Puget Sound Energy Wrapped Steel Service Assessment Program (WSSAP) Report

Final – March 15, 2007

Revision 5.0

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Executive Summary

The Wrapped Steel Service Assessment Program (WSSAP) implemented by Puget Sound Energy (PSE) is in accordance with the Settlement Agreement to the complaint regarding the Bellevue house fire. As part of the Settlement Agreement, PSE and the Washington Utilities and Transportation Commission (WUTC) agreed that PSE would undertake a review of available operational and environmental data for services installed more than 5 years before the application of cathodic protection. This review is intended to identify issues or trends of concern related to service lines of this vintage. PSE has simplified this criterion to mean any wrapped steel service that was installed prior to 1972. Services installed since 1972 have had cathodic protection from the date of initial installation in accordance with the requirements in 49 CFR Part 192. The Settlement Agreement further requires that PSE recommend follow up activities which may include additional testing, examination of the services, or replacement of the services.

PSE performed a comprehensive review of its more than 720,000 service lines to identify and inventory the pre-1972 wrapped steel services. This six month effort, beginning in January 2006 and ending in June 2006, identified approximately 100,000 services of this vintage.

To aid in the review and identification of potential issues or trends associated with these services, PSE developed a risk assessment model. This model was developed with assistance from W. Kent Muhlbauer of WKM Consultancy. Mr. Muhlbauer has gained valuable experience in the development of risk modeling for pipelines in his work on transmission integrity management programs. The risk model provides a relative risk ranking of the individual services consistent with the operating history of PSE's distribution system. A risk management decision criteria has been developed to identify how PSE will address the results of the risk assessment. This decision criteria identifies various conditions for services that would require replacement, additional leak surveys, or no further action.

PSE then began additional data gathering work that included capturing 36 different data points (risk variables) for each service necessary to run the risk model. This effort required queries of nine existing databases containing operational history. Additional pipeline data for use in the risk assessment was gathered by utilizing historical PSE construction standards, material purchase specifications, United States Department of Agriculture (USDA) soil maps, and county population information. Where data for the model is missing or unknown the most conservative data values were used.

PSE conducted a pilot risk assessment using data gathered on wrapped steel services from a single operations map in the City of Bellevue. This pilot was used to tune the risk assessment model and evaluate the model's effectiveness at ranking wrapped steel services. There are 2,700 pre-1972 wrapped steel services installed within the boundaries of this map. Based on the results of the risk modeling of theses 2,700 services, PSE selected 64 services to conduct additional field investigations to further evaluate the results of the model. These investigations included leakage surveys, cathodic protection electrical surveys, and direct examination. The results from these surveys have been analyzed and additional revisions were made to the risk model.

As a further validation of the effectiveness of the model at ranking services, PSE conducted a review of 61 services that had been replaced due to leakage reported to be caused by corrosion. In 52 instances, or 85% of the services reviewed, the risk model had prioritized the services at a level that would have required additional mitigation actions, such as replacement or additional leakage surveys.

PSE has met on numerous occasions with WUTC Pipeline Safety Staff and their consultant to review progress and discuss the development of the risk model. During these meetings and through follow up written correspondence, PSE has received feedback from Staff on our approach and specific issues related to the development of the risk model. Based on this input, we have continued to refine the risk model.

Risk modeling and risk assessment is an iterative process, requiring the application of information gathered in one cycle to improve upon the model and results in subsequent cycles. With this in mind, PSE has developed a Pre-1972 Wrapped Steel Service Mitigation Program. The program identifies mitigation actions to be applied to the services based on the results of the risk modeling. In addition, it includes steps to review the results of each year's actions and update the model on an annual basis.

PSE has since applied the risk model described in this report to the 100,000 identified wrapped steel services. Based on the prioritization results for the services utilizing the pre-established decision criteria, the corresponding follow-up actions have been determined.

In 2007, PSE is planning to replace approximately 516 services and will plan for the eventual replacement of approximately 8,470 services. In addition, a total of 23,100 services will be subject to increased leakage survey frequency. Also by 2009, PSE plans to conduct electrical surveys on 1,000 of the remaining population of pre-1972 wrapped steel services and services. The additional electrical surveys and subsequent direct examinations will help PSE further validate and tune the WSSAP risk model. These actions will be the basis for the continual improvement process outlined in the Pre-1972 Wrapped Steel Service Mitigation Program. As the proposed mitigation action is completed each year, PSE will continue to update the WSSAP database and rerun the risk model to determine if the prioritization of the services has changed.

Summary of Proposed Mitigation Program

Mitigation Category	**Action**	**Approximate Number of Services – Based upon 2006 WSSAP risk model results**
Priority Replacement	Service Replacement	516
Scheduled Replacement	Identify Replacement Projects and Twice Annual Leak Survey (until service is replaced)	8,470
Increased Leak Survey	Annual Leak Survey	23,100
Standard Mitigation	No Additional Action Required	69,281

It is anticipated that two existing programs, Isolated Facilities and Bare Steel Replacement, may impact many of the same services identified in this program and will require considerable coordination between the programs. The wrapped steel service program is projected to continue until all the services designated for replacement are replaced.

This report offers the project report and final program plan for PSE's Wrapped Steel Service Assessment Program (WSSAP).

1. Scope

As required by the 2005 Settlement Agreement with the Washington Utilities and Transportation Commission (WUTC) to the complaint regarding the Bellevue house fire, PSE is conducting a risk assessment and developing a plan for the mitigation of wrapped steel service lines that were without cathodic protection for 5 or more years. PSE has simplified this criterion to mean any wrapped steel service that was installed prior to 1972 (in late 1971 the federal pipeline safety rule was implemented requiring that all wrapped steel pipe be cathodically protected).

The intent of this effort is to conduct a detailed risk assessment to prioritize for further evaluation all wrapped steel services installed prior to 1972 and, depending on the results, perform any necessary follow-up action such as electrical surveys, leakage surveys or service replacements. The overall objectives of the risk model are as follows:

- Fulfill obligations under the Settlement Agreement
- Create useful overall risk assessment system (to support risk management and resource allocation)
- Create processes and begin to move toward data-centric risk-based integrity management systems

PSE has identified approximately 100,000 active wrapped steel services installed prior to 1972. PSE presently performs a 3-year leak survey on each wrapped steel service. These services should be cathodically protected and monitoring is either on a 9-year cycle for each separately protected service, or they are monitored annually as part of a larger cathodic protection system if the service is electrically continuous with one.

2. Program Plan

The approach for assessing the condition of PSE's wrapped steel services aligns with the integrity management program that was developed for PSE's transmission pipelines in 2004.

2.1. Identification of Threats

Failure likelihood, as it relates to pipeline integrity, is the relative measure of the likelihood of the pipeline failing as a result of a design or operating condition (threat). For the purposes of evaluating the susceptibility of pipelines to failure relative to one another, a probability of failure algorithm will be used categorize and classify appropriate distribution pipeline threats. ASME/ANSI B31.8S, *Managing System Integrity of Gas Pipelines*, classifies threats to pipelines in terms of "Time Dependent", "Stable" and "Time Independent" categories.

Time Dependent threats include:

1. External Corrosion;
2. Internal Corrosion; and,
3. Stress Corrosion Cracking (SCC);

Stable threats include:

4. Manufacturing Defects;
5. Welding/Fabrication Related; and,
6. Equipment Failure;

Time Independent threats include:

7. Third Party Damage;
8. Incorrect Operations; and,
9. Weather and Outside Force (Geotechnical)

PSE analyzed all of the above threat categories as they pertain to the PSE distribution system, and classified the following threats as being potentially viable, and therefore addressed in the risk model described in Section 2.2 of this document.

- External Corrosion
- Internal Corrosion
- Third Party Damage
- Incorrect Operations
- Weather/Outside Force (Geotechnical)

The remaining threats were not considered viable to PSE's wrapped steel services as explained below:

- Stress Corrosion Cracking (SCC) – industry research includes data indicating that certain conditions must be present in order for SCC to be a viable threat to a pipeline. An analysis of these required conditions indicates that SCC is not a viable threat to PSE's distribution pipe. The conditions required are as follows:
    - Age of pipe (>10 years old);
    - Operating stress level (>45% SMYS);
    - Operating Temperature (>100 degrees F);
    - Proximity to Compressor Stations (highest incidences within 20 miles of compressor stations, although significant SCC has been found further downstream of compressor stations);
    - Coating Type (all coating types other than FBE);
    - Environment (seasonally wet/dry or poorly drained conditions in shielding coating systems, and dry, high resistivity soils in non-shielding coatings; and,
    - Susceptible Seam types (e.g., low frequency electric resistance welded (ERW) pipe seams)

  The conditions of particular note that are not present in PSE's system include high operating stress level, high temperature and proximity to compressor stations.

- Manufacturing Defects – the primary manufacturing defect related threats on natural gas pipelines are hard spots and seam defects. The susceptibility to hard spots and seam defects is confined to a limited subset of pipe manufacturers, eras and method of manufacture. In addition, higher operating stress levels have greater potential for hard spot and seam failure, and industry experience has demonstrated that stress levels below 60% SMYS are below the levels which are required to precipitate hard spot or seam failures. Industry experience also indicates that pipe that is tested at values of at least 1.25 times the maximum operating pressure is sufficient to prevent operational failures due to seam defects. Though PSE may have installed pipe in the susceptible era and manufactured by companies that are known to be susceptible to manufacturing defects, due to the low stress level and PSE's historical testing standards it was determined that manufacturing defects are not a viable threat to PSE's distribution pipe.

- Welding/Fabrication Related – the data needed to support the threat of welding and fabrication of services is not being gathered during this phase of the project. As new data systems within PSE are implemented this data (obtained from D-4 cards) may be incorporated into the risk analysis.

- Equipment failure – the data needed to support the threat of equipment failure as it relates to services is not being gathered during the initial phase of this program. In future phases of this program and as new programs within PSE are implemented this data (obtained from D-4 cards) may be incorporated into this risk analysis.

In the future as Distribution Integrity Management develops, the applicable threats listed above may be incorporated into this risk analysis.

2.2. Risk Model Development

The final outcome from the risk assessment is a relative prioritization of the threats that contribute to the highest risk in PSE's distribution system with respect to wrapped steel services installed prior to 1972. A detailed description of the risk model and its development is located in Appendix B.

2.3. Identification of Pre-1972 Services and Data Gathering

2.3.1. Identified Areas of Higher Priority

Data related to system leakage, area soil types, Exposed Pipe Condition Reports (EPCRs), and anecdotal information was gathered and used to prioritize a review of system operation maps. The map prioritization was complete in mid February 2006. The higher priority maps were those that had the most corrosion related leaks, evidence of corrosion from EPCRs, and those thought to contain the highest concentration of pre-1972 wrapped steel services. The second tier of priority included maps with the most corrosive soils. The remaining maps were considered to be of equal but lower priority.

2.3.2. Data Gathering

The PSE Mapping, Records and Technology (MRT) department initiated a comprehensive review of PSE's system maps in January 2006. The maps were reviewed based on the priorities established in Section 2.3.1. In June 2006 PSE completed the review of 721,603 services and identified approximately 100,000 pre-1972 wrapped steel services.

In addition to the work being done by MRT, additional data gathering work includes:

- Populating the risk model with the 36 data points (risk variables) for each service. Existing databases were identified and evaluated for content.
- The PSE Information Technology (IT) department developed 13 different types of list edit queries within 9 existing databases. A Senior Applications Analyst was assigned to assist with the development and implementation of this phase of the project as well as additional support from numerous departments. The implementation of these data bridges is complete.
- Additional pipeline data for use in the risk assessment was gathered utilizing historical PSE construction standards, material purchase specifications, United States Department of Agriculture (USDA) soil maps, and county population information.
- Where data for the model is missing or unknown the most conservative data values are used.

The services identified are distributed throughout PSE's service territory. Most of the services are located in the following major areas/cities within PSE's service territory (the cities are shown as a percentage of the total pre-1972 wrapped steel services population):

- Tacoma, 17%;

- Seattle, 12%;
- Burien-Federal Way Region, 11%;
- Bellevue, 9%;
- Edmonds, Shoreline, Lynnwood, 7%;
- Bothell and Kenmore, 5%;
- Kent Valley, 4%;
- Olympia-Lacey Region, 4%
- Renton and Tukwila, 3%;
- Redmond, 2%;
- Kirkland, 2%;
- Everett, 2%;

The remaining services are scattered throughout the counties and smaller towns within PSE's service territory.

2.4. Analysis of Risk Results for Trends and Areas of Concern

Data recorded from the system maps and various maintenance databases was processed into the risk analysis using the risk model described in Section 2.2. The process to determine the appropriate follow-up action based on the risk model results is located in Appendix C, Figure 1.

The service data was imported into the risk analysis software and the services were prioritized. The service list was segmented based on threats and consequence. The services were ranked for follow-up action by inspecting common or overlapping priorities. The threat and consequence drivers for each prioritized segment are used in determining the appropriate follow-up action.

The risk model was sorted separately by five separate fields; risk, PoF, CoF, time dependent failure (TDF), and third party damage (TPD). The boundary lines for follow-up action were chosen by utilizing histograms specific to each threat ranking for the services. The upper boundaries were chosen by observing an obvious drop in the scores and the overall general characteristics of the services. The lower boundary was chosen utilizing the quartile method. The top 25% of the services in the Standard Mitigation Category were chosen to have additional leakage surveys performed.

Follow-up action will be prioritized based on the results of the model. All services with alerts for disbonded coating, leakage, or inadequate cathodic protection are placed in a higher priority for evaluation.

2.5. Recommendations for Follow-up Action

A review of the risk analysis data was performed to make a determination as to the significance of the information as it relates to the possible condition of the subject services.

PSE has added alerts to the risk model including indications of disbonded coating, inadequate cathodic protection, existing leak on the service, and if there is an EPCR for the service. Follow-up action for the services may be any of the following:

- Replacement of the service
- Increased or additional leak surveys
- No follow-up action required

- If the service analysis warrants, some recommendations may be expanded to include surrounding PSE facilities (i.e. mains)

Based upon the analysis described in Section 2.4 the service list was divided into follow-up action categories. The categories for the services, approximate number of services that fall within those categories, and the general characteristics of the services within those categories are provided in Appendix D, Figure 1.

The first two categories, priority and scheduled replacement indicate services that are candidates for replacement. Services within the priority category will be replaced in the following year. Services within the scheduled replacement category will be evaluated for logical replacement projects and prioritized for replacement, taking into consideration schedules for the Isolated Facilities and Bare Steel Replacement programs. Services within this category will have a leak survey performed twice annually until they are replaced. Services identified in the increased leakage survey category will have a leak survey performed annually not to exceed 15 months.

Services identified in the standard mitigation category will have no further action completed for those services and will be subject to normal operations and maintenance activities as required by company standards. Each year the entire risk model will be re-run to ensure the data gathered throughout the previous year during normal operations and maintenance activities is properly evaluated and addressed if necessary.

Cathodic Protection electrical surveys (CIS and DCVG) will be performed on a sample of the services categorized as increased leakage survey and standard mitigation to further validate the risk model. These electrical surveys will be conducted on 1,000 services by December 31, 2009 to ensure the validity of the risk model.

