Detection of Historical Pipeline Leak Plumes Using Non-intrusive, Surface-Based Geophysical Techniques at the Hanford Nuclear Site, Washington, USA - 11571

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ABSTRACT

Historical records from the Department of Energy Hanford Nuclear Reservation (in eastern WA) indicate that ruptures in buried waste transfer pipelines were common between the 1940s and 1980s, which resulted in unplanned releases (UPRs) of tank waste at numerous locations. A number of methods are commercially available for the detection of active or recent leaks, however, there are no methods available for the detection of leaks that occurred many years ago. Over the decades, leaks from the Hanford pipelines were detected by visual observation of fluid on the surface, mass balance calculations (where flow volumes were monitored), and incidental encounters with waste during excavation or drilling. Since these detection methods for historic leaks are so limited in resolution and effectiveness, it is likely that a significant number of pipeline leaks have not been detected. Therefore, a technology was needed to detect the specific location of unknown pipeline leaks so that characterization technologies can be used to identify any risks to groundwater caused by waste released into the vadose zone.

A proof-of-concept electromagnetic geophysical survey was conducted at an UPR in order to image a historical leak from a waste transfer pipeline. The survey was designed to test an innovative electromagnetic geophysical technique that could be used to rapidly map the extent of historical leaks from pipelines within the Hanford Site complex. This proof-of-concept test included comprehensive testing and analysis of the transient electromagnetic method (TEM) and made use of supporting and confirmatory geophysical methods including ground penetrating radar, magnetics, and electrical resistivity characterization (ERC). The results for this initial proof-of-concept test were successful and greatly exceeded the expectations of the project team by providing excellent discrimination of soils contaminated with leaked waste despite the interference from an electrically conductive pipe.

INTRODUCTION

Over the last 60 years several leaks have been found along waste transfer pipelines which could pose significant short-term risk to workers and long-term risk to groundwater. Nearly 200 miles of abandoned pipelines, dating back to the mid 1940s, traverse the Central Plateau at the Hanford Nuclear site [1]. These pipelines were used to transfer multiple waste streams from the reprocessing facilities, between waste tank farms, and from tank to tank. A comprehensive investigation into the cause of the pipeline failures between the 1940s and 1955 determined that most failures during this time were caused by local conditions adjacent to the pipe (e.g., corrosion due to soil, water, loss of coating) and construction or operating practices [2]. An additional 25 pipeline failures were documented between 1975 and 1995. A review of these failures showed corrosion attacking from the outside of the pipe.

Pipeline integrity and anti-corrosion measures, including cathodic protection systems, were adopted on pipelines installed as early as the 1940s. For example, the series of pipeline failures between 1940 and 1955 prompted additional anti-corrosion measures including encapsulation by asphalt wrap and eventually concrete encasement. Field tests conducted by the General Electric Company in the 1950s, however, determined that direct burial using coatings and tapes were not sufficient to prevent corrosion-based pipe failure. Therefore, very few direct burial stainless steel pipelines were installed after the 1950s. Pipelines evolved to include bituminous or plastic exterior coatings after additional pipeline failures occurred from 1975 to 1995.

Methods of leak detection performed on the pipelines over the decades consisted of visual observation of fluid on the surface, mass balance calculations (where flow volumes were monitored), and incidental encounters with waste during excavation or drilling. Because such detection methods are so limited, it is likely that a significant number of pipeline leaks have not been detected. In addition, mass balance measurements are unable to determine a specific leak origin, resulting in the entire pipeline being listed as a leak source. Furthermore, complex in-pipe characterization of the leaky pipelines that would identify leak location, severity of the leak, and identification of specific radionuclides are difficult to implement because many pipes are of small diameter (2-6 inches), under pressurized flow, have numerous elevation changes and bends, and limited access [1]. With these challenges, an innovative and non-intrusive pipeline leak characterization methodology would help minimize risks from unknown contamination sources.

In this paper, we describe a successful proof-of-concept, non-invasive geophysical application for characterizing a known historical leak from a buried waste transfer pipeline. The geophysical method is based on the transient electromagnetic (TEM) technique that is sensitive to electrically conductive features buried beneath the ground, including high moisture, salt content, and metal. Although electromagnetic methods have been demonstrated successfully at mapping the location of buried metal pipes [3], it has never been applied specifically as a leak mapping tool due to the potential of the more conductive pipeline metal interfering with the ability to see the less conductive ionic plume resulting from the leak. The proof-of-concept test, therefore, included several system configurations to optimize the leak mapping potential and minimize interferences from the metal pipe. We also demonstrate the success of the method by comparing the TEM results with the more familiar electrical resistivity plume mapping technology used extensively at Hanford to map waste disposal sites [4][5]. The resistivity technique requires physical contact with the earth via electrodes making it considerably more time consuming to implement than the TEM method which can be deployed on a mobile cart. The TEM method has the potential to rapidly characterize buried pipelines for historical leaks, as well as identify previously unknown contaminant sources for long-term modeling and management scenarios.

BACKGROUND

Pipeline leak detection can be separated into two categories: (1) active leaks and (2) historic leaks. A number of technologies are routinely used in industry for the detection of underground active leaks, including passive acoustic emission methods (monitoring of acoustic energy emitted during the leak) and ground penetrating radar. Active leaks present the maximum contrast in physical properties between leak material and the surrounding earth and are therefore less challenging to detect. Leak characterization of active leaks becomes easier if the leak has a surface expression, with the number of available technologies increasing to include chemically-based “sniffing” sensors, lasers, florescence, aerosol detection, and optical absorption spectroscopy.

By contrast, historic leaks are significantly more challenging to detect because they present little physical property contrast between leak material and surrounding earth based on dilution and migration of the plume over time. The commercial area of greatest interest in association with historic leaks is the evaluation of pipeline integrity. Pipeline integrity technologies, such as the magnetic flux leakage method or ultrasonic method [6] only characterize the fidelity of the pipe and not the external effects of previous leaks or failures. The commercial interest in the mapping the spatial influence of historic leaks external to the pipe has been minimal due to their unknown presence and the low contrast in physical properties between the residual contamination left by the leak and background soil being too small to detect.

