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Revision 0

Improved Three-Dimensional Resistivity Data Acquisition Capabilities at the Hanford Site - 14146

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
Office of River Protection under Contract DE-AC27-08RV14800

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ABSTRACT

Problem: Soil contamination is known to exist within the vadose zone around Hanford's tank farms due to historic planned and unplanned releases to the environment. Soil borings alone do not provide a complete picture with regards to contamination extent within the subsurface. Electrical resistivity is a remote imaging tool used at the Hanford Site for mapping of subsurface electrical anomalies that may correspond to contaminants with high moisture content or high ionic strength. The resulting data is used to help design interim surface barriers or other interim remediation or mitigation measures. Additionally, the data is used to support subsurface characterization initiatives associated with environmental assessments and site closure.

Historically, off-the-shelf commercially-available data acquisition systems have been used to collect resistivity data. These systems generally contained a maximum of eight channels for data acquisition at a given time due to technological restrictions. This severely limits the area of investigation for 3D resistivity surveys. To compensate for this at the Hanford Site, data sets are acquired over smaller areas and then stitched together in model space, resulting in pseudo-3D resistivity models. This process provides less accurate information than what could be achieved with a higher number of data acquisition channels used over the full area of investigation. Additionally, field project durations, necessary support personnel, and subsequent costs are directly related to the speed of data acquisition that can be achieved. Thus, a system with a greater number of available channels should result in efficiencies in project schedule and project costs, with improved data quality.

Solution: The recent 3D electrical resistivity characterization at 241-U Tank Farm represents the first full-farm true 3D environmental resistivity deployment in the world. Technological and manufacturing developments by the vendor resulted in a data acquisition system that far surpasses the ability of the previous off-the-shelf systems. The new data acquisition system allows for 180 channels, which enables the full-farm 3D acquisition without the inaccuracies associated with combining multiple datasets. This ultimately leads to a more accurate model of the subsurface and a better understanding of moisture and contaminant distribution within the vadose zone. Additionally, advancements in electrical noise filters and increased output power resulted in better quality data then previously acquired at the site, reducing the amount of poor quality data by more than half.

Ultimately, the new, improved system increased the speed of data acquisition and quality of the final results. The system allowed a reduction in field labor and field work duration to half the field budget estimates, resulting in a 25% reduction in overall project costs. The new resistivity data acquisition system represents technological advancements resulting in a greater quantity of data with decreased project costs.

BACKGROUND

The U.S. Department of Energy (DOE) Hanford Nuclear Waste Reservation (Hanford) site has a legacy of 149 underground single shell radioactive waste tanks (SSTs) containing byproducts of the plutonium production effort from 1944 through the mid 1990's [1]. The initial SSTs were constructed with a life expectancy of 30 years. All of the tanks are now well beyond their life expectancy and some have begun to fail as a result. Additionally, process history for the SSTs indicates multiple release sites due to tank over-fills and known releases from tank and pipelines throughout the system. While all of the SSTs have been interim stabilized, the continued degradation of the SSTs is anticipated.

The process to remove the remaining SST waste is complex, and entails potential health and environmental risks which contribute to the extended time frame necessary to complete waste retrieval. Presently the retrieval completion date for the SSTs is January 31, 2043 [2], which means these tanks are likely to continue to be in service well beyond their initial design life. As a result of this eventuality, interim measures are being explored to limit the impact of any existing releases as well as preparing for the potential future releases. Detailed characterization efforts of soil conditions in and around the SSTs are ongoing in an effort to better determine the necessary interim measures.

Soil characterization techniques employed across the site include the review of process history, soil characterization, geophysical logging, and electrical resistivity imaging. Resistivity imaging is a non-invasive geophysical imaging method that maps the variation of soil resistivity in the subsurface, allowing for optimization of other soil investigation methods. Resistivity imaging responds to increased moisture and ionic solutions. It measures the variations in subsurface soil and pore-water resistance which can be associated with the presence of soil contamination.