2.6. Budgeting and Planning of Follow-up Actions

PSE has developed the budget requirements and plan needed to carry out the follow-up actions. The following steps are accomplished when budgeting and planning for follow-up actions:

- Develop refined cost estimates necessary to carry out work
- Review budget impacts for current budget year and beyond
- Develop a preliminary schedule for construction, leak surveys and electrical surveys
- Develop resource needs to carry out follow-up activities per the preliminary schedule

The process to complete budgeting and planning of the recommended follow-up action is provided in Appendix E, Figure 1 and Table 1.

2.7. Performing Follow-up Actions

PSE personnel, PSE Service Provider crews, and/or additional contractor personnel will work to carry out any necessary follow-up actions on the services. The following steps will be accomplished when conducting follow-up action:

- Replace service in accordance with PSE Gas Operating Standards and Gas Field Procedures
- Perform additional or increased leak surveys in accordance with PSE Gas Operating Standards and Gas Field Procedures
- Perform Cathodic Protection electrical surveys in accordance with the procedure, criteria and process laid out in Appendix F

  - Coating and cathodic protection surveys. (DCVG or ACVG in combination with CIS)
  - Services will be selected for direct examination, replacement or no further action required
  - If the as-found condition does not match predictions, the analysis process will be reviewed and modified as required
- In areas of priority and scheduled service replacement, PSE will evaluate adjacent facilities (i.e. mains) for inclusion in the replacement project

2.8. Validation of Program Effectiveness

2.8.1. Risk Model Validation

PSE conducted a review of recent service replacement activity to assess the risk model's ability to appropriately prioritize services based on the identified threats. PSE input data into the WSSAP risk model for 28 services that were replaced in the pilot area due to leakage reported to be caused by corrosion (as presented in response to the WUTC data request submitted by PSE to the WUTC on October 6, 2006). The results of the 28 services input into the model are included in Appendix G, Table 1. PSE also evaluated the WSSAP risk model scores of 33 pre-1972 wrapped steel services that were replaced throughout PSE's service territory between January 2006 and September 2006 due to leakage reported to be caused by corrosion. The results of the 33 services are included in Appendix G, Table 2.

Combined, in 52 of 61 instances or 85% of the time (summarized below), the model prioritizes these services in the mitigation categories of priority replacement, scheduled replacement and increased leakage survey. This is significant in that the model is placing services that had previously been identified as requiring replacement into categories where PSE is proposing to take additional mitigative actions. Given this is the first iteration of the WSSAP risk model, PSE believes that the model is performing as expected.

Historical Service Replacement Summary

	Pilot Area		2006 Service Replacements		Combined		Combined Subtotal
Priority Replacement	0	0%	5	15%	5	8%	
Scheduled Replacement	2	7%	21	64%	23	38%	85%
Annual Leak Survey	19	68%	5	15%	24	39%	
Standard Mitigation	7	25%	2	6%	9	15%	15%
Total	28	100%	33	100%	61	100%	100%

Additionally, PSE will perform electrical surveys and soil resistivity tests on a random sample of services categorized in the "Annual Leak Survey" or "Standard Mitigation" categories. The field tests performed on the services within these categories will aid in validating the cathodic protection scoring and soil resistivity scoring of the WSSAP risk model by utilizing Close Interval Surveys (CIS) and soil resistivity measurements. The field tests will also include performing a Direct Current Voltage Gradient (DCVG) survey and excavation and examination of identified services. The excavation and examination of these services will provide additional data to further substantiate the theories regarding the condition of services.

PSE is confident in the results of this first iteration of the WSSAP risk model and will continue to improve the model's accuracy and performance through additional field tests and data gathering.

2.8.2. Mitigation Program Effectiveness

On an ongoing basis, PSE will analyze data as this program is implemented to determine the effectiveness of the mitigative measures employed. These actions may include any of the following:

- Electrical surveys on some services identified as not needing further action
- Potholing and examination of the condition of some services identified as not needing further action
- Analysis of leakage survey data to determine if the number of corrosion leaks on steel services has decreased as a result of the implementation of this program
- Analysis of leakage repair data to determine if the number of excavation damages on services has decreased
- Analysis of one call data to determine if number of locates for services has increased

If analysis of the program effectiveness shows the mitigative measures employed to reduce risk are ineffective PSE may reevaluate the decision criteria and revise the recommended follow-up action appropriately.

3. Program Schedule

Additional detail on the program schedule can be found in Appendix H, Figure 1. The schedule summary is as follows:

- The following actions have been completed:
  - All pre-1972 wrapped steel services identified (plat review)
  - All pre-1972 wrapped steel services and associated data points were assimilated into the risk analysis software and ranked
  - Electrical surveys conducted for the pilot project area
  - Follow-up recommendations made for all services requiring follow-up action
  - Excavation of identified services for the pilot project area

- The following actions are scheduled to be completed:
  - Budgeting and planning for all services requiring follow-up action
  - Repairs/replacements
  - Additional electrical surveys
  - Additional or increased leakage surveys

4. Conclusions

The Wrapped Steel Service Assessment Program has been implemented in accordance with the Settlement Agreement to the Bellevue house fire complaint. PSE has performed a detailed assessment of the condition of all wrapped steel services that were without cathodic protection for 5 or more years. PSE will continue to improve upon this initial assessment by performing follow-up action as outlined in this report to ensure the identified services requiring follow-up action are investigated and remediated as necessary.

Risk modeling and risk assessment is an iterative process, requiring the application of information gathered in one cycle to improve upon the model and results in subsequent cycles. With this in mind, PSE has developed a Pre-1972 Wrapped Steel Service Mitigation Program. The program identifies mitigation actions to be applied to the services based on the results of the risk modeling. In addition, it includes steps to review the results of each year's actions and update the model on an annual basis.

As described in Section 2.5 PSE is also planning on conducting additional electrical surveys on 1,000 of the remaining population of pre-1972 wrapped steel services. The additional electrical surveys and subsequent direct examinations will provide information to help PSE further tune the WSSAP risk model. As the proposed mitigation action is completed each year, PSE will update the WSSAP database and rerun the risk model to determine if the prioritization of the services has changed.

PSE intends to communicate with WUTC Staff and receive feedback on the continual improvement process and any resulting changes made to the WSSAP risk model. PSE will also communicate and seek agreement with Staff on new results of the WSSAP risk model and identification of any additional mitigative action that may be required. PSE will submit annual reports to the WUTC identifying targeted service replacements for the following year based upon the annual data repopulation and risk assessment utilizing the most current version of the WSSAP risk model. PSE will also provide an annual report summarizing the mitigative action for the previous year to allow WUTC Staff to monitor PSE's performance of the mitigation program.

Appendix A – Data Dictionary

Appendix A
Data Dictionary

Table 1. Data Dictionary for the Risk Model

Variable	Phase 1 data	Phase 2 data	Source	Comments/Scoring method	Default Scores	Additional Comments
Service address	Address		Maps/records			
Long/Short side service	Service length		Maps/records	L or S		
Service size	Pipe size		Maps/records	Size		When a service has multiple diameters the smallest diameter is utilized.
Pipe date	Installation date		Maps/records	Year	Default required	
Main size	Pipe size		Maps/records	Size		
Main material	Pipe material		Maps/records	S, I, P or CI		
Main pressure	Pressure		Maps/records	IP , LP or HP		
Main Date	Date		Maps/records	Date	Default required	
Pipe wall thickness	Pipe wall in inches/mils		Scoring mechanism	See scoring mechanism. Input inches/mils based on pipe size and year of install	Multiple sizes default to smallest diameter	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Coating type	Default "coal tar"		Scoring mechanism	See scoring mechanism. Score by date range 0, 4 or 7	Default coal tar	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Soil corrosivity	Corrosive score 0 - 3		GIS	0 - 3 See scoring mechanism	Default score "0"	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Soil movement potential	Slide area		GIS	Yes/No		

Appendix A
Data Dictionary

Variable	Phase 1 data	Phase 2 data	Source	Comments/Scoring method	Default Scores	Additional Comments
Atmospheric type score	Atmospheric characteristics		Scoring mechanism	SME to identify critical areas - default "2" if no information	Default "2"	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Criticality of supply	Interruptible customers		Industrial meters	Yes for Firm - No for an interruptible customer		This data comes from whether the customer is billed as an “Interruptible Customer” (No) or a “Firm Customer” (Yes). There are only 656 interruptible customers in PSE’s service territory
Isolated CP services	Ind/SVC		SAP - object type GDUT110	Yes/No		
CP system scoring	CP test sites		SAP - object type GDUT100 & GDUT140	Scoring mechanism (1 - 10)		The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Third party damages	Hit rate		LMS	Number of third party hits per plat annually		
Third party activity level	Growth rate		TESP	Growth percent annually by op map		
Cover attributes	Hard surface/Non hard surface		Maintenance Programs Leak Survey of Business districts	Yes/No		This data comes from the business district leak survey records where a business district is defined as an area where the facilities are under wall to wall paving. If the service is located within a business district it was given a “Yes” if the service is not on the business district leak survey then it was given a “No”.
Depth of cover	Service line depth		EPCR or default score	EPCR recorded depth or default to 12"	Default score 12"	

Appendix A
Data Dictionary

Variable	Phase 1 data	Phase 2 data	Source	Comments/Scoring method	Default Scores	Additional Comments
Population density	High occupancy		Maintenance Programs HOS leak survey data and Critical valve inspection data	High density/Low density		Population Density (BD/HOS/IDS/HOS-IDS/LOW): This score is based on the high occupancy structure (HOS) leak survey database, the business district (BD) database, and the critical service valve inspection database. Where an HOS is defined as a building or outside area that is occupied by 20 or more persons on at least 5 days a week for 10 weeks in any 12-month period. A critical service valve is defined as a service to facilities occupied by persons who are confined, are of impaired mobility, or would be difficult to evacuate, this is noted in this column as IDS (identified site). An HOS-IDS score in this column indicates that the service is to a structure that meets the definition of both HOS and critical service valve. LOW in this column indicates lower population density typically for residential areas and low occupancy structures.
Active service leak	Unknown service leak		LMS active leaks	Yes/No by address		
Air-soil interface	Pre 1966/post 1966		Maps/records by installation date	Pre 1966 (Yes) Post 1966 (No)		Quality of tape wrap method at MSA. Based on historical standards indicating that prior to 1966 tape wrap only was required, post 1966 primer and tape wrap were required.
Repaired corrosion service leaks by plat	Historical service leakage		LMS by plat map	Total number per plat		
Repaired service leak	Service leakage		LMS by service address	Yes/No		Leak clamp or other method of repair
Atmospheric protection score	Field coatings for aboveground pipe and fittings.		PSE Standards	NA	Default score 2.5	Based on the assumption that services identified within this scope have had a primer coat and an enamel top coat applied.

Appendix A
Data Dictionary

Variable	Phase 1 data	Phase 2 data	Source	Comments/Scoring method	Default Scores	Additional Comments
Coating condition	Service coating condition		EPCR or default score	EPCR scoring mechanism or default to 6	Default score 6	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Internal corrosion	LP services		Maps/records	LP (Yes) IP or HP (No)		
Prior Atmospheric condition score		Atmospheric corrosion	Meter Network service	1 - 3 score by address		Currently not part of model. Scheduled for Phase 2. Prior #3 corrosion rating could have paint over pitted surface
Current Atmospheric score		Atmospheric corrosion	Meter Network service	1 - 3 score by address		Currently not part of model. Scheduled for Phase 2.
Surface pitting depth score	Surface corrosion		EPCR or default score	Pit description score mechanism or default to 6	Default score 6	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Surface pitting frequency score	Surface corrosion		EPCR or default score	Pit description score mechanism or default to 6	Default score 6	The scoring mechanism explanation is located in Appendix B – Risk Assessment Model
Pipe SMYS	Default score 30,000 psi		Construction standards	N/A	Default score of 30,000 psi	
Introduction of potential corrosive agents		Internal Corrosion: Yes/ No	SME			
Low spots		Yes/No	SME	EPCR		GIS
Joint type		Weld/mechanical coupling	D4			
DCVG	No data at this time	Survey data				Survey database

Appendix A
Data Dictionary

Variable	Phase 1 data	Phase 2 data	Source	Comments/Scoring method	Default Scores	Additional Comments
CIS	No data at this time	Survey data				Plats, D4, SAP, LMS, EPCR (pipe and CP)
Casings	No data available	Service casings	D4			D4, SAP

Appendix B – Risk Assessment Model

PSE Risk Assessment Model
for
Wrapped Steel Service Assessment Program

Rev. 4.0

September 2006

WKM Consultancy, LLC

1. Measuring Exposure Level

The concept of measuring a threat as if there was absolutely no mitigation applied is a part of this process and is probably a new idea to most. It requires a bit of imagination. For example, in the case of third party damage in a rural area, one must envision the pipeline in an unmarked ROW (actually indistinguishable as a ROW), with no one-call system, no public education, and buried with only a few millimeters of cover. Then, a 'hit rate' is estimated—how often would such a pipe be struck by nearby utility work, homeowner activity, new construction, agricultural equipment, etc.?

This exercise is actually very illuminating in that it forces one to recognize the inherent threat exposure without the often taken-for-granted role of mitigation. A facilitated meeting with historical data and SME's is the recommended method of finalizing most exposure values for time-independent threats.

A brief discussion of some assigned exposure rates for the current risk assessment follow:

> Third party damage rate: total incidences per plat range from 0 to 2. A base hit rate of 1.0 is assumed. This implies that, in an unmitigated environment, each service per plat would be damaged by a third party once every year. This value is multiplied by (historical hit rate of the corresponding plat) + 1. The resulting range of exposures is 1 to 3 'hits' per year.
>
> Soil movement potential (yes/no): all rated 'no' in this op map, so no distinction among services. In the current assessment, the accumulation of all geotechnical threats are assigned a default value of 0.0001 failures per year for each service. This suggests one annual failure for each 10,000 services and is very conservative since actual failure rates are much lower.
>
> For time-dependent threats, mpy values for corrosion and cracking are used. These can be set using published values and/or engineering analysis of specific environmental and metallurgical factors. An unmitigated threat level is first measured—the aggressiveness of soil corrosion, atmospheric corrosion, crack growth rate under assumed loadings, etc. Then all mitigation measures are independently considered.

<u>Assumptions in Assignment of Exposure Levels</u>

1. All services have some atmospheric exposure
2. Human error potential not yet included in model
3. Geotechnical exposure is currently default

2. Measuring Mitigation

Each mitigation measure is assigned a maximum effectiveness, indicating that factor's ability to independently reduce the exposure that would otherwise occur. The maximum effectiveness levels are judged by envisioning the mitigation being 'performed' as well as can be envisioned. For example, the model reflect the belief that "depth of cover", when done as well as can be envisioned, can independently remove almost all threat of third party damage. It is a variable that can theoretically mitigate 99% of the third party damage exposure. If buried deep enough, there is very little chance of third party damage, regardless of any other mitigative actions taken. "Public Education" on the other hand, is recognized as an important mitigation measure but the model reflects the belief that, independently, it cannot be as effective as depth of cover in preventing third party damages. Some currently assigned mitigation effectiveness values are shown in Table 1.

