

Sacramento Regional County Sanitation District

CATHODIC PROTECTION ANALYSIS REPORT – YEAR 3



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Executive Summary

V&A Consulting Engineers, Inc (V&A) has completed the testing and evaluation of the cathodic protection (CP) systems and corrosion monitoring (CM) systems associated with piping owned and operated by Sacramento Regional County Sanitation District (Regional San). The piping within the scope included cement mortar lined and coated steel pipe, reinforced concrete cylinder pipe, pretensioned concrete cylinder pipe, and bare steel. The CP systems providing corrosion control to the piping include both impressed current CP (ICCP) systems and galvanic anode CP (GACP) systems. A survey was conducted to document the existing condition of the systems and measure the performance of the systems in accordance with NACE SP0169 criteria for adequate corrosion control. An ArcGIS dashboard has been prepared to accompany this report. The dashboard includes the collected field data, as well as site photos and a photo of each test station lid and test board at the located rectifier and test station.

The test methods performed during the survey included measuring the rectifier voltage and current outputs, “on” and “instant off” potentials at accessible test stations, galvanic anode current outputs and open-circuit potentials, and “corrosion monitoring” potentials at accessible test stations. The purpose of the evaluation was to document the existing conditions of the systems and to provide recommendations for improving their efficiency and facilitate future operations and maintenance. The need for the installation of a CP system was evaluated for pipelines that do not currently receive corrosion control from a CP system but instead have a corrosion monitoring system. The field survey was performed by V&A personnel between November 1 and November 16, 2021. The ICCP, GACP, and CM systems included various types of test stations. For the purposes of this report, each evaluated test station was classified into one of the three system types:

1. ICCP system test station: A test station that is influenced by the current output of an anode well energized by a rectifier (i.e., the measured pipe-to-soil potentials at the test station shifted as the rectifier was cycled on and off).
2. GACP system test station: A test station that includes galvanic anode test leads and is not influenced by the current output of a rectifier.
3. CM system test station: A test station that includes pipeline test leads but does not receive CP current from a rectifier or galvanic anode.

Due to the lack of historical “native” potential survey data, V&A was only able to evaluate the results of the testing using the NACE SP0169 “-850 mV polarized potential” criterion for adequate corrosion control. This criterion states that corrosion of a steel or ductile iron pipeline is mitigated if an “instant off” pipe-to-soil potential of -850 mV or more electronegative is measured at the test station. A “native” potential survey would be required to evaluate the results of the testing using the NACE SP0169 “100 mV polarization” criterion. Refer to Section 2.1.3 for further definitions and discussion of the NACE SP0169 criteria.

A summary of the evaluation results for each system type is presented as Table ES-1.

Table ES-1. Summary of Evaluated ICCP, GACP, and CM Systems

System Type	Facility Name	Conclusions	Recommendations
ICCP	Route 24 - Northeast Interceptor	<ol style="list-style-type: none"> 1. The rectifier and deep anode well were operating properly and do not require replacement at this time. 2. Corrosion of the pipeline was mitigated per NACE SP0169 –850 mV polarized potential criterion. 3. The current output of the rectifier was measured at approximately one amp which is well below the rated capacity of the rectifier (24 amps). Due to the pipeline achieving NACE criteria at a low rectifier current output, the expected remaining useable life of the rectifier is greater than 20 years. 4. Of the three total test stations, one test station could not be located. This test station is located adjacent to the rectifier and therefore does not require replacement. 5. Each of the located test stations were in good condition and did not require repairs. 	<ol style="list-style-type: none"> 1. Perform bi-monthly rectifier checks consisting of measuring rectifier voltage and current outputs to ensure the rectifier is operating properly. This may be achieved during field visits or remotely, if a remote monitoring unit is installed. 2. Perform an annual survey of the ICCP system consisting of measuring rectifier voltage and current outputs, individual anode current outputs, and “on” and “instant off” potentials at accessible test stations in accordance with NACE SP0169.
ICCP	Route 42 - Power Inn Pump Station	<ol style="list-style-type: none"> 1. The rectifier and shallow anode beds were operating properly and do not require replacement at this time. 2. Corrosion of the casings was mitigated per the NACE SP0169 –850 mV polarized potential criterion. 3. The current output of the rectifier was measured at approximately one amp which is well below the rated capacity of the rectifier (8 amps). The current output of the anodes should continue to be monitored as the rectifier does not appear to be a modern type of rectifier. 4. Of the four total test stations, one test station could not be located. This test station is located adjacent to another test station and therefore does not require replacement. 5. Each of the located test stations are in good condition and do not require repairs. 	<ol style="list-style-type: none"> 1. Perform bi-monthly rectifier checks consisting of measuring rectifier voltage and current outputs to ensure the rectifier is operating properly. This may be achieved during field visits or remotely, if a remote monitoring unit is installed. 2. Perform an annual survey of the ICCP system consisting of measuring rectifier voltage and current outputs, individual anode current outputs, and “on” and “instant off” potentials at accessible test stations in accordance with NACE SP0169.

System Type	Facility Name	Conclusions	Recommendations
GACP	Bradshaw Interceptor	<ol style="list-style-type: none"> 1. The pipeline was not achieving the NACE SP0169 –850 mV polarized potential criterion. 2. The galvanic anode associated with the GACP system was depleted and no CP current was being provided to the pipeline. 3. Additional testing must be performed to determine the required capacity of a new CP system. 4. Of the two total test stations, both test stations were located. 5. Each of the located test stations were in good condition and do not require repairs. 	<ol style="list-style-type: none"> 1. Perform current requirement testing to determine the required current capacity of a new CP system. The testing should be performed with a portable rectifier and temporary anode bed to discharge a test current to the pipeline. The level of polarization achieved as the result of the test current should be measured, and CP system design calculations should be performed to determine the configuration of the new CP system. 2. Design a new CP system to protect the Bradshaw Interceptor using the results of the current requirement testing. Perform a native potential survey before the system is energized. Perform a polarized potential survey after the system is energized. 3. Once a new CP system is installed, perform annual polarized potential surveys of the CP system at accessible test stations in accordance with NACE SP0169.

System Type	Facility Name	Conclusions	Recommendations
GACP	Route 30 - City Interceptors	<ol style="list-style-type: none"> 1. The pipeline was not achieving the NACE SP0169 –850 mV polarized potential criterion. A “native” potential survey is required to determine if the NACE SP0169 100 mV polarization criterion is being achieved. 2. One anode was electrically shorted to the pipeline and, therefore, no current output or open circuit potential was measured. The remaining galvanic anodes are operational and provide CP current to the pipeline. 3. The IJTS associated with the GACP system was providing effective isolation. 4. Of the 19 total test stations, four test stations could not be located. 5. Three test stations were identified as requiring repairs, as detailed in Section 3.2.2. The remaining test stations were in good condition and do not require repairs. 	<ol style="list-style-type: none"> 1. Replace the four missing test stations and remediate each of the three identified test station deficiencies. 2. Perform a “native” potential survey to determine if the pipeline is achieving the NACE SP0169 100 mV polarization criteria. The survey should be performed by disconnecting the anode lead wires from the pipeline drain wire and allowing the pipeline approximately four weeks to depolarize before “native” potentials are measured. The results of the “native” potential survey should be compared to the “instant off” potentials measured during the Year 3 survey to determine if the pipeline is achieving 100 mVs of polarization. 3. If the pipeline is not achieving the NACE SP0169 100 mV polarization criteria, then perform current requirement testing and design the rehabilitation of the existing CP system. Perform a polarized potential survey after the rehabilitated system is energized. 4. Perform annual surveys of the GACP system consisting of measuring “on” and “instant off” potentials, galvanic anode current outputs, and anode open circuit potentials in accordance with NACE SP0169.

System Type	Facility Name	Conclusions	Recommendations
GACP	Route 40 - New Natomas / Old Natomas Pumping Station	<ol style="list-style-type: none"> 1. Of a total of 14 test stations, the pipeline is achieving the NACE SP0169 -850 mV polarized potential criterion at two test stations. A “native” potential survey is required to determine if the NACE SP0169 100 mV polarization criterion is being achieved at the remaining 12 test stations. 2. Due to water filling the flush mounted test station valve boxes which resulted in corroded hardware, four of the shunts are broken, as detailed in 3.2.3, which prevented the current output from being measured. The remaining galvanic anodes are operational and provide CP current to the pipeline. 3. Each of the 14 test stations were located and tested. 4. With the exception of the corroded hardware outlined above, the remaining test stations were in good condition and do not require repairs. 	<ol style="list-style-type: none"> 1. Perform a “native” potential survey to determine if the pipeline is achieving the NACE SP0169 100 mV polarization criteria. The survey should be performed by disconnecting the anode lead wires from the pipeline drain wire and allowing the pipeline approximately four weeks to depolarize before “native” potentials are measured. The results of the “native” potential survey should be compared to the “instant off” potentials measured during the Year 3 survey to determine if the pipeline is achieving 100 mVs of polarization. 2. If the pipeline is not achieving the NACE SP0169 100 mV polarization criteria, then perform current requirement testing and design the rehabilitation of the existing CP system. Perform a polarized potential survey after the rehabilitated system is energized. 3. Perform annual surveys of the GACP system consisting of measuring “on” and “instant off” potentials, galvanic anode current outputs, and anode open circuit potentials in accordance with NACE SP0169. 4. Replace each of the four corroded shunts.

