FINAL REPORT

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Pacific Gas and Electric Company

Tree Root Interference Threat Analysis

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Executive Summary

Pacific Gas and Electric Company (PG&E) has commenced a right-of-way (ROW) management project to enhance public safety through better management of structures and vegetation (e.g., trees) along their ROW's. The study presented herein addresses the interaction between tree roots and buried pipelines. This study concluded that the presence of trees along the buried pipeline ROW adversely affects the risk profile by increasing the susceptibility to threats, decreasing the ability to monitor and protect the buried pipeline, and decreasing the ability to respond to emergencies as required by federal safety regulations for integrity assessments.

This study also concluded there is no obvious means to predict the interaction between the tree root and the buried pipeline prior to performing an excavation. It is not yet known, for instance, whether the same species of tree affects the pipeline and coating the same way in each instance, to what extent each variable may or may not contribute, and/or whether the variables will be repeatable or predictable for assessing tree root interaction.

While a complete understanding of all factors and their influence on pipeline integrity continues to evolve, the following recommendations are made at this time:

- To reduce the pipeline integrity risk profile for segments where trees are in proximity to the pipeline, a tree removal program is recommended with the following governing criteria:
    - All trees within 5 feet of the pipeline centerline should be removed.
    - Trees with a DBH* between 8 inches or larger located between 5 feet and 10 feet of the pipeline centerline, should be removed.
    - Trees with a DBH larger than 36 inch located between 10 feet and 14 feet of the pipeline centerline, should be removed.
    - Trees of a species likely to grow to a size that would require their future removal under these guidelines should also be removed.
- In cases where tree removal cannot be accomplished, alternative monitoring and mitigation strategies should be further developed and integrated into PG&E's integrity management program. This includes identifying and monitoring mitigative actions and their effect on the risk profile including threat susceptibility, ability to monitor, and ability to respond.
- Tree root investigations on the pipeline system should be continued in order to advance the knowledge base of tree root and pipeline interactions. Recommendations are made regarding refinement of the reports that are generated subsequent to these investigations.
- ILI and ECDA data should be correlated to the presence of tree roots to help establish the potential for corrosion influenced by presence of tree roots.
- Pipeline corrosion specialists should evaluate the potential for above-ground surveys (CIS, ECDA) to be adversely influenced by the presence of tree roots, and to evaluate the potential for cathodic shielding to occur as a result of the presence of tree roots.

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* DBH (Diameter at Breast Height) is the tree diameter at a height of 54-inches (4.5 feet)

- The PG&E Transmission Integrity Team should integrate the findings of this report into its integrity management program and consider all aspects of assessment, monitoring, and mitigation.
- Collaboration with industry is recommended in order to develop consensus standards and guidelines related to tree setback distances and their effect on pipeline integrity management and risk management.

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1. Introduction

As part of an ongoing commitment to pipeline integrity, Pacific Gas and Electric Company (PG&E) has commenced a right-of-way (ROW) management project to enhance public safety through better management of structures and vegetation (e.g., trees) along their ROW's. PG&E has retained Dynamic Risk Assessment Systems, Inc. (Dynamic Risk) to provide an assessment of the potential threats to pipeline integrity management, created by the presence of tree roots to PG&E's buried natural gas pipelines.

2. Background

In 2011, PG&E retained arborists (Randall Frizzell & Associates) to provide expertise and provide support for a number of excavations to evaluate the interaction between the tree roots and their buried pipelines as part of a vegetation management program. In 2012, PG&E commenced a 'Pilot Program' on a 10-mile section of Line 132 and a 10-mile section of Line 153 in order to improve their ROW management program. As part of this Pilot Program, PG&E identified structures and large trees on top of and/or in close proximity to the pipe centerline. The arborists were then retained to provide additional support in these matters.

PG&E commenced the Pilot Program to gather the necessary data, knowledge and experience to develop guidelines that will be used to identify and address encroachments and vegetation issues throughout their system. Ultimately, the guidelines resulting from this Pilot Program will be used to develop protocols that will be implemented throughout the entire PG&E pipeline transmission system.

The arborists retained by PG&E developed a 'white paper' on the interaction of tree roots with buried pipelines based upon publically available information. As a result, it was recommended that a number of pipeline excavations involving a representative sample of tree root systems should be performed and the results used to further determine how tree roots systems interact with buried pipelines.

