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Surface Geophysical Exploration of the S and SX Tank Farms at the Hanford Site

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Abstract: This report presents the results of an investigation at the S and SX tank farms at the Hanford Site for areas of potential contamination using electrical resistivity methods. Geophysical exploration involved collecting and analyzing resistivity data using shallow surface electrodes, wells, and buried electrodes.

Approved For Public Release

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LIST OF TERMS

3D	three-dimensional
CH2M HILL	CH2M HILL Hanford Group, Inc.
Columbia Energy	Columbia Energy & Environmental Services, Inc.
DOE	U.S. Department of Energy
GPR	ground penetrating radar
RMS	root mean square
RMS%	root mean square percent
SGE	surface geophysical exploration
SST	single-shell tank
WMA	waste management area
WTW	well-to-well

1.0 INTRODUCTION

This report documents initial geophysical exploration activities completed at the S and SX tank farms at the U.S. Department of Energy (DOE) site in Washington State in fiscal year 2008 (August through September 2008). hydroGEOPHYSICS, Inc. of Tucson, Arizona and Columbia Energy & Environmental Services, Inc. (Columbia Energy) of Richland, Washington, with support from technical staff of CH2M HILL Hanford Group, Inc. (CH2M HILL), conducted a geophysical survey of the subsurface of the SX tank farm, located in the central portion of the 200 West Area of the Hanford Site (Figure 1-1). This work is being performed as an integrated effort between CH2M HILL and Fluor Hanford, Inc. to investigate both the tank farms and the surrounding areas.

The initial part of the survey integrated ground penetrating radar (GPR) and electrical resistivity. High-resolution electrical resistivity data were collected in a well-to-well (WTW) survey using existing groundwater and vadose zone wells in the SX tank farm area.

Geophysical methods used at the S-SX tank farm area are generally termed surface geophysical exploration (SGE). The results of the GPR characterization can be found in *Surface Geophysical Exploration of SX Tank Farm at the Hanford Site: Results of Background Characterization with Ground Penetrating Radar* (RPP-RPT-38321). This report focuses only on the results of the initial WTW electrical resistivity characterization effort.

1.1 SCOPE

The scope of this electrical resistivity characterization survey included data acquisition on both groundwater and vadose zone wells, data processing that included the use of methods and controls to ensure quality in the processing and reduction of data collected, data visualization that included development of three-dimensional (3D) contouring of data collected in the WTW survey, and of the development and implementation of two 3D resistivity inversion models that utilized the WTW survey data.

Overall WTW characterization activities in the SX farm area study included data acquisition for the WTW survey, which began on August 22 and 23, 2008, collected resistivity data using existing steel-cased wells as current sources and receivers. This WTW survey made use of 21 groundwater wells and 132 vadose zone wells, totaling 153 wells. The individual wells used for the survey are listed in Table 4-1 in Section 4.0.

Inversion of data collected for the S and SX tank farm area, including areas inside the farm fence boundary, were modeled in two separate WTW inversion models. The inversion analysis was performed with an upgraded version of the resistivity inversion routine, called EarthImager3DCL®.

For this SX work, a dedicated computer server with 32 GBytes of memory and eight 3.0 GHz processors was used.

® EarthImager3DCL is a registered trademark of Advanced Geosciences, Inc.

1.2 OBJECTIVES

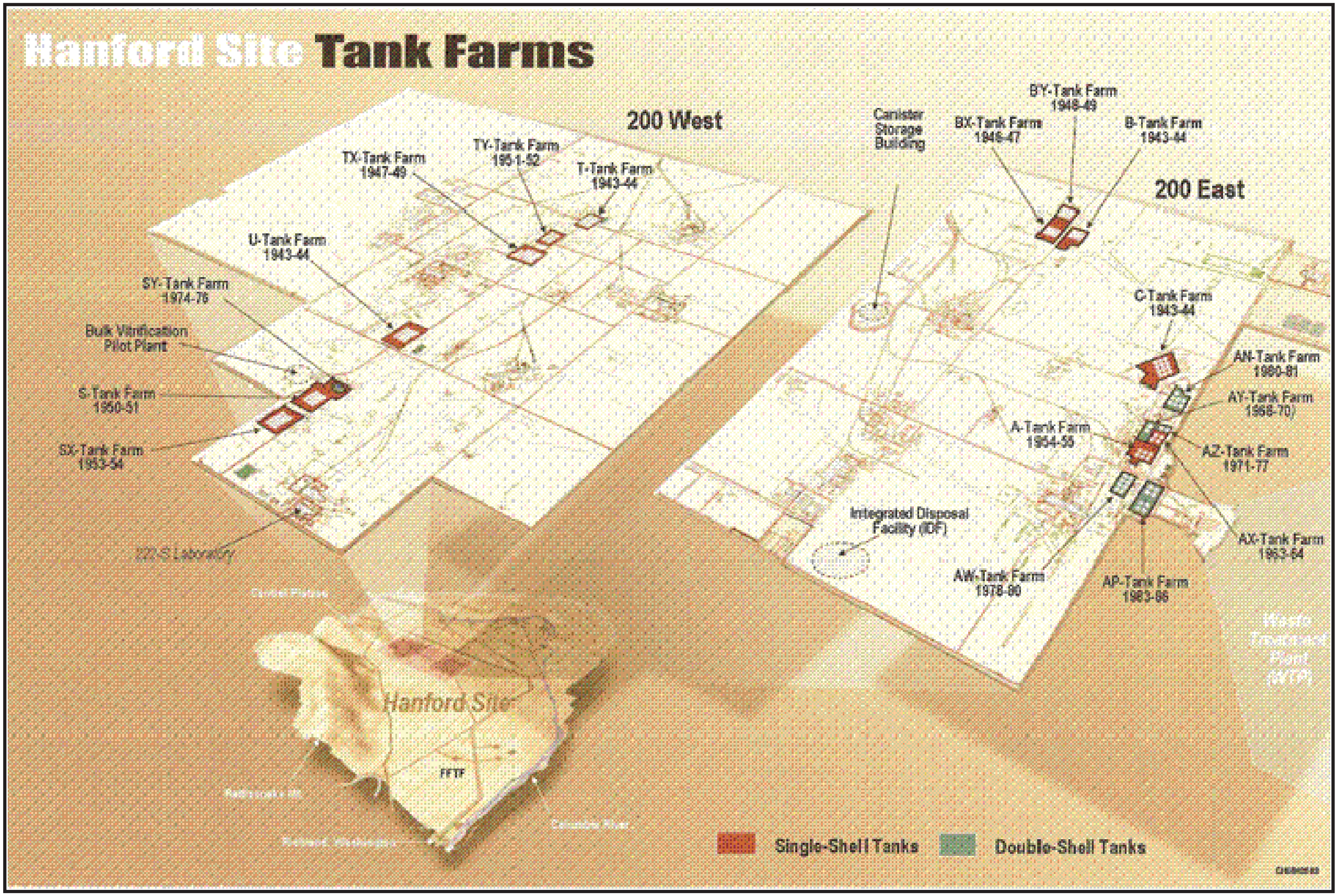
The main objective for this geophysical investigation was to collect and analyze electrical resistivity data to identify and locate low resistivity regions in and around the SX tank farm area and part of the S tank farm area. Low-resistivity is indicative of increased moisture or increased concentration of electrolytes compared to background conditions.

1.3 REPORT LAYOUT

This overall scope and content of this report is divided into several main sections as follows:

- **Section 1.0, Introduction** – Describes the scope and objectives of the investigation.
- **Section 2.0, Background** – Provides a brief summary of the past history of SX tank farm area including a brief discussion of the site geologic and hydrologic conditions.
- **Section 3.0, Quality Assurance** – Presents general methods and controls used to ensure the quality and control of data collection, reduction, and processing and configuration control of software and database changes used in this study.
- **Section 3.0, Data Acquisition -Well-To-Well Survey** - Summarizes details of data acquisition of this WTW resistivity survey.
- **Section 5.0, Analysis Results and Interpretations** – Presents the results from the electrical resistivity surveying effort and an interpretation of the WTW resistivity measurements including the results of the inversion analysis of two separate inversion models.
- **Section 6.0, Conclusions** – Provides a summary and conclusions drawn from the results and interpretations.
- **Section 7.0, References** – Lists reference documents cited in the report.

Figure 1-1. Location of S-SX Tank Farm and Other Tank Farms on the Hanford Site.



2.0 BACKGROUND

2.1 SITE DESCRIPTION

The SX tank farm contains 15 single-shell tanks (SST) and is included in the waste management area (WMA) S-SX. This WMA also includes the 12 SSTs of the S tank farm areas. This initial SGE investigation focuses inside of the SX tank farm area, but includes the southern half of the S tank farm area. The S and SX tank farms are located in the southern portion of the 200 West Area and include a number of past-practice liquid discharge facilities (i.e., cribs and trenches) located mainly to the west, southeast, and northeast of the SX tank farm. Figure 2-1 shows the details of the SX and S tank farm areas with assumed leaking tank locations, wells, and other facilities.

CH2M HILL has responsibility for vadose zone characterization at the tank farms under the direction of the DOE, Office of River Protection. Fluor Hanford, Inc. has responsibility for characterization of the cribs and trenches outside the tank farm. Fluor Hanford is also currently responsible for all groundwater monitoring at the tank farms and is integrated with CH2M HILL through the direction of the DOE, Richland Operations Office.

The SX tank farm comprises the following:

- 15 SSTs with 2,006,050-Liter capacity
- waste transfer lines
- leak detection systems
- tank ancillary equipment.

The S tank farm comprises the following:

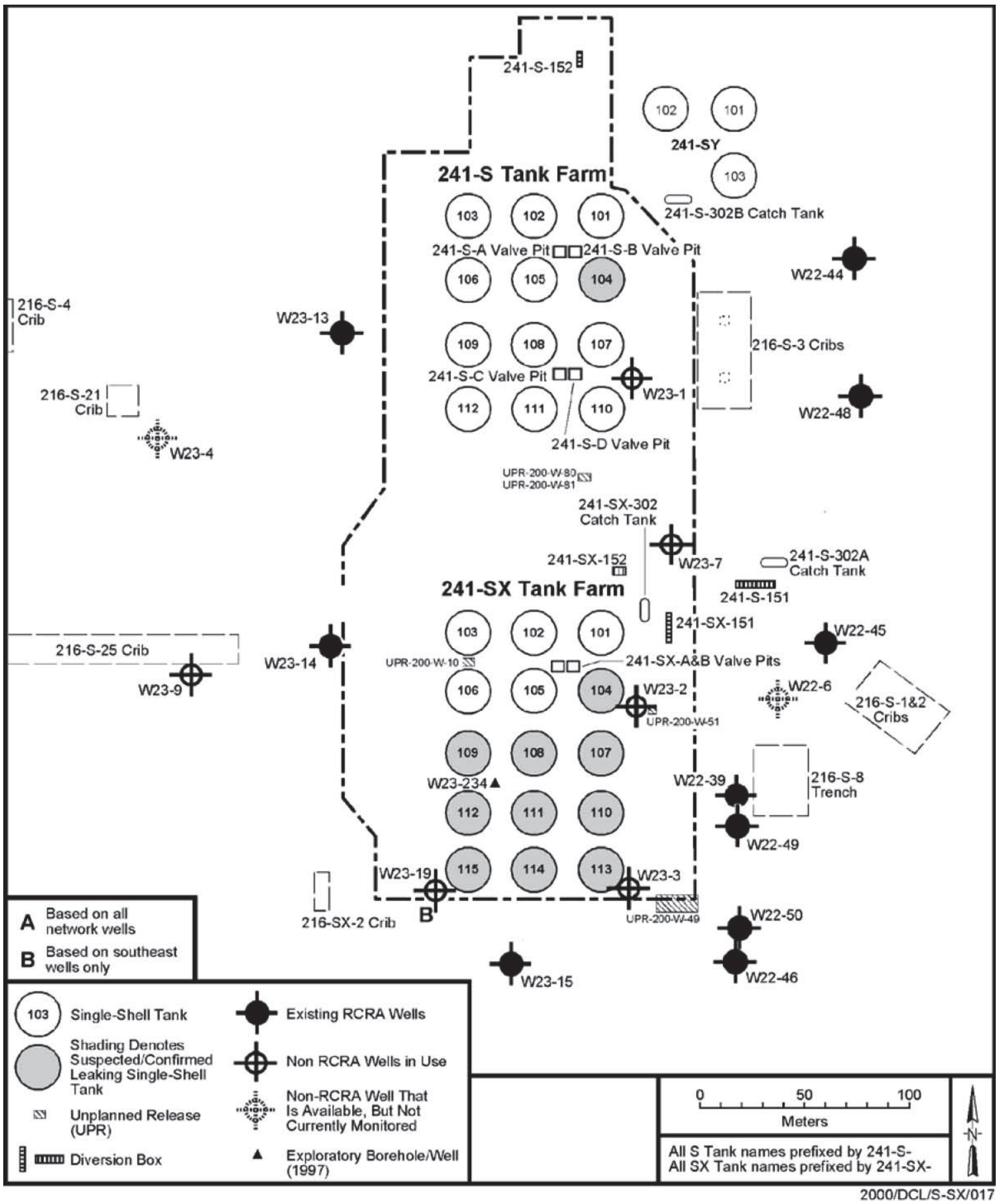
- 12 SSTs with 2,006,050-Liter capacity
- waste transfer lines
- leak detection systems
- tank ancillary equipment.

According to information provided in RPP-17209, *Modeling Data Package for an Initial Assessment of Closure of the S and SX Tank Farms,* the S and SX tank farms were constructed in the 1950s to support operations at the REDOX plant, which operated from 1952 through 1967. The S tank farm contains twelve 100-Series SSTs that were constructed between 1950 and 1951 and put into service in 1951. The SX tank farm contains fifteen 100-Series SSTs that were constructed between 1953 and 1954 and put into service in 1954. The two tank farms were used to store and transfer waste until the late 1970s and early 1980s.

The SSTs in the SX tank farms are 23 meters in diameter and approximately 11.4 meters tall from the base to the apex of the dome. The sediment cover from the apex of the dome to ground surface is 2.5 meters at the SX tank farms. All of the tanks have a concave shaped bottom. Schematic diagrams of the general configuration of the SST construction in the S and SX tank farms are provided in Figure 2-2.

