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Pacific Gas and Electric Company

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Tree Root Interference Assessment

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Executive Summary

A. Background

As part of an ongoing commitment to enhance pipelin e safety and integrity, Pacific Gas and Electric Company (PG&E) Gas Operations has undertaken a mult i-faceted right-of-way (ROW) maintenance program. It involves a comprehensive survey of PG&E 's natural gas transmission pipeline system, enhanced marking of the location of the pipeline, i mproved management and removal of certain structures, and the assessment and removal of certa in vegetation (e.g., trees) along the ROWs. This program was initiated in 2011, involved excavations of tree roots during 2012 and through several initiatives evolved into the Pipeline Pathways program, which began in 2013.

In 2013, pursuant to an earlier report on tree root interactions prepared by Dynamic Risk Assessment Systems, Inc. (Dynamic Risk), PG&E developed a util ity standard for right of way management TD-4490S which is being implemented ("the ROW Standard"). S ection 2 of ROW Standard establishes guidelines concerning the removal of trees and other vegetatio n from the ROW by defining required offset distances for vegetation from the pipeline.

In 2013, PG&E also retained Dynamic Risk to conduct additional tree root assessments ("Tree Root Study") that further targeted the investigation of trees that could affect buried pipelines. This rep ort is based on excavation and root growth assessments from 53 targeted excavations and evaluates recorded data and findings from a number of contractors incl uding DNV, Mears, GE, Frizzell & Associates, Tulsa Inspection Resources, Canus Corporation and Fresno State. Data was gathered through above ground surveys[a], excavations, and direct examinations [b] of the exposed pipelines and this report provides the findings and recommendations of these efforts.

B. Attributes for Tree Root Study

Recognizing that buried pipelines rely upon two bar riers to protect the external pipe surface – extern al coatings and cathodic protection (CP), a series of objectives were established for this Tree Root Stud y project. These included: evaluating whether trees and tree roots in close proximity to a buri ed pipeline could damage the external pipeline coating , could shield the effectiveness of CP, increase th e

[A] References to 'above ground survey' are cathodic protection surveys (e.g., DCVG, ACVG, PCM, and CIS) that w ere performed prior to the excavation of a site.
[b] Direct examination refers to exposing the buried pipe via exaction, removing the coating, and performing visu al and non-destructive examinations.

susceptibility to external corrosion or cracking, structurally damage the buried pipeline, or adversely affect the effectiveness of above ground surveys.

The 53 sites excavated as part of this Tree Root Study were identified in order to characterize a cross section of the attributes of interest that would provide insight into determining: (1) whether or not tree roots adversely affect the integrity of buried pipelines; (2) if so, how and to what extent; (3) whether there was any predictability of the impact of roots on a pipeline based on tree species or other readily ascertained information.

Examples of the range of attributes from this study includes 30 species of trees, tree diameters (measured at 54-inches above grade) ranging from 2-inches to 98.5-inches, pipe diameters ranging from 6-inches to 34-inches, three types of external pipeline coatings, and pipe installation years that ranged from 1931 to 1987. In addition, numerous variables which were specifically related to each unique local condition and/or environment were addressed. As a result of this broad cross section of attributes, there was limited ability to analyze information specifics and develop attribute-specific conclusions with a high degree of confidence.

Based on the data collected, this report provides recommendations for the next steps for PG&E to best utilize the results from this study for improved risk prioritization, integrity management, and right-of-way management, related to trees situated on the PG&E ROWs.

C. Summary of Findings

The results of the Tree Root Study conducted to date include:

1. At locations where pipelines and tree root systems co-exist, there is a high occurrence of tree roots causing damage to the external coating on the pipeline (40 out of 53 sites, or approximately 75%). The susceptibility for external corrosion to occur on the pipeline is increased because the primary protective barrier, namely the external coating, is compromised.

2. External corrosion was evident at 15 of the 40 sites (or approximately 38%), where coating damage was present. While external corrosion was evident in these locations, there was insufficient data collected in this study to substantiate or eliminate a direct

causal linkage between the presence of tree roots and external corrosion initiation and/or growth[c].

3. Available data provides no direct evidence that the presence of live tree roots in contact with the pipe increased the susceptibility to the initiation of stress corrosion cracking (SCC). However, by virtue of a failed protective coating, the susceptibility for cracking does increase.

4. There was insufficient data collected in this study to draw any conclusions as to whether the presence of dead tree roots in contact with the pipe has any impact on pipeline integrity.

5. Above ground surveys are not significantly affected by the presence of tree roots. In most cases, above ground surveys correlated with excavation results where coating holidays were observed at sites identified by above ground surveys [5]. Likewise, intact coating was observed at sites where above ground surveys did not produce an indication. Using CIS as a sole measure of the effectiveness of CP in the presence of tree roots, however, may have limitations.

   In addition, the effectiveness of External Corrosion Direct Assessment (ECDA) does not appear to be adversely affected by the presence of tree roots. ECDA is an assessment method that relies upon above ground surveys. ECDA is used to determine whether external corrosion is a potential integrity concern at specific locations along the pipeline. It requires at least two types of surveys (e.g., CI S, ACVG, DCVG, and PCM) be conducted as part of the assessment. The above ground surveys performed as part of this Tree Root Study relied upon at least two above ground survey methods and the correlation between those techniques and locations where coating damage was observed indicates the presence of tree roots does not appear to render ECDA ineffective.

6. The ability to cathodically protect buried pipe does not appear to be adversely affected by tree roots. This finding is based on the fact that tree roots do not apparently shield CP and calcareous deposits[d] were identified on the pipe. Nonetheless, CP is designed to

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[c] These instances of corrosion were identified at excavations undertaken before the full data recovery protocol was in place. Bacteria counts were not collected at any of the 15 stes and above ground surveys were conducted at only 2 ofthe 15 sites.
[d] Calcareous deposits are the result of the cathodic protection polarization process and are indicative that cathodic protection is affecting the buried pipe.

mitigate corrosion, and as a mitigation measure, adequate CP may not always be able to prevent or eliminate corrosion in cases where the external coating has failed.

7. While CP effectiveness and CP monitoring are not significantly affected by the presence of tree roots, it is evident that tree roots can damage the external coating of the pipe such that CP is required to mitigate corrosion.

8. There is the potential for tree roots to structurally damage the pipeline, including inducing increased bending strains, if tree roots are uprooted by external forces. While this was not observed at any of the 53 sites, one site in particular (Hall Road) clearly demonstrated the significance of this potential threat. The root ball was located directly above the pipe and the pipeline was fully encapsulated by the Valley Oak tree roots. In a similar situation, if external forces and events (such as seismic, high winds) caused movement of the tree and tree roots, the forces created by such movement could damage the buried pipeline.

9. The distance of the tree to the buried pipeline and the depth of the buried pipeline appear to be two primary attributes that can be used to predict potential interaction of tree roots with the buried pipeline. While the ROW Standard establishes guidelines with recommended offset distances for ranges of tree sizes (DBH), the data from this study suggests the z-factor, which considers both lateral offset and depth of cover may provide additional value in predicting the potential interaction of tree roots with buried pipelines. Given the limited breadth of data gathered in this Tree Root Study, however, PG&E may elect to collect and analyze further data on z-factor before modifying the ROW Standard.

10. While additional investigation of the impact of tree roots on various coating types is warranted, the current data indicates PG&E can consider coating as an attribute for predicting the interaction with tree roots. Of the 45 sites where the external coating types were either hot applied asphalt or coal tar enamel, coating damage was identified at 38 sites (or 84%). For the 8 remaining sites where the external coating type was polyethylene tape, 2 sites (25%) identified coating damage. The reason for this difference was not resolved as part of this study. None of the sites within this program contained pipe with fusion bonded epoxy (FBE) or other external coating types.

11. The vegetation offsets and proximity guidelines set forth in PG&E's ROW Standard are consistent with findings to date.

D. Next Steps

While much has been learned through the Tree Root Study, the information collected indicates additional work can be undertaken to provide further insight into to the management of trees located along the ROW to further safeguard and enhance pipeline integrity.

