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# Case Study – Sharing an AC Mitigation System

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## ABSTRACT

An alternating current (AC) interference study was conducted in 2019 following a utility development project that included constructing a new substation and upgrading approximately 24 km of new AC transmission powerline sections in Alberta, Canada. The study comprised six transmission powerlines owned by one utility and eight pipelines owned by two different operators.

The modelling results showed touch voltage hazards under steady-state and fault conditions and susceptibility to AC corrosion and coating stress above the established limits in the unmitigated state.

A shared AC mitigation system was designed to eliminate the hazards caused by AC interference on all eight pipelines. This approach reduced overall mitigation requirements, number of site visits, construction footprint, environmental impact, and project costs.

This paper describes the mitigation system's design, installation, and commissioning and discusses the benefits of a shared AC mitigation system approach.

Keywords: AC corrosion, AC interference, AC mitigation, pipeline integrity.

## INTRODUCTION

AC interference analysis between high voltage AC (HVAC) powerlines and buried pipelines is a matter of current interest due to the growing number of right-of-ways shared between powerline and pipeline infrastructure. This is only expected to increase as the worldwide energy demand grows considerably over the next 30 years,[1] and stricter environmental regulations and policies are applied. Therefore, AC interference will continue to be an issue of concern for powerline and pipeline operators to protect the public, environment, and maintain asset integrity.

AC interference hazards on pipelines resulting from nearby powerlines can occur under steady-state (normal operation) and fault conditions. Under steady-state conditions, the pipeline is subject to AC voltages induced by electromagnetic coupling between the pipeline and nearby HVAC powerline. These induced voltages can result in electrical shock to any person who touches an appurtenance that is electrically continuous with the pipeline. Induced voltages can also result in accelerated corrosion at pipeline coating defects, i.e., AC corrosion, as the AC current is discharged through any coating defects.

Under fault conditions, e.g., line-to-ground faults, the pipeline is subject to induced voltages due to electromagnetic coupling and currents flowing in the ground from the powerline structures, known as conductive coupling. Under these conditions, the AC interference can result in safety hazards for personnel, damage to the pipeline coating, and damage to the pipeline itself.[2-4]

This paper describes the AC interference analysis conducted as part of a power utility development project and the shared mitigation designed to prevent AC interference hazards under both steady-state and fault conditions, following industry standards in Canada.[5-8]

## STUDY BACKGROUND

In 2019, a power utility development project proposed constructing a new substation and approximately 24 km of new transmission line sections. The project comprises six 240 kV high voltage AC transmission lines owned by the same power utility. Short segments of the existing transmission lines were to be removed or altered.

The six powerlines included in the project run in parallel, i.e., are co-located, with eight existing pipelines owned by two different operators. The total length of powerline/pipeline co-location covered in the project is approximately 120 km. The separation distances between the powerlines and pipelines along the co-locations on average vary between 30-70 m. Figure 1 shows a simplified configuration of the area of study. Each pipeline is identified by two digits as follows: #-#. The first digit represents an Operator #, i.e., 1 and 2, and the second digit represents the pipeline #, i.e., 1 to 2 for Operator #1, and 1 to 6 for Operator #2.