Most of the pipeline leaks on the Hanford Site were due to historic failures, occurring 20 to 50 years ago, and can be expected to have a weak physical property contrast with the host media. Of the 100 pipelines investigated for failure [2], 86 failed during use or routine testing prior to use with failures ranging from pinhole sized leaks (pipeline 241-S-D-R5 near the S-107 tank), to corrosion cracking (241-5-152-6 near tank SY-103) to full collapse. In addition to actual pipeline failure, pipeline plugging could cause backflow and large leaks at junction points, such as diversion boxes and underground vaults.

At the onset of the leak, the saturation of the soil around the pipeline would increase dramatically. High leak rates were even known to cause subsidence and cave-ins at the surface, such as the incident from the waste transfer pipeline running from 241-T-105 to 241-T-118 via the 241-T-152 and 241-T-153 diversion boxes [7]. Overtime, the saturation near the leak location would decrease, as the moisture redistributed within the vadose zone, eventually returning to saturation levels similar to those prior to the leak. The final saturation will depend on the site-specific soil properties and its ability to retain moisture. In addition, the contaminants entrained in the liquid will diffuse over a broad area causing the concentrations to decrease substantially.

Several geophysical methods (galvanic resistivity, ground penetrating radar, capacitive coupled resistivity, radiometric, ultraviolet, etc.) were considered as part of the initial evaluation for a geophysical leak detection technique where the primary requirements included: sensitivity to low-contrast soil changes, ability to operate in close proximity to a steel pipeline, speed of data collection, and rapid data processing under production surveying.

With these challenges in mind, a proof-of-concept electromagnetic geophysical survey was conducted at a site of a historical leak in order to assess the viability of an innovative application of a conventional technique. The primary focus of this proof-of-concept test was to determine if a suitable data collection configuration and sampling resolution could be achieved to allow detection of a leak plume in the presence of a more electrically conductive waste transfer pipeline. Almost all pipes on the Hanford Site are metallic and can present large geophysical signatures themselves. Therefore, successful detection of pipeline leak plumes at this site required a technique that was sensitive enough to detect historical plume signatures, and with sufficient resolution to distinguish this signature from the large magnitude response caused by metallic pipelines.

TEST SITE SELECTION

For the proof-of-concept test, it was desirable to minimize the test variables by selecting a site outside of the industrial tank farm complex where external metallic infrastructure was minimized. Additionally, remediation activities or extensive soil removal was particularly undesirable. Site 200-E-116 (E-116) was selected because it contained a known leak of relatively high-volume release, the date of leak was generally understood, surface remediation activities did not influence or change subsurface soil properties, pipeline parameters were known, it was topographically flat with good access, and nearby infrastructure was minimal.

Site E-116 is located in the 200 East area of the Hanford Site, northeast of the intersection of 7th Street and Baltimore Ave. Surface contamination was detected northeast of the 241-B-154 diversion box in the vicinity of pipelines that run to the 241 C-151 and 241-C-152 Diversion Boxes. The area was posted as a high contamination area in September of 2000. In February 2001, the area was partially remediated by the installation of a surface bio-barrier (a non-woven geotextile with impregnated herbicide) and surface gravel. The remedial action resulted in downgrading the site to an underground radioactive material (URM) area over a portion of the pipeline. Another area of surface contamination was located along the same pipeline in June 2001. This area is located approximately east of the 241-B-154 diversion box. This area was covered with gravel and posted as a URM in August 2001 [8]. Based on operation logs for the waste transfer line, it is likely that both leaks occurred prior to the 1970s. The surface remediation activities did not remove or treat subsurface contamination which was important for studying a typical leak signature.

The site contains two 7.6 cm diameter stainless steel pipes buried approximately 0.6 m below ground surface (bgs); V130 and Line No. 8902. The pipelines transported process effluent from B-plant to the C tank farm. The depth of burial was confirmed by ground penetrating radar. The site had other minor infrastructure (water pipes and cathodic protection lines) that crossed the waste transfer lines at two locations. These features were discovered after site selection, but were not anticipated to cause many interferences on the test.

PIPELINE CHARACTERIZATION METHODOLOGY

Electrical and electromagnetic based geophysical methods have been used extensively at the Hanford site to map large leak volumes around buried infrastructure. The methods have been applied at the surface over waste sites that have typically received upwards of 400×10^6 L high ionic strength waste, where infrastructural influences would be minimal relative to the large signature expected from the waste plumes. For historical pipeline leak characterization, however, the leaks are likely of small volume (likely less than 4×10^3 L), hidden, and with a low residual ionic content.

The down selection of potential candidates for the proof-of-concept test included TEM and electrical resistivity. TEM has a distinct advantage over resistivity, in that the method can be adapted to a cart-mounted platform for a rapid reconnaissance of potential leak sites. The disadvantage in using TEM is in limited depth resolution and the ability to form a three-dimensional representation of the leak, for which the resistivity method is well suited. Together, these two methods could be applied to take advantage of their respective strengths.

TEM Test Configuration

The fundamental principle behind TEM is mutual inductance between a loop transmitter (Tx) and a loop receiver (Rx), with a two-loop configuration commonly employed. Each loop consists of a number of windings of copper wire of a given size, from centimeters to meters. The number of windings and the physical size of the loop controls sensitivity and depth of investigation. An alternating-current waveform is injected into the transmitter loop. Faraday's Law suggests that, conceptually, an image of the transmitter loop is propagated into the earth during each pulse. The amplitude of the pulse immediately begins to decay and generates eddy currents that, in turn, propagate downward and outward into the subsurface like a series of smoke rings. The amplitude of the secondary field is then recorded at the receiver after the transmitter is turned off. The amplitude is digitally sampled and recorded for a few milliseconds, and these data are used to assess subsurface conditions.

The depth of investigation, or diffusion depth, is a function of time, the loop configuration, and the time interval after shutoff of the current on the transmitter loop. Early time amplitude data are reflective of near surface conductivity; at late time, the receiver senses secondary fields from progressively greater depths. The intensity of the amplitude at the receiver is determined by the bulk conductivity of subsurface material, which is influenced by the porosity, porewater content, and mineralogy.

