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

Progress through May 2006

Revision 2.0

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Appendices

PSE Wrapped Steel Service Assessment Program (WSSAP) Report
Progress through May 2006

Executive Summary

The Wrapped Steel Service Assessment Program (WSSAP) was implemented by Puget Sound Energy (PSE) in accordance with the Spiritridge Settlement Agreement. As part of the Spiritridge Settlement Agreement PSE and the WUTC agreed that PSE would conduct a risk assessment and appropriate mitigation of all wrapped steel services 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. Services installed in 1972 and later had cathodic protection from the date of initial installation in accordance with the requirement in 49 CFR Part 192.

PSE has gathered data related to system leakage, area soil types, Exposed Pipe Condition Reports (EPCRs), and anecdotal information that was used to prioritize a review of system operation maps. The 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 lower priority. This allows the risk assessment and subsequent mitigation as appropriate to be completed for the higher risk areas and services first.

PSE has developed a risk assessment model with assistance from W. Kent Muhlbauer of WKM Consultancy. The risk model is developed and PSE is continuing to tune the model to ensure the risk ranking of the individual services is consistent with the operating history of PSE's distribution system. A risk management decision criteria has also 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 repair or replacement, electrical surveys, leak surveys, or no further action.

The PSE Maps, Records and Technology (MRT) department initiated a comprehensive review of PSE's system maps in January 2006. The maps are reviewed in order based on the priorities established above. As of May 2006 PSE has reviewed approximately 550,000 services (est. 650,000 total) and identified approximately 87,000 pre-1972 wrapped steel services (est. 90,000 total). The completion date for the map review and service identification will be June 30, 2006.

Additional data gathering work includes capturing the 36 different data points (risk variables) for each service that are necessary to run the risk model. The PSE Information Technology (IT) department will be developing 13 different types of list edit queries within 9 existing databases. To provide this information a Senior Applications Analyst has been assigned to assist with the development and implementation of this phase of the project as well as additional support from numerous departments. Additional pipeline data for use in the risk assessment is being 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.

PSE has conducted a pilot risk assessment using data gathered on wrapped steel services from a single operations map in the City of Bellevue in order to tune the risk assessment model and validate the models effectiveness at ranking wrapped steel services according to risk. This pilot has been completed and the risk model was further tuned as a result. There are 2,700 wrapped steel services installed prior to 1972 within the boundaries of this map. The risk results from the pilot operations map will now result in follow-up field action to assess the effectiveness of the proposed decision criteria. PSE is planning on conducting electrical surveys and leak surveys on approximately 150 services identified in the pilot. Upon completion of this field action PSE may revise the decision criteria as appropriate.

On December 20, 2005 and March 20, 2006 PSE briefed WUTC Pipeline Safety Staff on the program development and progress to date. In addition on March 14, 2006 PSE briefed WUTC Pipeline Safety Staff on the risk model development to date. At these times PSE also received feedback from Staff on our approach. Based on this input we have continued to develop the risk model and decision criteria outlining follow-up mitigation action as appropriate.

This report offers the program plan and project update for PSE's Wrapped Steel Service Assessment Program (WSSAP). The following sections of this report are fully developed and implemented as of May 2006:

- Section 1. Scope
- Section 2.1. Identification of Threats
- Section 2.2. Risk Model Development
- Section 2.3. Identification of Pre-1972 Services and Data Gathering (portions complete – see section for specific details)
- Section 2.4. Analysis of Risk Results for Trends and Areas of Concern (portions complete – see section for specific details)
- Section 3. Schedule

Additional sections are expected to be fully developed and implemented by the next progress report to be delivered in August 2006. The remaining sections will be completed and fully implemented by September 30, 2006.

1. Scope

As required by the 2005 Spiritridge Settlement Agreement with the Washington Utilities and Transportation Commission (WUTC), PSE is conducting a risk assessment and performing appropriate 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 program is to conduct a detailed risk assessment to prioritize for further evaluation all wrapped steel services installed prior to 1972 based on the predicted condition of the service and depending on the predicted condition, perform any necessary follow-up action such as electrical surveys or service replacements. The overall objectives of the risk model are as follows:

- Fulfill obligations under the Spiritridge 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

At this time it is estimated that there are approximately 90,000 active wrapped steel services installed prior to 1972, according to initial research efforts by PSE. 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 monitored annually as part of a CP system if electrically continuous with one. This program may identify services that are considered isolated facilities not under cathodic protection. These services will be given a higher priority for follow-up action.