Recommended additional steps for consideration by PG&E management include:

1. Gather additional information about specific targeted attributes of interest [e.g., species of tree, depth of cover, tape coated pipelines, sites with dead trees, additional MICKits (when available)] to provide assistance in refining the management of trees on the ROW.

2. Perform supplementary work on ground penetrating radar to determine if it is an effective means for identifying and characterizing the location and extent of roots near buried pipelines.

3. Develop and integrate a detailed summary of the attributes along PG&E's ROW related to managing the presence of trees on or near the ROW and to assess the potential extent of external corrosion and coating damage. This summary would include (a) pipeline attributes such as pipeline centerline, depth of cover, pipe diameter and external coating type; (b)tree attributes such as the lateral distance from the tree to the pipeline centerline, species of tree and tree size (DBH); (c) develop a consequence screening process that may consider designated high consequence areas (HCA's) or other information based upon the occupancy count of structures located along the pipeline ROW, and (d) any integrity monitoring or mitigation results for the specific pipeline segment including above ground surveys, in-line inspection, and hydrostatic testing.

4. Once the detailed summary of attributes and consequence screening results are finalized, develop and implement a risk management framework that relies upon the specific attributes to manage and reduce the increased risk to pipeline integrity presented by the presence of trees on the ROW. Utilize a public safety consequence analysis, such as HCA or the occupancy count of structures (for example, the average occupancy count or total occupancy count) to help prioritize the timing of management of trees on the ROW. This risk framework can then be relied upon to develop a consistent and defensible approach to manage trees located along the pipeline ROW, and may lead to additional excavations to obtain additional attribute-specific information related to the interaction of tree roots and buried pipelines (similar to the example in Table 9).

5. Further assess of the results produced by this portion of the Tree Root Study, with particular focus on consolidation and alignment of the observations from each of the contractors.

E. Conclusion

The results from the Tree Root Study program support the conclusions reached in the work performed to date that the presence of tree roots adversely affect the buried pipelines. The analysis demonstrates that the tree roots adversely affect the risk profile of the pipeline as it relates to susceptibility to external corrosion and structural damage to the pipeline due to tree movement caused by events (e.g., high winds, seismic). The analysis also provides a degree of confidence that above ground surveys (such as CIS combined with DCVG) and the use of ECDA as an assessment tool remains effective in the presence of roots. The data collected demonstrated a lack of predictability of the impact of roots based on tree species or other readily ascertained information such as soil types or irrigation practices. The study supports the continued use of PG&E's ROW Standard for managing vegetation on the ROW, but also provides additional knowledge related to certain attributes that can be used to evaluate and manage the potential risks of the interaction between tree roots and buried pipelines (such as the proximity of the tree to the pipeline) and the need for and prioritization of removal of trees from the ROW. In addition, these results provide information that may be relied upon for developing site-specific prioritization, assessment, monitoring, and mitigation strategies based upon additional site-specific information.

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1. Background

As part of an ongoing commitment to enhance pipelin e safety and integrity, Pacific Gas and Electric Company (PG&E) Gas Operations has undertaken a mult i-faceted right-of-way (ROW) program. It involves a comprehensive survey of PG&E's natural gas transmission pipeline system, enhanced marking of the location of the pipeline, improved managemen t and removal of certain structures, and the assessment and removal of certain vegetation (e.g., trees) along the ROWs. This program was initiated in 2011, involved excavations of tree roots during 2012 and through several initiatives evolved into t he Pipeline Pathways program, which began in 2013.

The evaluation of the interaction between tree root s and the pipelines was initiated during early 2011 and has evolved as follows:

- In 2011, PG&E retained Frizzell & Associates to pro vide arborist expertise and support for a number of exploratory excavations to evaluate the i nteraction between tree roots and buried pipelines as part of the PG&E Vegetation Management program.
- Frizzell & Associates prepared a 'White Paper' [1e] on the interaction of tree roots with buried pipelines from an arborist's point of view which wa s based upon their subject matter expertise and publicly information literature. This White Paper provided a summary review of known and potential root–pipeline interactions i n public literature and an arborist's assessment of the risks posed by tree roots for the safe operation and maintenance of pipelines. In addition, recommendations for managem ent of trees in proximity to buried pipelines were included.
- As a result of the White Paper, PG&E worked with Fr izzell & Associates to undertake a number of pipeline excavations and examinations inv olving a selected sample of tree root systems.
- Dynamic Risk Assessment Systems, Inc. (Dynamic Risk) was retained by PG&E in late 2012 to provide an assessment of the potential pipeline int egrity management related threats created by the presence of tree roots and to offer technical support during the tree root excavation program.
- In September 2012, PG&E commenced a ROW management 'Pilot Program' on a 10-mile section of Line 132 and a 10-mile section of Line 1 53, with the objective to better identify structures and trees encroaching upon the pipeline right-of-way (ROW). As part of this Pilot

[E] References are listed at the end of the text in Section 11, References.

Program, PG&E identified a number of pipeline excavation sites involving a representative sample of pipeline characteristics, tree species and root systems.

- Dynamic Risk produced a report [2] dated April 29, 2013 that summarized the results of the tree root excavations performed to date. This report provided recommendations related to tree root risk related mitigation of pipeline threats and expressed the need for continuation of the tree root excavation program in order to collect additional data.

- In 2013, pursuant to an earlier report on tree root interactions prepared by Dynamic Risk, PG&E developed a utility standard for the ROW management ("ROW Standard", TD-4490S[3]) which is being implemented. Section 2 of TD-4490S establishes guidelines that define required offset distances for vegetation along the ROW.

- In 2013, PG&E also retained Dynamic Risk to conduct additional assessment related to the interaction between tree roots and buried pipelines ("Tree Root Study"). This study targeted the investigation of trees with a range of attributes to obtain knowledge about the interaction between tree roots and buried pipelines.

This final report of the current Tree Root Study encompasses the findings and conclusions for the tree root examinations conducted during 2012 and 2013 and it expands upon the initial Dynamic Risk report[2]. This final report also serves as a follow-up to a Dynamic Risk produced interim project status power point presentation dated October 29, 2013[4].

2. Initial Tree Root Study Parameters

Based upon evaluation of agricultural conditions, application of historical data sets (In-Line Inspection and Direct Assessment results) and White Paper findings, the PG&E Integrity Management Department developed the following primary pipeline characteristic-based excavation site selection criteria for continuation of the tree root investigation:

- pipeline depth of cover (4 feet or less), and
- pipeline installation year (30 years or greater), and
- pipeline diameters (most common in PG&E system; 6 inch to 30 inch), and
- coating type [most common in PG&E system; Cold Tar Enamel (CTE), Hot Applied Asphalt (HAA), Polyethylene Tape (Tape)]

A secondary tree characteristic-based protocol for excavation site selection was developed by the PG&E Vegetation Management Group as follows:

- tree species,
- Diameter Breast Height (DBH),

- tree proximity to pipeline, and
- tree stump / previously cut.

A pre-excavation assessment to further evaluate the selected excavation sites on the basis of ROW access conditions and the potential to gain meaningful data was subsequently conducted by PG&E.

To assist in the continuing Tree Root Study, PG&E retained Dynamic Risk to:

- continue the assessment of the interaction of tree roots with PG&E's buried natural gas transmission pipelines to identify and understand the potential threats that tree roots may pose to pipeline integrity,
- provide continued technical support for the development and implementation of the Tree Root Study,
- conduct assessment of the results from the Tree Root Study, and
- develop findings from the Tree Root Study and produce a final report with findings and recommendations for submission to PG&E's Transmission Integrity Management team for further consideration.

3. Objectives of Tree Root Study

The objectives of the Tree Root Study were:

1. To evaluate the interaction of live tree roots with buried pipelines in order to determine and quantify threats to pipeline integrity, including addressing the following questions as to whether:

    a. Coating damage can occur where the pipe is in contact with tree roots.

    b. Conditions for corrosion initiation and/or accelerated corrosion exist where the pipe is in contact with tree roots.

    c. Deformation, ovality changes or other related damages that occur at locations where the pipe is in contact with tree roots.

    d. Additional attributes related to the presence of tree roots near/on the pipeline should be considered.

    e. Trees that may remain on the pipeline ROW can be subjected to other pipeline integrity monitoring efforts, such as ECDA or in-line inspection.