A state-of-the-art TerraTEM portable TEM system, produced by Monex GeoScope, Ltd. (Victoria, Austrailia) [9], was used to inductively map the soil conductivity around the two pipes at the E-116 site. For this test, only a single receiver loop was deployed, but the system is capable of supporting multi-channel receivers for additional data acquisition. The multi-channel capability will be crucial for successful future production-scale (i.e., routine field application) leak mapping and was one of the primary selection criteria for the system. A configurable test platform was fabricated from wood, which is non-electrically conductive. The test platform consisted of four sections that housed both transmitter and receiver loops (antennas) and could be configured in multiple orientations, heights, lengths and widths. The modular configuration allowed testing of various antenna geometries on the central flat surface. The overall height and size ranges were designed to simulate future deployment on a towed cart.

Figure 1 shows a sample TEM setup using an in-loop antenna geometry. The in-loop antenna geometry consists of a large Tx loop with Rx loop readings measured at various locations in-line and within the Tx loop. The multiple Rx readings within the Tx loop were designed to simulate future multi-channel capability where several Rx loops would be used simultaneously. Two additional platforms were fabricated in the same manner but were used for Rx loop placement outside the Tx loop. The outside Rx loop locations were either off-end and-in line with the long axis of the Tx loop or offset and parallel to the Tx. The different configurations have specific advantages and disadvantages in terms of sensitivity, ease of processing, upscaling for production, and data resolution.

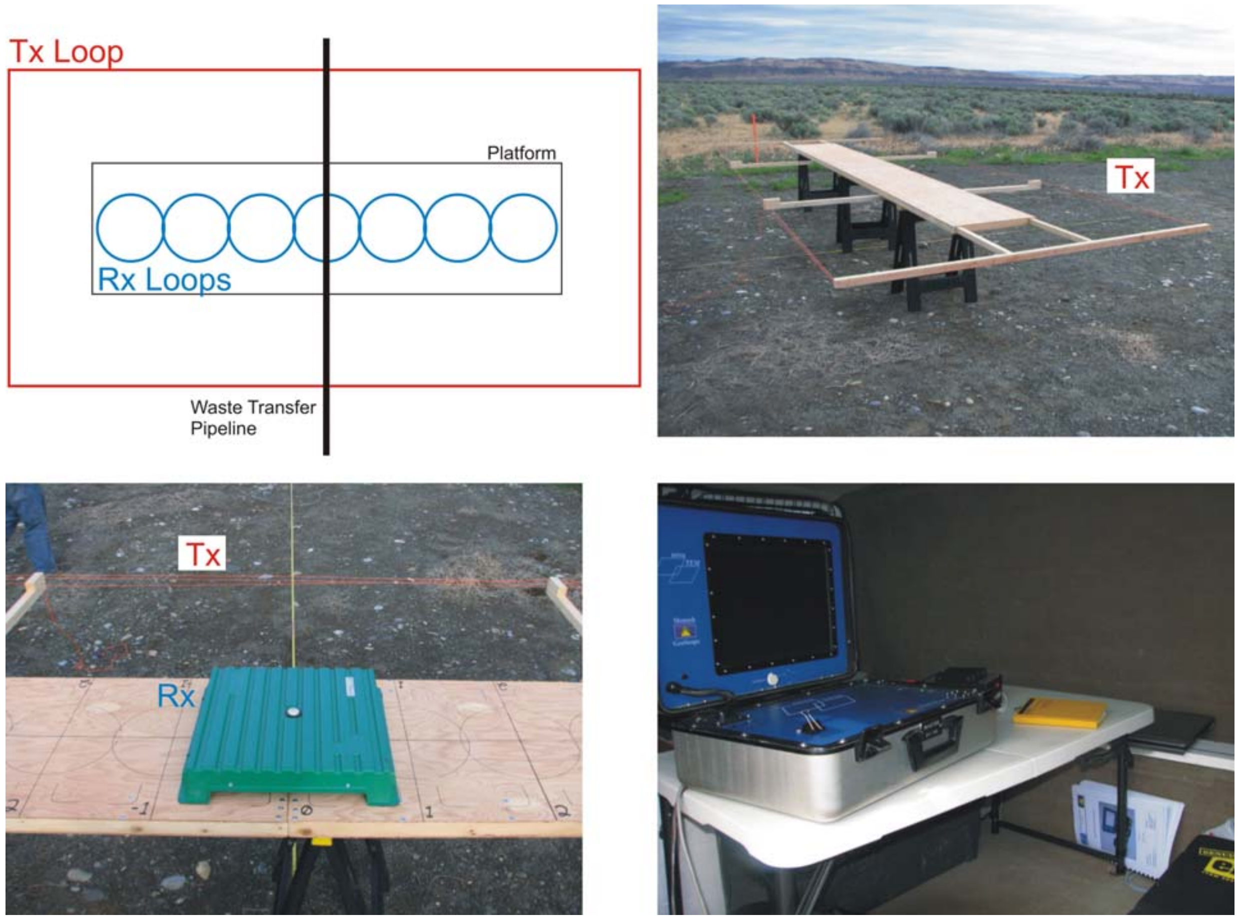

Figure 1. Sample TEM setup using an in-loop antenna geometry

The following design factors were evaluated during this project:

<u>Tx Loop</u>:

- The Tx antenna was fabricated using a horizontal rectangular coil. Various configurations of wire gage, coil size and number of windings were evaluated in order to determine the optimal antenna moment. The desire was to create an antenna of maximum strength that would not over-saturate the significantly smaller Rx antenna.
- 20 gauge insulated wire was selected in order to satisfy the necessary wire resistance for the terraTEM system.
- The final test configuration used three wire turns (windings) with an area of 45.38 m^2 multiplied by the three wire turns producing an effective area of 136.1 m^2.

<u>Rx Loop</u>:

- The Rx coil is a TRC1 HF (high frequency) and is produced by the same manufacturer as the TEM (Monex GeoScope, LTD).

