Investigation of Preferential Ground Water Flow Pathways in the 100-NR-2 Area Hanford Site

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June, 2006

Prepared for the U.S. Department of Energy
under Contract DE-FC06-91RL12266

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Summary

The Confederated Tribes of the Umatilla Indian Reservation was contracted by the U.S. Department of Energy (DOE) to conduct a geophysical investigation within the 100-NR-2 Area at the Hanford Site in Richland, Washington. The 100-N Area is located north of the 200 East Area and along the Columbia River. The purpose of the investigation was to test the effectiveness of the Aquatrack™ method, a proprietary electromagnetic technology developed by Willowstick Technologies, LLC™ to identify subsurface saturation zones and preferential ground water flow pathways. The ground water flow direction, from well data, is to the northwest past the 116-N-1 (1301-N) and 116-N-2 Liquid Waste Disposal Facility (LWDF) where liquid waste was disposed after passing through the 100-N reactor southwest of these trenches. Strontium-90 is the contaminant of greatest significance in ground water at this operable unit with levels that are over 1000 times in excess of drinking water standards. Strontium-90 is currently discharging to the Columbia River.

The AquaTrack™ method used at this site was intended to provide a rapid reconnaissance of the site with no disturbance of the land surface. The survey can detect the presence of electrically-conductive ground water flowing in preferential pathways from an induced current established through the zone of interest. This survey method was able to sample data from an area over 19.44 hectares in less than four days time with a reasonably dense coverage.

The investigation found that conductive highs and lows were readily visible from the collected data. The data was contoured and the magnetic contour lines are used to help visualize current flow through the subsurface. These contour lines represent relative strength of the magnetic field. These highs and lows appear to follow trends or paths that are most likely attributed to preferential ground water flow paths and correlate well to where springs are known or suspected to be discharging to the Columbia River. This variability in field strength is attributed to either high, or low groundwater saturation (assuming approximately homogenous ion concentrations), or areas of high or low ion content (assuming non-homogenous ion concentrations, low background ion concentrations, and approximately homogenous saturation levels), or a combination of the two. In the data collected, the tight contours observed close to the LWDF are likely attributed to a higher ion concentration in the ground water. This discharged water mixes with the ground water and flows in preferential flow pathways. The preferential flow paths and discharge of this water to the Columbia River appears to be concentrated in the southwest section of the survey. The AquaTrack™ survey appears to accurately and efficiently map groundwater concentrations and flow paths within the 100-NR-2 Operable Unit as well as track the footprint of the highly ionized contaminate waste plume influenced by the area's groundwater flow. This geophysical method could be used to help cut cleanup costs and better characterize the ground water and contaminate flow in the subsurface.

Acknowledgements

The Confederated Tribes of the Umatilla Indian Reservation (CTUIR) would like to thank the U.S. Department of Energy (DOE) for providing funding under Contract DE-FC06-91RL12266 to demonstrate the performance of the AquaTrack™ system. Special thanks are given to DOE employees Kevin Clarke, Jenise Connerly, and Mike Thompson for their review and support of this contract. The CTUIR coordinated the work and safety schedule with Fluor Hanford (FH). The FH point of contact was Russ Fabre who arranged the appropriate training for the CTUIR staff.

Thanks to CTUIR employees Julius Patrick, Toby Patrick; Arthur Van Pelt and Joseph Alexander for help in data collection. WillowStick employees Rich Montgomery and Karyl Montgomery were instrumental in setting up and overseeing the survey in the field, and training on the operation of the AquaTrack equipment.

Special thanks also to Val Kofoed, Jerry Montgomery, Rondo Jeffery, Michael Jessop, and Steven Lowry with WillowStick Technolo gies for data analysis, processing, analytical services, and contributing to this final report.

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Introduction

1.1 Site Location

The Hanford Site is located in the southeastern portion of Washington State in the Columbia River Basin near Richland, Washington. The area of interest for the geophysical survey is the 100-NR-2 Operable Unit located north of the 200 East Area (Figure 1.1) and next to the Columbia River. The subject site includes the 116-N-1 crib and trench, and the 116-N-3 crib and trench (Figure 1.2) where liquid waste was disposed of in an unlined disposal trench after passing through the 100-N reactor.

Figure 1.1 100-N Area Site Map

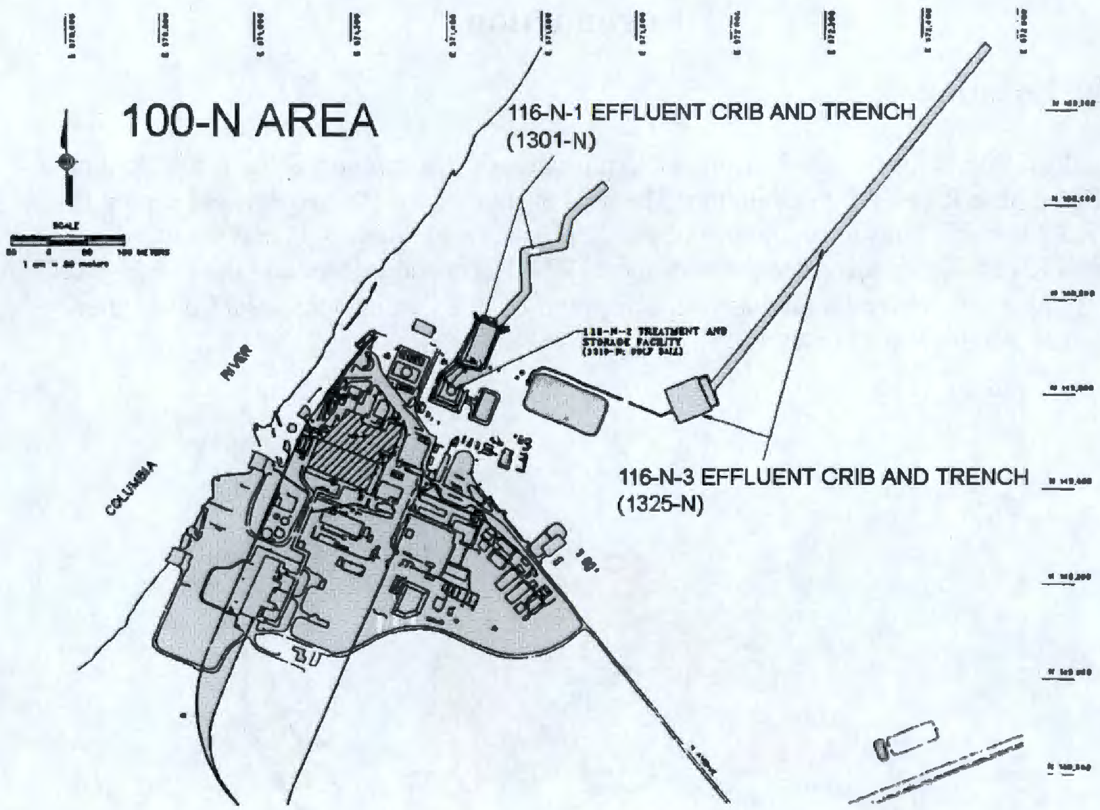

Figure 1.2 116-N-1 and 116-N-3 Crib and Trench

1.2 Objective of Investigation

The primary objective of this investigation was to characterize the subsurface of a portion of the 100-NR-2 site using a proprietary, state-of-the-art geophysical method developed by Willowstick Technologies, LLC™ to determine its effectiveness at the Hanford site to identify preferential ground water flow pathways. The advantage of using the AquaTrack™ method is that it is a non-invasive geophysical method using existing ground water wells to induce a current into the ground water and monitoring the resulting magnetic fields at the surface of the ground. The strength of the resulting magnetic fields follows the strongest electrical currents. The electrical currents path of least resistance is through more conductive conduits such as the ground water flowing through preferential pathways.