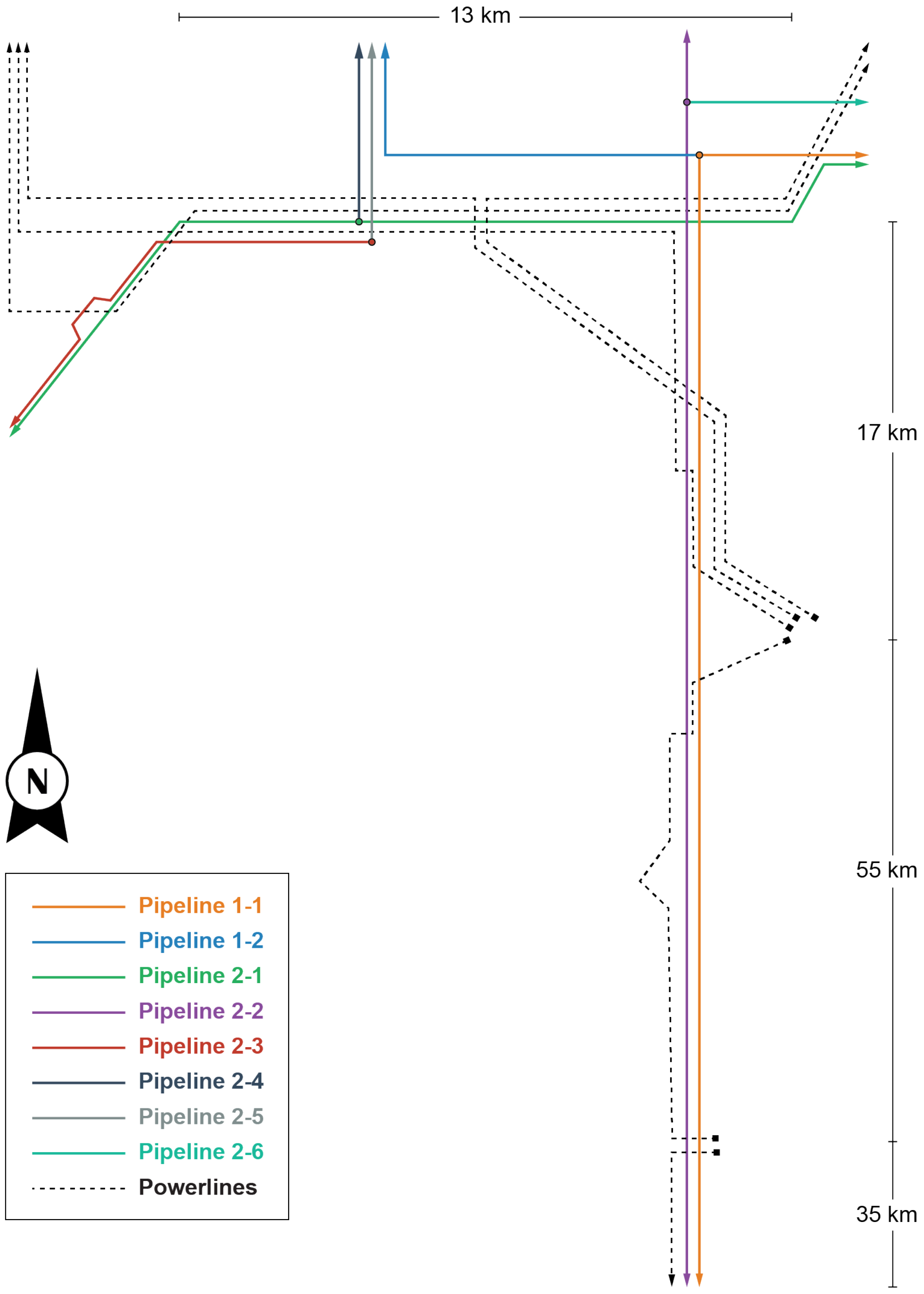

**Figure 1: Simplified Pipeline and Powerline Co-location Configuration**

Table 1 summarizes the pipeline data provided by the two operators involved in the project.

## Table 1
## Pipeline Data Summary

| Pipeline | NPS | Age | Coating System |
|---|---|---|---|
| 1-1 | 12 | 9 | Fusion bond epoxy |
| 1-2 | 8 | 8 | Fusion bond epoxy |
| 2-1 | 24 | 22 | Fusion bond epoxy |
| 2-2 | 16 | 45 | Extruded polyethylene |

| Pipeline | NPS | Age | Coating System |
|---|---|---|---|
| 2-3 | 36 | 14 | Fusion bond epoxy |
| 2-4 | 12 | 20 | Extruded polyethylene |
| 2-5 | 30 | 14 | Fusion bond epoxy |
| 2-6 | 16 | 34 | Fusion bond epoxy |

There are a total of 34 valve sites and stations located along the pipelines under study in the project scope. Field technicians conducted station surveys, including soil resistivity measurements, assessment of electrical continuity between metallic structures, site grading and electrical grounding inspection.