- The antenna maintained a fixed size and number of windings with an area of approximately 1 m^2 producing an effective area of 2,500 m^2

Antenna Geometry:

- In-loop – Large Tx loop with in-line small Rx loop inside the Tx loop
- Ex-loop Inline – Large Tx loop with in-line small Rx loop outside the Tx loop
- Ex-loop Offset – Large Tx loop with offset small Rx loop outside the Tx loop

The electrically conductive stainless steel pipelines were expected to dominate the TEM dataset. Therefore, the subtle variations parallel and orthogonal to the pipeline would possibly indicate the presence of historical leaks. To maximize the data coverage, many receiver loop locations were occupied relative to a single Tx loop. The in-loop configuration, for example, had seven positions of the Rx loop. Furthermore, because of the challenge of sampling within high conductivity gradients between the clean soil and pipe, multiple sensors, using a multi-channel version of the TerraTEM system, will provide increased definition of the conductivity gradient through the use of high-resolution sampling.

TEM Results

Data were collected along lines 1 through 10 for the test setup using the in-loop geometry (dark blue lines on Figure 2). The lines were placed perpendicular to the waste transfer pipe line and were segmented into three focus areas: Bio-barrier 1 included lines 1 to 4; bio-barrier 2 included lines 5 to 7 and a representative background or undisturbed area included lines 8 to 10. Figure 2 shows the line locations. Measurements using the ex-loop inline antenna geometry were collected along line 8. Green and red dots represent the location of galvanic resistivity survey lines that are discussed in the following section.

In all of the configurations, the time series of normalized Rx amplitude (in microvolts per ampere) was evaluated spatially for a leak signature. Figure 3 shows an example of a single time series dataset on one Rx loop location for the in-loop configuration. The time series of Rx amplitude represents either the primary electric field (straight from Tx to Rx) or secondary electric field (remnant field from the subsurface), with the extreme late times likely representing the pipeline effect. For the plot, the off-time amplitude was sampled on 72 time windows.

In general, the decay displayed a series of piecewise continuous linear segments in the log-log domain. Power function fits to various segments of the decay illustrate the variety of responses in the pipeline environment. Differences in the number of linear segments, their slopes, and variations in amplitude are all indicative of changes in the earth-system geometry and physical properties of the pipe and leak. For example, the transition between the steepest linear segment (green in Figure 3) and the intermediate segment (orange) occurs about midway between similar transitions observed in the coincident coil and offset coil. In more conventional uses of TEM for site characterization or exploration, such steep decays would be ignored, as the far-field ground response is the desired target. However, the challenge of detecting subtle changes in conductivity in an environment dominated by a very shallow and very strong conductor, such as a metallic pipeline, has forced consideration of these early time data as being meaningful.

