PUGET SOUND ENERGY
PIPE SEGMENT INTEGRITY STUDY
IN THE VICINTIY OF THE VASA PARK RECTIFIER

June 21, 2005

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Purpose

This integrity study was designed to locate coating holidays on pipelines adjacent to and isolated from nearby pipe that was cathodically protected by the Vasa Park rectifier during the period when the rectifier was misconfigured. PSE designed the study to identify locations that would exhibit corrosion if stray current originating from the pipe connected to the rectifier discharged from the pipe investigated in this study.

Survey Procedure and Scope

Area Surveyed

Six thousand feet of high pressure main, 9,000 feet of intermediate pressure main and 140 services were investigated in this study. The field work began in March and ended in May 2005.

The boundaries for the pipeline study were established by identifying pipe that was disconnected from the Vasa Park Cathodic Protection System when the Spirit Ridge piping was connected to the rectifier positive terminal. In total, piping within 2,500 feet of the Spirit Ridge piping was investigated. The targeted pipe for the integrity study was the main and services associated with:

- The high-pressure pipe, which extends east from 158 Avenue SE and SE Eastgate Way to SE 40 Place and W. Lake Sammamish Boulevard; and
- The intermediate-pressure pipe, which extends north from SE 38 Street and Lake Sammamish Parkway SE to SE 16 Street and 168 Avenue SE.

The pipe is shown in *Appendix A, Figure 1*.

Procedure and Equipment

The survey was undertaken within the described area to identify and determine locations of coating holidays. Coating holidays are areas of coating damage, which exposes the pipe to the soil. Coating holidays were classified based on severity of survey indication. All those prioritized as requiring immediate action were exposed for examination. Those classified as requiring scheduled action were

Continued on next page

Procedure and Equipment, *continued*

included on the examination list if they were within 1,500 feet of the Vasa Park rectifier. A close interval potential survey was conducted over the same pipe to assess cathodic protection levels. Coating holiday locations were then exposed and examined for signs of corrosion. For those locations that did show signs of corrosion, the morphology of the pits, characteristics of the related corrosion products and environmental data was gathered to aid in determining the cause for the loss of metal.

The pipeline was divided into sections for the convenience of surveying. Each section has its own stationing. Services were treated as individual sections and stationing commenced at the meter sets.

Two surveys were conducted simultaneously, close interval potential (CIS) and direct current voltage gradient (DCVG). The electrodes were placed on the ground at five-foot intervals over the main and three-foot intervals over services.

Testing was done at the commencement of the survey work to determine if valid measurements could be obtained through paving without drilling holes. A survey was conducted on 170 Place SE comparing the two methods. The paving was wet prior to surveying without drilled holes. The data obtained using the two methods was in agreement. This confirms results obtained by other utilities and contractors. A suggestion to re-survey regions with questionable data using a voltmeter with variable input impedance was adopted. Those areas were resurveyed using the standard equipment after wetting. If the data was still in question, then the variable impedance method was employed. Variable impedance allows the tester to reduce or eliminate the error associated with contact resistance between reference cell and earth.

The pipe was located using a Radiodetection RD4000 before performing the surveys. A M.C. Miller Direct Assessment Meter, copper sulfate reference cells attached to walking sticks and a Radiodetection Smart Interrupter were used to capture both pipe-to-soil and DCVG data. A M.C. Miller LC-4 digital voltmeter was used as an auxiliary pipe-to-soil measuring instrument.

Criteria

The threshold criterion for CIS measurements was an instant off potential of –850 mV. Measurements less negative were flagged as indications. The indications were rated minor, moderate or severe based on factors presented in *Appendix B, Table 3* for CIS and in *Appendix B, Table 4* for DCVG.

Continued on next page

Criteria, *continued*

The need for excavation for the purposes of directly examining each indication was established on the basis of the severity classifications of the indications, which in turn are an estimate of the likelihood of corrosion activity. All indications were categorized as *Immediate Action*, *Scheduled Action*, and *Suitable for Monitoring*. These terms are defined as outlined below:

- **Immediate Action.** This priority category includes all indications that are considered to be likely to have ongoing corrosion activity and that, when coupled with prior corrosion, pose an immediate threat to the pipeline under normal operating conditions. Additionally, this priority category is applied to indications which, when combined with other data, suggest the presence of third party damage.
- **Scheduled Action.** This priority category includes all indications that are considered to have ongoing corrosion activity but that, when coupled with prior corrosion, do not pose an immediate threat to the pipeline under normal operating conditions.
- **Suitable for Monitoring.** This priority category includes all indications that are considered to be inactive or as having the lowest likelihood of ongoing or prior corrosion activity.

The guidelines in *Appendix B, Table 5* were used for prioritizing the direct examinations.

Confirmatory Examinations

The affect of pipe size on the indication measurement was unknown at the commencement of the project. Excavations were performed to confirm correlation of coating holiday size to voltage gradient measurement, three for each of minor, moderate, severe and no indication.

Results

Forty sites were selected for excavation based on coating or pipe potential indications warranting further examination, including the twelve confirmatory examinations. A confirmation excavation at one of the sites was relocated due to landscape conflicts, resulting in forty-one entries listed in *Appendix B, Table 1*, List of Examination Sites. Seven of the entries were not examined, five after reevaluating the data, one was a duplicate entry and another was a service which was replaced. The site locations are shown in *Appendix A, Figure 2*, Examination Sites.

Continued on next page

No corrosion other than superficial rust was found on thirty of the thirty-four sites excavated. Four sites exhibited pitting. Two of the four sites with pitting had minor leakage associated with the corrosion. These sites, classified as Grade C, were located within six feet of each other, within the same excavation, and are therefore considered to be part of the same corrosion event.

With the exception of the damaged areas, the shop-applied coatings at all thirty-four examination sites are in good condition. Root cause of damage to the coatings is distributed in the following categories:

Category	No. of Examination Sites Affected
Third party	15
Application technique or material failure	6
Valve box extension settlement	1
Rock in the backfill	1
Unknown source	4
No coating damage	7

Soil Analysis

Samples of the soil, incrustations and corrosion products from the four examination sites exhibiting pitting were sent to a laboratory for analysis. The soil analysis results are listed in *Appendix B, Table 2*. The incrustation and corrosion product data is discussed in the assessment of the four sites. A JEOL 840A Scanning Electron Microscope (SEM) equipped with an energy dispersive spectroscopy (EDS) detector was used to determine the composition of the incrustation and corrosion product samples.