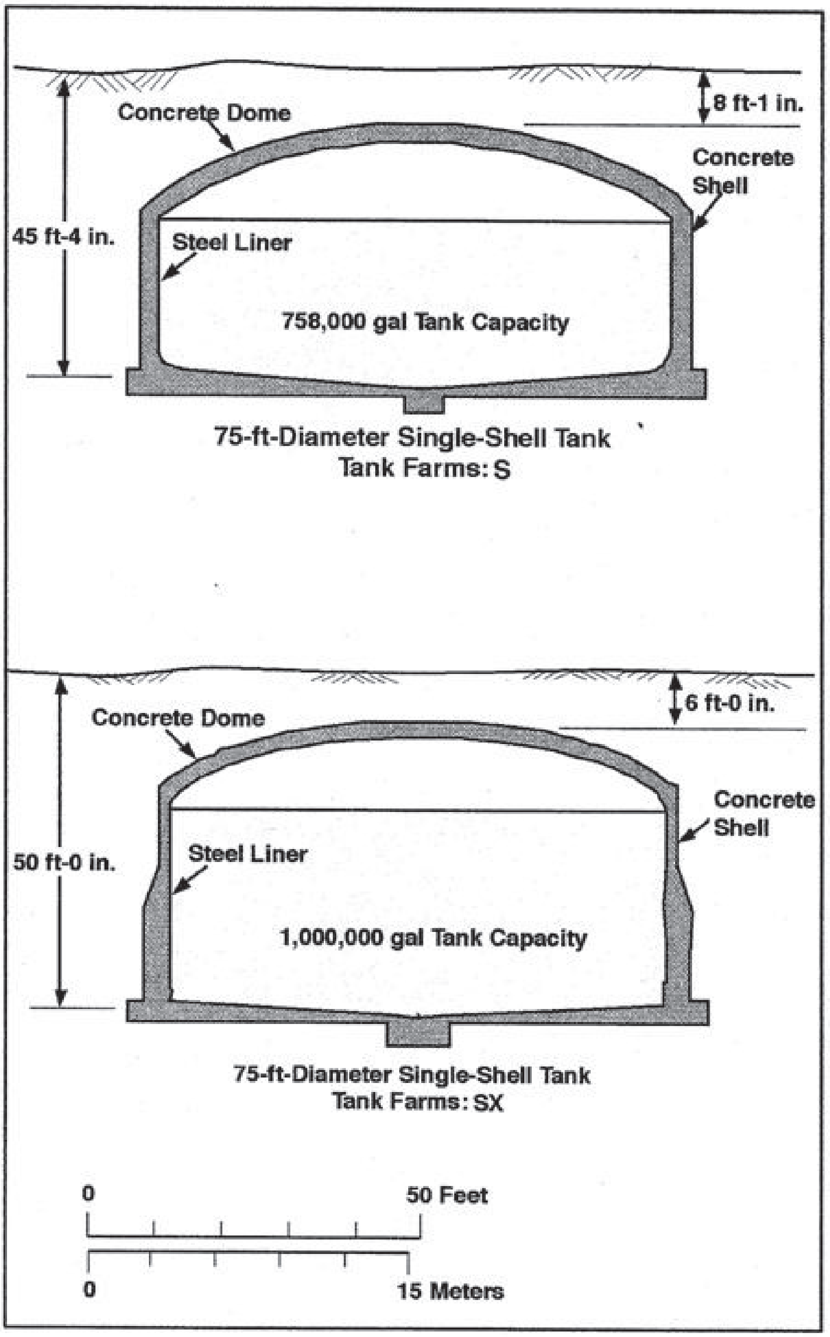
Ten of the 15 SSTs in the SX tank farm and one of the 12 SSTs in S tank farm are classified as assumed leakers (HNF-EP-0182, *Waste Tank Summary Report for Month Ending June 30, 2008*). Overall waste volumes currently in the SSTs within the SX and S tank farm based on information contained in HNF-EP-0182 and provided in Tables 2-1 and 2-2. Leak volume estimates for the SSTs classified as assumed to have leaked within the S and SX tank farms is based on the same reference (HNF-EP-0182) and provided in Table 2-3.

Figure 2-1. S-SX Tank Farm and Surrounding Facilities.



DOE/ORP-2008-01, 2008, *RCRA Facility Investigation Report for Hanford Single-Shell Tank Waste Management Areas* Revision 0, U.S. Department of Energy, Office of River Protection, Richland, Washington.

Figure 2-2. General Configuration of Tank Construction in Waste Management Area - SX.



Source: DOE/ORP-2005-01, 2006, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site*, Rev. 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

Table 2-1. Single-shell Tank Waste Volume Estimates for SX Tank Farm. (Adapted from Table 4.1, HNF-EP-0182)

Tank	Total Waste (gal × 1,000)	Supernate Liquid (gal × 1,000)	Sludge (gal × 1,000)	Salt-cake (gal × 1,000)	Solids Volume Update
241-SX-101	420	0	144	276	06/30/04
241-SX-102	342	0	55	287	08/31/04
241-SX-103	509	0	78	431	09/30/03
241-SX-104	446	0	136	310	04/30/00
241-SX-105	375	0	63	312	12/31/02
241-SX-106	396	0	0	396	01/31/03
241-SX-107	94	0	94	0	07/01/04
241-SX-108	74	0	74	0	06/30/04
241-SX-109	241	0	66	175	07/01/04
241-SX-110	56	0	49	7	07/01/04
241-SX-111	115	0	97	18	07/01/04
241-SX-112	75	0	75	0	07/01/04
241-SX-113	19	0	19	0	01/01/02
241-SX-114	155	0	126	29	07/01/04
241-SX-115	4	0	4	0	01/01/02

Table 2-2. Single-shell Tank Waste Volume Estimates for S Tank Farm. (Adapted from Table 4.1, HNF-EP-0182) (2 Sheets)

Tank	Total Waste (gal × 1,000)	Supernate Liquid (gal × 1,000)	Sludge (gal × 1,000)	Salt-cake (gal × 1,000)	Solids Volume Update
241-S-101	352	0	235	117	4/30/04
241-S-102	34	Retrieval in progress	10	6	4/27/07
241-S-103	237	1	9	227	6/30/04
241-S-104	288	0	132	156	12/20/84
241-S-105	406	0	2	404	01/01/02
241-S-106	455	0	0	455	02/2801
241-S-107	358	0	320	38	02/26/04
241-S-108	550	0	5	545	01/01/02

Table 2-2. Single-shell Tank Waste Volume Estimates for S Tank Farm. (Adapted from Table 4.1, HNF-EP-0182) (2 Sheets)

Tank	Total Waste (gal × 1,000)	Supernate Liquid (gal × 1,000)	Sludge (gal × 1,000)	Salt-cake (gal × 1,000)	Solids Volume Update
241-S-109	533	0	13	520	07/04/04
241-S-110	389	0	96	293	07/01/04
241-S-111	401	0	76	325	07/01/04
241-S-112	3	Retrieval completed	1	2	03/02/07

Table 2-3. Single-shell Tank Leak Volume Estimates in Waste Management Area S-SX Single-shell Tanks. (Adapted from Table 4.3, HNF-EP-0182)

Tank	Date Confirmed or Assumed Leak	Estimated Leak Volume	Interim/ Stabilized	Date of Leak Estimate
241-S-104	1968	24,000	12/84	1989
241-SX-104	1988	6,000	04/00	1988
241-SX-107	1964	<5,000	10/79	1983
241-SX-108	1962	2,400 to 35,000	08/79	1991
241-SX-109	1965	<10,000	05/81	1992
241-SX-110	1976	5,500	08/79	1989
241- SX-111	1974	500 to 2,000	07/79	1986
241- SX-112	1969	30,000	07/79	1986
241- SX-113	1962	15,000	11/78	1986
241- SX-114	1972	—	07/79	1989
241- SX-115	1965	50,000	09/78	1992

2.2 ENVIRONMENTAL SETTING

The geology of the S-SX tank farms and immediate vicinity is well understood as a result of several decades of site characterization activities. The geology of this site has been described in numerous reports, including the following publications:

- *Geology of the Separations Areas, Hanford Site, South Central Washington* (RHO-ST-23)

- *Geology Data Package for the Single Shell Tank Waste Management Areas at the Hanford Site* (PNNL-15955)
- *Geology, Hydrogeology, Geochemistry, and Mineralogy Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site* (RPP-23748).

2.2.1 Geology and Hydrology

Following is an overview of the geology of WMA S-SX. More detailed information can be found in RPP-23748; RPP-7884 *Field Investigation Report for Waste Management Area S-SX;* and HNF-4936, *Subsurface Conditions Description for the S-SX Waste Management Area*. Nine stratigraphic units are recognized within WMA S-SX. From oldest to youngest, the primary geologic units are:

- Columbia River Basalt Group
- Ringold Formation – member of Wooded Island
- Ringold Formation – member of Taylor Flat
- Cold Creek unit – lower carbonate rich sequence (CCU_l)
- Cold Creek unit – upper silt and sand sequence (CCU_u)
- Hanford formation – lower fine sand and silt sequence (H2 subunit)
- Hanford formation – middle coarse sand and gravel sequence (H1 subunit)
- Hanford formation – upper fine sand and top gravelly sand sequence (H1a subunit)
- Backfill.

The general characteristics of these units are described in more detail in RPP-23748. The SSTs at WMA S-SX were emplaced within the Hanford formation sediments of the upper sand-dominated (H1a) subunit, and may locally intercept the upper portions of the middle gravel-dominated Hanford (H1) unit. All but the surface of the Hanford formation have a general tendency to dip west to southwest toward the axis of the Cold Creek unit. The vadose zone beneath WMA S-SX is as much as 65 meters thick and consists of the Hanford formation, the Cold Creek unit, and the upper part of the Ringold Formation. Both the water table and the unconfined aquifer reside entirely within the Ringold Formation.

2.2.2 Unconfined Aquifer

The following is an overview of the hydrology of the uppermost unconfined aquifer beneath WMA S-SX. More detailed information can be found in RPP-23748, RPP-7884, HNF-4936, and DOE/RL-2008-01, *Hanford Site Groundwater Monitoring for Fiscal Year 2007*.

The current primary groundwater flow direction in the unconfined aquifer beneath WMA S-SX is to the east-southeast. The estimated hydraulic gradient in this region is 0.0018 to 0.0019. The general groundwater flow velocity ranges from 0.009 to 0.36 meters/day (DOE/RL-2008-01).

Water level data collected from monitoring wells located near and inside WMA S-SX (299-W23-1, 299-W23-3, 299-W23-4) indicate that between the early 1950s and mid 1960s, the water table in the vicinity of WMA S-SX rose about 11 meters in response to wastewater discharges to the 216-U-10 pond. The water table elevation remained fairly steady between 1965 and 1984. Water levels began to decline rapidly in 1985, when discharge to the 216-U-10 pond ceased. That decline continues today. Water levels have decreased by about 11 meters in the WMA S-SX area since 1985, and have returned to levels consistent with those observed in the early 1950s.

The aquifer resides in partially cemented sands and gravels of the Ringold Formation member of Wooded Island (subunit E). Currently, the water table beneath WMA S-SX lies approximately 136 meters above mean sea level, resulting in about 78 meters of vadose zone (RPP-17209). The unconfined aquifer is about 67 meters thick (RPP-23748), and hydraulic conductivity values reported for the aquifer in this area range from 0.15 to 17.2 meters/day (PNNL-14058, *Historical Vadose Zone Contamination from S and SX Tank Farm Operations*). Additional hydraulic property data from aquifer testing at wells near WMA S-SX are provided in RPP-23748 and DOE/RL-2008-01.

Groundwater beneath WMA S-SX was found to be contaminated with nitrate, technetium-99, and hexavalent chromium attributed to two general source areas within the WMA (DOE/RL-2008-01). The nitrate and technetium plume data are attributed to one source area to the north in the S tank farm and one area to the south in the SX tank farm (Figures 2-3 and 2-4). Tritium and carbon tetrachloride plumes are also present in groundwater beneath the WMA, but their sources are thought to be further upgradient of the WMA.

The northernmost plume is attributed to an apparent source in the S tank farm and has migrated eastward through well 299-W22-44 (see Figure 2-5), where chromium and nitrate concentrations increased approximately 360 µg/L and 150 milligrams/L, respectively, in fiscal year 2007 (DOE/RL-2008-01). Technetium-99 within this plume has a similar trend to those of chromium and nitrate where concentrations increased from about 1,230pCi/L in June 2006 to approximately 10,000 pCi/L in September 2007. A similar trend between these three constituents (Figure 2-5) indicates that they likely have the same source.

The contaminant plume located on the south portion of the WMA continues to slowly spread downgradient from its apparent source near tank SX-115. This plume is composed of nitrate, chromium, and technetium-99, as is the S tank farm plume to the north. The technetium-99 concentration in well 299-W23-19 (located inside the SX tank farm) peaked at 137,000 pCi/L during September 2005 (Figure 2-6), then decreased during FY 2006. During FY 2007, concentrations remained relatively stable in this well, fluctuating between 35,100 and 46,300 pCi/L.