System Type	Facility Name	Conclusions	Recommendations
CM	Dry Creek Interceptor	<ol style="list-style-type: none"> Each of the potentials measured on the pipeline fall within the expected range of a steel or ductile iron pipeline in negligibly to mildly corrosive soil based on the material of the interceptor. Of the two total test stations, both test stations were located. Each of the located test stations were in good condition and do not require repairs. 	<ol style="list-style-type: none"> Perform annual surveys of the CM system consisting of measuring “native” pipe-to-soil potentials. The results of the survey should be compared to the results of the Year 3 survey to determine if the pipeline’s level of electrical activity is increasing.
CM	McClellan Interceptor	<ol style="list-style-type: none"> None of the three test stations associated with this line could be located; therefore, an evaluation of the CM system could not be performed. 	<ol style="list-style-type: none"> Replace the three missing test stations to allow for an evaluation of the CM system. Perform annual surveys of the CM system consisting of measuring “native” pipe-to-soil potentials. The results of the survey should be evaluated to determine if the pipeline may be experiencing active corrosion.

<p>CM</p>	<p>Route 9 - Old Natomas Force Main</p>	<ol style="list-style-type: none"> 1. Each of the potentials measured on the pipeline are more electronegative than the expected range of a non-corroding pipeline based on the material of the pipeline; therefore, the pipeline may be experiencing active corrosion. 2. It is likely that the street has been paved since the time the GPS coordinates were collected, as a majority of the test stations could not be located. Of the 26 total test stations, the following 17 test stations could not be located, as detailed in Section 3.3.3. 3. Each of the tested IJTS were providing effective isolation. 4. Nine test stations were identified as requiring repairs, as detailed in Section 3.3.3. 	<ol style="list-style-type: none"> 1. Replace the 17 missing test stations, move the three test stations that currently require traffic control to behind the curb or to a location that is not subject to vehicular traffic, and remediate each of the six identified test station deficiencies. 2. Obtain pipeline as-builts and manufacturing documentation to determine whether the PCCP installed is suitable for the application of CP. If it is suitable, then perform current requirement testing to determine the required current capacity of a new CP system. The testing should be performed with a portable rectifier and temporary anode bed to discharge a test current to the pipeline. The level of polarization achieved as the result of the test current should be measured, and CP system design calculations should be performed to determine the configuration of the new CP system. 3. If suitable, design a new CP system to protect the Route 9 piping using the results of the current requirement testing. 4. If a new CP system is to be installed, perform an annual survey of the CP system consisting of measuring “on” and “instant off” potentials, anode current outputs, and anode open circuit potentials in accordance with NACE SP0169. 5. If a new CP system is not to be installed, perform an annual survey of the CM system consisting of measuring “native” pipe-to-soil potentials.
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System Type	Facility Name	Conclusions	Recommendations
CM	Route 20 - West Sacramento	<ol style="list-style-type: none"> Each of the potentials measured on the pipeline are more electronegative than the expected range of a non-corroding pipeline based on the material of the pipeline; therefore, the pipeline may be experiencing active corrosion. Each of the 18 IJTS are providing effective isolation. Of the 51 total test stations, six test stations could not be located. Six test stations were identified as requiring repairs, as detailed in 3.3.4. 	<ol style="list-style-type: none"> Replace the six missing test stations and remediate each of the six identified test station deficiencies. Perform current requirement testing to determine the required current capacity of a new CP system. The testing should be performed with a portable rectifier and temporary anode bed to discharge a test current to the pipeline. The level of polarization achieved as the result of the test current should be measured, and CP system design calculations should be performed to determine the configuration of the new CP system. Design a new CP system to protect the Route 20 piping using the results of the current requirement testing. Once a new CP system is installed, perform annual polarized potential surveys of the CP system at accessible test stations in accordance with NACE SP0169.
CM	Route 25 - Arden Force Main	<ol style="list-style-type: none"> Each of the potentials measured on the pipeline fall within the expected range of a non-corroding pipeline based on the material of the pipeline. Of the 10 total test stations, four test stations could not be located. Each of the located test stations were in good condition and do not require repairs. 	<ol style="list-style-type: none"> Replace the four missing test stations. Perform an annual survey of the CM system consisting of measuring “native” pipe-to-soil potentials. The results of the survey should be compared to the results of the Year 3 survey to determine if the pipeline’s level of electrical activity is increasing.

1 Introduction

V&A Consulting Engineers, Inc (V&A) has completed the testing and evaluation of the cathodic protection (CP) systems and corrosion monitoring (CM) systems associated with piping owned and operated by Sacramento Regional County Sanitation District (Regional San). The piping within the scope included cement mortar lined and coated steel pipe, reinforced concrete cylinder pipe, pretensioned concrete cylinder pipe, and bare steel. The CP systems providing corrosion control to the piping include both impressed current CP (ICCP) systems and galvanic anode CP (GACP) systems. A survey was conducted to document the existing condition of the systems and measure the performance of the systems in accordance with NACE SPO169 criteria for adequate corrosion control. An ArcGIS dashboard has been prepared to accompany this report. The dashboard includes the collected field data, as well as site photos and a photo of each test station lid and test board at the located rectifier and test station.

The test methods performed during the survey included measuring the rectifier voltage and current outputs, “on” and “instant off” potentials at accessible test stations, galvanic anode current outputs and open-circuit potentials, and “corrosion monitoring” potentials at accessible test stations. The purpose of the evaluation was to document the existing conditions of the systems and to provide recommendations for improving their efficiency and facilitate future operations and maintenance. The need for the installation of a CP system was evaluated for pipelines that do not currently receive corrosion control from a CP system but instead have a corrosion monitoring system. The field survey was performed by V&A personnel between November 1 and November 16, 2021.

1.1 Test Station Descriptions

The ICCP, GACP, and CM systems included various types of test stations. For the purposes of this report, each evaluated test station was classified into one of the three system types:

1. ICCP system test station: A test station that is influenced by the current output of an anode well energized by a rectifier (i.e., the measured pipe-to-soil potentials at the test station shifted as the rectifier was cycled on and off).
2. GACP system test station: A test station that includes galvanic anode test leads and is not influenced by the current output of a rectifier.
3. CM system test station: A test station that includes pipeline test leads but does not receive CP current from a rectifier or galvanic anode.

The following test station types were visited during the evaluation:

1. Potential Test Station (PTS): A test station that includes test leads that are each connected to the same electrically continuous structure. A PTS can be part of an ICCP system, a GACP system, or a CM system, depending on whether it is influenced by rectifier current output.
2. Insulating Joint Test Station (IJTS): A test station that includes test leads installed on each side of an insulated joint which is used to measure the effectiveness of the electrical isolation at the insulating joint. An IJTS can be part of an ICCP system, a GACP system, or a CM system, depending on whether it is influenced by rectifier current outputs.

3. Anode Test Station (ATS): A test station that includes one or more galvanic anode test leads, a pipeline test lead, and a pipeline drain wire. Each ATS is part of the GACP system.
4. Casing Test Station (CTS): A test station that includes test leads connected to a pipe casing. CTSs usually show up in pairs, one at each end of a casing. A CTS can be part of an ICCP system, a GACP system, or a CM system, depending on whether it is influenced by rectifier current outputs.

1.2 Regional San Facility Descriptions

The evaluated Regional San facilities intended to receive corrosion control from an ICCP system are summarized in Table 1-1.

Table 1-1. Summary of Evaluated ICCP Systems

Facility Name	Diameter	Pipe Material	No. of Rectifiers	Total No. of Test Stations	Appendix
Route 24 - Northeast Interceptor	Three parallel 48-inch pipelines	Cement mortar-lined and coated welded steel pipe	1	3	A
Route 42 - Power Inn Pump Station	One 36-inch and one 42-inch casing	Bare welded steel	1	4	B

The evaluated Regional San facilities intended to receive corrosion control from a GACP system are summarized in Table 1-2.