Technological advancements in the deployment of resistivity imaging at the tank farms are being realized [3]. Within each tank farm there is a significant amount of subsurface infrastructure, including the tanks themselves, which can contribute to electrical interference and misinterpretations of the resulting data. Rucker et. al. (2013), demonstrates technology improvements since the resistivity characterization program was initiated in the tank farms in 2005 (Figure 1). Some of the improvements listed in figure 1 include increased computing capabilities, use of existing infrastructure as measurement sensors (long electrodes), installation of depth electrodes (both individual and multiple), implementation of advanced processing code, inclusion of subsurface a-priori information, and three-dimensional (3D) data acquisition. Figure 1 is adapted from Rucker et. al. (2013) to show the 2013 improvements: improved data acquisition speed through increased acquisition channels, increased data volume, and increased model quality.

ANALYSIS

This paper considers three basic improvements: speed of data acquisition, volume of data acquired, and the quality of the resulting resistivity model. Speed of acquisition can be directly related to field costs which are a large component of the overall project costs. A greater volume of high quality data that is well distributed over the survey area should contribute to a data set that is more representative of subsurface conditions. Finally, the quality of the data should be such that the increased volume of data used in the model results in a better model of the subsurface.

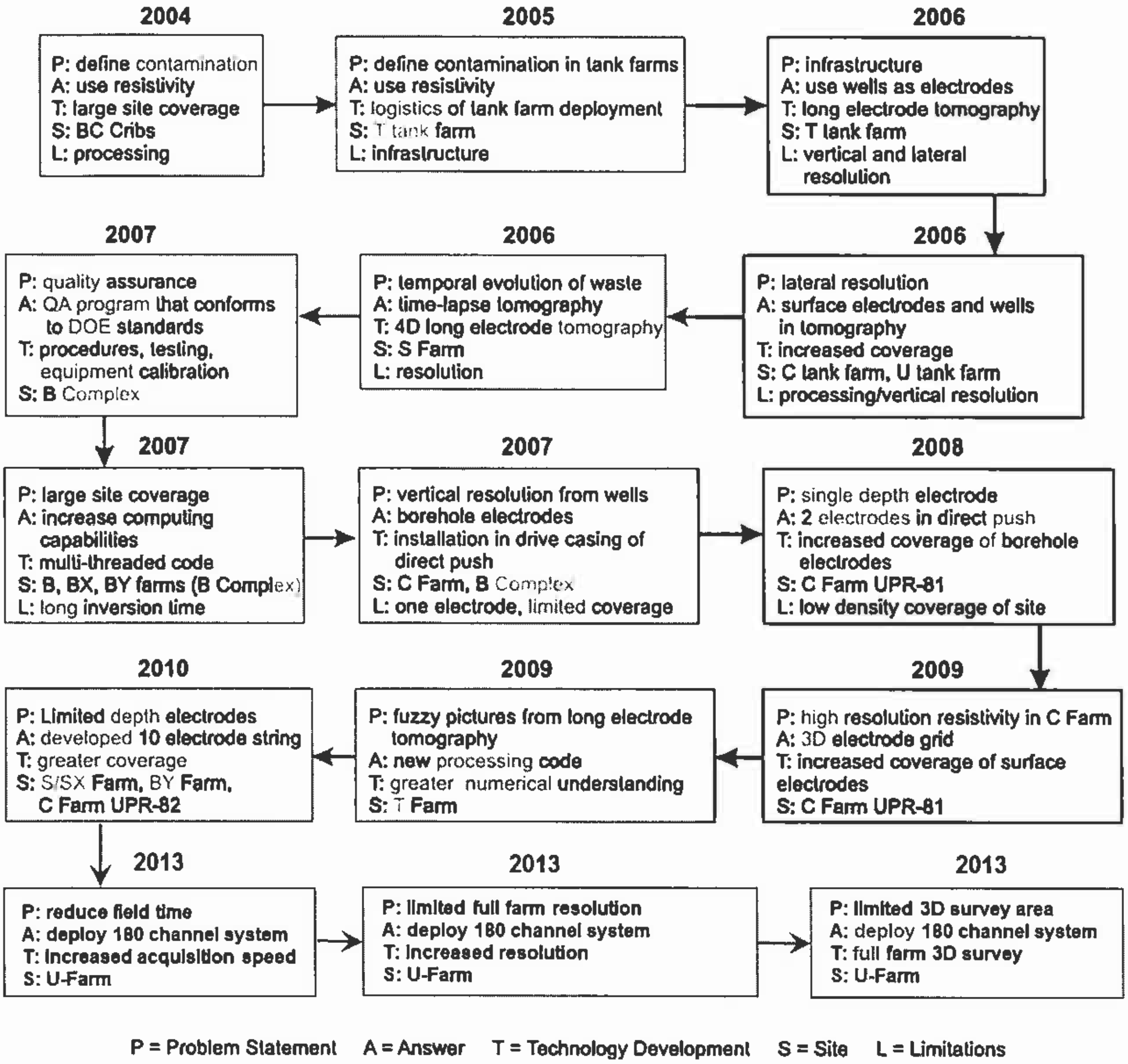

Fig. 1. Improvements in the application of resistivity as a subsurface imaging tool at the single shell tank farms on the DOE Hanford site since 2004.

To demonstrate the performance improvements using the 2013 resistivity deployment at U Farm, the U-Farm survey was compared to the next most recent resistivity imaging deployment completed at BY Farm in 2010 and 2011. The goal of each survey was to provide 3D resistivity imaging results for both farms and acquire data to support the decision process associated with the placement of interim surface barriers.