Strontium-90 is the principle ground water contaminant of concern within the test site. Levels nearly 1000 times above the drinking water standard (8 pCi/L) have been observed at this location. Monitoring wells and aquifer tubes are currently used to monitor the plume location and assumed flow direction. The AquaTrack™ method was used to map and delineate groundwater concentrations and flow paths likely influencing the flux of contaminants between the 1301-N liquid waste disposal facility and the Columbia River.

2.0 Background

2.1 Operational History

Hanford became a federal facility in 1943 when the U.S. Government took possession of the land to produce nuclear materials for defense purposes. Production of nuclear materials at the site continued through the late 1980's when the mission changed from producing nuclear materials to cleaning up the radioactive and hazardous waste that was generated during the 45+ years of operations.

The 100-N Reactor was constructed from 1958 through 1963. The reactor began producing plutonium for nuclear weapons in April 1964, and began generating steam for electrical power at the Washington Public Power Supply System Hanford Generating Plant in 1966. Both continued to operate until 1986 when the reactor was shut down for safety upgrades. In 1988, the DOE placed the reactor in cold standby, and in 1991, the DOE issued an order to prepare the 100-N Reactor for decontamination and decommissioning.

The operation of the 100-N Area nuclear reactor required the disposal of pass-through cooling water from the reactor's primary cooling loop, spent fuel storage basins, and other reactor-related sources. Two crib and trench liquid waste disposal facilities (LWDF) were constructed to receive these waste streams. The disposal system consisted of percolation of the wastewater into native soils. The first LWDF (1301-N) was constructed in 1963; about 244 meters (800 feet) from the Columbia River (see Figure 1.2). Liquid discharges to this facility contained radioactive fission and activation products, including cobalt-60, cesium-137, strontium-90 and tritium. Minor amounts of other hazardous wastes such as sodium, dichromate, phosphoric acid, lead, and cadmium were also part of the waste stream. When strontium-90 was detected at the shoreline of the Columbia River, disposal at LWDF 1301-N was terminated and a second crib and trench facility (1325-N LWDF) was constructed farther inland in 1983. Discharge to 1325-N ceased in 1993.

2.2 Site Conditions

As a result of roughly 30 years of wastewater discharge to the LWDFs, soil beneath the 100-N Site have become contaminated. To address contamination in the 100-N Area, the DOE has divided the site into two operable units (OU's). The 100-NR-1 OU contains all the source waste sites located within the main industrial area (reactor and generating plant) which include surface sediments and shallow subsurface soil associated with the LWDFs. The 100-NR-2 contains the contaminated groundwater aquifer and the contaminated vadose zone overlying the present-day aquifer beneath the 100-N Area, which is the targeted zone for this demonstration project.

The land on which the Hanford site lies was once inhabited by ancestors of the CTUIR. At the present time, the CTUIR has a vested interest in the lands on, adjacent to, and surrounding the Hanford Site. The CTUIR considers the water that flows out of Hanford and into and down the Columbia River the lifeblood of their society. A safe and high quality water supply is an essential part of their culture and religion. Without good clean water, CTUIR lives, as well as all life within the basin, may be placed at a higher risk. With this in mind, the CTUIR desires to demonstrate to the DOE a new technology (AquaTrack™) that can aid in quicker, more economical and better diagnosis of groundwater flow and the distribution of contaminants in groundwater.

2.3 Geology

The stratigraphy under the 100-N area has three principle formations of significance (Figure 2.1):

- Elephant Mountain Member of the Columbia River Basalt Group
- Ringold formation
- Hanford formation

The Elephant Mountain Member is an extensive basalt unit that underlies both the Ringold and Hanford formations. It is assumed that none of the contamination from the activities at the 100-N area has reached the Elephant Mountain formation.

The Ringold formation is composed of several fluviallacustrine lithologic facies deposited by the ancestral Columbia and Snake Rivers and consists of sands and gravels with some muddy layers. Of most interest at 100-N is the Ringold Unit E, which forms the unconfined aquifer beneath the Hanford formation, and the Ringold Upper Mud Unit, which forms the base of the unconfined aquifer and is believed to be an aquitard for Unit E.

The Hanford formation consists of a series of unconsolidated to semiconsolidated glaciofluvial deposits that were emplaced during the cataclysmic Spokane Floods approximately 6,000 years BP. The sediments at Hanford range from coarse gravels to fine-grained sands and silts.

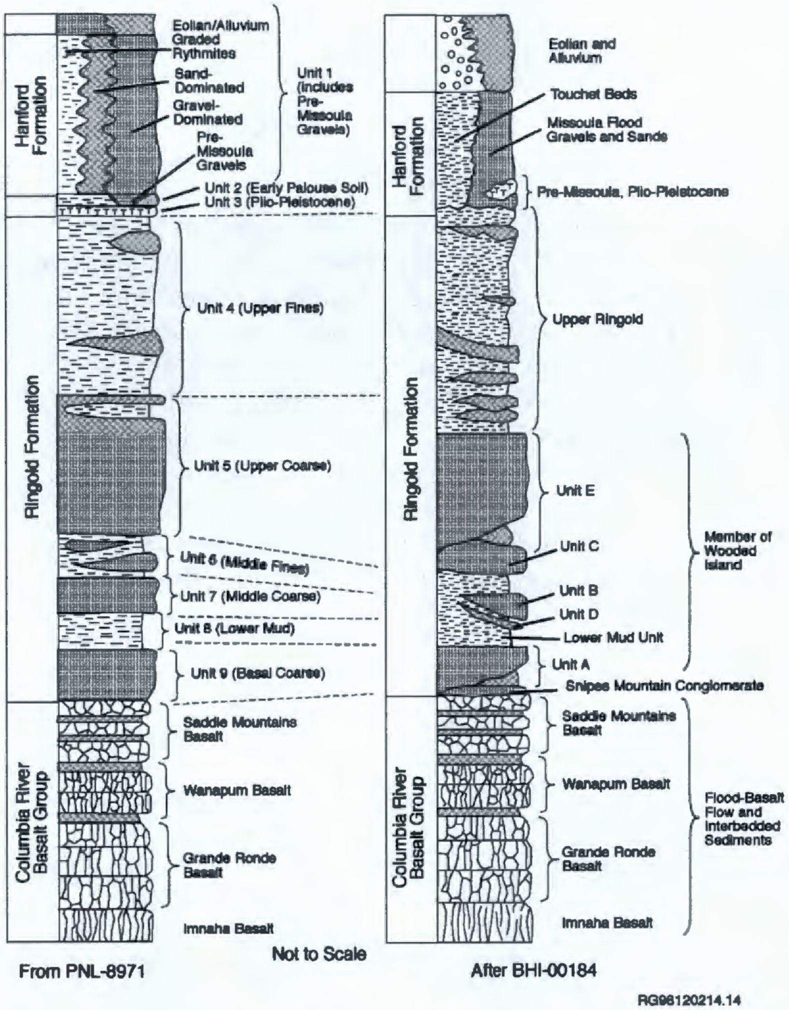

Figure 2.1 Hanford Stratigraphy. The geologic column on the right defines the lithostratigraphic units, based on mapping and physical properties of the sediments. The hydrogeologic column on the left defines hydrostratigraphic units based on hydraulic properties.