Table 1: Mitigation Effectiveness Values

Mitigation Measure	Description of Best Case	Max Mitigation Benefit
Depth of cover	80” or more of earth or equivalent pavement	99%
Signs/markers	easily and readily identified as buried utility location; visible from any possible dig site; redundancy in case of lost markers	50%
Public Education	Extremely robust program involving many media	20%
Line Locate	Strict and conservative procedures; extensive training, redundancy	50%
One-call	The most effective system: mandated and enforced by law; exceptionally well communicated, etc.	85%
Patrol	24/7 surveillance	90%
Cathodic Protection	Complete coverage with certainty; verified continuously	99%
Coating	Perfect barrier from electrolyte	90%

In the case of time-independent failure mechanisms, the percentage implies the proportion of exposures that do not reach the pipe because of the mitigation. To capture the reality of orders of magnitude spans in failure probability, the mitigation percentage is applied to a logarithmic span.

In the case of time-dependent mechanisms, the percentage is applied to the modeled metal loss rate, mpy.

<u>Assessment Rules: Corrosion</u>

Cathodic Protection (CP) (Scoring Tables E-5, E-7, E-8, E-8a)

- If active leak, then CP = 0% effective (until root cause analysis)
- If EPCR pitting, then CP = 0% effective (until root cause analysis)
- If IND/SVC, then CP effectiveness reduced by 50%.
- If service is off of STW main and not IND/SVC, then CP effectiveness is determined by scoring the CP system that the service is electrically continuous with in accordance with the scoring method in Tables E-7, E-8, and E-8a. These scores are then added together to achieve a CP effectiveness score ranging from 0 to 10 points for each service.
- If service off ST, PE or CI which are not IND/SVC are assumed to have no CP then CP = 0% effectiveness

Coating (Scoring Tables E-2, E-4, E-6, E-10)

- If active leak, then coating effectiveness = 0% (until root cause analysis)
- If EPCR pitting, then coating = 0% effective (until root cause analysis)
- If EPCR evaluation done, use table E-10a where BON = 95% effective coating
- Otherwise, use date to infer coating type to infer condition (Scoring Table E-2) for soil exposures
- Use date to infer protocol and effectiveness of atmospheric corrosion prevention (Scoring Table E-4)

EPCR information is a key part of the current assessment. Since there are apparent inconsistencies in data gathering on EPCR’s, several checks are performed to ensure conservative interpretations are made. If any pit depth was noted or any pit frequency was noted, then CP and coating were both assessed at 0%, even when coating was noted as ‘bonded’.

Scoring rules (modified in 6-9-06 meeting) related to use of EPCR data include:

- EPCR data from service: all pertinent data utilized.
- EPCR data from main: Do not utilize depth of cover. Service depth defaults to 12".
- EPCR data from main: Coating condition of main should not be used for service. Coating for service should be N/A
- EPCR data from main: Pitting depth and pitting frequency data shall be used for service score.

A higher incidence rate (per plat range of 0 to 14) of corrosion leak repairs reduces mitigation effectiveness by up to 20% in proportion to plat leak count.

Cover: business districts are assumed to have 'wall-to-wall' pavement. Pavement is modeled as having the same benefit as an additional 12" of cover. If under 'wall-to-wall' pavement service is assumed to be mostly in ROW where depth of cover is 18". Pending depth of cover information (to be extracted from EPCR's), a default of 12" is used. Therefore, possible cover values under the current protocols are either 12" or 30".

Other mitigation measures against third party damage are used in the assessment as described below:

<u>Signs/markers</u>: this variable is not yet used, might be appropriate only for rural areas mains and transmissions. 0% benefit assigned in current assessment.
<u>Public education</u>: defaulted to 20% of best possible program.
<u>Locating and marking protocols</u>: defaulted to 20% of best possible program.
<u>One-call effectiveness</u>: defaulted to 20% of best possible program.
<u>Patrol</u>: might be appropriate only for rural areas with mains and transmissions: possible credit for informal observations; defaulted to 10% of best possible program.

No mitigations included yet for geotechnical issues.

<u>Assumptions Underlying Mitigation Measure Assessments</u>

1. Active leaks or previous damage indicate conditions conducive to corrosion <u>and</u> breakdown of corrosion control mechanisms. Even though usually very localized, this will be evidence of failed mitigation until root cause analysis and appropriate follow-up actions prove otherwise.
2. All active leaks and pitting are on buried portions—no atmospheric damages.
3. High repair rate suggests more aggressive corrosivity and/or weakened mitigation systems, until a root cause analysis removes this penalty.
4. EPCR inspection of one point on service reflects conditions on entire service
5. Ignore apparent inconsistencies when, in EPCR, pitting or surface rust noted, but coating shown as 'bonded' (bonded is otherwise interpreted to mean 'good condition').
6. Maximum benefits have not yet been verified by PSE SME's and should be considered preliminary only.
7. Default values assigned are preliminary and not yet verified by PSE SME's.

3. Measuring Resistance

Resistance, as previously defined, is measured according to the rules discussed here.

- When a service has multiple diameters, the smallest diameter with the thinnest wall is used.
- Wall thicknesses are inferred from date of construction and service diameter (Scoring Table E-13)

- D/t is the ratio of diameter to wall thickness and is a rough measure of the structural strength of the pipe as a beam—its ability to withstand external forces. A simple proportional relationship is used to show up to a 20% benefit.
- Casing: no casing locations are currently identified. Once input into the model, these locations will show greatly increased external force resistance. They will also show increased chance of ineffective CP, in the assessment of corrosion potential.
- Stress level: lower stress levels suggest more resistance to external forces, currently modeled to a maximum benefit of 20% when stress is very low, as is the case for service lines.
- For external loadings, a wall thickness of 0.3" or more warrants an 80% resistance to external resistance and 0.1" or less warrants no resistance. Values in between are proportional.
- For available wall to resist time-dependent mechanisms, Final wall thickness estimate is based on:

  If active leak, then wall = 0"
  Otherwise, larger of
  - wall required for NOP (minimum of 0.01"),
  - wall at last pressure test minus wall loss since;
  - wall at last inspection minus wall loss since.

  minus the metal potentially lost before CP was applied (conservatively assumed to be 1972). This value is based on soil corrosivity and coating effectiveness (bare pipe has no mitigation).

Wall thickness potentially lost since last integrity verification (pressure test or robust inspection) is based on soil corrosivity and mitigation applied (CP and, in most cases, coating also). There are currently no integrity verifications applied to these services after their installation, so metal loss is based on time since installation.

The minimum of 0.01" for wall thickness estimate based on NOP is thought to be a reasonable minimum, even though strict application of the Barlow stress formula indicates that wall thickness could be less than 1 mil (0.001") for small diameter, low pressure pipe. While theoretically, less than 1 mil of wall could remain, it is thought that assuming 10 mils actually remain is still conservative and better reflects more probable conditions.

Adjustment factor based on possible strength-limiting manufacturing and construction issues, conservatively assumes the following limitations:

Table 2: Adjustment Factors

Issue	**Factor**
wrinkle bend	0.98
miter joint	0.98
injurious lamination	0.98
stress concentrator	0.95
seam	0.98
joint type	0.98

Since all could theoretically be present, overall adjustment factor is the product of all together for a value of 0.86. This means that only 86% of the previously-estimated available wall thickness is carried forward to the TTF calculation.

Assumptions Underlying Resistance Estimates

1. Soil corrosion and atmospheric corrosion are not additive at any location
2. No anomalies present at installation (but conservatively assume weaknesses—see adjustment factor).
3. Default values assigned are preliminary and not yet verified by PSE SME's.

4. Measuring Relative Consequences

Potential consequences from a service failure are estimated on a relative basis, based on two variables:

- Criticality of supply (yes or no, based on volume usage, assigned a value of 1 or 0.5)
- Population density (Scoring Table E-15)
- CoF = [criticality of supply] x [pop] and ranges from 1 to 11.

This is a large span, suggesting that real consequences can vary widely.

5. Conservatism

This analysis intentionally contains many layers of conservatism. This is done to encourage data collection and to protect the model's credibility. Sources of conservatism include:

- Assuming smallest diameter, thinnest wall
- Using historical incidence rates without adjusting for relevance
- Assuming observed poor conditions still exist, although permanent repairs were the norm.
- Using very aggressive corrosion rates
- Assuming no mitigation benefit for entire service when evidence shows only a single location has reduced mitigation (active leak, previous repair).
- Assuming poor performance of older coatings and coatings of a certain type, even though, in the vast majority of cases, most coatings continue to perform very well.
- Large range of potential consequences, even though potential for larger consequence events is extremely small.
- Assuming weaknesses in pipe strength
- Choice of relationship in predicting PoF from TTF

Less conservative assumptions are sometimes needed for practical reasons. For instance, a defect as much as 95% through a pipe wall could exist and not be leaking under normal internal pressures. It would be counter-productive to assume that such rare defects exist everywhere, even though such as assumption would be very conservative. Rather, the wall thickness implied by a Barlow stress calculation is used as the primary means to estimate the probable—and still conservative—wall thickness when no other confirmatory integrity information is available.

6. Specific Variables and Algorithms

Table 3: Calculated values from risk assessment model

Category	Variable	Calculation	Notes
Summary	Risk	=PoF*CoF	Overall risk value; can be monetized units

Appendix B
Risk Assessment Model

Category	Variable	Calculation	Notes
Summary	PoF	=1-(1-TTF-PoF)*(1-ThdPty)*(1-Geotech)	OR gate to combine individual threats
Summary	CoF	=IF([critical svc]="yes",2,1)*(11-[pop])	
Summary	TTF-PoF	See below	
Summary	Geotech	0.0001	default
Summary	ThdPty	See below	
TTF	psig	60	Fetch from database; Fixed
TTF	dia	=IF(diameter=34,0.75,IF(diameter=12,0.5,IF(diameter =114,1.25,IF(diameter=58,0.64,1))))	Convert text series into a numerical diameter; note default is 1” when multiple diameters listed
TTF	wall	=wall thickness	Fetch data from database
TTF	wall - man tol	=wall*0.92	Not currently used
TTF	SMYS	30000	Specified min yield stress;; Fetch from database
TTF	test press	90	Fetch from database; fixed
TTF	test date	=test date	Installation date
TTF	%SMYS press test	=[test press]*dia/(2*wall*SMYS)	Barlow formula
TTF	min wall def	=wall-(wall*(1-%SMYS/1.1))	Wall after max defect depth; not currently used
TTF	date	=[insp date]	Date of last inspection
TTF	anom depth (%)	=IF(ISBLANK([EPCR pit depth]),0,VLOOKUP([EPCR pit depth],[table E-11 value],2,FALSE))	From EPCR reports
TTF	min wall	=IF(date=0,0,wall*(1-[anomaly depth %]))	Wall after pit depth subtracted
TTF	ext corr atm	=VLOOKUP([atm type],[table E-3],2,FALSE)*(1-[coating atm])	Estimate of atmospheric corrosion
TTF	ext corr soil	=IF([soil corrosivity score],[table E-1])*(1-[mit (soil))	Estimate of soil corrosion
TTF	int corr	=IF([int corr LP]="yes",[1 mpy],[1 mpy]/5)	Estimate of internal corrosion
TTF	cracking	0.1	Default
TTF	mpy (after coat mit)	=IF([coating type score]=0,1,[coating type score]/10)*IF(,[soil corrosivity score]=0,[10.7 mpy],[6.6 mpy])	Corrosion rate if only coating, no CP
TTF	years of no CP	=IF(DATE>1972,0,(1972-DATE))	Assume all lines have CP as of 1972
TTF	mils lost	=[years of no CP]*[mpy after coat mit]	Mils lost prior to application of CP
TTF	NOP wall	=IF([PSIG]*[DIA]/(2*[SMYS])<0.01,0.01,[PSIG]*[DIA]/(2*[SMYS]))	Min wall estimate based on NOP
TTF	press test minus mils lost	=[min wall]-[mils lostl]/1000-(2006-MAX(1972,[test datel]))*(MAX([ext corr soil]*(1-[mit soill])/1000,[ext corr atm]*(1-[mit atm])/1000)+([int corr]+[cracking])/1000)	Est wall based on last press test and mils lost since
TTF	Insp minus mils lost	=IF(date=0,0,[min wall]-[mils lostl]/1000-(2006-MAX(1972,date))*SUM([ext corr soil]:[cracking]:[int corr])*(1-[mit soil])/1000)	Est wall based on last inspection and mils lost since
TTF	final est wall	=IF([active leak]="No",MAX([NOP wall],[press test	If not leaking, then use maximum

Category	Variable	Calculation	Notes
		minus mils lost wall],[insp minus mils lost wall]),0)	of inferred wall thickness estimates
TTF	wall_adj	=[wrinkle bend]*[miter joint]*[lamination]*[stress concen]*[seam]*[joint type]	
TTF	wall_avail	=([final est wall]-[min wall at non-leaking NOP])*[wall_adj]	
TTF	TTF	=[wall_avail]*1000/SUM([ext corr soil]:[cracking]:[int corr])	
TTF	PoF_time	=IF(TTF<=0,0.999,1-EXP(-1/TTF))	Conservative relationship between TTF and year-one-PoF is assumed
TTF	min wall at non-leaking NOP	=[min wall for NOP (Barlow)]-[max def surviving at NOP]	
TTF	min wall for NOP (Barlow)	=[PSIG]*[DIA]/(2*[SMYS])	
TTF	max defect depth surviving at NOP	=([min wall for NOP]*(1-[max % SMYS at NOP])/1.1)	
TTF	max % SMYS at NOP	=[PSIG]/(2*P18)*[DIA]/[SMYS]	
TTF	wrinkle bend	0.98	Default
TTF	miter joint	0.98	Default
TTF	injurious lamination	0.98	Default
TTF	stress concentrator	0.95	Default
TTF	seam	0.98	Default
TTF	joint type	0.98	Default
TTF	mit (soil)	=[assessed mit (soil)]*[adj to mit from repair hist]	
TTF	adj to mit from repair hist	=1-([repaired corr leak count by plat]/14)*0.2	0.2 is max ‘penalty’ for previous repair history
TTF	assessed mit (soil)	=1-(1-[coating soil])*(1-CP)	
TTF	coating soil	See ‘assessment rules for corrosion’ in previous text paragraphs	
TTF	CP	See ‘assessment rules for corrosion’ in previous text paragraphs	
TTF	coating atm	=IF(ISNUMBER([svc year date]),IF([svc year date]<1966,4/10,7/10),0)	
Thd Pty	PoF	=10^((LOG(exposure)-LOG(10/10E-5)*([threat red)))	10/10E-5 establishes scale range of exposure
Thd Pty	Exposure (hit rate)	=[thd pty hit rate for plat] + 1	
Thd Pty	threat_red	=1-(1-mitigation)*(1-resistance)	
Thd Pty	resistance	=1-(1-[pipe_wall_nom])*(1-[D/t])*(1-casing)*(1-[stress %max])	OR gate all resistance variables
Thd Pty	pipe_wall_nom	=(1-(0.3-[nom wall])/(0.3-0.1))*80%	
Thd Pty	D/t	=(1-(IF([D/t-data]>=100,0,IF([D/t-data]<=25,1,([D/t-	