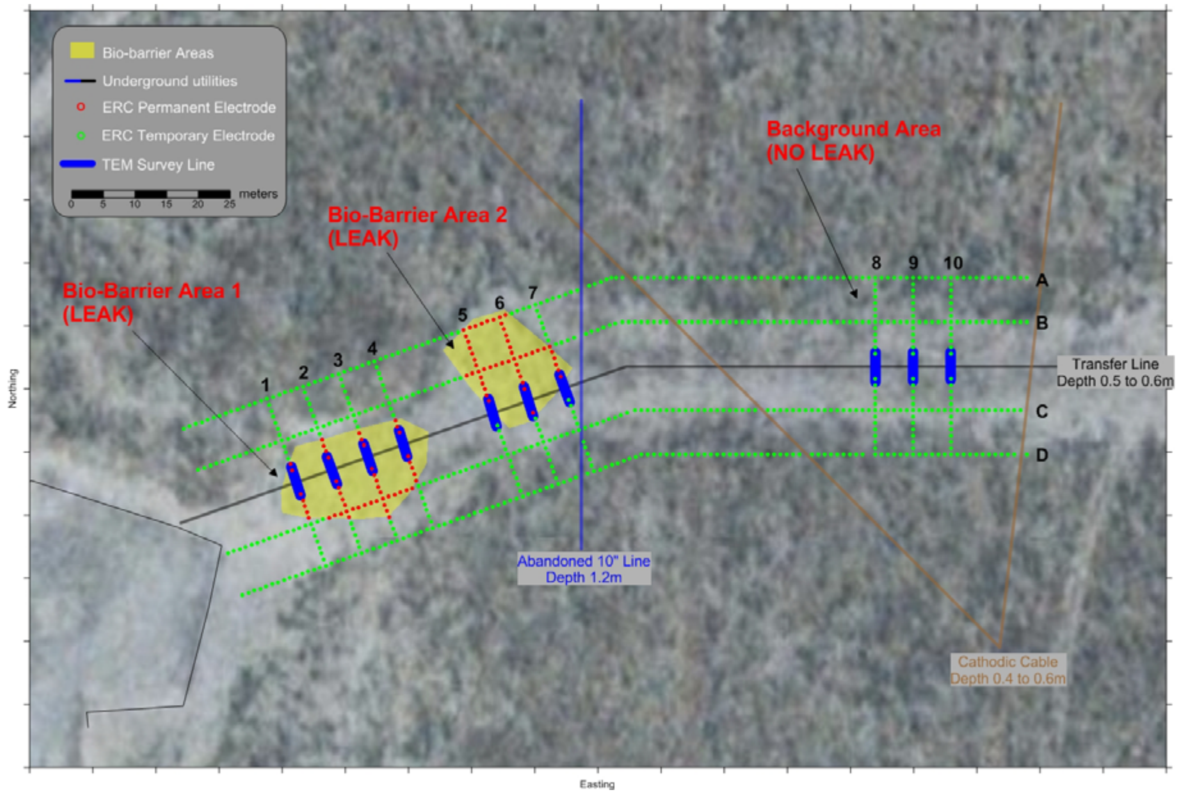

Figure 2. TEM & ERC line layout

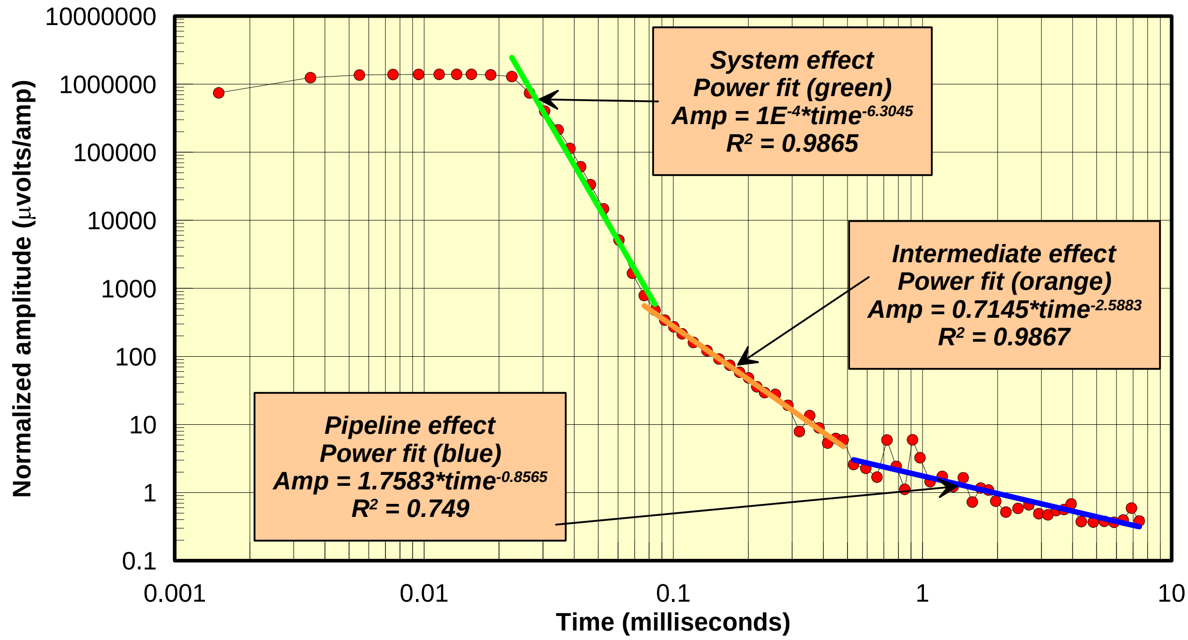

Figure 3. Example time series amplitude for the Rx loop, showing system effects from the immediate off time, soil conductivity from intermediate times, and pipeline effects from late off time.

The individual Rx loop measurements were then spatially related and contoured to provide a graphical visualization in order to detect subtle changes that may be indicative of a leak plume. Figure 4 shows the spatial relationship (for one particular time window) of the normalized amplitude for all ten TEM survey lines indicated on the location map (Figure 2). Low amplitude values are represented by blue/purple indicating more conductive areas, background or null response magnitudes are highlighted by green tones, and high amplitude values are represented by orange/red tones indicating areas of higher resistivity.

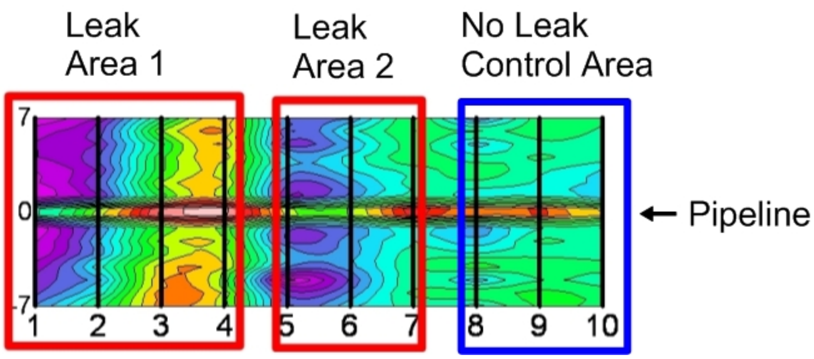

Figure 4. Example of Plan View Contoured TEM Data for In-Coil Configuration for Lines 1 through 10.

This initial spatial TEM graphic highlights three significant features: 1) a sharp response (distortion) along each survey line directly over the pipeline, and 2) a low magnitude response indicating more conductive areas within both leak areas, and 3) little to no response over the non leak area used as the control. The actual line spacing between the survey lines varies and is shown in Figure 4 as a constant spacing to aid in visualization. A fully geo-referenced spatial TEM plot is included in the final section of this paper and shows a comparison to ERC results.

Electrical Resistivity Test Configuration

A pole-pole galvanic electrical resistivity characterization (ERC) survey was performed along the waste transfer pipeline in order to verify TEM results over the leak sites. The ERC method requires physical contact with the earth through installation of steel rods, called electrodes. As a result, the method is more time consuming and less expedient than inductive methods, such as TEM.

Using a SuperSting R8/IP resistivity meter, resistivity data were acquired transverse to the direction of the waste pipeline along the same lines as the TEM data. Four additional survey lines of resistivity were acquired parallel in the direction of the waste pipeline but offset to either side. The transverse lines were of primary interest because they provided subsurface characterization for the site using a geophysical technique that has been confirmed through the application of SGE throughout the Hanford Site [9][10]. Accordingly, if the resistivity data show a conductive response (i.e., low resistivity relative to local background), then the TEM data should show a conductive response, provided that the same volume of earth is imaged for both methods.

Electrode placement consisted of stainless steel stakes inserted into the ground with penetration limited to less than 11 in. In the bio-barrier areas, special longer electrodes were fabricated so that the upper portion of the electrode was isolated from the sand and gravel covering the bio barrier, and only the lower portion of the electrode was in direct contact with the earth. This allowed simulation of placing electrodes in the ground without the presence of the cover material. Additionally, the design kept the active portions of the electrodes at the same level and penetration as with normal electrodes outside the bio-barrier areas.