2. To evaluate whether dead tree roots near or on the pipeline create a local environment that may be conducive to initiating external corrosion or accelerating corrosion growth.

3. To study effectiveness of above ground surveys [f] performed at locations with dense tree root systems, including addressing the following questions:

    a. Do tree roots near or around pipelines interfere with pipeline integrity surveys and assessments?

    b. Does the presence of the tree roots on/near the pipeline interfere with the ability to cathodically protect the buried pipeline?

    c. Does the presence of tree roots on/near the pipeline adversely affect above ground surveys?

    d. If it is determined that above ground surveys can be impacted by the presence of tree roots, does removing the tree, but leaving the root base, in accordance with the current PG&E ROW standard[3] reduce or eliminate this impact?

4. To evaluate PG&E's ROW Standard in regards to vegetation control, including Pipe Zone and the Border Zone, to determine if it is sufficient to appropriately manage pipeline integrity.

4. Additional Technical Support

The scope and nature of the objectives of the Tree Root Study called for technical expertise in both gathering and evaluating the different types of data. Below is a description of the additional contractors selected by PG&E and Dynamic Risk to provide specific expertise to the Tree Root Study, along with a brief summary of their scope of work and highlights from their referenced draft reports (which are attached in Volume II of this Report). While Dynamic Risk relied on the findings of these reports in reaching the findings and recommendations contained herein, we believe further work is necessary in one aspect of these reports. Specifically, additional work is necessary to fully evaluate and understand the nuances in the individual arborist reports related to the specific nature of certain tree species.

4.1. Det Norske Veritas (DNV)

DNV was tasked to support PG&E in determining how root systems can affect the susceptibility of buried pipelines to external corrosion and how the root systems impacted cathodic protection and the reliability of above ground survey measurements used to assess the effectiveness of CP. In addition, DNV was tasked with providing guidance on data collection and to assess the data collected at excavation sites in order to support and better develop their opinion regarding the potential damage tree roots inflict on buried pipelines. The three technical questions that DNV was requested to address included whether:

[F] Reference to 'above ground survey' is to cathodic protection surveys (e.g., DCVG, ACVG, PCM, and CIS) that are performed prior to the excavation of a site.

- the presence of tree roots (dead or alive) affect the likelihood or severity of external corrosion and/or stress corrosion cracking (SCC),
- the presence of tree roots alters the effectiveness of CP to mitigate external corrosion on a pipeline, and
- the presence of tree roots adversely affects above ground survey measurements.

DNV also performed a literature review to gather industry data on damage to oil and gas pipeline's protective coatings caused by tree roots.

In addition, DNV provided guidance with the data collection methods including Microbiological Induced Corrosion Kit (MICKit) tests to evaluate the local environment at contact points between the tree roots and the pipe surface. DNV relied upon the findings from the pre-excavation above ground surveys and the direct examination results and provided support in developing the findings for this study, specifically as it related to the potential for coating damage, corrosion, and cracking. Additional details from their report are provided in Reference 5.

4.2. General Electric Energy (GE)

GE Energy was tasked to assess site location, perform NDE inspections, document inspections, collect direct examination inspections/test data and generate completed modified PG&E H-form reports. GE Energy was replaced by Mears Group, Inc. in mid-September, 2013. Mears Group had resources available to provide a broader range of support required for the pre-excavation and excavation support required for this project.

4.3. Mears Group, Inc. (Mears)

Mears was tasked to conduct above ground surveys prior to the excavation as required to evaluate the existing level of CP, determine the extent of low potential areas, define the pipeline depth and identify locations of coating anomalies. In mid-September, 2013 Mears was also tasked with collecting direct examination inspections/test data as specified on the modified PG&E H-Form and obtaining MICKit water samples for bacteria analysis where appropriate. Compilation of the above ground survey data and completion of an alignment correlation of above ground survey results with direct examination results was also a Mears responsibility.

4.4. Frizzell & Associates

Frizzell & Associates were the on-site arborist representatives and were tasked with recording and documenting the extent of root activity in proximity to buried natural gas pipeline systems via a compilation of excavation site investigations. A summary of Frizzell & Associates responsibilities included:

- Record field inventory measurements of tree and root inventory data as well as growing patterns around buried pipelines,

- Work with Fresno State, in developing a means of assessment of potential tree and vineyard root growth near pipelines, and
- Build a document and photo library providing information on project specific examples of root growing patterns in and around buried pipelines.

A majority of the efforts provided by Frizzell & Associates were directed at characterizing the root structure in proximity to the pipe. Frizzell & Associates also provided guidance and observations related backfill types and textures, the types of roots that affected buried pipelines and coatings, and differences related to tree species, irrigation, and extent of area affected ('total contacts') by the tree root on the pipe. Additional details from their report are provided in Reference 6.

4.5. California State University Fresno Center for Irrigation Technology (Fresno State)

Fresno State was tasked with determining the potential for tree root growth in orchards based on a variety of attributes (for example, species of tree, tree size, irrigation patterns) and collecting data in order to assess the correlation between Ground Penetrating Radar (GPR) and direct examination findings for selected sites. This work was performed to determine (a) the effectiveness of using GPR to locate tree roots; (b) the potential for aggressive root structure growth of various orchard trees; and (c) the impact of soil type on tree root growth. Fresno State worked with Frizzell & Associates to develop an assessment of tree roots near buried gas pipelines and to provide a report on their findings.

Fresno State provided a comprehensive report covering many aspects of their work performed under the direction of PG&E. For the purpose of this program, a summary of the relevant portions of their report was provided. Fresno State used GIS to integrate the pipeline system with crop types identified through publically available databases. A pilot project using GPR was also completed by Fresno State to evaluate the degree and patterns of root systems. Additional details from their work are provided in Reference 7. Fresno's report contains analysis and evaluation of their findings are provided, but as noted above, additional work is necessary to evaluate and understand the differences between Fresno's report and that of Frizzell & Associates, specifically related to findings related to specific tree species.

4.6. Canus Corporation (Canus) & Tulsa Inspection Resources, Inc. (Tulsa)

Canus Corporation and Tulsa Inspection provided National Association of Corrosion Engineers (NACE) Certified Inspectors to act as the PG&E (owner) representative on each tree root excavation site. The NACE inspectors managed the overall safety for each excavation site and were responsible for verifying that the pipeline excavation crew (Snelson Companies, Inc.) followed PG&E protocols and specifications for the excavation. In addition, they were responsible for proper re-coat and backfill processes, collecting excavation data and completion of the PG&E A-Form.

Table 1. Overview of Information and Results Provided by Contractors

Documents	Received	Comments
NACE Inspectors (A-Forms)	47 of 53	6 reports were unavailable at the time of producing this report.
H-Forms	38 of 53 sites	No H-Forms for 15 of 53 sites (nocoating damage) Of the 38 sites with H-Forms Complete H-Forms (GE) for 15 of 38 sites Modified H-Forms (Mears) for 23 of 38 sites
Frizzell & Associates Arborists Reports Received	53 of 53	
Above ground Survey Reports Received	23 of 53	19 sites were available for analysis 4 sites eliminated In mid-September, Mears performed above ground surveys for the 23 sites remaining in the program, however 4 sites were subsequently not excavated due to casings and elimination of excavations.
Microbiologically Induced Corrosion Kits (MICKit) Received	9 of 53	In mid-September, MICKits were introduced into the data collection process. Of the 9 excavations suitable for MICKit analysis, none of the sites contained external corrosion.
Fresno State University (GPR)	2 of 53	No GPR performed at 51 of the sites

5. Data Collection and Organization

In order to meet the objectives of this program, 53 [g] sites were identified for excavation and direct examination based upon the selection criteria presented above. These sites were identified in order to characterize a cross section of the specific attributes that would provide insight into determining whether or not tree roots adversely affect the integrity of buried pipelines, and if so, how, to what extent, and under what conditions. Throughout the course of this program, the field data collection procedures, documentation, and excavation methods were improved and modified in order to obtain as much information as possible from each site. An overview of the excavation site data collection procedure is provided within Section 5.1, Figure 1 below. The PG&E Tree Root Spreadsheet [h] (Matrix

[g] While 57 locations originally were targeted for excavation, four (4) sites were eliminated from this analysis – two (2) sites exhibited casings (RWVIM-142-13, RWVIM-143-13) and two (2) sites were only subjected to above ground surveys, excavations were not performed (RWVIM-161-13, and RWVIM 164-13).