Category	Variable	Calculation	Notes
		data]-25)/75))))*20%	
Thd Pty	casing	=casing-data*100%	No casing info avail
Thd Pty	stress % max	=(1-[stress-data])*20%	
Thd Pty	pipe_wall_nom -data	=wall nom	
Thd Pty	D/t-data	=dia/[nom wall]	
Thd Pty	Casing-data	0	
Thd Pty	Stress-data	=[%SMYS]	
Thd Pty	mitigation	=1-(1-patrol)*(1-[one-call])*(1-locate)*(1-[pub ed])*(1-[signs/markers])*(1-cover)	OR gate all mitigation variables
Thd Pty	patrol	[assessed value]*[max benefit of mitigation]	
Thd Pty	one-call	[assessed value]*[max benefit of mitigation]	
Thd Pty	locate	[assessed value]*[max benefit of mitigation]	
Thd Pty	pub ed	[assessed value]*[max benefit of mitigation]	
Thd Pty	signs/markers	[assessed value]*[max benefit of mitigation]	
Thd Pty	cover	=IF([cover-data]<=6,0,IF([cover-data]>80,0.99,0.99*([cover-data])/(80-6)))	Set benefit based on scale parameters and data
Thd Pty	patrol	0.1	Default
Thd Pty	one-call	0.2	Default
Thd Pty	locate	0.2	Default
Thd Pty	pub ed	0.2	Default
Thd Pty	signs/markers	0	Default
Thd Pty	Cover-data	=IF([cover attribute hard surface]="Yes", 30, 12)	

7. Scoring Protocols

Threat Variables

Scoring Table E-1: Soil Corrosivity

Corrosivity Codes:	**Score**	**Soil Resistivity**	MPY (mils per year)
Not Corrosive	3	>20,000 Ohm.cm	1
Slightly Corrosive	2	10,000 - 20,000 Ohm.cm	5
Moderately Corrosive	1	3,000 - 10,000 Ohm.cm	10
Very Corrosive	0	< 3,000 Ohm.cm	16

Scoring Table E-2: Mainline Coating Type

Coating Type	**Score**
Bare	0
Unknown	0
Thermally-insulated without Primary Coating	0
Single-wrap PE Tape (line travel)	4
Asphalt (cold applied)	4
Double-wrap PE Tape Coatings (line travel)	5
Wax Coatings	6
Cold-applied PE tape with primer	6

Coal Tar Enamel (hot applied)	7
Liquid Polyurethane/Moisture cured liquid urethane Coatings	7
Hot Applied Tape (e.g. Tapecoat 20)	7
Cold- applied self priming PE tape	7
Extruded Polyethylene (e.g. Yellow Jacket)	8
Thermally-applied PE Powder	8
Thermally-applied metallic coatings (85% Zn/15% Al)	9
FBE	9
Liquid epoxy coating	9
Thermally-insulated with Primary Coating	9
Three-Layer Polyurethane Coatings	10

Scoring Table E-3: Atmospheric Type

Atmospheric Type	**Score**	mpy
Chemical & Marine	0	10
Chemical & high humidity	0.5	8
Marine, swamp, coastal	0.8	6
High humidity and high temperature	1.2	5
Chemical and low humidity	1.6	3
Low humidity and low temperature	2	1
No exposures	2	0.1

1. Atmospheric type: Reference Pipeline Risk Management Manual - Third Edition - W. Kent Muhlbauer

Scoring Table E-4: Atmospheric Coating Scoring

Installation year	**Score**
Unknown	0
1956 - 1965	4
1966 - 1972	7

1. Ref. Steel service history coating specifications
2. Measure of performance and reliability of wrap/coating used to prevent corrosion at air/soil interfaces.
3. Date of installation and SME experience used as surrogate for probable effectiveness in corrosion prevention/reduction.

Scoring Table E-5: CP System Performance by Gas Plat Map

CP System Performance by Gas Plat Map (0 - 10)
Good Performance: 8 - 10
Fair Performance: 5 - 7
Poor Performance: 0 - 4

1. CP System Scoring: See CP scoring legend. Scored all the systems within a plat and used the lowest (worst) score.

Scoring Table E-6: Field Joint/Fitting Coating Type

Coating Type	**Score**
Bare or Unknown	0

Thermally-insulated without Primary Coating	0
Single-wrap PE Tape	4
Asphalt (cold applied)	4
Double-wrap PE Tape Coatings	5
Cold-applied Liquid Mastic	6
Wax Coatings	6
Cold-applied PE tape with primer	7
Coal Tar Enamel (hot applied)	7
Liquid Polyurethane Coatings	7
Hot Applied Tape (e.g. Tapecoat 20)	7
Cold- applied self priming PE tape	8
Shrink Sleeves	8
Thermally-applied PE Powder	9
Liquid epoxy coating	9
Thermally-insulated with Primary Coating	9
Thermally-applied metallic coating	9
Field-applied FBE	9
No Oxide	10

Scoring Table E-7: CP Critical Bond Status

System Critically Bond Tested: 20%	
Variable	Score
Yes	2
No	0

Scoring Table E-8: Average CP Level

Average System CP Level: 30%	
Variable	Score
> -.950	3
> -.850 & < -.950	2
< -.850	0

Scoring Table E-8a: Average CP System Remediation Time

Average CP System Remediation Time: 50%

Variable	**Score**
No Remediation Required	5
< 30 days to remediate	3
> 30 & < 90 days to remediate	2
> than 90 days to remediate	0

1. System scoring to be validated through SME discussions with Corrosion Technicians.
2. Scored all the systems within a plat and used the lowest (worst) score.
3. Scores for separately protected services (IND/SVC) are penalized: 0.5 X CPS score.

4. All services off STW main and not IND/SVC are assumed to be protected by a CPS. All services off ST, PE or CI which are not IND/SVC are assumed to have no CP.

Scoring Table E-9: Internal Corrosion

Internal Corrosion LP Yes/No
0 = LP svc
1 = other than LP svc

1. Data from MRT main pressure field.
2. Low pressure services (LP) are assumed to be more susceptible to internal corrosion.

Exposed Pipe Condition Report Score

Scoring Table E-10: Coating Condition Score

Coating Descriptor	**Score**
Bonded	10
Cracked	8
Not filled out or "N/A"	6
Damaged	6
Missing or None	4
Disbonded	1

1. The coating condition description score will be assigned on the basis of the information filled out in the "Coating" field of the Exposed Pipe Condition Report.

Scoring Table E-10a: Coating Adhesion Score

Abrev used	**% effective**
BON	0.95
DAM	0.1
DIS	0

Scoring Table E-11: Pit Description Score

Pit Frequency Descriptor => / **Pit Depth Descriptor (Vertical)**	**No Pitting**	**Isolated Pits**	**Frequent Pits**	**No Original Surface Left**	
Not filled out or "N/A"	10	5	3	2	0.3
Surface Rust	10	7	4	3	0.1
Shallow Pits	6	5	3	2	0.3
Deep Pits	4	3	2	1	0.5

Scoring Table E-12

Pit Description	**Assumed % thru wall**

DP	0.5
non-blank	0.3
SP	0.3
SR	0.1

1. Scoring Table E-11 was converted to the above table to support more absolute quantification of available pipe wall. These values are used in the risk calculations for TTF.

Scoring Table E-13: Pipe Wall Thickness

Year	Service Sizes (inches)	Wall Thickness (inches)
1956	3/4	0.113
	1	0.133
	1 1/4	0.14
	1 1/2	0.145
	2	0.154
	3	0.216
	4	0.237
	6	0.25
1960	Same spec as 1956	Same spec as 1956
1966	1/2	0.109
	3/4	0.113
	1	0.133
	1 1/4	0.14
	1 1/2	0.145
	2	0.154
	4	0.188
1971	Same spec as 1966	Same spec as 1966
1972	1/2	0.035
	1/2	0.109
	3/4	0.113
	1	0.133
	1 1/4	0.14
	1 1/2	0.145
	2	0.154
	4	0.188
1977	Same spec as 1972	Same spec as 1972
1980	Same spec as 1972	Same spec as 1972
1986	1/2	0.109
	3/4	0.113
	1	0.133
	1 1/4	0.14
	1 1/2	0.145
	2	0.154
	4	0.188

1. Addresses with multiple sizes used smallest diameter.
2. The ones identified as 5/8 (plastic) the services had unknown size of steel; defaulted to smallest size pipe based on year.

Scoring Table E-14: Cover Attributes Hard Surface

Attribute	Score	Default depth cover	
In Business District (wall to wall paving)	yes	30	overriden if EPCR svc depth avail
not in Business District	no	12	overriden if EPCR svc depth avail

1. Data from Business District Leak Survey.

Scoring Table E-16
Third Party Mitigation

One-call effectiveness; locate; pub ed				
hard surface	one-call	locate	pub ed	
yes	0.7	0.7	0.8	permits required
no	0.2	0.2	0.2	

Based on SME discussions: "In R/W (paved surface) one calls were made 90% of the time. Homeowners (non paved) one calls were made 45% of the time."

Table E-17

LUT for CIS survey results:	
CIS Severity	**% CP effectiveness**
Acceptable CP	100.00%
Minor Indications	95.00%
Moderate Indications	50.00%
Severe Indications	0.00%
Minor indication aligns with DCVG	50.00%
Moderate indication aligns with DCVG	10.00%
Severe indication aligns with DCVG	0.00%

Notes:
Adopted CIS threshold criteria is -850 mV instant off.
Minor Indications: Isolated locations where the potential drops are small relative to adjacent areas, however the potential is maintained above the established threshold criteria.
Moderate Indications: Isolated locations where potential does not meet the established threshold criteria, and the dip below that criterion is small.
Severe Indications: Isolated locations where potential does not meet the established threshold criteria, and the dip below that criteria is large. Otherwise, a generalized area over which the potential does not meet the established threshold criteria.

Table E-18

LUT for DCVG survey results:	
DCVG Severity	**% Coating effectiveness**
No Indications	100.00%
Minor Indications <=15% IR	90.00%
Moderate Indications >15% to <=60% IR	50.00%
Severe Indications > 60% IR	0.00%

Consequence Variables

Scoring Table E-15: Population Density

Factor	Score
LOW=Low population density	10
IDS=Identified Site	6
HOS=High Occupancy Structure	3
HOS-IDS=High Occupancy Identified Site	2
BD=Business District	0

1. These values are subtracted from 11 since the model requires higher consequences to be higher numerical values.

8. Discussion of Modeling Approach

The following paragraphs discuss some of the features of the model used in this application. Specifically, the features that are a departure from previous ranking or scoring approaches are highlighted here.

Risk Triad

The basis for this model is an examination of each failure mechanism (threat) in three parts for:

- Exposure (unmitigated),
- Mitigation effects, and
- Resistance to failure.

These three elements make up the Risk Triad, for evaluating probability of failure (PoF). They are generally defined as follows:

- Exposure = likelihood of force or failure mechanism reaching the pipe when no mitigation applied,
- Mitigation = actions that keep the force or failure mechanism off the pipe, and
- Resistance = the system's ability to resist a force or failure mechanism applied to the pipe.

The evaluation of these three elements for each pipeline segment results in a PoF for that specific segment.

An intermediate level, termed "Probability of Damage"—damage without immediate failure—also emerges from this approach. Using the first two terms without the third—exposure and mitigation, but not resistance—yields the probability of damage.

- Probability of Damage (PoD) = *f* (exposure, mitigation)
- Probability of Failure (PoF) = *f* (PoD, resistance)

This avoids a point of confusion sometimes seen in previous assessments. Some older models are unclear as to whether they are assessing the likelihood of damage occurring or the likelihood of failure—a subtle but important distinction since damage does not always result in failure. Calculation of both PoD and PoF values creates an opportunity to gain better understanding of their respective risk contributions.

This three part assessment also helps with model validation and most importantly, with risk management. Fully understanding the exposure level, independent of the mitigation and system's ability to resist the failure mechanism, puts the whole risk picture into clearer perspective. Then, the role of mitigation and system vulnerability are both known independently and also in regards to how they interact with the exposure. Armed with these three aspects of risk, the manager is better able to direct resources more appropriately.

9. Model Features

Other characteristics of this model distinguish it from previous risk assessment approaches and include the following.

<u>Measurement Scales</u>

Mathematical scales that simulate the logarithmic nature of risk levels are employed to fully capture the orders-of-magnitude differences between "high" risk and "low" risk. The new scales better capture reality and are more verifiable—to some extent, at least. Some exposures are measured on a scale spanning several of orders of magnitude—"this section of pipeline could be hit by excavation equipment 10 times a year, if not mitigated (annual hit rate = 10)" and "that section of pipeline would realistically not be hit in 1000 years (0.001 annual hit rate)."

The new approach also means measuring individual mitigation measures on the basis of how much exposure they can independently mitigate. For example, most would agree that "depth of cover", when done as well as can be envisioned, can independently remove almost all threat of third party damage. As a risk model variable, it is theoretically perhaps a variable that can mitigate 95-99% of the third party damage exposure. If buried deep enough, there is very little chance of third party damage, regardless of any other mitigative actions taken. "Public Education" on the other hand, is recognized as an important mitigation measure but most would agree that, independently, it cannot be as effective as depth of cover in preventing third party damages.

Improved valuation scales also means a more direct assessment of how many failures can be avoided when the pipeline is more resistant or invulnerable to certain damages.

<u>Variable Interactions</u>

This model uses combinatorial math that captures both the influences of strong, single factors as well as the cumulative effects of lesser factors. For instance, 3 mitigation measures that are being done each with an effectiveness of 20% should yield a combined mitigation effect of about 49%. This would be equivalent to a combination of 3 measures rated as 40%, 10%, and 5% respectively, as is shown later. In other cases, all aspects of a particular mitigation must simultaneously be in effect before any mitigation benefit is achieved. An example is high patrol frequency with low effectiveness or a powerful ILI but with inadequate confirmatory investigations.

These examples illustrate the need for OR and AND "gates" as ways to more effectively combine variables. Their use eliminates the need for "importance-weightings" seen in many older models.

The new approach also provides for improved modeling of interactions: for instance, if some of the available pipe strength is used to resist a threat such as external force, less strength is available to resist certain other threats.

Meaningful Units
The new model supports direct production of absolute risk estimates. The model can be calibrated to express risk results in consistent, absolute terms: some consequence per some length of pipe in some time period such as "fatalities per mile year." Of course, this does not mean that such absolute terms must be used. They can easily be converted into relative risk values when those simpler (and perhaps less emotional) units are preferable. The important thing is that absolute values are readily obtainable when needed.

10. Mathematics
Orders of Magnitude
As noted, logarithmic scales are used to better characterize the range of failure probabilities. This is a departure from how most older scoring models approach risk quantification. It is a necessary aspect to properly mirror real-world effects and express risk estimates in absolute terms.

Since logarithms are not a normal way of thinking for most, a more intuitive substitute is to speak in terms of orders of magnitude. An order of magnitude is synonymous with a factor of 10 or "10 times" or "10X." Two orders of magnitude means 100X, and so forth, so an order of magnitude is really the power to which ten is raised. This terminology serves the same purpose as logarithms for the needs of this model. So, a range of values from 10E2 to 10E-6 (10^2 to 10^{-6}) represents 8 orders of magnitude (also shown by: log(10E2) – log(10E-6) = 2-(-6) = 8). This PoF model measures most mitigation effectiveness and resistance to failure in terms of simple percentages. The simple percentages apply to the range of possibilities: the orders of magnitude. So, using an orders of magnitude range of 8, mitigation that is 40% effective is reducing a an exposure by 40% of 8 orders of magnitude which has the effect of reducing PoF by 3.2 orders of magnitude. For example, if the initial PoF was 0.1—the event was happening once every 10 years on average—it would be reduced to $0.1 / 10^{(40\% \times 8)} = 0.1 / 10^{3.2}$ = 6.3E-5. The mitigation has reduced the event frequency by over 1000 times—only one in a thousand of the events that would otherwise have occurred will occur under the influence of the mitigation.