2.4 Hydrogeology

The uppermost stratigraphic unit in the 100-N area is the Hanford formation (Figure 2.1), which consists of uncemented and clast-supported pebble, cobble, and boulder gravel with minor sand and silt interbeds. The matrix in the gravel is composed mostly of coarse-grained sand, and an open-framework texture is common. For most of the 100-N Area, the Hanford formation extends from ground surface to just above the water table, 5.8 to 24.5 meters (19 to 77 feet) in thickness. However, channels of Hanford gravels extending below the water table occur. The uppermost Ringold stratum at 100-N is Unit E, consisting of variably cemented pebble to cobble gravel with a fine- to coarse-grained sand matrix. Sand and silt interbeds also may be present. Unit E forms the unconfined aquifer in the 100-N Area and is approximately 12 to 15 meters thick. The base of the aquifer is situated at the contact between Ringold Unit E and the underlying, much less transmissive, silty strata referred to locally as the Ringold Upper Mud, approximately 60 meters (197 feet) thick.

The overlying Hanford formation is much more transmissive than the underlying Ringold Unit E. However, due to geologic heterogeneity, the hydraulic conductivity in both units is highly variable. Typical values of 15 and 182 m/d have been used for modeling purposes for the Ringold and Hanford units, respectively.

Figure 2.2 depicts a cross-section of the Hanford and upper Ringold units in the near-river environment. As illustrated in Figure 2.2, the Ringold aquifer outcrops into the Columbia River channel and the high river stage rises into the Hanford formation. Groundwater flows primarily in a north-northwesterly direction most of the year and discharges to the Columbia River. The groundwater gradient varies from 0.0005 to 0.003 m/m. Near the LWDF facilities, average groundwater velocities are estimated to be between 0.03 and 0.6 m/d (0.1 and 2 ft/d), where 0.3 m/d (1 ft/d) is generally considered as typical. However, groundwater flows near the river are significantly influenced by the Columbia River's seasonal high and low water levels. The hydraulic gradient varies from slightly inland in the northern part of this operable unit during high river stages, to groundwater flow toward the Columbia River during low river stages. Springs, seeps, and subsurface discharge along the Columbia River bank are the primary pathway of 100-N groundwater contaminants to the Columbia River.

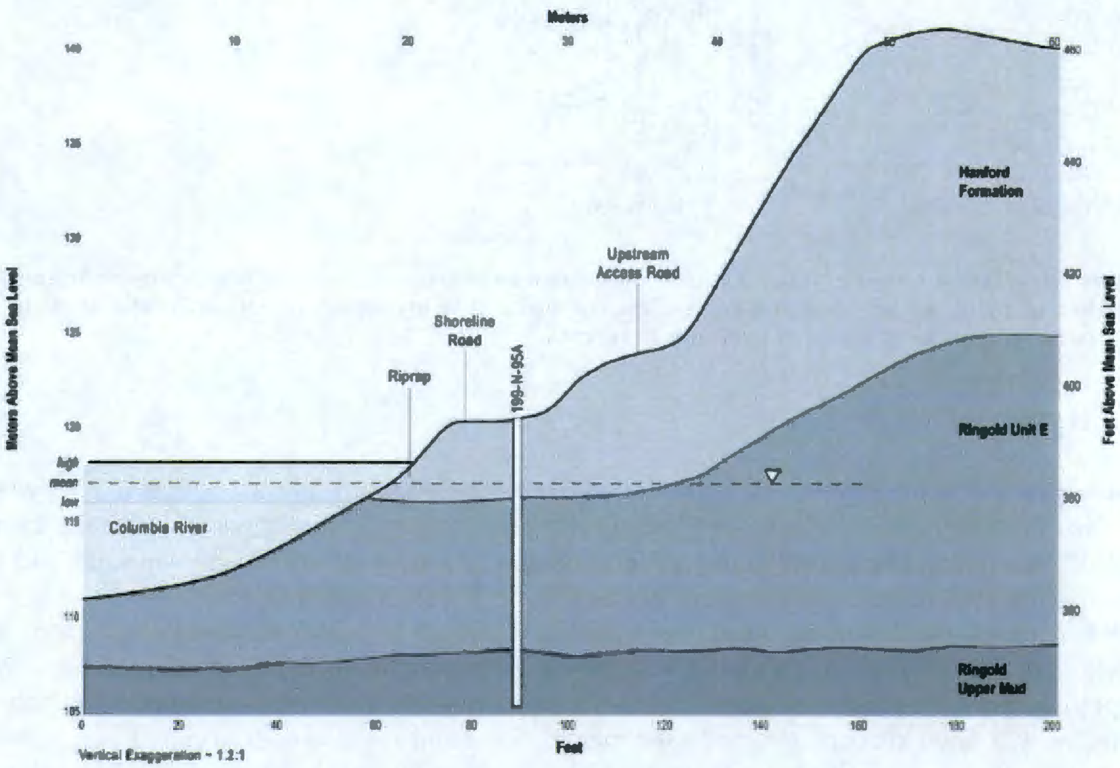

Figure 2.2 Conceptual Model of the 100-NR-2 Operable Unit in Cross Section

2.5 ^{90}Sr Contamination

Groundwater at 100-N has been contaminated with various radionuclides and non-ionic and ionic constituents. Of primary concern is the presence of Strontium-90 in the groundwater and the discharge of Strontium-90 to the Columbia River via groundwater and springs. Strontium-90 is more mobile than other radiological contaminants found at the site (with the exception of tritium), and because of its chemical similarity to calcium, it bioaccumulates in plants and animals. With a half-life of 28.6 years, it will take approximately 300 years for the Strontium-90 concentrations present in the subsurface at 100-N to decay to below current drinking water standards.

The zone of Strontium-90 contaminated soils resulting from 30 years of wastewater discharge to the LWDFs includes the portions of the vadose zone that was saturated during discharge operations, and the underlying aquifer which extends to the Columbia River. During operations of the reactor at the 100-N area, a groundwater mound approximately 6 meters (20 feet) high was created. Not only was the water table raised into more transmissive Hanford and Ringold sediments, but steeper hydraulic gradients were created, increasing the groundwater flow toward the river. While the 100-N Reactor was operating, riverbank seepage was pronounced. Since that time, the number of springs and seeps has decreased in proportion to the decrease in artificial recharge caused by the wastewater disposal.

The majority of the 1,500 curies (Ci) of Strontium-90 remaining in the unsaturated and saturated zones in the 100-N Area as of 2003, is assumed to be present in the vadose zone above the aquifer. An estimated 72 Ciof Strontium-90 are contained in the saturated zone, and approximately 0.8 Ci are in the groundwater. Data from soil borings collected along the riverbank indicate that Strontium-90 concentrations in soil reach a maximum near the mean water table elevation and then decrease with depth. Groundwater concentrations reflect the soil concentrations. Because Strontium-90 has a much greater affinity for sediment than water (high Kd), its rate of transport in groundwater to the river is considerably slower than the actual groundwater flow rate. The relative velocity of Strontium-90 to groundwater is approximately 1:100. Under current conditions, approximately 0.14 to 0.19 Ci are released to the Columbia River from the 100-N Area annually.

In 2005, the Strontium-90 groundwater plume extended approximately 400 meters (1,300 feet) along the river's length between the 1,000 picocuries per liter (pCi/L) contours, and approximately 800 m (1,600 feet) between the 8 pCi/L (the drinking water standard) contours (Figure 2.3). The maximum concentrations observed in ?scal year (FY) 2005 was 9,710 pCi/L from well 199-N-67 (Figure 2.4).