Table 1-2. Summary of Evaluated GACP Systems

Facility Name	Diameter (in)	Pipe Material	Total No. of Test Stations	Appendix
Bradshaw Interceptor	108-inch	Reinforced concrete cylinder pipe	2	C
Route 30 - City Interceptors	Unknown	Unknown	19	D
Route 40 - New Natomas / Old Natomas Pumping Station	Unknown	Unknown	14	E

The evaluated Regional San facilities with a CM system are summarized in Table 1-3.

Table 1-3. Summary of Evaluated CM Systems

Facility Name	Diameter (in)	Pipe Material	Total No. of Test Stations	Appendix
Dry Creek Interceptor	Unknown	Bare steel	2	F
McClellan Interceptor	33-inch	Bare steel	3	N/A
Route 9 - Old Natomas Force Main	24-inch	Pretensioned concrete cylinder pipe	26	G
Route 20 - West Sacramento	Two parallel 60-inch pipelines	Cement mortar-lined and coated welded steel pipe	51	H
Route 25 - Arden Force Main	60-inch	Cement mortar-lined and coated welded steel pipe	10	I

2 Approach

2.1 General

2.1.1 Corrosion and Cathodic Protection

Corrosion of a buried metallic pipeline is caused by an electrochemical reaction between the pipeline and its environment and involves the flow of direct current (DC) in what is referred to as a corrosion cell. The following components must exist for a corrosion cell to form:

1. **Anode:** Active metal; electronegative location where corrosion occurs
2. **Cathode:** Noble metal; electropositive location that does not corrode
3. **Electrolytic Path:** Solution containing ions that allows current to flow from the anode to the cathode
4. **Metallic Path:** Conductive structure allowing current to return to the anode from the cathode

When a metallic structure corrodes, current is discharged from the surface of the structure at the anodic location. The current flows through the electrolyte (typically a body of soil or water) to a different area on the surface of the structure at the cathodic location. The corrosion current flows through the structure back to the anodic location to complete the flow of current in the corrosion cell. Corrosion occurs at the anode while the cathode is protected from corrosion.

CP is a method of corrosion control that uses an external anode to convert the entire surface of a structure into the cathode in a corrosion cell. CP current flows from the anode through the electrolyte to the structure, along the structure to a cable connecting the structure and the anode, and along the cable to the anode to complete the flow of CP current. Properly designed, installed, and maintained CP systems mitigate corrosion of the structure. The two types of CP systems are referred to as impressed current cathodic protection (ICCP) systems and galvanic anode cathodic protection (GACP) systems.

ICCP systems are generally applicable to situations where the structure has a large current requirement (such as bare or poorly coated structures or where protective current must be applied for long distances) and the surrounding electrolyte has a relatively high resistivity. ICCP systems use a rectifier as the DC power source to impress current from the deep well anode beds to the pipelines. The negative terminal of the rectifier is connected to the pipeline and the positive terminal is connected to the external anodes. An advantage of an impressed current CP system is the ability to adjust the amount of protective current applied to the pipeline.

GACP systems are generally applicable to situations where the structure has a low current requirement (such as well-coated structures or where protective current is only required in a localized area) and the surrounding electrolyte has a relatively low resistivity. GACP systems use anodes constructed from a metallic material more active than steel such as magnesium, aluminum, or zinc. CP current flows from the anode to the structure driven by the difference in electrical potential between the anode and the steel. Assuming equal resistance through the electrolyte, a larger potential difference will result in a larger amount of current flow.

2.1.2 Electrical Continuity and Isolation

Effective corrosion protection of a pipeline is dependent on the electrical continuity of the CP circuit. If an electrical discontinuity or a location of high resistance exists anywhere in the CP circuit, whether the anode lead wires are cut or one of the joints of the pipeline is electrically discontinuous, there will be a break in the electrical circuit and the CP system will not provide current to the entire pipeline as intended. It is for this reason that the entire pipeline intended to receive CP current as well as the CP components themselves are electrically continuous.

Conversely, if the project pipeline becomes electrically continuous with a pipe vault, valve vault, pump station, crossing foreign pipeline, or other metallic structure, a low resistance path for the CP current will be created and current will flow to the foreign structure. A portion of the CP current will take the low resistance path and flow to the unintended structure instead of the project pipeline. An electrical short between a pipeline and a structure will drain CP current away from the pipeline where it is necessary for corrosion protection.

Insulating joints are used to break the path of electric current between a pipeline and other existing pipelines or reinforced concrete structures. A common type of insulating joint is a dielectric insulating flange, which consists of an insulating gasket, insulating washers, and insulating sleeves around each bolt. The non-metallic components of the insulating joint prevent the flow of electric current past the joint. A dielectric insulating flange kit should be present at the beginning and end of each pipeline to prevent CP current from draining to structures not intended to be a part of the CP system.

2.1.3 Cathodic Protection Criteria

The criteria used to determine whether a pipeline is adequately protected from corrosion is provided in NACE International (NACE) Standard SP0169. Section 6.2.1.3 describes what is commonly called the "850 millivolt (mV) polarized potential criterion" and states the following:

"A structure-to-electrolyte potential of -850 mV or more negative as measured with respect to a saturated copper/copper sulfate (CSE) reference electrode. This potential may be either a direct measurement of the polarized potential or a current applied potential. Interpretation of a current applied measurement requires consideration of the significance of voltage drops in the earth and metallic paths."

In addition to the above criterion, NACE SP0169, Section 6.2.1.2, commonly called the "100 mV polarization criterion", states the following:

"A minimum of 100 mV of cathodic polarization; either the formation or decay of polarization can be measured to satisfy this criterion."

The 100 mV polarization criterion is satisfied if the difference between the "instant off" and the "depolarized" potential is at least 100 mV.

2.1.4 Corrosion Monitoring Systems Data Evaluation

Although the potentials measured from a CM system are typically used as baseline measurements by which future potentials can be compared to determine if the level of electrical activity (corrosion) is increasing over time, they can also be compared to the expected ranges of non-corroding pipeline based on the pipeline material to determine if the pipeline is experiencing active corrosion.

Based on the guidelines provided in ASTM C876, which is a test method for determining if the reinforcing steel embedded in concrete is experiencing active corrosion, the expected range for non-

corroding mortar coated steel pipe materials is -200 to -350 mV_{CSE}. If the measured potentials are more electronegative than this range, it is possible that the steel cylinder is experiencing active corrosion, and the requirements for a CP system to mitigate further corrosion of the pipeline should be evaluated.

Based on V&A's extensive experience in evaluating corrosion monitoring systems, the expected range of potentials for non-corroding bare steel, dielectrically coated steel, and ductile iron pipelines is -400 to -600 mV_{CSE}. If the measured potentials are greater (more electronegative) than this range, it is possible that the pipeline is experiencing active corrosion, and the requirements for a CP system to mitigate further corrosion of the pipeline should be evaluated.

2.2 Test Methods

2.2.1 Rectifier Outputs

The voltage and current outputs of the rectifiers were measured using a Fluke Model 289 Digital Voltmeter (Fluke 289). The voltage was measured directly by connecting the voltmeter leads across the output terminals of the rectifier. The current output of the rectifier was determined by measuring the voltage drop across the shunt on the face of the rectifier. By knowing the voltage drop across the shunt and the resistance or calibration factor of the shunt, the current was calculated from Ohm's Law (the voltage of a circuit is equivalent to circuit current multiplied by circuit resistance, $V = IR$). The rectifier output measured using the test meter was compared to the meters on the face of the rectifier. The current output of the individual anodes was determined by measuring the voltage drop across the shunts in the anode junction box.

2.2.2 Pipe-to-Soil Potentials

Pipe-to-soil potentials were measured using the Fluke 289. Potentials were measured versus a copper/copper sulfate (CSE) reference electrode placed in contact with the soil at the test stations. The Fluke 289 is a high-impedance voltmeter used to reduce the effects of contact resistance between the electrode and the soil and to prevent the electrode from polarizing. The pipeline test lead was connected to the positive terminal of the meter and the reference electrode was connected to the negative terminal of the voltmeter. Using this configuration for the meter and test lead connections, the potentials will have a negative polarity. A structure is determined to meet NACE criteria for corrosion protection if the polarized potential is -850 mV or more electronegative. As an example, a polarized potential of -900 mV meets NACE criteria whereas a polarized potential of -800 mV does not meet NACE criteria.

Pipe-to-soil potentials were measured with CP current flowing to the pipeline and with CP current momentarily interrupted. "On" potentials were measured with the rectifier impressing current from the anodes or with the galvanic anodes connected to the pipeline. "Instant off" potentials were measured with the rectifier current output momentarily interrupted or with the galvanic anodes momentarily disconnected from the pipeline. "Instant off" potentials were measured to determine the polarized potential of the structures, as required by the NACE criteria, and to eliminate "IR error" in the readings. "IR error" is due to CP current (I) flowing through the soil (R) and results in measured potentials that are greater (more electronegative) than the true potential of the structures. When the rectifier is momentarily turned off, the current flowing through the soil (I) is negligible and therefore the "IR error" is also negligible.