Existing AC mitigation systems were identified at 22 locations along the pipelines and were included in the model. The mitigation systems were based on available as-built drawings, alignment sheets, and survey data; conservative assumptions were made where required.

All pipelines are cathodically protected using impressed current systems. Each operator's pipelines are electrically continuous with each other, but the two systems are electrically separate.

Powerline Parameters

Table 2 summarizes the powerline data provided by the utility operator.

## Table 2
## Powerline Data Summary

| Powerline | Line Voltage (kV) | Annual Peak Load (A) | Annual Average Load (A) | Maximum Total Fault Current (kA)* | Fault Duration (ms) |
|---|---|---|---|---|---|
| 1 | 240 | 557 | 296 | 17.8 | 100 |
| 2 | 240 | 320 | 149 | 13.3 | 100 |
| 3 | 240 | 311 | 144 | 13.3 | 100 |
| 4 | 240 | 538 | 229 | 18.2 | 100 |
| 5 | 240 | 351 | 239 | 11.1 | 100 |
| 6 | 240 | 244 | 140 | -** | -** |

* Single line-to-ground fault current contributions were provided for each powerline at 0%, 25%, 50%, 75%, and 100% of the powerline route. The maximum value is shown for reference.

** Fault analysis was not included as part of the project scope.

The following parameters were also provided by the utility and apply to all powerlines:

- Dominant structure type: wood H-frame.
- Overhead shield wire type: galvanized steel.
- Maximum tower grounding resistance: 10 Ω.

Soil Conditions

Soil resistivity measurements at 84 locations were conducted using the Wenner 4-pin method. The equivalent earth structure model and soil layers were determined using computer modelling software. The soil resistivities generally ranged between 10-120 Ω·m.

## METHODOLOGY

The AC interference analysis was conducted using computer modelling software, site survey information and the data provided by the pipeline and powerline operators. The configuration shown in Figure 1 was constructed as a base case by using the pipeline and powerline GIS routes and applying the established parameters to the model. The below scenarios were then created and analyzed.

### Steady-State AC Voltages

For steady-state AC voltage analysis, the powerlines in the model were energized with their peak load conditions. The peak load was used for this assessment to ensure personnel safety at all times under normal powerline operations. The applicable limit for steady-state AC voltages is 15 V per CSA(1) C22.3 No. 6-13 and NACE(2) SP0177. [5, 7]

### Steady-State AC Corrosion

According to NACE SP21424,[6] the AC current density (ACCD) should not exceed a time-weighted average of 30 A/m$^2$ if the DC current density (DCCD) exceeds 1 A/m$^2$ or 100 A/m$^2$ if the DCCD is less than 1 A/m$^2$. With no DCCD data available, all stakeholders agreed on applying the more conservative ACCD limit of 30 A/m$^2$ for this study.

The powerlines in the model were energized with their average load conditions to compute the induced AC voltages. All stakeholders agreed that the average powerline load would be appropriate for the assessment. Using the computed AC voltages and applicable soil resistivities along the pipelines, the ACCD discharged were calculated. A 1 cm$^2$ holiday was used for the calculations per NACE SP21424.[6]

### Fault AC Voltages

For the fault analysis, model files were created for select powerline structures in the area study. For each model file, the powerline phase conductor was shorted to the required powerline structure, and the powerline phase conductor was energized with its calculated short-circuit currents. The computed AC voltages were then evaluated against the IEEE(3) Std 80-based limits for touch and step voltages.[9]

## RESULTS AND MITIGATION

In the unmitigated state, AC interference from the HVAC powerlines resulted in AC voltage safety hazards and susceptibility to AC corrosion on the pipelines in the study. Table 3 shows the results of the different modelled scenarios in the unmitigated conditions.

