limited, to better reflect the issues actually discussed in the document, or most of the comments in the draft should be developed and incorporated into the document to better address the various issues that are not covered in the current draft of "Corrosion Considerations for Ductile Iron Pipe".

6. There was no disagreement on the first conclusion of the document, that the use of polyethylene encasement for corrosion protection of ductile iron pipe is a controversial subject. Because of this, it was generally agreed that Reclamation had little choice other than to carefully consider past experience and establish a conservative guideline that they will consistently follow.

7. There was no disagreement concerning the first recommendation, use polyethylene encasement as per revised (2004) Table 1, presented for the Questions session with the panel. This appears to be a reasonable technical position, based on available knowledge and their past experience.

8. The topics targeted for research in the recommendations were agreed to include the important and pressing issues.

MERL-2004-01

~~Corrosion Considerations for Ductile Iron Pipe~~
Considerations in using Polyethylene Encasement with Ductile- Iron Pipe

Comment [SL1]: The original title of this draft report, as prepared by Tom Johnson (formerly Reclamation's corrosion engineer), was "Corrosion Considerations for Ductile Iron Pipe"

The Review Panel was asked to review a February 12, 2004, draft report prepared by Tom Johnson (formerly Reclamation's corrosion engineer). The title of the draft report was "Corrosion Considerations for Ductile Iron Pipe." The Panel's comments are included in the right margin of the draft report. The Panel's recommended additions are underlined, and their recommended deletions are shown as strikeout.

~~D. Thomas Johnson~~
U.S. Department of Interior
Bureau of Reclamation
Denver Technical Service Center
Materials Engineering and Research Laboratory
With Panel Peer Review and Comments

~~February 12, 2004~~
April 2004

Contents

Comment [BOR2]: Note that this document was converted to Word 2007 in Feburary 2010. Redline and strikeouts have been re-done to match the original publication.

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Corrosion Considerations for Ductile Iron Pipe

Introduction

Because of corrosion concerns recently ~~raised relative to~~ raised regarding the use of cathodically protected, polyethylene encased, ductile iron pipe Reclamation has initiated a study to evaluate the corrosion mitigation alternatives listed in the table titled Corrosion Prevention Criteria and Requirements (See Table 1). The original study was to take approximately 18 months with a completion date of December 2004 and was to include all pipe options used by Reclamation. As a result of the language within Reclamation's 2004 Budget with its accompanying March 2004 deadline, the original study was modified such that the ductile iron pipe alternative would be evaluated first. Therefore, this report concentrates on the corrosion control considerations of ductile iron pipe. Corrosion considerations for ductile iron pipe are reviewed and recommendations are given for Reclamation positions on the criteria listed in Table 1 for ductile iron pipe.

This report is based on Reclamation's experience, the experience of other professionals in the corrosion and water industries, a review of pertinent national standards, recommended practices, and a review of relevant literature.

As the study progressed it became apparent that significant technical issues remain regarding corrosion ~~mitigation~~ control methods for ductile iron pipe and, therefore, an economic analysis of the corrosion mitigation alternatives for ductile iron pipe was not performed. However, economic considerations are relevant to pipeline design and material selection. The two corrosion prevention methods listed in Table 1 for ductile iron pipe will have different costs for design, construction, and normal O&M, and the effectiveness of the selected corrosion prevention method will have future economic consequences (i.e. leak repair cost, property damage, and pipeline service life). There are some quantitative data on the failure rates of both methods, but the uncertainty of the data precludes a definitive life cycle cost analysis for deciding between the two methods. Therefore, selection of the form of the protection should be based on the technical merits and weaknesses of each method.

Background

The Bureau of Reclamation first considered using ductile iron pipe on projects in the mid 1960's. At that time Reclamation's position was that from a corrosion standpoint ductile iron pipe would be treated as steel pipe and coated with a bonded dielectric coating. In the late 1970's Reclamation added polyethylene encasement as an alternative corrosion mitigation method for ductile iron pipe. In the early 1990's Reclamation placed a restriction on the pipe weight and diameter for which polyethylene encasement could be used and, as such, polyethylene encasement currently is applicable only for smaller and lighter ductile iron pipe. Currently within Reclamation, ductile iron pipe can be installed with either polyethylene encasement (for smaller and lighter pipe) or a bonded dielectric coating (for all pipe sizes), and cathodic protection may be used with both coatings.

Comment [m3]: Who? Based on what?

Comment [gecb4]: Was cathodic protection required also? If not why not? If so state it.

Comment [gecb5]: What was the reason for the change?

Comment [gecb6]: Again, what was the reason for the change?

Comment [gecb7]: Was weight used as a means of limiting pressure ranges and therefore pipe thickness?

Comment [gecb8]: 24-inch diameter??

Comment [dh9]: Need to name the particular reference standard that you used "RP o169 NACE

Comment [gecb10]: What are the design criteria for cathodic protection? Does Reclamation require -850 mv to SCE for both pipes? Has there ever been a failure on a cathodically protected polyethylene encased pipe? How about dielectrically coated steel pipe with CP?

Within Reclamation the decision to use cathodic protection on buried pipelines is based on soil resistivity, but all buried metallic pipelines receive corrosion monitoring systems as a minimum. Pipelines traversing lower resistivity soils, measured by field tests and data interpretation according to Reclamation standards, require cathodic protection. The corrosion prevention criteria and requirements (Table 1) are guidelines used by Reclamation when making corrosion prevention recommendations for buried line pipe alternatives. It should be noted that other parameters such as performance history and stray current exposure for a given route, criticality of the structure, conservatism employed in the design, and specific client requests should be considered when determining corrosion prevention requirements for a specific pipeline. In addition, the specified corrosion prevention requirements for a particular pipeline should be developed by a corrosion engineer working directly with the pipeline designer. The guidelines are not intended to be rigid in use but used as a tool in formulating the corrosion protection scheme on a particular pipeline.

Currently within Reclamation cathodic protection is recommended (depending on soil resistivity) on ductile iron pipe with either a bonded dielectric coating or a polyethylene encasement.

Overall Reclamation's use of ductile iron pipe is ~~somewhat~~ limited as a line pipe alternative. ~~To the best of the author's knowledge,~~ Reclamation has been involved with installation of over 330 miles of ductile iron pipe. Approximately 30 miles of ductile iron pipe has been installed on Reclamation designed projects. The ductile iron pipelines on Reclamation designed projects were installed beginning in the late 1970's and are 24 inches in diameter or less. Additionally, over 300 miles of ductile iron pipe has been installed on non-Reclamation projects where Reclamation has had oversight responsibilities (the projects were not designed by Reclamation). Ductile iron pipelines installed with Reclamation oversight typically have been installed with polyethylene encasement and cathodic protection. To date there has not been a reported corrosion failure of any ductile iron pipeline on a Reclamation designed project or on a project for which Reclamation has had an oversight responsibility.

Appendix A for this report contains fundamental concepts relative to corrosion and corrosion mitigation. This report assumes that the reader has some understanding of the fundamental concepts and, therefore, all readers are encouraged to review these fundamental concepts.

Corrosion of Ductile Iron Pipe

The corrosion experienced ~~on~~ by buried metallic structures is more dependent on the environmental characteristics than the compositional variations within a specific type of material (Romanoff, 1957). It is ~~widely~~ generally accepted that ~~steel, cast iron, and ductile iron~~ steel and iron pipe materials corrode at similar rates in similar soils (Kroon, 2004; FHWA, 2001; Fitzgerald, 1968; Romanoff, 1968).

Both cast iron and ductile iron contain ~~free~~ carbon in the form of graphite (Anver, 1974). The graphite in ~~gray~~ cast iron is in the form of flakes, where as, in ductile iron it is in the nodular or spheroidal form. The ~~different~~ differing forms of graphite in ~~gray~~ cast iron and ductile iron ~~have resulted~~ result in differences of mechanical ~~properties, with ductile iron having the~~ properties. Ductile iron has greater ductility and ~~tensile strength. However, the different forms of graphite~~

Comment [m11]: Why not electrically isolate the area that need CP and not have to CP the entire length? In many cases, we have been able to segment alignments, provide CP where necessary and not burden the project with unnecessary corrosion requirements.

Comment [m12]: What is methodology (sampling) for the 10% probability determination? Weibull (sp) plots per mile or 1000 meters? Are the tests field or laboratory tests? If laboratory tests, what is the moisture content? What is the interval of testing? Are all of the tests from pipe depth?

Comment [m13]: Either here or later on, there should be some mention of the other factors and issues related to corrosivity discussed by AWWA C105 or DIPRA…while resistivity is a major factor, there are other factors. The reality is that the Reclamation limits on resistivity are such that for virtually every pipeline, coatings or encasement and CP will be required for both steel and DIP.

Comment [m14]: Don't you really mean the Risk of Failure (Probability of Corrosion Failure X Consequence of Failure)?

Comment [m15]: Does Reclamation assume or require electrical isolation from appurtenances and other external factors? I have found that isolation from external galvanic cells is more important than soil corrosivity.

Comment [m16]: Need to state how many total miles of pipe Reclamation has been involved in the installation of during the same period.

Comment [m17]: Design, construction, what was the role of Reclamation?

Comment [m18]: if to date there has not been a reported corrosion failure of any ductile iron pipeline on a Reclamation designed project or on a project for which Reclamation has had an oversight responsibility. Then what is the concern for corrosion damage? Something needs to be described here for justification for the concern. I thought the materials on page 8 under Discussion touch this issue, but they need to be expanded and moved up here. Although no failures have been reported, failures in other areas have been cited. So, there are possibilities that corrosion of ductile iron pipes with BOR's designs or under BOR's oversight might occur. It also might be important to state that the cost of a failure will be enormous. Along the same line, it is worthwhile to estimate the failure probability of ductile iron pipes due to corrosion. This is might be complicated due to many factors involved, such as the pipe dimension, soil properties and environment, etc. But it can be done on assumed realistic conditions. ... [1]

Comment [m19]: If there is only one appendix, A is not needed.

~~have not resulted in differences in their corrosion characteristics~~ higher strength than cast iron. However, the corrosion rates of cast and ductile iron are not significantly different (Makar et al., 2002; Romanoff, 1968).

Although ~~they corrode at approximately~~ ductile/cast iron and steel corrode at nominally the same rate there is a very important difference between the corrosion characteristics of steel and that of cast iron or ductile iron. Cast and ductile iron pipe typically corrode by graphitization or pitting. ~~Graphitization does not occur with steel, which typically corrodes by pitting.~~ Graphitic corrosion is a ~~type of dealloying~~ process in which the iron rich matrix ~~within the iron/carbon matrix of cast and ductile iron is~~ surrounding the graphite (carbon) preferentially ~~corroded~~ corrodes due to the galvanic couple between the iron and graphite. Iron is anodic to graphite and when ~~galvanically coupled~~ electrically-coupled in contact with an electrolyte with graphite the iron will ~~experience accelerated corrosion. As the iron corrodes,~~ corrode at an accelerated corrosion rate. As the iron rich regions corrode, it is replaced by a porous ~~the iron/carbon matrix transforms to a porous iron oxide/carbon marix with an accompanying~~ iron oxide corrosion product and this change in the microstructure is accompanied by a reduction of mechanical properties (e.g., density, ductility and tensile strength). The graphitized material tightly adheres to the metal substrate. There is generally no visible evidence of graphitic corrosion; the original pipe surface remains the same including contour, texture, and color (there may be a very slight color change). Pitting corrosion is usually easily identified and is visually evident by surface cavities and/or color variation due to the presence of corrosion products. In either case, graphitization or pitting, the end result is the same; there is a cavity in the pipe wall.

Comment [m20]: What is the reference for this? In general, I find that there is a change in surface condition, in particular the soil in the area of the graphitization is tightly adhered and that there is a smoothing of the surface.

Comment [m21]: It would be recommended that a brief discussion of localized versus general corrosion be included here. You may want to include this in the appendix that gives the primer on corrosion. The four parts of the corrosion cell are all the same, only the length scale is different. This is important because general corrosion is not as important as pitting because for a pipeline, a single perforation constitutes a failure.

Experience indicates that it is prudent to account for corrosion, especially when metal pipe is buried. The practice of adding extra wall thickness as a means of extending service life for corrosion that occurs over time has been used historically and is employed today in some cases. However, the use of an effective corrosion protection system allows the most economical use of pipe material because excessive wall thickness is not required. The wall thickness of gray cast iron was gradually reduced as manufacturing techniques improved and alloys became stronger and more consistent, and this trend has continued with ductile iron. Modern ductile iron pipe can have substantially thinner walls than comparable old cast iron pipe for the same pressure service. However, corrosion rates haven't changed, so thinner walls make corrosion control a more important consideration for ductile iron pipe.

Figures 1 and 2 are of a gray cast iron pipe removed from a pipeline, which was approximately 60 years old. This specific pipe section had not failed in service although the pipeline was replaced due to repeated failures. ~~Prior to sand blasting it~~ It was evident in initial inspections that the pipe section had experienced graphitic corrosion, ~~(evident by scraping away the outer pipe wall with a knife)~~ although the extent of corrosion was not apparent. After sand blasting, which removed only the porous carbon/corroded iron regions of the pipe, it was readily apparent that a large percent of the surface experienced corrosion and at three locations the pipe wall was ~~completely~~ perforated due to graphitic corrosion.

Because of the tightly adhering nature of graphitic corrosion products, graphitized pipe is capable of ~~containing~~ withstanding significant pressure even when corrosion has ~~fully penetrated~~ perforated the pipe wall (Romanoff, 1957; Smith, 1963). Although this is a desirable ~~property it~~

~~can not~~ property, it cannot be relied upon as an engineering property. The ~~brittle nature of~~ low toughness of the graphitic corrosion products result in the graphitized pipe being susceptible to failures from stress caused by such factors as surges, freeze/thaw, expansive soils, temperature changes, and vehicular loading.