2.2.3 Galvanic Anode Measurements

Similar to pipe-to-soil potentials, anode open circuit potentials were measured using a Fluke 289 versus a CSE reference electrode placed in contact with the soil at the test locations. The anode lead wires were connected to the positive terminal of the meter once the anode lead wire had been disconnected from the pipeline drain wire. The open-circuit potential of an anode provides an indication of the status of the anode. For sacrificial magnesium anodes to provide adequate CP current to a pipeline, the open circuit potential of a standard anode should be approximately $-1,500$ millivolts versus a CSE reference electrode or more electronegative. The open-circuit potential of an anode will shift positively over time as the anode becomes consumed.

Galvanic anode current outputs were determined in the same manner as individual impressed current anode measurements by measuring the voltage drop across the shunt. Anode current output is then determined using the resistance of the shunt and Ohm's Law.

3 Findings

3.1 Impressed Current Cathodic Protection Systems

The evaluation of the ICCP systems included measuring rectifier voltage and current outputs as well as individual anode current outputs in the “as-found” condition. A current interrupter was then installed in the output of the rectifier, and “on” and “instant off” potentials were measured at each accessible test station to determine if the pipeline was achieving the NACE SP0169 –850 mV polarized potential criteria for adequate corrosion control, or if the rectifier outputs needed to be adjusted.

3.1.1 Route 24

Route 24 consisted of three paralleling 48-inch diameter cement mortar-lined and coated welded steel pipelines. The ICCP system intended to provide corrosion control to the pipelines consisted of one 30-volt, 24-amp rectifier energizing eight anodes installed in a deep well configuration. The pipeline had a total of three test stations associated with the ICCP system.

Based on the rectifier output measurements, the rectifier and deep anode well were operating as intended and did not require replacement at that time. Based on the results of the pipe-to-soil potential survey, the pipeline was achieving the NACE SP0169 –850 mV polarized potential criterion for adequate corrosion control and the rectifier outputs did not require adjustment. Even though corrosion of the pipeline was mitigated, the rectifier was found to be discharging approximately 1 amp, which is well below its rated capacity of 24 amps. Due to the pipeline achieving NACE criteria at a low current output, the expected remaining useful life of the rectifier and deep anode well is greater than 20 years.

V&A was unable to locate one test station (N24-CTS0033C). Based on the GPS coordinates provided by Regional San, the missing test station is located adjacent to the rectifier (where pipeline potentials can be measured using the rectifier drain test lead), and therefore the test station does not require replacement. Neither of the located test stations were damaged or required repairs.

Complete field data collected from the Route 24 ICCP system is presented in Appendix A.

3.1.2 Route 42

Route 42 consisted of parallel 36-inch and 42-inch welded steel casings. The ICCP system intended to provide corrosion control to the casings consists of one 24-volt, 8-amp rectifier energizing three anodes installed horizontally from each other in a shallow well configuration. The casings have a total of four test stations associated with the ICCP system.

Based on the rectifier output measurements, the rectifier and anode wells are operating as intended and do not require replacement at this time. Based on the results of the casing-to-soil potential survey, the casings are achieving the NACE SP0169 –850 mV polarized potential criterion for adequate corrosion control and the rectifier outputs did not require adjustment. Even though corrosion of the pipeline was mitigated, the rectifier was found to be discharging approximately 1 amp, which is well below its rated capacity of eight amps. The current outputs of the anodes should continue to be monitored as the rectifier does not appear to be a modern type of rectifier.

V&A was unable to locate one test station (N52-CTS0006B). Based on the GPS coordinates provided by Regional San, the missing test station is located adjacent to test station N52-CTS0006A (where pipeline potentials can be measured), and therefore the test station does not require replacement. None of the located test stations were damaged or required repairs.

Complete field data collected from the Route 42 ICCP system is presented in Appendix B.

3.2 Galvanic Anode Cathodic Protection Systems

The evaluations of the GACP systems included measuring “on” and “instant off” potentials, anode current outputs, and anode open circuit potentials at each accessible test station to determine if the pipeline was achieving the NACE SP0169 -850 mV polarized potential criterion for adequate corrosion control. “Native” potentials of the pipeline are unknown; therefore, it could not be determined if the pipelines were achieving the NACE SP0169 100 mV polarization criterion.

3.2.1 Bradshaw Interceptor

The Bradshaw Interceptor consists of a 108-inch diameter reinforced concrete cylinder pipeline. The GACP system intended to provide corrosion control to the pipeline consists of one ATS and one PTS.

Based on the results of the pipe-to-soil potential survey, the pipeline is not achieving the NACE SP0169 -850 mV polarized potential criterion for adequate corrosion control. The anode at the ATS has reached the end of its useable life and is not providing CP current to the pipeline. Based on the diameter and length of the pipeline, it is unlikely that the one anode associated with the existing GACP system would have provided a sufficient amount of current to adequately mitigate corrosion of the pipeline. Current requirement testing should be performed to determine the required capacity of a new CP system.

V&A was able to locate both test stations. Although the CP system needs to be replaced, neither of the test stations were damaged or required repairs.

Complete field data collected from the Bradshaw Interceptor GACP system is presented in Appendix C.

3.2.2 Route 30

The diameter and pipeline material of Route 30 are unknown. The GACP system intended to provide corrosion control to the pipeline consists of 19 total test stations including one PTS, one IJTS, 13 ATS, and four test stations that could not be located.

Based on the results of the pipe-to-soil potential survey, the polarized potentials of the pipeline ranged from -490 to -701 mV_{CSE}, and therefore the pipeline is not achieving the NACE SP0169 -850 mV polarized potential criterion for adequate corrosion control. With the exception of CTS1248, the anodes are not depleted, and CP current is being provided to the pipeline. At CTS1248, the anode was found to be shorted to the pipeline even after the anode lead wire was disconnected from the pipeline drain wire, and therefore no current output was measured. A “native” potential survey is required to determine if the pipeline is achieving the NACE SP0169 100 mV polarization criterion.

The one IJTS (CTS1015) is providing effective electrical isolation.

The following four test stations could not be located:

1. CTS1198
2. CTS1199
3. CTS1201
4. CTS1238

The following test station deficiencies were identified:

1. CTS1015: The post-mounted test station was knocked over.
2. CTS1239: Missing post mounted test station lid
3. CTS1249: Sealed post mounted test station lid.

Complete field data collected from the Route 30 GACP system is presented in Appendix D.

3.2.3 Route 40

The diameter and pipeline material of Route 40 are unknown. The GACP system intended to provide corrosion control to the pipeline consists of 14 ATS.

Based on the results of the pipe-to-soil potential survey, two test stations achieved the NACE SP0169 –850 mV polarized potential criterion for adequate corrosion control. For the remaining 12 test stations, polarized potentials ranged from –417 to –777 mV; therefore, the NACE SP0169 –850 mV polarized potential criterion was not achieved. A “native” potential survey is required to determine if the pipeline is achieving the NACE SP0169 100 mV polarization criterion.

V&A was able to locate each of the 14 test stations.

Due to water filling the flush mounted test station valve boxes which resulted in corroded hardware, the following test stations were found to have a broken shunt. CP current is not able to flow from the anode to the pipeline when the shunt is broken. The shunts were not replaced in the field due to the crowded test station boards.

1. N51-CTS1003
2. N51-CTS1005
3. N51-CTS1006
4. N51-CTS1007

At the other 10 ATS locations, the anodes are not depleted, and CP current is being provided to the pipeline.

Complete field data collected from the Route 30 GACP system is presented in Appendix E.

3.3 Corrosion Monitoring Systems

The evaluations of the CM systems included measuring “native” potentials at each accessible test station to approximate the amount of electrical activity occurring on the pipeline. CP current is not provided to pipelines with a CM system; therefore, the potentials measured on a CM system do not apply to NACE criteria. The expected range for non-corroding mortar coated steel pipe materials is -200 to -350 mV_{CSE}. The expected range of potentials for non-corroding bare steel, dielectrically coated steel, and ductile iron pipelines is -400 to -600 mV_{CSE}. If the measured potentials are greater (more electronegative) than this range, it is possible that the pipeline is experiencing active corrosion, and the requirements for a CP system to mitigate further corrosion of the pipeline should be evaluated.