To determine data acquisition speed, the time stamps on the field data files were compiled for each site, summed, and rounded to the nearest hour. Using actual field time for each site would be misleading, as procedures are frequently changing requiring increased field support to complete field work safely, and new challenges are frequently arising during field work operations that can turn into unanticipated time sinks.

Volume of data was determined by the number of data points acquired for each site using surface electrodes only. Lastly, to assess the quality of the final model for U Farm and BY Farm it was necessary to look at the total number of data points used in the final model, the time it takes for the final model to complete the inversion process (convergence), and the root mean squared error (RMS) which is an indicator of the goodness of fit of the starting data to the final model. In addition to building the new data acquisition system the subcontractor also upgraded their computing capabilities in between working at the two sites. Therefore, the comparison of convergence time is not a fair metric as the convergence time is directly related to the computing capabilities of the machine. However, the increase in computing capabilities did result in an improvement in overall processing time.

The work completed at BY Farm was spread over two different field deployments to accommodate the area of investigation due to technology limitations at the time [4,5]. Figure 2 shows the survey area associated with both BY Farm and U Farm deployments. Note that the survey area for U Farm is approximately 16,560 square meters, while the total BY Farm survey area is 11,850 square meters [5,6,7]. For the comparison of the two field surveys to be accurate, the BY Farm statistics were scaled by a factor of 1.4 which accounts for the disparity between the two total survey areas and subsequently the total number of surface electrodes. Both surveys were completed with six meter inter-electrode spacing on an orthogonal grid.