2. Program Plan

The proposed 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. The proposed approach will be conducted on a prioritized basis beginning with those services believed to represent a higher level of risk, see Section 2.3 for additional detail on prioritization methodologies. In summary, this proposed approach relies on a variety of information (measurable, subjective, and anecdotal) to identify services that may constitute an area of concern for PSE.

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 Dependant", "Stable" and "Time Independent" categories.

Time Dependant 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 as a result of this exercise, the following threats were classified as being potentially viable, and therefore will be 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 distribution system or the scope of this project 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)

- 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 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.

- 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 approach will be 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.

2.2.1. Risk Assessment Scope

This risk assessment shows the relative risks to the public created by service pipelines during their operation. The focus is on abnormal situations, specifically the unintentional releases of natural gas. Risks from normal operations or potential construction risks associated with new pipeline installations are not considered.

1. The risk model recognizes time dependent failure modes of corrosion. The model also recognizes more random failure modes of third party strikes, human error (incorrect operations), and geohazards.
2. Random failure modes are assumed to either cause immediate failure or create a defect that leads to a time-dependent failure mechanism.
3. Time-dependent failure mechanisms of corrosion and fatigue are measured in mils-per-year (mpy) pipe wall metal loss. This mpy is used to determine the time to fail (TTF) with the assumption that failure occurs just below the wall thickness required for maximum internal pressure.
4. Integrity verification re-sets the clock at the measured wall thickness. Mpy is then applied to the new measured wall thickness to determine again when failure theoretically occurs.
5. A previous incident impacts the degree of belief about future failure potential in proportion to its relevance as a predictor. Historical incident information, properly adjusted for relevance, is used to tune or calibrate the model's probability of failure estimates when absolute estimates of risk are needed.
6. Increased uncertainty is treated the same as increased risk. This is conservative, ensures model credibility, and shows the value of acquiring information.

2.2.2. Risk Assessment Model

Risk can be defined as the probability of likelihood of failure of a pipeline segment and the consequences of such failure. It can therefore be expressed in terms of the product of failure likelihood (PoF) and consequences (CoF).

$$\text{Risk} = \text{PoF} \times \text{CoF}$$

Each piece of information used in the risk assessment will fall into one of the following three categories:

1. Exposure = likelihood of force or mechanism reaching the pipe when no mitigation applied
2. Mitigation = keeping the force or mechanism off the pipe
3. Resistance = ability to resist a force or mechanism applied to the pipe

Probability of Failure (PoF)

This model is designed to encompass virtually all conceivable failure rates. It is then calibrated using historical incident rates, tempered by knowledge of changing conditions. This results in current failure probabilities that match the judgment and intuition of those most knowledgeable about the pipelines, in addition to recent failure experience.

Probabilities are combined to give an overall failure probability for the segment. PoF values are combined using the widely accepted premise in probability theory that the "chance of one or more failures by any cause" is equal to 1 minus "the chance of surviving cause A" times "the chance of surviving cause B" times … etc. Therefore this model functions as follows:

$$\text{PoF}_{\text{overall}} = 1-[(1-\text{PoF}_{\text{thdpty}}) \times (1-\text{PoF}_{\text{time-dep}}) \times (1-\text{PoF}_{\text{incops}}) \times (1-\text{PoF}_{\text{geohazard}})\ldots]$$

Probability of failure (PoF) for time independent threats is calculated differently than for time dependent threats.

$$\text{PoF}_{\text{time-indep}} = [\text{unmitigated event frequency}] / 10^{[\text{threat reduction}]}$$

Where:

[threat reduction] = f (mitigation, resistance)

$$\text{PoF}_{\text{time-dep}} = f\,(\text{TTF})$$

Where:

TTF = "time to failure"
= 1 / [(available pipe wall) - (wall loss rate) x (1 – mitigation)]

And then:

$$\text{PoF} = f(\text{PoF}_{\text{time-indep}}, \text{PoF}_{\text{time-dep}})$$

Time-dependent mechanisms of corrosion and fatigue are expressed as metal degradation rates, mils-per-year (mpy) of pipe wall loss (1 mil = 1/1000th of an inch). Theoretically, this rate applies to every square centimeter of a pipe segment – the degradation could be occurring everywhere simultaneously. The probability of failure (PoF) calculation estimates the time to failure, measured in years since the last integrity verification, by using the estimated metal loss rate and the theoretical pipe wall thickness and strength. A TTF estimate is an intermediate calculation in this estimate. TTF and converting a TTF estimate to a year one PoF are discussed in Appendix B. The relationship used in the current PoF estimates is:

PoF = 1- EXP(-1/TTF)

For time-independent failure mechanisms such as third party damage, weather, human error, and earth movement events, the process is a bit simpler. Constant failure rate or random failure rate events are assessed with a simple ‘frequency of occurrence’ analysis. The estimated frequency of occurrence of each time-independent failure mechanism can be directly related to a failure probability and then combined with the failure probabilities from the time-dependent mechanisms. As a matter of fact, the frequency values and probability values are numerically the same at the low levels that should be seen in most pipelines. For example, a failure frequency of once per 1000 mile-years for third party damage is approximately a 0.001 or 0.1% probability of failure per mile year.

These modeling protocols are valid for all pipe materials. Initial risk assessments will focus on wrapped steel services per the scope of this program. Future assessments may be expanded to cover additional materials.

<u>Consequence of Failure (CoF)</u>
Potential consequences from a pipeline leak or rupture include loss of product, property damage, environmental damages, human injuries and fatalities, service interruption costs, legal costs, regulatory costs, and others. The focus of this assessment is on consequences to public safety and property primarily and service interruptions secondarily. In the current assessment, potential consequences are expressed in relative terms only.

Hazards associated with the subject pipelines are primarily thermal effects—burning natural gas that has escaped from a leaking or ruptured pipeline. Although most leaks and ruptures from distribution systems do not ignite, in the unlikely instance of ignition, torch fires or flame jets are considered the more likely thermal events, with fireballs more rare possibilities. A confined vapor cloud explosion is another possible scenario if escaped gas accumulates and is subsequently ignited. This is a more remote possibility.

Assumptions driving the consequence assessment include:

- Higher population density leads to higher consequences since more individuals might be impacted. Associated with the higher population density are a higher density of service lines and more opportunities for slow leaks to accumulate in confined spaces.
- More critical services are those that are classified as firm customers (not interruptible)

The algorithms used by PSE that make up the risk model for probability of failure and consequence are located in Appendix B.

2.2.3. Data to Support Risk Assessment

The data contained in Table 1 in Appendix A shall be assimilated into the risk assessment model. Risk scores by plat and/or by service address only are anticipated for preliminary risk assessments. Whenever data supports better resolution, smaller segments shall be created.

The following variables are included in the risk model but, due to difficulties in data acquisition and/or their current limited ability to discriminate differences across the pipeline systems, they are not used in this first phase of this risk assessment:

- Signs and markers
- Locating and marking processes
- Patrol
- Training systems
- Pipe material
- Manufacturing and construction flaws
- Other geohazard information
- Elevations
- Liquid accumulation calculations

In many cases, PSE performed preliminary calculations and screenings to establish values of variables that were subsequently used in the risk calculations. For instance, PSE personnel used historical references and other information to infer wall thicknesses and coating types from dates of installation.

Each piece of information used in the assessment will fall into one of the following three categories, as defined above

- Exposure
- Mitigation
- Resistance

When importances are judged or weightings assigned, these values come from studies and expert opinion, or engineering judgment when study data is unavailable.

A facilitated meeting with subject matter experts (SME's) was the method used by PSE to set the exposure values for time-independent threats. For time-dependent threats, the mpy values for corrosion were set using published values and/or engineering analysis of specific environmental and metallurgical factors.

2.3. Identification of Pre-1972 Services and Data Gathering

2.3.1. Identified Areas of Higher Priority

The prioritization effort was implemented as a way of prioritizing PSE's approach to the program in that areas deemed as a higher priority will be reviewed and analyzed first, recommended for follow-up action first, and budgeted and planned for ahead of lower priority areas.

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 Maps, Records and Technology (MRT) department initiated a comprehensive review of PSE's system maps in January 2006. The maps are reviewed based on the priorities established above. As of May 2006 PSE has reviewed approximately 550,000 services (est. 650,000 total) and identified approximately 87,000 pre-1972 wrapped steel services (est. 90,000 total). The completion date for the map review and service identification will be June 30, 2006.