3.3.1 Dry Creek Interceptor

The Dry Creek Interceptor consisted of a bare steel casing of an unknown diameter. The CM system associated with the casing consists of two CTS. Due to the material of the interceptor, the potentials measured during the survey are compared to the expected range of -400 to -600 mV_{CSE}.

Based on the results of the pipe-to-soil potential survey, the potentials ranged from -552 to -599 mV, which is typical for steel in negligibly to mildly corrosive soil.

V&A was able to locate both test stations, and each test station was in good condition.

Complete field data collected from the Dry Creek Interceptor CM system is presented in Appendix F.

3.3.2 McClellan Interceptor

The McClellan Interceptor consisted of a 33-inch diameter bare steel pipeline. The CM system associated with the pipeline consisted of three PTS. None of the test stations associated with the pipeline could be located; therefore, an evaluation of the CM system could not be performed.

3.3.3 Route 9

Route 9 consisted of 24-inch diameter prestressed concrete cylinder pipe. The CM system associated with the pipeline consisted of 26 total test stations including three PTS, three IJTS, three test stations that require traffic control to be assessed, and 17 test stations that could not be located. Due to the material of the pipeline, the potentials measured during the survey are compared to the expected range of -200 to -350 mV_{CSE}.

Based on the results of the pipe-to-soil potential survey, the potentials measured on the pipeline ranged from -356 to -588 mV, which is greater (more electronegative) than the expected range for non-corroding mortar coated pipeline materials; therefore, the pipeline may be experiencing active corrosion.

Each of the three tested IJTS were providing effective isolation.

It is likely that the street had been paved since the time the GPS coordinates were collected, as a majority of the test stations could not be located. Of the 26 total test stations, the following 17 test stations could not be located:

- | | | |
|-----------------|------------------|------------------|
| 1. S30-CTS0001A | 7. S30-CTS0002F | 13. S30-CTS0003J |
| 2. S30-CTS0001B | 8. S30-CTS0003C | 14. S30-CTS0004B |
| 3. S30-CTS0001C | 9. S30-CTS0003D | 15. S30-CTS0004C |
| 4. S30-CTS0002C | 10. S30-CTS0003E | 16. S30-CTS0004D |
| 5. S30-CTS0002D | 11. S30-CTS0003F | 17. S30-CTS0004E |
| 6. S30-CTS0002E | 12. S30-CTS0004H | |

The following test station deficiencies were identified:

1. S30-CTS0001D: One test lead is cut, and the test board is missing.
2. S30-CTS0002A: Test board is missing.
3. S30-CTS0002B: Test station traffic box is located in a high-speed road.
4. S30-CTS0002G: Test board is missing.
5. S30-CTS0002H: Test station traffic box is located in a high-speed road.
6. S30-CTS0003A: Test board is missing.
7. S30-CTS0003B: Test station traffic box is located in a high-speed road.
8. S30-CTS0003G: Test board is missing.
9. S30-CTS0004A: Test board is missing.

Complete field data collected from the Route 9 CM system is presented in Appendix G.

3.3.4 Route 20

Route 20 consisted of two paralleling 60-inch diameter cement mortar-lined and coated welded steel pipes. The CM system associated with the pipelines consisted of a total of 51 test stations including 26 PTS, 18 IJTS, one test station that was located within private property, and six test stations that could not be located. Due to the material of the pipeline, the potentials measured during the survey were compared to the expected range of -200 to -350 mV_{CSE}.

Based on the results of the pipe-to-soil potential survey, the potentials measured on the pipeline ranged from -413 to -716 mV, which was greater (more electronegative) than the expected range for non-corroding mortar coated pipeline materials; therefore, the pipeline may be experiencing active corrosion.

Each of the 18 tested IJTS were providing effective isolation.

Of the 51 total test stations, the following six test stations could not be located:

1. N51-CTS0004C
2. N51-CTS0004D
3. N51-CTS0004E
4. N51-CTS0005D
5. N51-CTS0016A
6. N51-CTS0016B

The following test station deficiencies were identified:

1. N51-CTS0005A: The test lead wires were cut, and the test board is missing.
2. N51-CTS0005B: The test lead wires were cut, and the test board is missing.
3. N51-CTS0006A: Test board is missing.
4. N51-CTS0009A: Replace the flush-mounted test station traffic box lid.
5. N51-CTS0017C: The test station traffic box is located within the boundaries of a gated fence belonging to a private residence.
6. N51-CTS0018B: One test lead is cut.

Complete field data collected from the Route 20 CM system is presented in Appendix H.

3.3.5 Route 25

Route 25 consisted of a 60-inch diameter cement mortar lined and coated welded steel pipe. The CM system associated with the pipelines consists of a total of 10 test stations including six PTS and four test stations that could not be located. Due to the material of the pipeline, the potentials measured during the survey were compared to the expected range of -200 to -350 mV_{CSE}.

Based on the results of the pipe-to-soil potential survey, the potentials measured on the pipeline ranged from -189 to -332 mV., which is within the expected range for non-corroding mortar coated pipeline materials.

Of the 10 total test stations, the following four test stations could not be located:

1. N19-CTS0029D
2. N19-CTS0030D
3. N19-CTS0026D
4. N19-CTS0026E

Each of the located test stations was in good condition and did not require repairs.

Complete field data collected from the Route 25 CM system is presented in Appendix I.

4 Conclusions

4.1 Impressed Current Cathodic Protection Systems

4.1.1 Route 24

1. The rectifier and deep anode well were operating properly and do not require replacement at this time.
2. Corrosion of the pipeline was mitigated per NACE SP0169 -850 mV polarized potential criterion.
3. The current output of the rectifier was measured at approximately one amp which is well below the rated capacity of the rectifier (24 amps). Due to the pipeline achieving NACE criteria at a low rectifier current output, the expected remaining useable life of the rectifier is greater than 20 years.
4. Of the three total test stations, one test station could not be located. This test station is located adjacent to the rectifier and therefore does not require replacement.
5. Each of the located test stations were in good condition and did not require repairs.

4.1.2 Route 42

1. The rectifier and shallow anode beds were operating properly and do not require replacement at this time.
2. Corrosion of the casings was mitigated per the NACE SP0169 -850 mV polarized potential criterion.
3. The current output of the rectifier was measured at approximately one amp which is well below the rated capacity of the rectifier (8 amps). The current output of the anodes should continue to be monitored as the rectifier does not appear to be a modern type of rectifier.
4. Of the four total test stations, one test station could not be located. This test station is located adjacent to another test station and therefore does not require replacement.
5. Each of the located test stations are in good condition and do not require repairs.

4.2 Galvanic Anode Cathodic Protection Systems

4.2.1 Bradshaw Interceptor

1. The pipeline was not achieving the NACE SP0169 -850 mV polarized potential criterion.
2. The galvanic anode associated with the GACP system was depleted and no CP current was being provided to the pipeline.
3. Additional testing must be performed to determine the required capacity of a new CP system.
4. Of the two total test stations, both test stations were located.
5. Each of the located test stations were in good condition and do not require repairs.

4.2.2 Route 30

1. The pipeline was not achieving the NACE SP0169 –850 mV polarized potential criterion. A “native” potential survey is required to determine if the NACE SP0169 100 mV polarization criterion is being achieved.
2. One anode was electrically shorted to the pipeline and, therefore, no current output or open circuit potential was measured. The remaining galvanic anodes are operational and provide CP current to the pipeline.
3. The IJTS associated with the GACP system was providing effective isolation.
4. Of the 19 total test stations, four test stations could not be located.
5. Three test stations were identified as requiring repairs, as detailed in Section 3.2.2. The remaining test stations were in good condition and do not require repairs.

4.2.3 Route 40

1. Of a total of 14 test stations, the pipeline is achieving the NACE SP0169 –850 mV polarized potential criterion at two test stations. A “native” potential survey is required to determine if the NACE SP0169 100 mV polarization criterion is being achieved at the remaining 12 test stations.
2. Due to water filling the flush mounted test station valve boxes which resulted in corroded hardware, four of the shunts are broken, as detailed in 3.2.3, which prevented the current output from being measured. The remaining galvanic anodes are operational and provide CP current to the pipeline.
3. Each of the 14 test stations were located and tested.
4. With the exception of the corroded hardware outlined above, the remaining test stations were in good condition and do not require repairs.

4.3 Corrosion Monitoring Systems

4.3.1 Dry Creek Interceptor

1. Each of the potentials measured on the pipeline fall within the expected range of a steel or ductile iron pipeline in negligibly to mildly corrosive soil based on the material of the interceptor.
2. Of the two total test stations, both test stations were located.
3. Each of the located test stations were in good condition and do not require repairs.

4.3.2 McClellan Interceptor

1. None of the three test stations associated with this line could be located; therefore, an evaluation of the CM system could not be performed.