Soil resistivity is an indicator of soil corrosivity. Resistivity of the soil at the excavation sites was measured using an Agra X10 Soil Box and a Nilsson Model 400 Soil Resistance Meter. The resistivities are included in *Appendix B, Table 1*. The resistivity values range from 5,000 to 320,000 ohm-centimeters. Values greater than 10,000 ohm-centimeters are typically classified as negligibly corrosive. Five examination sites had measured values between 5,000 and 10,000 ohm-centimeters. These values are considered moderately corrosive. In addition, soils with resistivity changes of an order of magnitude or more may drive corrosion cells on pipeline traversing those regions. Five sites, 14, 18,19, 28 and 31, fall into the moderately corrosive classification. Corrosion pitting was found at three of those sites.

The soil sample data, for the four examination sites, is presented in *Appendix B, Table 2*, Soil Analysis. The results are indicative of a moderately to negligibly corrosive environment. The oxidation – reduction (redox) potentials greater than 400 mV indicate an environment which is not favorable for anaerobic bacterial corrosion[1]. The minimum measured redox potential is 443 mV.

[1] M. Romanoff, Underground Corrosion, NBS Circular 579, p154 (1957)

Assessment of Four Examination Sites

Examination Site 2

This site exhibited minor pitting at a large coating holiday. The coal tar enamel coating damage was attributed to third party excavation. The coating is tightly bonded to the pipe. A crusty material adhered tightly to the exposed pipe steel surface at the holiday. The cross-section of the incrustation exhibited a thin white colored layer adjacent the pipe surface covered by a thicker layer with a rust colored matrix embedded with backfill material. The incrustation is an indication that the corrosion at this site had not occurred recently. Enough time had elapsed since the pitting occurred for ions to migrate to the pipe and form an incrustation on the exposed steel pipe surface as shown in the following photograph. Cathodic protection promotes ion migration in the electrolyte[2]. It is very likely this process commenced with the application of protection in the 1980's and the corrosion predates this event.

Two pits were discovered at the holiday. Their dimensions were 1/2″ x 1/8″ and 30 to 40 mils deep. The soil resistivity measured at the site is 150,000 ohm-centimeters. The laboratory resistivity measurement in a saturated condition is 50,000 ohm-centimeters. Both resistivity values indicate the soil is not very corrosive at this site and the degree of corrosion supports this conclusion. The soil is sandy with round rock up to 6″ diameter.

This incrustation at Examination Site 2 was typical of that found at most of the coating holiday sites exposed during the investigation.

[2] H. H. Uhlig, Corrosion and Corrosion Control, p8 (John Wiley & Sons, 1985)

Examination Site 14

A moderate sized coating holiday was discovered at this site with dimensions of 2″ wide by 11″ long axially oriented on the pipe at about 3 o'clock. The cause of the coating damage could not be determined. The coal tar enamel coating is tightly bonded to the pipe surface. The bare steel at the coating holiday was covered with a tightly adherent crust which had round rock, up to 3 inches in diameter, embedded in it. Removal of the incrustation exposed minor pitting to 10 mils deep in a 3-inch diameter area. Within the corroded area is 30 mils deep x 1-1/8″ diameter pit. The formation of a crust over the pitted area and the lack of corrosion product, suggests the corrosion did not occur recently and is not active. The EDS analysis indicates a sample taken from the incrustation is composed of silicon, aluminum, and iron with minor constituents of calcium, potassium, magnesium oxygen and carbon, elements typically found in soils.

The soil adjacent to the corroded area is sandy with round rock up to 3 inches diameter. This soil has a resistivity of 32,000 ohm-centimeters. Soil within 2 feet of the corroded area is blue colored clay with a resistivity measured in the field of 8,000 ohm-centimeters. The laboratory resistivity measurement is 5,100 ohm-centimeters. The resistivity values are typical of moderately corrosive soils. The clay is more corrosive than the sandy material and the change in resistivities of adjacent soils is characteristic of a local corrosion cell.

Examination Site 14, *continued*

The incrustation at the coating holiday found at Examination Site 14 exhibits round rock cemented to the pipe surface. Removal of the incrustation revealed minor pitting in a 3-inch area as shown in the following photograph.

Examination Sites 28 and 31

Six coating holidays were discovered at this site located at 12 and 1 o'clock. The locations suggest a third party caused the damage. The holidays were heavily encrusted. Rocks up to 1 inch in diameter were embedded in the incrustation.

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Examination Sites 28 and 31, *continued*

The EDS analysis indicates a sample taken from the incrustation is composed of silicon and aluminum, with minor constituents of iron, calcium, potassium, magnesium, oxygen and carbon, elements typically found in soils. The coating is coal tar enamel tightly bonded to the pipe.

Four pits, which had penetrated the 0.188″ thick pipe wall, were discovered under the incrustation. Pitting was observed within the larger pits.

A black, moist substance was removed from the pit closest the bottom of the photograph above. It was analyzed using EDS technology. Two spectra were recorded. One run had major peaks for iron, sulfur, silicon, sodium, and aluminum with minor peaks of potassium, calcium, oxygen and manganese. These elements are characteristic of corrosion. Another run exhibited major peaks for the elements silicon, aluminum and iron with minor peaks of sulfur, potassium, calcium, carbon and oxygen. The elements detected in the latter portion of the sample are typical of soil. This substance indicates corrosion may have been actively occurring in the pit.

The soil is sandy blue clay with rounded rock up to 6 inches in diameter. The resistivity measured in the field is 7,000 ohm-centimeters and that in the laboratory is 6,600 ohm-centimeters. These values are typical of moderately corrosive soil.

Conclusions

Procedure Appropriate

The procedures used for both CIS and DCVG proved effective and appropriate for the conditions encountered during the survey. A comparison of measurements made with and without drilling holes through the paving resulted in negligible differences in the measurements when the paving was wet. Dry paving resulted in less consistent results.

The methodology used to perform the survey accurately located coating holidays on the pipeline facilities, including services. Invariably, the damaged coatings were found on the excavated pipe directly beneath the anomaly marks on the paving.

Criteria Appropriate

A concern was the effect of pipe diameter on the voltage gradient measured at coating holidays using the DCVG method. An assumption was made that the IR measurement is directly proportional to the coating holiday size and current flow, and inversely proportional to the pipe size. Ten of the twelve confirmation digs confirmed this assumption. These relationships support the criteria used at PSE that assigns severity of DCVG indications based on IR without specifying pipe size.

Two of the confirmation digs had holidays that did not correlate to the voltage gradients. Those locations are:

- **Examination Site 14.** 4% IR (minor indication) and a 22 square-inch coating holiday (moderate). Suspect resistance of incrustation and shielding by the backfill material embedded in the incrustation may have affected the voltage gradient measurement.
- **Examination Site 28.** No IR measured and two holidays measuring a total of 7.25 square inches. Suspect resistance of incrustation and shielding by the backfill material embedded in the incrustation may have affected the voltage gradient measurement.

