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Remedial Testing and Cathodic Protection Design on a Deep Trenchless Crossing

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ABSTRACT

The ability to adequately monitor and protect long, deep trenchless crossings installed in rock is critical to ongoing safe operation of pipelines. This paper is a case study of a long horizontally directionally drilled crossing that was subject to significant coating damage at installation.

The pipeline was protected by an impressed current system and a test method was developed to estimate the current pick-up along the pipeline from existing rectifiers. Subsequently, a current requirement test was performed to estimate the effectiveness and efficiency of a supplemental groundbed to be installed adjacent to the crossing.

A permanent cathodic protection system including monitoring was designed and installed. Recommendations for identifying this type of deficiency during the construction phase are proposed.

Key words: deep coupon, deep groundbed, horizontal direction drill (HDD), remedial cathodic protection, trenchless crossing

INTRODUCTION

Trenchless crossings are widely used in the pipeline industry to minimize environmental and social impacts. For long crossings, horizontal directional drill (HDD) techniques are used to install pipelines in a minimally invasive fashion. However, unlike open-trench construction wherein QC checks can be completed on the whole pipeline and select backfill is used, the coating cannot be visually checked for damage sustained during installation. Remediation is also made more difficult because access is generally limited.

Improved coatings and installation techniques have reduced coating damage severity, but uncertainty remains. To help address this gap, the industry has been researching the subject through the Pipeline Research Council International (PRCI). Key advances have included the introduction and update of the coating conductance and current requirement test method[1,2] and an evaluation of the effectiveness of cathodic protection and monitoring techniques, including modelling, at deep trenchless crossings[3].

This paper applies some of the learnings from this research to a specific pipeline which was found to require additional cathodic protection to arrest corrosion growth identified during an in-line inspection (ILI).

BACKGROUND INFORMATION

The subject pipeline is a 2014 NPS 36 pipeline with the section of interest at a river crossing. The HDD span at the river crossing is 972 m long and the coating conductance test (based on the PRCI methodology) indicated the coating quality was very poor, with approximately 1.76% bare area. For comparison, testing performed on many trenchless crossings indicates less than 0.001% bare area.

A schematic of the pipeline is shown in **Figure 1**. The pipe itself is shown as a green dashed line, while the test posts are marked as chainages (in metres) and upstream (US) and downstream (DS) valves are also marked. After installation, the pipeline was protected by a remote impressed current cathodic protection (CP) system plus remedial magnesium anodes installed upstream and downstream of the HDD. The location of the temporary rectifier and groundbed at the US valve site is also shown.