4.3.3 Route 9

1. Each of the potentials measured on the pipeline are more electronegative than the expected range of a non-corroding pipeline based on the material of the pipeline; therefore, the pipeline may be experiencing active corrosion.
2. It is likely that the street has been paved since the time the GPS coordinates were collected, as a majority of the test stations could not be located. Of the 26 total test stations, the following 17 test stations could not be located, as detailed in Section 3.3.3.
3. Each of the tested IJTS were providing effective isolation.

4. Nine test stations were identified as requiring repairs, as detailed in Section 3.3.3.

4.3.4 Route 20

1. Each of the potentials measured on the pipeline are more electronegative than the expected range of a non-corroding pipeline based on the material of the pipeline; therefore, the pipeline may be experiencing active corrosion.
2. Each of the 18 IJTS are providing effective isolation.
3. Of the 51 total test stations, six test stations could not be located.
4. Six test stations were identified as requiring repairs, as detailed in 3.3.4

4.3.5 Route 25

1. Each of the potentials measured on the pipeline fall within the expected range of a non-corroding pipeline based on the material of the pipeline.
2. Of the 10 total test stations, four test stations could not be located.
3. Each of the located test stations were in good condition and do not require repairs.

5 Recommendations

5.1 Impressed Current Cathodic Protection Systems

5.1.1 Route 24

1. Perform bi-monthly rectifier checks consisting of measuring rectifier voltage and current outputs to ensure the rectifier is operating properly. This may be achieved during field visits or remotely, if a remote monitoring unit is installed.
2. Perform an annual survey of the ICCP system consisting of measuring rectifier voltage and current outputs, individual anode current outputs, and “on” and “instant off” potentials at accessible test stations in accordance with NACE SP0169.

5.1.2 Route 42

1. Perform bi-monthly rectifier checks consisting of measuring rectifier voltage and current outputs to ensure the rectifier is operating properly. This may be achieved during field visits or remotely, if a remote monitoring unit is installed.
2. Perform an annual survey of the ICCP system consisting of measuring rectifier voltage and current outputs, individual anode current outputs, and “on” and “instant off” potentials at accessible test stations in accordance with NACE SP0169.

5.2 Galvanic Anode Cathodic Protection Systems

5.2.1 Bradshaw Interceptor

1. Perform current requirement testing to determine the required current capacity of a new CP system. The testing should be performed with a portable rectifier and temporary anode bed to discharge a test current to the pipeline. The level of polarization achieved as the result of the test current should be measured, and CP system design calculations should be performed to determine the configuration of the new CP system.
2. Design a new CP system to protect the Bradshaw Interceptor using the results of the current requirement testing. Perform a native potential survey before the system is energized. Perform a polarized potential survey after the system is energized.
3. Once a new CP system is installed, perform annual polarized potential surveys of the CP system at accessible test stations in accordance with NACE SP0169.

5.2.2 Route 30

1. Replace the four missing test stations and remediate each of the three identified test station deficiencies.
2. Perform a “native” potential survey to determine if the pipeline is achieving the NACE SP0169 100 mV polarization criteria. The survey should be performed by disconnecting the anode lead wires from the pipeline drain wire and allowing the pipeline approximately four weeks to depolarize before “native” potentials are measured. The results of the “native” potential survey should be

compared to the “instant off” potentials measured during the Year 3 survey to determine if the pipeline is achieving 100 mVs of polarization.

3. If the pipeline is not achieving the NACE SP0169 100 mV polarization criteria, then perform current requirement testing and design the rehabilitation of the existing CP system. Perform a polarized potential survey after the rehabilitated system is energized.
4. Perform annual surveys of the GACP system consisting of measuring “on” and “instant off” potentials, galvanic anode current outputs, and anode open circuit potentials in accordance with NACE SP0169.

5.2.3 Route 40

1. Perform a “native” potential survey to determine if the pipeline is achieving the NACE SP0169 100 mV polarization criteria. The survey should be performed by disconnecting the anode lead wires from the pipeline drain wire and allowing the pipeline approximately four weeks to depolarize before “native” potentials are measured. The results of the “native” potential survey should be compared to the “instant off” potentials measured during the Year 3 survey to determine if the pipeline is achieving 100 mVs of polarization.
2. If the pipeline is not achieving the NACE SP0169 100 mV polarization criteria, then perform current requirement testing and design the rehabilitation of the existing CP system. Perform a polarized potential survey after the rehabilitated system is energized.
3. Perform annual surveys of the GACP system consisting of measuring “on” and “instant off” potentials, galvanic anode current outputs, and anode open circuit potentials in accordance with NACE SP0169.
4. Replace each of the four corroded shunts.

5.3 Corrosion Monitoring Systems

5.3.1 Dry Creek Interceptor

1. Perform annual surveys of the CM system consisting of measuring “native” pipe-to-soil potentials. The results of the survey should be compared to the results of the Year 3 survey to determine if the pipeline’s level of electrical activity is increasing.

5.3.2 McClellan Interceptor

1. Replace the three missing test stations to allow for an evaluation of the CM system.
2. Perform annual surveys of the CM system consisting of measuring “native” pipe-to-soil potentials. The results of the survey should be evaluated to determine if the pipeline may be experiencing active corrosion.

5.3.3 Route 9

1. Replace the 17 missing test stations, move the three test stations that currently require traffic control to behind the curb or to a location that is not subject to vehicular traffic, and remediate each of the six identified test station deficiencies.
2. Obtain pipeline as-builts and manufacturing documentation to determine whether the PCCP installed is suitable for the application of CP. If it is suitable, then perform current requirement testing to determine the required current capacity of a new CP system. The testing should be performed with a portable rectifier and temporary anode bed to discharge a test current to the pipeline. The level of polarization achieved as the result of the test current should be measured,

and CP system design calculations should be performed to determine the configuration of the new CP system.

3. If suitable, design a new CP system to protect the Route 9 piping using the results of the current requirement testing.
4. If a new CP system is to be installed, perform an annual survey of the CP system consisting of measuring “on” and “instant off” potentials, anode current outputs, and anode open circuit potentials in accordance with NACE SP0169.
5. If a new CP system is not to be installed, perform an annual survey of the CM system consisting of measuring “native” pipe-to-soil potentials.

5.3.4 Route 20

1. Replace the six missing test stations and remediate each of the six identified test station deficiencies.
2. Perform current requirement testing to determine the required current capacity of a new CP system. The testing should be performed with a portable rectifier and temporary anode bed to discharge a test current to the pipeline. The level of polarization achieved as the result of the test current should be measured, and CP system design calculations should be performed to determine the configuration of the new CP system.
3. Design a new CP system to protect the Route 20 piping using the results of the current requirement testing.
4. Once a new CP system is installed, perform annual polarized potential surveys of the CP system at accessible test stations in accordance with NACE SP0169.

5.3.5 Route 25

1. Replace the four missing test stations.
2. Perform an annual survey of the CM system consisting of measuring “native” pipe-to-soil potentials. The results of the survey should be compared to the results of the Year 3 survey to determine if the pipeline’s level of electrical activity is increasing.

Appendix A

Route 24 Field Data

Rectifier Name	N24-CPNL0033A	Location:	Route 24
Manufacturer:	Farwest Corrosion Control	Rectifier Shunt Size:	50 mV = 25 A
Model No.:	ASAI	AC Input:	115/230 V
Serial No.:	105227	DC Output:	30 V, 24 A

Test By:	MS and LR	
Date:	11/2/2021	
Condition:	As found	
Tap Settings:	Coarse: 1/5	Fine: 3/5
	Panel	Meter
Rectifier Voltage (V):	4	3.992
Potential Across Shunt (mV):	N/A	2.1
Current Output (A):	1	1.05
Anode No.	Current Output (A)	
1	0.09	
2	0.15	
3	0.07	
4	0.16	
5	0.09	
6	0.06	
7	0.15	
8	0.23	



Photo 5-1. N24-CPNL0033A Rectifier Panel



Photo 5-2. N24-CPNL0033A Anode Junction Box

Test Station ID	Test Station Type	Wire ID	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Instant Off			
N24-CTS0033A	PTS	West 1	White	1,114	969	Yes	Good	
		West 2	White	1,114	969			
		Central 1	White	1,114	969			
		Central 2	White	1,114	969			
		East 1	White	1,114	969			
		East 2	White	1,114	969			
N24-CTS0033B	PTS	West	White	1,030	895	Yes	Good	
		East	White	1,030	895			
N24-CTS0033C								Could not locate

Appendix B

Route 42 Field Data

Rectifier Name	N52-CPNL0001A	Location:	Route 42
Manufacturer:	Corrpower	Rectifier Shunt Size:	50 mV = 10 A
Model No.:	CSAYSA 24-8 AZ256,822	AC Input:	115 V
Serial No.:	C-051778	DC Output:	24 V, 8 A