One of the confirmation digs was classified more severe than the IR measurement would indicate even though the size of the holiday correlated with the voltage gradient. This is because the data indicated current was discharging from the holiday. Discharging current is an indication of an anodic condition. An anodic condition is classified as severe regardless of the size of the holiday. That location is:

- **Examination Site 13.** 13% IR (minor indication) and a minor coating holiday. Indication classified as severe due to current discharge indication. Good CIS potentials, -1,530 mV on and –910 mV off indicate an anode might be buried nearby.

Corrosion

There was little if any corrosion discovered at most of the examination sites. Four of the thirty-four sites had pitting and two of those had leaks associated with the pitting.

Six coating holiday indications were identified within 1,500 feet of the Vasa Park Cathodic Protection System rectifier. All were examined. Only one of the sites, exhibited corrosion. Lack of moist black or white corrosion product, and a tightly adherent incrustation over the pitting, indicates corrosion activity at that site was not recent.

Nine of the twenty-one sites with coating holidays had incrustations adhering to the bare steel exposed at coating holidays. This type of product is not unusual on cathodically protected pipe exposed to the electrolyte. Ions migrate in the electrolyte with chemical reduction occurring at the cathodic regions on the pipe surface. The reduced ions plate out on the surface of the cathode[3] forming a crust, typically composed of carbonates. The crust protects the steel to an extent and is an indication that cathodic protection is active.

Cathodic protection (CP) was not applied to the pipe until approximately 20 years after commissioning. It is likely corrosion processes were acting on the pipe until CP was applied. After the cathodic protection current polarized the pipe, incrustations formed at the former corrosion sites. This sequence of events aids in differentiating historical corrosion from actively corroding cells on the pipe surface.

The pitting and incrustation observed indicate the pipe is not actively corroding with the exception of two locations, Examination Sites 28 and 31. The soils analysis indicates local soil conditions probably caused the corrosion.

Had stray current affected the investigated pipe, the path would have led to current discharge off the main and back to the source. Since the Vasa Park rectifier had been operating with the Spirit Ridge pipe connected to the anode terminal, the Spirit Ridge pipe would have had to discharge current onto the pipe studied in this investigation. The investigated pipe at these current pick-up locations would be receiving cathodic protection. The path the current would take would be the lowest resistance path to the source. Once on the pipe, the investigated pipe would be the least resistant path for the current to follow. The current would then discharge to the Vasa Park impressed current anode, completing the circuit. The most likely location for stray current corrosion to occur on the investigated pipe would be near the Vasa Park rectifier. This investigation found no evidence of such corrosion.

[3] H. H. Uhlig, Corrosion and Corrosion Control, p8 (John Wiley & Sons, 1985)

Corrosion, *continued*

The pipe investigated is constructed of materials and installed with workmanship typical for pipe of similar vintage throughout the PSE gas distribution system. The investigation found nothing unique about this pipe. The corrosion processes acting on the pipe are not unusual and are typical of those to be expected at any other location in the gas distribution system.

Cathodic Protection

The pipeline under investigation has had a history of adequate cathodic protection since the 1980's, when the impressed current cathodic protection equipment was first installed. The high pressure main was installed in 1956. The intermediate pressure piping and services were installed from the mid 1950's to present with the majority installed in the 1950's and 1960's.

The incrustations found at coating holidays and the lack of corrosion at nearly 90% of the examination sites indicate the cathodic protection is effective.

Repairs

All exposed indications were cleaned and coated in accordance with PSE Gas Operating Standards and Gas Field Procedures. None of the pipe at these sites required replacement or downrating. The two leak sites were repaired with the installation of leak clamps. Services with an unusual number of indications or indications in areas of the customer's property that were difficult to get to were scheduled for replacement. Fifteen of the one hundred-forty services fell into this category.