[H] See Attachment 7 of Volume II – Tree Root Threat Assessment

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Spreadsheet) was produced to summarize the results, and an overview of the spreadsheet attributes is provided below within Section 5.2.

5.1. Excavation Site Data Collection

A consistent data collection and reporting process was developed that included pre-excavation above ground survey reporting (Mears Form), excavation methods used to expose the tree root system and buried pipeline (mechanical and hydro-vacuum), external pipeline coating condition assessment and excavation site reporting (PG&E A-Form) [i], and pipeline direct examination reporting (PG&E H-Form). The H-Form currently used by PG&E was subsequently modified to provide increased focus on the direct examination objectives for this study ('Modified H-Form') [j].

The excavation process and data collection procedure is summarized in Figure 1. As noted in this figure, two (2) excavation methods were used – mechanical excavation and hydro-vacuum. The hydro-vacuum was used initially in order to preserve the root structure such that the root structure could be accurately mapped between the tree and the buried pipeline. Mechanical excavation was used at selected sites so that additional data could be collected specifically related to corrosion, CP, and the local environment (e.g., contact area of tree root and pipe surface), recognizing that if water from the hydro-vacuum was used, it would alter the local environment. Above ground surveys and GPR were also undertaken at selected sites prior to excavation. The results provided by the contractors were collected, reviewed, and summarized in the Matrix Spreadsheet.

[i] See Attachment 6 of Volume II – Tree Root Threat Assessment
[j] See Attachment 5 of Volume II – Tree Root Threat Assessment

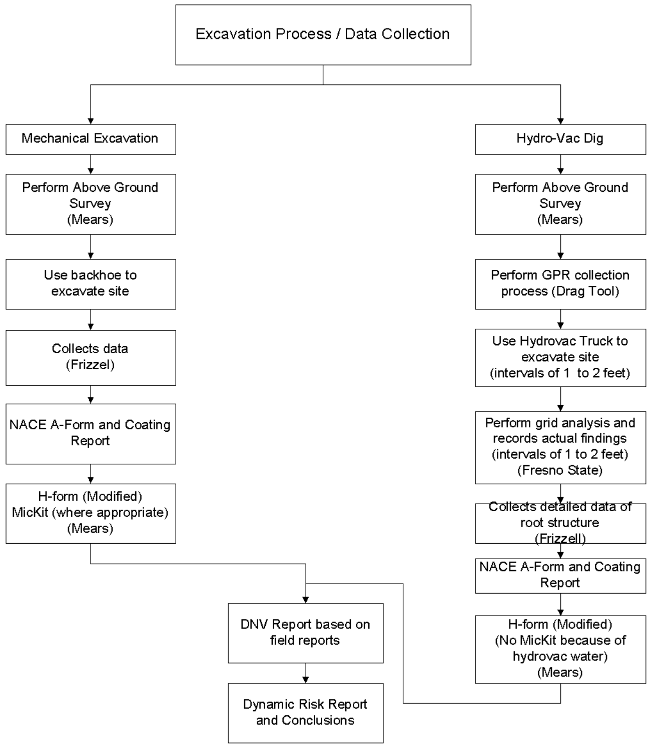

Figure 1. Excavation Process

5.2. Tree Root and Pipeline Interaction Matrix Development

The Matrix Spreadsheet was developed to assimilate the results from each excavation site. This Matrix Spreadsheet considered the primary variables used t o evaluate the interaction between tree roots and buried pipelines. A summary of these primary variables is as follows:

- species of tree (e.g., type and size of root system),
- size of the tree (e.g., DBH, age),
- z-factor to characterize the distance from the tree to the buried pipeline (depth of cover and offset distance from the tree),
    - lateral offset distance (e.g., proximity of tree to pipeline centerline)
    - depth of cover measurement
- local environment (e.g., irrigation, land use, water table depth, etc.),
- soil (e.g., native backfill, etc.),
- type of coating (pipeline and girth weld),

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- pipe diameter, and
- installation year of the pipe.

The primary role for the various contractors used to support the information gathering for this project is summarized below:

- Frizzell & Associates performed a detailed field study that characterized the tree root system in proximity to the buried pipeline[6].
- Fresno State provided information related to GPR[7].
- Mears provided a pre-excavation and direct examination results[8] and a summary of the results[9].
- Tulsa and Canus provided direct examination results[10].

5.3. Overview of Target Excavations and Results

Once all of the excavations were completed and the information was provided by all of the contributing contractors, the Matrix Spreadsheet was finalized. This Matrix Spreadsheet was then used to analyze the range of attributes across the 53 sites. An overview of the range of these attributes from this study is as follows:

- Thirty (30) species of trees,
- Range of Tree Sizes: DBH ranging from 2-inches to 98.5-inches. Average was 30-inches and a standard deviation[k] of 18-inches,
- Range of Years of Pipeline Installation: 1931 to 1987. Average was 1951 with a standard deviation of 15 years,
- Range of Pipeline Diameters: 6-inch to 34 inch,
- Three (3) coating types: Hot Applied Asphalt (32), Coal Tar Enamel (13), and Polyethylene Tape (8),
- z-factor ranging from 3-feet to 12.5 feet. Average was 6.0 feet with a standard deviation of 2.4 feet,
  - ◊ Depth of Cover above the pipe: 2.5 feet to 8 feet. Average was 4.2 feet with a standard deviation of 1.2 feet.
  - ◊ Lateral offset distance: 0 feet to 11 feet. Average was 3.6 feet with a standard deviation of 3.0 feet.

[k] For a normal distribution, 68% of the data will lie within plus-or-minus 1 standard deviation. For example, one would expect 68% of the DBH's to fall within 12-inches and 48-inches (i.e., 30 inches plus or minus 18 inches).

This broad cross section of attributes, and limited nature of data collection, presents challenges in establishing a high degree of confidence regarding attribute-specific conclusions. For example, particular focus on a single attribute (e.g., species of tree, depth of cover, or land use) would target specific information that could be better used to evaluate the impact of a few of the attributes. While the analysis, observations, findings, and recommendations presented herein are supported by and based upon the available information and subject matter expert interpretation of results, some of the data limitations that should be recognized are as follows:

- The study targeted only vintage pipe coatings (Tape Wrap, Hot Applied Asphalt, Cold Tar Enamel) as these coatings form the basis for the majority of PG&E system pipelines where older and larger trees exist in the right-of-way. Newer pipe coatings (e.g., FBE) were not targeted since application of this coating type is relatively recent within the PG&E system and the trees on these portions of the system have not progressed to sufficient size (e.g. DBH) to qualify for the study.
- The study targeted primarily live trees. Very few previously cut trees (stumps) or dead trees were targeted for excavation.
- The study targeted many species and sizes of trees coupled with a range of distances between the tree and the buried pipeline.
- The study incorporated a range of local environment such as historic climatic conditions, irrigation approach, soil type, and land use.

6. Analysis of Results

The Matrix Spreadsheet was used to identify commonalities and trending conditions related to the potential for tree roots to affect buried pipelines from the 53 sites. The particular focus of this analysis was on:

- External coating damage and external corrosion,
- Structural damage (e.g., root caused pipe deformation, pipe damage due to weather and outside force),
- Effectiveness of above ground surveys, and
- Effectiveness of current PG&E vegetation control standards and procedures.

A summary of the findings for each of the above focus areas is provided below.

6.1. Pipeline Threat Susceptibility- Coating Damage, External Corrosion, and Cracking

Buried pipelines rely upon external coating and 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 along the pipe between the coating and the pipe surface[1,2].