Figure 2-3. Average Nitrate Concentrations at Waste Management Area S-SX, Upper Part of Unconfined Aquifer. (Adapted from DOE/RL-2008-01)

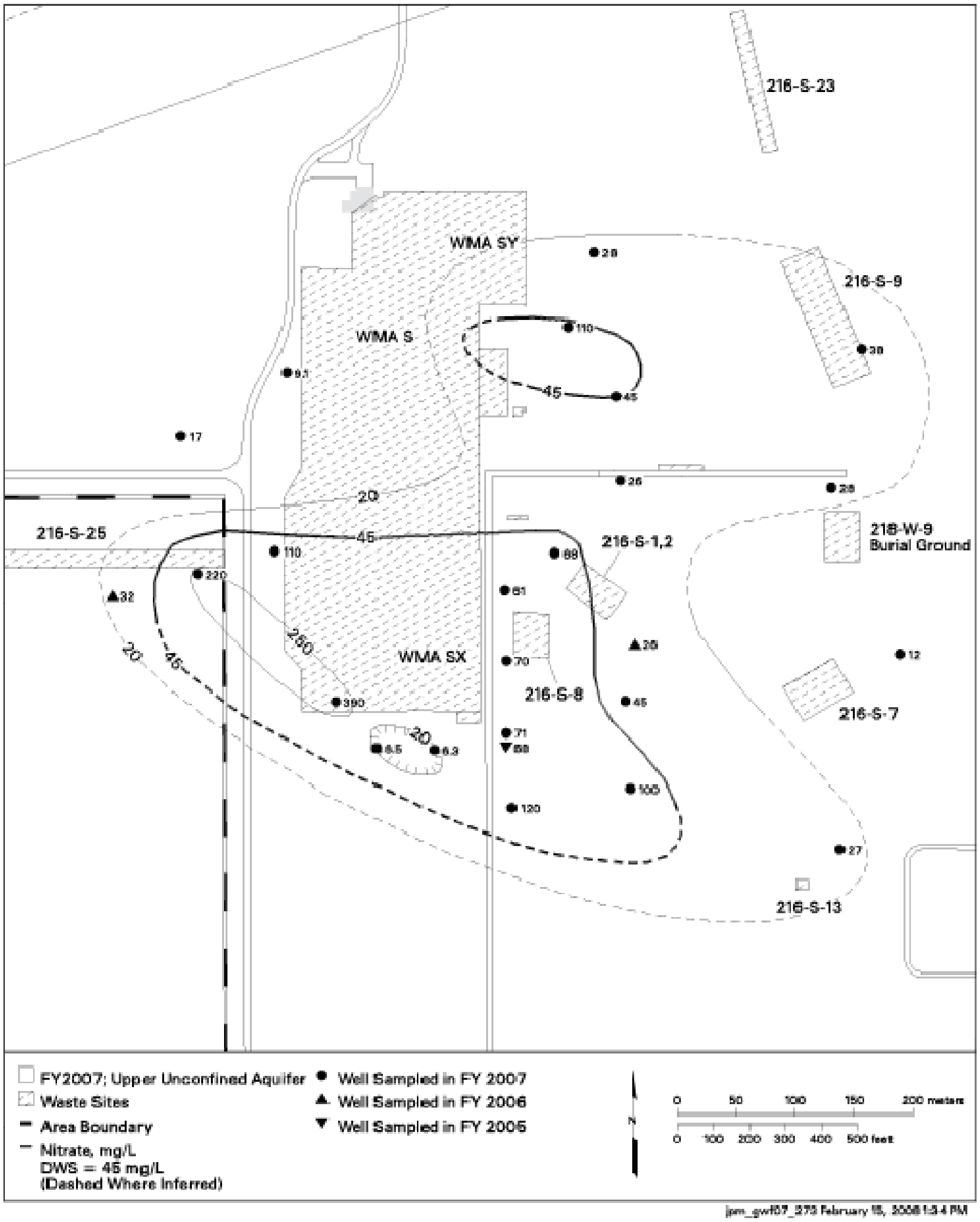


Figure 2-4. Average Technetium-99 Concentrations at Waste Management Area S-SX, Upper Part of Unconfined Aquifer. (Adapted from DOE/RL-2008-01)

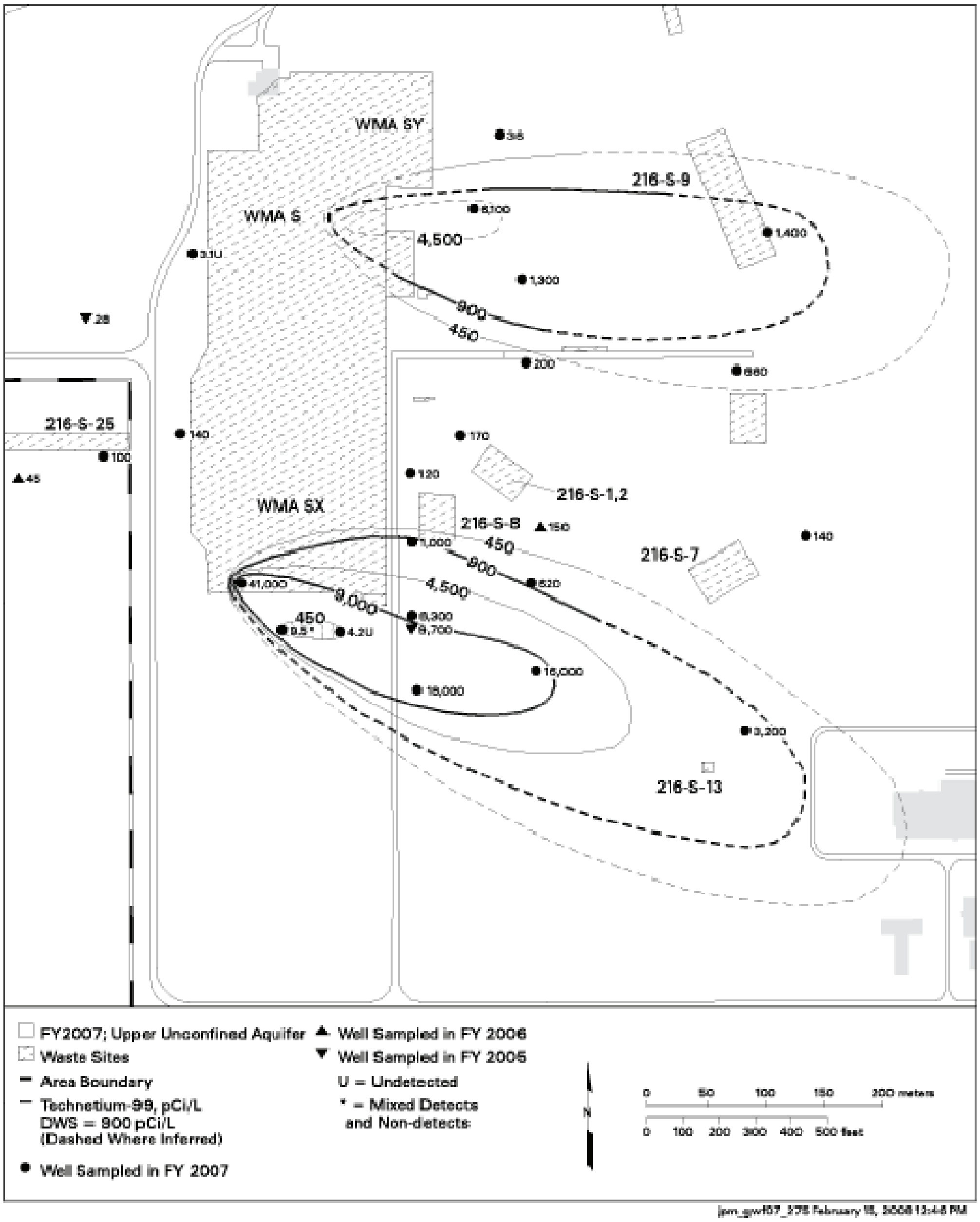


Figure 2-5. Concentrations of the Mobile Tank Waste Constituents Nitrate, Chromium, and Technetium-99 Downgradient from S Tank Farm. (Adapted from DOE/RL-2008-01)

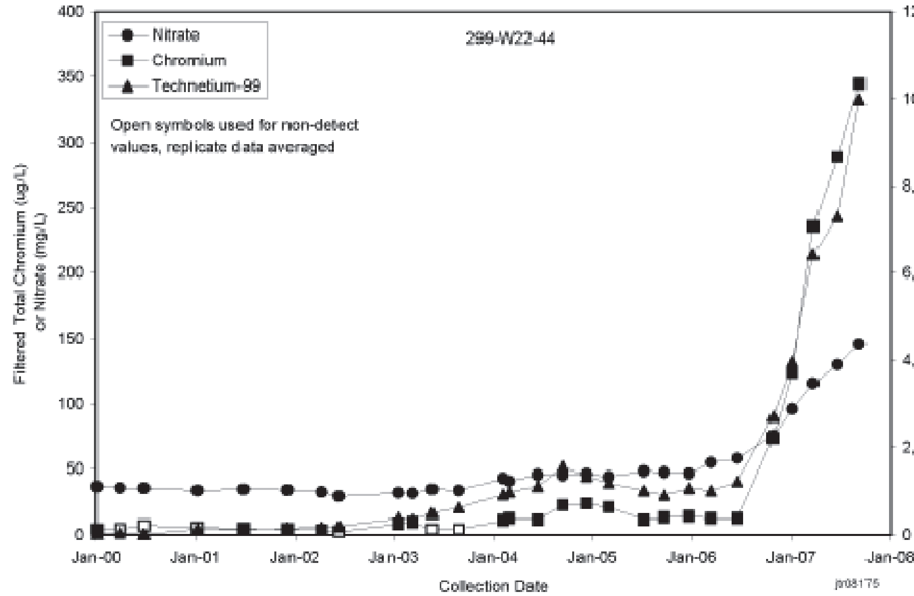
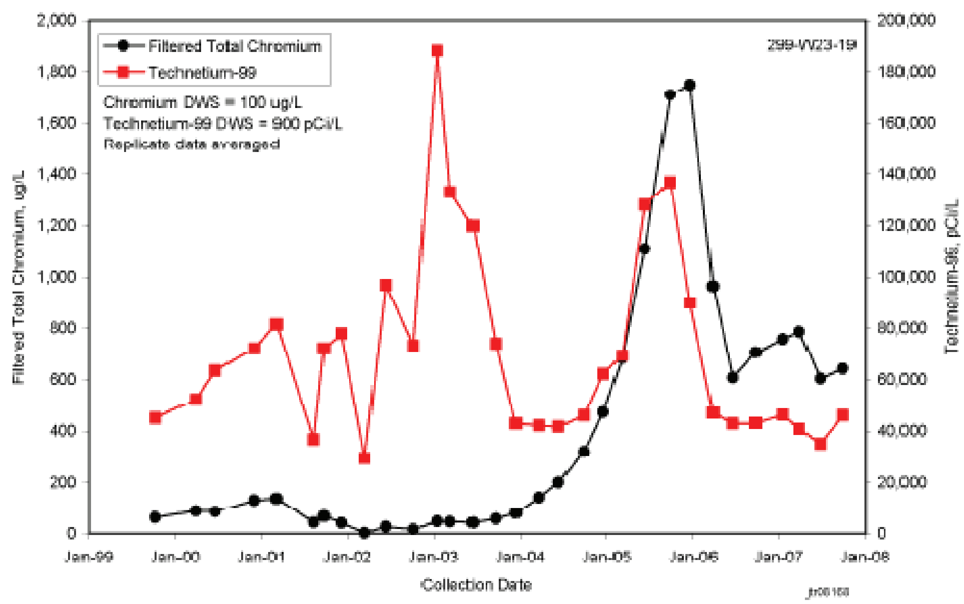


Figure 2-6. Chromium and Technetium-99 Concentrations in Well 299-W23-19 Near a Source Area Within the South Portion of Waste Management Area S-SX. (Adapted from DOE/RL-2008-01)



2.2.3 Vadose Zone Contamination

The following section is an overview of S and SX tank farm construction and operations along with historical information on soil surface and vadose zone contamination in WMA S-SX as provided in HNF-SD-WM-ER-560. A detailed description of contaminant occurrences and environmental conditions at the WMA S-SX is provided in HNF-4936.

The field investigation report for WMA S-SX (RPP-7884) provides an in-depth analysis of the history and vadose zone data collected through 2001. Based on this analysis, it was determined that three main areas of contamination exist in the vadose zone underlying the S and SX tank farms. These three zones include the areas around the following tanks:

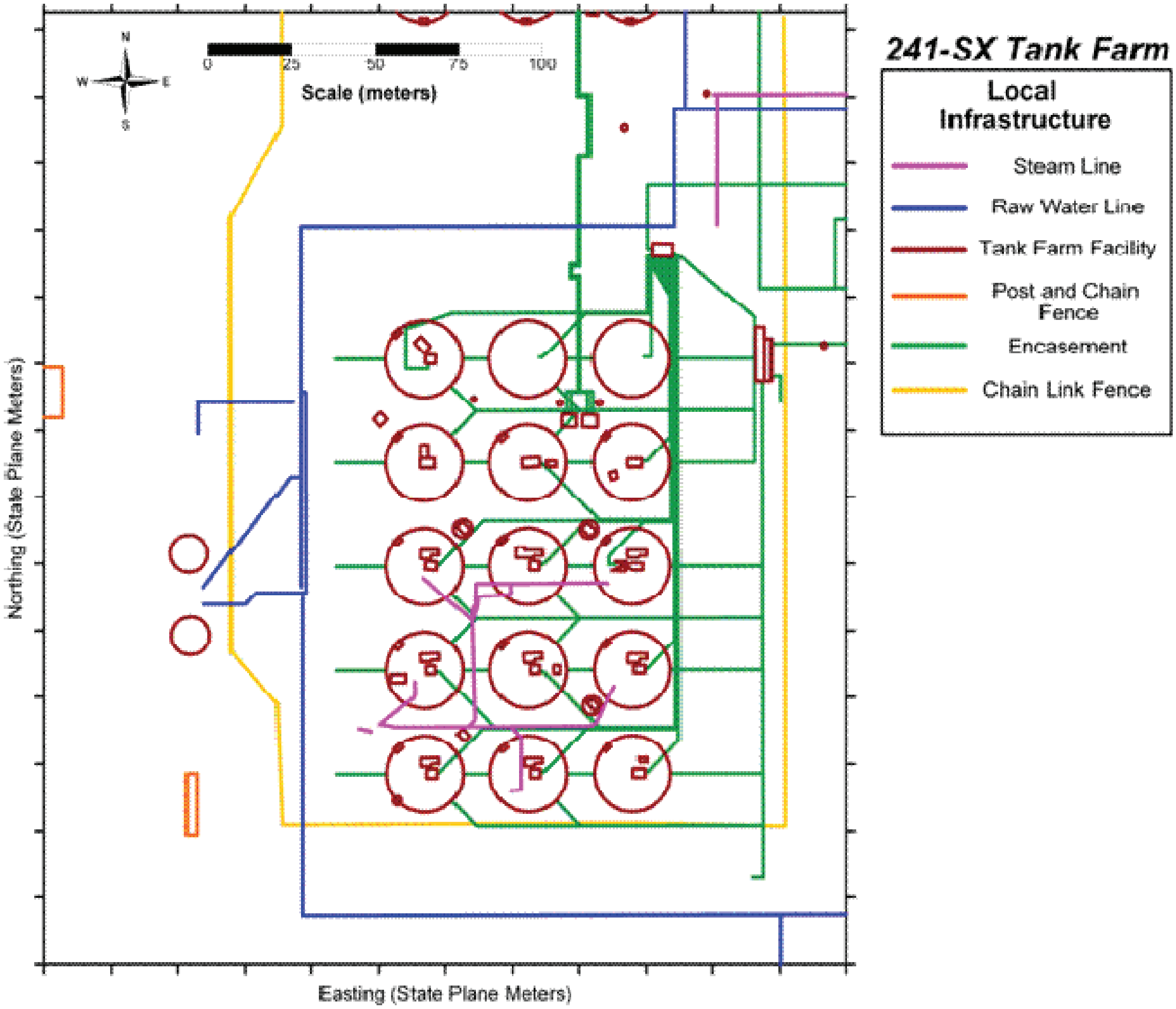
- Tanks SX-107, SX-108, SX-109
- Tanks SX-113, SX-115
- Tank S-104.