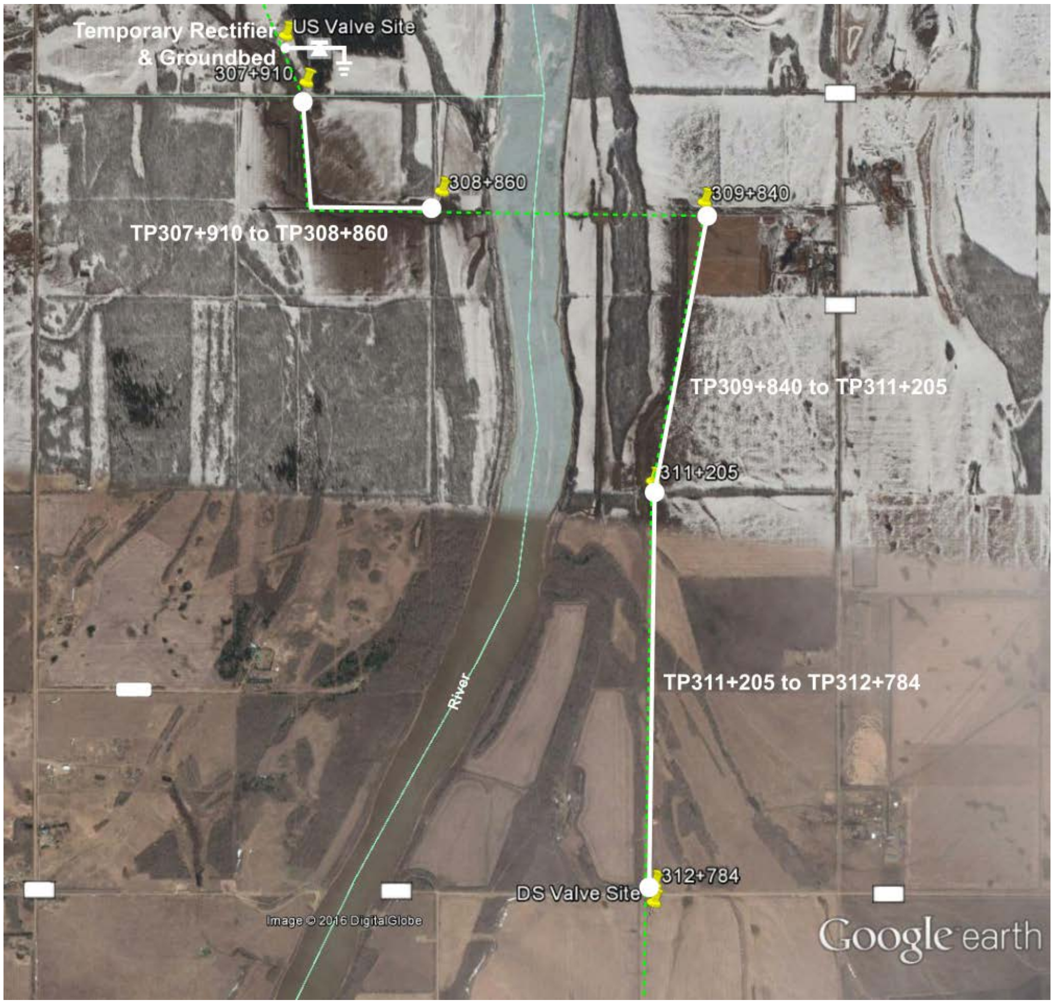

Figure 1: Test post and pipe configuration

The existing cathodic protection system was found to be insufficient, as corrosion growth was observed during an ILI conducted a few years after installation. Subsequently, modelling of the CP effectiveness on the HDD was performed. From the modelling, it was concluded that the existing CP system was insufficient, and installation of either three anode beds under the HDD or a distributed (linear) anode system aligned next to the HDD pipeline was recommended. The model also indicated that a very small current would be required to protect the HDD crossing, but that only a small percentage of the applied current, even from local CP sources, would be picked up by the HDD section. That is, even if a local groundbed has an output of 1 A, only 60 mA or 6% would be drained by the HDD section.

FIELD TESTING

Field testing was performed to confirm the results of the modelling and support the design of a practical CP system to provide enough cathodic protection to the subject pipeline. The practical options for field testing were somewhat limited:

- current mapping using an in-line inspection tool was not considered to be sufficiently sensitive to detect changes in CP current along the test section
- as is typical, there were no provisions for measurement of the pipeline current upstream or downstream of the crossing
- deep coupons had not been installed

The key data identified as necessary for satisfying the objectives was the current distribution along the pipeline from both existing rectifiers and a new local groundbed and polarization resulting from the local groundbed on each end of the HDD section.

Current Distribution Testing

In the absence of 4-wire test stations, it was decided to improvise a 4-wire arrangement using the closest test posts on both sides of the crossing. A 4-wire test relies on knowing the metallic resistance between two points, and measuring the resulting voltage drop between these two points. Essentially, the pipe itself is turned into a current shunt:

$$I_{\text{section}} = \frac{V_{\text{section}}}{R_{\text{section}}} \qquad \text{Eq. 1}$$

Where:

I_{section} = average current in the pipeline section, A

V_{section} = measured voltage across pipe section, V

R_{section} = resistance of section, Ω

Like every 4-wire test, this test assumes that the current along the section is constant. This is a reasonable assumption since the sections were installed using traditional open-cut techniques with extensive quality control performed and there are no take-offs, bonds, valves, etc. along the sections. However, confirmatory coating quality testing was also performed as described in the next section of this report.

A standard four-wire test was conducted to directly measure the resistance of the section between TP307+910 and TP308+860, but telluric activity was high enough during this test that the voltage resulting from the test current could not be accurately differentiated. Due to limited time available on site and because the pipe geometry was known, the section resistances were instead estimated using the cross-section and length of the section:

$$R_{\text{section}} = \frac{4\rho L}{\pi[D_{\text{out}}^2 - (D_{\text{out}} - 2t)^2]} \qquad \text{Eq. 2}$$

Where:

ρ = resistivity of steel, 18 μΩ·cm (assumed)

L = section length, m

D_{out} = pipe diameter, 0.9144 m

t = wall thickness, 0.0124 m

The section lengths and resistances calculated using **Eq. 2** are given in **Table 1**.