APPENDIX A

FIGURES

Figure 1 Site Plan – Survey Area

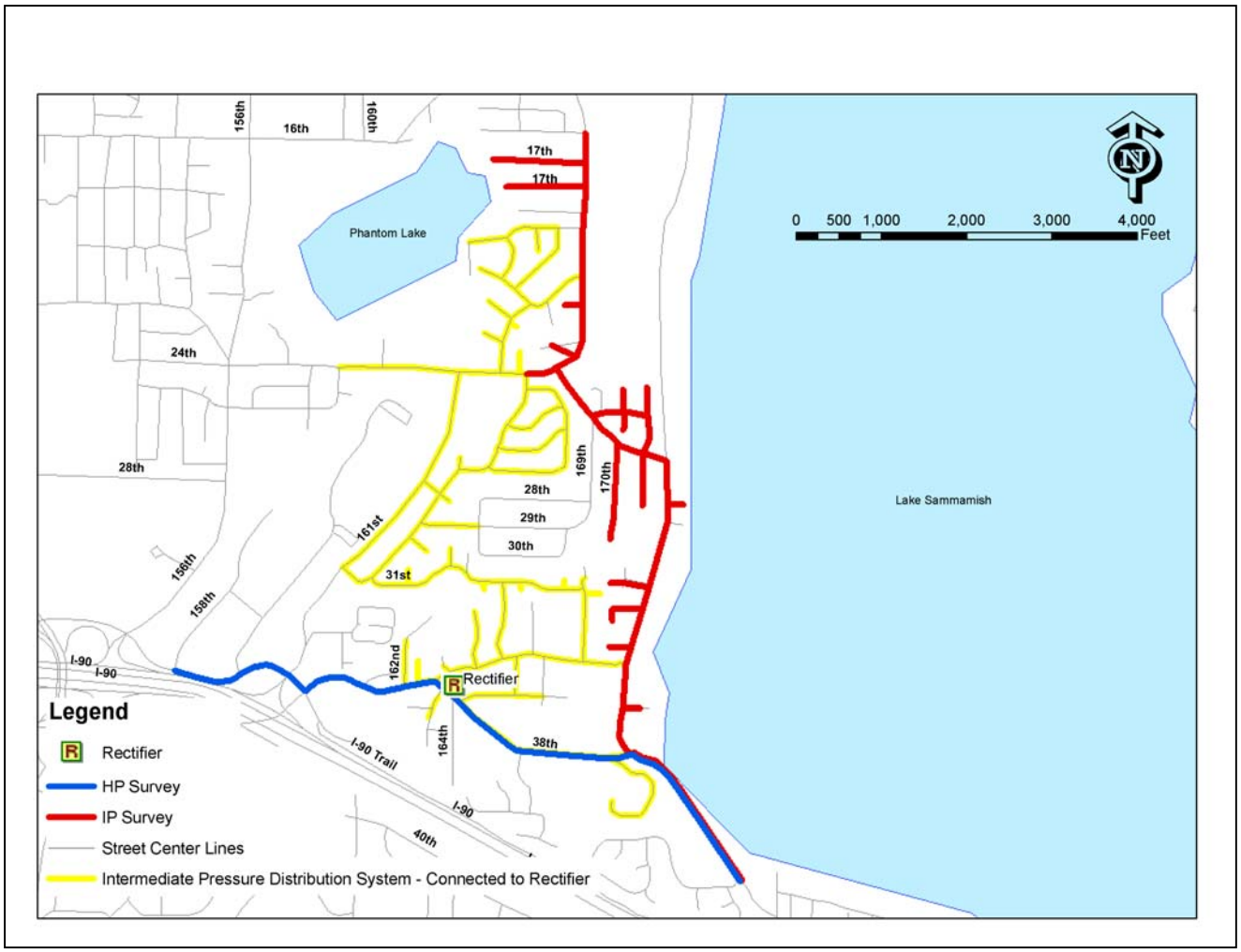
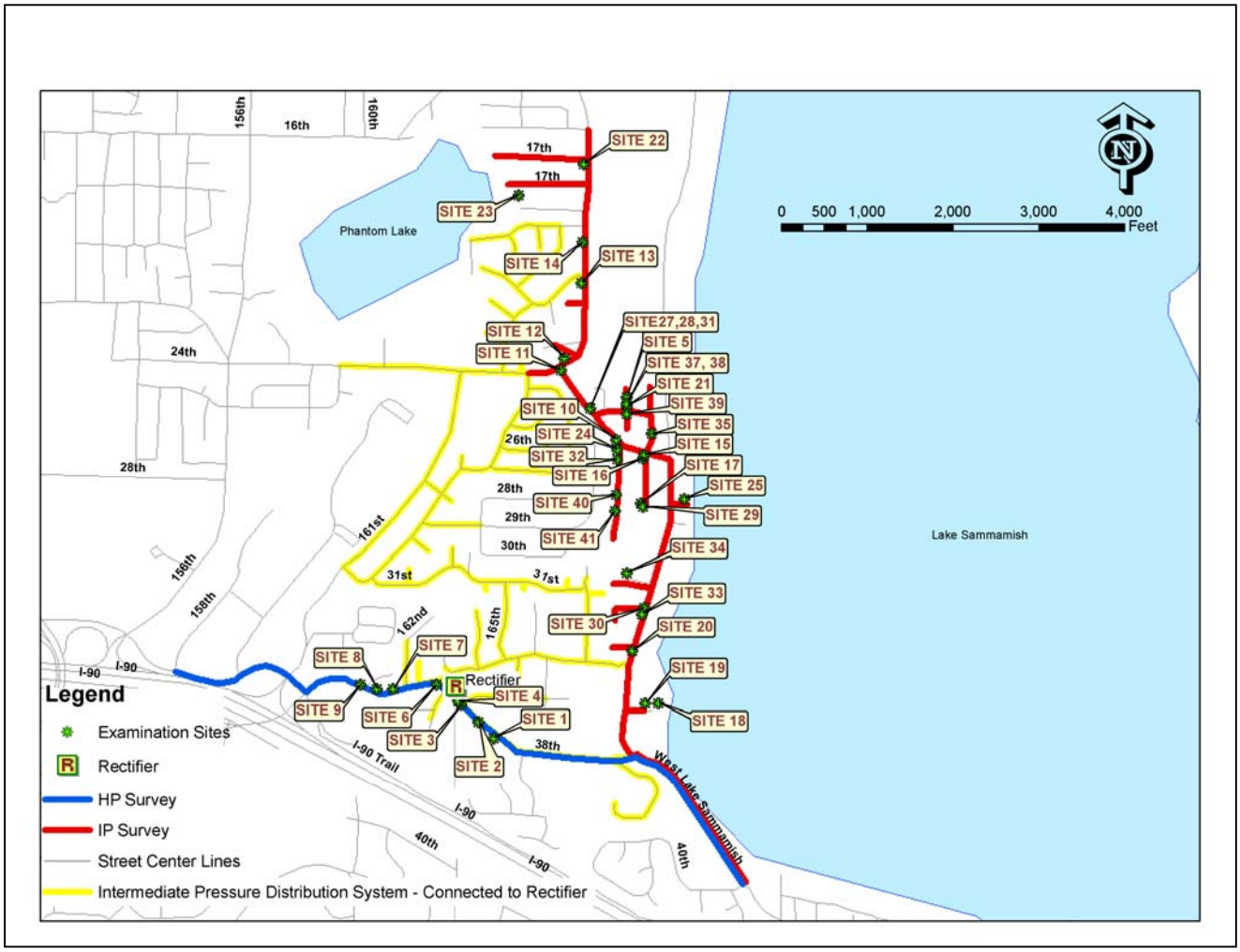


Figure 2 Examination Sites



APPENDIX B

TABLES

TABLE 1
List of Examination Sites

			indications		examinations	
	planned	actual	CIS	DCVG	scheduled	completed
HP main [3]	6,000	6,000	8	12	8	6
IP main	14,700	14,700	17	53	18	18
services	140	140	18	32	10	10

Notes:

1) Direct examinations of mains completed on 04/25/05.
2) Direct examination on services completed on 04/29/05.
3) Stationing is from Power Pole 3410 located a few feet east of the Vasa Park rectifier. STA 0+00W (PP-3410) = STA 23+00E.

EXAMINATIONS

	location					
	plat	station	address	facility	comments	root cause
1	195.090	STA 15+09E	3636 164 PL SE	8" HP	Severe DCVG and minor CIS indications. Small coating holiday (3/4" diameter at 5:30) and moderate sized area (16" x 4" at 7:00) of thinly applied, damaged coating. Minor surface rust under damaged coating and no pitting. Remaining coating is coal tar enamel bonded to pipe. Collected soil and coating samples. Good pipe potential (-1,250 mV). Soil resistivity = 18,000 ohm-cm. Soil description: sandy with rounded rock to 6” diameter.	Rock in backfill probably damaged coating. Minor surface rust on pipe.
2	195.090	STA 16+80E	3629 164 PL SE	8" HP	Moderate DCVG indication. Large coating holiday (66” x 5”) at 12 o’clock. Remaining coating is coal tar enamel bonded to pipe. Thick, tightly bonded incrustation on exposed steel The incrustation was composed of a thin white layer adjacent the steel with a thick outer rust colored layer. Two minor corrosion pits (40 mils x 1/2” x 1/8” and 30 mils x ½” x 1/8”) under incrustation. Good pipe potential (-1,270 mV). Collected soil sample only. Soil resistivity = 150,000 ohm-cm. Soil description: sandy with rounded rock to 6” diameter.	Probably third party damage. Minor pitting. Significant incrustation over pits indicates the corrosion is not recent
3	195.090	STA 19+37E	3615 164 PL SE	8" HP	Minor DCVG indication. A small (2" x 1/2" at 2 o'clock) and a moderate sized coating holiday (20" x 1/4" at 1 o'clock). Thin white incrustation with thicker rust colored outer layer bonded to exposed pipe. No corrosion or damage to steel. Remaining coating is coal tar enamel bonded to pipe. Good pipe potential (-1,700 mV). Collected soil sample. Soil resistivity = 72,000 ohm-cm. Soil description: sandy clay with rounded rock to 3” diameter.	Probably third party damage. No corrosion on pipe.