Test By:	MS and LR	
Date:	11/4/2021	
Condition:	As found	
Tap Settings:	Coarse: B/E	Fine: 1/5
	Panel	Meter
Rectifier Voltage (V):	6	6.77
Potential Across Shunt (mV):	N/A	4.8
Current Output (A):	0.9	0.96
Anode No.	Current Output (A)	
1	0.38	
2	0.32	
	0.27	

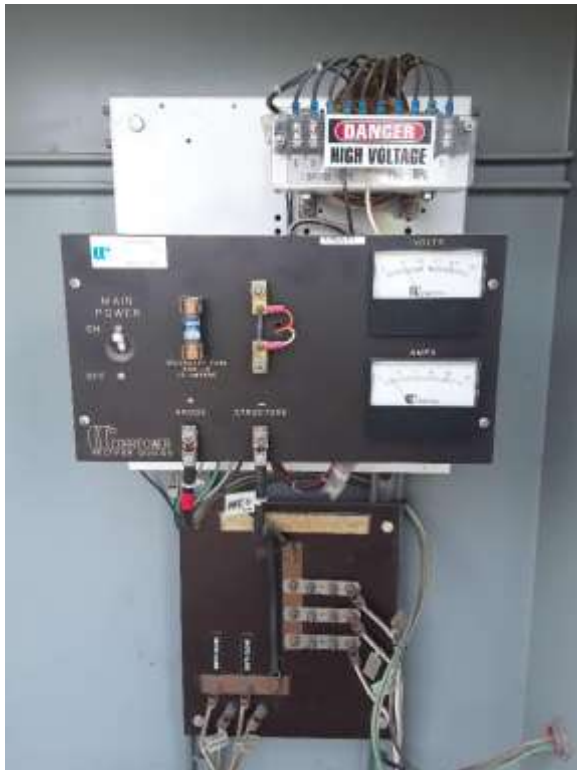


Photo 5-3. N52-CPNL0001A Rectifier Panel



Photo 5-4. N52-CPNL0001A Anode Junction Box

Test Station ID	Test Station Type	Wire ID	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Instant Off			
N52-CTS0001A	CTS	Top	Green	2,044	1,030	Yes	Good	Messy board, many spliced wires.
		Bottom	Green	2,044	1,030			
N52-CTS0001B	CTS	Top	White	1,390	985	Yes	Good	
		Bottom	White	1,390	985			
N52-CTS0006A	PTS	Pipe Lead 1	Green	875	875	Yes	Good	
		Pipe Lead 2	Green	875	875			
		Pipe Lead 3	Green	875	875			
		Pipe Lead 4	Green	875	875			
N52-CTS0006B								Could not locate

Appendix C

Bradshaw Interceptor Field Data

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Anode Current Output (mA)	Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Off				
N38-CTS0022A	ATS	Drain	White	422	429		No	Good	Depleted anode left disconnected
		Test	White	422	429				
		Anodes	Black	422	216	0			
		Ref Cell	Black	99	88				
N38-CTS0022B	PTS	1	Black	88			No	Good	
		2	Black	88					

Appendix D

Route 30 Field Data

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Anode Current Output (mA)	Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Off				
CTS1028	PTS	Test 1	White	291			No	Good	
		Test 2	White	291					
CTS1015	IJTS	Pipe Test	White	27			No	Damaged	Test station is knocked over
		IJ Test	Red	136					
CTS1201									Could not locate
CTS1199									Could not locate
CTS1198									Could not locate
CTS1237	ATS	Drain	White	739	490		No	Good	
		Test	White	739	490				
		Anodes	Black	740	1,551	209			
CTS1238									Could not locate
CTS1239								Damaged	Could not open
CTS1240	ATS	Drain	White	855	646		No	Good	
		Test	White	850	646				
		Anodes	Black	862	1,713	491			
CTS1241	ATS	Drain	White	791	680		No	Good	
		Test	White	784	680				
		Anodes	Black	798	1,716	507			
CTS1242	ATS	Drain	White	739	665		No	Good	
		Test	White	739	665				
		Anodes	Black	744	1,713	378			
CTS1243	ATS	Drain	White	766	638		No	Good	
		Test	White	766	638				
		Anodes	Black	769	1,700	265			

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Anode Current Output (mA)	Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Off				
CTS1244	ATS	Drain	White	801	682		No	Good	
		Test	White	801	682				
		Anodes	Black	801	1,447	212			
CTS1245	ATS	Drain	White	815	633		No	Good	
		Test	White	815	633				
		Anodes	Black	822	1,771	313			
CTS1246	ATS	Drain	White	845	685		No	Good	
		Test	White	845	685				
		Anodes	Black	845	1,846	226			
CTS1247	ATS	Drain	White	1,095	701		No	Good	
		Test	White	1,083	701				
		Anodes	Black	1,102	1,696	410			
CTS1248	ATS	Drain	White	1,491	1,462		No	Good	Test lead not continuous with drain wire. Anode is shorted to the pipeline.
		Test	White	685	683				
		Anodes	Black	1,491	1,489	0			
CTS1249	ATS	Drain	White	950	640		No	Damaged	Missing lid.
		Test	White	944	640				
		Anodes	Black	957	1,699	425			
CTS1250	ATS	Drain	White	877	579		No	Good	
		Test	White	877	579				
		Anodes	Black	877	1,760	720			

Appendix E

Route 40 Field Data

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Anode Current Output (mA)	Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Off				
N51-CTS1001	ATS	Drain	White	1249	1,002		Yes	Good	
		Test	White	1246	1,002				
		Anode 1	Black		1,575	31			
		Anode 2	Black		1,460	25			
		Anode 3	Black		1,588	30			
		Anode 4	Black		1,646	56			
N51-CTS1002	ATS	Drain	White	428	417		No	Good	
		Test	White	426	417				
		Anodes	Black		1,416	77			
N51-CTS1003	ATS	Drain	White		213		No	Damaged	Board is completely corroded. Drain wire disconnected.
		Anodes	Black		1,316	0			
N51-CTS1004	ATS	Drain	White	696	574		No	Damaged	Invalid shunt reading.
		Test	White	701	574				
		Anodes	Black		1,772				
N51-CTS1005	ATS	Drain	White		790		No	Damaged	Shunt is broken. Corroded board.
		Test	White		790				
		Anodes	Black		1,455	0			
N51-CTS1006	ATS	Drain	White		266		No	Damaged	Shunt is broken. Corroded board.
		Test	White		266				
		Anodes	Black		1,330	0			
N51-CTS1007	ATS	Drain	White		240		No	Damaged	Shunt is broken. Corroded board.
		Test	White		240				
		Anodes	Black		1,311	0			
N51-CTS1008	ATS	Drain	White	784	603		No	Good	

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Anode Current Output (mA)	Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Off				
		Test	White	783	603				
		Anodes	Black		1,354	246			
N51-CTS1009	ATS	Drain	White	525	511		No	Damaged	Invalid shunt reading.
		Test	White	524	511				
		White	Black		1,414				
N51-CTS1010	ATS	Drain	White	1,066	601		Yes	Good	
		Test	White	978	601				
		Anode 1, 2	Black		1,655	180			
		Anode 3, 4	Black		1,557	355			
		Anode 5, 6	Black		1,523	316			
		Anode 7, 8	Black		1,615	364			
N51-CTS1011	ATS	Drain	White	835	701		No	Good	
		Test	White	820	701				
		Anode 1	Black		1,419	79			
		Anode 2	Black		1,563	117			
		Anode 3	Black		1,439	78			
		Anode 4	Black		1,462	110			
		Anode 5	Black		1,558	106			
		Anode 6	Black		1,431	32			
		Anode 7	Black		1,473	47			
		Anode 8	Black		1,434	62			
N51-CTS1012	ATS	Drain	White	1,361	939		Yes	Good	Invalid shunt reading.
		Test	White	1,361	939				
		Anodes	Black		1,379				
N51-CTS1013	ATS	Drain	White	1,037	635		No	Good	

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})		Anode Current Output (mA)	Meets NACE -850 mV Criterion?	Test Station Condition	Comments
				On	Off				
		Test	White	1,033	635				
		Anodes	Black		1,557	283			
N51-CTS1014	ATS	Drain	White	1,003	777		No	Good	
		Test	White	995	777				
		Anodes	Black		1,616	280			

Appendix F

Dry Creek Interceptor Field

Data

Test Station ID	Test Station Type	Wire ID	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
N17-CTS0041B	CTS	Test 1	White	552	Good	
		Test 2	White	552		
N17-CTS0041C	CTS	Test 1	White	599	Good	
		Test 2	White	599		