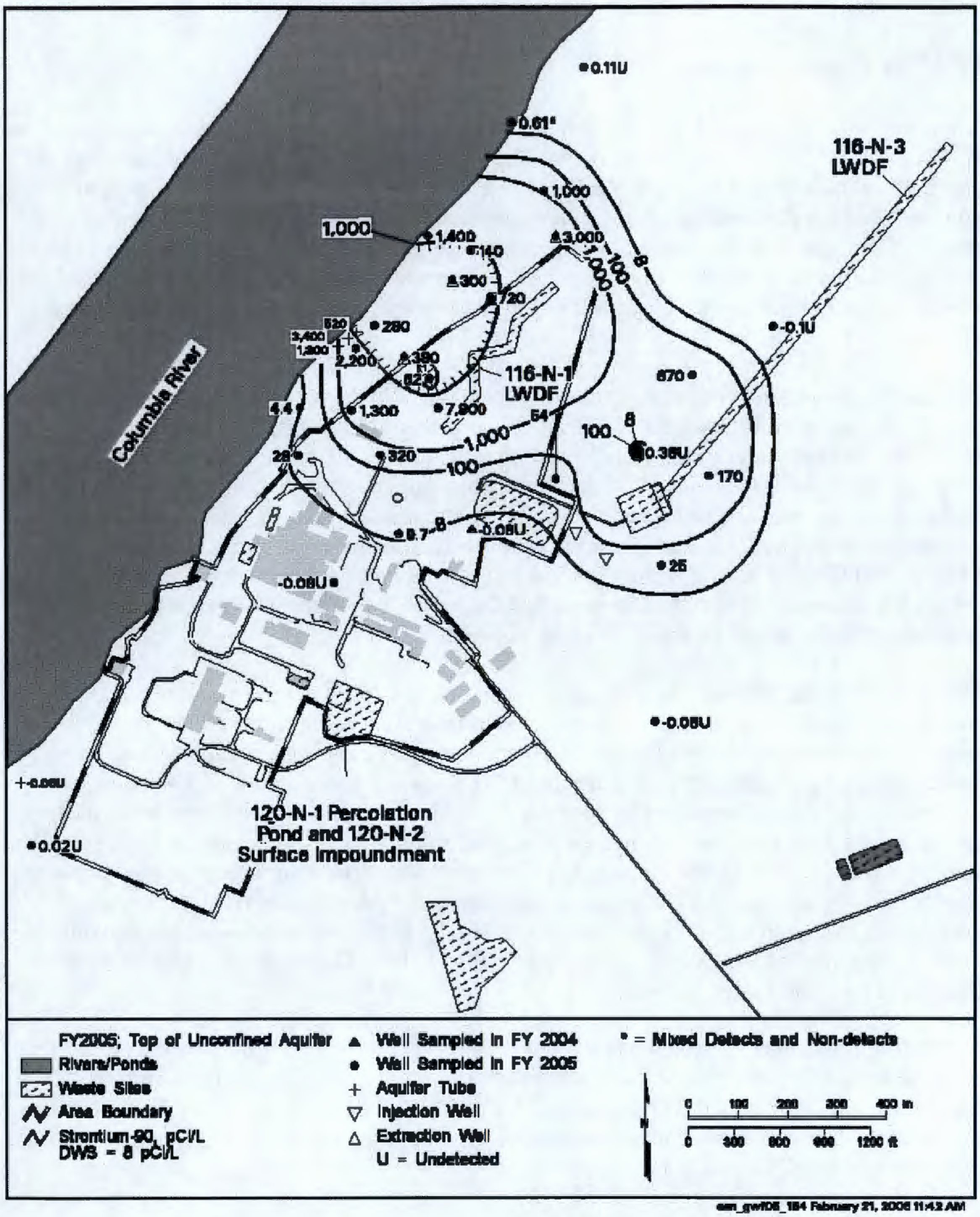

Figure 2.3 Average Strontium-90 Concentrations in 100-N Area, Top of Uncon?ned Aquifer

In the past, there was assumed to be an area of "preferential flow" between wells N-94 and N-46 to explain the high Strontium-90 values observed along the shore. This was explained, from well data, as an erosional feature in the Ringold Unit where the Hanford formation dips below the water table at this location, forming a more transmissive flow path between the disposal crib and the Columbia River. Wastewater appears to have concentrated along this route, resulting in higher concentrations in this area than would be predicted based on regional groundwater flow direction.

Recent clam data collected for the ecological risk assessment (ERA) show that the highest concentrations of Strontium-90 in clams were observed along approximately 90 meters (300 feet of riverbank that encompasses NS-1, NS-2, NS-3, and NS-4 (Figure 2.4). Well NS-3 and the neighboring monitoring wells N-46 and N-8T have currently and historically shown the highest Strontium 90 concentrations along the shoreline, with concentrations as high as 15,000 pCi/L Strontium 90 observed at N-46. The previous N-Springs data, recent aquifer tube data, groundwater data, and clam data (DOE-RL, 2005) all indicate that treating the 300 feet of shoreline near N-46 will address the highest concentration portion, if not the majority, of the near-shore Strontium-90 contamination.

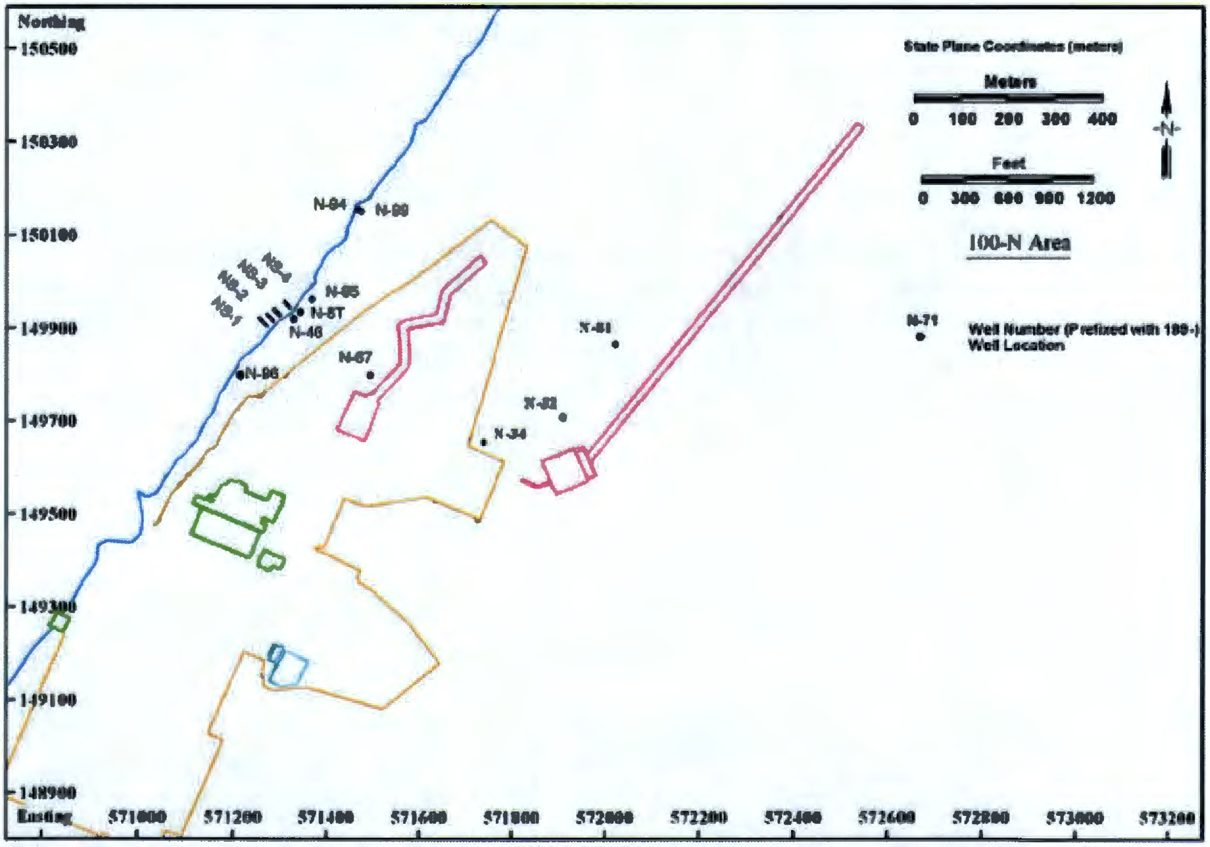

Figure 2.4 Well and Aquifer Tube Locations in the 100-N Area.