TABLE 1
List of Examination Sites

EXAMINATIONS

	location					
	plat	**station**	**address**	**facility**	**comments**	**root cause**
4	195.090	STA 19+74E	3615 164 PL SE	8" HP	Moderate DCVG indication. Two moderate sized areas of coating damage (29" x 2" at 1 o'clock and 20" x 6" at 3 o'clock). Thin white incrustation with thicker rust colored outer layer bonded to exposed pipe. No corrosion or damage. Remaining coating is coal tar enamel bonded to pipe. Good pipe potential (-1,750 mV). Collected soil sample. Soil resistivity = 68,000 ohm-cm. Soil description: sandy clay with rounded rock to 3" diameter.	Probably third party damage. No corrosion on pipe.
5	194.090	no STA	2433 170 PL SE near SE 25 ST	1 1/4" STW IP	Minor DCVG indication. Service connection with failed hot-applied coal tar pipe tape. No corrosion under tape. Good pipe potential (-1,250 mV). Collected soil sample. Soil resistivity = 33,000 ohm-cm. Soil description: rocky clay with angular rock to 4" diameter.	Improperly applied coating. No corrosion on pipe.
6	195.089	STA 1+35W	SE 35 Pl & 164 PL SE	8" HP	Severe CIS indication. Tightly bonded coating in good condition. No corrosion. Good pipe potential (-1,920 mV). Collected soil sample. Soil resistivity = 320,000 ohm-cm. Soil description: sand with rounded rock to 3" diameter.	No damage to pipe or coating. CIS indication attributed to poor contact with earth.
7	195.089	STA 6+96W	210' W of 162 PL SE	8" HP	Minor DCVG and moderate CIS indications. Tightly bonded coating in good condition. No corrosion and no damage to coating. Good pipe potential (-1,860 mV). Collected soil sample. Soil resistivity = 35,000 ohm-cm. Soil description: rocky sand with small angular rock to 2" diameter.	No damage to pipe or coating.
8	195.089	STA 8+60W	350' W of 162 PL SE	8" HP	Minor DCVG and moderate CIS indications. Re-surveyed and identified no anomalies and good potentials. The DCVG anomaly was data interpretation error. This site was not excavated.	No excavation.
9	195.089	STA 9+50W	440" W of 162 PL SE	8" HP	Moderate CIS indication. Re-surveyed and found no anomalies and good CP potentials. This site was not excavated.	No excavation.
10		STA 6+55	SE 26 ST & W Lk Samm heading uphill	4" STW IP	Minor DCVG indication. Confirmation excavation completed. Two minor coating holidays (13" X 3" & 6" x 3" at 1 o'clock). No corrosion or damage to steel. Remaining coating is coal tar enamel bonded to pipe. Good pipe potential (-1,500 mV). Soil resistivity = 46,000 ohm-cm. Soil description: sandy clay with rounded rock to 6" diameter. Results confirm indication classification.	Third party damage. No corrosion on pipe.
11		STA 17+30	SE 26 ST & W Lk Samm heading uphill	4" STW IP	Moderate DCVG indication. Confirmation excavation completed. One coating holiday (6" X 4" at 3 o'clock). Thin rust colored incrustation bonded to exposed pipe. No corrosion or damage to steel. Remaining coating is coal tar enamel bonded to pipe. Good pipe potential (-1,500 mV). Soil resistivity = 40,000 ohm-cm. Soil description: sandy brown clay with small rounded rock. Cast iron valve box extension in contact with pipe, affecting DCVG measurent. Results confirm indication classification.	Possibly third party damage. No corrosion on pipe.

TABLE 1
List of Examination Sites

EXAMINATIONS

	location					
	plat	**station**	**address**	**facility**	**comments**	**root cause**
12		STA 0+85	2300 168 AV SE & SE 26 ST IP northbound	2" STW IP	Severe DCVG indication. Confirmation excavation. Excavation completed. Minor sized coating holiday at 1" service tee. Remaining coating is coal tar enamel bonded to pipe. Good pipe potential (-1,560 mV). Soil resistivity = 70,000 ohm-cm. Soil description: sandy with small rounded rock to 2" diameter. Results confirm indication classification. Galvanic anode found buried adjacent pipe causing DCVG indication to appear severe. No corrosion on pipe.	Improperly applied coating. No corrosion on pipe.
13		STA 12+47	168 AV SE & SE 26 ST IP northbound	2" STW IP	Severe DCVG indication. CIS measurements indicate good CP and possible galvanic anode location. Confirmation excavation. Excavation completed. Minor sized coating holiday at 3 o'clock directly under copper water service line crossing. Thin white incrustation with thicker rust colored outer layer bonded to exposed pipe. Remaining coating is coal tar enamel bonded to pipe. Coating holiday correlated with %IR. No corrosion or pipe damage. Good pipe potential (-1,510 mV). Soil resistivity = 78,000 ohm-cm. Soil description: sandy with large rounded rock to 8" diameter.	Probably third party damage to coating. No corrosion on pipe.
14		STA 16+65	168 AV SE & SE 26 ST IP northbound	4" STW IP	Minor DCVG indication. Confirmation excavation. Moderate sized coating holiday (11" x 2" at 3 o'clock) larger than %IR indicated. Remaining coating is coal tar enamel bonded to pipe. Thick, tightly bonded incrustation on exposed steel. 3" diameter pitted area, to 10 mils, under incrustation. A 30 mils x 1 1/8" diameter corrosion pit was found within the pitted area. Good pipe potential (-1,630 mV). Collected one incrustation sample and one soil sample. Soil resistivity = 8,000 ohm-cm, 2' south of corroded area, and 32,000 ohm-cm, adjacent corroded area. Soil collected from trench wall. Soil description: sandy with rounded rock up to 3" diameter adjacent corroded area and blue clay 2' south of corroded area at edge of excavation.	Corrosion cell due to signifcant change in soil resistivity coupled with possible shielding of exposed steel by rock embedded in incrustation.
15		STA 0+12	SE 26 ST & 171 AV SE heading south	2" STW IP	Severe DCVG indication. Excavation completed. Found bare 2" main valve. Classified as a moderate sized coating holiday. No holidays on main. Coating on main is coal tar enamel in good condition and bonded to pipe. Galvanic anode found buried adjacent pipe causing DCVG indication to appear severe. No corrosion on pipe. Good pipe potential (-1,600 mV). Soil resistivity = 35,000 ohm-cm. Soil description: sandy with small round rocks. Results confirm classification.	Galvanic anode resulting in false indication of severity of holiday. No corrosion on pipe.
16		STA 0+88	SE 26 ST & 171 AV SE heading south	2" STW IP	Severe DCVG indication. Excavation completed. Moderate sized coating holiday (28" x 2") where mastic had failed. Remaining coating on main is coal tar enamel in good condition and bonded to pipe. Galvanic anode found buried adjacent pipe causing DCVG indication to appear severe. No corrosion on pipe. Good pipe potential (-1,500 mV). Soil resistivity = 58,000 ohm-cm. Soil description: brown clay with small round rocks.	Galvanic anode resulting in false indication of severity of holiday. No corrosion on pipe.