The Matrix Spreadsheet was analyzed to identify attributes that characterized the effect of tree root systems on buried pipelines with particular focus on locations where coating damage and/or corrosion was observed during the excavation. Attributes were identified where trends were identified and included DBH, tree species, pipe depth, tree distance from centerline of pipe, and pipeline coating type. Coating damage was trended based upon observations at a number of excavation sites that exhibited damage due to tree root contact.

Coating damage was observed at 40 of the 53 sites. External corrosion was evident at 15 of the 40 sites (or approximately 38%), where coating damage was present[l]. While external corrosion was evident in these locations, there was insufficient data collected in this study to substantiate or eliminate a direct casual linkage between the presence of tree roots and external corrosion initiation and/or growth.

The distribution of damage as a function of external coating type is summarized in Table 2. These results show that for the excavations performed, over 80% of the sites with CTE or HAA coating types [m] had coating damage attributed to the tree root system. While there are limited results for the sites with tape coating (8 sites), the propensity for coating damage appeared to be much lower. Examples of CTE and Tape coating damage caused by tree roots are presented in Figure 3 (RWVIM-107-13, Weber Lane) and Figure 4 (RWVIM-74-13, Atascadero), respectively. Since none of the excavations sites within this study contained pipe with fusion bonded epoxy (FBE) and there are limited results for pipe with polyethylene tape coating, there is insufficient information within the results to understand whether or not these coatings are less susceptible to damage from tree roots.

For each of the excavation sites, Wet Fluorescent Magnetic Particle Inspection (WFMPI) was performed after the coating was removed and the pipe surface was prepared prior to performing WFMPI. The purpose of WFMPI is to identify and characterize any cracking that may exist on the pipe surface. Within this study, no cracking was identified.

In order to further assess the local environment at the contact points between the tree roots and the pipe surface, MICKit analysis was performed at 9 sites (see Table 1). The MICKit is used to quantify and qualify chemical parameters such as Calcium, Carbonates, Ferric iron ($Fe3+$), Ferrous iron ($Fe2+$), pH, and Sulfide. The results from the analysis can then be used to determine whether or not the local environment is conducive to corrosion, accelerated corrosion growth, and/or crack initiation (for example, stress corrosion cracking or hydrogen induced cracking). In addition, it can provide an indication as to whether CP is effective at the location of sampling.

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[l] These instances of corrosion were identified at excavations undertaken before the full data recovery protocol was in place. Bacteria counts were not collected at any of the 15 stes and above ground surveys were conducted at only 2 ofthe 15 sites.
[m] The coating type as reported on the A-Form was used.

In mid-September, MICKits were introduced into the data collection process. Of the 9 excavations suitable for MICKit analysis, none of the sites contained external corrosion. Therefore, the MICKit results are inconclusive.

Within this program, the potential effect of tree roots on CP effectiveness has been evaluated specifically related to CP shielding, CP effectiveness, and reliability of above ground surveys. Analysis of the available data suggests the following:

- No evidence of CP shielding was identified. Tree roots are conductive and thereby reduce the potential for CP shielding 5. Based upon the excavation results, there was no evidence that corrosion was any more significant at tree root contact points when compared to adjacent areas of coating damage and external corrosion.

- Above ground surveys are not significantly affected by the presence of tree roots. In most cases, above ground surveys correlated with excavation results where coating holidays were observed at sites identified by above ground surveys5. Likewise, intact coating was observed at sites where above ground surveys did not produce an indication.

- The ability to cathodically protect and monitor buried pipe does not appear to be adversely affected by tree roots. Since the tree roots do not apparently shield CP, above ground surveys are capable of detecting coating holidays, and calcareous deposits[n] were identified on the pipe, there was no evidence that tree roots adversely affect cathodic protection. However, it should be recognized that cathodic protection is designed to mitigate corrosion, but is not always able to eliminate corrosion, in cases where the external coating has failed.

- While CP effectiveness and CP monitoring are apparently not affected by the presence of tree roots, it is evident that tree roots damage the external coating such that CP is required to mitigate corrosion.

- No evidence of cracking was identified by the WMPI.

6.2. Development of the z-factor

In evaluating the results from the 53 sites, a comparison between the lateral offset distance and depth of cover was produced and is presented in Figure 5. The legend provided in this figure discriminates the data based upon the tree diameter (DBH) and whether or not coating damage was evident.

If the offset distances referenced within the ROW Standard are applied to the findings from the 53 sites, the following summary is produced (see Table 3):

[N] Calcareous deposits are the result of the cathodic protection polarization process and are indicative that cathodic protection is affecting the buried pipe.

- Lateral Offset Distance less than 5-feet
  - 35 of 39 sites (90%) exhibited coating damage
- Lateral Offset Distance between 5-feet and 10-feet, and DBH greater than 8-inches
  - 3 of 12 sites (25%) exhibited coating damage
  - Note: None of these sites had a DBH less than 8-inches
- Lateral Offset Distance great than 10-feet, and a DBH greater than 36-inches
  - 2 of 2 sites (100%) exhibited coating damage.

As is evident from Figure 5, there is no obvious trend from these results. This is likely due to the number of attributes that influence the results. However, it is evident that tree size (DBH), offset distance, and depth of cover may be indicators as to whether or not coating damage has occurred.

One of the attributes that warrants further investigation is whether incorporating depth of cover into the offset distances referenced within the ROW Standard is warranted. In order to consider both lateral offset distance and depth of cover, the 'z-factor' was developed to assess the shortest distance between the tree and the top of the buried pipeline. The 'z-factor' is a function of the horizontal offset distance between the pipe and the tree (x) and the depth of cover [illegible]. A schematic of this is provided in Figure 2 and is calculated using the equation shown below:

For the 53 sites, the Matrix Spreadsheet was analyzed to determine whether or not there was a correlation between coating damage and distance between the tree and the buried pipeline as characterized by the z-factor. The results of this analysis are presented in Table 4 show that coating damage was observed at 90% of the sites (22 of 24 sites) where the z-factor was less than 5-feet [o]. In addition, coating damage was observed at 67% of the sites (16 of 24 sites) where the z-factor ranged from 5-feet to 10-feet [p]. For the five (5) sites where the z-factor was greater than 10-feet, coating damage was observed at 40% of the sites (2 of 5 sites).

In order to further evaluate the ROW Standard guidelines, results similar to those presented in Table 3 have been produced, except that the z-factor has been used as opposed to lateral offset distance. The results for the 53 sites are presented as a function of DBH and z-factor in Table 5 and Table 6 for those sites with coating damage (40) and without coating damage (13), respectively.

A summary table was then produced (see Table 7) and establishes the correlation of sites with and without coating damage as function of DBH and z-factor. The results presented in this table suggest a stronger correlation than the ROW Standard guidelines based upon lateral offset distance. However, it

[o] For reference, this results in an offset distance of 5.2-feet for a typical 36-inch depth of cover.
[p] For reference, this results in an offset distance ranging from 5.2-feet to 9.54-feet for a typical 36-inch depth of cover.

should be recognized that these correlations are ba sed upon limited information, but does suggest that the ROW Standard guidelines may be modified as additional information becomes available.

Table 2. Coating Type Analysis

Coating Type	Damaged	Percentage
CTE	12 of 13 sites	92%
HAA	26 of 32 sites	81%
Tape	2 of 8 sites	25%
Totals	40/53	75%

Table 3. Offset Distance Based Upon ROW Standard Guidelines

Offset Distance (feet)	Coating Damage	Percentage
< 5 feet	35 of 39 sites	90%
5 to 10 feet, DBH > 8 inches	3 of 12 sites	25%
10 to 14 feet, DBH > 36 inches	2 of 2 sites	100%
Totals	40/53	75%

Table 4. z-Factor Analysis

z-factor (feet)	Coating Damage	Percentage
< 5 feet	22 of 24	91%
5 feet to 10 feet	16 of 24	67%
> 10 feet	2 of 5	40%
Totals	40/53	75%

Table 5. z-Factor Analysis compared to Tree Size (DBH)[q] for 40 sites with Coating Damage

	z-factor		
DBH, inches	0 to 5 feet	5 feet to 10 feet	> 10 feet
< 8 inches	4		
> 8 inches	18	16	2
>36 inches	1	5	2

Table 6. z-Factor Analysis compared to Tree Size (DBH)[r] for 13 sites without Coating Damage

	z-factor		
DBH, inches	0 to 5 feet	5 feet to 10 feet	> 10 feet
< 8 inches			
> 8 inches	2	8	3
>36 inches	1	2	1

Table 7. Comparison of Table 5 and Table 6

	z-factor			
DBH, inches	0 to 5 feet	5 feet to 10 feet	> 10 feet	
< 8 inches	4/4 (100%)			4/4 (100%)
> 8 inches	18/20 (90%)	16/24 (67%)	2/5 (40%)	36/49 (75%)
>36 inches	1/2 (50%)	5/7 (71%)	2/3 (60%)	8/12 (67%)
	23/26 (88%)	21/31 (68%)	4/8 (50%)	

[q] This table does not add up to 40 sites since the DBH's greater than 8-inches also include the DBH's greater than 36 inches.
[r] This table does not add up to 13 sites since the DBH's greater than 8-inches also include the DBH's greater than 36 inches.