Numbers for mitigated PoF will get very, very small whenever the starting point (unmitigated PoF) is small: 1000 times better than a "1 in a million" starting point is very small; 1000 times better than a "1 in a 100" starting point is not so small. See also mitigation.

It might take some out of their comfort zone to begin working with numbers like this. If so, relative scales are easily created to be surrogates for the complex numbers. However, having access to the complex—and more correct—values at any time will add greatly to the risk model's ability to support a wide range of applications.

Creating a correct range of orders of magnitude for a model is part of the tuning or calibration process.

AND gates OR gates
The probabilistic math used to combine variables to capture both the effects of single, large contributors as well as the accumulation of lesser contributors is termed "OR" & "AND" "gates." Their use in pipeline risk assessment modeling represents a dramatic improvement over most older

methods. This type of math better reflects reality since it uses probability theory of accumulating impacts to:

- Avoid masking some influences;
- Captures single, large impacts as well as accumulation of lesser effects;
- Shows diminishing returns;
- Avoids the need to have pre-set, pre-balanced list of variables;
- Provides an easy way to add new variables; and
- Avoids the need for re-balancing when new info arrives.

<u>OR Gates</u>
OR gates imply independent events that can be added. The OR function calculates the probability that any of the input events will occur. If there are *i* input events each assigned with a probability of occurrence, P_i, then the probability that any of the *i* events occurring is:

$$P = 1 - [(1-P_1) * (1-P_2) * (1-P_3) * \ldots *(1-P_i)]$$

OR Gate Example:
To estimate the probability of failure based on the individual probabilities of failure for stress corrosion cracking (SCC), external corrosion (EC) and internal corrosion (IC), the following formula can be used.

$$\begin{aligned} P_{failure} &= OR[P_{SCC}, P_{EC}, P_{IC}] = P_{SCC} \text{ OR } P_{EC} \text{ OR } P_{IC} \\ &= OR\ [1.05E\text{-}06, 7.99E\text{-}05, 3.08E\text{-}08] \\ &= 1 - [(1-1.05E\text{-}06)*(1-7.99E\text{-}05)*(1-3.08E\text{-}08)] \\ &= 8.10E\text{-}05 \end{aligned}$$

The OR gate is also used for calculating the overall mitigation effectiveness from several independent mitigation measures. This function captures the idea that probability (or mitigation effectiveness) rises due to the effect of either a single factor with a high influence or the accumulation of factors with lesser influences (or any combination).

$$\begin{aligned} \text{Mitigation \%} &= M_1 \text{ OR } M_2 \text{ OR } M_3\ldots.. \\ &= 1 - [(1-M_1) * (1-M_2) * (1-M_3) *\ldots\ldots..*(1-M_i)] \\ &= 1 - [(1-0.40) * (1-0.10) * (1-0.05)] \\ &= 49\% \end{aligned}$$

or examining this from a different perspective,

Mitigation % = 1 – [remaining threat]
Where remaining threat = [(remnant from M_1) AND (remnant from M_2) AND (remnant from M_3)] …

<u>AND Gates</u>
AND gates imply “dependent” measures that should be combined by multiplication. Any sub-variable can alone have a dramatic influence. This is captured by multiplying all sub-variables together. For instance, when all events in a series will happen and there is dependence among the events, then the result is the product of all probabilities. In measuring mitigation, when all things have to happen in concert in order to gage the mitigation benefit, this means a multiplication—therefore, an AND gate instead of OR gate. This implies a dependent relationship rather than the independent relationship that is implied by the OR gate.

AND Gate Example:
Here, the modeler is assessing a variable called "CP Effectiveness" (cathodic protection effectiveness) where confidence in all sub-variables is necessary in order to be confident of the CP Effectiveness—[good pipe-to-soil readings] AND [readings close to segment of interest] AND [readings are recent] AND [proper consideration of IR was done] AND [low chance of interference] AND [low chance of shielding] . . . etc. If any sub-variable is not satisfactory, then overall confidence in CP effectiveness is dramatically reduced. This is captured by multiplying the sub-variables.

When the modeler wishes the contribution from each variable to be slight, the range for each contributor is kept fairly tight. Note that four things done pretty well, say 80% effective each, result in a combined effectiveness of only ~30% (0.8 x 0.8 x 0.8 x 0.8) using straight multiplication.

TTF

This represents the time period before failure would occur, under the assumed wall loss and available strength assumptions. TTF = 1 / [(available pipe wall) - (wall loss rate) x (1-mitigation effectiveness)]. For these time-dependent mechanisms, TTF is an intermediate calculation leading to a PoF estimate.

A new integrity inspection can "reset the clock" for this calculation as can any new information that would lead to a revised wall thickness estimate.

From TTF to PoF

The PoF is calculated as the chance of one or more failures in a given time period. The degradation rate is assumed to be occurring everywhere simultaneously. Therefore, the number of degradation points in a segment does not theoretically impact the estimate. In reality, there is an uncertainty associated with each degradation estimate and larger segments will have more possible degradation points and increased chance of outliers—locations having larger than estimated degradation rates. The calculated probability assumes that at least one point in the segment is experiencing the estimated degradation rate and no point is experiencing a more aggressive degradation rate.

The relationship between TTF and year one PoF is an opportunity to include segment length as a consideration, at the modeler's discretion. A relationship that shows increasing PoF as segment length increases is defensible since the longer length logically means more uncertainty about consistency of variables and more opportunities for deviation from estimated degradation rates.

The PoF calculation estimates the time to failure, measured in time units since the last integrity verification, by using the estimated metal loss rate and the theoretical pipe wall thickness and strength. It is initially tempting to use the reciprocal of this days-to-failure number as a leak rate—failures per time period. For instance, 1800 days to failure implies a failure rate of once every (1800/365) = 4.9 years or 1/(1800/365) = 0.202 leaks per year. However, a logical examination of the estimate shows that it is not really predicting a uniform leak rate. The estimate is actually predicting a failure rate of ~0 for 4 years and then a nearly 100% chance of failure in the fifth year.

Some type of exponential relationship can be used to show the relationship between PoF in year one and TTF. The relationship: PoF = 1-EXP(-1/ TTF) where PoF = (probability of failure, per mile, in year one) produces a smooth curve that never exceeds PoF = 1.0 (100%), but produces a fairly uniform probability until TTF is below about 10 (i.e., a 20 yr TTF produces ~5% PoF). This does not really reflect the belief that PoF's are very low in the first years and reach high levels only in the very last years of the TTF period. The use of a factor in the denominator will shift the curve so that PoF values are more representative of this belief. A Poisson relationship or Weibull function can also better show this, as can a relationship of the form PoF = 1 / (fctr x TTF^2) with a logic trap to prevent PoF from exceeding 100%. The relationship that best reflects real world PoF for a particular assessment is difficult if not impossible to determine. Therefore, the recommendation is to choose a relationship that seems to best represent the peculiarities of the particular assessment, chiefly the uncertainty surrounding key variables and confidence of results. The relationship can then be modified as the model is tuned or calibrated towards what is believed to be a representative failure distribution.

11. Calibration of Risk Assessment

The risk assessment model is calibrated or 'tuned' to produce results that are consistent with beliefs about the real failure probabilities. Such beliefs are normally based on historical experience, tempered by knowledge of changing factors. The process of calibrating PSE's STW risk assessment begins with establishing plausible future leak rates based on relevant historical experience. These rates become 'targets' for risk assessment outputs, with the belief that large populations of services, over long periods of time, would have their overall failure estimates approach these targets. The risk assessment model is then adjusted so that its outputs do indeed approximate the target values.

The steps employed to calibrate the risk assessment results are generally described below:

1. Review of results of application of model to all PSE STW services (provided by PSE after equations were loaded into Oracle SQL and run against all STW lines).
    - Produce various correlations, calculate summary statistics, perform rough sensitivity analyses
2. Determine Benchmark Leak Rates
    - Gather failure history data
    - Filter for services, material types, failure causes
    - Gather pipeline inventory (count of services) by year
    - Extract date of installation for STW services
    - Compile list of date of installation for STW (Linda Johnson spreadsheet)
    - Compare installation date counts
    - Correlate pipeline inventory, installation date, and leak counts
    - Calculate leak rates per year
    - Calculate average leak rates
3. Make adjustments to model to fit expected targets
    - For each failure mechanism, perform trial and error process of adjusting exposure, mitigation, and resistance levels to not only approach targets, but to also remain consistent with originally established engineering judgments

<u>Risk Model Sensitivity Analysis</u>

As a rough sensitivity analysis on risk results (two sets—overall STW and Ops Map 188086), the following steps were taken:

<u>Review PSE System-wide data</u>

1. Create database from received spreadsheets of risk calculations (received information was for STW services and contained summary risk calculations and the underlying input data. Intermediate risk calculations not included. ~100K records.)

2. Create queries to calculate summary statistics for summary risk variables while grouping by characteristics such as: EPCR, pipe wall thicknesses, service year, etc. as shown in Appendix K.
3. Create histograms of summary values to evaluate the pattern of results. Some of these histograms (tabulated values only) are shown in Appendix K. All can be found in the mdb database produced as part of this project.

Many queries were built to investigate model performance. By inspection, the model calculations are performing as expected. That is, behavior of various statistics depending on group, are consistent with underlying beliefs. Given the complex nature of some of the calculations and interactions among variables, a simple inspection is not very revelatory, however. More thorough checking is recommended prior to potentially expensive reliance on model results.

See Appendix K for results of many of the summary statistics queries and what such summaries suggest about the model performance.

Review Ops Map s188086 data

1. Migrate spreadsheets into database
2. Queries to link all data together in database
3. Extract various variables for correlation analyses

12. Leak History Correlations

Leak data provides a means of better understanding the leak potential. PSE reports that significant changes to leak detection and reporting occurred in 1992. The data provided reflects this, with data from periods prior to 1992 appearing highly suspect. In 1992, there were 900+ leaks (on steel) while in every previous year, there were less than 10. This same pattern is seen for all other pipe material types.

Using values provided by PSE on inventory of STW services per year and historical leak counts, an overall annual leak rate on STW services is estimated to be 0.461%. The overall (from all causes) historical leak rate of 0.46% suggests about one leak each year for every 220 STW service lines. It is recognized that the historical data is neither complete nor sufficient for high confidence in estimates, due to issues such as:

- Repairs with no cause stated
- Repairs with cause noted as “other”
- Unrepaired (active leaks probably under-reported in data received)
- Changes in construction/operating/maintenance practices during the period

Using an overall annual leak rate of 0.46% along with the reported leak causes, produces leak rates by cause, as shown in the table below.

Cause	Leak count since 1992	Cause fraction	Leak rate from cause
corr	4210	30%	0.1363%
thd pty	3351	24%	0.1085%
natural causes	1538	11%	0.0498%
operator caused	138	1%	0.0045%

material defect	598	4%	0.0194%
constr defect	957	7%	0.0310%
other/unkn	3423	24%	0.1108%
		100%	
corr + unkn	7633	54%	0.2471%
historical leak rate, STW, all causes			0.461%

See calculations in spreadsheet [results3.xls] for details.

It would be interesting to view Risk or PoF scores grouped by Ops Map and compared to leaks grouped by Ops Map. However, there was no Ops Map reference included with leak data, so can't make this comparison. There are over 13,000 plats in leak data alone, so not useful to do a similar grouping by plat.

Initial third party PoF estimates produced by the risk model are within a factor of 2 (higher—more conservative than historical) of historical rates—0.2% overall average for Ops Map 188086 versus 0.11% suggested by leak database. If some of the 'unknown' causes include third party, the values would be even closer.

The model is not yet set up for assessment of failures from other mechanisms of material defects, natural causes, construction defects, and operator-caused, so no calibration can be done for those failure mechanisms.

Based on the above analyses, the results of the uncalibrated risk assessment appear to be overstating PoF-TTF levels by an average of about 100 times. Target annual failure probabilities for tuning the PoF-TTF estimates should be in the range of 0.14 to 0.25%. Uncalibrated results for Ops Map 188086 were averaging about 26% (including values of 99% for active leaks).

13. Model Tuning

The model is 'tuned' to produce results approximating the target values, by adjusting one or more of the following model components:

- Exposure
- Mitigation
- Resistance

The current version of the risk model produces estimates for failure modes of corrosion/cracking and third party damage, only. Initial third party PoF estimates are reasonably close and conservatively overstate historical rates, so no calibration of that portion of the model has been done. Changes to the pipe adjustment factor might impact the resistance portion of the third party estimate if a future version of the model uses effective pipe wall instead of the nominal pipe wall.

Since corrosion, as measured by PoF-TTF has caused possibly 54% of all historical failures and since the initial estimates of PoF-TTF overshadows all other contributors to the PoF, the corrosion potential warrants most scrutiny. The total leak rate—0.46% for all causes—is used for TTF calibration to partially offset the suspected higher count of unrecorded/unrepaired leaks and other uncertainties associated with the historical leak data.

The preliminary exposure estimates for PoF-TTF calculations are highly sensitive to soil corrosivity. The values assigned to this exposure variable are conservative, but plausible and certainly not overstated by orders of magnitude. It seems reasonable to assume that the preliminarily assigned values for mitigation are probably more in need adjustment than the exposure estimates.

The coating effectiveness is a prime candidate for modeling improvement. Coating effectiveness was initially judged on the basis of coating type, with effectiveness assigned to each coating currently in the system. Values range from 0 to 100%. These values were provided by PSE, presumably reflecting company experience with the relative failure history of the coatings. In reality, any of the coatings used in the past might be highly effective in any particular application. Even a coating in relatively poor condition will be protecting a very high percentage of the pipe surface area, thereby greatly decreasing the probability of active corrosion.

CP effectiveness was initially judged as described earlier. Effectiveness values range from 0 to 50%. These are very conservative since in the vast majority of situations, the CP is actually 100% effective in preventing corrosion at coating holidays.

Preliminary calibration is achieved by raising and narrowing the impact of these two mitigations. The effectiveness estimating process is preserved but now is calibrated to produce effectiveness values ranging from 90% to 100% instead of 0% to 100%, unless there is an active leak or active corrosion in which case, both are still judged to be 0% effective. This intuitively better fits the reality for reasons described above.

Finally, changes are made to the pipe adjustment factor. These are not yet based on ‘hard’ data. Initial estimates appear too severe in light of the low stress levels of service lines. The changes brought the effective pipe wall adjustment factor from 0.86 to 0.94, effectively increasing the assumed pipe wall by ~8%.

14. Tuning Results

These model changes together bring the average PoF-TTF in Ops Map 188086 down from about 27% to about 6% for each service. This value is influenced by the use of 99% failure probability for services with active leaks.

After the tuning, over half the 188086 services—61%--have a PoF-TTF of less than 2.2%. The new failure rates suggest a leak frequency of about once every 20 years for a service on average (6%), with most having a once in 60 year failure rate/probability (2%). Another way to view this is that the 6% implies that about one in every 20 services will leak each year—the 2% value implies that one in every 50 will leak each year.

The 6% value is about 10 times higher than the leak-repair database rate (0.46% for all causes) suggests. The 2% value is about 4 times higher than the historical average. However, it is not known how these rates compare with total leak counts—repaired and unrepaired—which would logically bring the count closer but probably still not as high as the prediction. Nonetheless, in the interest of conservatism, this likely overstatement of leak potential seems appropriate for an initial calibration.

It is recommended that the tuning revisions be applied to the entire STW population to see if similar changes result. That has not been done as part of this report since the STW population exceeds the capabilities of the spreadsheet-based model and a SQL-based model has not been prepared by these authors.