TABLE 1
List of Examination Sites

EXAMINATIONS

	location					
	plat	**station**	**address**	**facility**	**comments**	**root cause**
17		STA 6+70	SE 26 ST & 171 AV SE heading south	2” STW IP	Moderate DCVG indication. Confirmation excavation canceled due to location directly under large plant. Selected new moderate confirmation dig at service address 16940 SE 32 PL, STA 0+78 (Site 30).	No excavation.
18		STA 0+50	W Lk Samm Pkwy & SE 35 St Esmt @ 17130 SE 35 ST	1” STW IP	Severe DCVG indication. Confirmation excavation completed. Service connection with damaged coating and 1 minor holiday (1/4" x 1/4" at 12 o'clock) on main. Remaining coating on main is coal tar enamel bonded to pipe. 3/4" service line coating damaged at 12 o'clock next to tee exposing mastic under extruded PE jacket. Coating appeared to have been damaged from boring in the service. No corrosion on pipe. Good pipe potential (-1,760 mV). Soil resistivity = 6,000 ohm-cm. Soil description: blue clay. Results confirm classification.	First party damage to service and poor field installation of coating at tee. No corrosion on pipe.
19		STA 1+23	W Lk Samm Pkwy & SE 35 St Esmt @ 17130 SE 35 ST	1” STW IP	Moderate DCVG indication. Confirmation excavation completed. Two small coating holidays (1/4" x 1/4" & 1" x 1" at 12 o'clock). Remaining coating on main is coal tar enamel bonded to pipe. No corrosion on pipe. Good pipe potential (-1,740 mV). Soil resistivity = 5,000 ohm-cm. Soil description: blue clay with small round rocks. Results confirm classification.	Probably third party damage. No corrosion on pipe.
20		STA 2+70	W Lk Samm Pkwy @ 3251 heading east on Esmt	1” STW IP	Severe DCVG and moderate CIS indications. Moderate sized coating holiday (1" x 4' at 12 o'clock). No incrustation or corrosion on pipe. Remaining coating on main is in good condition and bonded to pipe. Good pipe potential (-1,670 mV). Soil resistivity = 32,000 ohm-cm. Soil description: hard pan silt with round rock to 3" diameter. DCVG indication size confirms % IR results. Noted as severe indication because of CIS indication alignment.	Third party damage. No corrosion on pipe.
21		STA 4+19	SE 25 ST & SE 26 ST eastbound	2" STW IP	Severe CIS indication. Resurveyed. Found no indication of an anomaly. No excavation scheduled.	No excavation.
22		STA 0+10	SE 17 ST & 168 AV SE west on 17 ST	2" STW IP	Severe DCVG indication. Excavation completed. Cast iron valve box touching valve on main caused DCVG indication to appear severe. Remaining coating on main is coal tar enamel bonded to pipe. No corrosion on pipe. Good pipe potential (-1,630 mV). Soil resistivity = 17,000 ohm-cm. Soil description: brown and blue clay with large round rocks. Results confirm classification.	First party damage. No corrosion on pipe.
23		STA 7+55	168 AV SE & SE 17 PL heading west	2" STW IP	Severe DCVG indication and moderate CIS indication. No excavation scheduled. Anomaly at service tie to main. Service replacement planned (16601 SE 17 PL).	Not excavated.

TABLE 1
List of Examination Sites

EXAMINATIONS

	location					
	plat	**station**	**address**	**facility**	**comments**	**root cause**
24		STA 0+94	SE 26 ST & 170 AV SE heading south 2609 170 AVE SE	2" STW IP	Severe DCVG indication and moderate CIS indication. Excavation completed. Found 4 coating holidays (ranging in size from 1/2" x 1/2" to 1 1/2" x 2" at 12 - 1 o'clock) spread over an area of 31". Remaining coating on main is coal tar enamel bonded to pipe. 3/4" copper water service line touching pipe. Thin layer of rust colored incrustation on some of the exposed steel and between the water and gas pipe. No corrosion on pipe. Good pipe potential (-1,540 mV). Soil resistivity = 36,000 ohm-cm. Soil description: brown and blue clay with rounded rock to 3" diameter. Results confirm classification.	Third party damage. No corrosion on pipe.
25		STA 3+85	W LK Samm Pkwy & 2800 Blk Esmt	1" STW IP	Severe CIS indication. This is a single pipe potential bracketed by good potentials on electrically continuous pipe. Assume the data is in error. No excavation scheduled.	No excavation.
26		STA 2+70	W LK Samm Pkwy @ 3251 PL heading east on Esmt	1" STW IP	Severe DCVG and moderate CIS indications. Excavation completed. Duplicate with Site 20 (STA 2+70) Site mistakenly scheduled twice.	Duplicate entry.
27		STA 10+95	SE 26 ST & W Lk Samm heading uphill	4" STW IP	No indications. Confirmation excavation completed. Coating on main is coal tar enamel bonded to pipe. No corrosion on pipe. Good pipe potential (-1,600 mV). Soil resistivity = 40,000 ohm-cm. Soil description: sandy clay with round rocks to 6" diameter. Results confirm classification.	No coating damage or corrosion on pipe.
28		STA 11+16	SE 26 ST & W Lk Samm heading uphill	4" STW IP	No indications. Confirmation excavation completed. Found two coating holidays (12 o'clock) with heavily encrusted pipe measuring 3" x 2 ¼" and 1" x ½". Rocks embedded in the incrustation. Two pits (¼" x ¼" each) through pipe wall (0.188" wt). Remaining coating is coal tar enamel bonded to pipe. This location is 6' from a severe DCVG location, STA 11+22 (Site 31). Collected one soil sample with broken up incrustation mixed in it. Pipe potential = -1,500 mV. Soil resistivity = 7,000 ohm-cm. Soil description: sandy blue clay with rounded rock up to 6" diameter.	Third party damage. Pitting through pipe wall.
29		STA 6+88	2664 - 171 AV SE	2" STW IP	Minor DCVG indication. Confirmation excavation completed. Weld not wrapped properly. Thin white incrustation with thicker rust colored outer layer bonded to exposed pipe. Remaining coating is coal tar enamel bonded to pipe. Coating holiday correlated with %IR. No corrosion. Good pipe potential (-1,300 mV). Soil resistivity = 143,000 ohm-cm. Soil description: sandy with rounded rock to 8" diameter.	Poor field installation of coating. No corrosion on pipe.