It is recognized within the corrosion industry that graphitic corrosion is not easily identifiable and as a result it is believed that many failures of gray cast iron and ductile iron pipes are not identified as corrosion related, ~~where as,~~ however, the root cause of the failure may indeed be due to corrosion (Romanoff, 1968; Fitzgerald, 1968; Gummow, 1978; Chambers, 1983; CANMET, 1983; Jakobs and Hewes, ~~1987,~~ 1987; Makar et al., 2000). This recognition, along with the recognition of corrosion and corrosion mitigation in general, has not been widely transferred to the water industry (Fitzgerald, 1968; FHWA, 2001; Spicklemire, 2002). As a result, the actual number of corrosion related failures of gray cast iron and ductile iron pipes are likely higher than the statistics indicate (CANMET 1983; Jakobs and Hewes, 1987; Szeliga and Simpson, 2003). Canadian studies investigating water main failures indicate that corrosion is a primary cause in the majority of water main failures (Chambers, 1983; CANMET, 1983; Jakobs and Hewes, 1987; Brander 2001)~~. It is interesting to note that because the majority of water main failures are corrosion related they could have been prevented with theimplementation of available corrosion mitigation techniques.~~

Stray current corrosion ~~is~~ should always be a consideration for buried pipelines. Rubber gasketed, bell and spigot joints are often used on pipelines in the water industry and ~~often~~ can result in a pipeline ~~which~~ that is not electrically continuous, see Figure 3. Another factor for corrosion mitigation on ductile iron pipe is the possibility of non-electrically continuous joints. ~~The electrical continuity across the joint is dependent on the~~Rubber-gasketed joints are commonly used in ductile iron pipe, so continuity is an issue when stray current is considered. Electrical continuity may or may not occur depending upon the extent of physical contact between the bell and spigot. Joint bonds are generally necessary if continuity is to be ~~spigot ends of a joint. If physical contact exists electrical continuity can occur, although without installation of electrical continuity joint bonds positive continuity is not obtained.~~ assured. An electrically discontinuous pipeline collects less stay current than an electrically continuous pipeline which results in less stray current corrosion (Bonds, 1997). However, any current that is collected on an electrically discontinuous pipeline can cause stray current corrosion when the current leaves the pipe surface ~~to get~~ and gets around ~~an~~ the electrically discontinuous pipe joint. Preventing stray current corrosion usually requires establishing a metallic path (wire) between the affected piping and a suitable drain point or connection to the source of the current. Bonding the pipe joints helps ensure that a metallic path is provided from the drain point to all parts of the pipeline, thereby preventing a corrosive stray current discharge directly from the pipe to the soil.

In ~~summary;~~ summary, steel, cast iron, and ductile iron ~~are capable of corroding~~ corrode when buried. They corrode at approximately the same rate and the corrosion ~~experienced is highly~~ damage is dependent on the ~~corrosion characteristics of the soil and/or stray currents.~~ corrosivity of the soil, the stray currents, and details of the design and construction. In the absence of protective measures, the time required for corrosion to penetrate the pipe wall is determined by the severity of the corrosive condition and the wall thickness of the pipe.

Comment [m22]: These points are generally true for all metal pipe. The wording should be revised to make it more readable for the non-specialist.

Comment [m23]: It is my belief and practice that making pipelines electrically continuous is simply a matter of preserving options in the future. From a stray current standpoint, by making pipelines electrically continuous more stray current is collected, but only electrically continuous pipelines can be monitored for stray current and when identified, can be effectively mitigated using standard pipeline methods. Further, the application of cathodic protection at any time is simplified. Pipelines should be made intentionally electrically continuous using appropriately sized joint bonds as a matter of general practice.

Comment [m24]: Continuing with the line of thinking from above, discontinuous pipe is not an option because you can not monitor discontinuous pipelines for stray current.

Corrosion Mitigation Methods Typically Used for Ductile Iron Pipe

Corrosion mitigation methods typically used for ductile iron pipe include polyethylene encasement, bonded dielectric coatings, select backfill, and/or cathodic protection.

Polyethylene Encasement

It has been over 40 years since polyethylene encasement was first used on a buried pipeline. The use of polyethylene encasement within the water industry has been and still is controversial. This section will introduce the more prominent issues that are generally presented by the proponents and opponents of using polyethylene encasement.

Polyethylene encasement is a dielectric ~~coating~~ barrier, which is not bonded to the underlying metallic surface. Within this report there are two concepts used to identify pipe surfaces in relation to the polyethylene encasement, which require some explanation. The concepts are pipe surfaces ~~"opposite~~ "adjacent to holidays in the polyethylene encasement" and "under intact polyethylene encasement." As indicated in Appendix A, and shown in Figure 4, a holiday is a discontinuity in a ~~coating which~~ barrier that exposes the underlying metallic surface ~~directly to the corrosive environment. The pipe surface opposite a holiday in the polyethylene encasement refers to the pipe surface which is directly under the holiday.~~ in the vicinity of the holiday to the environment (electrolyte). The pipe surface under intact polyethylene encasement refers to the pipe surface directly under polyethylene encasement ~~which~~ that does not contain a holiday at that specific location; however, holidays in the polyethylene encasement located away from the specific location of interest may be present.

Proponents of using polyethylene encasement indicate that in most corrosive soils polyethylene encasement alone is the recommended corrosion mitigation technique (AWWA M41, 2003). However, in uniquely severe environments other corrosion mitigation techniques, such as tight bonded coating and/or cathodic protection, should be considered (Stroud, 1989). This also includes the use of cathodic protection with polyethylene encased ductile iron pipe, where the polyethylene encasement reduces the ~~amount of~~ current required for cathodic protection ~~current required~~ (Smith, 1970; Clark, 1972; Stroud, 1989; Schiff and McCollom, Lisk, 1997). American Water Works Association (AWWA) C105 "Polyethylene Encasement For Ductile-Iron Pipe Systems" is a national standard which is often referenced as supporting documentation for polyethylene encasement. The main body of AWWA C105 covers materials and installation procedures for polyethylene encasement of ductile iron pipe. ~~The thrust of AWWA C105 is materials and installation, and not under what conditions to use it.~~ Appendix A of C105 gives conditions for use of PE as well as other corrosion control methods for ductile iron pipe.

Proponents of polyethylene encasement generally agree with the following:

1. The mechanisms of corrosion protection provided by polyethylene encasement are that of placing a dielectric barrier between the pipe wall and soil, ~~and causing~~ which causes oxygen starvation ~~within~~ of the corrosion cell.

Comment [m25]: What about the use of clean sand backfill? See below. Add reference here.

Comment [m26]: Suggest using some figures here. Also suggest mentioning the criteria in C105 for deciding to use polyethylene encasement include resistivity of 700 ohm-centimeters, which is suataintially below Reclamation criteria in Table 1. (The test methods are different (AWWA C105 uses a soil box versus Reclamation field test) but the resistivity criteria are still widely different.

Comment [m27]: Actually, C105 Appendix A gives the 10 point system and suggests that PE encasement be used when 10 points are required. You should discuss the 10 point system, its components and merits at this time. In addition, a discussion of ASTM A888 used for CIP should be discussed and cited in this section.

Comment [m28]: Suggest listing reference for each point, if possible.

2. Intact Voids in polyethylene generally occur at bell and spigots where the polyethylene wrap is not necessarily in direct contact with the pipe surface. Polyethylene encasement acts as a barrier and prevents direct contact between the pipe and soil.
3. The polyethylene encasement is not bonded to the pipe. Therefore, if space exists between the encasement and the pipe surface and, as such, allows moisture can exist within the annular space between the pipe and polyethylene encasement. The moisture Moisture, when present, and its dissolved oxygen will initially result in corrosion on the pipe surface, but once the dissolved oxygen is consumed by the initial corrosion reaction further corrosion will be stifled. The moisture devoid of oxygen within the annulus space then provides a noncorrosive, uniform environment to the pipe surface.
4. The polyethylene encasement retards the transport of dissolved oxygen to and corrosion products away from the pipe surface.
5. Significant exchange of moisture within the annulus is prevented by the weight and compaction of the backfill. backfill, which presses the polyethylene against the pipe.
6. Stray current corrosion from external sources is reduced by the dielectric barrier of the polyethylene.
7. Although it may be required, polyethylene Polyethylene encased pipe can be cathodically protected.

Opponents of Opponents of using polyethylene encasement indicate that the pipe surface opposite surfaces adjacent to holidays in the polyethylene encasement experience corrosion, that pipe surfaces under intact polyethylene encasement experience corrosion, and that corrosion occurring under intact polyethylene encasement can not be mitigated by cathodic protection due to the shielding created by the unbonded encasement, see Figure 5, (Fitzgerald, 1968; Garrity et al., 1989; Noonan, 1996; Szeliga and Simpson, 2001; Spickelmire, 2002). The opponents further indicate that corrosion under intact polyethylene encasement cannot be detected by above ground corrosion monitoring methods (e.g., pipe-to-soil potential surveys) and corrosion under intact polyethylene will go undetected until failure (Szeliga and Simpson, 2003). Thus, opponents favor direct bonded coatings and test stations.

The opponents of using polyethylene encasement often reference the following three national documents as supporting documentation of their position. The first is position:

- The NACE International's RPO 169-2002 Recommended Practice RP0169-2002 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems." RPO 169 requires a tight bonded dielectric coating for Systems";
- buried pipeline applications and indicates that unbonded coatings (polyethylene encasement is considered an unbonded coating) can create electrical shielding of the pipeline that could jeopardize the effectiveness of the cathodic protection system. The second is The Code of Federal Regulations (CFR) Title 49 parts Parts 192 and 195 (October 1, 2002) as enforced by the U. S. Department of Transportation's Office of

Comment [m29]: Voids in polyethylene generally occur at bell and spigots where the polyethylene wrap is not necessarily in direct contact with the pipe surface. Add this comment to point 3 of the text, last sentence

Comment [m30]: Make bullets of these item , like abve

Comment [m31]:

Comment [m32]: The correct reference is RP0169-2002 (it is a zero not an "O").

Pipeline Safety. 49 CFR 192 and 195 does not allow unbonded coatings as an acceptable corrosion mitigation technique for federally regulated pipelines. Federally regulated pipelines include pipelines which transport natural gas or hazardous Safety;

- liquids. It should be noted that water pipelines are not federally regulated. The third is The Docket No. OPS-5A (Federal Register Vol. 36, No. 166 – Thursday, August 26, 1971).

While the 3 documents were primarily developed for the oil and gas industry. RP0169 requires a tight bonded dielectric coating for buried pipeline applications and indicates that unbonded coatings (polyethylene encasement is considered an unbonded coating) can create electrical shielding of the pipeline that could jeopardize the effectiveness of the cathodic protection system. The 49 CFR 192 and 195 do not allow unbonded coatings as an acceptable corrosion mitigation technique for federally regulated pipelines, and federally regulated pipelines include pipelines which transport natural gas or hazardous liquids. (Water pipelines are not federally regulated.) In Docket No. OPS-5A, the Office of Pipeline Safety specifically denied a petition to permit the use of a loose polyethylene encasement for cast and ductile iron pipes as an alternative method of corrosion control, and as indicated by 49 CFR 192 and 195 this is the Office of Pipeline Safety's current position.

Proponents of polyethylene encasement correctly point out that in order for corrosion monitoring and cathodic protection systems to be effective, the facilities must be actually used and maintained. They contend that the added expense of constructing the systems, combined with the effort and expense to maintain them, places an additional burden on the owner/operator, compared to polyethylene encasement.

In summary, proponents and opponents of using polyethylene encasement agree that corrosion can occur at locations where holidays in the polyethylene encasement expose the pipe wall to the soil and that the resulting corrosion can be mitigated by cathodic protection. Proponents and opponents agree that corrosion can take place under intact polyethylene encasement, however, they do not agree on the severity of corrosion which that can take place. The opponents indicate the potential benefits of a corrosion monitoring system far exceed the costs of constructing it concurrently with the pipeline, and there is minimal risk of increasing stray current if the that under most situations the corrosion reaction occurring under intact polyethylene encasement will be stifled and significant corrosion does not occur pipeline is made electrically continuous at the joints. The opponents indicate that the corrosion reaction under intact polyethylene encasement is not stifled, significant corrosion can occur, and cathodic protection cannot be used to mitigate the corrosion.

Bonded Dielectric Coatings

Bonded dielectric coatings can be and have been successful applied to ductile iron pipe (Szeliga et al., 1993; Garrity et al., 1989; Pimentel, 2001; Brander, 2001; Lieu and Szeliga, 2002; Fogata, 2003). AWWA M41 – Ductile Iron Pipe and Fittings lists tight bonded coatings as an alternative corrosion mitigation method for ductile iron pipe. Coatings similar to those applied to steel pipe can be applied to ductile iron pipe, however, but special methods for surface preparation and

Comment [m33]: This is for oil and gas, it does not mean it is applicable…there are lots of other requirements in the CFR's that are also not followed in the water industry. Unless you are willing to accept the entirety of the requirements, you might want to tone down the use of these CFR's. (e.g. CP is required, monitoring is required, recordkeeping is required, etc., etc.). This is a slippery slope you might not want to go down all the way.

Comment [m34]: Suggest adding a paragraph containing arguments against non-polyethylene encasement approach

Comment [m35]: Suggest noting that the advocares of this position usually make no distinction among the pipelines where it applies, regardless of whether small distribution lines or major transmission lines are considered.

cleanliness must be applied. Preparation guidelines for the surface of steel pipe ~~generally~~ (Steel Structures Painting Council a.k.a. SSPC) cannot be used for ductile iron pipe. This is because the steel surface preparation standards for steel do not represent the same levels of cleanliness on iron due to the differences in the microstructure (particularly for Delavaud cast pipe). In addition, application of steels standards can lead to overblasting and damage to the iron surfaces which negate/preclude the application of thin film liquid applied coating systems. In 2000, the National Association of Pipe Fabricators, Inc. (NAPF) published a standard for surface preparation for ductile iron pipe and fittings (NAPF 500-03, 2000). Prior to the NAPF standard, there were no national standards for the surface preparation of ductile iron pipe and most organizations had to write their own surface preparation and coating specifications.