Table 1: Section Lengths and Resistances

Section	Length (m)	Calculated R_{section} (Ω)
TP307+910 to TP308+860	950	0.00487
TP309+840 to TP311+205	1200	0.00615
TP311+205 to TP312+784	1670	0.00855

The voltages drops measured along each section and current calculated based on the section resistances per **Eq. 1** are shown in **Table 2**. Note that the measurement precision was limited by telluric activity, the low lineal resistance of the large diameter pipeline, and measurement variations inherent at these low voltages. To improve accuracy, several measurements were repeated and averaged together. A positive voltage represents a positive pipeline current in the direction of increasing chainage.

Table 2: Measured Voltage Drops and Calculated Section Currents

Section	Measured Voltage Caused By:			Calculated Current Caused By:		
	Remedial Anodes @ ~80 mA	Remote Rectifiers	Temp. Rectifier @ 5.1 A	Remedial Anodes @ ~80 mA	Remote Rectifiers	Temp. Rectifier @ 5.1 A
TP307+910 to TP308+860	0.5 mV	-1.7 mV	-14.9 mV	0.10 A	-0.37 A	-3.07 A
TP309+840 to TP311+205	-0.3 mV	-0.3 mV	-8.9 mV	-0.05 A	-0.05 A	-1.44 A
TP311+205 to TP312+784	-0.2 mV	-0.6 mV	-11.9 mV	-0.02 A	-0.07 A	-1.39 A

By subtracting the current in the section upstream of the crossing from the current in the section downstream of the crossing, the current picked-up along the HDD section can be estimated. This process is shown in **Figure 2** for the temporary rectifier case from **Table 2**.