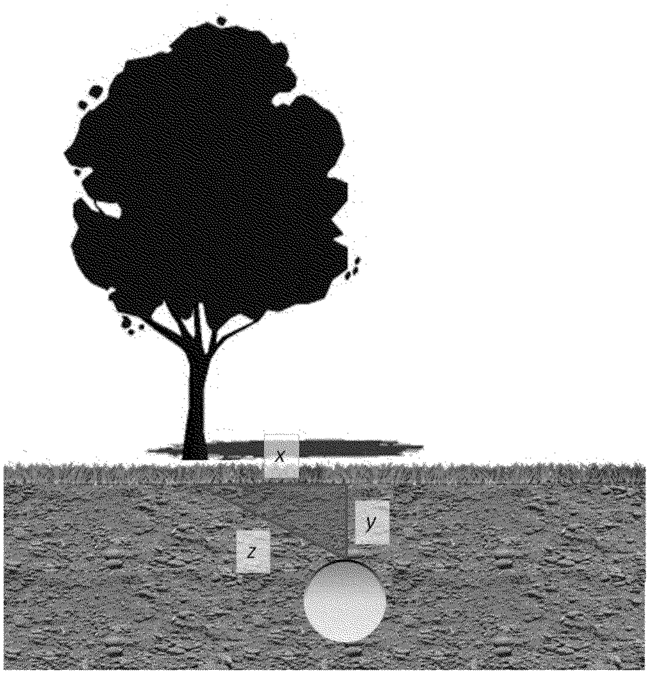

Figure 2. Calculation of z-factor

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Figure 3. RWVIM-107-13 (Weber Lane)
(CTE coating damage)

Figure 4. RWVIM-74-13 (Atascadero)
(Tape coating damage)

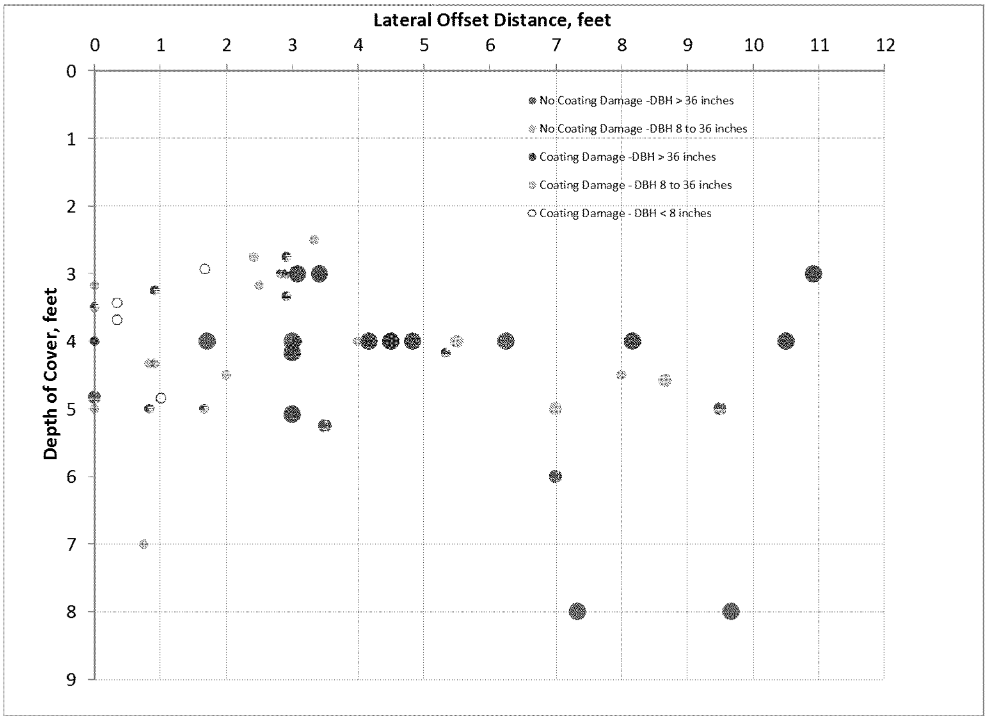

Figure 5. Depth of Cover versus Lateral Offset Distance[5].

6.3. Pipeline Threat Susceptibility – Structural Damage

Tree root and pipeline interactive conditions were reviewed relative to the potential for pipeline structural damage. An example of one location where the tree root ball was situated directly on top of the pipe and the tree roots encapsulated the buried pipe is presented in Figure 6 (RWVIM-90-13, Hall Road).

While there is a concern for the tree root ball and root system to directly and adversely affect the pipe (e.g., produce ovality, dents, increase bending strain), there was no evidence that this occurred at any of the excavation sites, including the Hall Road site. It is recognized, however, that any movement of the tree and/or the buried pipeline could result in deformations to the pipe.

[5] It is worth noting that the two data points (green filled circle) with a depth of cover equal to 8-feet were also tape coated sections of pipe.

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The Hall Road site provides evidence of what can oc cur when a tree root ball and root system is locate d in close proximity to a buried pipeline. A primary concern under these conditions is that weather (e. g., high force winds, flooding, seismic events) may cau se tree and root movement, resulting in pipe damage. In addition, since the buried pipeline and tree root systems are interconnected, a lightning strike to the tree would most likely also impact th e pipeline and provide an electrical path for the s trike and may also provide a path for the electrical discharge.

Figure 6. RWVIM-90-13 (Hall Road)

6.4. Above Ground Survey Effectiveness

Pipeline operators perform above ground surveys to evaluate the effectiveness of CP systems. These above ground surveys include, but are not limited t o, close interval surveys (CIS), direct current vol tage gradient surveys (DCVG), alternating current voltag e gradient surveys (ACVG) and pipeline current mapper (PCM). In cases where access to the ROW is o bstructed due to vegetation overgrowth or the presence of structures, such CP surveys are not possible.

Buried pipelines rely upon two barriers to protect the external pipe surface – external coatings and C P. At locations where pipelines and tree root systems co-exist, it has been demonstrated that the tree root systems have the potential to damage one of the barriers, namely external coating.

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, ACVG and DCVG, the results from the ECDA may be inaccurate if above ground survey results are impacted due to the presence of tree roots.

Above ground surveys were available at 19 sites prior to excavation. Upon completion of the excavations, it was determined that 14 of the 19 above ground survey locations aligned spatially[t] with the actual excavation site locations and were relied upon for this analysis. Results of 12 of those 14 above ground surveys correlated with the direct examination findings. The remaining 2 above ground surveys did not provide results that correlated with direct examination findings.

Of these 12 sites that correlated, analysis of the above ground surveys identified the potential for coating damage at eight (8) sites, which was subsequently confirmed by the direct examination. No above ground survey indications were reported for four (4) sites and subsequent excavations confirmed that there was in fact, no coating damage.

These results suggest the following:

- DCVG/ACVG indications existed in close proximity to locations of coating damage subsequently identified through direct examination.

- CIS data indicated a moderate level of correlation with coating damage. If CIS was the only above ground survey tool used, it may prove difficult to assess whether or not tree roots have damaged the external pipeline coating.