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

- There are 36 data points (risk variables) for each service identified that are used to populate the risk model. Existing databases were identified and evaluated for content.
- The PSE Information Technology (IT) department will be developing 13 different types of list edit queries within 9 existing databases. A Senior Applications Analyst has been assigned to assist with the development and implementation of this phase of the project as well as additional support from numerous departments. The implementation progress for these data bridges is on-going and estimated to be complete by May 2006.
- Additional pipeline data for use in the risk assessment is being 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.

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

Data recorded from the system maps and various maintenance databases will be processed into the risk analysis programmed into a SQL server database using the risk model described in Section 2.2. The process and decision criteria to determine the appropriate follow-up action based on the risk model results are located in Appendix C, Figure 1 and Table 1. This criterion will be further developed and completed by July 31, 2006. The determination of what constitutes higher versus lower risk will be determined and integrated into the process by July 31, 2006.

- The data will come from the highest priority areas first.
- The data will be imported in the risk analysis software and the services will be ranked in order of higher risk.
- This analysis is ongoing as long as Section 2.3 is being performed.

2.5. Recommendations for Follow-up Action

A review of the risk analysis data will be performed to make a determination as to the significance of the information as it relates to the possible condition of the subject services. Using the decision criteria described in Section 2.4 of this document, the following recommendations for follow-up action may be made:

- Repair or replace service
- Conduct coating and cathodic protection surveys (more data needed for determination)
- No follow-up action required
- Increased or additional leak surveys
- Some recommendations will be confirmed in the field to validate analysis methodology
- If the service analysis warrants, some recommendations may be expanded to include surrounding PSE facilities (i.e. mains)

2.6. Budgeting and Planning of Follow-up Actions

PSE will develop the budget requirements and plan needed to carry out the follow-up actions. The following steps will be 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

2.7. Performing Follow-up Actions

PSE personnel in addition to PSE Service Provider crews will work to carry out any necessary remediations and follow-up actions on the services. The following steps will be accomplished when conducting follow-up action:

- Replace or repair service
    - If the as-found condition does not match predictions, the analysis process will be reviewed and modified as required.
- Perform further testing
    - Coating and cathodic protection surveys. (DCVG or ACVG in combination with CIS).
    - Services will be selected for direct examination or no further action required.
    - If the as-found condition does not match predictions, the analysis process will be reviewed and modified as required.
    - Additional or increased leak surveys may be performed
- If the condition of services in a certain area warrants it, PSE will consider performing an inspection of surrounding facilities (i.e. mains).

2.8. Validation of Program Effectiveness

PSE personnel will perform various field actions to validate the risk results and decision criteria described in Section 2.4. In addition, PSE may also 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

3. Program Schedule

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

- The following actions will be completed before September 30, 2006:
    - All pre-1972 wrapped steel services identified (plat review)
    - All pre-1972 wrapped steel services and associated data points will assimilated into the risk analysis software and ranked
    - Follow-up recommendations made for all services requiring follow-up action
    - Field validation of selected recommendations

  - Budgeting and planning for all services requiring follow-up action

- The following actions will be completed after September 30, 2006:
  - Electrical surveys
  - Repairs/replacements
  - Identification, analysis, recommendations, budgeting, and remediation for services not identified as part of the initial plat review

4. Conclusions

This program as outlined in Sections 1-3 of this document have been implemented to ensure PSE performs a detailed assessment on the condition of all wrapped steel services that were without cathodic protection for 5 or more years. Furthermore, implementing this program as outlined will ensure any services found requiring follow-up action are investigated and remediated as necessary.

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		
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						No scoring method at this time

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		Prior #3 corrosion rating could have paint over pitted surface
Current Atmospheric score	Atmospheric corrosion		Meter Network service	1 - 3 score by address		
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 – 35,000 psi		Construction standards	N/A	Default score of 30,000 psi	Currently not part of the model
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. 2.1

April 14, 2006

WKM Consultancy, LLC

Appendix B
Risk Assessment Model

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'.

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 largest 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.

<u>Assumptions Underlying Resistance Estimates</u>

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 2)
- Population density (Scoring Table E-15)
- CoF = [criticality of supply] x [pop] and ranges from 1 to 22.