Ductile iron pipe manufactures and the Ductile Iron Pipe Research Association (DIPRA) often contend that the expenses of tight bonded dielectric coatings are not generally warranted (Stroud, 1989).

Comment [m36]: What is the purpose of this statement? What is the opposing position on the issue? You need to put in something here to complete the thought

Discussion

It ~~must~~ should be noted that there are several important issues ~~which~~ that influence ~~our~~ Reclamation's position relative to corrosion control. ~~We will present these issues~~ These issues are presented below prior to discussing the underlying issue of this document, that being the use of polyethylene encasement as a corrosion control method. Reclamation projects typically require a life of 50 years or greater. Reclamation work can involve both transmission and distribution pipelines. In relation to distribution pipelines~~;~~ , transmission pipelines tend to be larger in diameter, are more critical ~~in nature,~~ elements of the infrastructure, have greater consequences associated with failure, and have fewer appurtenances (e.g., household services). Therefore, ~~our~~ this evaluation and the position ~~is focused~~ presented focus on transmission pipelines requiring a minimum ~~50 year life. Our position~~ life of 50 years. Positions on the use of corrosion monitoring systems and protective coatings are presented below.

Comment [m37]: With proper inspection and maintenance, infrastructure should have an indefinite life…you need to talk about maintenance issues.

Corrosion Monitoring Systems

Irrespective of the amount of environmental testing that is conducted prior to pipeline design, there is always a potential for a buried pipeline to have ~~corrosion related~~ corrosion-related problems. Without a corrosion monitoring system, ~~corrosion related~~ corrosion-related problems can be difficult to detect prior to a ~~corrosion related~~ corrosion-related failure. If a ~~corrosion related~~ corrosion-related problem is identified, the corrosion monitoring system allows a means to investigate and address the problem. Without a corrosion monitoring system the options available to identify, investigate, and address ~~corrosion related~~ corrosion-related problems are limited. It should be noted that providing positive electrical continuity of a pipeline will increase the probability of pipeline corrosion resulting from long line and/or stray currents. However, the corrosion monitoring system can be used to investigate, identify, and mitigate long line and stray current corrosion. The benefits of a corrosion monitoring system far exceed the risks. Our position has been and continues to be that buried pipelines be installed with corrosion monitoring systems.

Comment [m38]: What kind of test stations are you talking about? 2 wire or 4 wire (line drops)…you need to be more specific.

Comment [gecb39]: What about ER probes? Rohrback Cosasco has them part number 620DI-S100-25 for about $350 each and they work very well.

Protective Coatings

For the purpose of this report, polyethylene encasement is considered a protective coating (its intended function is to protect the pipe from corrosion) and the 1-mil asphaltic coating applied to ductile iron pipe is not considered a corrosion control or barrier protective coating for the exterior of a buried pipeline.

Buried metallic pipelines have the potential to corrode and typically require some form of corrosion protection. Without a protective coating the remaining corrosion protection alternative is cathodic protection. A bare pipe can be adequately protected with a cathodic protection system, however, the amount of current required to protect a bare pipeline is significantly greater than the amount of current required to protect a ~~well coated~~ well-coated pipeline. The larger current requirement results in a larger number of cathodic protection ground beds (locations at which the protective current is injected into the ground) which increases the design, installation, operation and maintenance, and power requirements associated with the cathodic protection system.

Another important consideration is the effect the cathodic protection may have on buried, adjacent, metallic structures. In addition to existing structures, future development along the pipeline should be considered as future development tends to increase the number of buried metallic structures adjacent to the pipeline. The probability of a cathodic protection system negatively effecting, by cathodic interference, existing and future buried adjacent structures is significantly increased with a bare pipeline.

Therefore, our position has been and continues to be that buried pipelines be installed with protective coatings and that the protective coatings be compatible with cathodic protection.

Polyethylene Encasement

The major controversies related to ductile iron pipe involve the effectiveness of polyethylene encasement as a corrosion mitigation method and the compatibility of polyethylene encasement and cathodic protection. The technical disagreements generally are focused on the occurrence of corrosion under intact polyethylene encasement and the mitigation of that corrosion by the use of cathodic protection.

As with bonded dielectric coatings, installed polyethylene encasement will not be holiday free. Holidays within the polyethylene encasement can occur during manufacturing, installation, and/or deterioration with time. At holidays the pipe wall is exposed to the soil and corrosion will occur as governed by the corrosion characteristics of the soil. It is widely accepted that corrosion can occur on the pipe wall opposite of polyethylene encasement holidays and that this corrosion can be mitigated by cathodic protection.

DIPRA has an inspection program where they have conducted a number of inspections on operating pipelines with polyethylene ~~encasement,~~ encasement; the inspection program indicates positive results with the use of polyethylene encasement (Stroud, 1989).

Comment [gecb40]: IT IS AN ECASEMENT NOT A COATING.

Comment [gecb41]: Based on the cost of cathodic protection, you can show that from an economic standpoint you should never pay more than $3 per square foot for a coating because you can cathodically protect it for that amount. Reference: G.E.C. Bell, Value Engineering and Corrosion Control, AWWA Cal-Nevada Section, Spring Meeting, April 10, 1997, San Jose, CA.

Comment [gecb42]: Use the word stray current (since you use it elsewhere in the document) and show a schematic. Stray current is a design issue and with proper design and testing, is easily mitigated. Since you reference the oil and gas CFR, this is also required and not a big deal.

Comment [m43]: Suggest adding a sentence summarizing the converse of the previous two paragraphs, to emphasize that a highly efficient and compatible coating makes cathodic protection more economical and safer by reducing the potential for stray current from the system to affect other underground facilities.

Comment [gecb44]: I do not see how this follows from the facts. As stated above, stray current is not the death knell of a project. This statement is not supported by facts…possibly economics, but it depends on the price of coatings.

Comment [m45]: Suggest adding some subheading for this section to highlight key points and improve readability.

Others have reported that the rate of corrosion corrosion under undamaged polyethylene encasement is very low (Schiff and McCollom, 1993). A continuation of the Schiff and McCollom work indicates that corrosion under undamaged polyethylene encasement has remained low, that the corrosion rate under undamaged polyethylene is an order of magnitude less than that experienced outside the polyethylene within sand backfill, and that cathodic protection is effective under undamaged polyethylene (Bell, 2003).

Corrosion occurring under intact polyethylene encasement has been reported (Szeliga and Simpson, 2003; ~~Spicklemire,~~ Spickelmire, 2002; Fogata, 2003). It is widely accepted that the presence of foreign material (e.g., soil) between the polyethylene encasement and pipe surface results in corrosion of the pipe surface in contact with the foreign material. Several of the Cast Iron Pipe Research Association (CIPRA) and Ductile Iron Pipe Research Association (DIPRA) excavations indicate that corrosion pits have been observed under foreign material on the pipe wall which was located under undamaged polyethylene encasement. (CIPRA, 1968; CIPRA 1969; DIPRA, 1981; Stroud, 1989). The CIPRA/DIPRA reports of the inspections typically have speculated that the corrosion under foreign materials had stopped (CIPRA, 1968; CIPRA, 1969; DIPRA, 1981). The ductile and grey cast iron pipelines inspected in San Diego during the CIPRA 1968 and DIPRA 1981 excavations have experienced ~~corrosion related~~ corrosion-related failures (Fogata, 2003). The San Diego cast iron pipeline was one of the initial installations of polyethylene encasement, installed in 1961, and the soil in which the pipelines were buried are considered very corrosive (DIPRA, 1981).

As recommended by the 1993 Schiff and ~~McCollum~~ McCollom report, corrosion resistance probes were placed under polyethylene encasement at various distances from a slit (holiday) intentionally cut in the polyethylene encasement (McCollom, 2003). The probes were installed at a location along the pipeline where ground water was expected at pipe depth. This work indicates that cathodic protection may not be effective in mitigating corrosion occurring under undamaged polyethylene located adjacent to holidays in the polyethylene encasement.

Dielectric coatings allow penetration of moisture, gases, and ionized ~~substances, the rates at which they allow this~~ substances. The penetration rates are dependent on coating characteristics, environmental conditions, and time (Toncre, 1981). It has been shown that metal exposed at holidays in dielectric coatings ~~are~~ is anodic ~~to metal under intact dielectric coatings~~(Craig and Olson, 1976). This demonstrates the conductive abilities of dielectric coatings and that they generally are not perfect electrical insulators.

Corrosion and the mitigation of corrosion under disbonded coatings ~~has~~ have been a concern within the corrosion industry for a number of years and, therefore, there has been research conducted in these areas. Corrosion can occur under disbonded dielectric coatings (Koehler, 1971 and 1977; Fessler et al., 1983; Leidheiser, 1983; Scantlebury et al., 1983; Jack et al., 1994; National Energy Board, 1996; Beavers and Thompson, 1997; Daikow et al., 1998; Song et al., 2003; FHWA, 2001). Unfortunately, the studies conducted have included common coatings used on steel pipe and have not included the polyethylene encasement used on ductile iron pipe. However, there are studies ~~which~~ that have included a polyethylene tape system for pipelines. The polyethylene tape is composed of a polyethylene film laminated with an adhesive/mastic. The adhesive/mastic is used to provide a bond to the metal substrate and, therefore, the

Comment [m46]: See inserts above. The damaged/undamaged work is not really complete and needs to be discussed in terms that perhaps the use of coupons caused the tears to be worse than they are. See comments below.

Comment [m47]: Did any of these projects have cathodic protection?

Comment [m48]: Suggest reorganizing by moving last sentence to start of paragraph.

Comment [m49]: This work is preliminary and the actual reason for the changes has not been identified. Further, the size of the probes themselves may be a factor the at skews and accelerates the corrosion since the shape does not allow the encasement to lay flat against the pipe surface. That is, the pipe surrogate (electrical resistance probe) may not be a good surrogate for the pipe wall.

Comment [m50]: Suggest stating that the discussion is extrapolating the finding from studies on pipeline tape because the polyethylene backing of the tape is the most similar studied material to polyethylene sheet. He notes that this would likely be challenged by DIPRA.

Comment [m51]: Isn't polyethylene tape more flexible and pliable than polyethylene encasement? Since the mechanical and physical properties will greatly impact the moisture permeation, shouldn't you compare/state these properties as well as simply the material type.

polyethylene tape is considered a tight bonded dielectric coating. The polyethylene tape systems are generally applied ~~by the application of~~ with one to three polyethylene tape layers. These studies indicate that most dielectric coatings are capable of conducting ~~current. However,~~ current, but not the polyethylene ~~tape is one dielectric coating that the studies typically indicate does not conduct current~~ tape, and cathodic protection is not effective under disbonded polyethylene tape away from holidays (Barlow and Zdunek, 1994; National Energy Board, 1996; Beavers and Thompson, 1997). Furthermore, it has been reported that oxygen readily diffuses through polyethylene tape systems (Beavers and Thompson, 1997). There have been cases where corrosion has occurred under disbonded polyethylene tape when testing indicated that the pipeline was receiving adequate levels of cathodic protection (National Energy Board, 1996; Beavers and Thompson, 1997).

AWWA C105 requires the removal of obvious surface contamination but does not address less obvious surface contamination. Proper surface preparation is critical for the ~~long term~~ long-term success of protective coatings. An important step in surface preparation is the removal of contaminates from the surface to be coated. Surface contaminates include rust, chlorides, oil, grease, soil, and etc. Surface contaminates can effect adhesion of bonded coatings and they can promote corrosion of the surfaces beneath bonded or unbonded coatings. Since polyethylene encasement is installed on pipe at the construction site, there are opportunities for surface contaminates to collect on the pipe during storage, transportation, and installation. Because surface contaminates can and do promote corrosion, investigations should be conducted within this area. This is an area where further investigation might shed more light on the potential for corrosion under intact polyethylene.

The above indicates that ~~long term~~ long-term corrosion can occur under intact polyethylene encasement with or without the presence of foreign material. Therefore, there must be an active mechanism ~~which~~ that replenishes moisture and/or dissolved oxygen within the annulus between the polyethylene encasement and pipe wall. There are two ~~methods in~~ mechanisms by which moisture and/or oxygen can enter the annular space. Moisture and oxygen can enter the annular space through holidays in the polyethylene encasement or through the polyethylene encasement itself. Therefore, corrosion under intact polyethylene encasement is highly dependent upon the diffusion of moisture and oxygen through the polyethylene encasement, and/or transportation of moisture and oxygen through polyethylene encasement holidays. The ~~dominate~~ dominant route is expected to be through the holidays. Once in the annulus, moisture can be transported ~~within the annulus by~~ by free flow and/or capillary action.

~~Time has provided cases where~~ Successful applications of polyethylene encasement ~~has been successful and where it has not been successful.~~ have been reported. Unsuccessful applications have also been reported. To complicate matters further, the nature of the corrosion experienced on cast and ductile iron pipe is such that the recognition of ~~corrosion related~~ corrosion-related failures is not readily apparent and, as such, corrosion failures may not be fully accounted for. It is unfortunate, but after 40 years of use there are still basic issues regarding the use of polyethylene encasement that must be addressed.

Comment [m52]: The purpose of surface preparation is to promote adhesion of a bonded coating. For some coatings, little or no surface preparation is required. I can also argue that since polyethylene encasement is an unbonded coating that adhesion is not a requirement. I think what you actually are getting at surface cleanliness

Comment [m53]: Isn't this a construction inspection issue? Can the same thing occur to pipes with bonded coatings?

Comment [m54]: I would submit that unless the surface contaminants support the reduction reaction, then so long as oxygen is excluded, corrosion is mitigated. Chloride is certainly a depolarizing agent and should be excluded.

Comment [m55]: With or without cathodic protection? Can't the same thing happened with other coatings? What about the application problems with coatings…not just on DIP but on all surfaces? Coatings are not fail safe.

Comment [m56]: Reference? Or has this been measured?

Comment [m57]: What forms the annulus? Doesn't the weight of the soil push the polyethylene up against the pipe?