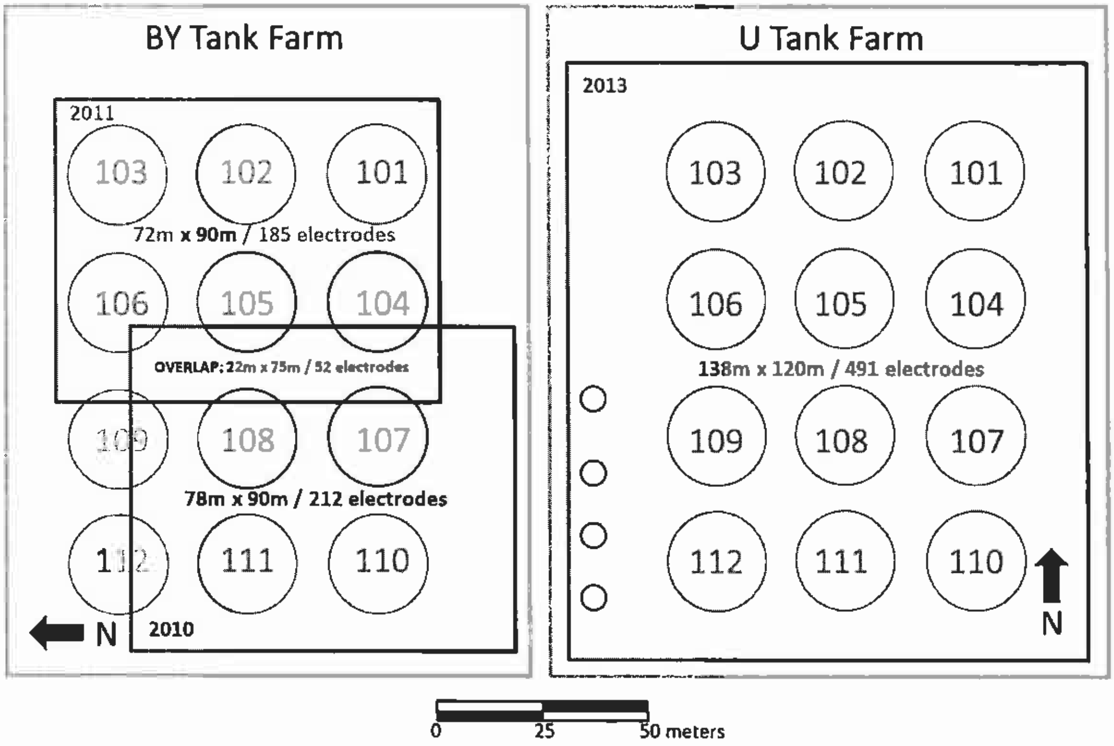

Fig. 2. Investigation area and electrodes associated with BY Farm and U Farm.