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 largest 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
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

Appendix B

Risk Assessment Model

Category	Variable	Calculation	Notes
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	35000	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,(1072-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 soilll])/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 minus mils lost wall],[insp minus mils lost wall]),0)	If not leaking, then use maximum 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])	

Appendix B

Risk Assessment Model

Category	Variable	Calculation	Notes
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-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]	

Category	Variable	Calculation	Notes
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 =>	**No Pitting**	**Isolated Pits**	**Frequent Pits**	**No Original Surface Left**	
Pit Depth Descriptor (Vertical)					
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
In Business District (wall to wall paving)	yes
not in Business District	no

1. Data from Business District Leak Survey.

Consequence Variables

Scoring Table E-15: Population Density

Factor	Score
LOW=Low population density	10
High Occupancy Structure 6 = IDS=Identified Site	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.

Measurement Scales

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.

Variable Interactions

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 $0.1 / 10^{(40\% \times 8)} = 0.1 / 10^{3.2} = 6.3E\text{-}5$. 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.

OR Gates

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:

$$P = 1 – [(1-P_1) * (1-P_2) * (1-P_3) *…*(1-P_i)]$$

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.

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

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).

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

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)] …

AND Gates

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.

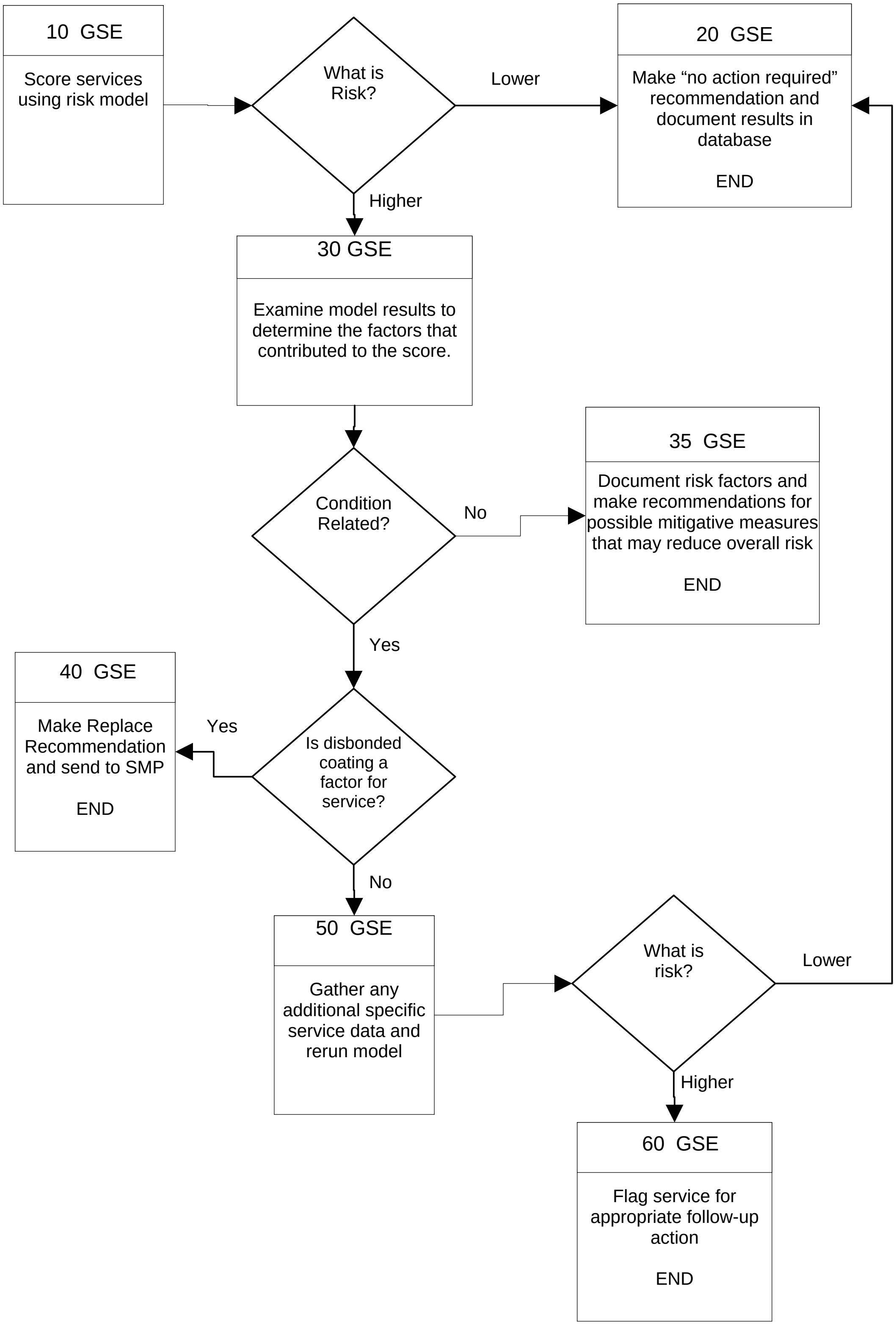
The PoF calculation estimates the time to failure, measured in time units since the last integrity verification, by using the estimated metal loss rate and the theoretical pipe wall thickness and strength. It is initially tempting to use the reciprocal of this days-to-failure number as a leak rate—failures 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.