3.0 AquaTrack™ Methodology

3.1 General Description

The AquaTrack™ geophysical technology uses Controlled Source – Audio Frequency Domain Magnetics (CS-AFDM). AquaTrack™ utilizes a low voltage, low amperage audio frequency electrical current to energize the groundwater of interest. Electrodes are placed in strategic locations to facilitate contact with the groundwater. Following the best available conductor, the electrical current concentrates in highly saturated zones; and, for a given porosity or level of saturation, it concentrates to a greater extent in areas of higher Total Dissolved Solids (TDS) or higher ion content between the energizing electrodes. As the electrical current takes various paths through the area of investigation, it creates a magnetic field (Biot-Savart law) characteristic of the injected electrical current. This unique magnetic field is identified and surveyed from the surface using three highly sensitive coils oriented at right angles to each other. Geographic control for the locations of field measurement stations is identified using a Trimble navigation differential Global Positioning System (GPS) unit, and they are recorded with a data logger along with the magnetic field readings. The measured magnetic field data are then processed, contoured, and interpreted in conjunction with other hydrogeologic data, resulting in enhanced definition of the extent of subsurface water saturation in the vicinity of the study area.

3.2 Equipment

The equipment used to measure the magnetic field induced by electrical current flowing through the groundwater includes: three magnetic sensors oriented in the orthogonal directions (x, y, and z); a data logger used to collect, filter, and process the sensor data; a Global Positioning System (GPS) instrument used to spatially define the field measurements; and a Windows-based handheld computer to couple and store the GPS data with the magnetic field data. According to the contractor's information, the accuracy of the Trimble GPS is within a few meters. This equipment is mounted on a surveyor's pole and hand carried to each measuring station (Figure 3.1).

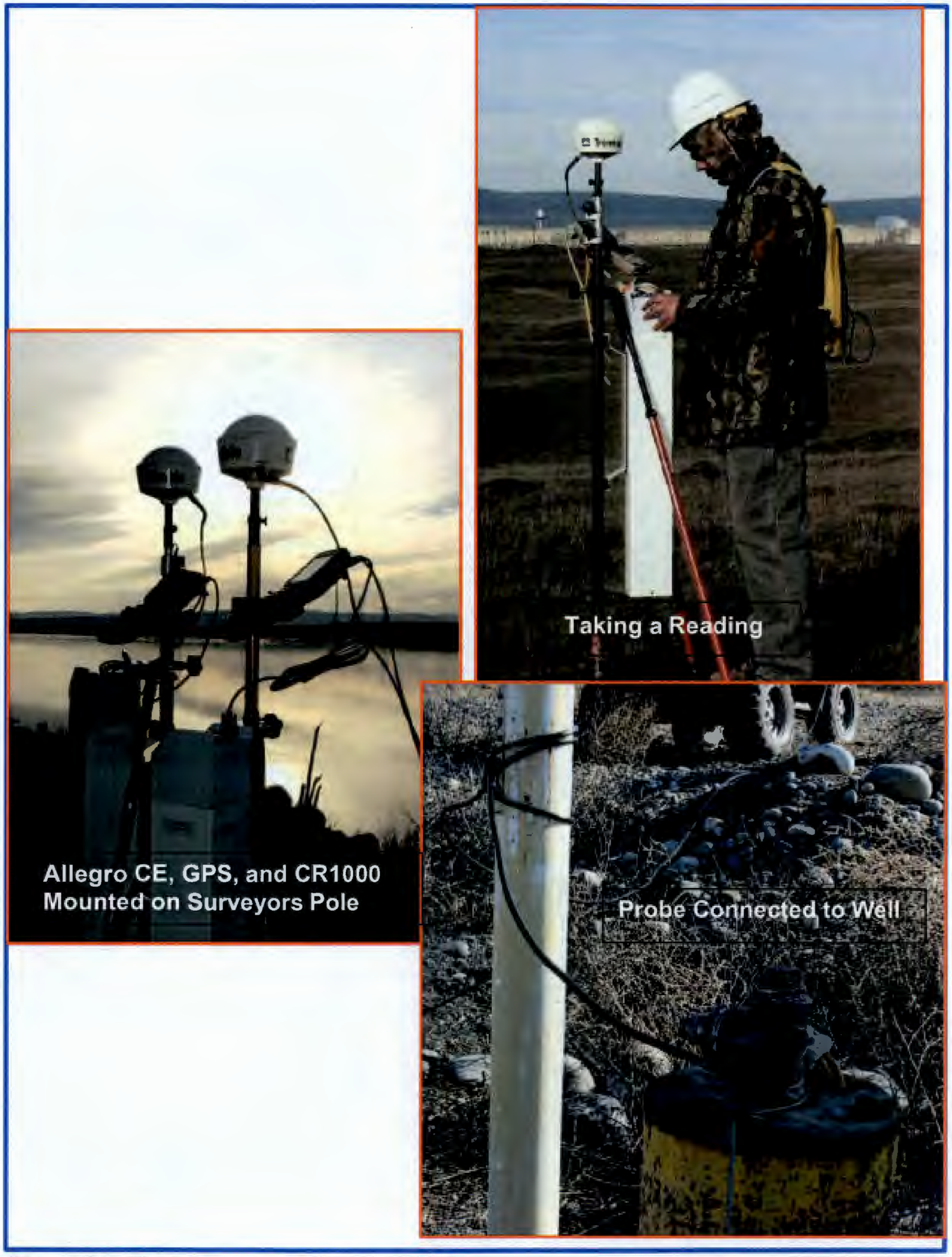

Figure 3.1 Field Activities at the 100-N Site

3.3 Data Collection

The AquaTrack™ instrument measures the signal across the three sensors corresponding to the strength of the magnetic field at each measurement station. For quality control, a base station location is established within the survey area, and base station measurements are taken simultaneously by both instruments at the beginning, midpoint and end of each field day (Figure 3.2). In addition, the base station site is reoccupied by the field equipment prior to starting a new survey line. The base data are used to identify any changes in the background magnetic field and/or diurnal drift. The magnetic field measurements collected during the survey are then normalized to compensate for these factors.

Figure 3.2 Reoccupying the Base Station to Calibrate the Instruments

To ensure data quality at each measurement station, the data logger calculates the signature frequency magnetic field strength which is measured for a sufficient length of time to assure measurement repeatability and validity and compares the signal to the background or ambient magnetic field strength at numerous frequencies. These data are compared to pre-determined signal quality criteria and signal-to-noise ratio criteria to establish data quality and repeatability.

Prior to initiating the fieldwork, the antenna array(s), electrode placement, and grid measurement stations and intervals are all pre-determined and the station locations are entered in the data logger. The antenna/electrode configurations and measurement grid are established to optimize the data collected and to define the areas of high water saturation and/or elevated ion content throughout the subsurface study area. The field crew's task is then to walk to the station locations, as displayed on the Allegro CE's screen, and begin the data collection.

The antenna arrays are composed of wires and electrodes in contact with the ground water to complete the transmitter circuit. In some surveys and depending upon the given site conditions, one or more sets of antenna configurations may be used. This survey at the 100-N area only required the setup of a single antenna wire in the Columbia River with the electrical current flowing back to electrodes placed on three wells. In all cases where possible, antenna wires are routed around the survey area and far enough away to have little effect on the readings. Electrode placement is based on optimizing contact with the targeted groundwater as well as the total area to be surveyed. Measurement stations and density of measurement stations are based on specific site requirements.