- Intact coating (e.g., no coating damage) was confirmed at locations where no associated DCVG, ACVG, or CIS indications were present. With any above ground survey, regardless of the presence of tree roots, this correlation cannot always be guaranteed. Relatively small coating holidays caused by another source (other than tree root) may in fact be undetectable by the tools.

6.5. Effectiveness of Current Vegetation Control Standard

PG&E's ROW Standard[3] establishes the requirement for vegetation and structures when managing ROW for natural gas transmission pipelines and distribution mains including all equipment and physical facilities that transport gas, such as pipe, valves, compressor units, metering stations, regulator stations, delivery stations, and fabricated assemblies. This standard defines two specific zones; pipe zone and border zone as illustrated below:

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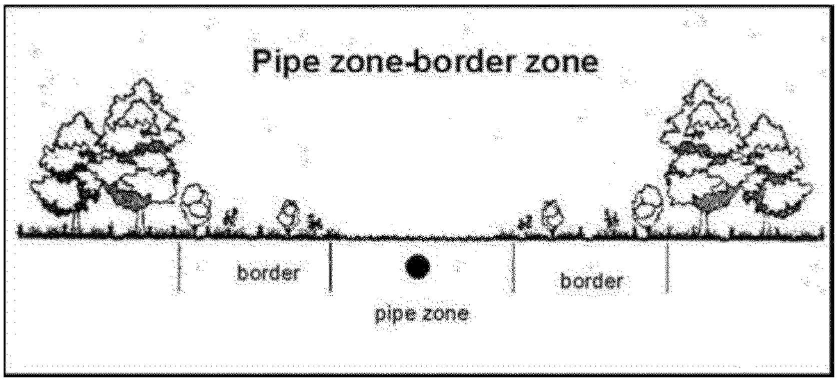
[t] Excavations were performed at 5 sites that were done some distance away from where the above ground surveys were performed, primarily due to access issues. Therefore, the above ground surveys were not aligned to the excavation location.



Vegetation control requirements are structured to minimize the presence of a "hard cut" border zone transition, allowing instead for a "feathered environmentally balanced" transition to be applied within the 5 foot pipe zone and the 14 foot border zone (both zones measured from pipe center line), subject to the following restrictions (summarized in Table 8) :

- … "trees, woody shrubs, and woody vegetation must be removed and are not permitted to be planted in the Pipe Zone".
- … "trees, woody shrubs or woody vegetation exceeding 8 inches or of a species likely to exceed 8 inches but less than 36- inches in diameter at 4.5 feet above ground diameter at breast height (DBH) at maturity, and the trunk or main branch is 5- to 10-feet from the centerline of the pipeline, must be removed and not permitted to be planted in the Border Zone".
- … "trees, woody shrubs or woody vegetation exceeding 36 inches in DBH or is of a species likely to grow to and exceed 36 inches in DBH at maturity, and the trunk or main branch is 10- to 14-feet from the centerline of the pipeline, must be removed and not permitted to be planted in the Border Zone".

The ROW Standard [3] currently does not address depth of cover. For this reason, the z-factor was developed within this program in order to consider both the offset distance and the depth of cover. As additional information becomes available, the ROW Standard guidelines may be modified accordingly.

Table 8. ROW Standard TD-4490S[3] Guidelines

Offset Distance Parameter, feet	DBH Parameter, inches
< 5 feet	...trees, woody shrubs, and woody vegetation must be removed (DBH independent)
≥ 5 feet < 10 feet	DBH ranging from 8-inches to 36-inch inches must be removed
≥ 10 feet < 14 feet	DBH greater than 36-inches must be removed

7. Findings

A summary of the findings are presented below and are categorized into the primary focus areas for this investigation. The analysis, observations, finding s, and recommendations presented herein are based upon the available information and interpretation o f results [5,6,8,10] that considers subject matter expertise. It is expected that if and/or when addi tional information is available, these findings wil l be updated accordingly.

Presented herein is a summary of the findings as th ey relate to the objectives outlined for this progr am. The definitions for the answers to the questions posed are as follows:

- Probable. Evidence that condition may occur more than 50% of the time.
- Unlikely. No direct evidence from Tree Root Study; however, could not be ruled out completely.
- Possible. No direct evidence from this program but condition is plausible.
- Indirect. Influences and/or promotes the condition.
- Inconclusive. Insufficient information from literature and industry experience.

Susceptibility to Coating Damage, Corrosion and Cracking

- Does pipe contact with tree roots result in coating damage?
  - **Probable**. In 40 of 53 sites (75%) excavated, coating damage[u] was observed. Tree roots can promote coating damage because they can compromise the protective coating barrier, but the extent of damage observed varies by coating type and other local conditions. For example, some roots were several feet from the stump and still had large diameters and significant damage to pipe coatings. It is inconclusive as to whether site characteristics have more to do with deep root growth than inherent tree species characteristics. It was observed that significant root interaction occurred when drought tolerant trees were growing near pipelines and that soil texture has an effect on the proliferation of roots specifically related to the hardpan layers and trench effects. The predictability of tree root interactions with buried pipelines is very difficult to predict given the numerous attributes that influence the result.
- Does pipe contact with tree roots result in corrosion initiation?
  - **Indirect.** The tree roots contributed to coating damage at 40 locations, of which 15 of the locations (38%) exhibited external corrosion.
- Does pipe contact with tree roots result in an accelerated corrosion condition?
  - **Unlikely**. In cases where the tree roots have compromised the external coating, the susceptibility for external corrosion increases since at least one of the two barriers for external corrosion has been compromised. However, there was no evidence that corrosion was any more significant at tree root contact points when compared to adjacent areas of coating damage and external corrosion.
- Does pipe contact with tree roots result in SCC?
  - **Unlikely**. There was no documented evidence from this study to indicate that live tree roots promoted SCC in areas of coating damage. The effects of dead tree roots are inconclusive since there is insufficient information to make any type of conclusion; however the resistivity of dead tree roots is not expected to differ significantly when compared to live tree roots5.

[u] Coating damage includes disbondment, root impressionsand root intrusions into the coating

CP and Above Ground Surveys

- Do tree roots near or around pipelines interfere with pipeline integrity surveys and assessments?
  - **Unlikely**. Above ground surveys are not significantly affected by the presence of tree roots. In most cases, above ground surveys correlated with excavation results where coating holidays were observed at sites identified by above ground surveys [4]. Likewise, intact coating was observed at sites where above ground surveys did not produce an indication.
- Does the presence of the tree roots on/near the pipeline interfere with CP or with testing for the presence and effectiveness of CP?
  - **Unlikely** (same as above). The ability to cathodically protect and monitor the buried pipe does not appear to be adversely affected by tree roots. Since the tree roots do not apparently shield CP, above ground surveys are capable of detecting coating holidays, and calcareous deposits were identified on the pipe, there was no evidence of tree roots adversely affect cathodic protection. However, it should be recognized that cathodic protection is designed to mitigate corrosion, but is not capable to eliminating corrosion, in cases where the external coating has failed.

Line Pipe Deformation

- Does pipe contact with tree roots result in deformation, ovality change or related or other damage to the pipe steel?
  - **Possible**. No evidence of structural damage to the line pipe (e.g., deformation, ovality, bending strain) was observed at the 53 sites. However, the Hall Road excavation highlighted the potential for damage to occur either directly by the tree ball and root system or from external forces and events (e.g., seismic, high winds, lightning). In addition, trees and root systems have the potential to induce additional bending strains onto the pipe.

Risk Prioritization

- What are primary attributes that must be accounted for when PG&E assesses the risk arising from the presence of tree roots near/on the pipeline?
  - The primary factors identified within this study included the z-factor (distance between the buried pipe and the tree) and the coating type, with CTE and HAA coating types perceived to have greater coating damage susceptibility.
- If trees remain on the pipeline ROW, what other mitigation efforts could PG&E undertake to manage pipeline integrity?
  - Above ground surveys can be used to identify coating holidays that could be indicative of locations for external corrosion. However, CIS alone may not be sufficient.
  - Integrity assessments including hydrostatic testing, ECDA, and in-line inspection can be used to assess whether coating failure and/or external corrosion has occurred.