Comment [m58]: Suggest considering the positions of the Europeans and other international groups on the issue. He states that it is his understanding that polyethylene encasement has not been accepted as the sole form of protection for ductile iron in Europe. Also consider noting that in the U.S., the situation with respect to polyethylene encasement seems to have resulted in the evolution of 3 camps: (1) those outright rejecting polyethylene encasement and treating of ductile iron pipe the same as steel pipe, (2) those completely accepting polyethylene encasement, and (3) those somewhere between these two positions. This would seem to reinforce the conservative position recommended by Reclamation, namely, limiting the use of polyethylene encasement until research answers the fundamental questions posed in the Recommendations section.

Comment [m59]: Just like every other corrosion control system…cathodic protection is not fool proof, coatings are not perfect. The most fail safe and perhaps cost effective is clean backfill.

Comment [gecb60]: Further, it is my experience that the failures that are reported are not fully investigated to identify root causes beyond simple corrosivity testing…again, my experience is that there are typically other factors that lead to the failure beyond simply soil corrosivity.

Conclusions and Recommendations

~~Conclusions:~~

1. ~~The use of polyethylene encasement for corrosion protection of ductile iron pipe is a very controversial subject.~~

2. ~~Graphitic corrosion can occur on cast and ductile iron pipelines. Graphitic corrosion is difficult to visually detect and as a result failures resulting from graphitic corrosion are often not recognized as corrosion related failures.~~

3. ~~There are two general categories of corrosion which can occur with the use of polyethylene encasement. Corrosion can occur on the pipe wall opposite holidays in the polyethylene encasement and corrosion can occur on the pipe wall under intact polyethylene encasement.~~

4. ~~Corrosion opposite holidays in the polyethylene encasement is highly dependent upon the corrosion characteristics of the soil.~~

5. ~~Corrosion under intact polyethylene encasement is highly dependent upon the availability of oxygen under the intact polyethylene encasement.~~

6. ~~The corrosion rates associated with the two categories are generally not the same. With all other factors being equal, it would be expected that the corrosion cell occurring opposite of holidays will have a higher corrosion rate than the corrosion cell occurring under intact polyethylene encasement (this is not applicable to microbiologically influenced corrosion).~~

7. ~~The corrosion experienced on the pipe wall opposite holidays in the polyethylene encasement can be mitigated with the application of cathodic protection.~~

8. ~~Detecting corrosion that occurs under intact polyethylene encasement with above ground monitoring methods is very unlikely.~~

9. ~~Mitigating corrosion that occurs under intact polyethylene encasement with cathodic protection is very unlikely.~~

~~Recommendations:~~

1. ~~Do not use polyethylene encasement until the following issues are addressed to our satisfaction:~~

    a. ~~What are the mechanisms and what is the extent of corrosion occurring on metallic surfaces under intact polyethylene encasement? This should include microbiologically influenced corrosion.~~

   b. ~~Is cathodic protection effective in mitigating corrosion occurring under intact polyethylene encasement?~~

2. ~~Continue the evaluation of the corrosion mitigation alternatives listed in the Corrosion Prevention Criteria and Requirements table, with the focus being on the other pipe alternatives listed.~~

3. ~~Conduct research to address the issues identified in Recommendation 1. Research conducted on existing structures could provide a wealth of data. The performance of protective coatings and their compatibly with cathodic protection is considered very important; the results could impact what protective coatings can be used with all metallic pipe alternatives. Surface contaminates beneath unbonded dielectric coating should be investigated.~~

4. ~~Form partnerships such that the research can be efficiently performed. Partners from federal, state, local, and industry should be sought. In addition, partners from Canadian organizations should be sought. Canadian organizations have and continue to research common areas of interest.~~

Conclusions:

1. The literature review here indicates that the use of polyethylene encasement for corrosion protection of ductile iron pipe is still a controversial subject.

2. Graphitic corrosion can occur on grey cast and ductile iron pipelines, but is frequently not recognized as a root cause of failure.

3. For ductile iron, with PE and no cathodic protection:

   a. Corrosion can occur on the pipe wall adjacent to holidays in the polyethylene encasement and on the pipe wall under intact polyethylene encasement;

   b. Corrosion that occurs adjacent to holidays in the polyethylene encasement is dependent upon the corrosion characteristics of the soil;

   c. Corrosion under intact polyethylene encasement (as well as most all corrosion cells) is dependent upon the availability of oxygen under the intact polyethylene encasement;

   d. It would be expected that the corrosion cell occurring adjacent to holidays will have a higher corrosion rate than the corrosion cell occurring under intact polyethylene encasement.

Comment [m61]: The conclusion might be more effective as a Summary & Conclusion section, with narrative reviewing major issues and then the conclusion (all but one of the numbered paragraphs in the original draft is about encasement, and #6 refered to micrbiologically induced corrosion, which is only mentioned in the appendix. (Need to include in body of text.)

Comment [m62]: This may be true but it is not clear why this is important enough to listed as a conclusion. I assume that it is related to the fact that this makes it difficult to get a proper count of "corrosion failures" and this make it hard to evaluated the various choices you might have for constructions.

4. For ductile iron, with PE and cathodic protection

   e. The corrosion experienced on the pipe wall adjacent to holidays in the polyethylene encasement can be mitigated with the application of cathodic protection;

   f. Mitigating corrosion that occurs under intact polyethylene encasement with cathodic protection is inconclusive and additional research is needed.

5. Detecting corrosion that occurs under intact polyethylene encasement with above ground monitoring methods is, as with any disbonded coating, difficult.

Recommendations:

1. Use polyethylene encasement, as per revised (2004) Table 1.

2. There are a number of issues that need to be addressed, including the following:

   a. What are the mechanisms and what is the extent of corrosion occurring on metallic surfaces under intact polyethylene encasement? This should include microbiologically influenced corrosion.

   b. Is cathodic protection effective in mitigating corrosion occurring under intact polyethylene encasement?

   c. The performance of protective coatings and their compatibility with cathodic protection, with variables such as surface contaminates beneath unbonded dielectric coating, and the effects of pipe zone backfill on PE should be investigated

3. Conduct research to address the issues identified in Recommendation 2.

4. Continue the evaluation of the corrosion mitigation alternatives listed in the Corrosion Prevention Criteria and Requirements Table 1, for the other pipe alternatives listed.

5. Form partnerships, so that the research can be most efficiently performed. Partners from federal state, local, and industry should be sought. In addition, partners from Canadian organizations, who continue to research common areas of interest, should be sought.

Comment [m63]: Suggest presenting the recommendations as a short narrative, but leaving 1a and 1b as stated (because these are profound questions). He adds that a related question is what is the relationship between polyethylene performance and pipe bedding and backfill materials (At one time imported pipe zone materials were required to be fine-grained to minimize damage to polyethylene. But resent versions of AWWA C105 don't include these limitations - and confirmed by DIPRA, without any evidence of research to support this change.) Also, the recommendations should include how Table 1 would look if polyethylene encasement is deleted, and reiterate that Reclamation's other requirements for corrosion monitoring and cathodic protection would still apply. The call for additional research (3 and 4) is apropiate but may deserve further consideration if Reclamation is obligated to perform the recommend actions.

Comment [gecb64]: Does this include with or with out CP, See graphs from above. Why do you need to know the mechanism if corrosion control is effective?

Comment [gecb65]: If you are going to talk about this, you had better discuss this earlier and get all of the information on the table.

Comment [m66]: Reword as a statement, rather than a question

Comment [m67]: Reword to fit into the flow here.

Comment [gecb68]: Agreed, but you need to define the conditions under which the measurements are made. In general, I would say that your criteria are too conservative, but Reclamation can make whatever internal design requirements that they want…at the end of the day, it is your pipe.

Comment [m69]: The cited references are abundant, bordering on too many.

Cited References

Avner, S.H., 1974. *Introduction to Physical Metallurgy*, Second Edition, McGraw-Hill.

AWWA M41, 2003. *Ductile-Iron Pipe and Fittings, AWWA Manual M41*, Second Edition, American Water Works Association, Denver, CO.

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Table 1.—Corrosion Prevention Criteria and Requirements

Corrosion Prevention Criteria and Requirements (Updated on April 23, 2003)					
Pipe Alternative	External Protection (primary/supplemental)	Soil Resistivity - 10% probability value (ohm-m)		Corrosion Monitoring System	Cathodic Protection System
		Irrigation	M&I		
Ductile iron	Polyethylene encasement*	>15 ≤15	>30 ≤30	x x	 x
	Bonded** dielectric	>10 ≤10	>20 ≤20	x x	 x
Prestressed concrete***	Mortar/coal-tar epoxy	>25 ≤25	>50 ≤50	x x	 x
Pretensioned concrete	Mortar	>20 ≤20	>40 ≤40	x x	 x
	Mortar/coal-tar epoxy	>15 ≤15	>30 ≤30	x x	 x
Reinforced concrete	Concrete	>20 ≤20	>40 ≤40	x x	 x
	Concrete/coal-tar epoxy	>15 ≤15	>30 ≤30	x x	 x
Steel	Mortar	>20 ≤20	>40 ≤40	x x	 x
	Mortar/coal-tar epoxy	>15 ≤15	>30 ≤30	x x	 x
	Bonded** dielectric	>10 ≤10	>20 ≤20	x x	 x

* Applicable to pipe with corrosion allowance, 24-in inside diameter maximum, and 150 lb/ft maximum.
(NOTE: Given recent pipe industry experience with ductile iron pipe, Reclamation plans to re-examine this provision.)

** Bonded directly to the metal to be protected.

*** Reclamation currently has a moratorium on this pipe alternative.

Comment [m77]: What is 10% probability value?

Comment [m78]: a note stating "X" indicates that it is recommended is needed for the table.

Figures

Comment [m79]: Appropriate figures would include: corrosion cell, corrosion at and away from pinholes in polyethylene, cathodic protection preventing corrosion, shielding, stray current corrosion, joint bond, test station.

Figure 1: Cast iron pipe section prior to sand blasting. Note color and appear of surface.

Comment [gecb80]: Need to place details on the pipe.

Figure 2: Same pipe section as shown in Figure 1 after sand blasting. Note extensive metal loss and the perforation of the pipe wall at three locations. This example demonstrates the difficulty in visually identifying areas ~~which~~ that have experienced graphitic corrosion.

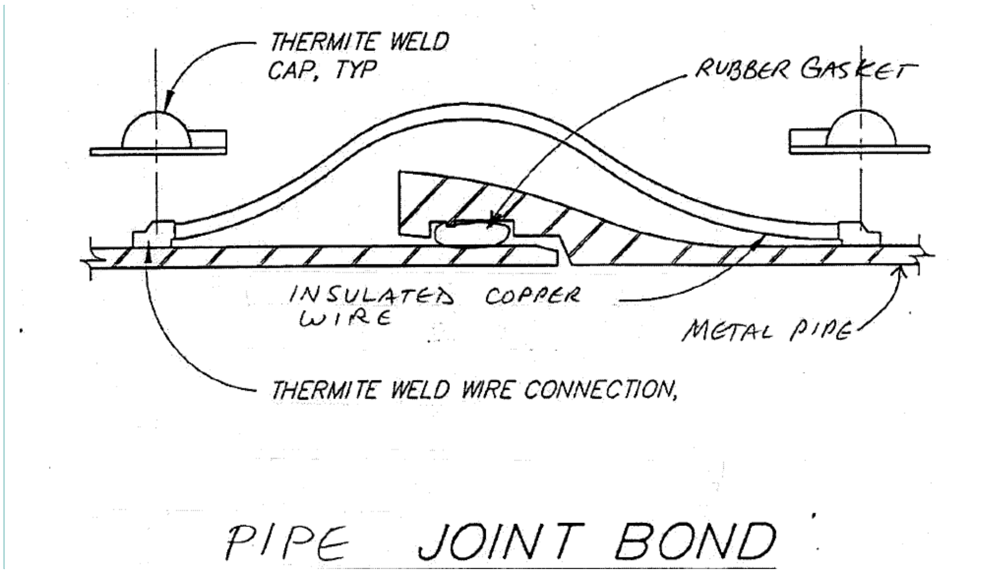

Figure 3: Pipe Joint Continuity

Comment [SL81]: Figures 3, 4, and 5 were added by the Review Panel

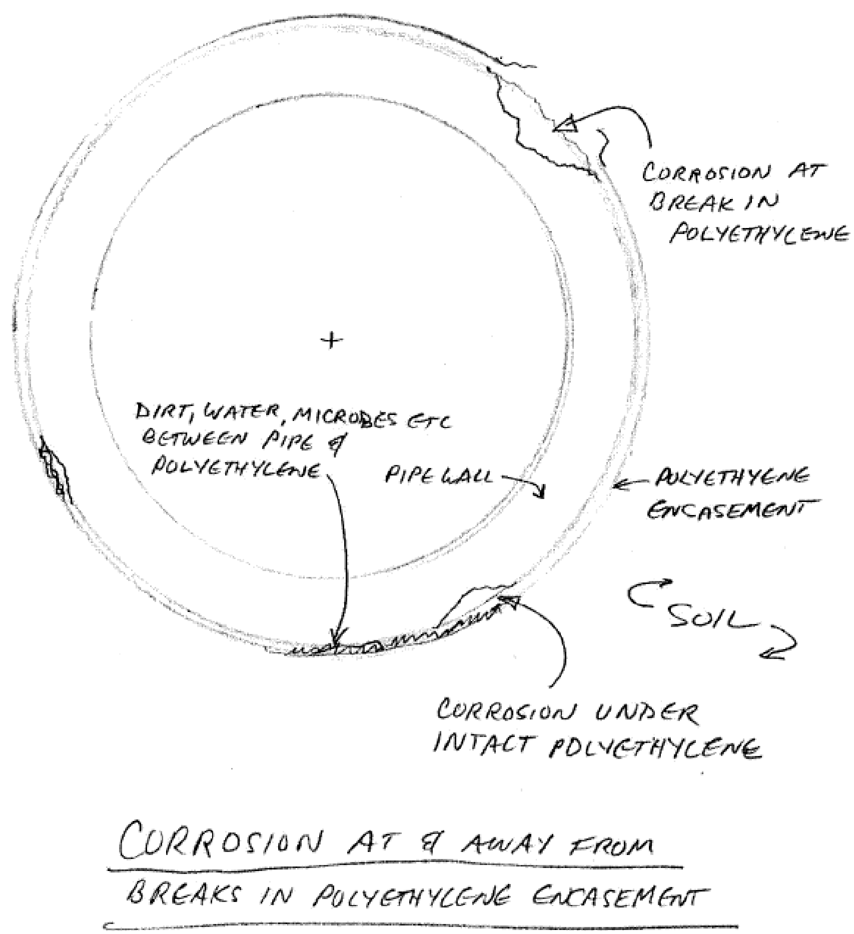

Figure 4: Corrosion Occurring at Breaks in Polyethylene Encasement (Holidays) and Under PE