Evidence from the historical record suggests that the largest leaks in WMA S-SX came from these tanks or associated infrastructure. Comparison of gamma data within these three areas shows cesium-137 to be much more extensively distributed both horizontally and vertically in the area around tanks SX-107, SX-108, and SX-109. In the areas around tanks SX-113, SX-115, and S-104, cesium-137 is measured in one drywell very close to the side of each tank. Spectral gamma logging data also indicate the presence of generalized near-surface contamination across WMA S-SX. A number of surface and near-surface spills and unplanned releases were documented in and around WMA S-SX. Summary descriptions of these events are provided in HNF-SD-WM-ER-560. Most appear to have been minor releases that made relatively insignificant contributions to vadose zone contamination. Recent field characterization efforts for the S-SX field investigation report (RPP-7884) were mostly directed toward the areas around larger known release events. Relatively small amounts of recent characterization data have been collected for the areas around minor release events.

2.3 INFRASTRUCTURE AND WASTE DELIVERY TO SX TANK FARM AREA

In addition to the intentional liquid waste discharges to the cribs and unplanned waste releases, leaks from water distribution lines in and around the tank farm and known meteorological events may have contributed to waste migration in the vadose zone (RPP-7884). Figure 2-7 shows the infrastructure, including pipes, tanks, and diversion boxes used to transfer waste and supply the tank farm with water.

Figure 2-7. Infrastructure Map of Study Area that Includes SX Tank Farm and Part of S Tank Farm.



3.0 QUALITY ASSURANCE

Collection and analysis of SGE data are performed under a project-specific quality assurance plan using a graded approach that conforms to applicable requirements from Columbia Energy quality assurance procedures (CEES-0333, *Quality Assurance Plan for Surface Geophysical Exploration Projects*). These procedures implement the requirements of ASME NQA-1, *Quality Assurance Requirements for Nuclear Facility Applications* and DOE Order 414.1C, *Quality Assurance*. Work not covered in the quality assurance plan will conform to accepted industry standards for SGE and sound engineering principles.

This quality assurance plan implements the criteria of DOE Order 414.1C and the following requirements from ASME NQA-1:

- Organization (Requirement 1)
- Quality Assurance Program (Requirement 2)
- Instructions, Procedures, and Drawings (Requirement 5)
- Document Control (Requirement 6)
- Corrective Action (Requirement 16)
- Quality Assurance Records (Requirement 17).

Columbia Energy and hydroGEOPHYSICS, Inc. collect data using designed systems or off-the-shelf commercially available hardware. Designed systems conform to applicable requirements in approved procedures that address design, design analysis, design verification, and engineering drawing.

A project-specific software management plan, CEES-0338, *Software Management Plan for Surface Geophysical Exploration Projects*, was prepared to implement a graded approach to software management in accordance with the following requirements documents:

- ASME NQA-1, Subpart 2.7
- CEES-0333
- CE-ES-3.5, So*ftware Engineering*
- DOE Order 414.1C.

3.1 DATA COLLECTION

The setup, operation, and maintenance of the SGE equipment used in collecting and analyzing resistivity data is described in CEES-0360, *Surface Geophysical Exploration System Design Description*. This document identifies the requirements for the hardware and software used for data collection and analysis and provides a rationale for the hardware and software selected for use.

Calibration requirements are described for hardware used to collect geophysical data. As an example, the manufacturer (Advanced Geosciences, Inc.) of the resistivity data acquisition instrument (SuperSting R8®) recommends a yearly calibration of internal calibration resistors. The calibration is performed at the manufacturer's facility and a certificate of calibration is provided. A copy of the calibration documentation, serial numbers, and expiration dates are maintained in project files.

In addition, daily inspection of the receiver calibration is performed onsite using the manufacturer-supplied calibration resistor test box. The supplied test box is connected to the SuperSting R8 before commencing the daily survey. A specific calibration test firmware is provided within the SuperSting and provides the operator with a pass/fail indication for each of the eight receiver channels. If any of the channels fail, a recalibration or repair is required.

3.2 DATA PROCESSING

Data processing is performed using a number of software packages. The requirements and responsibilities for the identification, evaluation, development, testing, and maintenance of quality-affecting software acquired, developed, or modified in support of the SGE efforts are defined in the CEES-0338.

Verification and testing of the software modifications made for the SGE projects was performed and documented in RPP-34974, A detailed description of the test performed and the results are provided in RPP-34974. Verification and testing was performed on the existing two-dimensional and 3D versions of the software, as well as the upgraded version developed for the previous tank farm area SGE analysis.

The objective of the verification and testing study was to demonstrate that the EarthImager series of resistivity inversion codes were comparable to an industry standard or to known conditions from a pilot-scale field resistivity experiment. The industry standard was established by showing RES2DINV and RES3DINV (developed by Geotomo Software, Penang, Malaysia) (designated as RES#INV as reference to both codes) are used ubiquitously and accepted by geophysicists. RES2DINV and RES3DINV use has been cited in a large body of scientific literature. Subsequently, a benchmark study between the industry standard and the EarthImager series was conducted in both two and three dimensions for a variety of geological conditions with the same pole-pole array system and conditions deployed at SGE sites.

A pilot-scale field resistivity experiment was previously established to benchmark the WTW inversion methodology used in the Hanford tank farms. In the tank farms, surface-based resistivity data may be highly influenced by the buried metallic infrastructure, masking the waste plume. To circumvent the infrastructure issue, the vertical stainless-steel monitoring wells were used as long electrodes for both transmitters and receivers. Another advantage of using the wells is the direct contact of the electrode with the waste. The disadvantages are the limited depth resolution and the fixed spatial distribution of the measurement locations.

The pilot-scale field experiment was used to test the WTW inversion methodology by establishing a known conductive target in the subsurface and making measurements with a set of 27 wells. To date, there is no industry standard for the WTW resistivity imaging technique; therefore, the field experiment was designed to test EarthImager 3D®'s ability to replicate a target of known

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geometry. Additionally, the pilot-scale experiment was necessary due to the inability of RES2DINV to model the WTW resistivity technique. The subsurface geophysical target was an amended, electrically conductive soil, buried approximately 0.5 meters below ground surface. The 27 wells were distributed around the target in a pattern similar to tank B-105 in the B tank farm.

4.0 DATA ACQUISITION—WELL-TO-WELL SURVEY

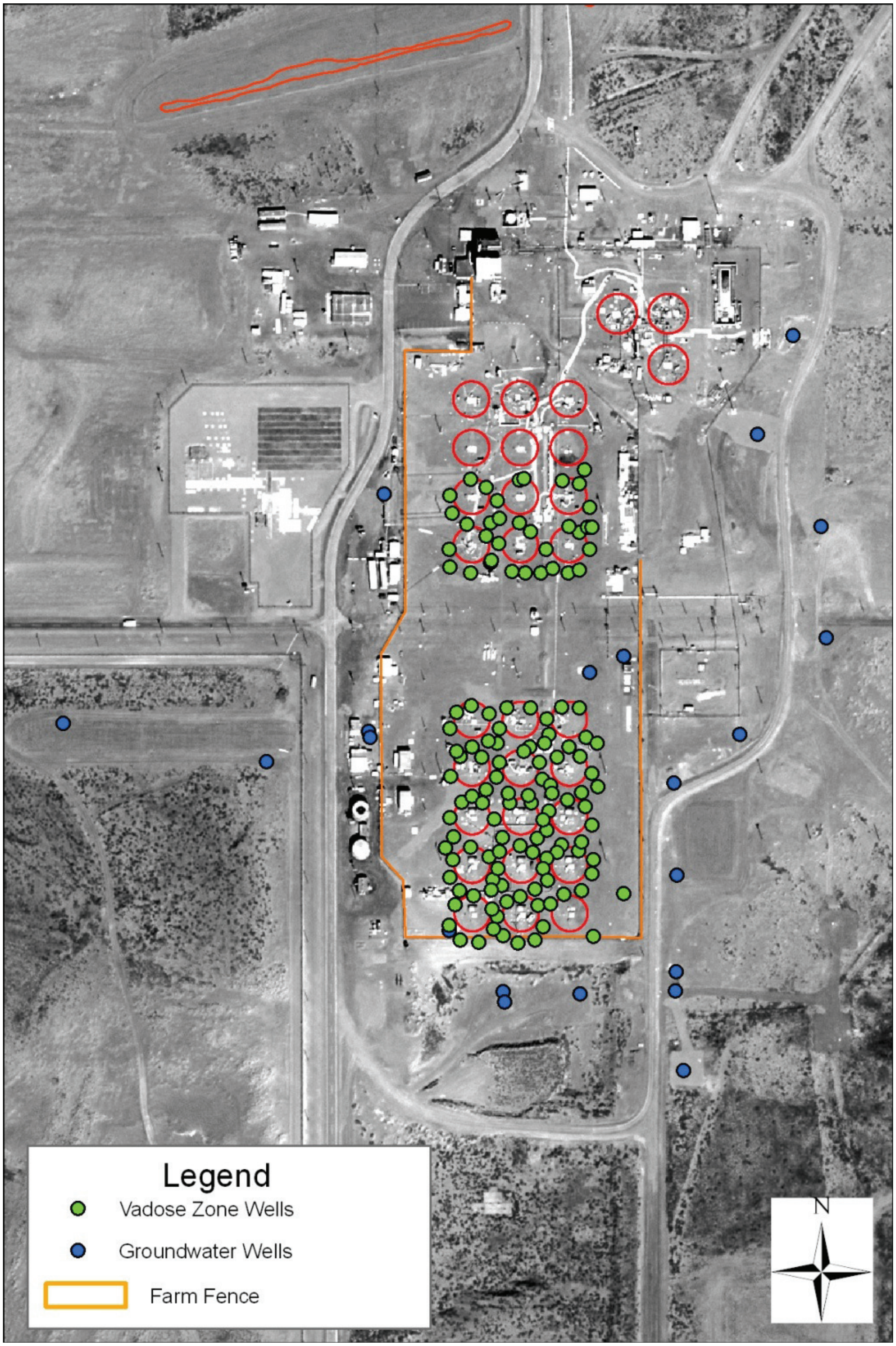
Data acquisition for the WTW survey of the SX tank farm area and the southern half of the S tank farm area, which began on August 22, 2008, and completed on August 23, 2008, collected resistivity data using existing steel-cased wells as current sources and receivers. The WTW survey made use of 21 groundwater wells and 132 vadose zone drywells, totaling 153 wells (Figure 4-1). In general, the well locations do not fit a grid or linear arrangement (Figure 4-1) and follow circular patterns around tanks or other areas of interest.

The groundwater wells and the vadose zone drywells used for the survey are listed in Table 4-1.

Table 4-1. Wells Used in WTW Survey.

Well ID	Well ID	Well ID	Well ID	Well ID	Well ID
Groundwater Wells					
W23-19	299-W22-47	299-W23-11	2-W22-45	2-W22-48	299-W22-85
299-W23-15	299-W22-46	2-W23-9	W23-7	2-W22-44	—
NO NAME	2-W22-50	2-W23-21	SX-152	299-W22-84	—
2-W22-80	2-W22-49	299-W23-14	2-W23-20	2-W22-81	—
Vadose Zone Drywells					
41-15-07	41-10-11	41-08-06	41-04-03	41-02-08	40-10-13
41-15-09	41-11-02	41-08-04	41-04-01	41-02-11	40-10-01
41-15-05	41-10-10	41-07-08	41-01-06	41-02-02	40-00-04
41-14-06	41-11-03	41-07-03	41-04-11	41-01-10	40-07-04
41-14-08	41-10-08	41-09-09	41-05-02	41-01-11	40-07-06
41-15-03	41-11-05	41-09-11	41-01-08	41-01-01	40-10-09
41-14-09	41-11-06	41-06-06	41-01-07	41-01-04	40-11-01
41-15-02	41-11-08	41-09-02	41-02-05	41-00-02	40-08-06
41-14-11	41-12-03	41-09-03	41-05-12	41-08-03	40-12-02
41-14-04	41-12-04	41-06-05	41-02-07	40-12-09	40-09-05
41-14-03	41-12-06	41-08-11	41-05-08	40-12-07	40-08-08
41-14-02	41-15-10	41-05-07	41-05-10	40-12-06	40-09-06
41-13-10	41-12-07	41-08-02	41-06-02	40-12-04	40-09-08
41-00-05	41-12-09	41-07-10	41-03-05	40-11-08	40-09-09
41-00-04	41-12-10	41-05-05	41-03-06	40-11-07	40-09-01
41-10-06	41-00-08	41-05-03	41-06-23	40-11-09	40-09-02
41-10-05	41-09-07	41-04-08	41-06-11	40-11-05	40-08-09
41-10-03	41-09-06	41-04-07	41-06-09	40-00-06	40-08-12
41-10-02	41-12-02	41-07-12	41-03-09	40-10-08	40-08-01
41-10-01	41-11-09	41-04-05	41-03-10	40-10-06	40-07-11
41-07-05	41-11-10	41-07-02	41-03-12	40-10-05	40-04-05
41-07-07	41-08-07	41-00-03	41-03-02	40-10-03	40-07-01

Figure 4-1. Well Layout for WTW Resistivity Survey—S and SX Farm Areas.