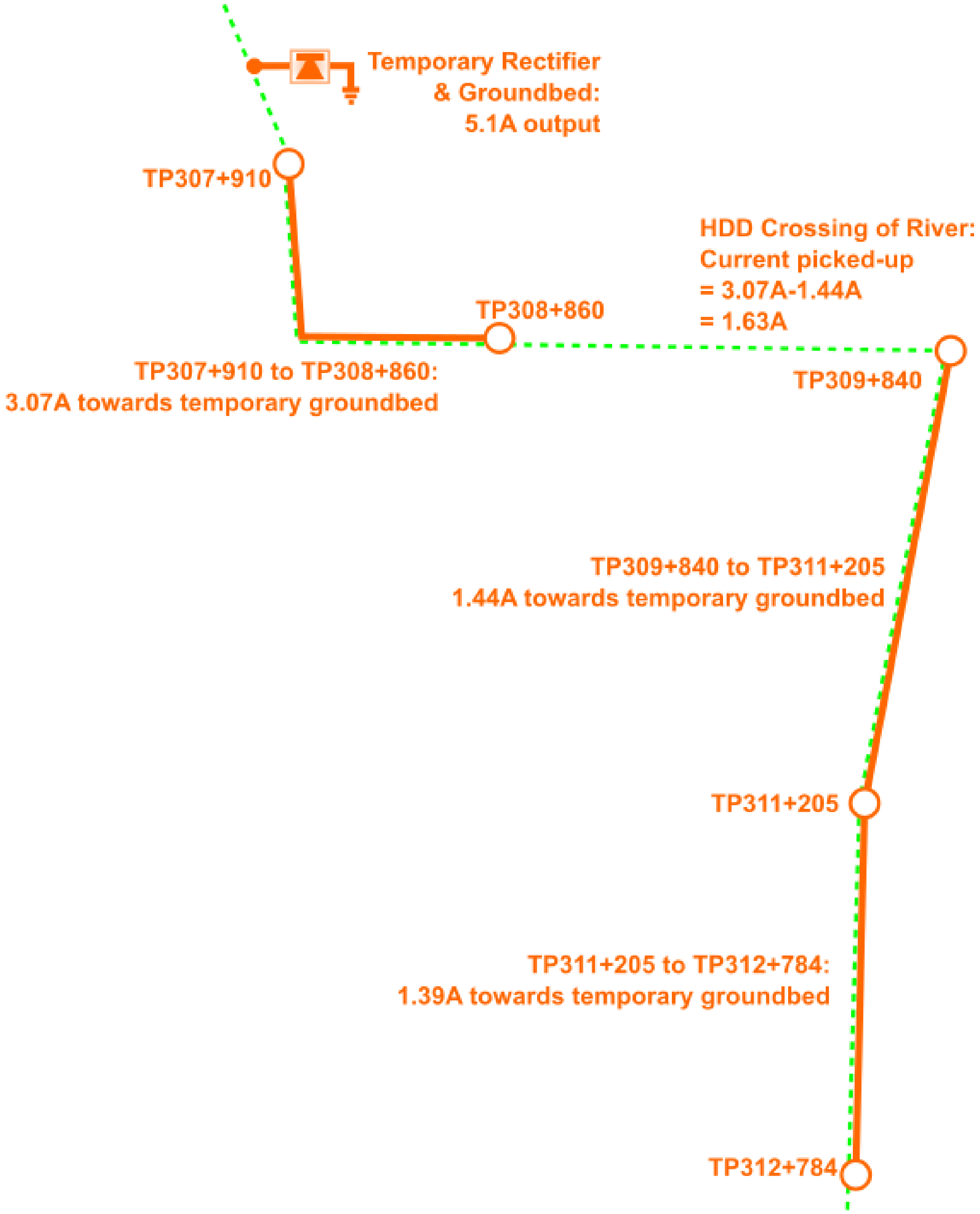

Figure 2: Explanation of Determining Current Pick-Up Along HDD

Although the measurement from TP311+205 to TP312+784 is not required for calculation of the HDD current pick-up, it is included for verification purposes. As expected, it confirms that the change in current along a well-coated section is low.

On a side-note: for an estimated change in current of 0.05 A (i.e. 1.44 A - 1.39 A) and the distance between the midpoints of the downstream test posts being 1472 m, the calculated current density from the temporary rectifier is 12 μA/m^2). Since the protection levels along the line were already relatively good (e.g. -1400 mV$_{CSE}$ was identified at TP309+840 with the primary rectifiers interrupted), this incremental change in current density seems reasonable for a new pipeline coating.

The estimated current pick-up along the HDD from each source is summarized in **Table 3**.

Table 3: Current Pick-Up Along HDD

Source of Current	Estimated HDD Current (A)
Remedial Anodes	0.0 ~ 0.1
Remote Rectifiers	0.3
Temporary Rectifier	1.6

The current pick-up from the temporary rectifier, 1.6 A, corresponds to 32% of the total output of the temporary rectifier. This indicates that a remedial groundbed would provide relatively efficient current distribution to the HDD. The results also indicate that the HDD receives a significant current (i.e. 0.3 A) from the existing rectifiers, though based on the ILI results this was not enough to achieve full cathodic protection.

Coating Quality Testing

To confirm the assumption about good coating quality along these test sections, and to provide additional confirmation of the poor coating quality on the river crossing, an AC Current Attenuation (ACCA) test was performed.