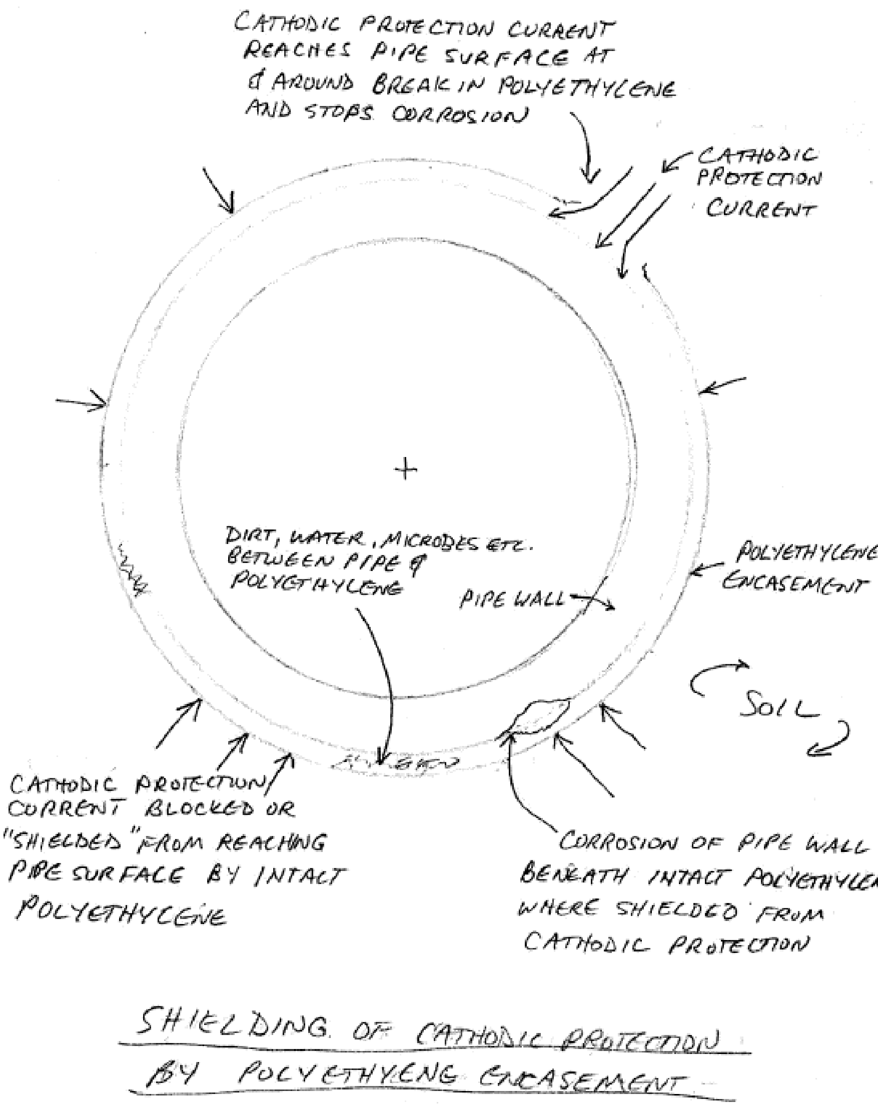

Figure 5: Shielding of Cathodic Protection by Polyethylene Encasement

Appendix A

Comment [m82]: If only appendix, A not needed

Comment [m83]: the Appendix is appropriate and useful.

Corrosion

The Basic Corrosion Cell

Corrosion is the deterioration of a material or its properties due to a reaction with its environment. This document is limited to the corrosion of metallic materials. Corrosion is a natural electrochemical reaction, see Figure A-1, between a metal and an electrolyte in which the refined metal is returned to its natural state as an ore. The following are the four required components of a corrosion cell:

1. Anode - The anode is the electrode of the corrosion cell ~~which~~ that experiences the physical destruction of corrosion (i.e., metal loss). Current (positive or conventional current) flows from the anode surface into the electrolyte taking metal ions with it.

2. Cathode - The cathode is the electrode of the corrosion cell ~~which~~ that does not experience the destructive nature of corrosion. Current collects on the cathode surface from the electrolyte. Because current is collecting on the surface metal ions are not lost.

3. Metallic path - There must be a metallic path between the anode and cathode. Current flows from the cathode to the anode within the metallic path.

4. Electrolyte - The anode and cathode must be in contact with the same electrolyte. Current flows from the anode to the cathode within the electrolyte. Ions within the electrolyte are responsible for the conduction of currents through the electrolyte.

During the corrosion process, current flows between the anode and cathode while chemical reactions occur at both the anode and cathode surfaces. At the anode current leaves the metal surface and enters the electrolyte taking metal ions with it, see Figure A-2. The metal ions are a part of the corrosion products of the corrosion reaction. Rust is the corrosion product of steel. The current flows through the electrolyte from the anode to the cathode.~~and collects on the cathode surface~~ The current then flows through the metallic path and returns to the anode. Corrosion will cease if one of the four required elements of a corrosion cell is eliminated.

Corrosion is a direct current phenomenon and can be modeled by electrical circuit analysis. Ohm's Law ~~(V=IR)~~ ($\Delta V=\Delta IR$) is commonly used in analysis of corrosion cells. Ohm's Law indicates that there must be a potential (voltage) difference between the anode and cathode for current to flow between them. Potential differences between anodes and cathodes can be formed in many ways. In a corrosion cell, the amount of corrosion (metal loss) is directly proportional to the amount of current flowing. From Ohm's Law it can be seen that for a given resistance, larger potential differences result in greater corrosion. Conversely, smaller potential differences result in less corrosion. For a given voltage, less corrosion occurs in corrosion cells with higher resistance than those with lower resistance.

Comment [gecb84]: You might want to refer to AWWA M27 which is the newly updated version of External Corrosion Control for Water Pipelines. It give a very complete overview of the subjects.

Comment [m85]: Suggest adding a reference to Faraday's Law, in para 3, to support statement regarding metal loss as a function of current (but I am not sure if this is the correct page)

Comment [m86]: Suggest noting that the reduction of oxygen is the principal and often rate-controling cathodic reaction in neutral or alkaline conditions. This would support the points in the tect regarding restriction of oxygen to control corrosion

Anodes and cathodes can be on the same metal surface or they can be on two different metals ~~which~~ that are in contact with one another**.** Anodes and cathodes can be atoms apart, they can be inches apart, or on large structures, such as pipelines, they can be miles apart.

Factors Influencing Corrosion

As indicated above if there is a potential difference between the anode and cathode, corrosion can occur. There are many factors ~~which~~ that can cause potential differences.

Corrosion of metals can be grouped into two categories: galvanic ~~and stray current.~~ (dissimilar material couples) and electrolytic (stray current), see Figure A-3. The difference between the two is the source from which the corrosion current is derived. In galvanic corrosion the source of current is within the corrosion cell itself, that being the potential difference between the anode and cathode. For stray current corrosion the source of current is external to the corrosion cell. It should be noted that the overall result is the same, corrosion occurs at the anode.

Galvanic corrosion cells can be formed by material differences and environmental differences. One of the most widely recognized galvanic corrosion cell caused by material differences is that of dissimilar metals. When two different metals are joined and are in contact with a common electrolyte, one metal will become the anode and the other ~~metal will become~~ the cathode. As a result of the coupling the corrosion rate of the anodic metal will be accelerated while the corrosion rate of the cathodic metal will be reduced or eliminated. It should be noted that dissimilar metals are not the only type of materials differences. Material differences can also occur on the same metal and can be caused by many conditions, including metallurgical variables, differences in stress, surface imperfections such as scratches, mill scale on steel, and etc.

Environmental differences can result in galvanic corrosion. Examples of environment difference include differences in oxygen concentrations, pH, temperature, soils, velocity and etc. The oxygen concentration corrosion cell is common. In the oxygen concentration corrosion cell the surface in contact with the higher dissolved oxygen concentration becomes cathodic to the surfaces in contact with the lower dissolved oxygen concentration, which becomes anodic. The anodic areas (lower dissolved oxygen concentration) experience accelerated corrosion as a result of the oxygen concentration cell. Deposits on a surface, such as mud or sand, can cause an oxygen concentration cell. The oxygen concentration under the deposit is less than that in the surrounding electrolyte, resulting in accelerated corrosion occurring under the deposit. Crevices can also form an oxygen concentration cell, with corrosion occurring in the crevice due to the lower oxygen concentration being within the crevice as compared to the electrolyte outside of the crevice.

Comment [m87]: velocity of what?

An important consideration in the analysis of galvanic corrosion cells ~~are~~ is the relative surface areas of the anode and cathode. As the surface area of the anode decreases in relation to the surface area of the cathode, the intensity of corrosion on the anode surface increases. This results from an increase in current density discharging from the anode surface. No matter what condition has initiated the corrosion cell, if the anodic area is relatively small with respect to the cathodic area, corrosion will tend to be intense. If, on the other hand, the anodic area is large as compared to the cathodic area, corrosion will be relatively mild.

Polarization of a corrosion cell is an important factor ~~which~~ that controls the rate of corrosion. The anodic and cathodic reactions result in products being formed on the surfaces of the anodes and cathodes. Corrosion in neutral and near-neutral electrolytes results in formation of a hydrogen film on cathode surfaces. The hydrogen film can act as an insulating barrier. Current flow through this insulting film provides a voltage drop across the film ~~which~~ that is in opposition to the original driving voltage of the corrosion cell. The overall effect of the voltage drop is a reduction in the driving voltage of the corrosion cell, which in turn, results in less current flow and, therefore, less corrosion. This process is known as polarization and reduces the amount of corrosion occurring. Anything that disrupts the polarization film (depolarization) increases the corrosion rate. Depolarization can occur from mechanical and/or chemical means. Water flow can strip polarization films from anode and cathode surfaces. Dissolved oxygen within an electrolyte can be a major factor in ~~depolarization, the~~ depolarization. When oxygen combines with ~~the~~ hydrogen ~~and when it does it is breaking~~ to form water, it breaks down the hydrogen film.

In neutral or near-neutral environments, oxygen and moisture are required for corrosion. From a corrosion standpoint, soil is a neutral or near-neutral environment. Therefore, oxygen has an important role in corrosion by soils.

Two prominent factors affecting corrosion in soils are the soil resistivity and aeration. Soil resistivity has an impact on the overall circuit resistance of the corrosion cell. A decrease in soil resistivity generally results in a decrease of the overall circuit resistance. According to Ohm's Law as the circuit resistance decreases the current flow increases (assuming a constant voltage). Therefore, soils with lower resistivities are generally more corrosive than soils with higher resistivities. Aeration affects corrosion by promotion of oxygen concentration cells.

Comment [m88]: Actually, oxygen is the cathodic reduction reaction that supports the anodic oxidation reaction. If there is no oxygen in a neutral solution, there is no corrosion. A potential difference will exist, but since the reduction reaction is gone, there can not be any further oxidation.

Stray current corrosion or interference results from the unintentional collection of current on a structure from a foreign power source. The collected current must return to the source from which it originated and to do so it must leave the structure on which it collected. Accelerated corrosion is experienced on the surface of the structure where the stray current discharges from the structure into the electrolyte on its return to the originating source.

Comment [m89]: Typically an impressed current cathodic protection system on an adjacent pipeline or structure

Microbiologically influenced corrosion occurs as a result of the metabolic process of microorganisms. They can influence corrosion by promoting concentration cells, creating corrosive conditions, and behaving as cathodic and anodic depolarizers. A common form of micro-biologically influenced corrosion involves sulfate-reducing bacteria. Sulfate-reducing bacteria require an anaerobic environment ~~which~~ that includes sulfates and hydrogen. A source of hydrogen for their metabolic process can be cathodic surfaces and, thus, they can act as a cathodic depolarizer. In addition, a by-product of their metabolism, hydrogen sulfide, is a corrosive substance.

When ~~corrosion related~~ corrosion-related leaks occur on a given pipeline system, the leak data can be used to predict the number of future leaks. It has been shown that the frequency of ~~corrosion related~~ corrosion-related leaks increases ~~logarithmically and when the accumulated~~ exponentially and when the cumulative leaks versus time is plotted on a semi logarithmic graph paper the resulting plot will tend to be a straight line. ~~Corrosion related~~ Corrosion-related failures tend not to be a single occurrence and as additional failures occur they occur more rapidly.

Comment [gecb90]: Reference is Peabody Pipeline Corrosion Control

Corrosion Mitigation

Corrosion Monitoring Systems

A corrosion monitoring system allows for testing of the pipeline without excavation and is used in the application of cathodic protection to the pipeline should the need arise. The basic corrosion monitoring system provides electronic access to the pipeline, electrical continuity of the pipeline, and electrical isolation of the pipeline from appurtenances, see Figure A-4. Electronic access to the pipeline is provided by test stations in which insulted electrical cables originating from the pipeline terminate. Test stations are installed at critical locations and at regular intervals along a pipeline. Positive electrical continuity is provided by welded pipe joints or installation of joint bonds across mechanical type pipe joints (flanges, bell and spigot joints, dresser couplings, and etc.). The pipeline is electrically isolated as necessary from appurtenances by the installation of insulated fittings.