Sixteen-gauge machine tool wire was used to connect the resistivity meter to each well. The wire was strung from a central location outside the S farm complex fence to each of the 153 wells within the survey area. Wells were prepared in two ways: (1) a small area of rust was removed from the well casing and a wire with a stainless-steel strap attached to the casing wall, or (2) small hose clamps were used to attach the wire to monitoring components inside the well casing.

The SuperSting R8/IP® resistivity data collection system was selected for collecting resistivity data in and around the tank farms. The SuperSting R8/IP is a state-of-the-art, multi-channel portable memory earth resistivity meter with memory storage of readings and user-defined measurement cycles.

Switchboxes are used to direct or multiplex measurements through individual conductors (wires). The Advanced Geosciences, Inc. SwitchBox 56 resistivity multiplexer was selected for the project because it satisfied specific functional requirements for a minimum switching capacity of 153 electrode switching via any combination of multiplexer boxes. Three 56-electrode switchboxes were selected for use in this survey.

A custom-fabricated distribution panel was used to provide a means of connecting individual wires between the dry wells and groundwater wells and the Switchbox 56 multiplexer. The patch panel connects to the resistivity multiplexer using standard resistivity cables and can be used to verify continuity between individual sampling wells during field data collection.

The coordinates of each well were measured with a high resolution real time kinematic (RTK) global positioning system manufactured by Leica to facilitate geo-referencing the data.

The pole-pole electrical resistivity array was selected to maximize signal quality and target resolution as determined during previous SGE efforts (RPP-34690, *Surface Geophysical Exploration of the B, BX, and BY Tank Farms at the Hanford Site*). Two sets of data were acquired: an initial (forward) set and a reverse set. The two sets of data ensured that each well acted as both transmitter and receiver and are needed for quality control. The percent difference between each forward and reverse reading was computed and data measurements with a relative percent difference greater than 1.5 percent were considered unacceptable and removed before inversion. Figure 4-2 shows a histogram of the reciprocal percent difference values for all WTW measurements from vadose zone wells and groundwater wells.

The raw apparent resistivity data distribution for all WTW measurements is compared between SGE sites in Figure 4-3. The distribution and average apparent resistivity of the raw data at S-SX farm (purple line) are similar to the results found at other SGE sites.

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Figure 4-2. Histogram Showing Results of Reciprocal Analysis for WTW Measurements.

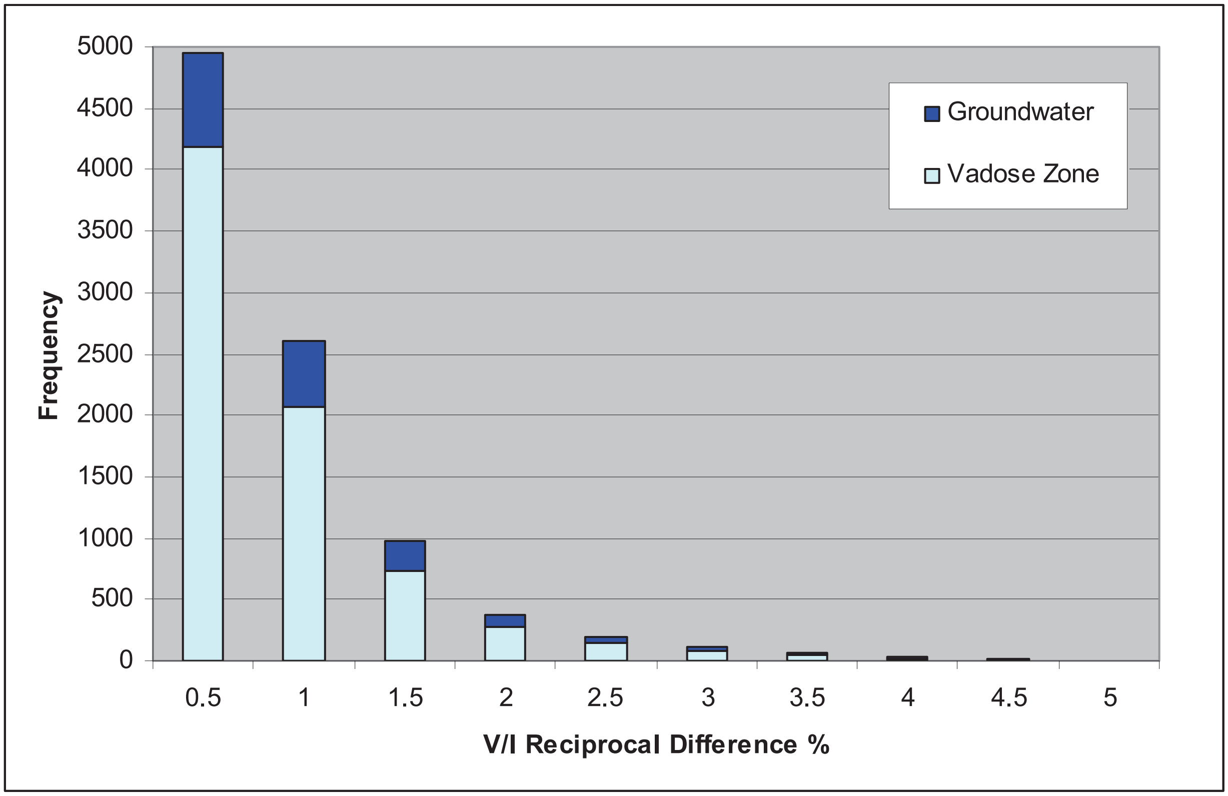
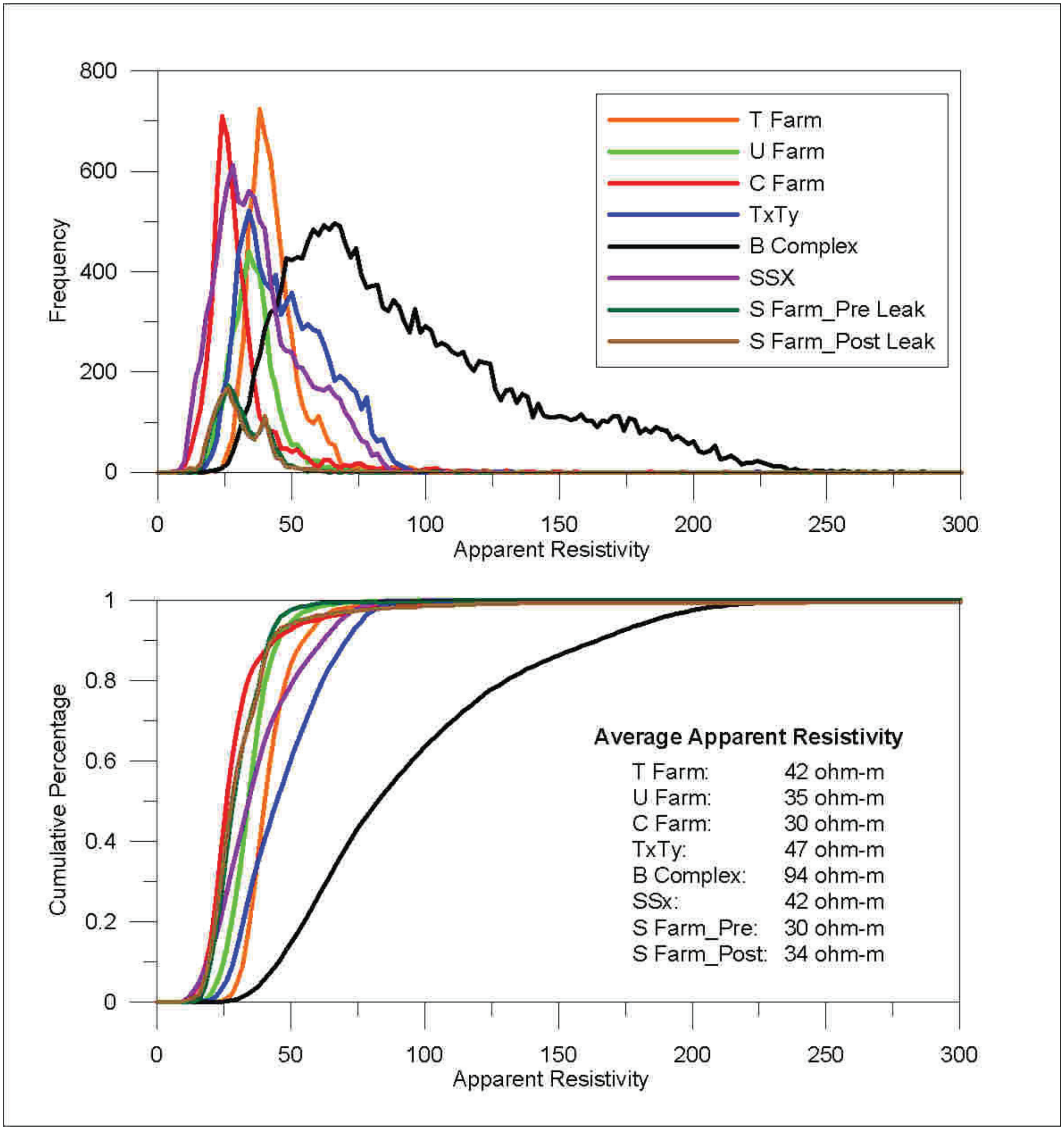


Figure 4-3. Histogram Comparison of Raw Apparent Resistivity Data.



5.0 ANALYSIS RESULTS AND INTERPRETATION

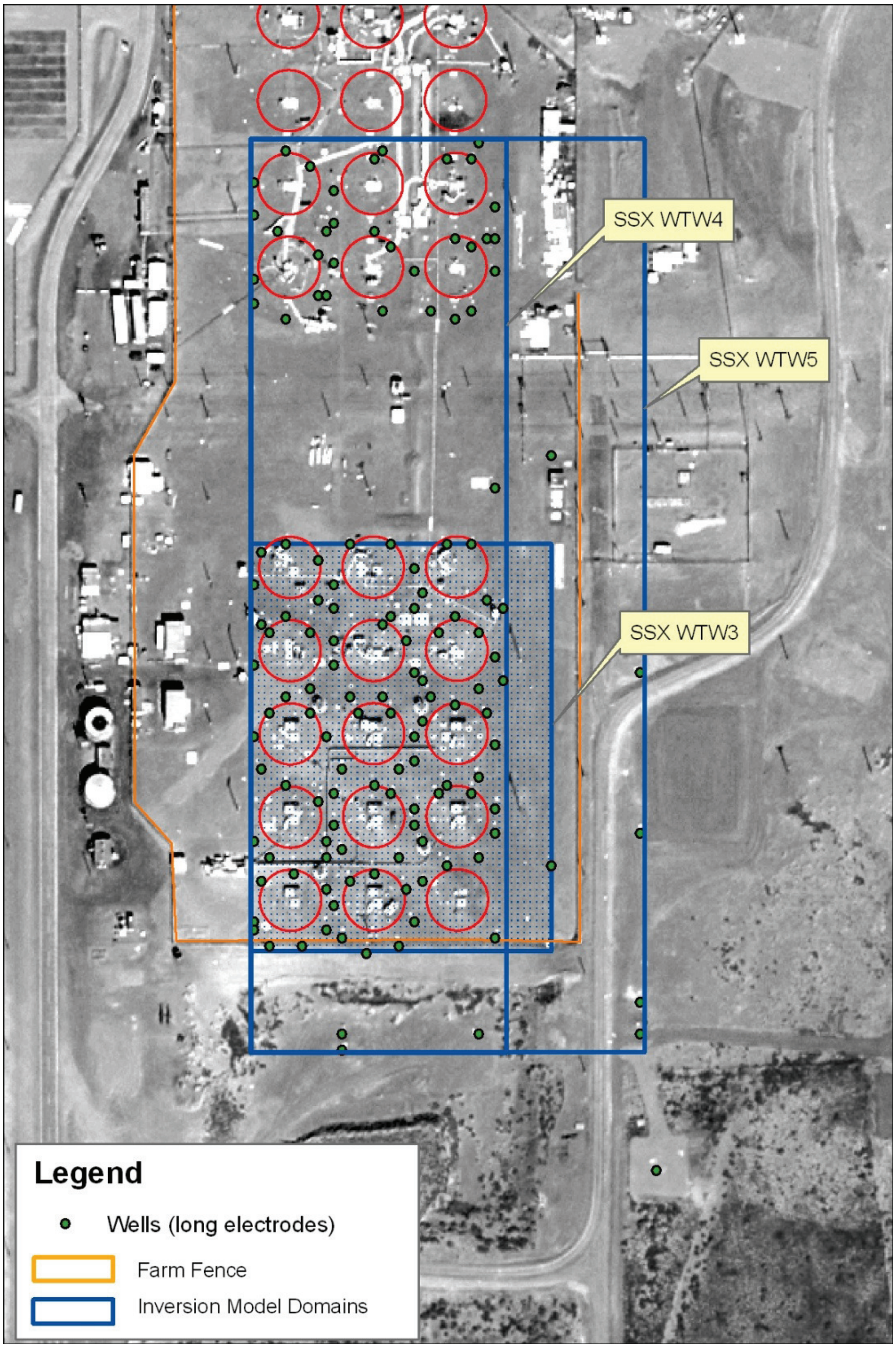
This section presents the resistivity results along with interpretation of the resistivity based on several inversion models over different domains. The methodology used for the S-SX tank farm investigation parallels the recently completed SGE investigation of the T and TX-TY tank farms. A description of the specific acquisition methodology and data quality is discussed in Section 4.0. A description of the data processing methods, theory, and limitations associated with using electrical resistivity methods in a tank farm environment are described in RPP-RPT-28955, *Surface Geophysical Exploration of T Tank Farm at the Hanford Site*.