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## Table 3
## Unmitigated Results Summary

| Pipeline | Steady-State AC Voltage | | Steady-State ACCD | | Fault AC Voltage | |
|---|---|---|---|---|---|---|
| | Total Length Exceeding Limit (km) | Maximum Predicted Voltage (V) | Total Length Exceeding Limit (km) | Maximum Calculated ACCD (A/m$^2$) | Total Length Exceeding Limit (km) | Maximum Predicted Voltage (kV) |
| 1-1 | 17.79 | 47.5 | 26.88 | 162.6 | 94.12 | 4.6 |
| 1-2 | 8.02 | 21.3 | 10.72 | 72.8 | 48.03 | 2.1 |
| 2-1 | 6.46 | 32.6 | 12.34 | 334.4 | 40.90 | 32.6 |
| 2-2 | 31.71 | 50.9 | 77.36 | 158.0 | 89.77 | 5.0 |
| 2-3 | 8.95 | 22.0 | 11.62 | 187.1 | 19.71 | 2.5 |
| 2-4 | 0 | 8.3 | 6.45 | 50.0 | 15.65 | 2.5 |
| 2-5 | 0 | 8.4 | 7.62 | 50.8 | 27.41 | 2.4 |
| 2-6 | 0 | 8.8 | 0.50 | 37.3 | 12.31 | 1.4 |
| **Total** | **72.93** | - | **153.49** | - | **347.89** | - |

The conventional approach to mitigate AC interference touch hazards and ACCD on pipelines is for each pipeline operator to independently install dedicated AC mitigation systems, similar to cathodic protection systems. Understandably, operators prefer to keep their cathodic protection systems independent to operate and adjust their systems as required. However, unlike cathodic protection, AC mitigation systems do not require the same level of operation and maintenance. From an operations perspective, AC mitigation systems are passive systems, since they only provide grounding to the pipelines, and there aren't any components of the system that require adjustment.

Considering the length of the pipelines exceeding applicable limits and extent of required mitigation, the project stakeholders agreed to a shared mitigation system approach. The mitigation system would rely on horizontal bare copper wire installed adjacent to the pipelines and connected to the pipelines via DC decouplers. Any pipelines that do not share a cathodic protection system would be connected via separate DC decouplers to ensure that the pipelines remain isolated in DC.

Table 4 summarizes the mitigation provisions used in the models to reduce AC voltages and current densities along the pipelines, and Figure 3 shows the corresponding mitigation locations. Table 5 shows the modelling results after mitigation.

## Table 4
## Mitigation Provisions Summary

| No | Copper Wire Length (m) | DC Decouplers | Connected Pipelines |
|---|---|---|---|
| 1 | 315 | 2 | 1-1, 2-2 |
| 2 | 190 | 2 | 1-1, 2-2 |
| 3 | 100 | 2 | 1-1, 2-2 |
| 4 | 495 | 3 | 1-1, 2-2 |
| 5 | 620 | 4 | 1-1, 2-2 |
| 6 | 295 | 2 | 1-1, 2-2 |
| 7 | 380 | 1 | 2-2 |
| 8 | 695 | 2 | 2-2 |
| 9 | 250 | 1 | 1-1 |
| 10 | 250 | 2 | 1-1, 2-2 |
| 11 | 100 | 1 | 2-2 |
| 12 | 150 | 2 | 1-1, 2-2 |
| 13 | 100 | 1 | 2-1, 2-2 |
| 14 | 150 | 1 | 2-3 |
| 15 | 100 | 1 | 2-1, 2-3 |
| 16 | 600 | 2 | 1-1, 2-2 |