TABLE 1
List of Examination Sites

EXAMINATIONS

	location					
	plat	**station**	**address**	**facility**	**comments**	**root cause**
30		STA 0+78	16940 SE 32 PL	3/4" SVC	Moderate DCVG indication. Confirmation excavation completed. Found 3 coating holidays 12" x 1", 13" x 1" & 6" x 1/4" all at 12 o'clock) on pipe. New water service and box close to damaged coating location. Remaining coating is in good condition and bonded to pipe. No corrosion or damage to pipe. Results confirm classification. Good pipe potential (-1,630 mV). Soil resistivity = 45,000 ohm-cm. Soil description: rocky sand.	Third party damage. No corrosion on pipe.
31		STA 11+22	SE 26 ST & W Lk Samm heading uphill	4" STW IP	Severe DCVG indication. Excavation completed. Found 4 coating holidays (at 12 o'clock and 1 o'clock) with heavily encrusted pipe. Rocks embedded in the incrustation. Four pits found with two through the pipe wall (0.188" wt). The pits exhibited small pits within the larger pits. Remaining coating is coal tar enamel bonded to pipe. This site is 6' from a confirmation dig at Site 28, STA 11+18. Collected one incrustation sample, one soil sample and one corrosion product sample. Pipe potential = -1,500 mV. Soil resistivity = 7,000 ohm-cm. Soil description: sandy blue clay with rounded rock up to 6" diameter.	Third party damage. Pitting through pipe wall.
32		STA 1+80	SE 26 ST & 170 AV SE heading south 2615 170 AVE SE	2" STW IP	No indications. Confirmation excavation completed. Results confirm indication classification. Coating is coal tar enamel bonded to pipe. Good pipe potential (-1,580 mV). Soil resistivity = 40,000 ohm-cm. Soil description: brown and blue clay with rounded rock to 3" diameter.	No coating damage or corrosion on pipe.
33		STA 0+03	3215 W. Lk. Samm. Pkwy SE	1/2" SVC	Severe DCVG indication. Large coating holiday (1/4" x 16" at 12 o'clock) on pipe. 4" PVC was pipe found lying on pipe at holiday. Remaining coating is in good condition and bonded to pipe. Third party damage. No corrosion on pipe. Good pipe potential (-1,610 mV). Soil resistivity = 30,000 ohm-cm. Soil description: brown loam with small round rock. Results confirm indication classification.	Third party damage. No corrosion on pipe.
34		STA 0+27	3031 - 170 PL SE	1/2" SVC	Severe DCVG indication. Excavation completed. No coating holiday. Galvanic anode found buried adjacent pipe causing DCVG indication to appear severe. No corrosion on pipe. Good pipe potential (-1,630 mV). Soil resistivity = 70,000 ohm-cm. Soil description: hard pan silt with small round rock.	Galvanic anode resulting in false indication of holiday. No corrosion on pipe.
35		STA 0+81	2526 - 171 AV SE	1/2" SVC	Severe DCVG indication. Found 2 small coating holidays (3" x 1/2" and 1/2" x 1/2"). Remaining coating is extruded PE in good condition and bonded to pipe. No corrosion on pipe. Good pipe potential (-1,550 mV). Soil resistivity = 35,000 ohm-cm. Soil description: wet gray sandy clay with round rock to 3" diameter. DCVG indication size confirms % IR results. Noted as severe indication because cathodic/anodic classification.	Cause of damage unknown. No corrosion on pipe.

TABLE 1
List of Examination Sites

EXAMINATIONS

	location					
	plat	**station**	**address**	**facility**	**comments**	**root cause**
36		STA 0+12	17014 - SE 25 ST	1/2" SVC	Severe DCVG indication. No coating holiday. Galvanic anodes found buried adjacent pipe at STA 0+12 and STA 0+39 causing DCVG indication to appear severe. Coating is in good condition and bonded to pipe. No corrosion on pipe. Good pipe potential (-1,120 mV). Soil description: sandy brown clay with round rock to 3" diameter.	Galvanic anode resulting in false indication of holiday. No corrosion on pipe.
37		STA 0+39	17014 - SE 25 ST	1/2" SVC	Severe DCVG indication. No coating holiday. Galvanic anodes found buried adjacent pipe at STA 0+12 and STA 0+39 causing DCVG indication to appear severe. Coating is in good condition and bonded to pipe. No corrosion on pipe. Good pipe potential (-1,120 mV). Soil description: sandy brown clay with round rock to 3" diameter.	Galvanic anode resulting in false indication of holiday. No corrosion on pipe.
38		STA 0+87	17015 - SE 25 ST	1/2" SVC	Severe DCVG indication. Excavation completed. Found 2 minor coating holidays (1/8" diameter and 1" diameter). Remaining coating is in good condition and bonded to pipe. Cause of damage unknown. Galvanic anode found buried adjacent pipe causing DCVG indication to appear severe. No corrosion on pipe. Good pipe potential (-1,250 mV). Soil description: sandy with round rock to 2" diameter.	Galvanic anode resulting in false indication of holiday. No corrosion on pipe.
39		STA 0+81	2435 - 170 PL SE	3/4" SVC	Severe DCVG indication. Found 1 small coating holiday (3" x 1"). Remaining coating is in good condition and bonded to pipe. No corrosion on pipe. Good pipe potential (-1,300 mV). Soil resistivity = 30,000. Soil description: hard pan with round rock to 2" diameter. DCVG indication size confirms % IR results. Noted as severe indication because cathodic/anodic classification.	Cause of damage unknown. No corrosion on pipe.
40		STA 0+15	2801 - 170 AV SE	1/2" SVC	Severe DCVG indication. Found 2 small coating holidays (1/2" x 1" and 1/4" x 1/4"). Remaining coating is in good condition and bonded to pipe. Steel fence post making contact with pipe at indication caused DCVG indication to appear severe. No damage or corrosion on pipe. Good pipe potential (-1,300 mV). Soil description:brown loam with round rock to 8" diameter.	Third party damage. No corrosion or damage on pipe.
41		STA 0+27	2821 - 170 AV SE	3/4" SVC	Severe DCVG indication. Excavation complete. Found 1 small coating holiday (1/2" x 3"). Thin layer of rust colored incrustation adhered to exposed steel. Remaining coating is in good condition and bonded to pipe. Two small cables found laying on service near holiday. No corrosion on pipe. Good pipe potential (-1,540 mV). Soil resistivity = 45,000. Soil description: sand with small round rock. Indication size confirms % IR results. Noted as severe indication because cathodic/anodic classification.	Third party damage. No corrosion on pipe.