Data were acquired by transmitting electrical current on one pair of electrodes and measuring the resulting voltage on all other pairs of electrodes. Each electrode pair has a turn at passing current. With the pole-pole array, one electrode from each electrode transmitting and receiving pair is placed far from the survey area. The procedure was repeated for all 14 lines.

ERC Results

The electrical resistivity data collected along profiles were modeled using an inverse procedure that aims to estimate the subsurface electrical properties given the voltage data measured by the resistivity meter. The inversion routine is conducted iteratively using a nonlinear least squares optimization procedure that aims to minimize the difference between modeled and measured voltages. Each line typically takes four to five iterations to complete with a goodness of fit, as calculated through a root mean square error which is typically less than 5%.

Figure 5 shows an example set of profiles from lines 1-4 over the bio-barrier leak area 1. The transfer pipelines are located near the center of the leak area 1 where the leak was observed on the ground surface. However, the precise location and extent of the leak plume beneath the ground is unknown. Survey lines 1 to 4 were completed to image the lateral and vertical extents of the leak plume in order that the location of the most conductive soil areas could be known for direct comparison with the TEM results.

All four lines show a low resistivity response at various locations within the section. The pipeline is located at station 14. The locations of the most conductive regions do not appear to correlate directly with the location of the pipeline. Within the 2D inversion plots, there is little evidence of a pipeline response that is typical of many resistivity sections recorded on the Hanford Site. We suspect that the two transfer pipelines are encapsulated in an insulating wrap and are electrically isolated the pipeline from the surrounding earth. The low resistivity response likely represents the location of the residual plume remaining from the historical leak. All four lines also show moderate to high resistivity magnitudes within the top 4 m that are indicative of dry soil.

The two other sites characterized by ERC include the bio-barrier leak area 2 and an area considered background with no leak (but with a pipe). The bio-barrier 2 is located to the east of bio-barrier 1 and is mostly located northwest of the transfer pipelines. The bio-barrier only marks the location where increased soil moisture was located on the ground surface, but does not reflect the subsurface extent of the leak. Although not shown within this paper, the results are similar to lines 1 to 4 and the data indicate low moisture within the first 4 m with no evidence of a pipeline response within the 2D inversion results. The soil appears to become less resistive with depth, which appears to corroborate a downward migration of the leak from the pipeline.

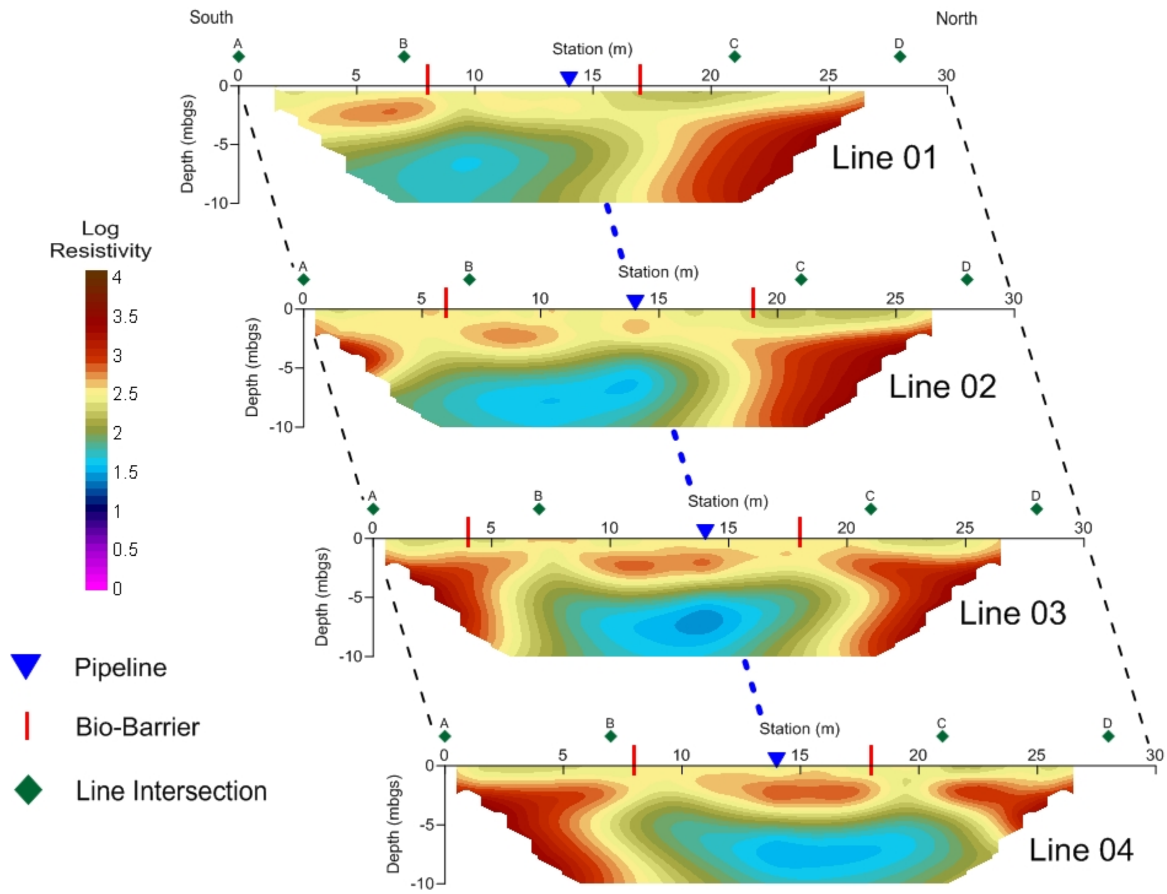

Figure 5. Resistivity Results Showing a Set of Stacked 2D Inversion Sections for Lines 1 to 4.

Data acquired in the vicinity of known leaks are useless without a comparison to data from a similar area with no leak. The third site just east of the known leak area but far enough away to represent undisturbed soil conditions was used as the control. The selection of the site was critical because the location needed to contain the same or similar infrastructure as the leak areas such that only difference would be the absence of a leak plume. Soil composition and surface vegetation are similar to the contaminated bio-barrier areas, with the exception of the additional thin gravel cover that was placed on the bio-barriers.