Improved calibrations can be made after the risk assessment includes all failure mechanisms. Material defects, natural causes, construction defects, and operator-caused are all contributing to the leak frequency, but not yet included in the risk assessment.

Since the primary use of the model output is to be prioritization, the calibration has little direct impact on risk management. The tuned results are more directly applicable to determinations of overall spending and resource allocation strategies.

Appendix K Calibration and QA/QC

The following tables are produced from the database of risk results, using software that calculates histograms based on user-defined bin limits and counts. These can be charted for more powerful visual impact, but the record count itself illustrates the distribution implied by the variable being examined. These examinations help to understand model performance as well as actual pipeline system characteristics.

histo2-risk scores		
risk	**Count**	**range**
1	9138	category 1 is < 0.1
2	14985	Category 2 is >= 0.1 AND < 0.2
3	5753	Category 3 is >= 0.2 AND < 0.3
4	4686	Category 4 is >= 0.3 AND < 0.4
5	27154	Category 5 is >= 0.4 AND < 0.5
6	9561	Category 6 is >= 0.5 AND < 0.6
7	6227	Category 7 is >= 0.6 AND < 0.7
8	17536	Category 8 is >= 0.7 AND < 0.8
9	2600	Category 9 is >= 0.8 AND < 0.9
10	478	Category 10 is >= 0.9 AND < 1.0
11	1545	Category 11 is >= 1.0 AND < 1.1
12	324	Category 12 is >= 1.1 AND < 1.2
13	49	Category 13 is >= 1.2 AND < 1.3
14	143	Category 14 is >= 1.3 AND < 1.4
15	50	Category 15 is >= 1.4 AND < 1.5
16	22	Category 16 is >= 1.5 AND < 1.6
17	30	Category 17 is >= 1.6 AND < 1.7
18	17	Category 18 is >= 1.7 AND < 1.8
19	199	Category 19 is >= 1.8 AND < 1.9
20	2070	Category 20 is >= 1.0

histo2-pof		
pof	**Count**	**range**
1	9697	category 1 is < 5.0
2	7666	Category 2 is >= 5.0 AND < 7.5
3	7101	Category 3 is >= 7.5 AND < 10.0
4	4141	Category 4 is >= 10.0 AND < 12.5
5	2014	Category 5 is >= 12.5 AND < 15.0
6	1732	Category 6 is >= 15.0 AND < 17.5
7	1964	Category 7 is >= 17.5 AND < 20.0
8	3166	Category 8 is >= 20.0 AND < 22.5
9	18130	Category 9 is >= 22.5 AND < 25.0
10	11353	Category 10 is >= 25.0 AND < 27.5
11	3705	Category 11 is >= 27.5 AND < 30.0
12	4026	Category 12 is >= 30.0 AND < 32.5

Appendix B
Risk Assessment Model

histo2-pof		
pof	Count	range
13	2959	Category 13 is >= 32.5 AND < 35.0
14	1654	Category 14 is >= 35.0 AND < 37.5
15	5435	Category 15 is >= 37.5 AND < 40.0
16	13003	Category 16 is >= 40.0 AND < 42.5
17	1428	Category 17 is >= 42.5 AND < 45.0
18	559	Category 18 is >= 45.0 AND < 47.5
19	268	Category 19 is >= 47.5 AND < 50.0
20	2566	Category 20 is >= 50.0

histo2-TTF		
ttf-pof	Count	range
1	13734	category 1 is < 5.0
2	6964	Category 2 is >= 5.0 AND < 7.5
3	5348	Category 3 is >= 7.5 AND < 10.0
4	3428	Category 4 is >= 10.0 AND < 12.5
5	1744	Category 5 is >= 12.5 AND < 15.0
6	1728	Category 6 is >= 15.0 AND < 17.5
7	3088	Category 7 is >= 17.5 AND < 20.0
8	2770	Category 8 is >= 20.0 AND < 22.5
9	21774	Category 9 is >= 22.5 AND < 25.0
10	8617	Category 10 is >= 25.0 AND < 27.5
11	1902	Category 11 is >= 27.5 AND < 30.0
12	4604	Category 12 is >= 30.0 AND < 32.5
13	2562	Category 13 is >= 32.5 AND < 35.0
14	1207	Category 14 is >= 35.0 AND < 37.5
15	13803	Category 15 is >= 37.5 AND < 40.0
16	4731	Category 16 is >= 40.0 AND < 42.5
17	1305	Category 17 is >= 42.5 AND < 45.0
18	536	Category 18 is >= 45.0 AND < 47.5
19	168	Category 19 is >= 47.5 AND < 50.0
20	2554	Category 20 is >= 50.0

Appendix B
Risk Assessment Model

The following tables are the results of queries used against risk results in a database. These summary statistics with various groupings are intended to illustrate a few of the many relationships among variables that can be examined as part of a QA/QC effort.

risk stats-CP sys grp										
cp system score	**CountOfidd**	**MaxOfpof**	**AvgOfpof**	**MinOfpof**	**MaxOfttf-pof**	**AvgOfttf-pof**	**MinOfttf-pof**	**MaxOfthd pty**	**AvgOfthd pty**	**MinOfthd pty**
	2	55.75	47.95	40.15	55.2	47.30	39.4	0.002825859	0.0022810855	0.001736312
0	43601	99.9	32.71	1.8	99.9	31.88	0.8	0.01479704	2.05106748044784E-03	0.00000144
2	459	99.9	30.12	2.07	99.9	29.25	1.1	0.004484296	2.4418893050109E-03	0.00000664
3	9811	99.9	25.29	1.7	99.9	24.40	0.7	0.00691186	1.83060272041584E-03	0.00000299
4	1169	72.54	24.80	2.27	72.2	23.93	1.2	0.006209026	1.5167775106929E-03	0.00000589
5	29575	99.9	18.63	1.57	99.9	17.64	0.6	0.02320066	2.00956291016085E-03	0.00000177
6	881	59.87	19.80	1.8	59.2	18.82	0.7	0.01225651	2.2279526106697E-03	0.0000118
7	15073	99.9	11.43	1.53	99.9	10.37	0.5	0.01225651	1.92422251370006E-03	0.00000257
8	598	99.9	10.01	1.56	99.9	8.87	0.6	0.007382029	2.5476919464883E-03	0.00000429
9	4	3.82	3.19	2.95	2.4	1.80	1.6	0.00502375	0.0045527735	0.004081797
10	1394	99.9	10.62	1.39	99.9	9.52	0.4	0.01054576	2.16074972740315E-03	0.0000043

<u>Expectation</u>: PoF-TTF would decrease with increasing CP effectiveness score. This is generally true, but one exception should be investigated.

<u>Other possible issues to examine:</u>
The number of services in each group—patterns?
Any possible correlation with Third Party results expected?

risk stats--EPCR grp										
epcr on service	**CountOfidd**	**MaxOfpof**	**AvgOfpof**	**MinOfpof**	**MaxOfttf-pof**	**AvgOfttf-pof**	**MinOfttf-pof**	**MaxOfthd pty**	**AvgOfthd pty**	**MinOfthd pty**
	99948	99.9	24.50	1.39	99.9	23.58	0.4	0.01076513	2.02793179646431E-03	0.00000463
Service has been exposed	2619	99.9	11.59	1.51	99.9	10.60	0.5	0.02320066	9.74678445589921E-04	0.00000144

Appendix B
Risk Assessment Model

Expectation: PoF-TTF would decrease after an EPCR since uncertainty is removed and pipe would presumably be left in a good condition. This is true.

Other possible issues to examine:
Correlations between mitigation and EPCR findings
Input into coating condition versus age and type

risk stats--pipe-wall grp										
pipe wall thickness	**CountOfidd**	**MaxOfpof**	**AvgOfpof**	**MinOfpof**	**MaxOfttf-pof**	**AvgOfttf-pof**	**MinOfttf-pof**	**MaxOfthdpty**	**AvgOfthdpty**	**MinOfthdpty**
	2	55.75	47.95	40.15	55.2	47.30	39.4	0.002825859	0.0022810855	0.001736312
0.109	43463	99.9	17.44	1.45	99.9	16.42	0.4	0.02320066	2.23791797232106E-03	0.00000256
0.113	50387	99.9	28.97	1.48	99.9	28.11	0.5	0.01225651	1.96951079568188E-03	0.00000257
0.125	735	99.9	29.88	1.56	99.9	29.11	0.6	0.007288706	8.68690537414965E-04	0.00000283
0.133	516	99.9	26.36	1.72	99.9	25.54	0.6	0.009004626	1.00882886627907E-03	0.00000507
0.14	7326	99.9	30.28	1.39	99.9	29.51	0.4	0.005070807	1.02181893898446E-03	0.00000177
0.141	106	99.9	25.02	1.66	99.9	24.22	0.7	0.00493772	4.93736367924528E-04	0.00000144
0.145	32	72.56	29.82	3	72.2	29.04	1.9	0.002456754	0.00107042925	0.00000463

Expectation: PoF-TTF would decrease with increasing wall thickness. This does not hold true. Since the TTF calculation is also based on stress level, that correlation might be more appropriate. So, a pressure-diameter-SMYS-wall thickness (Barlow calculation) could be tested against failure probability

Other possible issues to examine:
Number of services in each group.
Relationships between nominal wall and available wall (intermediate calculation not available for all services).

Appendix B
Risk Assessment Model

risk stats-svc yr grp																
service year	**CountOfidd**	**MaxOfrisk**	**AvgOfrisk**	**MinOfrisk**	**MaxOf pof**	**AvgOfpof**	**MinOf pof**	**MaxOf cof**	**AvgOfcof**	**Min Ofcof**	**MaxOf ttf-pof**	**AvgOfttf-pof**	**MinOf ttf-pof**	**MaxOfthd pty**	**AvgOfthd pty**	**MinOfthd pty**
	1519	10.98911	0.84	0.04414535	99.9	50.80	4.4	11	1.67906517445688	0.5	99.9	50.21	3.4	0.00933101	1.74769658327846E-03	0.0000043
	3	0.442476	0.31	0.2483214	44.25	31.34	24.83	1	1	1	43.6	30.47	23.9	0.003472624	2.30881766666667E-03	0.001255938
1955	92	10.98911	0.96	0.04458934	99.9	48.75	4.46	11	1.91847826086957	1	99.9	48.12	3.4	0.006209026	1.68400063043478E-03	0.00000539
1956	421	5.339255	0.51	0.02012247	99.9	38.56	2.01	11	1.3646080760095	1	99.9	37.81	0.9	0.006945248	1.96490868408552E-03	0.00000478
1957	884	10.98911	0.53	0.02265698	99.9	36.83	1.77	11	1.48076923076923	0.5	99.9	36.07	0.7	0.00784961	1.9078129841629E-03	0.00000323
1958	1632	10.98911	0.50	0.01593071	99.9	36.22	1.59	11	1.41605392156863	1	99.9	35.45	0.5	0.007535626	1.91137181556372E-03	0.00000357
1959	3328	8.991128	0.41	0.01699787	99.9	33.38	1.7	11	1.23347355769231	1	99.9	32.57	0.7	0.01479704	1.97048624879801E-03	0.00000264
1960	4007	5.751912	0.42	0.01677448	99.9	33.17	1.68	11	1.26491140504118	0.5	99.9	32.38	0.6	0.01225651	1.78805070551528E-03	0.00000458
1961	6013	10.98911	0.40	0.01761413	99.9	32.14	1.76	11	1.22700814901048	1	99.9	31.32	0.6	0.01069332	1.86871853650414E-03	0.00000283
1962	8145	10.98911	0.38	0.0143497	99.9	31.55	1.43	11	1.19650092081031	1	99.9	30.73	0.4	0.008278701	1.8023528018415E-03	0.00000257

Appendix B

Risk Assessment Model

risk stats-svc yr grp																
service year	CountOfidd	MaxOfrisk	AvgOfrisk	MinOfrisk	MaxOfpof	AvgOfpof	MinOfpof	MaxOfcof	AvgOfcof	MinOfcof	MaxOfttf-pof	AvgOfttf-pof	MinOfttf-pof	MaxOfthd pty	AvgOfthd pty	MinOfthd pty
1963	8156	6.124405	0.38	0.01586115	99.9	31.88	1.59	11	1.21689553702795	1	99.9	31.07	0.6	0.008294231	1.88580530345745E-03	0.00000366
1964	6520	10.98911	0.39	0.01458192	99.9	31.12	1.39	11	1.25996932515337	0.5	99.9	30.29	0.4	0.01370948	1.95168691671768E-03	0.00000177
1965	7224	10.98911	0.37	0.01542974	99.9	30.47	1.53	11	1.21338593576966	1	99.9	29.62	0.5	0.01076513	2.02195215683819E-03	0.00000263
1966	8745	10.98911	0.23	0.01685888	99.9	18.25	1.69	11	1.21435105774728	1	99.9	17.25	0.6	0.02320066	2.00731411549451E-03	0.00000357
1967	10755	10.98911	0.21	0.01418877	99.9	17.36	1.41	11	1.19562993956299	0.5	99.9	16.35	0.4	0.01069332	2.13890981106466E-03	0.00000144
1968	11257	10.98911	0.20	0.01604813	99.9	16.78	1.6	11	1.17806698054544	0.5	99.9	15.76	0.5	0.009313539	2.12793894039265E-03	0.00000256
1969	10395	10.98911	0.24	0.01395893	99.9	16.51	1.4	11	1.36907166907167	1	99.9	15.49	0.4	0.01160033	2.1239205418951E-03	0.00000304
1970	7025	10.98911	0.20	0.01481372	99.9	15.44	1.48	11	1.27857651245552	0.5	99.9	14.41	0.5	0.01054576	2.07923318320286E-03	0.00000299
1971	6167	7.975178	0.21	0.01477379	99.9	15.35	1.45	11	1.38819523269012	1	99.9	14.32	0.4	0.01076513	2.05485825668883E-03	0.00000299
1972	125	0.4353838	0.07	0.02376354	9.26	4.15	2.38	11	1.64	1	8.3	2.97	1.1	0.008278701	0.002244828848	0.00000589
1973	33	1.014833	0.14	0.05371445	9.63	8.69	5.37	11	1.60606060606061	1	8.3	7.58	4.3	0.005529488	1.97614963636364E-03	0.00000606
1974	28	0.1868206	0.09	0.01632	9.79	6.95	1.63	11	2.428571	1	8.3	5.80	0.6	0.006209	2.247315	0.0000262