TABLE 2
Soil Analysis[2]

Site	resistivity, ohm-cm	moisture, %	pH soil	total acidity, mg $CaCO_3$/kg	total alkalinity, mg $CaCO_3$/kg	chlorides, mg/kg	sulfates, mg/kg	oxidation - reduction potential[3], mV	corrosivity (LPR[4]), mils/year
2	50,000	10.0	6.55	70.0	27.8	5.0	147.7	662	1.3
14	5,100	16.1	6.75	45.0	47.7	4.8	141.7	587	11.1
31[1]	6,600	13.1	6.82	50.0	13.1	13.8	152.6	443	2.4

Notes:

1. Examination Sites 28 and 31 are in one excavation. The soil sample obtained applies to both sites.
2. Puget Sound Energy, Summary of Findings-Coating Survey - Spirit Ridge Subdivision (F4434-01G), CC Technologies, June 9, 2005
3. Oxidation-reduction (redox) potentials are referenced to a Saturated Hydrogen Electrode (SHE).
4. Coupons were placed in the soil samples to establish the corrosion rate using Linear Polarization Resistance measurements.

TABLE 3
Threshold Criteria for Various CIS Measurement Techniques

Circumstance	Optimal Measurement Technique(s)	Adopted Threshold Criteria[♣]
Sacrificial anode CP system (not designed to allow interruption of all anodes simultaneously)	"On" Survey - Compensate for IR error by placing reference electrode directly over pipeline and as remote as possible from sacrificial anode. - If in doubt, or when potential readings are questionable, excavate to allow placement of reference electrode as close as possible to pipeline.	-850 mV "on"
Sacrificial anode CP system (designed to allow interruption of all anodes simultaneously)	Polarization survey	-100 mV polarization shift.
Impressed Current CP system - Distributed anode impressed current system - Coating in relatively good condition	Instant-off or Polarization Survey (for pipelines with a high dielectric strength coating, the instant-off technique may be easiest to use, however polarization technique may also be used)	-850 "off" (for instant-off); -100 mV polarization shift (for Polarization Survey)
Impressed Current CP system - Distributed anode impressed current system - Bare pipeline, or coating in poor condition	Polarization Survey	-100 mV polarization shift
Impressed Current CP system - Remote anode system - Low soil resistivity - High coating dielectric strength - Low circuit resistance of CP system	Instant Off Survey, Polarization Survey, On Survey - If an "on" survey is used, care should be taken to place the reference cell as close to the pipeline as possible. If in doubt, or when potential readings are questionable, excavate to allow placement of reference electrode as close as possible to pipeline.	- If an "on" survey is used, threshold criterion should be established on basis of knowledge of the dielectric strength of the coating, size of the pipeline, soil resistivity, distance and voltage at the anodes, rectifier output voltage, and rectifier output current. - If "instant off" survey is used, criterion should be -850 mV - If polarization survey is used, criterion should be –100 mV.
Impressed Current CP system - Remote anode system, relatively good coating	Instant Off Survey, Polarization Survey	-850 mV instant off, -100 mV polarization shift
Impressed Current CP system - Remote anode system, bare, or poorly coated pipeline	Polarization Survey	-100 mV polarization shift

[♣] All potentials listed are relative to a $Cu/CuSO_4$ reference cell.

TABLE 3
Threshold Criteria for Various CIS Measurement Techniques

Once the above factors have been considered, the following may be used as general guidelines for assigning severity criteria:

Minor Indications:	Isolated locations where the potential drops are small relative to adjacent areas, however the potential is maintained above the established threshold criterion.
Moderate Indications:	Isolated locations where potential does not meet the established threshold criterion, and the dip below that criterion is small.
Severe Indications:	Isolated locations where potential does not meet the established threshold criterion, and the dip below that criterion is large. Otherwise, a generalized area over which the potential does not meet the established threshold criterion.

TABLE 4
Guidelines for Severity Classification of Indications
Utilizing DCVG Technique

Indication Classification	Defining Criteria (1st Application of DCVG)	Defining Criteria (Subsequent Applications of DCVG)	Comments
Minor	<= 15% IR AND cathodic / cathodic current flow characteristics	<= 15% IR AND cathodic / cathodic current flow characteristics	Indications in this category are often considered of low importance, and repair is usually not required. A properly maintained CP system generally provides effective long-term protection to these areas.
Moderate	<=35% IR AND cathodic / neutral current flow characteristics OR >15% to <=35% IR AND cathodic / cathodic current flow characteristics	<=60% IR AND cathodic / neutral current flow characteristics OR >15% to <=60% IR AND cathodic / cathodic current flow characteristics	In this category, the indications tend to be larger, and/or the pipe at the location of the indications returns to native potential when the CP is interrupted, suggesting that the pipe at the location of such indications may corrode if there is an upset in the CP system.
Severe	> 35% IR OR cathodic / anodic current flow characteristics OR anodic / anodic current flow characteristics	> 60% IR OR cathodic / anodic current flow characteristics OR anodic / anodic current flow characteristics	Indications in this category are largest and/or the pipe at the location of the indications is anodic at some point in the interruption cycle, suggesting that that the pipe at the location of these indications may corrode even when the CP system is operating properly.

TABLE 5
Guidelines for Prioritizing Indirect Inspection Indications

Immediate Action	Scheduled Action	Suitable for Monitoring
• Multiple *severe* indications in close proximity to one another; • Isolated indications that are classified as *severe* by more than one indirect inspection technique at roughly the same location; • Where significant prior corrosion is suspected, individual indications that are classified as *severe* by one or more indirect inspection technique; • Where significant prior corrosion is suspected, groups of indications that are classified as *moderate* by one or indirect inspection technique♣; and, • Indications which, when combined with other data, suggest the presence of third party damage	• Regardless of the suspected prior corrosion activity, all *severe* indications that were not placed in the "immediate" category; • Where moderate prior corrosion is suspected, all indications that are classified as *moderate* by one or more indirect inspection technique, and that were not placed in the "immediate" category; and, • In regions where severe prior corrosion is suspected, groups of indications, regardless of severity classification that were not placed in the "immediate" category♣.	• All indications not otherwise classified as "immediate" or "scheduled".