Protective Coatings

Protective coatings are widely used for corrosion protection. Selection of protective coatings is highly dependent on environment conditions. This discussion will be limited to protective coatings for buried pipeline applications. Coatings for buried pipelines can be divided into two categories, those with relatively high electrical resistance and those with relatively low electrical resistance. Low resistance coatings include mortar coatings and concrete encasements, and are not included in this report. For this report the term dielectric coating will be used to describe the relatively high resistance type coating. Bonded dielectric coatings are designed to tightly adhere to the metallic surface and have a high electrical resistance. The principal corrosion protection mechanism of a bonded dielectric coating is to provide a physical barrier between the corrosive environment and the underlying metallic surface. In addition, a bonded dielectric coating protects the underlying metallic surfaces by increasing the effective circuit resistance of the corrosion cell, which in turn reduces the current flow within the corrosion cell in accordance with Ohm's Law. Because there are no perfect coatings there are always locations where there are discontinuities in the coating, ~~these discontinuities~~ which are generally called holidays.

Holidays expose the underlying metallic surface directly to the corrosive environment. Contrary to common belief, dielectric coatings typically used on buried pipelines are not perfect insulators and, therefore, can conduct current. Moisture and oxygen can also diffuse through coatings. The rate at which current, moisture, and oxygen can move through a coating is dependent on the coating characteristics (e.g., resistivity and thickness), environmental conditions, and time. Once a protective coating is placed into service it begins to absorb moisture, which in turn reduces its effective resistivity over time.

Because dielectric coatings are capable of conducting current, the surface beneath intact dielectric coating is available to behave anodically or cathodically. Studies have indicated that metallic surfaces under intact bonded dielectric coatings are cathodic to the metallic surfaces exposed at the coating holidays, which are anodic. The severity of this corrosion cell is dependent on both coating and soil properties.

All coatings deteriorate with ~~as~~ time, and as they do, their ability to provide corrosion protection also deteriorates.

Although protective coatings are a very useful and effective tool in corrosion mitigation of buried pipelines, they do not eliminate corrosion of the pipeline. As a result, cathodic protection is often used on buried ~~pipelines, this~~ pipelines. This is especially true for pipelines in corrosive soils.

Cathodic Protection

Cathodic protection is a proven method of mitigating corrosion and is the only corrosion control method, which can potentially halt ongoing corrosion of a buried structure. Cathodic protection uses a corrosion cell to the benefit of the protected structure. With cathodic protection the structure that is to be protected is made the cathode of the corrosion cell (corrosion does not occur at the cathode). Since we still have an operating corrosion cell we must have an anode. Therefore, an anode material must be installed, which will be sacrificed for the sake of the structure to be protected. It should be noted that corrosion is not stopped but is transferred. It is transferred from the structure that is to be protected to sacrificial material, which is installed to be consumed.

Since cathodic protection is a corrosion cell, current must flow. As with the corrosion cell, current flows from the anode to the cathode within the electrolyte, and from the cathode to the anode within the metallic path. For pipeline installations the electrolyte is the surrounding soil. The metallic path is the pipeline itself and the cables that may be installed with the cathodic protection system. A pipeline must be electrically continuous for the successful application of cathodic protection; therefore, a corrosion monitoring system is required on a cathodically protected pipeline.

There are two types of cathodic protection systems, galvanic anode and impressed current. Both systems require the installation of a sacrificial material as the anode. Galvanic anode cathodic protection requires the installation of galvanic anodes. A galvanic anode is a material ~~which~~ that is more electro-chemically active than the structure to be protected, see Figure A-5. Galvanic anodes use the natural potential difference between the anode material and the structure to cause current to flow. For soil applications zinc and magnesium are typically used as the galvanic anode material. Galvanic anodes are typically installed some distance from a pipeline and connected to the pipeline through cables.

With an impressed current cathodic protection system, external power is required to supply the current required for cathodic protection, see Figure A-6. Any DC type power supply can be used for cathodic protection, although, a rectifier is typically used. A rectifier converts AC power into DC power. The positive terminal of the DC power supply is connected to the anodes, and the negative terminal is connected to the pipeline. Impressed current requires the installation of anodes and a power supply, the power supply is connected between the structure and anodes. Because external power is providing the driving force for the cathodic protection current, a wide range of anode materials can be used. Some commonly used impressed current anode materials include high silicon cast iron, graphite, mixed metal oxides, and platinum.

The cathodic protection system must be capable of supplying sufficient current to provide adequate cathodic protection. Galvanic anode cathodic protection systems are limited in the current ~~which~~ that they can provide and therefore are typically used in situations with small current requirements (e.g., smaller pipelines or well coated pipelines). Impressed current cathodic protection systems can provide a large and variable amount of current and can be used in situations requiring small or large current requirements (e.g., larger pipelines or poorly coated pipelines).

Synergistic Effects of Protective Coatings and Cathodic Protection

Protective coatings and cathodic protection are widely used as synergistic corrosion mitigation methods. There are no perfect coatings; they have holidays, can be damaged, and deteriorate with time. The metal exposed at the coating holidays is susceptible to corrosion. The corrosion process enlarges the coating defects by undercutting the intact coating adjacent to the holidays. Coatings effectively reduce the amount of metal surface area which requires cathodic protection and as a result less cathodic protection current is required for a ~~well coated~~ well-coated structure than for a poorly coated or bare structure. In return, cathodic protection extends the useful life of the coating by reducing undercutting of the coating and effectively limiting the growth of defective coating areas.

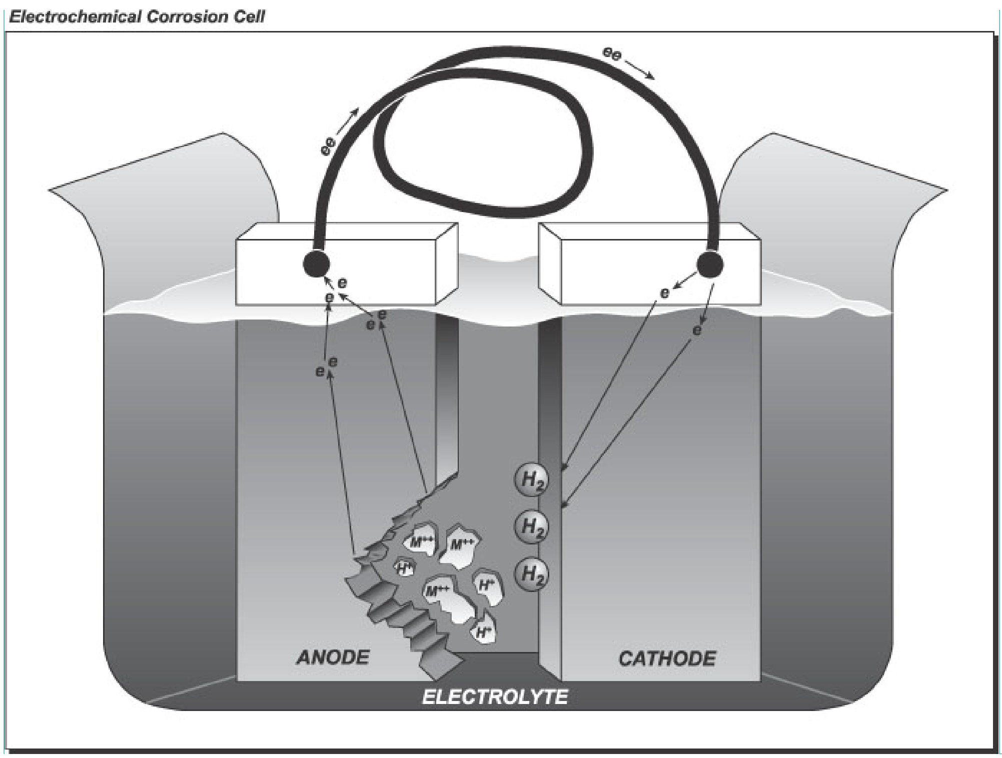

Figure A-1 – The Electrochemical Corrosion Cell.

Comment [SL91]: Figures A-1 through A-6 were added by the Review Panel

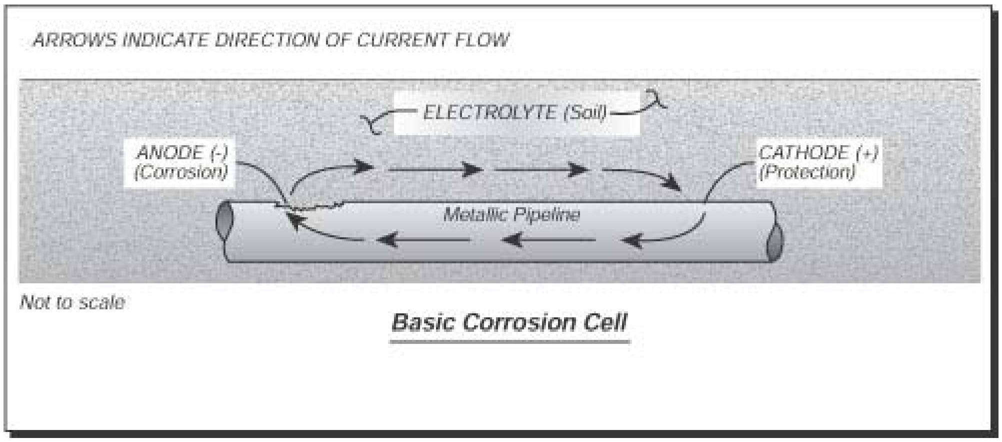

Figure A-2 – Basic Corrosion Cell with a buried pipe.

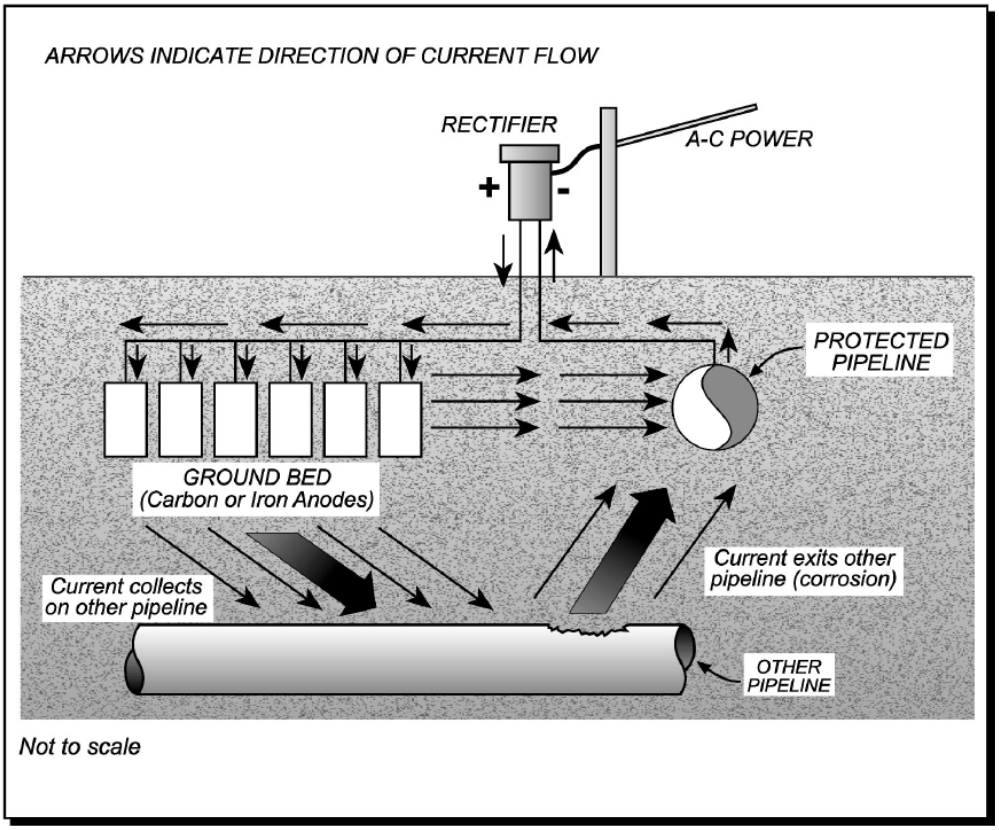

Figure A-3 – Corrosion due to stray current.

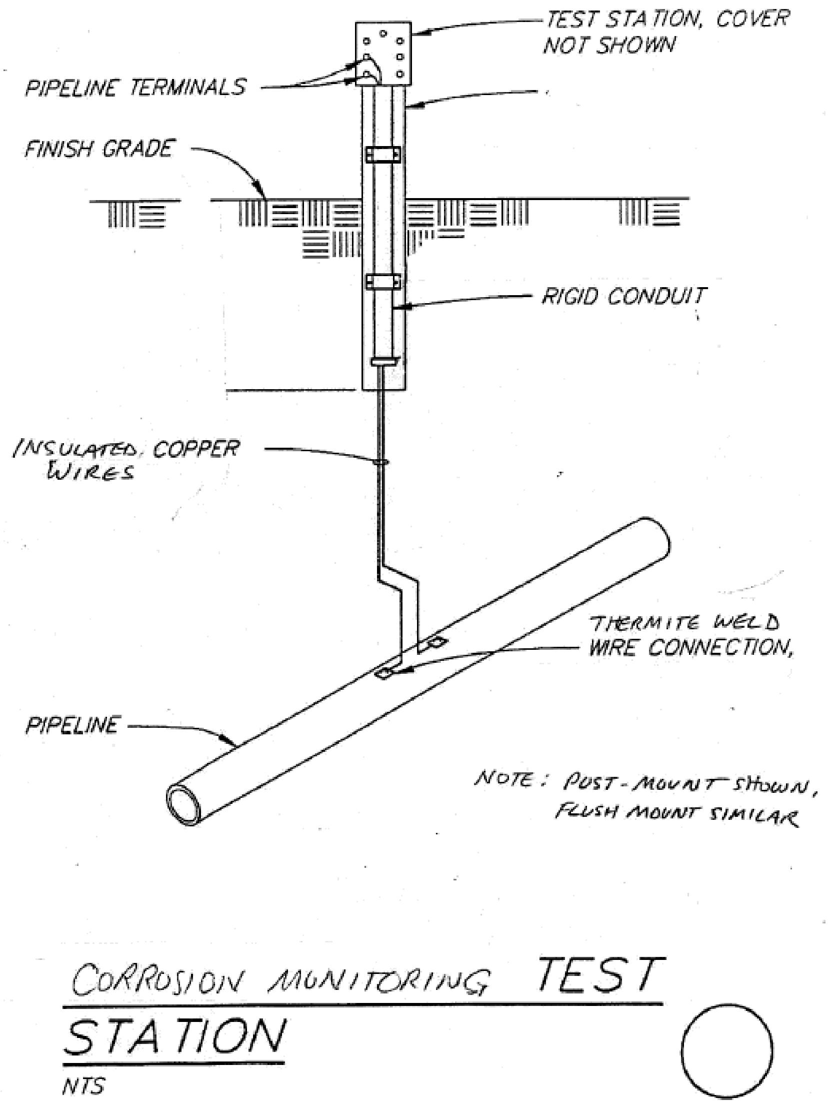

Figure A-4 – Corrosion Monitoring System.