For the processing of S-SX tank farms WTW data, the tomographic inversion code EarthImager3DCL was selected. EarthImager3DCL was first developed during the B Complex SGE effort (RPP-34690) in order to effectively process very large and complex 3D resistivity inversion models, which were not previously possible using commercial software. The well placement, casing length, and distribution of the electric field require a full 3D measurement and processing method be used.

Each steel casing was modeled in EarthImager3DCL as a linear source. The linear source was accommodated in the numerical model by establishing a set of very conductive cells (0.001 ohm-m) at the well's location. The length of the linear set of conductive cells was equivalent to the casing length for each well.

For the analysis of resistivity within the S-SX farms, several inversion models were run on different domains of increasing complexity and size. The modeling strategy was to learn the best inversion parameters on smaller and faster domains and apply those parameters to the larger slower domains. Figure 5-1 shows the series of modeling domains used in the modeling analysis to date. Preliminary results of results from analysis of model domains WTW3, WTW4, and WTW5 are presented in Sections 5.1, 5.2, and 5.3, respectively. Domain WTW3 was established to examine the vadose zone drywells of SX farm only. Domain WTW4 increased the domain size to include the drywells of S farm. Domain WTW5 included the wells of WTW4 and groundwater wells east of the tank farms.

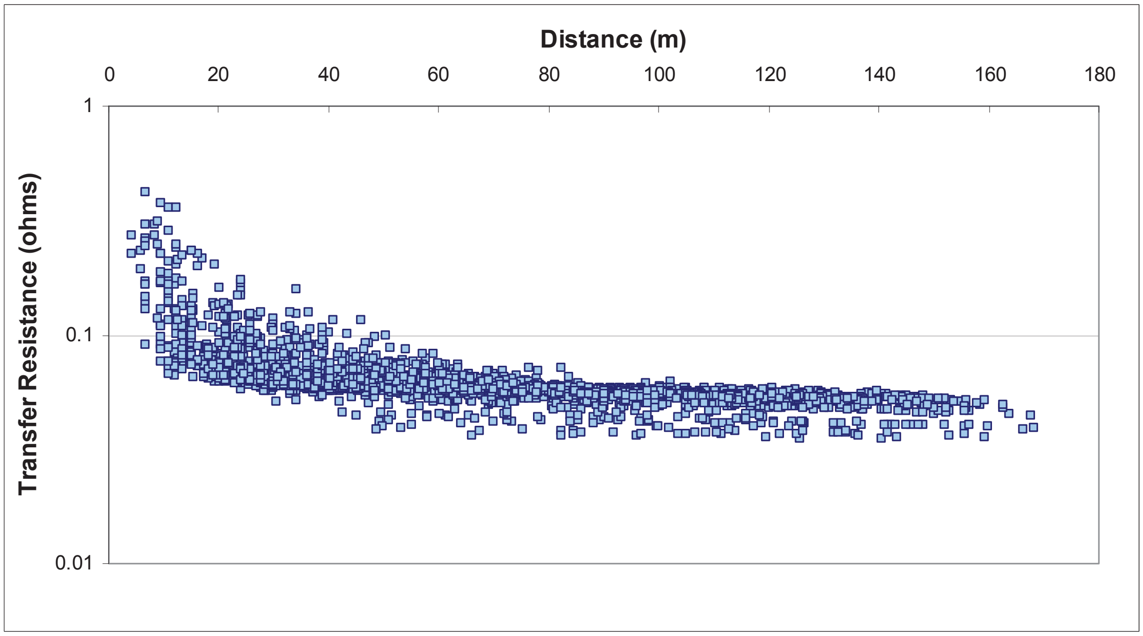
Figure 5-1. WTW Model Domains for the S-SX Characterization.



5.1 WELL-TO-WELL INVERSION OF SX FARM DRYWELLS

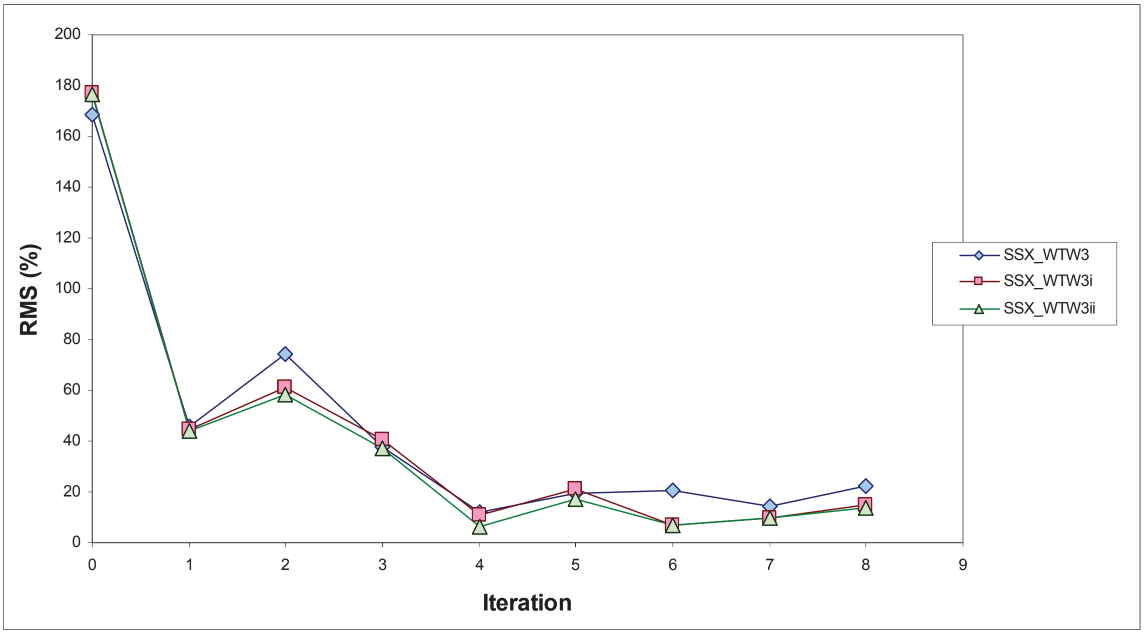
The WTW3 inversion involved the use of drywells as current transmission and voltage potential measurement electrodes. The background and theory for the WTW inversion can be found in RPP-RPT-28955. For the SX tank farm characterization, a total of 95 drywells were used for the data acquisition phase (Figure 5-1). During acquisition, reciprocal resistivity data were acquired, and the reciprocal error was used as a cut-off to remove noisy data. For all S-SX tank farm simulations, differences in measurements for reciprocal pairs in excess of 1.5 percent were removed. Figure 5-2 shows the distribution of remaining data used as input for domain WTW3. The transfer resistance data count is 3931.

Figure 5-2. Transfer Resistance Data (V/I) Versus Distance Used for Model Domain WTW3.



The tomographic inversion for WTW3 took a total of three separate runs, with each run having eight iterations. After each run, the iteration with the best (lowest) root mean square (RMS) error was filtered to remove those measurements that cause the greatest error. For the first model run (WTW3), iteration four was used for evaluating the noisiest data and a cut-off of plus or minus 30 percent RMS error was used as the filter for data removal. The second model run (WTW3i) also used iteration four for noise evaluation, which used a cut-off of plus or minus 20 percent to create the third and final model run (WTW3ii). Figure 5-3 shows the convergence curves for all three model runs.

Figure 5-3. Convergence Curves for Model Runs within Domain WTW3.



During filtering, a cumulative frequency curve is generated to understand the distribution of the calculated model error. The cumulative frequency curve for WTW3ii in Figure 5-4 indicates that the model has a relatively balanced (i.e., unbiased) Gaussian distribution of model misfit. Because the inversion modeling code assumes a Gaussian distribution of error, this curve indicates that modeling code is able to converge properly to a solution while using the level of noise present in these raw data.

Figure 5-4. Cumulative Frequency Distribution of Model Misfit for Domain WTW3ii.

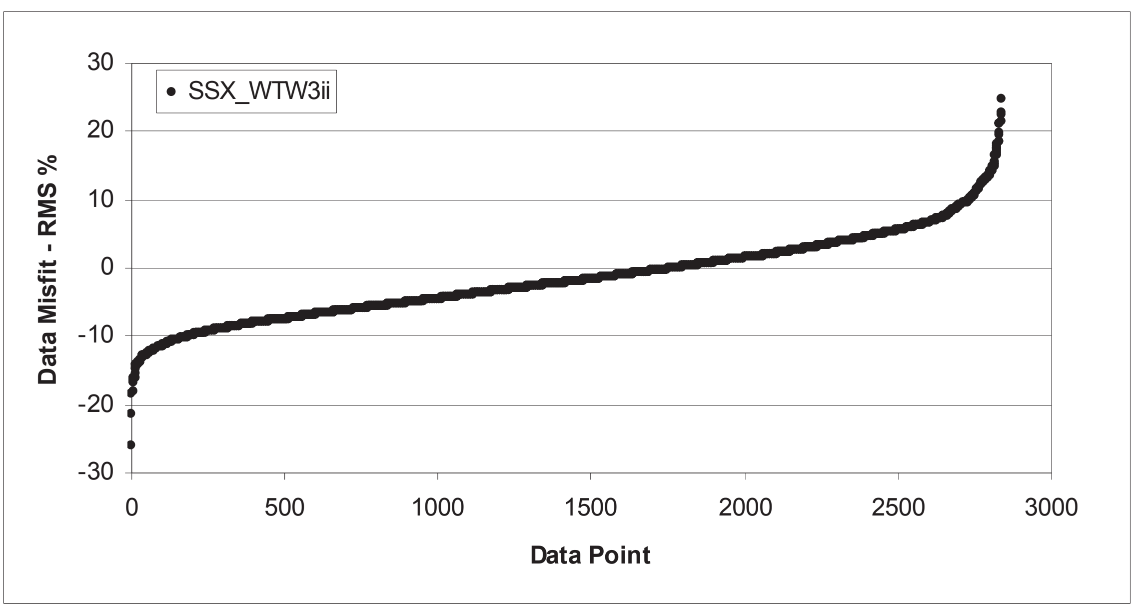
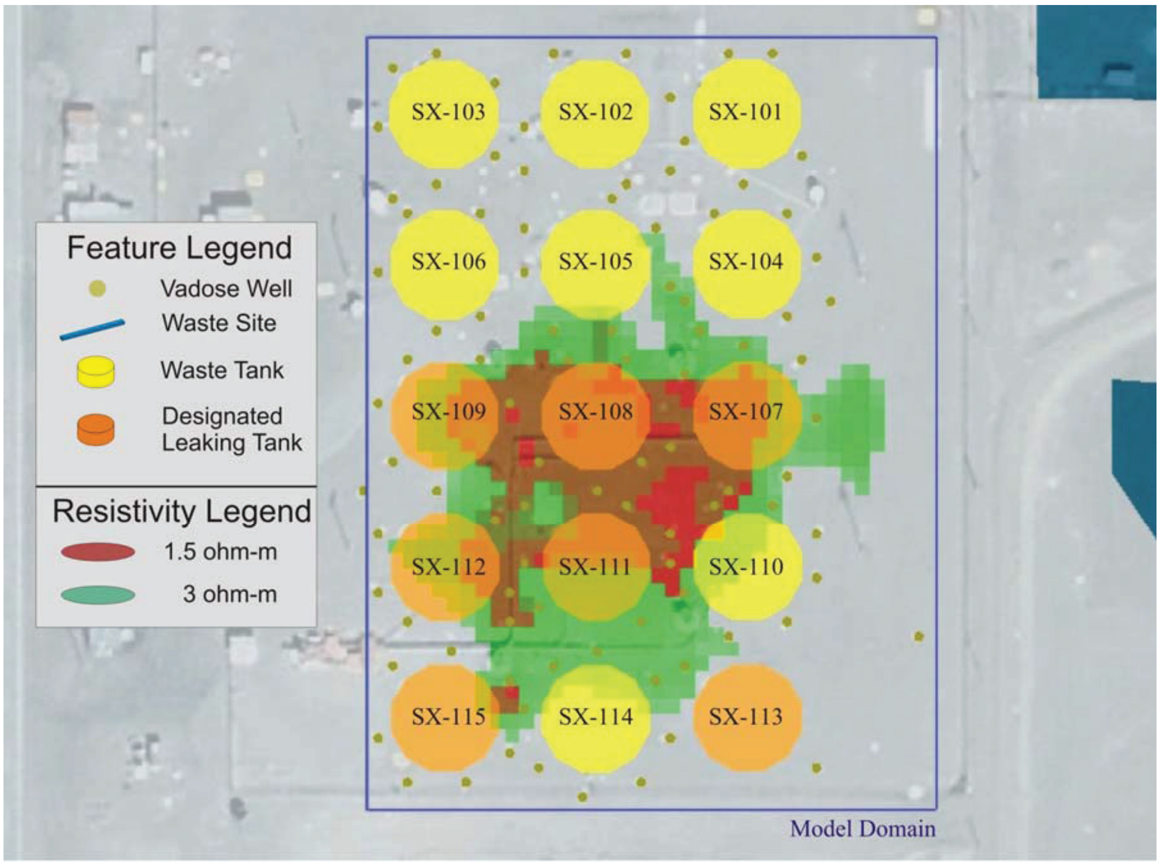


Figure 5-5 shows the results of domain WTW3, using iteration four from model run WTW3ii. The results are segregated into two values: the smallest and lowest resistivity anomaly in semitransparent red represents values less than 1.5 ohm-m; the larger anomaly in transparent green represents values between 1.5 and 3 ohm-m. There is clear spatial correlation between the low-resistivity features and the tanks designated as historically leaking. Tank SX-108 appears to be at the epicenter of the anomaly.