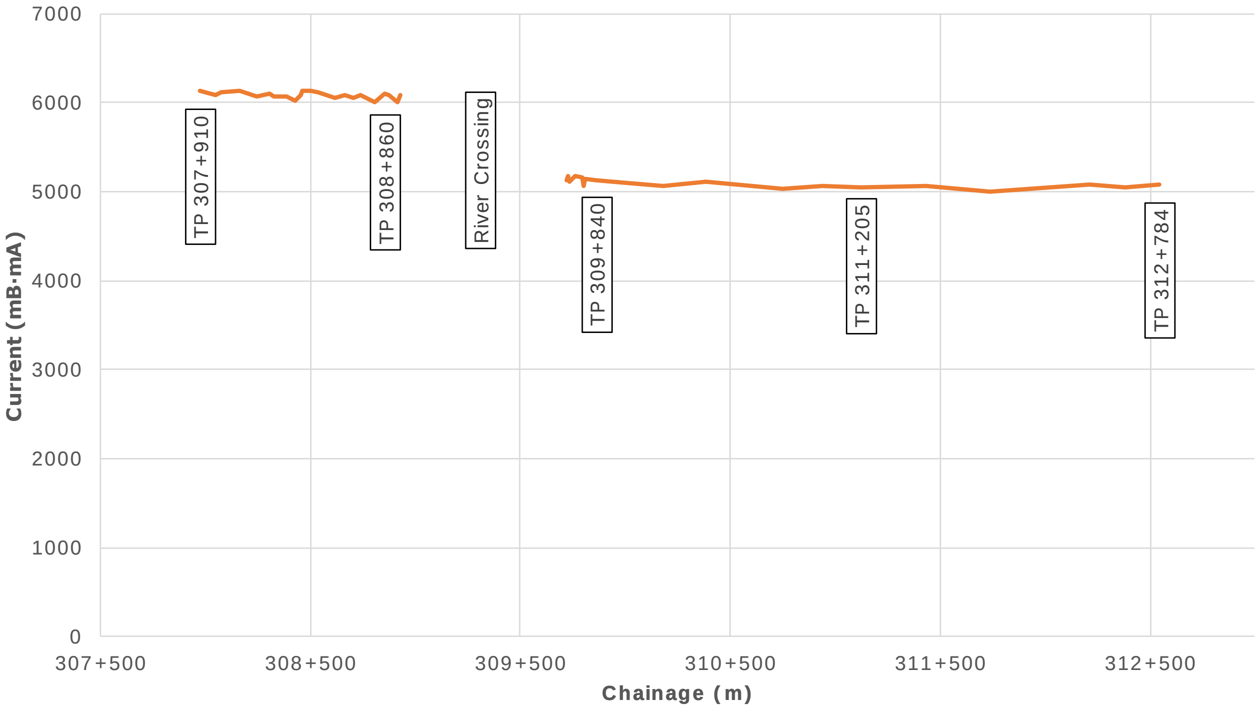

Figure 3: AC Current Attenuation Results

As expected, the current upstream and downstream of the crossing was very stable, but the attenuation at the crossing was high. The actual attenuations are given in **Table 2** and the results are consistent with the expected poor coating quality based on the conductance test.

Table 4: Measured Attenuation

Section	Length (m)	Attenuation (mB/m)
Upstream of HDD	807	0.07
HDD	909	1.12
Downstream of HDD	2450	0.04

Current Requirement Testing

A current requirement test was performed by recording the potentials on both sides of the river while energizing the temporary rectifier at 5.1 A. Unfortunately, due to long-term telluric activity (see **Figure 3**), it was not possible to determine the resulting polarization.