As of the date of the writing of this report, 18 locations (excavations that are planned, underway or completed) have been considered within this evaluation.

3. Objective

Identify and assess potential pipeline integrity threats and provide recommendations that will mitigate the risks related to vegetation management, specifically trees, along PG&E's ROW.

4. Approach

The objectives of this analysis have been achieved through the successful execution of the following activities:

- Literature Review
- Review of Completed and Planned Excavations
- Pipeline Integrity Management Considerations

- Risk Assessment
- Conclusions
- Recommendations

Each is described below.

5. Literature Review

5.1. Review of the White Paper

In April 2012, PG&E commissioned a study to investigate the interaction of tree roots with natural gas transmission pipelines[1] ('white paper'). The white paper collated information regarding then-available industry experience on tree root interaction and expert commentary regarding the behavior of tree roots. The report recognizes it was the beginning of a process to further expand industry knowledge of tree roots and their potential effects on natural gas pipelines and calls for further study of the issues. The report also puts forward recommendations regarding the reduction of tree root interference based on botanical considerations. These recommendations include:

- Increased distance between tree and pipeline.
- Root pruning and installation of root barriers.
- Limiting the presence of trees in proximity to pipelines.

The white paper states that while tree roots can emanate from the base of a tree to a radius of up to several hundred feet, or several times the radius of a tree's drip-line, the majority (90%) of the total tree root system is usually within 3 feet of the surface. While large and medium size roots are less likely to reach such distances, the same research shows that the presence of pipelines can affect the path of root systems as they provide channels for water to collect, creating a preferred path for tree roots. This interaction between pipelines and tree root growth patterns means that the normal assumptions regarding the directionality and depth of tree roots is difficult to rely upon for determining safe distances between trees and pipelines. In this work, the potential for tree roots to enhance and interact with other pipeline threats was characterized as a function of distance. Accordingly the authors provided "distance category" guidelines to characterize tree proximity based on tree diameter.

5.2. Pipelines and Informed Planning Alliance (PIPA)

Pipelines and Informed Planning Alliance (PIPA) was established to improve the safety and reduce risks related to land use near buried natural gas transmission pipelines. PIPA is comprised of 130 stakeholders (local governments, regulators, property developers, property owners, real estate boards, and transmission pipeline operators) and is sponsored by the U.S. Department of Transportation (DOT) Pipeline and Hazardous Materials Safety Administration (PHMSA). A guiding principle in PIPA's work is that to be successful in reducing risk related to land use near natural gas transmission pipelines, all stakeholders need to be committed to the risk management of buried pipelines. PIPA provides a mechanism to achieve this goal by providing recommended practices.

PIPA has established that transmission pipeline operators need to protect their pipelines from potential damage by activities on or near pipeline ROW's. PIPA created a recommended practice[2] that states that trees, crops and orchards are not acceptable on the pipeline ROW, since tree root structures may be deep and extend beyond tree canopies. In cases of significant tree root encroachment, damage to transmission pipeline coatings can occur, leading to the potential for corrosion.

These guidelines have also established the need for pipeline operators to have unrestricted access to the pipeline ROW for maintenance and emergency response[2]. In some cases, the presence of trees on the ROW could affect the ability of operators to comply with federal pipeline safety regulations. For instance, federal safety regulations stipulate:[3]

> *"Each operator shall have a patrol program to observe surface conditions on and adjacent to the transmission line right-of-way for indications of leaks, construction activity, and other factors affecting safety and operation."*

Additionally, the following recommended practice was made by PIPA:[2]

> *"After a transmission pipeline is installed, the pipeline right-of-way (ROW) must be maintained by the pipeline operator to allow for inspection of surface conditions as required by federal law. The transmission pipeline operator must maintain the ROW vegetation so that it will not hinder pipeline inspection and maintenance activities. Extensive landscaping or other obstructions can block the view of and impede the operator's access to the pipeline."*

5.3. Review of Industry Best Practices

The development and implementation of comprehensive ROW vegetation management programs is considered as a best-practice approach across the pipeline industry. A sample review of a few selected programs is as follows:

- Duke Energy has an established program noting 'vegetation harmful to the integrity of the pipeline will be removed'.*
- Columbia Pipeline Group does not permit trees on the ROW.†
- Questar has developed a brochure that explains why 'planting deep-rooted vegetation, specifically trees, in pipeline rights-of-way is not permitted'.‡
- NorthWestern Energy describes how tree roots can damage coating and may have a detrimental effect on cathodic protection of the buried pipeline.§
- Louisville Gas & Electric describes right-of-way encroachment and through their public awareness program indicates that "access to the right-of-way is inhibited by trees and other vegetation, fences, buildings, and other structures".**

* http://www.duke-energy.com/safety/right -of-way-management/pipeline-clearance-faqs.asp
† http://columbiapipelinegroup.com/en/landowners/maintenance.aspx
‡ www.questargas.com/brochures/59090.pdf
§ http://www.northwesternenergy.com/display.aspx?Page=Planting_Trees_Natural_Gas&Item=265
** http://www.lgeenergy.com/rsc/lge/LGE_IN_2012_Public_Awareness.pdf

- Local government, in conjunction with Atmos Energy, explains that 'keeping trees, shrubs, buildings, fences, and other structures and encroachments well away from the pipelines promotes maintenance of pipeline integrity and safety'.*

In all of these cases, there is a consistent message that clear ROW's are required for effective integrity management of buried pipelines.

5.4. Pipeline Failure Data

A review of publicly available PHMSA Gas Transmission incident data (2002 – current)† was completed to determine whether or not tree roots have been identified as root cause or contributing factor to natural gas pipeline failures. While, this review did not specifically identify tree roots as a direct or contributing cause of pipeline failure, there are several reasons for this deficiency, including reporting guidelines and reporting forms. For example, a pipeline failure cause may be reported as 'external corrosion' but there is no clear means to report whether the presence of tree roots, contributed to the external corrosion. The PHMSA incident reporting requirements over this time period are quite rigorous, but the forms are not set up to consistently report whether or not a tree and/or tree root system was a contributing cause or direct cause to a failure. In addition, there are certain limiting criteria for reporting a pipeline incident (e.g., injury/fatality, property damage, ignition, etc.), so not all failures are captured. Furthermore, the majority of transmission pipelines maintain cleared pipeline ROW corridors between 25-feet and 50-feet wide and therefore, the incident rate due to the encroachment of trees may not be well represented.

Transmission pipeline environments, where pipelines are typically located on dedicated ROW's or within road allowances, differ significantly from distribution environments, which are characteristically much more congested in terms of adjacent land use. Therefore, a similar review was conducted on PHMSA Gas Distribution incident data (2004 – present)‡‡. This review revealed five (5) incidents related to tree roots. Three (3) of those five (5) incidents involved service lines or meter sets and are summarized as follows:

1. Uprooted tree damaged above ground meter set (2005 #20050026 Central Indiana Gas Company). Release ignited and produced $700,000 in property damage.
2. Tree root cracked 0.75-inch diameter PE service tee (2012, South Jersey Gas Co). Release ignited and produced an explosion and produced $320,000 in property damage.
3. Uprooted tree pulled out 1.25-inch PE service line from foundation (2012 #20120094, Keyspan Energy). Release ignited, produced an explosion, resulted in one (1) injury, and produced $750,000 in property damage.

Two (2) of those five (5) incidents involved mains; in both cases, the mains were small-diameter, non-steel, as summarized below:

* http://www.wellingtonhoa.net/picture/faq_s_-_r-o-w_maintenance_102012.pdf

† http://phmsa.dot.gov/portal/site/PHMSA/menuitem.ebdc7a8a7e39f2e55cf2031050248a0c/?vgnextoid=fdd2dfa122a1d110VgnVCM1000009ed07898RCRD&vgnextchannel=3430fb649a2dc110VgnVCM1000009ed07898RCRD&vgnextfmt=print

4. Tree root loading caused rupture of 2-inch cast iron main operating at 60 psig, resulting in gas ignition and evacuation (2005 20060021, Centerpoint Energy). Release ignited, produced an explosion, resulted in one (1) injury, and produced $140,000 in property damage.
5. Tornado uprooted tree and pulled up 2-inch PE main, operating at 25 psig, resulting in release of gas (2011 20110161, City of Mapleton, IA).

The above evidence suggests that pipelines located in close enough proximity to tree roots that are sufficiently large to cause either high root loading forces, or significant entanglements, are susceptible to failures related to tree root damage. The evidence suggests that this susceptibility may be particularly enhanced for small-diameter (≤2-inch), non-steel pipelines.