The two-dimensional inversion results for all fourteen ERC profiles were placed into Rockworks (Rockware, Inc.) software to produce a 3D interpolation rendering. Figure 6 shows a plan (panel a) and isometric (panel b) view from the 3D interpolated results. The line spacing was too sparse for a true 3D inversion to be conducted. Nevertheless, the interpolated results provide a volumetric assessment over the entire project site. The yellow outlines mark the locations of the bio-barrier leak areas, the black lines mark the resistivity line locations, the red line represents the transfer pipelines and lastly the purple lines how the location of the near surface cathodic lines. The green contour shell has a resistivity of approximately 30 Ohm-meters and the more conductive red shell has a resistivity of 10 Ohm-meters. Note, the units for the 2D inversion cross sections are in log Ohm-meters. The comprehensive ERC results show a low resistivity feature extending from the south west of bio-barrier leak area 1 to the eastern edge of the bio-barrier leak are 2. The most conductive regions, highlighted in red generally correlate with the location of the bio-barrier areas. In addition, there is no low-resistivity response over the non-leak control area to the east.

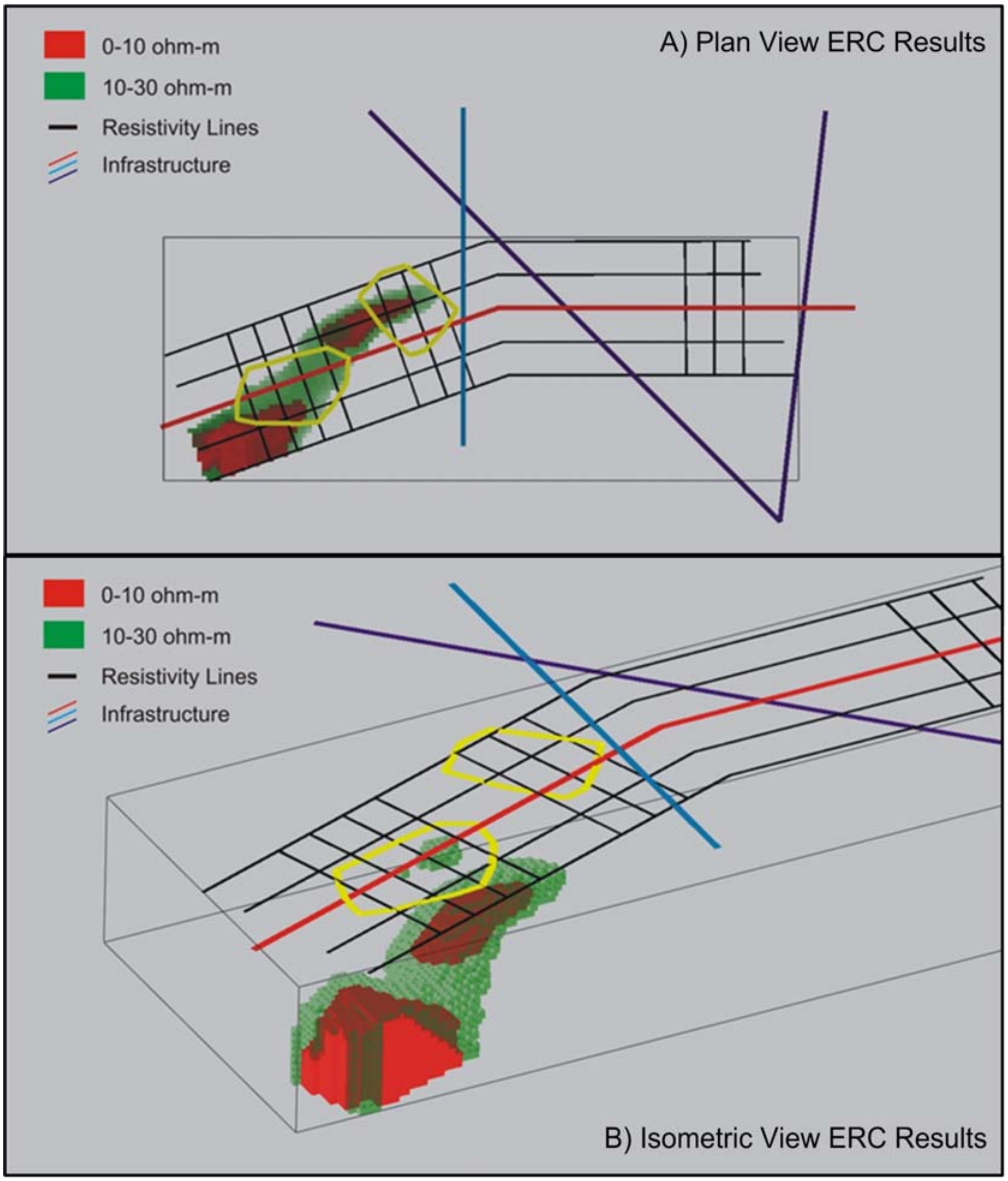

Figure 6. Resistivity Results from 2D Inversion Data Using 3D Interpolation Visualization

SPATIAL REPRESENTATION OF HISTORICAL LEAK

Figure 7 shows a geo-referenced comparison of results for the TEM and ERC surveys. Note that the imaging area of the resistivity survey is considerably greater than that of the TEM survey. The figure shows color contoured TEM results where blue/yellow colors show resistive areas and red/purple colors show conductive areas believed to be associated with the leak plume. ERC results are represented by a red and green contour outline showing the most conductive regions. The TEM results are derived from time window 30, which was chosen because it illustrates a representative residual response without early time system effects or late time pipeline effects. For reference, the figure also shows the location of the most conductive ERC response along each ERC survey line. These features are marked with a black circle with a center cross and are interpreted to represent the suspected leak plume.

Within the vicinity of bio-barrier leak area 1, the TEM data shows a single, northeasterly trending and narrow conductive response (red/purple tones), which correlates well with the axis of the ERC resistivity low. However, the TEM survey area within bio-barrier leak area 2 is too far from the suspected leak plume (derived from the ERC results) to show much response. Future testing may include additional profiles over the larger resistivity survey area to draw additional correlations over suspected plume areas.