Appendix C – Decision Criteria

Appendix C
Decision Criteria

Figure 1. Decision Criteria Process



Appendix C
Decision Criteria

Table 1. Decision Criteria

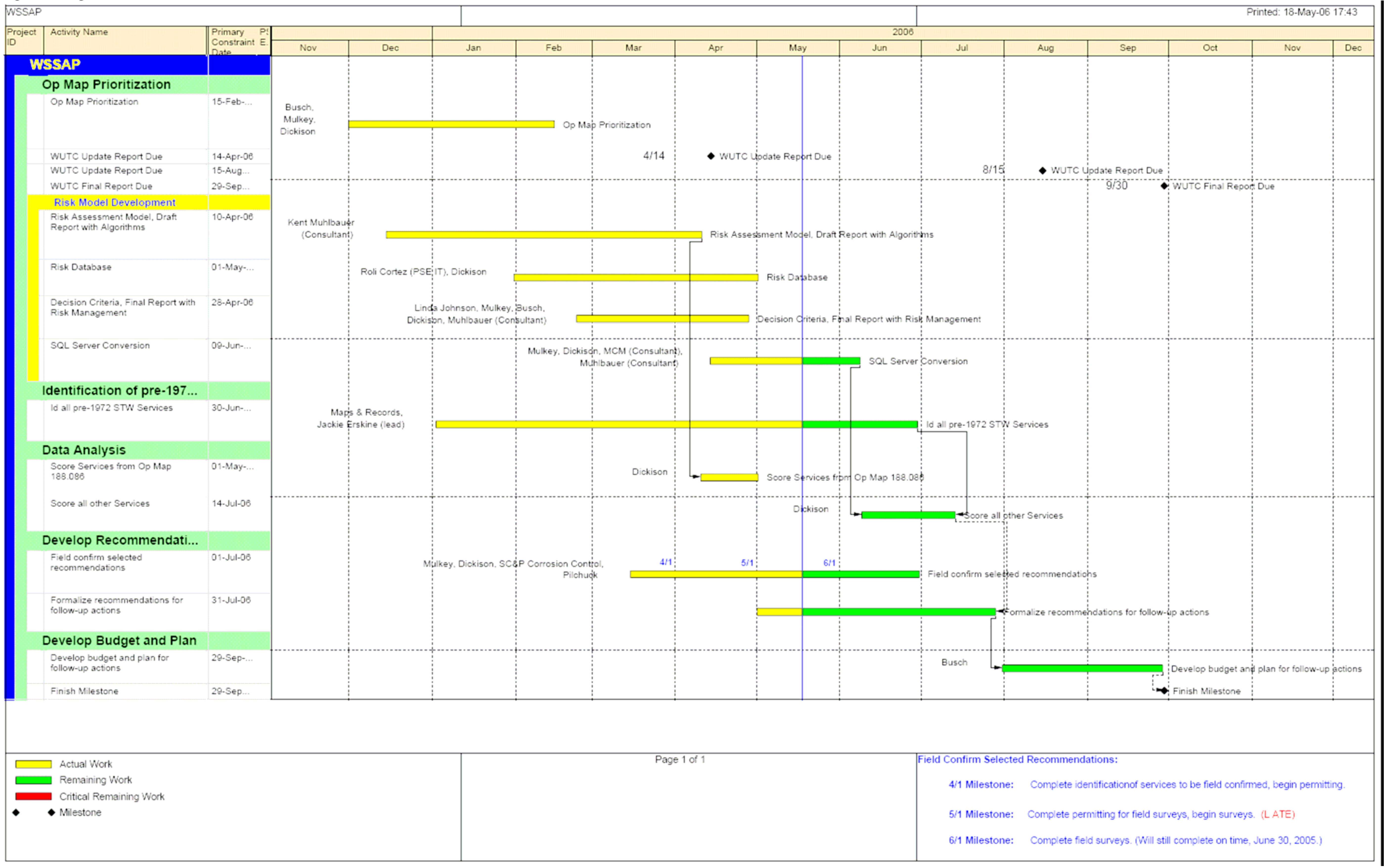
	Action	**Description**	**Resource**
10	Score services using risk model	The Gas System Engineering (GSE) subject matter expert (SME) will use scrubbed data taken from a central database that is linked to various other databases such as SAP, LMS, and the EPCR database. That data will be used to populate the ProActive risk model which will yield results indicating potential risk the service poses. The risk "score" will include such considerations as pipe condition, soil conditions, potential for third party damage and population density, among others. The output of the model will be risk based and indicate whether the service is categorized as higher or lower risk.	Gas System Engineering (GSE)
20	Make "no action required" recommendation and document results in central database	The SME has analyzed the results of the risk model for a given service and made the determination that the service requires no follow-up action. This determination is made because the variables and threats used in the model indicate a lower level of risk. The WSSAP central database will be updated with this determination.	GSE
30	Examine model results to determine the factors that contributed to the score.	For services categorized as higher risk, the SME examines the risk drivers to determine whether or not the drivers (threats and variables) are related to the predicted condition of the service.	GSE
35	Document risk factors and make recommendations for possible mitigative measures that may reduce overall risk.	If the service has a higher risk due to factors unrelated to the predicted service pipe condition, the service will be flagged and recommended for further investigation into possible mitigative measures that will reduce the overall risk. SMEs will be responsible for deciding the proper mitigative measures (if any).	GSE System Maintenance Planning Standards and Compliance
40	Disbonded coating - Make Replace Recommendation and send to SMP	Evidence of disbonded coating will be flagged for replacement because of the following: • Historical evidence of inadequate coating specification. • CP is not effective • Electrical surveys will not detect corrosion on pipe with disbonded coating	GSE