6. Review of Completed and Planned Excavations

PG&E is performing a series of pipeline excavations to better characterize the interaction between tree roots and buried pipelines. It began this effort in 2012 and is continuing through 2013. A summary of these excavations is provided in Table 1 for the 2012 excavations and the 2013 excavations (completed and in-progress).

The pipeline excavations performed in 2012 produced baseline knowledge that was relied upon to enhance aspects of the excavation program for 2013 and to develop an encroachment specific detailed and consistent reporting mechanism. As a result of this evolving process, the information available from the 2013 excavations is more comprehensive than that obtained from the 2012 excavations. In addition, four (4) of the 2013 pipeline excavation sites were visited by Dynamic Risk personnel.

Based upon a review of these excavations results, discussions and observations during the field visit, it is evident tree roots do cause damage to the pipeline coatings. It is also clear there are numerous variables that affect the interaction of tree roots on pipelines, including the following:

- Species of tree (e.g., type and size of root system)
- Size of the tree (e.g., DBH, age)
- Proximity of tree to pipeline centerline (e.g., distance)
- Depth of Cover
- Local Environment (e.g., irrigation, sidewalks, land use, water table depth, etc.)
- Soil (e.g., native backfill, etc.)
- Type of Coating (pipeline and girth weld)
- Pipe Diameter.

Based upon these findings and observations, there is no obvious means to predict the interaction between the tree root and the buried pipeline prior to performing an excavation. Moreover, it is not yet known:

- whether the same species of tree affects the pipeline and coating the same way in each instance,
- to what extent each variable may or may not contribute, and/or

- whether the variables will be repeatable or predictable for assessing tree root interaction.

There is a high potential for tree roots to compromise the two (2) primary barriers that protect buried pipelines from external corrosion - external coating and cathodic protection. While in many cases tree roots are in contact with the pipe have not yet resulted in damaged coating, there is the potential for tree root growth to eventually damage the coating as the tree grows. Moreover, while the data from excavations show no active corrosion resulting from the damaged coating, there remains the potential for corrosion to occur in these locations over time.

7. Pipeline Integrity Management Considerations

The presence of tree roots on or near the ROW adversely affects the risk profile for a pipeline system. Vegetation, including trees in proximity to buried pipeline systems, can adversely affect several aspects of pipeline integrity management including:

- Increased susceptibility to threats
- Decreased ability to monitor
- Decreased ability to respond.

7.1. Increased susceptibility to Threats

7.1.1 External Corrosion/Cracking

Buried pipelines rely upon external coating and cathodic protection (CP), to protect the pipe and mitigate external corrosion, stress corrosion cracking, and hydrogen induced cracking. Tree roots can damage external protective coatings by creating coating holidays (coating voids or gaps), growing against the pipe, and penetrating between the coating and the pipe surface.

Depending upon the tree root system and/or coating systems, disbonded (but still intact) coating can also prevent CP from adequately protecting the pipe surface in a phenomenon known as CP shielding. Shielding can be exacerbated by the presence of tree root entanglements surrounding the pipe surface. Additionally, the presence of tree roots may affect the ability to measure CP effectiveness using above ground measurements.

Therefore, tree roots can negatively affect two barriers used to protect the external pipe surface – external coatings and cathodic protection.

7.1.2 Lightning

Lightning is also a threat to pipelines and the likelihood of this threat is increased when trees are in proximity to the buried pipeline. Since lightning strikes often involve trees, the tree roots can provide the mechanism for increasing the susceptibility of lightning damage to the buried pipeline. Lightning can strike a tree and propagate through the roots to the soil surrounding a pipeline:[2]

> *"The lightning passed down the tree and through the wet clay. The moisture in the clay instantly vaporized. In the region where the current passed through the soil, an instant and violent*

expansion of the moisture in the soil occurred creating the crater in the ground around the perfectly smooth dent in the top of the pipe. The resulting tension in the pipeline initiated a crack in a girth weld a few feet away."

7.1.3 Weather and Outside Force

Wind and flooding are also factors to consider where tree roots affect buried pipelines. When a tree is uprooted by wind or flooding, large tree roots entangled around a pipeline can potentially pull on, or even extract a pipeline from the ground.

7.1.4 Fatigue

Metal fatigue can occur if the tree roots are affecting a pipeline. Over time, wind can create movement of the pipeline where the movement can produce a fatigue environment that can negatively impact the structural integrity of girth welds or other discontinuities that may exist.