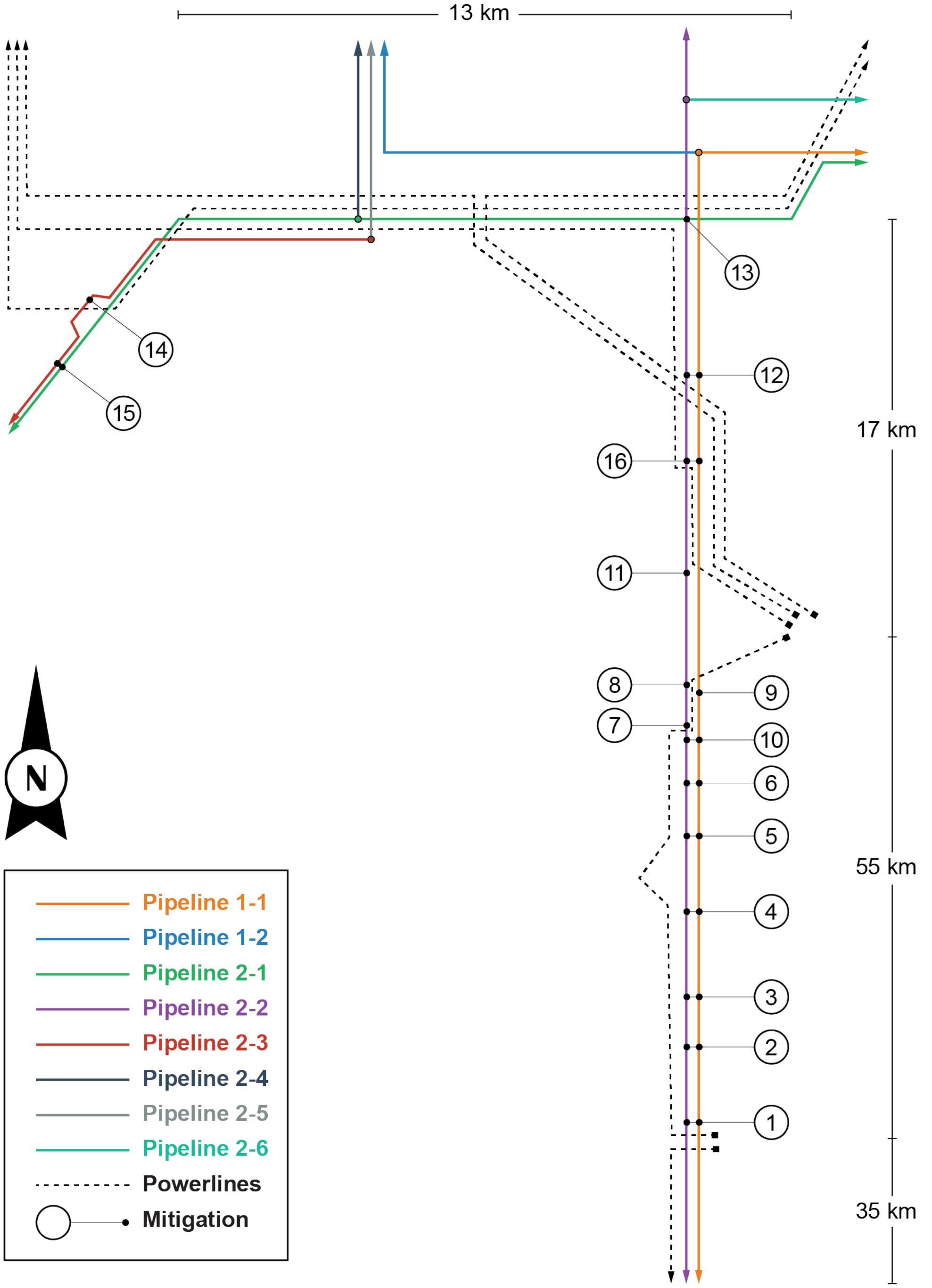

**Figure 3: Simplified Pipeline and Powerline Co-location Configuration with Mitigation Locations**

**Table 5**
**Mitigated Results Summary**

| Pipeline | Steady-State AC Voltage |  | Steady-State ACCD |  | Fault AC Voltage |  |
|---|---|---|---|---|---|---|
|  | Total Length Exceeding Limit (km) | Maximum Predicted Voltage (V) | Total Length Exceeding Limit (km) | Maximum Calculated ACCD (A/m$^2$) | Total Length Exceeding Limit (km) | Maximum Predicted Voltage (kV) |
| 1-1 | 0.09 | 15.1 | 0 | 29.7 | 32.48 | 3.0 |
| 1-2 | 0 | 1.7 | 0 | 12.3 | 0 | 0.3 |
| 2-1 | 0 | 7.7 | 0 | 28.8 | 26.11 | 2.4 |
| 2-2 | 0 | 13.6 | 0 | 26.4 | 23.40 | 2.7 |
| 2-3 | 0 | 7.7 | 0 | 28.9 | 4.65 | 1.0 |
| 2-4 | 0 | 1.0 | 0 | 2.5 | 7.21 | 0.9 |
| 2-5 | 0 | 0.7 | 0 | 2.5 | 11.67 | 0.9 |
| 2-6 | 0 | 1.1 | 0 | 3.7 | 10.23 | 1.2 |
| **Total** | **0.09** | - | **0** | - | **115.75** | - |