	Action	Description	Resource
50	Gather any additional specific service data and rerun model	For those services that are categorized as higher risk due to the predicted condition related factors (not including disbonded coating evidence), then the model will be populated with as much relevant (as determined by the SME) service specific data as is available via existing records (e.g. D-4) and possible site visits. This may be a combination of new data entered into the model and validation of the "plat-level" data that may have driven the risk higher.	GSE
60	Flag service for appropriate follow-up action	The risk model is rerun with any updated data. Those services categorized as having a higher level of risk will be flagged for appropriate follow-up actions (as determined by the SME) which may be in the form of replacements, electrical surveys, and leak surveys among others. Any services that are categorized as having a lower level of risk will be documented as described in Task 20.	GSE

Appendix D – Program Schedule

Appendix D
Program Schedule

Figure 1. Program Schedule



WSSAP

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Project ID	Activity Name	Primary Constraint Date
	WSSAP	
	Op Map Prioritization	
	Op Map Prioritization	15-Feb-...
	WUTC Update Report Due	14-Apr-06
	WUTC Update Report Due	15-Aug...
	WUTC Final Report Due	29-Sep...
	Risk Model Development	
	Risk Assessment Model, Draft Report with Algorithms	10-Apr-06
	Risk Database	01-May-...
	Decision Criteria, Final Report with Risk Management	28-Apr-06
	SQL Server Conversion	09-Jun-...
	Identification of pre-197...	
	Id all pre-1972 STW Services	30-Jun-...
	Data Analysis	
	Score Services from Op Map 188.086	01-May-...
	Score all other Services	14-Jul-06
	Develop Recommendati...	
	Field confirm selected recommendations	01-Jul-06
	Formalize recommendations for follow-up actions	31-Jul-06
	Develop Budget and Plan	
	Develop budget and plan for follow-up actions	29-Sep-...
	Finish Milestone	29-Sep...

🟨 Actual Work
🟩 Remaining Work
🟥 Critical Remaining Work
◆ ◆ Milestone

Page 1 of 1

Field Confirm Selected Recommendations:

4/1 Milestone: Complete identificationof services to be field confirmed, begin permitting.

5/1 Milestone: Complete permitting for field surveys, begin surveys. (L ATE)

6/1 Milestone: Complete field surveys. (Will still complete on time, June 30, 2005.)