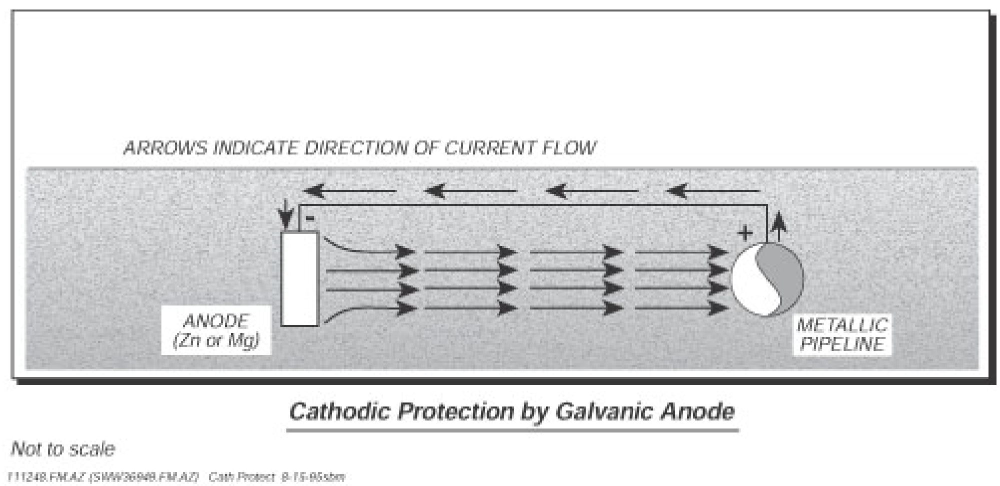

Figure A-5 – Galvanic Anode.

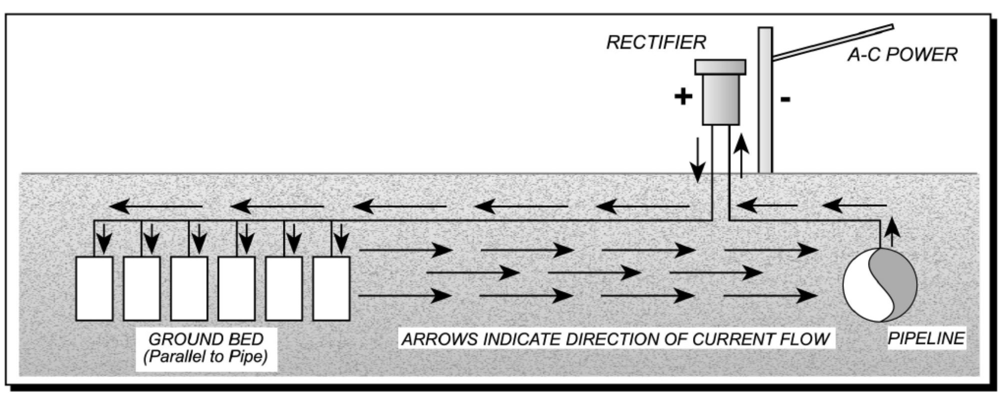

Figure A-6 – Impressed current Cathodic Protection System.

Page B-2 [1] Comment

(*continued*) if to date there has not been a reported corrosion failure of any ductile iron pipeline on a Reclamation designed project or on a project for which Reclamation has had an oversight responsibility. Then what is the concern for corrosion damage? Something needs to be described here for justification for the concern. I thought the materials on page 8 under Discussion touch this issue, but they need to be expanded and moved up here. Although no failures have been reported, failures in other areas have been cited. So, there are possibilities that corrosion of ductile iron pipes with BOR's designs or under BOR's oversight might occur. It also might be important to state that the cost of a failure will be enormous. Along the same line, it is worthwhile to estimate the failure probability of ductile iron pipes due to corrosion. This is might be complicated due to many factors involved, such as the pipe dimension, soil properties and environment, etc. But it can be done on assumed realistic conditions.

Page B-11 [2] Comment

(*continued*) Suggest considering the positions of the Europeans and other international groups on the issue. He states that it is his understanding that polyethylene encasement has not been accepted as the sole form of protection for ductile iron in Europe. Also consider noting that in the U.S., the situation with respect to polyethylene encasement seems to have resulted in the evolution of 3 camps: (1) those outright rejecting polyethylene encasement and treating of ductile iron pipe the same as steel pipe, (2) those completely accepting polyethylene encasement, and (3) those somewhere between these two positions. This would seem to reinforce the conservative position recommended by Reclamation, namely, limiting the use of polyethylene encasement until research answers the fundamental questions posed in the Recommendations section.

Appendix C

E-Mail Messages from Mike Woodcock (Washington Suburban) to James Keith (Reclamation) 3/11/04

Mike Woodcock works for Washington Suburban as a metallurgist. The following are excerpts from several E-mail messages:

James,
The Commision has some steel pipe most are only 10 years old+/-, these were tape coated and cathodically protected. The oldest is 30 inch at least 50 years probably 60 years with little maintenance history, no CP, and was Coal Enamel Tar Coated. We have experienced a few pin hole leaks which were fairly easy to patch/repair. It has straight lengths of pipe with couplings. We have had some leaks on near the couplings usually because of damage in the original coating.

I suggest you look at steel pipeline lives in oil and gas country where many steel pipelines are over 100 years old.

All but the aboved mentioned pipeline are welded, cement lined, tape coated with CP are large diameter,36-96 inch and fairly recent(10-15 years).
Mike Woodcock,
WSSC Systems Infrastructure Group.

-----Original Message-----
From: James Keith [mailto:JKEITH@do.usbr.gov]
Sent: Thursday, March 11, 2004 1:12 PM
To: lleahy@wsscwater.com; Mwoodco@wsscwater.com
Subject: Re: FW: DIP life query from Corps Engineers ref your telcon query yesterday

Lori and Mike,
Thanks for the info on ductile iron. Does Washington Suburban have any experience/info on the service life for steel pipe?

>>> "Leahy, Loretta" <lLeahy@wsscwater.com> 03/11/04 10:48AM >>>
fyi

Lori Leahy
WSSC Systems Inspection Group Leader
office-301 2068039
cell-301 7850116
fax- 301 2068860
lleahy@wsscwater.com

> -----Original Message-----
> From: Woodcock, Mike
> Sent: Thursday, March 11, 2004 12:13 PM
> To: Leahy, Loretta
> Cc: Debevoise, Ana
> Subject: DIP life query from Corps Engineers ref your telcon query

> yesetrday
>
> Lorie, you can get the engineer to call me direct. This is a very
> complicated query to answer and needs background justification for
values
> given
> The following are Mike Woodcock's (Metallurgist/ Systems
Infrastructure)
> predictions. DIP in WSSC is too young to have established lives but
trends
> are developing.
>
> Theoretical Life unwrapped DIP - pit penetration start after 25
years
> -useful life 35 years (Howard County MD currently replacing
unwrapped
> 20-25 year old DIP and we are just beginning to see Pitting
failures.
> Failure mode/trend will be an increasing frequency of pitting leaks
until
> pipelines become sprinkler systems.
>
> Theoretical Prediction ranges from to 40-45 years for Polyethylene
> encased pipe--- pits at some locations (dependant on soil, damage to
wrap,
> copper service line connections, acid ground water etc) life
dependant on
> frequency of maintenance required.
>
> To get 100 year life follow European practices -zinc/aluminum
metallic
> spray coat, epoxy top coat plus polyethylene encasement.
> or blast clean off magnetite coating- coat with either fusion bond
epoxy
> (not currently available), or coat with extruded polyethylene
coating
> system then add CP ---100 years
>
> Remember to get pipeline long life also requires long life for
fittings,
> and appertnances-- currently low life components.
>
> Recommend review work done by NRC-NRC Canada Dr. Balvant Rajani
>
> DC Local water utilities have recently formed a regional forum on
DIP to
> challenge DIP industry marketing policies, product qa/qc, coating
> questions, and pressure classes.
>
> Never use bell and spigot steel pipe.(too thin--- difficult to
corrosion
> protect---- danger in long term of stress failures in shoulders of
pipe
> ends rolled joints)
>
> Mike Woodcock
> Mwoodco@wsscwater.com
> 301-206-8572
****

James,
The terminology you use "breaks/mile/year" should strictly not be used for

DIP. This terminology was created for CIP cast iron pipe (&PCCP) which fail
by brittle fracture and the pipe splits into two sections. Only DIP with low
notch toughness and brittle should fail this way (poor manufacturing). DIP
by definition should not break,but splits open when extensive pits join in a
straight line yes. The failure mechanism for DIP is pitting failures. Please
remember DIP is very young when compared to CIP and theorectically DIP as
expected by us is only just beginning to show signs of distress in WSSC
area, i.e pitting failures and some splits. The oldest WSSC DIP is in the
order of 27 years old we expect to see increasing events from from now on.
my estimate was by age 35 we should see alot of events.The Commission has
approximately 2000 miles of DIP 3-54 inch diameter. Most was installed
without polyethylene encasement. some is now showing signs of severe
pitting. 36 inch and above was blast cleaned and either epoxy or tape coated
and CP was applied. Because we have such a high quantity of DIP maintenance
events per mile per year is not very large,at this time, my guessimate is
in order of .025 for 2001-2002 and for 1997 was or order of
0.0003/mile/year. For comparision our 2003 CIP rate was approx. 0.617
breaks/mile/year
I suggest you talk to Don Lieu at Howard County(Howard county adjoins our
service to the north of us and their pipe is a little older). 410-313-6121
Dlieu@co.ho.md.us
mike w

-----Original Message-----
From: James Keith [mailto:JKEITH@do.usbr.gov]
Sent: Friday, March 12, 2004 7:41 PM
To: mWoodco@wsscwater.com
Subject: RE: FW: DIP life query from Corps Engineers ref your telcon
queryyesterday

Mike,
What is Washington Suburban's figure for breaks/mile/yr for ductile
iron? Thanks

>>> "Woodcock, Mike" <mWoodco@wsscwater.com> 03/11/04 12:16PM >>>
James,
The Commision has some steel pipe most are only 10 years old+/-, these
were
tape coated and cathodically protected. The oldest is 30 inch at least
50
years probably 60 years with little maintenance history, no CP, and was
Coal
Enamel Tar Coated. We have experienced a few pin hole leaks which were
fairly easy to patch/repair. It has straight lengths of pipe with
couplings.
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the original coating.

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steel pipelines are over 100 years old.

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To: lleahy@wsscwater.com; Mwoodco@wsscwater.com
Subject: Re: FW: DIP life query from Corps Engineers ref your telcon
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experience/info on the service life for steel pipe?

>>> "Leahy, Loretta" <lLeahy@wsscwater.com> 03/11/04 10:48AM >>>
fyi

Lori Leahy
WSSC Systems Inspection Group Leader
office-301 2068039
cell-301 7850116
fax- 301 2068860
lleahy@wsscwater.com

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> Sent: Thursday, March 11, 2004 12:13 PM
> To: Leahy, Loretta
> Cc: Debevoise, Ana
> Subject: DIP life query from Corps Engineers ref your telcon
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> are developing.
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years
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> pipelines become sprinkler systems.
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> copper service line connections, acid ground water etc) life
dependant on
> frequency of maintenance required.
>
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metallic

> spray coat, epoxy top coat plus polyethylene encasement.
> or blast clean off magnetite coating- coat with either fusion bond
epoxy
> (not currently available), or coat with extruded polyethylene
coating
> system then add CP ---100 years
>
> Remember to get pipeline long life also requires long life for
fittings,
> and appertnances-- currently low life components.
>
> Recommend review work done by NRC-NRC Canada   Dr. Balvant Rajani
>
> DC Local water utilities have recently formed a regional forum on
DIP to
> challenge DIP industry marketing policies, product qa/qc, coating
> questions, and pressure classes.
>
> Never use bell and spigot steel pipe.(too thin--- difficult to
corrosion
> protect---- danger in long term of stress failures in shoulders of
pipe
> ends rolled joints)
>
> Mike Woodcock
> Mwoodco@wsscwater.com
> 301-206-8572

Appendix D

A review panel was convened by Reclamation in March of 2004 to peer review Reclamation's evaluation of the effectiveness of unbonded coatings on metallic pipe. The panel consisted of three materials scientists from the National Institute of Standards and Technology (NIST) (C.N. McCowan (Panel Chair) and Y. Cheng, Materials Reliability Division, Boulder, CO; and R.E. Ricker, Metallurgy Division, Gaithersburg, MD) and two private sector corrosion engineers (G.E.C. Bell, M.J. Schiff & Associates, Claremont, CA; and R.Z. Jackson, CH_2M Hill, Sacramento, CA.

Questions for the Panel and Panel Conclusions

1. **Reclamation currently requires protection on pipe alternatives (i.e., no bare pipe is installed) should problems be encountered in the future due to either environmental corrosion or stray current.**

    Does the Panel concur with this practice?
    Does the panel have comments with regard to this practice?