3.4 Data Reduction and Interpretation

The field data are processed and corrected to account for distance from the source electrode, to reduce the effects of antenna interference and to remove the effects caused by ambient and shallow subsurface sources of signal, if necessary. The processed and corrected data (reduced data) are used to generate contour maps of the induced magnetic field. Relative changes in the magnitude and/or gradient of the magnetic field—rather than the absolute magnitude of the induced field—are used for making interpretations. The results are presented in map view to show areas of either highest concentration of ground water (assuming approximately homogeneous ion content within the groundwater being mapped), or areas of elevated groundwater TDS (assuming homogeneous water content and lower background TDS).

The magnetic field observed at the surface, due to subsurface electrical current flow in groundwater, is controlled by electronically conductive paths in the subsurface. Interpretations of subsurface saturation are based primarily on the strength of the magnetic field. These readings provide sharp horizontal resolution that characterizes groundwater channels or preferential flow paths and vertical hydrologic barriers.

3.5 Field Noise

Once the field data has been reduced, natural and manmade interferences must then be accounted for. It is preferred that manmade interferences are noted prior to the survey. If unknown, these interferences can often be recognized by their specific signature signals in the data. Once recognized, these features can be accounted for, corrected, and/or removed from the final reduced data set. Some examples of interferences include:

- Ground noise from 60 Hertz signal (from nearby electrical generating equipment, overhead or buried power lines, any subsurface cathodic protection of pipes, etc.)
- Cultural features (buried pipes, steel cased wells, etc.)

- Atmospheric noise (diurnal magnetic variations, electrical storms, solar activity and related magnetosphere activity, etc.)

These various features, specific to an individual site and time, need to be identified, reported and portrayed.

3.6 Presentation

The final reduced data are then presented on contour maps or in profile plots. Any identified cultural features relative to the survey are also shown to aid in interpretation. Finally, any additional geological and hydrogeological information pertinent to the study is also integrated, resulting in a complete and comprehensive interpretation of the groundwater system being investigated.

4.0 Scope of Work

4.1 Safety Training

Many portions of the subject site are located within restricted zones with radioactive subsurface contamination. As a result, all field personnel were required to complete the Hanford General-Employee Training (HGET). Before accessing the field, an Automated Job Hazard Form (AJHA) was also completed. All personnel and equipment were surveyed daily for radiological contamination by a radiological technician. Personal protective equipment included wearing a hardhat, heavy soled or steel-toed boots, protective eyewear, and gloves. In addition, a daily safety briefing was held before field work commenced to provide notice of potential on-site hazards and weather conditions.

4.2 Equipment Setup

The area of principle investigation covered roughly 35 acres (650 meters by 250 meters) or 14.16 hectares. The fieldwork was completed within a four day period of time (Friday, March 10, 2006 through Monday, March 13, 2006). This was the time frame provided by Fluor Hanford to demonstrate the technology and when activity on the site would be shut down. A larger area of approximately 19.44 hectares was surveyed that included data from the East side of the 1301-N trench. This data was not included in the final analysis since the large gap from opposite sides of the trench made correlations across from the tight station spacing inexact.

The electrical line that induces the current in the ground was laid out with an all-terrain vehicle (ATV). Where possible, the ATV drove on old roads or previously disturbed ground to limit any impacts to the native soils and plants. The large tires of the ATV and dry weather and soil conditions also helped to limit any impacts to the ground (Figure 4.1). The bare conductive wire to induce a current from the river into the ground water was placed from a CTUIR boat (Figure 4.1). The boat stayed a little over 100 feet from shore with its position recorded on the GPS data logger. The wire was weighted and dropped into the river from the back of this boat. There was an initial attempted to cross the river so that a conductive element would have been on the opposite shore. The strong currents in the Columbia River and the short amount of time granted for this survey made this approach difficult to achieve. Future surveys however, will have the antenna located on the far bank of the Columbia River to limit the influence of this wire on the data.