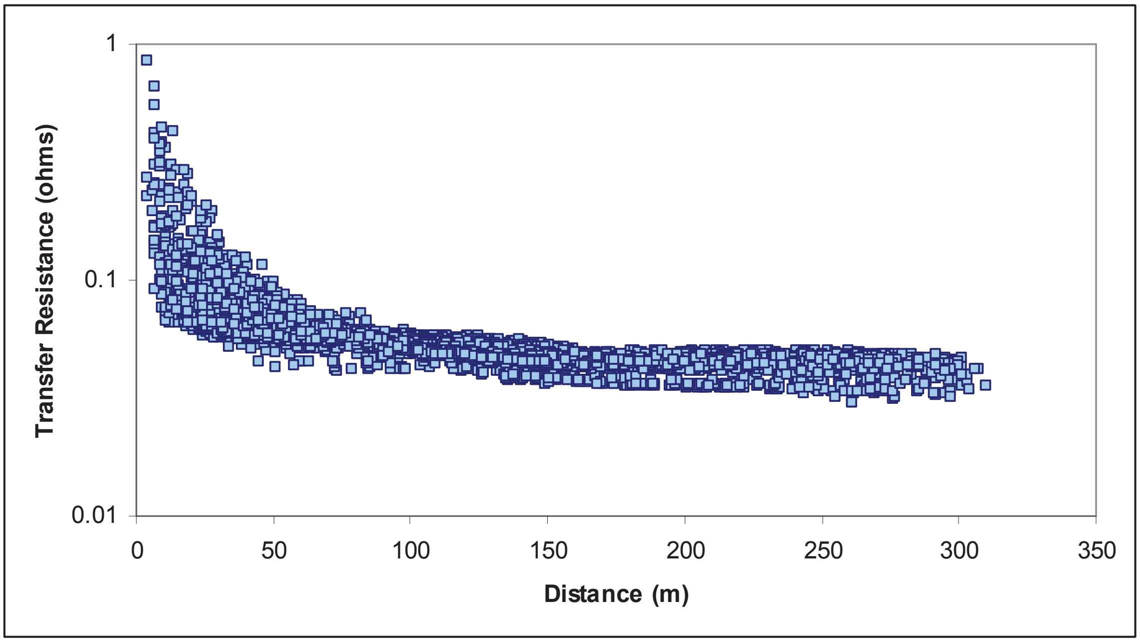
Figure 5-5. Electrical Resistivity Results for Model Domain WTW3 at SX Farm.



5.2 WELL-TO-WELL INVERSION OF S AND SX FARM DRYWELLS

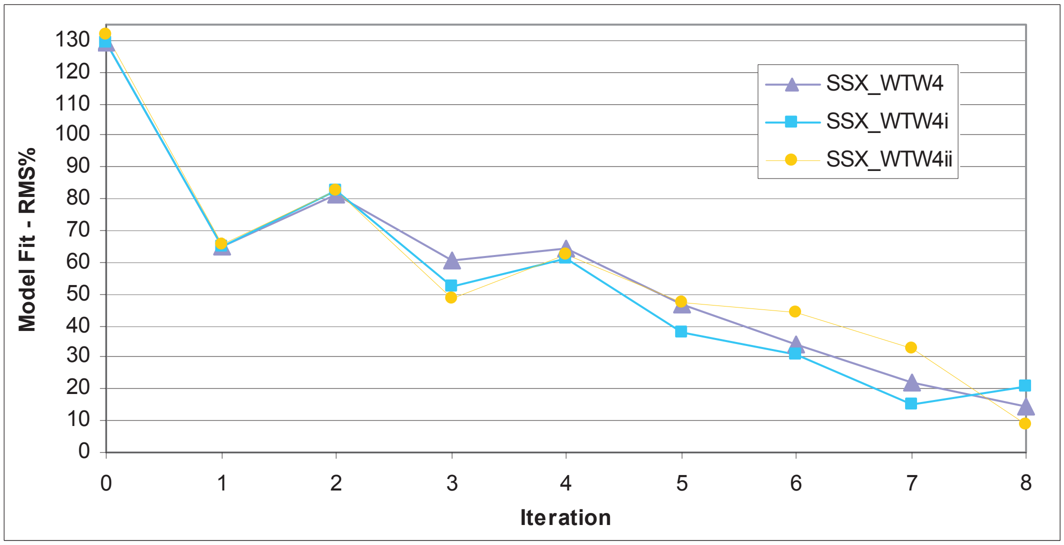
The model domain WTW4 represents all vadose zone wells for the southern portion of S farm and all available vadose zone wells in SX farm. For resistivity inversion model WTW4, a total of 129 wells were used for the modeling with a data count of 6904. Figure 5-6 shows the distribution of raw data expressed as voltage/amperage or transfer resistance.

Figure 5-6. Transfer Resistance Data (V/I) Versus Distance used for Model Domain WTW4.



For domain WTW4, a total of three runs were completed, with each run having eight iterations and successively lower final root mean square percent (RMS%) values. After each run, the iteration with the best fit (lowest) RMS error was filtered to remove those measurements that cause the greatest error. For the model first run (WTW4), iteration eight was used for evaluating the most noisy data and a cut-off of plus or minus 30 percent RMS error was used as the filter for data removal. The second model run (WTW4i) also used iteration eight for noise evaluation, which used a cut-off of plus or minus 30 percent to create the third run (WTW4ii), which has converged to a final RMS of 9.1 percent. Figure 5-7 shows the convergence curves for the three completed model runs. The results show that simulation WTW4ii is only marginally better than simulation WTW4.

Figure 5-7. Model RMS% Convergence for Model Domain WTW4.



During filtering, a cumulative frequency curve is generated to understand the distribution of the RMS% error. The cumulative frequency curve in Figure 5-10 shows that model WTW4ii is skewed towards a negative RMS% misfit. Because the inversion modeling code assumes a Gaussian distribution of error, a skewed distribution indicates that some noisy data still remain in this particular model domain. Additionally, the model is creating regions of lower than measured resistivity.

Figure 5-8. Cumulative Frequency Distribution of Model Misfit for Domain WTW4ii.

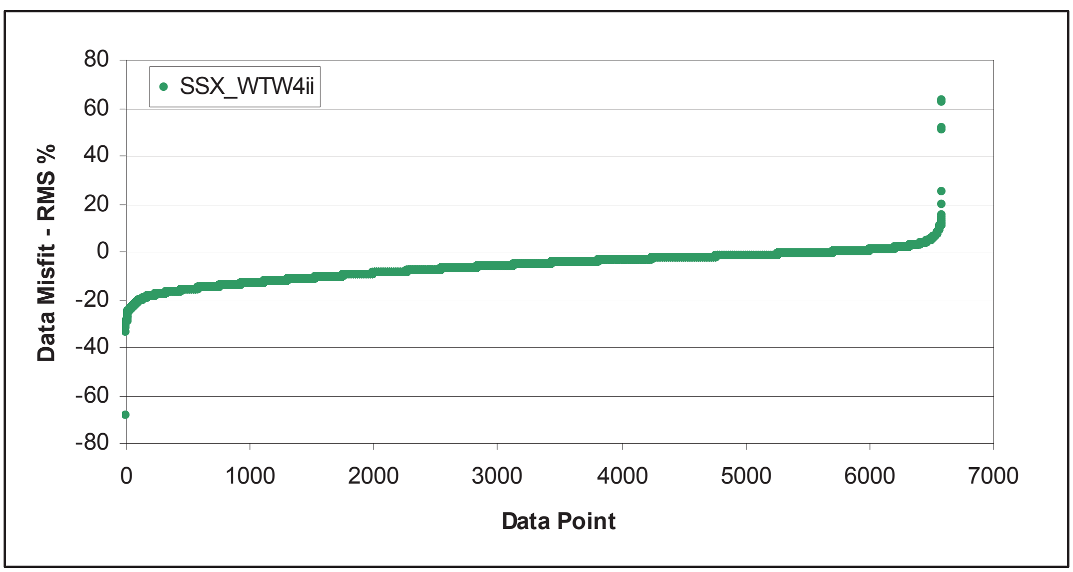
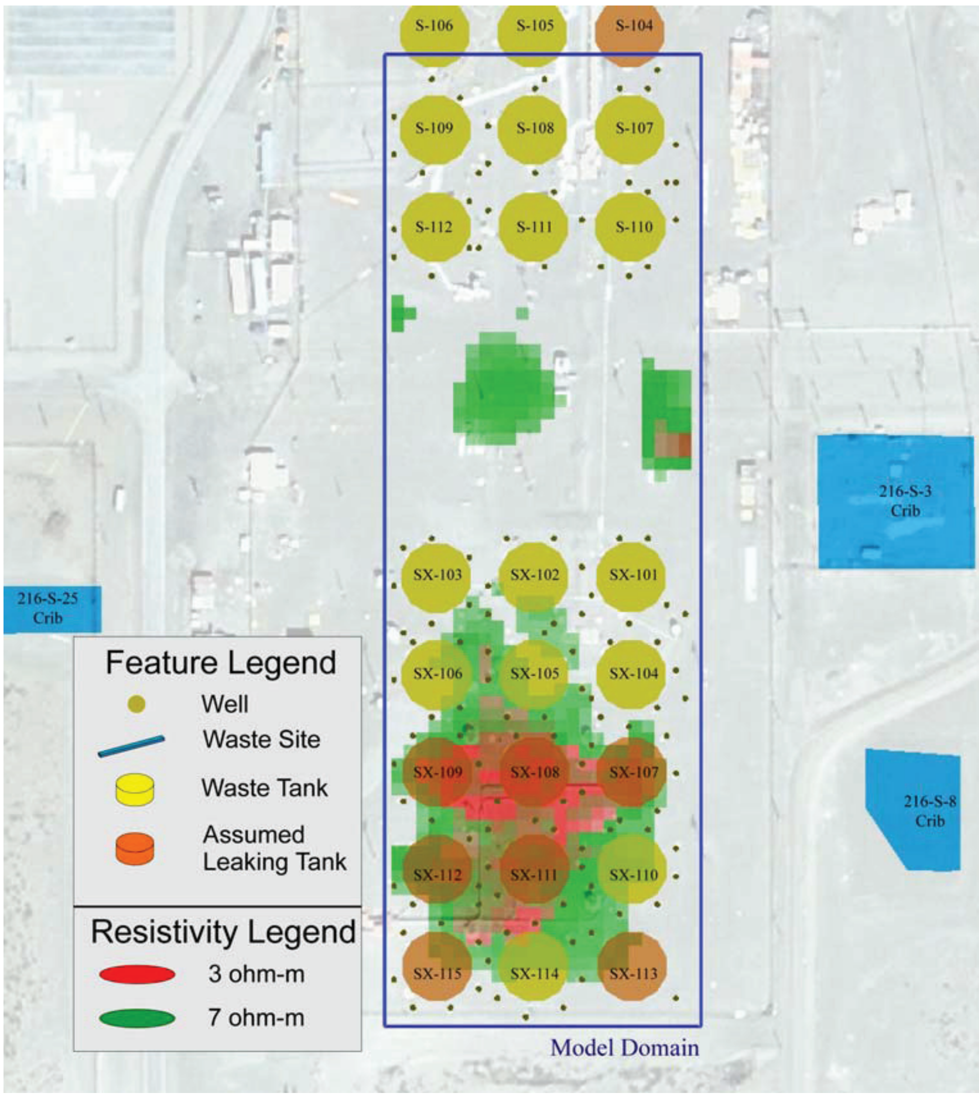


Figure 5-9 shows the resistivity results of domain WTW4, using iteration eight from model run WTW4ii. The results are segregated into two values: the smallest and lowest resistivity anomaly in semitransparent red represents values less than 3 ohm-m; the larger anomaly in transparent green represents values between 3 and 7 ohm-m. There is clear spatial correlation between the low resistivity features and the tanks designated as assumed to have leaked in the past. The low resistivity feature representing less than 3 ohm-m (in red), is equivalent to the larger resistivity feature (in green) shown in Figure 5-5.

Figure 5-9. Electrical Resistivity Results for Model Domain WTW4ii at S and SX Farm.

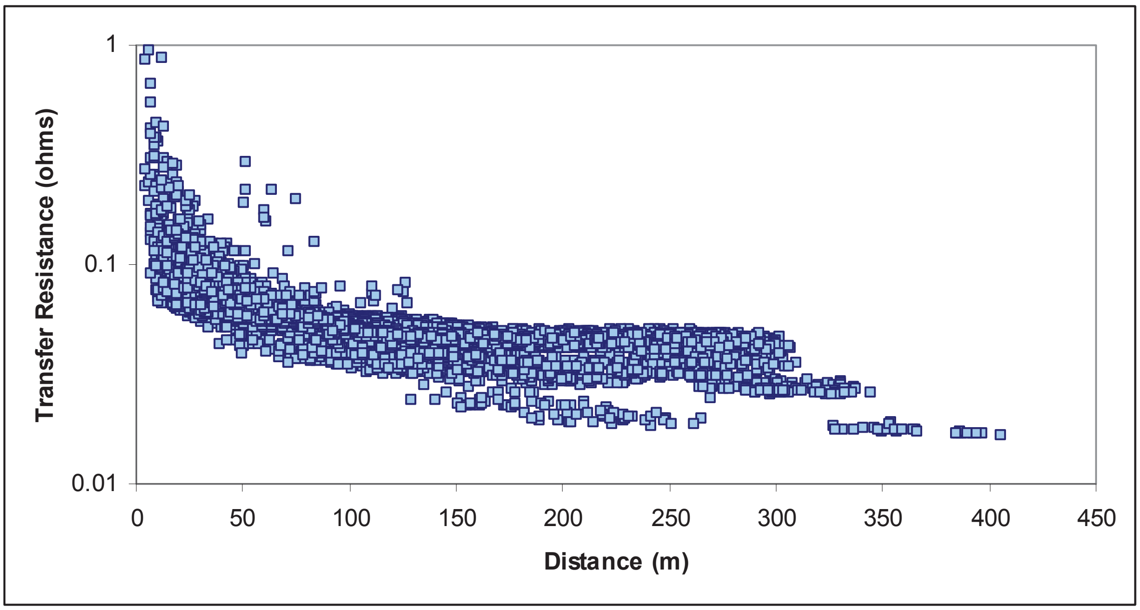


The area between tanks SX-108 and SX-109 appears to be central to this low resistivity feature, which is also found in model domain WTW3ii. Another minor low resistivity anomaly is located in the area between S and SX farms. The feature between the farms should be interpreted with caution as (1) some noisy data are still present in the modeling domain; (2) the model is tending to be skewing the calculations to a lower resistivity as indicated in Figure 5-10; (3) and region has relatively low model sensitivity due to its distance from available wells.