The designed mitigation system consisted of 4,790 m of bare copper mitigation wire to be installed in open field. Out of the total mitigation wire, 3,015 m of were shared between pipelines 1-1 and 2-2. Following mitigation, all ACCD along all pipelines were reduced below the 30 A/m$^2$ limit. AC voltages for one 90 m section of pipe remained marginally above the 15 V limit. However, there are no above-grade appurtenances in this area, and therefore there is no risk to personnel or the public.

The total length of pipeline at risk under fault conditions was reduced by 66.7%. Any test stations that fell in the areas still exceeding the established limits were converted to dead-front configuration with no exposed metallic parts. Stations and valve sites were mitigated by ensuring AC continuity between metallic objects and using gradient control grids sized to keep touch and step voltages below the IEEE Std 80-based limits.[9]

Finally, monitoring provisions including AC coupons, DC coupons, and electrical resistance (ER) probes were specified along the pipelines to monitor AC and DC current densities, polarized potentials, and corrosion rates.

## INSTALLATION AND COMMISSIONING

The AC mitigation systems were installed and commissioned in 2020. All mitigation measures were installed as specified, including right-of-way mitigation sites, AC continuity and gradient control grid mitigation at stations and valve sites, test station conversions, and monitoring provisions.

The commissioning survey was completed following the operators' specifications. Both "ON" and "Instant OFF" potentials were measured during the survey. However, as the installed DC decouplers discharge current during the interruption of the cathodic protection systems, true pipe instant-OFF potentials were impractical to measure. Instead, potentials were measured at DC coupon locations where the coupon can be temporarily disconnected from CP facilities.

The risk of AC corrosion was evaluated by measuring the ACCD discharging to the soil surrounding the pipe using 1 cm$^2$ AC coupons. Based on the peak AC locations from the mitigated model and field observations, dataloggers were installed at select AC coupon locations to record AC voltages and AC/DC current densities for approximately 24-72 hours. The survey results showed that all AC voltages and AC current densities were below the established limits except for one location along Pipeline 2-6. After one week of recording, the AC coupon at this location exhibited an average AC voltage of 2.4 V, ACCD of 84.2 A/m$^2$, and DCCD of 10.1 A/m$^2$. For, comparison, the predicted AC voltage and ACCD were 1.5 V and 28.2 A/m$^2$, respectively. The higher than predicted values are more likely attributed to a lower coupon spread resistance than that calculated using the measured bulk soil resistivity. Further investigation and remedial work were completed at this location, which included the installation of local grounding connected to the pipe through a DC decoupler.

## CONCLUSIONS

In this paper, an AC interference study conducted on six HVAC powerlines and eight underground pipelines was described. Computer modelling software was utilized to model the shared right-of-way to assess the safety risks due to high AC voltages and susceptibility to AC corrosion. The results showed AC interference hazards on all pipelines in the unmitigated state.

The designed mitigation system consisted of 4,790 m of bare copper mitigation wire to be installed in open field. Out of the total mitigation wire, 3,015 m of were shared between pipelines 1-1 and 2-2. Sharing the AC mitigation resulted in considerable benefits to the project, including reduced overall mitigation requirements, number of site visits, construction footprint, environmental impact and project costs. AC continuity and Gradient control grids were specified to mitigate AC touch and step voltages at stations and valve sites. Monitoring provisions including AC coupons, DC coupons, and ER probes were also specified.

Survey results from the installation and commissioning phase of the project showed that all AC voltages and AC current densities were below the established limits except for one location along Pipeline 2-6. Further investigation and remedial work was completed at this location.

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