7.2. Decreased Ability To Monitor

7.2.1 Damage Prevention

A clear and designated ROW is required to adequately monitor the threats and hazards that may affect a pipeline. A clear ROW will provide the opportunity to detect encroachments before they occur and/or cause damage to the pipeline.

Independent study has identified that one of the most significant factors contributing to the threat of someone inadvertently striking and damaging a pipeline (referred to as 3rd Party Damage and includes anyone knowingly or unknowingly performing an excavation along the ROW) is the ability of the public to identify and recognize a pipeline ROW[4]. Heavy vegetation within the ROW prevents corridor recognition and contributes to the potential for inadvertent impact of a pipeline by a 3rd party excavator.

7.2.2 Cathodic Protection Surveys

Pipeline operators perform CP surveys to evaluate the effectiveness of CP systems. These above ground surveys include, but are not limited to, close interval surveys (CIS) and direct current voltage gradient survey (DCVG). In cases where access to the ROW is limited due to vegetation overgrowth and the presence of structures, such CP surveys are not possible. In addition, the validity of such surveys when performed, can be in question due to the presence of potential shielding by root systems.

External Corrosion Direct Assessment (ECDA) is an assessment method used to determine whether external corrosion is a potential integrity concern. Since ECDA relies upon above ground surveys such as CIS and DCVG, the results from the integrity assessment may be inaccurate if there is limited confidence in the above ground surveys due to the presence of tree roots.

7.3. Decreased ability to respond.

A clear pipeline ROW and access along the ROW is critical for timely emergency response and effective reaction to the presence of threats discovered through integrity assessments [e.g., ECDA, in line inspection (ILI), etc.]. During emergency situations, any obstructions in the ROW will impact the ability to respond in a timely manner.

8. Risk Assessment

Pipeline operators perform risk assessments in order to develop a consistent and defensible methodology for the evaluation of potential threats and consequences across their pipeline infrastructure. The risk assessment results then become part of an overall risk management program that consider viable monitoring and mitigation strategies used to manage enterprise risk and to comply with federal safety requirements. An integral part of an effective risk management program is to incorporate lessons learned from either internal programs or from external stakeholders.

As part of this tree root interference analysis, a model has been developed to consider variables that have been identified through work performed to date. Based upon this model, a threat assessment has been performed to characterize the degree of interaction with each of the relevant threats identified. Based upon the risk assessment results, examples of monitoring and mitigative activities that can be considered in developing a comprehensive integrity management and risk management program are presented.

Each is described below.

8.1. Tree Root 'Interaction Model'

In order to perform a high-level risk assessment, definitions are required to evaluate the interaction between the trees and the buried pipeline. As described above, the potential interaction between trees and pipelines is a function of many factors including, but not limited to:

- Species of tree (e.g., type of root system)
- Size of the tree (e.g., age)
- Proximity of tree to pipeline centerline (e.g., distance)
- Depth of Cover
- Local Environment (e.g., irrigation, sidewalks, land use, etc.)
- Soil (e.g., native backfill, etc.)
- Type of Coating (pipeline and girth weld).

Since it is not yet possible to establish and validate a model that predicts all tree root interactions ('interaction model'), a simplified interaction model has been relied upon for the purpose of this assessment. It is recognized that this interaction model may evolve as more information becomes available.

The interaction model proposed herein is based upon the information and knowledge developed to date and establishes a correlation between a tree's proximity to the pipe centerline and the tree diameter. The proximity of the tree to the pipeline is characterized by immediate, adjacent, and distal defined as follows:

Immediate Proximity. Tree trunks are considered to be in Immediate Proximity if any portion of the trunk is either directly above the centerline or close enough that the size of roots in contact with the pipeline are expected to be of the same size as roots directly below the tree. Trees in Immediate Proximity are most likely to interfere due to the presence of large roots including tap roots, and oblique roots. Threats that are related to the presence of large roots are most affected by trees in immediate proximity, and the potential and severity of the threat interaction should consider the likelihood of substantial roots with a large surface of contact between the root and the pipeline.

Adjacent Proximity. Adjacent Proximity trees are defined as those likely to cause interference with lateral roots. Such roots may grow along pipelines for considerable distances so the effect of lateral roots may interact with other threats along significant portions of the pipeline. Determination of the severity of influence for trees in Adjacent Proximity should consider the likelihood of lateral roots coming in contact with pipelines and growing along their length.