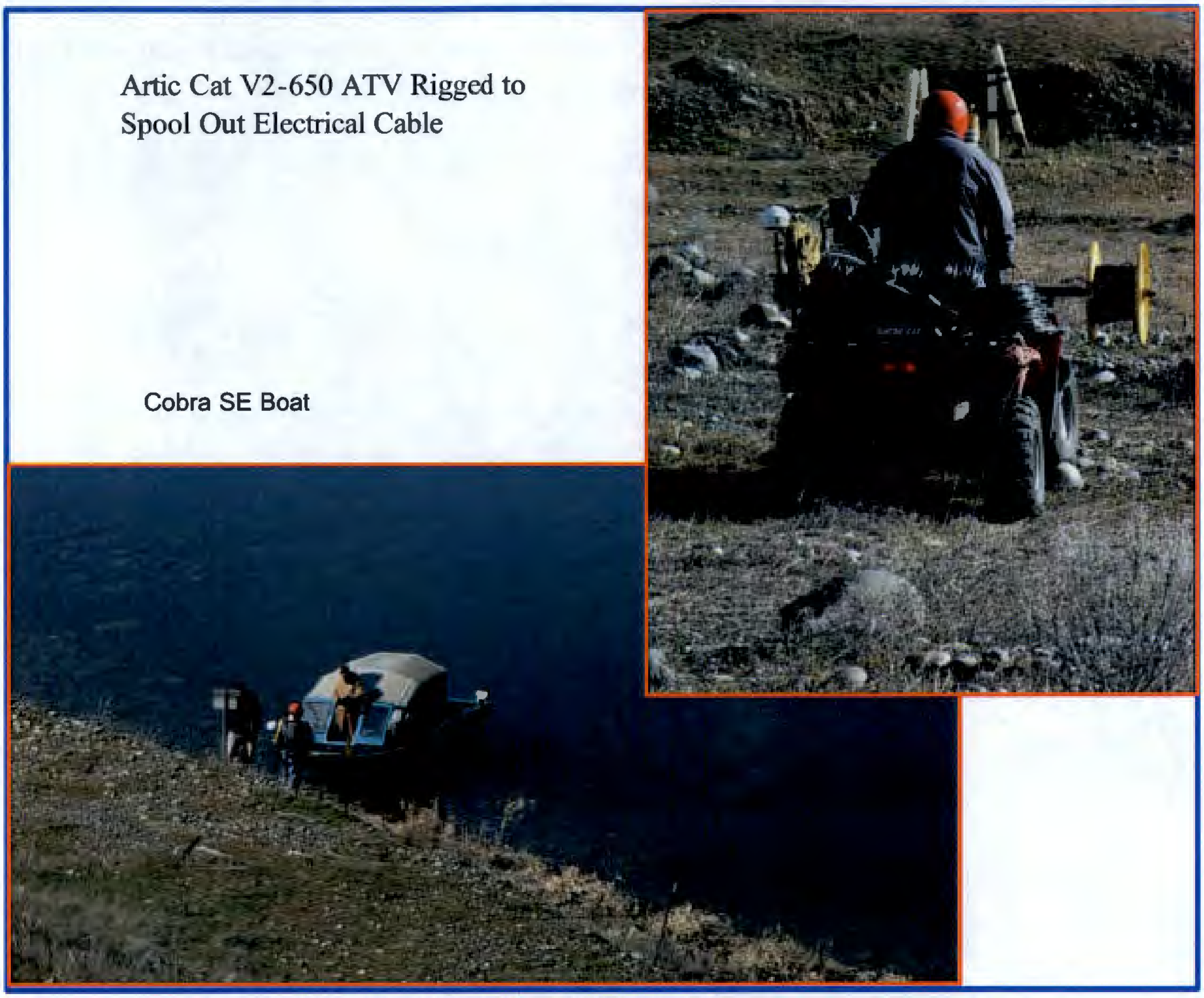

Figure 4.1 Laying Out the Wire to Generate the Electrical Current in the Ground

4.3 Approach to the Work

A horizontal dipole antenna/electrode configuration was employed to energize the subsurface study area for the purpose of conducting the AquaTrack™ geophysical groundwater investigation (see Figure 4.2). This required the attachment of three injection electrodes to the steel discharge pipe connected to submersible pumps of three active monitoring wells located southeast (up-gradient) of the 1301-N LWDF. The active monitoring wells selected for the investigation were wells N-81, N-32 and N-34. At each of these wells, an electrode, attached to an insulated wire, was attached to the steel, conductive pipe that was in contact with the localized groundwater regime. These monitoring wells were originally drilled, screened and designed to monitor and sample groundwater in the upper unconfined water bearing zone. A return electrode was placed in the Columbia River which is the discharge location for the ground water and hence in contact with it. This return electrode was placed in such a way as to allow the entire Columbia River in the survey vicinity to be energized, acting as one long continuous return electrode. Joining the injection electrodes (monitoring wells) with the return electrode (Columbia River) via an antenna wire, and inducing a current, was aimed at energizing the groundwater between the 1301-N LWDF and the Columbia River (study area) to investigate preferential pathways and elevated ion concentrations in the upper unconfined water bearing zones within the Hanford and Ringold formations, down-gradient of the 1301-N LWDF.

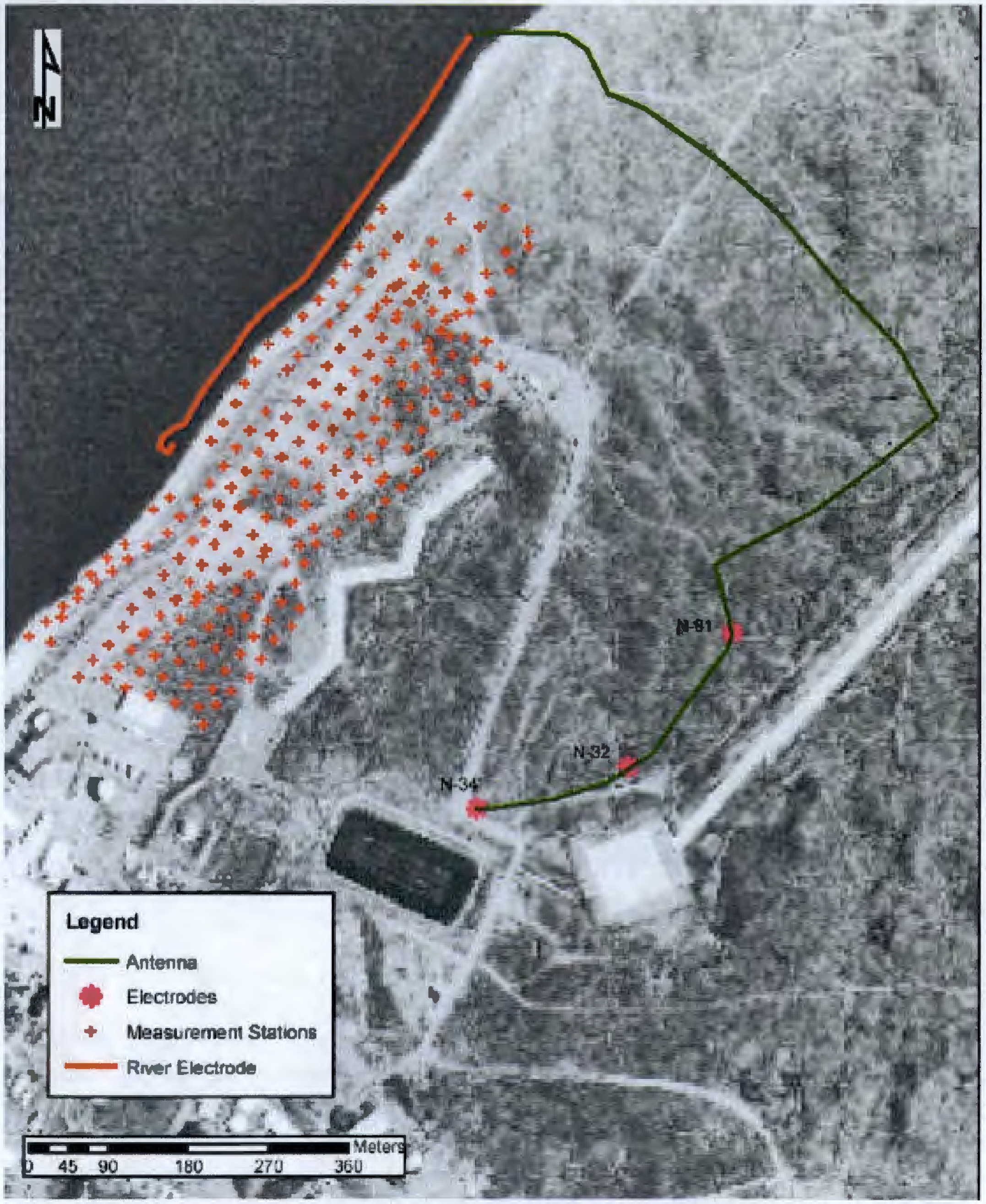

Figure 4.2 Antenna/Electrode Configuration and Station Locations

It should be noted that the electrodes utilized in this horizontal dipole configuration are located outside of the area where magnetic field measurements were measured and recorded (denoted by small red "+" signs in the figures). It is important that the electrodes establish groundwater contact outside the study area wherever possible. Note also that the antenna wire connecting electrodes is routed around or away from the survey area. Very near the energized antenna wire and electrodes, the magnetic field is strong enough that no other discernable information can normally be obtained. The signal from the antenna/electrodes would overwhelm the signal coming from the current flowing through the ground water. Given the area of investigation, the antenna/electrode configuration was designed to utilize the most advantageous locations available at the site in order to optimize current flow through the targeted water bearing formations.

The overall approach to the fieldwork included injecting and driving an electrical current between the injection and return electrodes to determine where electrical current flows and concentrates in the subsurface formation. A Coleman 3500 watt generator provided power to a Pacific Power FC 110 AC power source. Initially, the survey used a 1.5-amp, 55-volt, AC current with a specific signature frequency (400 Hertz) applied to the electrodes. Part of the survey was re-run with a 0.55-amp, 20-volt current to determine the influence of the close proximity of the river electrode to the survey stations located next to Columbia River. The resulting alternating current, flowing between the electrodes, followed and concentrated in the preferential flow paths beneath the study area. As the electrical current flowed through the subsurface, it generated a recognizable magnetic field that was measured and recorded from the surface of the ground.

Approximately 257 magnetic field measurements were obtained from the antenna/electrode configuration (Figure 4.2). These measurement stations were roughly established on lines spaced 33 meters apart with measurements taken on each line at roughly 25 meter intervals (these distances varied slightly depending upon terrain and access between the LWDF and the Columbia River, resulting in an approximate 33 meter by 25 meter grid covering the entire study site. The measurement pattern or grid configuration was established to provide sufficient detail and resolution for adequate groundwater delineation. Many measurement stations were occupied several times during the fieldwork for quality control purposes. The X, Y, and Z coordinates of each measurement station were recorded as part of the field work. These spatial locations are critical to data processing, data comparison and interpretation.

As will be shown later, the overall quality of the magnetic field strength data was very good, having a high signal-to-noise ratio. No significant drift from diurnal, antenna, equipment, or other intermittent sources were observed. Repeatability of base station and repeat station readings were excellent throughout the field process.

The processed and contoured data showed significant changes and trends in the magnetic field created from the signature current flowing through the ground. High electrical conductance was identified immediately down-gradient of the LWDF from which the interpretive information follows.