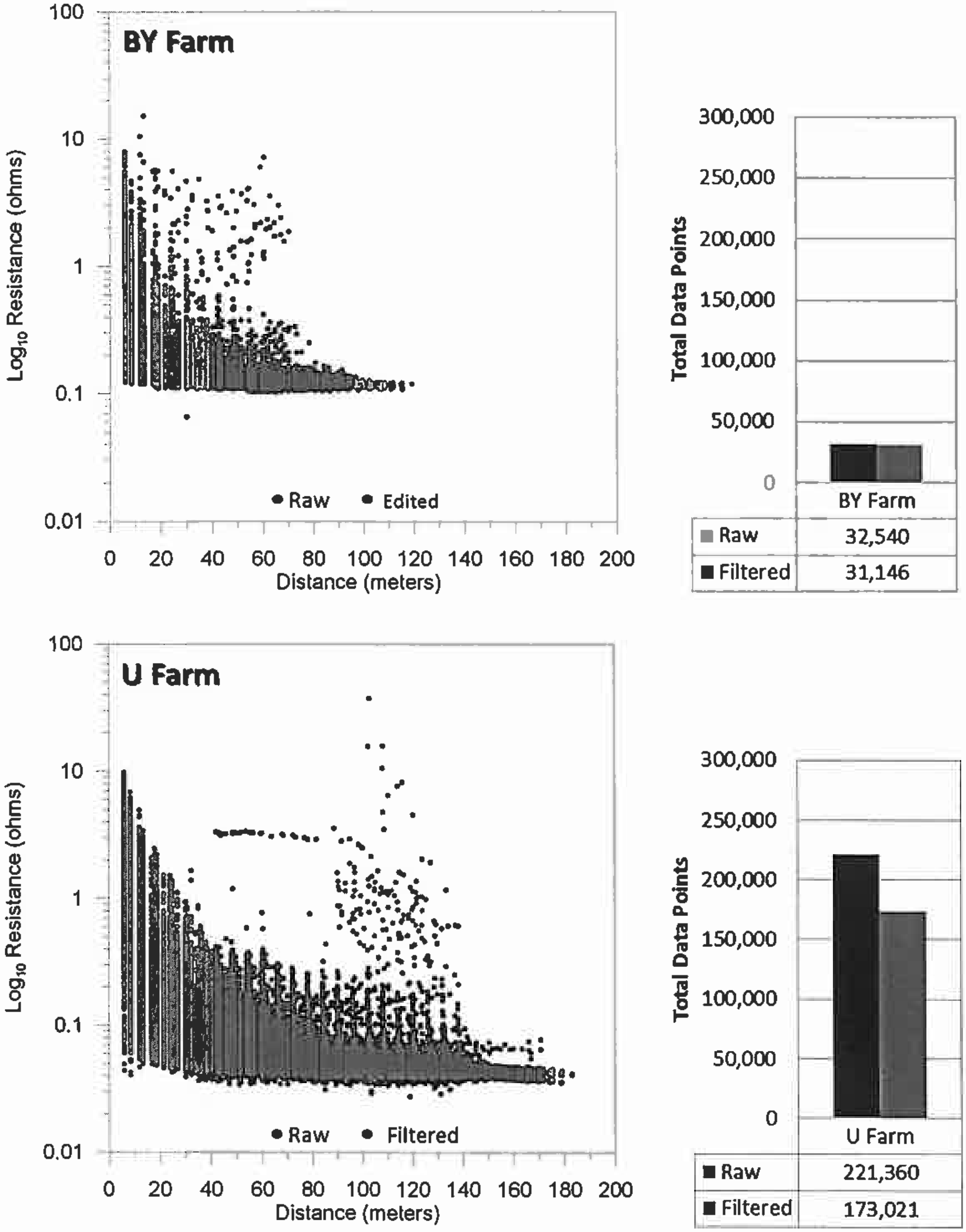

Fig. 3. BY Farm and U Farm total raw and modeled data sets.

RESULTS

Figure 3 shows the data obtained for each site (black) and the resulting filtered data prior to modeling (red). The scatter plot shows the data with regards to resistance data versus distance, while the actual number of data points obtained are plotted on the bar graph immediately adjacent to each scatter plot. Note the overall increase of data obtained at U Farm relative to the data obtained at BY Farm.

Table 1 displays the actual and scaled values for BY Farm as well as the actual values for U Farm and the percent improvement for each metric. The greatest improvement is in the speed of data acquisition; U-Farm data were acquired in less than 1/5th the amount of time that the old system would have required for the same coverage area at BY Farm. If the old system were deployed for the U-Farm survey, and was required to obtain the same number of data points, it would have taken approximately 748 hours compared to 28 hours with the new system.

The next highest percent improvement was observed for the total quantity of raw data obtained. The data are filtered to remove high error data points (points with greater than 5% reciprocal error) prior to inversion modeling. The filtering process reduced the BY Farm data by a factor of 4.3%; however, the U Farm data set was reduced by a factor of 24%. This may be a function of a survey environment with greater electrical noise, or a result of greater measurement spacing with the increased survey area. Generally, this would be a concern with the new approach except that the overall data retained is still 4 times the amount obtained at BY Farm. The U-Farm survey acquired nearly five times the amount of data in less than 1/5th the amount of time spent at BY Farm.

The inversion model convergence time was significantly lower which in part is attributed to the new data processing computer, but could also be a result of a greater body of data available for use in the inversion modeling; however, this is speculation only. In addition, the RMS was significantly better in the U Farm data, suggesting that the higher volume of data input to the model allowed for a better fit between model and field data, and improved the quality of the final model.

TABLE 1. U Farm vs. BY Farm performance data

	BY Farm		**U Farm**	**Improvement**
	Actual	Scaled		
Electrodes	345	491	491	NA
System Run Time (hours)	110	157	28	559%
Raw Data	32,540	46,311	221,360	478%
Modeled Data	31,146	44,327	173,021	390%
Convergence Time	73.8	--	38.3	--
Model Error (RMS)	10.18	--	6.9	32%

NA – Not Applicable

CONCLUSIONS

Ultimately, the new, improved system increased the speed of data acquisition, increased the survey area, provided for a greater volume of data, and better resulting resistivity model quality when compared to the next best deployment at BY Farm. The increased data acquisition speed allowed a reduction in field labor and field work duration to half the field budget estimates, resulting in a 25% reduction in overall project costs. Additionally, the new resistivity data acquisition system allowed for a 390% increase in data volume, representing technological advancements resulting in better quality resistivity results and decreased project costs.

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