Distal Proximity. Distal Proximity trees are not likely to contact the pipeline with large roots, but may still interfere with fine roots and far-reaching lateral roots.

Based upon these definitions, the table below provides guidance (provided in white paper), to characterize tree root interaction for the purpose of this assessment:

Tree Root Interaction Categories*

DBH†	Immediate	Adjacent	Distal
< 8 inches	< 5 ft.	5-10 ft.	> 10 ft.
> 8 inches	< 10 ft.	10-14 ft.	> 14 ft.
> 36 inches	< 14 ft.	> 14 ft.	> 14 ft.

8.2. Threat-Based Risk Assessment

ASME B31.8S provides guidance on the threat assessment to pipelines. The threats provided in B31.8S have been used as guidance in this assessment and the attribute of each threat has been considered as they relate to tree root interaction with the pipe.

Table 2 characterizes the degree of interaction with each relevant threat based on the proximity categories defined above. The threat interaction severities ('high', 'medium', and 'low'), reflect the perceived severity for tree root interaction only, and do not necessarily denote absolute threat levels from the perspective of pipeline failure, defined as loss of containment. For example, the descriptor 'high' found

* These distances should therefore be considered a guideline, which is subject to re-evaluation as more information is gathered. Larger zones of influence than those provided below are possible, and consideration of the factors discussed above should be given with respect to the potential for larger zones of influence to exist.

† DBH (Diameter at Breast Height) is the tree diameter at a height of 54-inches (4.5 feet).

in Table 2, represents the greatest interaction potential for tree roots, however this does not suggest an absolute level of elevated threat.

This threat-based risk assessment has assumed that the tree roots are alive and in proximity to the buried pipeline. One factor not considered in this assessment, and also requires consideration as part of the development of a tree root removal program, is the effect of tree roots that are not alive and have the potential to decompose. It is recognized that the decomposition of organic matter will produce carbon dioxide (CO_2) and this has the potential to increase the susceptibility to cracking of the outside diameter pipe surface. Further study, assessment and consideration for this phenomenon is required.

8.3. Risk Mitigation and Monitoring

The removal of trees will reduce the risk profile but on a case-by-case basis, alternative monitoring and/or mitigation strategies may also provide required risk reductions. A listing of example actions and their perceived effect on threat management are provided in Table 2. The further development of Table 2 as part of a comprehensive integrity management program will provide further guidance on mitigation strategies and their effect on risk management.

Similar mitigative measures can also be undertaken to reduce the risk profile related to their effect on ability to monitor and ability to respond. For example, tree trimming will provide a better visual along the right of way that will increase the likelihood to identify encroachments and will better identify a designated corridor. Similar to the development of mitigation strategies related to the threats presented in Table 2, all monitoring and mitigative activities should be identified that will reduce the risk profile for ROW monitoring and response.

9. Conclusions

1. Trees located in close proximity (< 5 ft) from the pipeline centerline damage the external coating and therefore have the potential to cause direct damage to the pipe's pressure-retaining capacity. This may be particularly true for small-diameter (≤ 2 inch), non- steel pipelines that have burial depths of less than 3 ft.
2. Trees located within the pipeline ROW and adjacent to the pipeline ROW adversely affect the risk profile for a pipeline system in the following ways:
    - Increased threat susceptibility
    - Degradation in barriers designed to protect the pipeline
    - Reduction in damage prevention capabilities
    - Reduction of recognizable ROW
    - Impact on ability to perform routine maintenance and monitoring
    - Increase in time frame required for emergency response and pipeline integrity investigations.
3. Tree root interaction with pipelines is difficult to predict based upon study results produced to date.

- Numerous variables (e.g., tree species, local environment, proximity to pipeline, etc.) require more knowledge in order to develop and validate an interaction model.
- It is not yet known, whether the same species of tree affects the pipeline and coating the same way in each instance, to what extent each variable may or may not contribute, and/or whether the variables will be repeatable or predictable for assessing tree root interaction

4. Cathodic protection surveys, including ECDA used for performing integrity assessments may be affected by the root system between the surface of the ground and the pipe and the roots in proximity to the pipe.
5. Removal of trees in close proximity (< 5 ft) to the pipeline will reduce the risk profile related to:
   - Pipeline threats
   - Damage prevention
   - Emergency response.