Appendix G

Route 9 Field Data

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
S30-CTS0001A						Could not locate
S30-CTS0001B						Could not locate
S30-CTS0001C						Could not locate
S30-CTS0001D	PTS	Test 1	Black	588	Damaged	Test 2 is cut. Missing board.
		Test 2	Black	59		
S30-CTS0002A	IJTS	IJ 1	Red	849	Damaged	Missing board.
		Test 1	Black	465		
S30-CTS0002B						Traffic control required
S30-CTS0002C						Could not locate
S30-CTS0002D						Could not locate
S30-CTS0002E						Could not locate
S30-CTS0002F						Could not locate
S30-CTS0002G	PTS	Test 1	Green	28	Damaged	Missing board. Not connected to pipeline.
S30-CTS0002H						Traffic control required
S30-CTS0003A	PTS	Test 1	Red	356	Damaged	Missing board.
S30-CTS0003B						Traffic control required
S30-CTS0003C						Could not locate
S30-CTS0003D						Could not locate
S30-CTS0003E						Could not locate
S30-CTS0003F						Could not locate
S30-CTS0003G	IJTS	IJ 1	Red	355	Damaged	Missing board.
		Test 1	Black	530		
S30-CTS0003H						Could not locate
S30-CTS0003J						Could not locate
S30-CTS0004A	IJTS	IJ 1	Red	335	Damaged	Missing board. TS dug out by field crew.
		Test 1	Black	441		
S30-CTS0004B						Could not locate
S30-CTS0004C						Could not locate
S30-CTS0004D						Could not locate
S30-CTS0004E						Could not locate

Appendix H

Route 20 Field Data

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
N51-CTS0001A	PTS	Test 1	White	452	Good	
		Test 2	White	452		
N51-CTS0001B	PTS	Test 1	White	380	Good	
		Test 2	White	380		
N51-CTS0001C	PTS	Test 1	White	580	Good	
		Test 2	White	580		
N51-CTS0002A	PTS	Test 1	White	571	Good	
		Test 2	White	571		
N51-CTS0002B	PTS	Test 1	White	427	Good	
		Test 2	White	427		
N51-CTS0002C	PTS	Test 1	White	458	Good	
		Test 2	White	458		
N51-CTS0002D	PTS	Test 1	White	544	Good	
		Test 2	White	544		
N51-CTS0002E	PTS	Test 1	White	413	Good	
		Test 2	White	413		
N51-CTS0003A	IJTS	IJ 1	Red	502	Good	
		IJ 2	Red	502		
		Test 1	White	621		
		Test 2	White	621		
N51-CTS0003B	IJTS	IJ 1	Red	637	Good	
		IJ 2	Red	637		
		Test 1	White	607		
		Test 2	White	607		
N51-CTS0004A	IJTS	IJ 1	Red	548	Good	
		IJ 2	Red	548		
		Test 1	White	552		
		Test 2	White	552		
N51-CTS0004B	IJTS	IJ 1	Red	572	Good	
		IJ 2	Red	572		
		Test 1	White	558		
		Test 2	White	558		
N51-CTS0004C						Could not locate
N51-CTS0004D						Could not locate
N51-CTS0004E						Could not locate

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
N51-CTS0005A	PTS	Test 1	White	562	Damaged	Missing board.
		Test 2	White	562		
N51-CTS0005B	PTS	Test 1	White	460	Damaged	Missing board, wires have been cut.
		Test 2	White	460		
N51-CTS0005C	IJTS	IJ 1	Red	528	Good	
		IJ 2	Red	528		
		White 1	White	716		
		White 2	White	716		
N51-CTS0005D						Could not locate
N51-CTS0006A	PTS	Test 1	White	446	Damaged	Missing board.
		Test 2	White	446		
N51-CTS0008A	IJTS	IJ 1	Red	650	Good	
		IJ 2	Red	650		
		Test 1	White	499		
		Test 2	White	499		
N51-CTS0008B	IJTS	IJ 1	Red		Good	Invalid data.
		IJ 2	Red			
		Test 1	White			
		Test 2	White			
N51-CTS0009A	PTS	Test 1	White	562	Damaged	Damaged Lid.
		Test 2	Red	562		
		Test 3	Blue	562		
		Test 4	Yellow	562		
N51-CTS0009B	PTS	Test 1	White	546	Good	
		Test 2	Red	546		
		Test 3	Blue	546		
		Test 4	Yellow	546		
N51-CTS0010A	IJTS	IJ 1	Red	562	Good	
		IJ 2	Red	562		
		Test 1	White	709		
		Test 2	White	709		
N51-CTS0010B	IJTS	IJ 1	Red	530	Good	
		IJ 2	Red	530		
		Test 1	White	255		
		Test 2	White	255		

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
N51-CTS0010C	IJTS	IJ 1	Red	678	Good	
		IJ 2	Red	678		
		Test 1	White	617		
		Test 2	White	617		
N51-CTS0010D	IJTS	IJ 1	Red	688	Good	
		IJ 2	Red	688		
		Test 1	White	585		
		Test 2	White	585		
N51-CTS0012A	PTS	Test 1	White	610	Good	
		Test 2	White	610		
N51-CTS0012B	PTS	Test 1	White	631	Good	
		Test 2	White	631		
N51-CTS0012C	PTS	Test 1	White	607	Good	
		Test 2	White	607		
N51-CTS0012D	PTS	Test 1	White	634	Good	
		Test 2	White	634		
N51-CTS0013A	PTS	Test 1	White	615	Good	
		Test 2	White	615		
N51-CTS0013B	PTS	Test 1	White	602	Good	
		Test 2	White	602		
N51-CTS0013C	PTS	Test 1	White	616	Good	
		Test 2	White	616		
N51-CTS0014A	PTS	Test 1	White	559	Good	
		Test 2	White	559		
N51-CTS0014B	PTS	Test 1	White		Good	Invalid data.
		Test 2	White			
N51-CTS0015A	IJTS	IJ 1	Red	595	Good	
		IJ 2	Red	595		
		Test 1	White	564		
		Test 2	White	564		
N51-CTS0015B	IJTS	IJ 1	Red	584	Good	
		IJ 2	Red	584		
		Test 1	White	560		
		Test 2	White	560		
N51-CTS0016A						Could not locate

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
N51-CTS0016B						Could not locate
N51-CTS0017A	PTS	Test 1	White	544	Good	
		Test 2	White	544		
N51-CTS0017B	PTS	Test 1	White	553	Good	
		Test 2	White	553		
N51-CTS0017C						Located behind the fence of a private residence.
N51-CTS0017D	IJTS	IJ 1	Red	544	Good	
		IJ 2	Red	544		
		Test 1	White	535		
		Test 2	White	535		
N51-CTS0017E	IJTS	IJ 1	Red	547	Good	
		IJ 2	Red	547		
		Test 1	White	457		
		Test 2	White	457		
N51-CTS0017F	IJTS	IJ 1	Red	544	Good	Different readings for pipe test leads.
		IJ 2	Red	544		
		Test 1	White	450		
		Test 2	White	439		
N51-CTS0018A	PTS	Test 1	White	446	Good	
		Test 2	White	446		
N51-CTS0018B	PTS	Test 1	White	445	Good	Test 1 may be damaged.
		Test 2	White	445		
N51-CTS0020A	IJTS	IJ 1	Red	430	Good	
		IJ 2	Red	430		
		Test 1	White	488		
		Test 2	White	488		
N51-CTS0020B	IJTS	IJ 1	Red	419	Good	
		IJ 2	Red	419		
		Test 1	White	498		
		Test 2	White	498		

Appendix I

Route 25 Field Data

Test Station ID	Test Station Type	Wire	Wire Color	Pipe-to-Soil Potential (-mV _{CSE})	Test Station Condition	Comments
N19-CTS0025C	PTS	Test 1	Black	189	Good	
		Test 2	Black	189		
N19-CTS0025D	PTS	Test 1	Black	249	Good	
		Test 2	Black	249		
N19-CTS0026C	PTS	Test 1	Blue	222	Good	
		Test 2	Blue	222		
N19-CTS0026D						Could not locate
N19-CTS0026E						Could not locate
N19-CTS0028C	PTS	Test 1	Blue	256	Good	
		Test 2	Blue	256		
N19-CTS0028D	PTS	Test 1	Blue	264	Other	Flush mounted TS in muddy area. TS was dug out by field crew.
		Test 2	Blue	264		
N19-CTS0029D						Could not locate
N19-CTS0030C	PTS	Test 1	Blue	332	Good	
		Test 2	Blue	332		
N19-CTS0030D						Could not locate

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