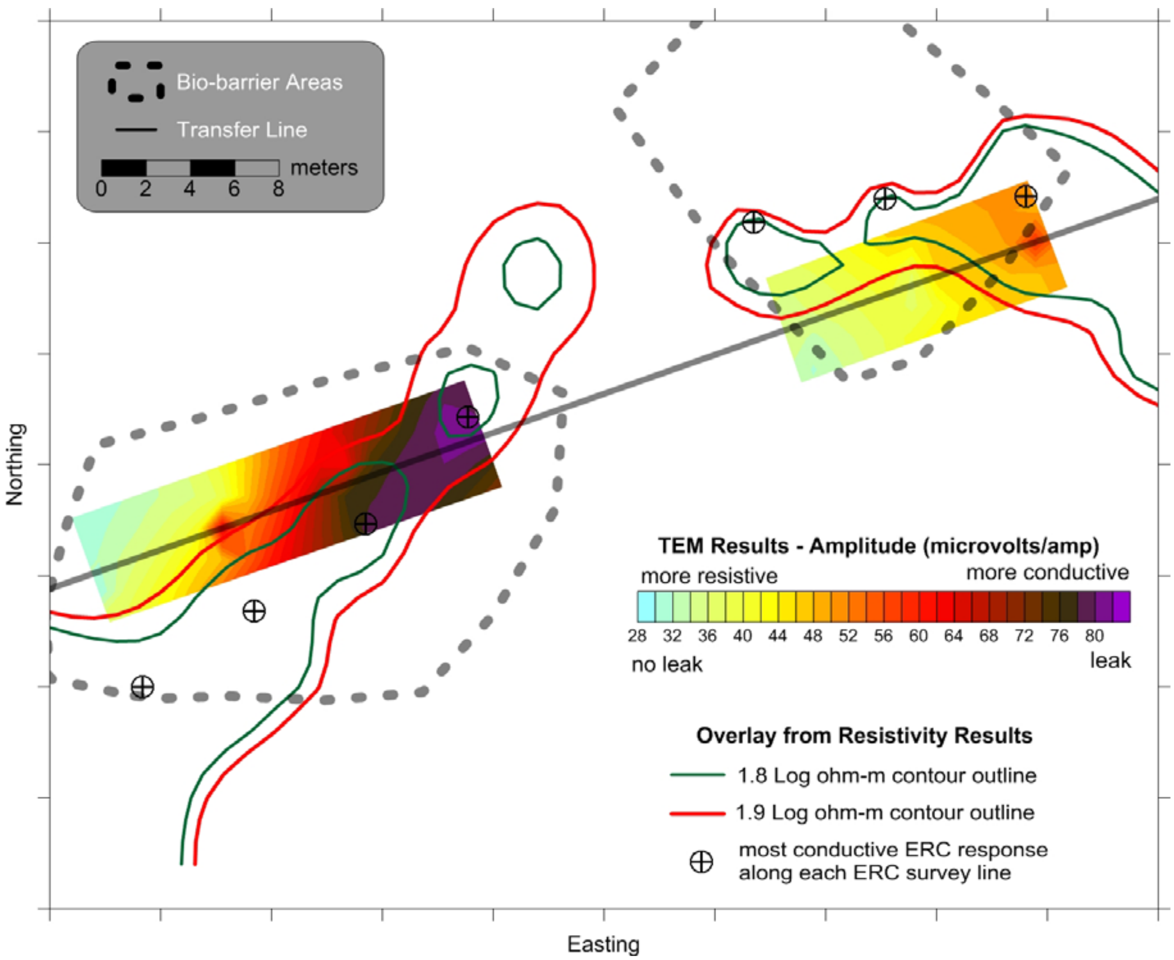

Figure 7. Comparison of Contoured Data from ERC and TEM Data over Bio-Barrier Areas

CONCLUSIONS

A proof-of-concept, electromagnetic-based geophysical survey was conducted over the waste transfer pipeline at the 200-E-116 UPR site. The survey was designed to test an innovative electromagnetic geophysical technique that could be used to rapidly map the extent of historical leaks from pipelines into the vadose zone within the Hanford Site complex. Nearly 200 miles of abandoned pipelines traverse the Central Plateau, and several leaks have been documented along a portion of them. Current methods used to detect leaks on the Hanford site are greatly limited in resolution and effectiveness and it is likely that a significant number of pipeline leaks have not been detected. The leaked waste may pose significant short-term risk to workers and long-term risk to groundwater. Any mapping tool that could discriminate regions of previously unknown contaminated soil from clean soil would help to define these risks, especially as the pipes are being considered for stabilization and removal.

The primary focus of this proof-of-concept test was to determine if a suitable data collection configuration and high-density sampling could be achieved to allow detection of a leak plume in the vadose zone within close proximity of a pipeline. The results for this initial proof-of-concept test were successful and greatly exceeded the expectations of the project team by providing excellent discrimination of vadose zone soils contaminated with leaked waste despite the interference of the electrically conductive pipe.

The key conclusion from this project is that the proof-of-concept has been established and that TEM and ERC methods warrant further development for implementation of pipeline leak detection surveying using a mobile towed platform. The TEM successfully mapped high-conductivity soils in close proximity to the pipeline in areas of known soil contamination. These leak waste areas provided an excellent target because they were not remediated; rather a surface bio-barrier coverage of gravel was added to protect human health. The TEM survey coverage was limited to just 7 m to each side of the pipeline. Despite the limited survey coverage, the TEM mapped high-conductivity areas coincident with low resistivity data from the ERC survey that occupied a significantly larger area. Where the two methods overlapped, the TEM results match the ERC data with enough confidence that a larger TEM survey would likely produce a similar leak plume boundary in a small fraction of the time required for the ERC survey. In addition, the assessment also provided a data set to be used for future design and fabrication of TEM antennas that would be needed for mobile deployment as a leak detection mapping tool on the Hanford Site.

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