10. Recommendations

1. Tree removal as follows will reduce the risk profile:
   - All trees within 5 feet of the pipeline centerline should be removed.
   - Trees within between 5 feet and 10 feet of pipeline centerline and DBH 8 inches and greater should be removed.
   - Trees within 10 feet and 14 feet of pipeline centerline and DBH greater than 36 inches should be removed.
   - Trees that will likely affect the buried pipeline in the future should also be removed.
2. Refine reports for Tree Root Investigations produced for the Pilot Program.
   - Further develop a consistent and concise fact-based report to document field findings related to the interaction between the trees and the buried pipelines.
   - Develop definitions and/or comparators to describe the classifications and observations (e.g., moderate, significant, etc.)
3. Develop procedure for tree removal. Consideration for the procedure may include the following.
   - Training programs, in conjunction with Operator Qualification requirements, should be implemented as part of the procedure implementation.
   - Decomposition and CO2 production could increase susceptibility to cracking. Further study, assessment and consideration for this phenomenon is required.
   - The effects of leaving tree root systems in place and how they could affect future pipeline integrity and/or future integrity surveys that may be required.
   - Cautionary guidance while removing trees that may already be affecting a pipeline.
   - Consistent procedures for excavation, non-destructive examination, remediation, documentation, etc.

4. Continue to perform tree root excavations to develop the knowledge related to all of the variables affecting the interaction between tree roots and buried pipelines.
    - This should include diverse species of trees and environments that could potentially affect the interaction.
    - Integrate available ILI data and ECDA data with potential tree root excavation locations and consider excavating where corrosion may be coincident with a tree root system.
5. Develop better understanding of the effects of tree roots on external protective coatings and cathodic protection of the buried pipeline.
    - Consider the impact of tree roots on effectively protecting the buried pipeline including the possibility of shielding.
    - Pipeline corrosion specialists should be retained to evaluate the potential for the presence of tree roots to affect above ground cathodic protection measurements (e.g., CIS, DCVG, etc.).
6. Further develop monitoring and mitigation strategies that can be used for effective risk management in cases where tree removal is not a viable option.
    - Identify all mitigative actions and their effect on the threat susceptibility, ability to monitor, and ability to respond (e.g., root barrier systems).
    - Quantify the effect of the monitoring and mitigative strategies on the risk profile.
7. Work with industry to develop consensus standards and guidelines related to tree setback distances and their effect on pipeline integrity management and risk management.

Table 1. Severity of Threat Interaction Attributed to Tree Roots

Threat Description	Potential for Interaction between Tree Roots and Buried Pipeline			
Threat*	**Threat Attribute**	**Immediate**	**Adjacent**	**Distal**
External Corrosion	Monitoring Accessibility (CIS, DCVG, etc.)	High	N/A	N/A
	ECDA Accessibility	High	N/A	N/A
	Cathodic Protection Interference	High	Med	N/A
	Coating Damage to Susceptible Coatings	High	Med	Med
Internal Corrosion	ICDA Accessibility Interference	Med	Low	N/A
Environmentally Assisted Cracking	Accessibility for Monitoring and Patrol	High	N/A	N/A
	Cathodic Protection Interference	High	Med	N/A
	Coating Damage to Susceptible Coatings	High	Med	Med
Third Party Damage	Increased Activity from Landscaping / Tree Crops	High	Med	N/A
	Depth of Cover Survey Access Interference	Med	N/A	N/A
Weather Related and Outside Forces	Lightning Strikes	High	N/A	N/A
	Uprooting During a Hurricane, Flood, or Tornado	High	Low	N/A
Manufacturing and Construction Related Defects	Stresses Due to Radial Growth	High	Med	N/A

* Threat categories established by B31.8S.

Table 2. Examples of Monitoring and/or Mitigation Actions and Effect on the Risk Profile.

	Will 'action' reduce the threat likelihood?			
Monitoring and/or Mitigation Action	External Corrosion/ Cracking	Lightning*	Weather/ Outside Force	Fatigue
Tree and Root Removal	Yes	Yes	Yes	Yes
Tree Removal	Maybe	Yes	Yes	Yes
Root Barrier System (e.g., barriers, sever between tree and pipe)	Maybe	Yes	Yes	Yes
Tree Trimming	No	Maybe	Yes	Maybe

* For lightning, methods may identify prior damage versus simply protecting from the initial damage.