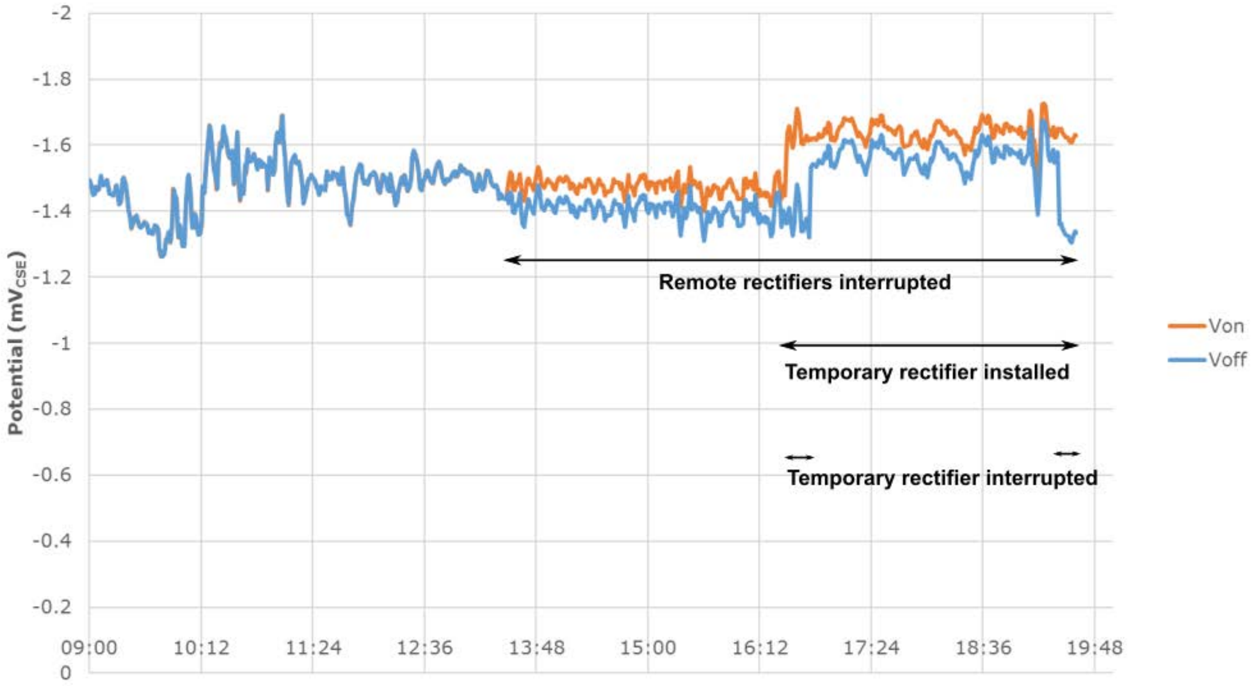

Figure 4: Telluric Activity During Polarization Testing (Recorded at TP 309+840)

Note that the current requirement portion of the test, even if it had been successful, may not have been a reliable measure of the ability to polarize the pipe at depth in rock since a reference electrode at grade at the test post is most sensitive to protection levels at ‘close’ coating defects.

CATHODIC PROTECTION DESIGN AND MONITORING

To provide confidence that holidays at depth were receiving full protection after the remedial installation, large coupons (50 cm^2) were installed on both sides of the river near the ends of the HDD. The intent was to confirm that large, deep holidays could be protected. To improve the monitoring capability of each coupon borehole, multiple coupons were installed at varying depths. Note that the interaction between the coupons in a single borehole was modelled and found to be minimal because of the relatively low soil resistivity at depth. For resistivities more typical of rock (e.g. 500 Ω·m), interaction between coupons can be expected.

Follow-up testing was also recommended at a time when telluric activity was less significant to validate the current distribution findings and to determine whether the current distribution from a surface groundbed differs from the current distribution from a deep groundbed.

In terms of remedial groundbed design, although installing a temporary groundbed at grade resulted in a significant current pick-up along the HDD, a deep groundbed was chosen to avoid increasing the pipeline’s existing land footprint. It is also expected that the current distribution from a deep groundbed to the pipeline sections in rock will be at least as good as that from a shallow groundbed.

The modeling indicated that a very low current (i.e. 32 mA) would be sufficient to protect the pipe. As at least 30% of the groundbed output is expected to be picked up along the HDD based on the current distribution testing with a temporary groundbed at grade, the groundbed was conservatively sized at 4 A, which far exceeds the current requirements from the modeling and the existing current pick-up along the HDD from remote CP sources. The actual rectifier setting was determined based on polarization of the deep coupons.

RECOMMENDATIONS FOR FUTURE PROJECTS

To more effectively characterize the cathodic protection requirements on future installations, the following are recommended:

- install 50 cm^2 coupons on both sides of long HDDs in geotechnical bores to the maximum expected pipe depth
- conduct coating conductance and current requirement testing on all trenchless crossings
- when the testing indicates there is significant coating damage, install provision for measurement of current on both sides of the HDD to facilitate further testing. This could consist of insulating flange kits at nearby valves, monolithic isolating joints, or 4-wire test stations. The 4-wire configuration would generally need to span a minimum of 250 m, depending on the available voltage measurement equipment
- extend existing research on HDD protection levels assessments. Possible paths for research include probes installed *in situ* and probes installed in direct contact with bedrock

These changes would allow for the efficient collection of additional information so the pipe system can be accurately modelled and appropriate remedial measures can be designed, if required.

CONCLUSIONS

This paper documents the testing of a section of pipeline installed using HDD techniques. Coating conductance testing during construction indicated that the coating was severely damaged, and corrosion growth was observed in a subsequent ILI.

Computer modelling indicated that more CP would be required, but that the efficiency in terms of current picked-up on the HDD section would be low, even for a local CP groundbed. Existing survey techniques were successfully adapted to the situation to test the accuracy of the model and to guide a remedial CP installation.

Recommendations for future projects include installing coupons prior to construction, always conducting coating quality testing, and prearrangements for current monitoring specific to the HDD section. These provisions will simplify future testing and provide a high-degree of confidence that the pipeline is receiving sufficient cathodic protection current.

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