5.3 WELL-TO-WELL INVERSION OF S AND SX FARM DRYWELLS AND GROUNDWATER WELLS

The model domain WTW5 uses long electrode resistivity data from most of the vadose zone and groundwater wells for the southern portion of S farm and all of SX farm. For model domain WTW5, a total of 138 wells were used as long electrodes (128 vadose zone wells and 11 groundwater wells) with a raw data count of 8102. Figure 5-10 shows the distribution of transfer resistance data. When comparing Figure 5-6 with just vadose zone wells to Figure 5-10, the effects of the groundwater wells are noticeable. The groundwater wells tend to produce a data population that is different from that of the vadose zone wells.

Figure 5-10. Transfer Resistance Data (V/I) Versus Distance Used for Model Domain WTW5.



One run with seven iterations has been completed for WTW5 with an RMS% of 10.34 percent. Figure 5-11 shows the convergence curve for the model run. A cumulative frequency curve was generated to understand the distribution of the model error. The cumulative frequency curve for WTW5 in Figure 5-12 shows that model is skewed toward negative values. Because the inversion modeling code assumes a Gaussian distribution of error, a skewed distribution indicates that some noisy data still remain in this particular model domain.

Figure 5-11. Electrical Resistivity Results for Model Domain WTW5 at SX Farm.

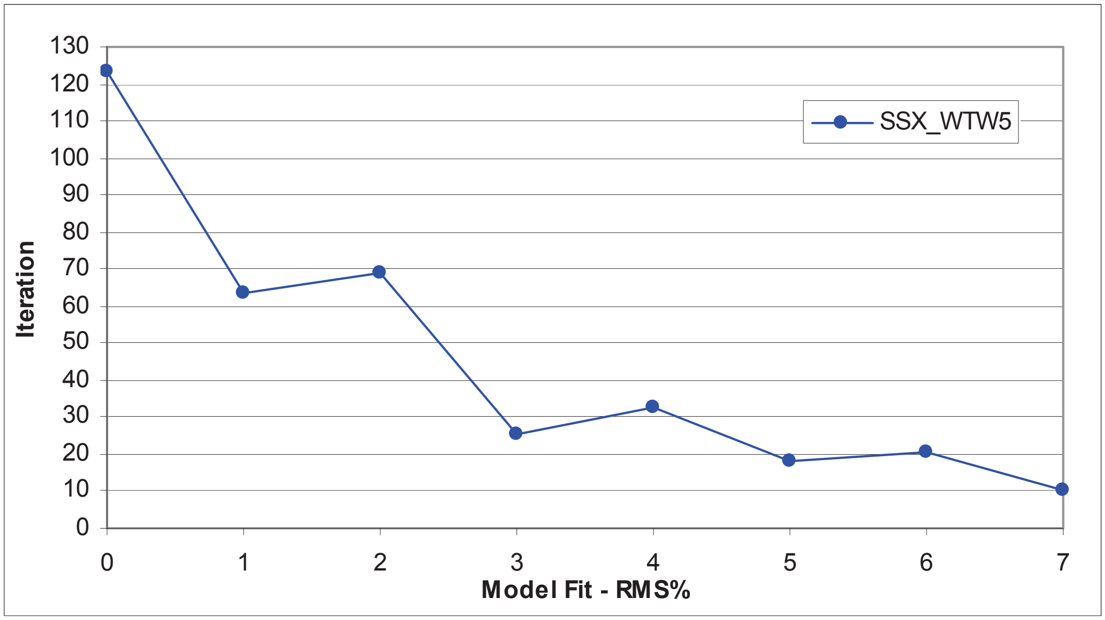


Figure 5-12. Cumulative Frequency Distribution of Model Misfit for Domain WTW5.

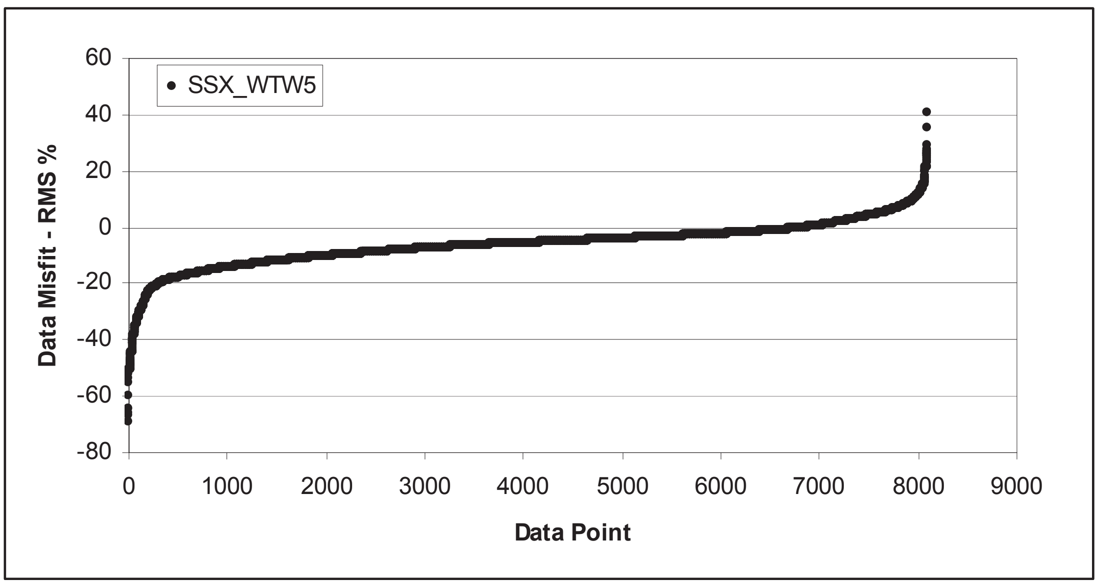
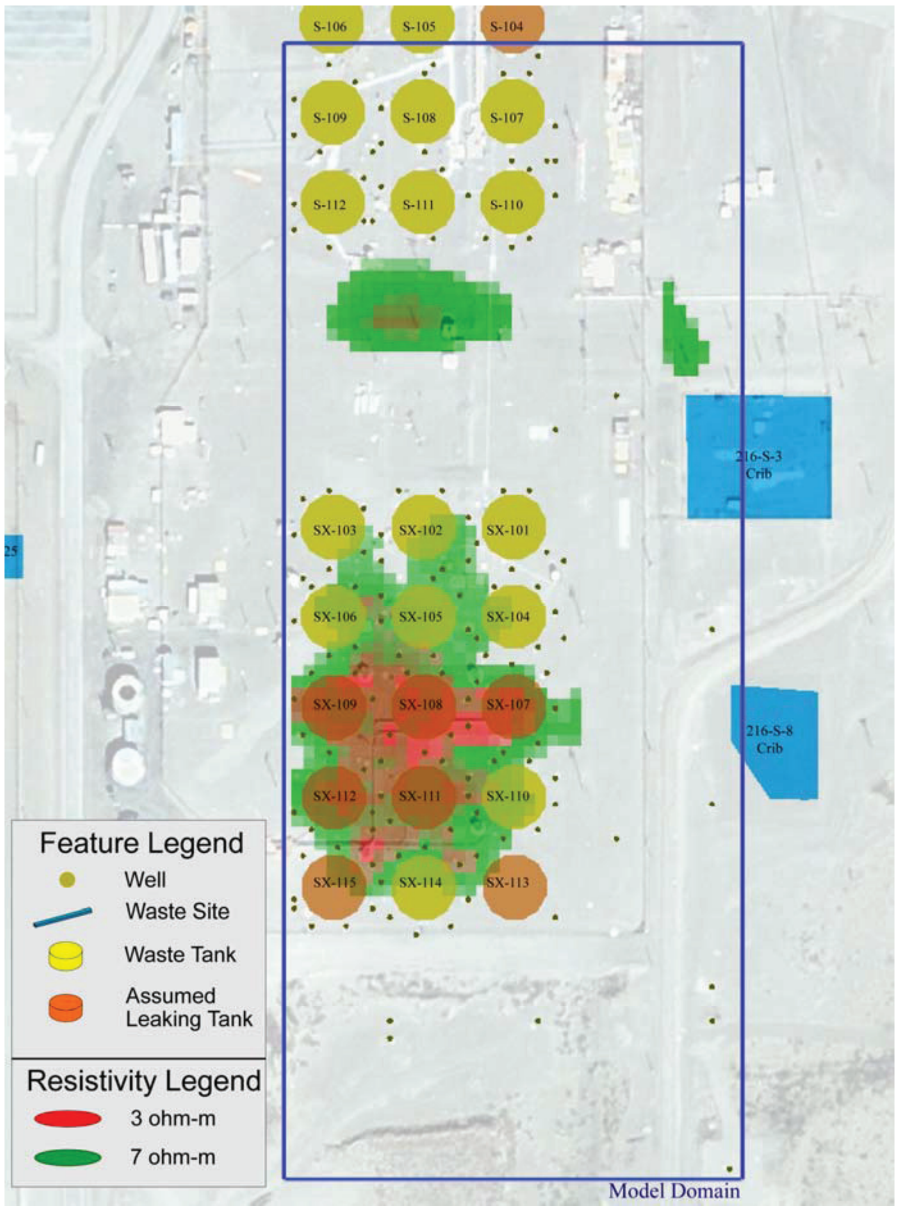


Figure 5-13 shows the results of domain WTW5, using data from iteration seven. The results are segregated into two values: the smallest and lowest resistivity anomaly in semitransparent red represents values less than 3 ohm-m; the larger anomaly in transparent green represents values between 3 and 7 ohm-m. There is clear spatial correlation between the low resistivity features and the tanks designated as assumed to have leaked in the SX farm. The area between tanks SX-108 and SX-109 appears to be central to this low resistivity feature, which is also found in model domain WTW3ii and WTW4ii. An additional low resistivity feature is located in the area between S and SX farms and near the north-west corner of 216-S-3. These features should be interpreted with caution as some noisy data is still present in the modeling domain based on analysis in Figure 5-12 and the features themselves are found in a region of the model domain which has relatively low sensitivity due to the distance from available wells.

Figure 5-13. Electrical Resistivity Results for Model Domain WTW5 at S and SX Farm.



6.0 CONCLUSIONS

This section presents the conclusions drawn from the results and interpretations presented in Section 5.0. The primary objective of this investigation was to demonstrate the ability to map areas or regions of low resistivity in and around the SX and southern S tank farm using the WTW electrical resistivity method.

The region was split into three domains (WTW3, WTW4, and WTW5) of increasing size. Domain WTW3 includes vadose zone wells in the SX farm. The results of the modeling show a low resistivity target beneath tanks that have been designated as historically leaking. In particular, these include the tanks in the central to south portion of the farm and the resistivity target appears to be centered at tank SX-108. The results, then, appear consistent with hydrologic expectations.

Domains WTW4 and WTW5 included southern S farm, with WTW4 focusing only on vadose zone wells and WTW5 including groundwater wells. The results from these domains showed a low resistivity body coincident with that of domain WTW3 as wells as a body between the farms. The low resistivity body between the farms should be viewed with caution, however, as there are no wells in this region. The lack of wells between the farms makes the model insensitive here. Thus, large variability in modeled resistivity would have little effect on the value of the transfer resistance on the wells.

7.0 REFERENCES

ASME NQA-1, 2000, *Quality Assurance Requirements for Nuclear Facility Applications*, American Society of Mechanical Engineers, New York, New York.

CEES-0333, 2006, *Quality Assurance Plan for Surface Geophysical Exploration Projects*, Revision 0, Columbia Energy & Environmental Services Inc., Richland, Washington.

CEES-0338, 2006, *Software Management Plan for Surface Geophysical Exploration Projects*, Revision 0, Columbia Energy & Environmental Services, Inc., Richland, Washington.

CEES-0360, 2007, *Surface Geophysical Exploration System Design Description*, Revision 0, Columbia Energy & Environmental Services, Inc., Richland, Washington.

CE-ES-3.5, 2006, *Software Engineering*, Revision 0, Columbia Energy & Environmental Services, Inc., Richland, Washington.

DOE O 414.1C, 2005, *Quality Assurance*, U.S. Department of Energy, Washington, D.C.

DOE/ORP-2005-01, 2006, *Initial Single-Shell Tank System Performance Assessment for the Hanford Site*, Revision 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

DOE/RL-2008-01, 2008, *Hanford Site Groundwater Monitoring for Fiscal Year 2007*, Revision 0, U.S. Department of Energy, Fluor Hanford, Richland, Washington.

RHO-ST-23, 1979, *Geology of the Separations Areas, Hanford Site, South Central Washington*, Rockwell Hanford Operations, Richland, Washington.

HNF-4936, 1999, *Subsurface Conditions Description for the S-SX Waste Management Area*, Revision 0, Lockheed Martin Hanford Company, Richland, Washington.

HNF-EP-0182, 2008, *Waste Tank Summary Report for Month Ending June 30, 2008*, Revision 243, CH2M HILL Hanford Group, Inc., Richland, Washington.

HNF-SD-WM-ER-560, 2001, *Historical Vadose Zone Contamination from S and SX Tank Farm Operations*, Revision 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

PNNL-14058, 2002, *Prototype Database and User's Guide of Saturated Zone Hydraulic Properties for the Hanford Site*, September 2002, Pacific Northwest National Laboratory, Richland, Washington.

RPP-7884, 2002, *Field Investigation Report for Waste Management Area S-SX*, Revision 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-17209, 2006, *Modeling Data Package for an Initial Assessment of Closure of the S and SX Tank Farms*, Revision 1, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-23748, 2006, *Geology, Hydrogeology, Geochemistry, and Mineralogy Data Package for the Single-Shell Tank Waste Management Areas at the Hanford Site,* Revision 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-34690, *Surface Geophysical Exploration of the B, BX, and BY Tank Farms at the Hanford Site,* Revision 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-34974, *Verification and Testing of the EarthImager Series of Electrical Resistivity Inversion Codes – A Benchmark Comparison*, Revision 0, CH2M HILL Hanford Group, Inc., Richland, Washington.

RPP-RPT-28955, 2006, *Surface Geophysical Exploration of T Tank Farm at the Hanford Site*, Revision 0, CH2M HILL Hanford Group, Inc., Richland, Washington.