Table 3. Summary of Tree Root Excavations

DIG ID	Documentation*	Species
2012 Examinations		
Orville[5]	Report	California Sycamores
	Report	American Ash
Yuba City[6]	Report	Walnut Orchard
Kiefer Road[7]	Report / Photos	Liquid Amber
2013 Excavations (Reports Completed)		
132-8[8] (Redacted	Report/Photos	Incense Cedar
153-1[9] (	Report/Photos	Old Monterey Pine
153-3A[1	Report	Monterey Cypress
153-4[11]	Report/Photos	Italian Stone Pine
2013 Excavations (In Progress - Preliminary Information)		
132-1[12,1 Redacted	Photos/DR Field Visit	Redwood
132-2[13]	Photos	Magnolia
132-7[12,1	Photos/DR Field Visit	Privet
132-9A[1	Photos/DR Field Visit	Black Walnut
132-9B[1	Photos/DR Field Visit	Elm
132-10[13	Photos	Juniper (multi-stem)
153-7[12,1	DR Field Visit	Palm
153-9.1[1	Photos	Poplar
153-10[13	Photos	Willow (dead)
153-12[13	Photos	Mulberry

* Report (Excavation Report completed by Frizzell), Photos (Site photos and/or excavation photos available), DR Field Visit (locations visited by Dynamic Risk).

Table 4. Summary of Selected Results from Tree Root Excavations

ID	153-1	153-3A	132-8	153-4	Oroville		Yuba City	Kiefer Road
Species	Monterey Pine	Monterey Cypress	Incense Cedar	Italian Stonepine	California Sycamore	American Ash	Walnut (orchard)	Liquid Amber
Tree Diameter (base)	28”	36”	26”	36”	34”			
Tree Diameter at DBH	34.5”/19.1”	17”/17”/16” 12”/6	20”	35”	18”	35”		
Tree edge to Pipe Centerline	2.5’	< 0.5’	7’	0’				27.8’
Depth of cover	4’	4’	6’	4’		3’10”		
Visual tree root interaction with pipe? (subjective)	Moderate	Insignificant	Moderate / Extensive	Extensive	No			Yes
Coating Impression	Yes	No	Yes	Yes	No		Yes	Yes
Coating Holiday? (intact visually)	No	No	Yes	Yes	No		Yes	
Visual evidence of External Corrosion?	No	No	No	No	No		No	

11. References

[1] Frizzell, Randall, Tree Root Interactions with Natural Gas Transmission Pipelines. Prepared for Pacific Gas & Electric Company by Randal Frizzell and Associates, Nevada City, CA (April, 2012)

[2] "Partnering to Further Enhance Pipeline Safety In Communities Through Risk-Informed Land Use Planning", Pipelines and Informed Planning Alliance (November 2010), Final Report

[3] CFR 192.705(a) Transmission Lines: Patrolling

[4] Fuglem, M.K., Chen, Q., and Stephens, M.J., "Pipeline Design for Mechanical Damage", PRCI Report No. PR-244-9910, October, 2001.

[5] Randall Frizzell & Associates, Oroville, June 2012 Tree Root Interactions With Natural Gas Transmission Pipelines (June, 2012).

[6] Randall Frizzell & Associates, Yuba City, June 2012 Tree Root Interactions With Natural Gas Transmission Pipelines (June, 2012).

[7] Randall Frizzell & Associates, Photos, Kiefer Road (June, 2012).

[8] Randall Frizzell & Associates, Tree Root Excavation Gas Transmission Line 132 734 Manzanita Avenue, Sunnyvale, California (January, 2013).

[9] Frizzell & Associates, Tree Root Excavation Gas Transmission Line 153 15633 Wicks Blvd, San Leandro, (January, 2013).

[10] Frizzell, Randall and Frizzell, Mark. Tree Root Excavation – 15667 Wicks Blvd, San Leandro, CA. Prepared for Pacific Gas & Electric Company by Randal Frizzell and Associates, Nevada City, CA (February, 2013).

[11] Randall Frizzell & Associates, Tree Root Excavation Gas Transmission Line 153 15685 Wicks Blvd., San Leandro, California (January 2013).

[12] Field Visit Photo-documentation by Dynamic Risk Personnel, February 27, 2013.

[13] Photo documentation provided by Randall Frizzell & Associates.