Appendix B
Risk Assessment Model

risk stats-svc yr grp																
service year	CountOfidd	MaxOfrisk	AvgOfrisk	MinOfrisk	MaxOfpof	AvgOfpof	MinOfpof	MaxOfcof	AvgOfcof	MinOfcof	MaxOfttf-pof	AvgOfttf-pof	MinOfttf-pof	MaxOfthd pty	AvgOfthd pty	MinOfthd pty
				452					42857143					026	92857143E-03	
1975	4	0.09787732	0.09	0.07522887	9.79	8.55	7.52	1	1	1	8.3	7.38	6.4	0.006209026	0.00267333075	0.000689892
1976	8	0.4870163	0.12	0.03896368	9.63	6.80	3.9	11	2.25	1	8.3	5.66	2.8	0.005174188	0.001937052875	0.00000482
1977	6	0.3503872	0.12	0.03830051	9.69	6.39	3.19	11	2.6666666666667	1	8.3	5.30	2.2	0.005183895	1.43763883333333E-03	0.00000963
1978	9	0.1426029	0.10	0.05720019	14.26	9.93	5.72	1	1	1	12.9	8.72	4.5	0.005529488	3.17349288888889E-03	0.000490723
1979	7	1.014834	0.22	0.07494307	14.26	9.26	7.49	11	2.4285714285714 3	1	12.9	8.21	6.5	0.005529488	1.29721485714286E-03	0.0000182
1980	2	0.09349358	0.08	0.0760026	9.35	8.48	7.6	1	1	1	8.3	7.40	6.5	0.00147217	0.0014259765	0.001379783
1981	1	1.015379	1.02	1.015379	9.23	9.23	9.23	11	11	11	8.3	8.30	8.3	0.0000729	0.0000729	0.0000729
1982	2	0.0845598	0.08	0.0758512	8.46	8.03	7.59	1	1	1	7.3	6.90	6.5	0.00294434	0.002126468	0.001308596
1983	1	0.08136535	0.08	0.08136535	8.14	8.14	8.14	1	1	1	6.9	6.90	6.9	0.003794405	0.003794405	0.003794405
1984	2	0.04340613	0.04	0.04340613	4.34	4.34	4.34	1	1	1	3.3	3.30	3.3	0.000691186	0.000691186	0.000691186
1985	8	1.347277	0.25	0.07290727	12.25	10.12	7.29	11	2.25	1	11.4	9.06	6.2	0.003453828	0.001559678375	0.0000431
1986	2	0.09002179	0.07	0.04042363	9	6.52	4.04	1	1	1	8	5.45	2.9	0.001724729	0.001176349	0.000627969
1987	2	0.08651465	0.07	0.04605317	8.65	6.63	4.61	1	1	1	7.7	5.65	3.6	0.000654298	0.0004239035	0.000193509
1988	1	0.09380668	0.09	0.09380668	9.38	9.38	9.38	1	1	1	8.3	8.30	8.3	0.001724729	0.001724729	0.001724729

Appendix B
Risk Assessment Model

risk stats-svc yr grp																
service year	CountOfidd	MaxOfrisk	AvgOfrisk	MinOfrisk	MaxOf pof	AvgOfpof	MinOf pof	MaxOf cof	AvgOfcof	Min Ofcof	MaxOf ttf-pof	AvgOfttf-pof	MinOf ttf-pof	MaxOfthd pty	AvgOfthd pty	MinOfthd pty
1989	2	0.09286731	0.09	0.09286731	9.29	9.29	9.29	1	1	1	8.3	8.30	8.3	0.000689892	0.000689892	0.000689892
1990	4	0.09443295	0.09	0.07539713	9.44	8.79	7.54	1	1	1	8.3	7.70	6.5	0.002414621	0.00159308425	0.000817872
1991	5	0.1123414	0.09	0.06945634	11.23	8.68	6.95	1	1	1	10.2	7.66	5.9	0.00147217	0.0010606402	0.000627969
1992	2	1.014713	0.55	0.09202307	9.22	9.21	9.2	11	6	1	8.3	8.15	8	0.002825859	0.0014159595	0.00000606
1993	2	0.09002179	0.07	0.05873615	9	7.44	5.87	1	1	1	8	6.30	4.6	0.003449459	0.002038714	0.000627969
1994	4	0.1431988	0.10	0.07615393	14.32	9.63	7.62	1	1	1	12.9	8.30	6.5	0.00691186	0.0044281545	0.001635744
1996	3	0.1016451	0.09	0.06322402	10.16	8.87	6.32	1	1	1	9.2	7.87	5.2	0.001727965	9.83908666666667E-04	0.000544946
1997	1	0.09570855	0.10	0.09570855	9.57	9.57	9.57	1	1	1	8.3	8.30	8.3	0.003819886	0.003819886	0.003819886
2000	1	0.08320808	0.08	0.08320808	8.32	8.32	8.32	1	1	1	7.3	7.30	7.3	0.00147217	0.00147217	0.00147217
2002	1	0.07329243	0.07	0.07329243	7.33	7.33	7.33	1	1	1	6.3	6.30	6.3	0.001382372	0.001382372	0.001382372
2003	2	0.07524574	0.05	0.02178603	7.52	4.85	2.18	1	1	1	6.5	3.85	1.2	0.000654298	0.000504461	0.000354624
2004	5	0.08599257	0.03	0.01798975	8.6	3.16	1.8	1	1	1	7.3	2.10	0.8	0.004232152	0.0010495604	0.000184744
2005	4	0.01739454	0.02	0.01736987	1.74	1.74	1.74	1	1	1	0.7	0.70	0.7	0.000147624	0.000135081	0.000122538
4962	1	0.06232929	0.06	0.06232929	6.23	6.23	6.23	1	1	1	5.1	5.10	5.1	0.002197891	0.002197891	0.002197891
8530	1	0.05752617	0.06	0.05752617	5.75	5.75	5.75	1	1	1	4.5	4.50	4.5	0.002759567	0.002759567	0.002759567

<u>Expectation</u>: PoF-TTF would decrease with decreasing age. This seems to be true.

<u>Other possible issues to examine</u>:
Number of services in each group.
Correlate age with material defect failure rate
Does vintage of pipe somehow help characterize the neighborhoods?

risk stats-main press grp																
main pressure	Count Ofidd	MaxOfrisk	AvgOfrisk	MinOfrisk	MaxOfpof	AvgOfpof	MinOfpof	MaxOfcof	AvgOfcof	MinOfcof	MaxOfttf-pof	AvgOfttf-pof	MinOfttf-pof	MaxOfthd pty	AvgOfthd pty	MinOfthd pty
	14	0.5574957	0.38	0.07757449	55.75	38.08	7.76	1	1	1	55.2	37.33	6.6	0.003139844	2.01869292857143E-03	0.000347262
HP	157	6.020755	0.63	0.02805781	99.9	32.90	2.4	11	2.18471337579618	0.5	99.9	32.17	1.4	0.004395782	7.04722987261147E-04	0.00000478
IP	101041	10.98911	0.30	0.01395893	99.9	23.89	1.39	11	1.25902356469156	0.5	99.9	22.97	0.4	0.02320066	2.01191936238769E-03	0.00000144
LP	1355	6.558156	0.50	0.02896506	99.9	43.29	2.9	11	1.14428044280443	1	99.9	42.64	1.9	0.008474942	1.33960334833949E-03	0.00000478

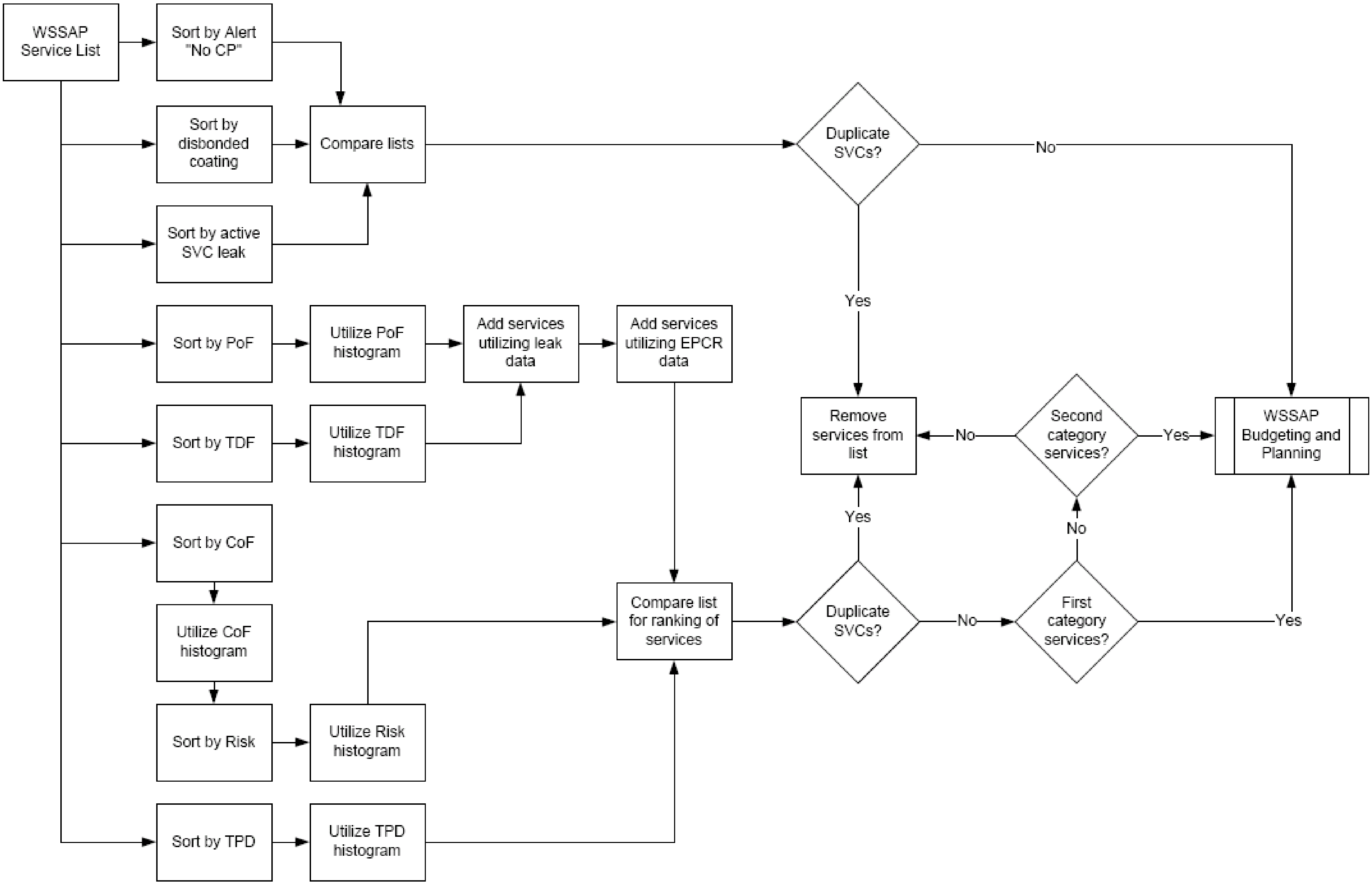
<u>Expectation</u>:
PoF-TTF would decrease with increasing operating pressure. This does not seem to be true. Perhaps because of the small number of services in HP.
Perhaps also because of the stress level being a more appropriate comparative metric (see previous correlation with wall thickness).
CoF would increase with increasing pressure. This is true, but is mostly coincidental because current calculations do not directly use pressure.
Correlation might exist because the higher pressure services are near to more populated areas.

<u>Other possible issues to examine</u>:
Number of services in each group.
Correlate stress level with material defect failure rate

Appendix C – Service Prioritization Process

Appendix C
Service Prioritization Process

Figure 1. WSSAP Service Prioritization



Appendix D – Recommended Follow-up Action

Appendix D
Recommended Follow-up Action

Figure 1. Recommended Follow-up Action

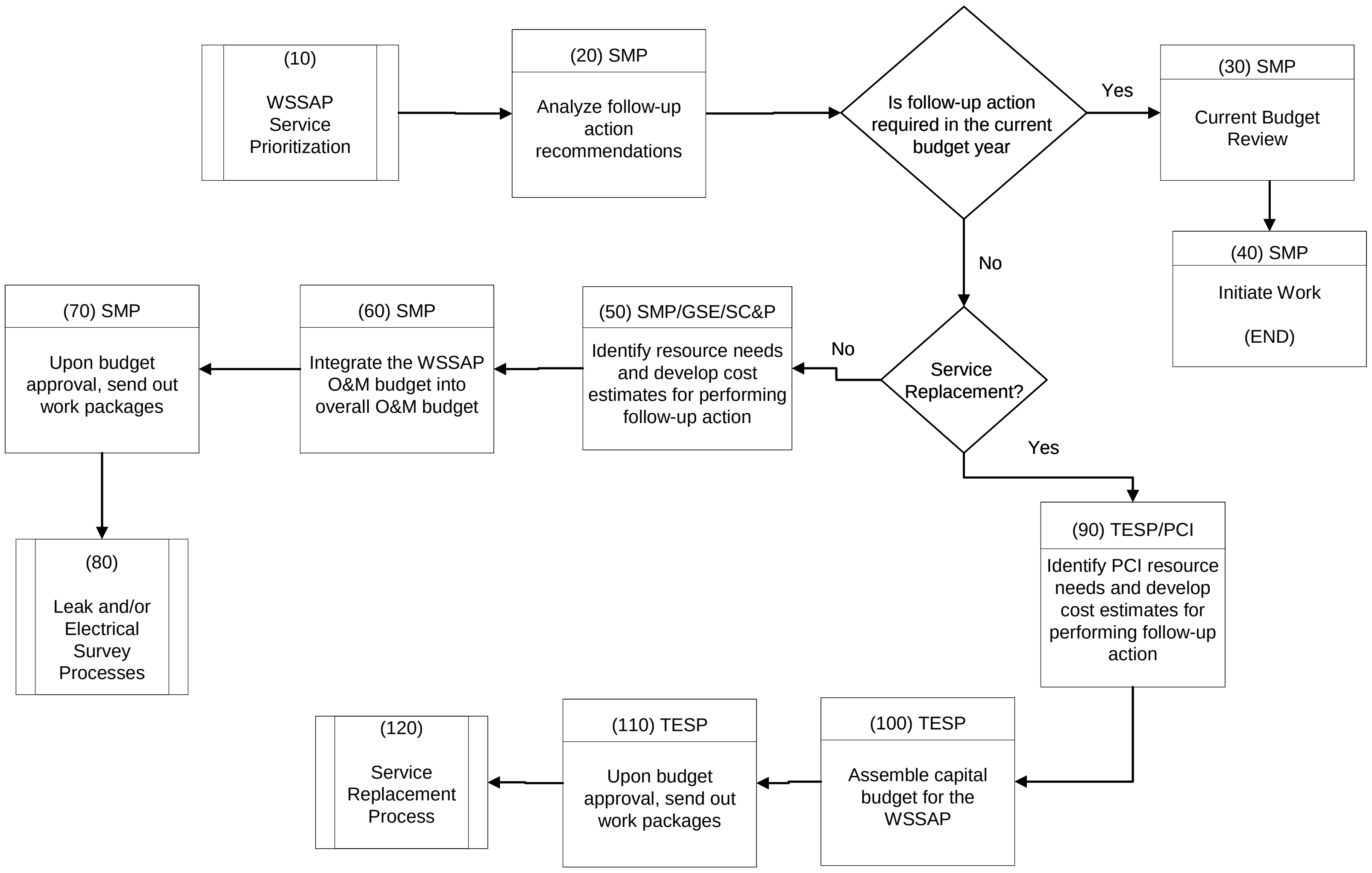
Mitigation Category	Action	General Characteristics (Not indicative of all services within these categories)	Approximate Number of Services – Based upon 2006 WSSAP risk model results*
Priority	Service Replacement	Monitored leak on service from LMS Disbonded coating from EPCR Existing leak repair EPCR indicates corrosion	516
Scheduled Replacement	Identify Replacement Projects and Twice Annual Leak Survey (until service is replaced)	No CP alert EPCR indicates corrosion EPCR indicates damaged coating EPCR indicates surface rust Higher concentration of repaired corrosion leaks by plat	8,470
Increased Leak Survey	Annual Leak Survey	Older services Historically moderate CP performance Services with moderately corrosive soils Higher concentration of individually cathodically protected services Higher consequence of failure	23,100
Standard Mitigation	No Action Required	Historically adequate levels of CP Services with low corrosive soils Newer services Lower concentration of repaired corrosion leaks per plat	69,281