- Does the remaining presence of dead tree roots have any impact on management of pipeline integrity?
  - **Inconclusive**. The effects of dead tree roots are inconclusive since there is insufficient information to make any type of conclusions; however the resistivity of dead tree roots is not expected to differ significantly when compared to live tree roots[5].

Alignment with Existing PG&E Standards

- If above ground surveys are determined to be impacted, does removing the tree, but leaving the root base, in accordance with the current PG&E ROW standard reduce or eliminate this impact?
  - **Not applicable**. No evidence that tree roots deleteriously affect above ground surveys.
- Is clearing the Pipe Zone and the Border Zone of vegetation in accordance with the current PG&E ROW standard sufficient to appropriately managing pipeline integrity?

  Probable. The results of this study support the guidelines but potential modifications are provided that include the z-factor, coating type, and tree diameter restrictions.

8. Recommendations

8.1. Additional Excavations

A strategic plan for completing additional excavations is recommended to enhance the results in the Matrix Spreadsheet. This strategic plan should rely upon the results available to date and then target specific attributes where necessary. For example, if a specific tree species exists at numerous locations along the pipeline ROW, a target program may be warranted.

8.2. Risk Framework

The development of a risk framework will provide a defensible approach for evaluating and prioritizing trees located along the pipeline ROW. Within this risk framework, the consequences of a failure could be focused on public safety and based upon the Average Occupancy Count (AOC) and Total Occupancy Counts (TOC) methodology already utilized by PG&E. The probability of failure, or potential for tree roots to adversely affect buried pipelines, could be developed using the results within the Matrix Spreadsheet. As an example of this approach, see Table 9 in which a first attempt to classify the attribute as high, medium and low may provide a first step in the prioritization process. This is only an example and is not meant to be representative of the actual values for each of the tree species.

Table 9. Example Only: Possible Attributes and Rankings for Consideration

Parameter	Classification	Parameter	Classification
Coating Type		**Horticultural Factors**	
a. Tape	low	a. Herbaceous crops - annual	low
b. CTE	high	b. Herbaceous crops - bi-annual (e.g., sugar beets)	med
c. HAA	high	c. Herbaceous crops - perennial (e.g., alfalfa)	med
d. FBE	UNK	d. Shrubs and vines - perennial (e.g., grapes)	med
		e. Perennial Tree crops	high
z-Factor		**Soil Survey**	
a. < 5 feet	high	a. No significant changes through profile	UNK
b. 5 to 10 feet	med	b. Slight changes in texture from one layer	UNK
c. > 10 feet	low	c. More significant changes	UNK
		d. Well-developed soils, but not cemented hardpan	UNK
Tree Species			
Ailanthus	high		
Cottonwood	high		
Deodar cedar	high		
Eucalyptus	high		
Hackberry	high		
Italian stone pipe	high		
Palm tree	high		
Afghan pine	med		
Coast Redwood	med		
Black walnut	low		
Black Walnut (Dead)	low		
Elm	low		
Monterey pine	low		
Oak	low		
Privet	low		

8.3. Further Assessment and Integration of Findings

Draft reports provided by contractors require furth er review, assessment, and integration. The draft reports provided by contractors require reconciliation between the findings and recommendations. This is particularly evident in the work performed by Fr esno State and Frizzell & Associates where both contractors have opined on specific attributes (e.g ., species of tree, soils). This review should als o further consider the arborist view that certain backfills may produce an environment that promotes tree root growth.

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8.4. PG&E ROW Standard

The ROW Standard's proximity guidelines for vegetation offset distances are generally supported by the findings within this report. PG&E should review the standard for consideration of modifications to include pipe depth as a criteria component, external coating type, and refinement of tree diameter restrictions as based upon the findings within this report and inclusion of information gathered in the future.

9. Conclusion

The results from this Tree Root Study provide supports the conclusions reached in earlier reports that the presence of tree roots near buried natural gas pipelines adversely affects pipeline integrity. The analysis demonstrates that the tree roots adversely affect the risk profile of the pipeline as it relates to susceptibility to external corrosion and structural damage to the pipeline due to tree movement caused by events (e.g., high winds, seismic). The analysis also provides a degree of confidence that above ground surveys, such as CIS combined with DCVG, and the use of ECDA as an assessment tool remain effective regardless of the presence of roots. The data collected demonstrated a lack of predictability of the impact of roots based on tree species or other readily ascertained information such as soil types or irrigation practices. The study supports the continued use of PG&E's ROW Standard for managing vegetation on the ROW, but also provides additional knowledge related to certain attributes that can be used to evaluate and manage the potential risks of that interaction between tree roots and buried pipelines (such as the proximity of the tree to the pipeline) and the need for and prioritization of removal of trees from the ROW. In addition, these results provide information that may be relied upon for developing site-specific prioritization, assessment, monitoring, and/or mitigation strategies based upon additional site-specific information.

10. Glossary of Terms

Abbreviation	Terms
ACVG	Alternating Current Voltage Gradient
AOC	Average Occupancy Count
CIS	Close Interval Survey
CP	Cathodic Protection
CSUF-CIT	California State University of Fresno Center for Ir rigation Technology (Fresno State)
CTE	Cold Tar Enamel coating
D/S soil pH	Downstream soil pH
DBH	Diameter Breast Height (54-inches above grade)
DCVG	Direct Current Voltage Gradient
DE	Direct Examination
DNV	Det Norske Veritas
Dynamic Risk	Dynamic Risk Assessment Systems, Inc.
ECDA	External Corrosion Direct Assessment
FBE	Fusion Bonded Epoxy coating
GPR	Ground Penetrating Radar
HAA	Hot Applied Asphalt coating
Hydrovac excavation	A method of excavation that utilizes pressurized wa ter and a vacuum system to expose underground infrastructure
ILI	Inline Inspection
IM	Integrity Management
Mechanical excavation	An excavation method that involves the removal of soil by means of mechanical excavating equipment (e.g., bac khoe, earth mover)
MICKit	Microbiological Induced Corrosion Kit
NACE	National Association of Corrosion Engineers
PCM	Pipeline Current Mapper
PG&E	Pacific Gas and Electric Company
PHMSA	Pipeline and Hazardous Materials Safety Administration
PIPA	Pipelines and Informed Planning Alliance
ROW	Right of Way
SCC	Stress Corrosion Cracking
Tape	Polyethylene Tape Coating
TOC	Total Occupancy Count
U/S soil pH	Upstream soil pH
WFMPI	Wet Fluorescent Magnetic Particle Inspection (MPT)

11. References

[1] Redacted, "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] Redacted, "Tree Root Interference Threat Analysis", Dynamic Risk Final Report prepared for Pacific Gas & Electric Company, April 29, 2013 (Revision 2)

[3] Pacific Gas and Electric Utility Standard: TD-4490S, 06/19/2013 Rev: 0, Gas Pipeline Rights-of-Way Management

[4] Redact, "Tree Root Interference Pipeline Threat Analysis (Draft)", Dynamic Risk Power Point Presentation provided to Pacific Gas & Electric Company, October 29, 2013.

[5] Redacted "Effects Of Tree Roots on External Corrosion Control", Draft Status Report, December 19, 2013

[6] Frizzell and Associates. "Assessment, Documentation, and Reporting of Roots Near Gas Transmission Pipelines". December 20, 2013

[7] Redacted "Evaluation of Horticultural Factors and Soil Conditions Related to Root Systems Development of Orchard Trees Planted Near Gas Transmission Lines", California State University Fresno Center for Irrigation Technology (CSUF-CIT), November 21, 2013.

[8] Mears Group, Inc. and GE Energy DE Technicians. "Completed PG&E External Corrosion Direct Examination Data Sheet, Form H (modified)", Rev. 10. (40 sites)

[9] Mears Group, Inc., Compilation of Tree Root Study Direct Examination (DE) results, "PGE 2013 Tree Root Inv DE Summary (2) xlsx", December 17, 2013.

[10] Tulsa and Canus - NACE Certified Inspectors. "Completed Leak Repair, Inspection, and Gas Quarterly Incident Report (A-Form)" (Rev 03/11). (49 sites)