    Jackson-

    Concurred

    Bell-

    Concurred, but noted that cost is a consideration. He said coatings should be used for costs up to $3/ft^2, because cathodic protection can be applied for about this cost.

    Cheng-

    Concurred

2. **Reclamation currently requires bonded joints and Corrosion Monitoring for all pipeline installations in order to monitor and assess pipe corrosion activity.**

    Does the Panel concur with this practice?
    Does the panel have comments with regard to this practice?

Jackson-

Concurred; but said one should allow for exceptions.

He said that in special cases where there are stray currents one should consider isolation rather than conductivity. For example, he worked on a project where a pipeline paralleled a high voltage power line. In that situation, isolation from other structures is definitely needed, and can be achieved by reducing the continuous length of pipe that can draw a stray current.

Bell–

Concurred that bonded joints and test stations are needed, and that isolation from other structures is important. He also stated that with a bonded coating, one may not be able to see changes in the potentials on the pipeline, meaning it may be difficult to detect if corrosion is occurring. He felt that newer technologies, such as electrical resistance coupons, may be better.

Cheng-

Concurred with the practice of corrosion monitoring. He also stated that one needs to monitor for unusual circumstances and changes in potential, and have a practice or written guideline to establish what changes to look for and what to do if changes are found.

Other comments:

Connections from sublaterals to main pipeline account for 90 percent of all corrosion problems on distribution systems. Isolation is the key.

Cathodic protection is the last resort if there are problems.

3. **Reclamation currently uses soil resistivity and stray current as an indicator of need for CP. Additionally, in some cases Reclamation will examine chlorides and sulfates concentrations in the soil. This approach does not consider, or may be considered to**

assume, other parameters of soil chemistry, pH, Oxidation Reduction Potential (Redox), cyclic wetting and drying (moisture), etc. This parameter is quick, easy and cheap to measure in the field.

Does the Panel concur with this practice?
Does the panel have comments with regard to this practice?

Jackson-

He stated that field resistivity is one part of the data gathering. CH_2M Hill prefers the collection of additional information for major pipelines, e.g., pH, chlorides, and sulfates. Resistivity values are calculated in the laboratory (saturated) as well as in the field. He stated that the potential for stray currents needed to be evaluated, and that a conservative assumption would be that every project is likely to have stray current. The use of PE encasement to provide shielding from stray currents is a good idea.

Bell-

He felt the best approach was to get the pipe in the ground and then determine what is needed. He stated that even hazardous pipelines are given 1 year of operation to allow for tweaking of CP to meet exact needs of a particular pipeline.

He stated that resistivity is a good indicator of corrosion mitigation needs, but that the use of Electro-Magnetic Conductivity Surveys may be better. Measurements could be taken every 20 feet to 15 feet of depth. This method should be used to find where there are changes, and that data should be used to determine the field sampling locations. He stated that the anions–chlorides and sulfides—as well as the cations—calcium, magnesium, and sodium need to be measured. He felt that there is a small price difference between a full analysis and a partial analysis, and that this extra analysis helps determine where to put magnesium beds.

Other comments:

A conservative assumption would be to use good coatings and CP for lower resistivity soils.

Stray current is difficult to assess. The conservative view is to assume projects are likely to have future potential for stray current.

4. **PE effectiveness is a disputed issue both for its ability to protect pipe from corrosion, possible installation damage and potential shielding which impacts Corrosion Monitoring and CP. For example, NACE International's RPO 169-2002 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," requires a bonded dielectric coating for buried pipeline applications and indicates that unbonded coatings (PE encasement is considered an unbonded coating) can create electrical shielding of the pipeline that could jeopardize the effectiveness of the CP system. Reclamation is concerned by this dispute.**

Does the panel have comments with regard to the effectiveness of PE encasement as a corrosion measure and/or its effect on the ability to monitor pipe corrosion and to apply effective CP?

Jackson-

He felt that PE encasement is not a perfect answer, but there are locations in less corrosive environments where it can be used. He agreed that Reclamation has a legitimate concern and needs to take a conservative view, and should make changes to corrosion mitigation criteria if warranted.

He has used PE encasement with CP, and has not had any cases where he has been called to go back and inspect the pipe. This would indicate that there have been no specific problems for these cases.

He said that two other aspects should be considered:

1. As the pressure class decreases, the pipe thickness decreases, making the thinner pipe more susceptible to penetration. The pipe thickness also decreases as the size decreases.

2. Bedding and backfill are critical and must be considered carefully. CH2M Hill likes to use sand as a bedding material for DIP with PE. A minus ¼" gravel may be reasonable. Dig-ups have shown damage to the PE, especially around the top of the pipe. Two layers of PE encasement could help eliminate this problem.

CH_2M Hill is more conservative with larger diameter pipe because the flows are larger, the implications of the failure are greater, and large diameters are more expensive to fix. With larger pipe, a more conservative approach is warranted. With 12-inch and smaller pipe, less conservatism may be needed.

Bell-

He stated that he leans towards the use of PE encasement with CP applied, because he has seen it work. He agreed that PE encasement cannot be considered to be a coating; it is an encasement only. He said that data has recently been published which indicates DIP with a select backfill can be protected with PE encasement to reduce corrosion, and that CP works under intact PE.

He noted that RP0169 (RP stands for Recommended Practice) recommends a tight bonded coating, but that it is not a requirement; it is only a recommended practice. He stated that he has never specified tight bonded coating with DIP.

He stated that he has had good experience with PE encasement and with the application of CP on polyethylene encased DIP. He stated that the costs of PE encasement are on the order of $0.05/diameter inch of pipe. He also stated that the cost of CP for DIP with PE encasement can be considered to be 28 times that of steel, but that it is still a small number when put in context of the entire project cost.

He advised Reclamation to look at its own experience. He stated that if Reclamation has not had failures with PE encasement, then it should keep doing what has been done. He said that he has never seen significant failures of DIP protected with PE encasement and CP.

He said that damage to the PE encasement is not due to the weight or size of the pipe, but the fact that the wrong type of PE encasement is used. He stated that the quality of PE encasement can vary greatly, and that lower-quality PE may not have enough thickness or tensile strength.

He felt that the size restriction on pipe with PE encasement should be eliminated. He agreed that the consequences of failure need to be considered. Larger diameter pipe generally does have higher consequences.

He stated that the fittings on the pipe cause the most problems, because the pipe is manufactured in a controlled environment, whereas the fittings are a field installation and not controlled as well. He felt that close inspection during installation is the best investment.

Other comments:

The quality of the PE is important.

Inspections and cathodic system maintenance are important.

5. **Reclamation is prepared to recommend an updated approach for pipe alternative coatings or encasements installed in various soil conditions. The newest recommendation is enclosed as Table 2.**

Does the Panel concur with the Table?
Does the panel have comments with regard to the Table?

Bell-

He stated that a bonded dielectric coating is more difficult to apply and more expensive for DIP than for steel pipe. With DIP, a thicker coating is needed due to the dimpling on the pipe, and that the larger the diameter, the greater the coating thickness becomes. Thick coatings can cause problems at the joints, making the pipe hard to assemble. Mortar and reinforced concrete need to be handled differently. Mortar coating in conditions with chlorides and sulfides is a problem. In wetting and drying conditions, the mortar can act like a sponge, and eventually lead to chlorides accumulating on the metal. Corrosion protection additives can be put into the coating. If coal tar epoxy is used, it should be used directly on the steel, with mortar on the outside for rock protection. He stated that three layers of tape with mortar coating are pretty much bullet proof. He said that a seal coat over mortar is not a good system, because it could cause shielding of CP and allow corrosion to occur under any disbonded mortar coating. The mortar should be used over the dielectric coating.

He said that both coal tar epoxy and PE encasement can shield CP.

He said that for soil resistivities below 1,500 Ohm-cm, PE encasement with CP should be used.

He stated that the Reclamation table is geared towards conservatism, and that this makes sense if it agrees with a good history of installation.

He stated that if CP systems are not always well maintained, one should never depend totally on CP to protect a pipeline.

Jackson-

He stated that if a bonded dielectric coating is required, alternatives will probably be more limited, because pipe will probably not be obtainable from DIP manufacturers. He said that it is a good idea to make sure there is more than one pipe alternative available in order to keep capital costs down.

He felt that there could be problems with corrosion in any soils with resistivities below 3,000 Ohm-cm. For resistivities below 2,000, he felt that corrosion protection designs should definitely be considered. For resistivities below 1,000, he felt that there could be really serious problems.

In the end, he felt that the user should adhere to the criteria with which they are the most comfortable.

Other comments:

Coal tar epoxy can be placed directly on the pipe with mortar over the epoxy for rock protection.

If the coal tar epoxy is on the outside of the mortar and the mortar becomes disbonded from the pipe, salty water can be a problem.

6. **Pipe life cycle costs, or other economic considerations are important in the overall design and O&M budgeting and expenditures over the life of a project. Reclamation is prepared to use pipe life cycle costs as a bid correction item.**

    Does the Panel concur with this practice?
    Does the panel have comments with regard to this practice?

Jackson-

In general, he felt that life cycle costs are needed in specifications. He concurred with using bid adjustments in specifications for increased costs due to CP. As an example, CH_2M Hill did use long-term costs for the Mni Wiconi Project, but it did not change the pipe option selected for the project. The lowest life cycle costs were for DIP with PE encasement and CP.

Bell-

He said he has never used life cycle costs, but he would have no problem with including it. He stated that it would be important to be definitive about how the calculation will be made.

He said that, in general, the cost of installation of CP is about $2,000 to $3,000 per installed amp. The current required for ductile iron is about 28 to 30 times that required for steel.

He felt that the average service life for a pipe project should be assumed to be 40-60 years, so a good starting point would be 50 years. He has known clients that have asked for as high as 100 years.

Appendix E

Exterior Coating Cost Analysis

Exterior Coating Cost Analysis
Unit Price per SF
Ductile Iron Pipe Study
Daniel L. Maag
Tuesday, April 06, 2004

Pipe Diameter (Inches)	8-mil Poly Tubes (F&I) Price/SF **$/SF**	3/4" Mortar Coating Price/SF **$/SF**	Pipe Wrapping Price/SF **$/SF**
2			$2.30
2.5			$2.00
3	$1.40		$1.80
4	$1.10	$5.30	$1.70
6	$0.80	$4.50	$1.80
8	$0.70	$3.50	$2.00
10	$1.30	$3.40	$2.10
12	$1.10	$3.40	$2.10
14	$1.20	$3.10	$2.30
16	$1.10	$3.20	$2.50
18	$1.10	$3.10	$2.60
20	$1.00	$3.10	$2.70
24	$1.00	$3.10	$2.80
26			$3.10
28			$3.20
30	$1.00		$3.30
32			$3.50
34			$3.60
36	$0.90		$3.60
40			$3.90
42			$4.00
48			$4.30
Average Price Per SF	**$1.10**	**$3.60**	**$2.80**

NOTES:
1. The unit prices for poly tube include a cost component for installation of tube on pipe section.
2. The unit prices for mortar coating and pipe wrapping include cost for installation on pipe section.
3. For internal mortar lining, Richardsons noted that for quantities less than 200 lf, add 40 percent to the above costs.
4. For internal mortar lining, Richardsons noted that for quantities greater than 500 lf, deduct 25 percent from the above costs.
5. For external mortar coating, Richardsons noted that for quantities less than 200 lf, add 30 percent to the above costs.
6. For external mortar coating, Richardsons noted that for quantities greater than 500 lf, deduct 40 percent from the above costs.
7. Nominal pipe diameters were used to calculate these costs per square foot.
8. Average prices per square foot (above) are based on mathematical averages of all diameters for each option (column).

Appendix F

April 2004 Southwest Pipeline Excavation

The Southwest pipeline project is a water supply system designed to deliver water from Lake Sakakawea on the Missouri river to municipalities and rural communities located in southwestern North Dakota. The Southwest Pipeline is a Reclamation funded project which was installed in1989. The pipeline was constructed with ductile iron pipe with joint bonding and PE encasement. In 1991, cathodic protection was implemented on the pipeline. Testing conducted in late 1997 and early 1998 indicated low protective potentials in a low-lying area near Taylor, ND. In April 2004, several PE encased ductile iron pipe units were excavated on the Southwest pipeline (See Figure 1). Two excavations were performed approximately 50-ft apart. The first excavation was performed at Sta. 239+30 and the second excavation at Sta. 239+84. Water was encountered in both excavations. The water was entering the trench from a coal seam along the trench wall. The excavated ductile iron pipe diameter was approximately 30 inches.

Figure 1—Excavated 30-inch diameter Southwest pipe unit with PE encasement

A third excavation site near the location of a rectifier station (approximately Sta. 200+00) was attempted. However, the third excavation site could not be completed due to water flow into the pipe trench. The pumps provided for the dewatering effort could not keep up with the inflow of water.

Reclamation representatives from the Technical Service Center and Dakotas Area Office were present during the inspection. Sections of the PE encasement were removed from the ductile iron pipe units including underneath the ductile iron pipe unit. The overall condition of the excavated ductile iron pipe unit was visually observed to be good. Surface corrosion was noted on the excavated ductile iron pipe underneath the PE encasement (See Figure 2). Corrosion pitting or graphitization was not visually observed.

Figure 2—Surface corrosion noted underneath PE encasement

A section of the PE encasement was removed and visually inspected. Visual inspection of the PE encasement located underneath the pipe unit (invert) indicated numerous perforations likely due to the pipe bedding material used. The pipe bedding consisted of angular material which likely resulted in development of numerous perforations in the PE encasement. A section of the PE encasement which was located underneath the pipe unit is shown in Figure 3.

Figure 3.—PE encasement with numerous perforations.

Figure 4 provides a close-up which illustrates with greater detail the numerous perforations visually observed on the PE encasement shown in Figure 3. The numerous perforations in the PE encasement are likely the cause of the very high currents required to achieve the required protective potentials in this area.

Figure 4.—Close up view of PE encasement with numerous perforations.