***NOTE: The number of services may change as the WSSAP risk model is updated and re-run annually**

Appendix E – Budgeting and Planning Process

Appendix E
Budgeting and Planning Process

Figure 1. WSSAP Budgeting and Planning



Appendix E
Budgeting and Planning Process

Table 1. Annual WSSAP Budgeting Process

	Action	Description	Resources
10	WSSAP Service Prioritization	Refer to the "WSSAP Service Prioritization" process for specific details. The tasks included in this process will be performed annually during 1st quarter in preparation for the O&M and capital budgeting processes.	GSE IT
20	Analyze follow-up action recommendations	GSE will send the list of services and associated follow-up action to SMP. SMP will examine the list of services and look for trends and areas in which it will make sense to focus budget dollars for the upcoming year.	SMP
30	Current Budget Review	If there is any service remediation/investigation that GSE feels cannot wait until the next budget year, SMP will budget for those in the current budget. This could be any unsafe situation that GSE discovers while gathering updated data on a given service such as severe corrosion or leakage. SMP will work with the OAs in reviewing the budget, determine where the work will be funded from, and determine if any less critical work may need to be deferred to fund the work.	SMP OA
40	Initiate Work	SMP will take the lead in creating notifications and work packages for any proposed remediation/investigation that is to take place in the current budget year. SMP will ensure the appropriate parties (SC&P, PCI, or a Contractor) receive and understand the scope of work.	SMP
50	Identify resource needs/cost estimates for O&M work	SMP will determine the volume of O&M work (electrical surveys, leak surveys) to be performed in the upcoming budget year. SMP will coordinate with GSE and MP to develop cost estimates. SMP, GSE and SC&P will coordinate on resource needs and determine if the work (electrical surveys) can be done in-house or if a contractor will be required to perform the work.	SMP GSE SC&P MP
60	Finalize O&M Budget	SMP will use the resource requirements and cost estimates obtained in step 50 to finalize the O&M budget. This will include IDOT entry and all justification documentation. This work is generally begins in March/April and is completed by June.	SMP

	Action	Description	Resources
70	Issue work packages	SMP will take the lead on creating maintenance notifications (and associate work packages) and working with MP on setting up leak surveys. If needed, SMP will work closely with SC&P, Contract Administration, and GSE in developing a scope of work for an outside contractor to perform electrical surveys. This work typically begins in September after budget approval and is complete by November.	SMP GSE MP CA
80	Leak Survey Process Electrical Survey Process	Services requiring non-replacement remediation or investigation will be scheduled for leak surveys and/or electrical surveys depending on whether the services selected as part of the electrical survey sample population for that given budget year. Services selected for electrical survey may also undergo direct examination depending on the results of the survey. Both leak and electrical surveys are covered under existing processes. SMP and GSE will track progress of contractor work and remediation.	GSE SC&P Contractor SMP MP Heath
90	Identify service provider resource needs and develop cost estimates for capital work	Capital work for the WSSAP will be largely service replacements. Prior to budget finalization, TESP will work with PCI on cost estimates (units) and availability of resources to perform the work which could impact the volume of work that can be done in a given budget year. These discussions will typically take place in the March-May timeframe.	TESP PCI
100	Assemble Capital Budget	TESP will use information gathered in discussions with PCI to develop the capital budget for the WSSAP. This will include IDOT entry, peer review, and all justification documentation.	TESP
110	Issue work packages	TESP will coordinate with PCI in creating notifications and work packages for any service replacements. SMP will send list of services requiring replacement to PCI by November in any given year.	TESP PCI
120	Service Replacement Process	An existing process is in place to address services requiring replacement. PCI will perform the work and TESP will track progress and budget through SAP.	PCI TESP

Resource Codes:

CA	Contract Administration
GSE	Gas System Engineering
IT	Information Technology
MP	Maintenance Programs
OA	Operations Analyst
PCI	Pilchuck Contractors, Inc.
TESP	Total Energy System Planning
SC&P	System Control and Inspection
SMP	System Maintenance Planning

Appendix F – Electrical Survey Procedure and Criteria

Appendix F
Electrical Survey Procedure and Criteria

PURPOSE

1. This integrity study is designed to locate anomalies on wrapped steel services identified and selected utilizing PSE's WSSAP risk model. The anomalies will be evaluated and repairs made in accordance with PSE's Gas Operating Standards.

PROCEDURE

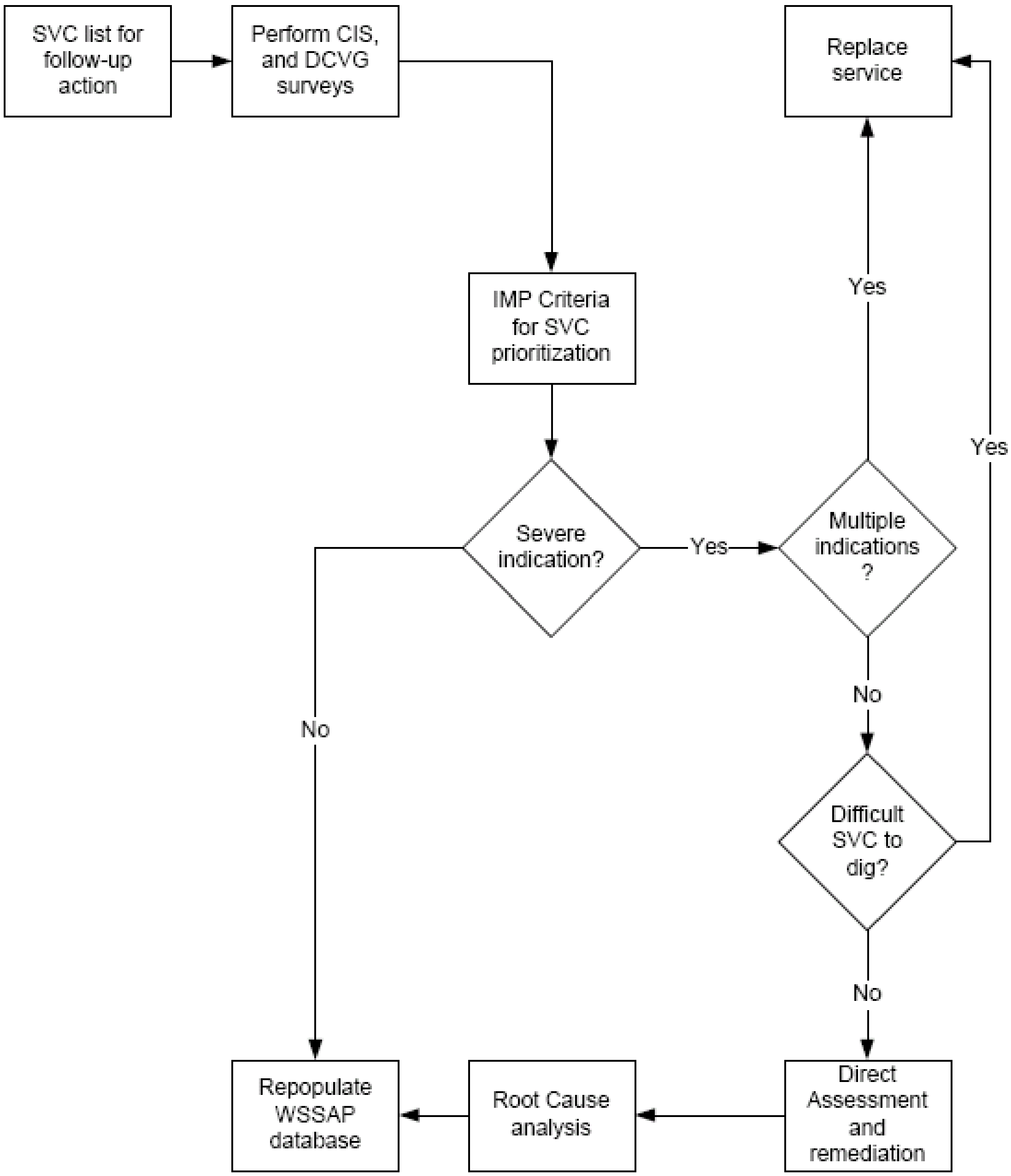
1. Gather service specific data on services utilizing PSE's plat maps and service design drawings (D4's).
2. Locate and mark out service line.
3. Install additional test stations as required to perform the surveys.
4. Identify regions by factors that will affect the survey tools performance based on Table 6.1 of IMP Standard 7500.4100, "External Corrosion Direct Assessment Plan."
5. Run two surveys, Close Interval Survey (CIS) and Direct Current Voltage Gradient (DCVG). The surveys will be performed in accordance with PSE's Gas Field Procedures 4515.1710, "Conducting a Close Interval Survey (CIS)," and 4515.1720, "Conducting a Direct Current Voltage Gradient (DCVG) Survey."
6. Data for the services will be presented both graphically and in a table.
7. Indication severity will be determined using criteria set forth in IMP Standard 7500.4100, "External Corrosion Direct Assessment Plan," Tables 9-1 and 10-1.
8. If the results from the indirect inspection are not consistent with the historical and construction data, then tool selection for the indirect inspections will be reassessed.
9. Direct examination excavation sites will be chosen based on indication prioritization Table 13-1 of IMP Standard 7500.4100, "External Corrosion Direct Assessment Plan."
10. The inspections at excavation sites will be made in accordance with PSE's Direct Examination Procedure.
11. A direct examination of all survey indications prioritized as immediate action will be made within 180 days of completing the prioritization of survey data classifications. In cases where there is sensitivity on the part of the homeowner or direct examination might be unacceptable, services with severe anomalies will be replaced rather than examined.
12. A direct examination of all survey indications prioritized as scheduled action will be carried out within 12 months of completing the prioritization of survey data classifications.
13. Where significant corrosion activity is found during the course of the direct examinations, a root cause analysis shall be performed to determine the underlying causes of the significant corrosion activity.
14. If the root cause analysis that is performed at areas of significant corrosion activity reveals conditions that exceed the limitations of the indirect inspection tools that were selected, the service will be replaced.
15. At the completion of the direct examination the WSSAP database will be re-populated with the survey results.
16. Inspection and examination records will be maintained for the life of the pipeline.

References

Gas Operating Standards	2575.1700 Repairing Steel and Cast-Iron Pipelines 2575.2800 Examining Buried Pipelines 2600.1100 Field Coatings for Pipe and Fittings
Gas Field Procedures	4515.1710 Conducting a Close Interval Survey 4515.1720 Conducting a Direct Current Voltage Gradient Survey 4515.1755 Examining Buried Pipe 4515.1210 Taking Pipe-to-Soil Potential Reads

	4515.1760 Taking a Pit Depth Measurement
IMP Standard	7500.4100 External Corrosion Direct Assessment Plan
Forms	2453 Exposed Pipe Condition Report 4023 Indication alignment and Prioritization 4027 Excavation Site Description 4029 Root Cause Analysis

Figure 1. Electrical Survey Process



Appendix G – Historical Service Replacements

Table 1
Risk Assessment of Sample of Replaced Services within/and near Pilot Area

Street Address	PoF	Mitigation Category
235-153RD PL SE	55.3%	Scheduled Replacement
516-172 PL NE	43.5%	Scheduled Replacement
218-164 AVE NE	41.1%	Annual Leak Survey
163-164 AVE SE	40.8%	Annual Leak Survey
544-156 AVE SE	40.8%	Annual Leak Survey
15937-Main ST	40.8%	Annual Leak Survey
15950-Main ST	40.8%	Annual Leak Survey
16028-Main ST	40.8%	Annual Leak Survey
238-164 AVE SE	40.3%	Annual Leak Survey
412-166 AVE SE	40.3%	Annual Leak Survey
413-166 AVE SE	40.3%	Annual Leak Survey
16713-SE 2 PL	40.3%	Annual Leak Survey
811-164 AVE SE	38.4%	Annual Leak Survey
15918-SE 1ST ST	35.6%	Annual Leak Survey
409-173RD PL NE	34.5%	Annual Leak Survey
16924-NE 2 PL	28.1%	Annual Leak Survey
434-172 PL NE	27.5%	Annual Leak Survey
1201-172 AVE NE	26.4%	Annual Leak Survey
1460-169 PL NE	26.3%	Annual Leak Survey
1628-177 AVE NE	24.2%	Annual Leak Survey
15032-NE 13 ST	24.1%	Annual Leak Survey
14517-NE 5 ST	23.4%	No Action
13831-BELL-RED RD	15.9%	No Action
1821-177 AVE NE	12.3%	No Action
1629-177 AVE NE	6.8%	No Action
14852-NE 16 ST	5.1%	No Action
431-140 AVE NE	5.1%	No Action
1641-167 AVE NE	4.9%	No Action

Table 2
2006 Pre-1972 STW Service Replacements throughout PSE's Service Territory Due to Corrosion
(Jan. 2006 – Sep. 2006)

Street Address	PoF	Mitigation Category
14204-79TH AVE NE	99.0%	Priority Replacement
732-1ST AVE E	99.0%	Priority Replacement
6830-192ND PL SW	99%	Priority Replacement
19455-122ND PL SE	99.0%	Priority Replacement
115-E 66TH ST	72.5%	Priority Replacement
2693-SW 334TH PL	55.8%	Scheduled Replacement
10833-SE 218TH ST	55.8%	Scheduled Replacement
4311-N ORCHARD ST	55.8%	Scheduled Replacement
12638-SE 54TH ST	55.7%	Scheduled Replacement
12517-SE 14TH ST	55.7%	Scheduled Replacement
2312-S SPENCER ST	55.7%	Scheduled Replacement
19307-73RD PL W	55.7%	Scheduled Replacement
4529-47TH AVE SW	55.7%	Scheduled Replacement
32820-22ND AVE SW	55.7%	Scheduled Replacement
13410-191ST AVE SE	55.7%	Scheduled Replacement
2934-181ST AVE NE	55.7%	Scheduled Replacement
2412-169TH PL SE	55.7%	Scheduled Replacement
5245-123RD AVE SE	55.7%	Scheduled Replacement
13826-115TH AVE NE	55.7%	Scheduled Replacement
9320-112TH ST CT SW	55.7%	Scheduled Replacement
20240-106TH AVE SE	55.7%	Scheduled Replacement
829-NE 103RD ST	55.2%	Scheduled Replacement
19527-104TH AVE NE	55.2%	Scheduled Replacement
6304-220TH PL SW	55.0%	Scheduled Replacement
5629-S FIFE ST	45.5% Alert no CP	Scheduled Replacement
2120-S C ST	41.8%	Annual Leak Survey
11004-RIVIERA PL NE	39.9%	Annual Leak Survey
14719-MERIDIAN AVE N	39.8%	Annual Leak Survey
7808-S ASOTIN ST	33.1%	Annual Leak Survey
115-N 85TH ST	26% Alert No CP	Scheduled Replacement
607-E TITUS	24.1%	Annual Leak Survey
334-DEVOE ST NE # 4	3.8%	No Action
17601-SOUTH CENTER PRKWY	1.0%	No Action

Appendix H – Program Schedule

Appendix H
Program Schedule

Figure 1. Program Schedule