5.0 Results

5.1 Field Data Reduction and Normalization

The analysis of the AquaTrack™ geophysical investigation entailed reduction of field data to processed and corrected (reduced) data set ready for interpretation. The data set was subject to a number of comparisons and corrections for atmospheric noise (diurnal magnetic variations, magnetosphere activity, etc.) and ground noises (60 Hertz power grid) as well as the effects induced by the electrodes and antenna. The data set was analyzed by generating a magnetic field contour map of the processed data using Surfer™ software.

An aerial photograph of the study area was obtained from LandVoyage.com and was used as a basemap for many of the figures in this report. The GPS coordinates of many wells and other features pertinent to the investigation have been recorded and drawn on the maps to supplement the information contained on the basemap. Some well locations were determined by digitizing and georeferencing figures provided by the DOE that showed well locations.

5.2 Magnetic Field Map and Interpretive Information

The uninterpreted magnetic field map or "footprint" map of the conductive highs and lows is provided in Figure 5.1. The dark blue shading indicates conductive highs and the light blue shading indicates conductive lows beneath the study area. In the most general interpretation, conductive highs could be the result of either high ground water saturation with a homogeneous ion concentration, or from a high ion content assuming non-homogenous ion concentrations with a low background ion concentration and a homogenous ground water saturation level. Similarly, low electrical conductive regions could correspond to either low ground water saturation with a homogeneous ion concentration, or from areas of low ion content assuming non-homogenous ion concentrations with a homogeneous ground water saturation. It is most likely that the conductive regions are a combination of both higher ground water saturation and higher ion concentrations compared to the background levels. Electrical current could also be biased as dictated by electrode placement and conductive zones within the area of investigation. It is for this reason that the data collected on the southeast side of the 1301-N trench is not included in the interpretation since the data was not continuous enough to carry the interpretations across the trench.

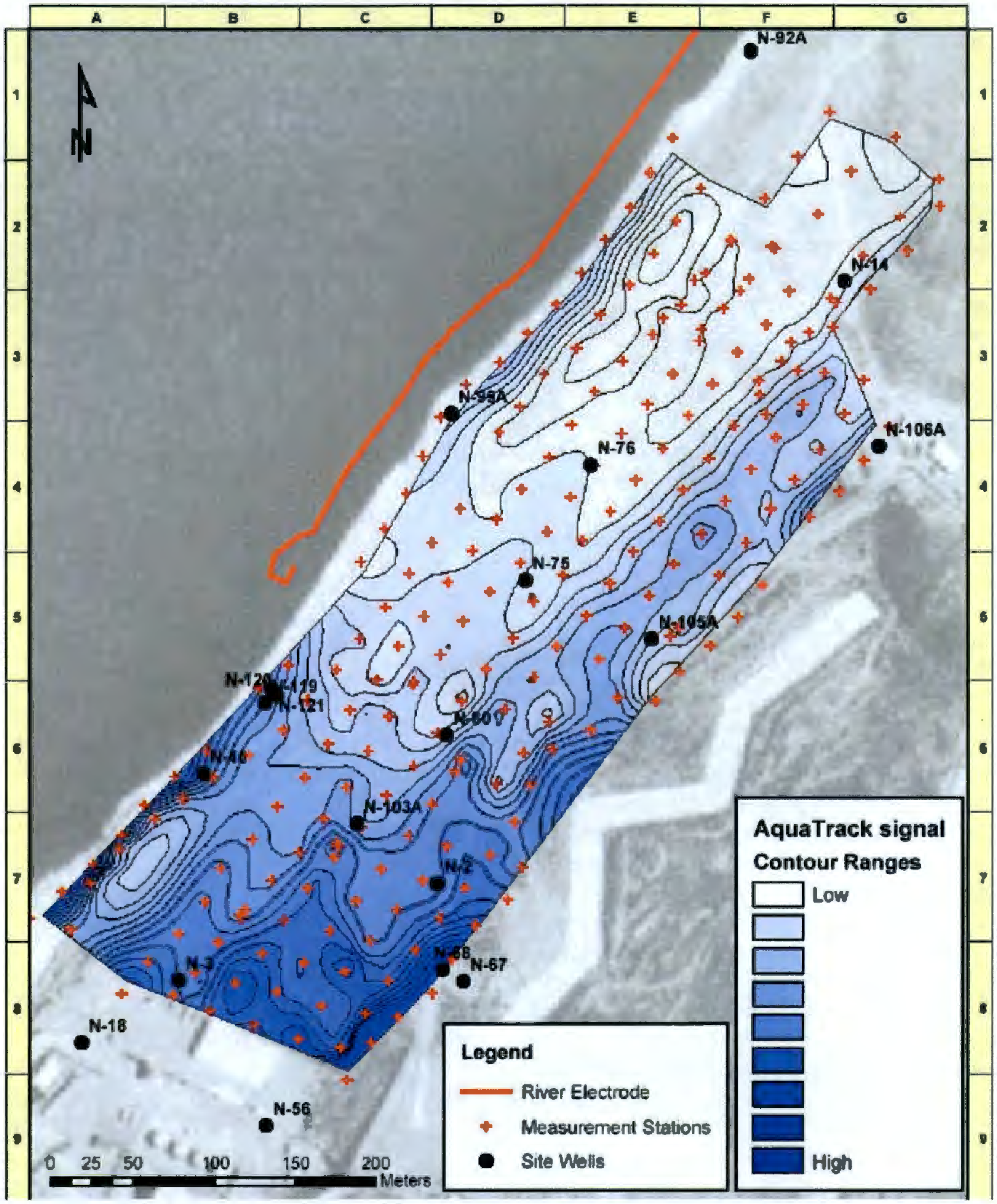

Figure 5.1 Magnetic Field Map

The magnetic contour lines shown in Figure 5.1 are used to help visualize current flow through the subsurface. These contour lines represent relative strength of the magnetic field and are not calibrated to real-world magnetic field readings. At this survey location, these magnetic contours vary by 1.5 to 2 orders of magnitude. The AquaTrack™ technology uses relative magnetic field contours to visualize current flow, in contrast to elevation contour lines that have a bench mark for standardization. Standardization for magnetic field strength for the AquaTrack™ technology would be difficult because of the varying conditions of each survey (antenna/electrode configuration, voltage and amperage requirements, geologic conditions, variations in time, Fourier transform and antenna correction in the data processing, etc.). The magnetic field contours shown herein are provided for comparison purposes to determine where electrical current flowing in the targeted study area concentrates and gathers. Nothing more should be construed from the magnetic contour lines; hence absolute values to the contour lines are not assigned. The AquaTrack™ technology best identifies the contrast between areas of high conductance and low conductance. If no anomalies are found between high and low areas of conductance, then it is because the current content in the energized space is dispersing uniformly. If there are contrasts between high and low areas of conductance then these areas can be identified, mapped and modeled.

There are five criteria used to determine the quality of the magnetic field data. These criteria are as follows and will be explained further in this report:

1. Circuit continuity between electrodes
2. Signal strength
3. Signal-to-noise ratios
4. Signal repeatability
5. Changes in ambient (background) noise

Figure 5.2 is a reproduction of Figure 5.1 with added interpretations and notations to highlight the anomalies observed in the AquaTrack™ survey. This particular map shows the "footprint" of the magnetic field contours. The magnetic field was generated from a large electric circuit consisting of the antenna wire connecting the well electrodes with the river electrode. The circuit continuity in this antenna / electrode configuration was very strong with minimal resistance in the circuit from the ground. In the majority of the study area, the magnetic field strength and signal-to-noise ratios were very high, indicating excellent data. The noise floor, (mean ambient field noise, determined from a sampling of several frequencies in the noise spectrum) remained fairly consistent throughout the area of investigation. By reoccupying both the base station and many of the survey site locations, numerous measurements were repeated throughout the course of the fieldwork. These repeated sites showed the equipment was providing clean, consistent and reliable data.

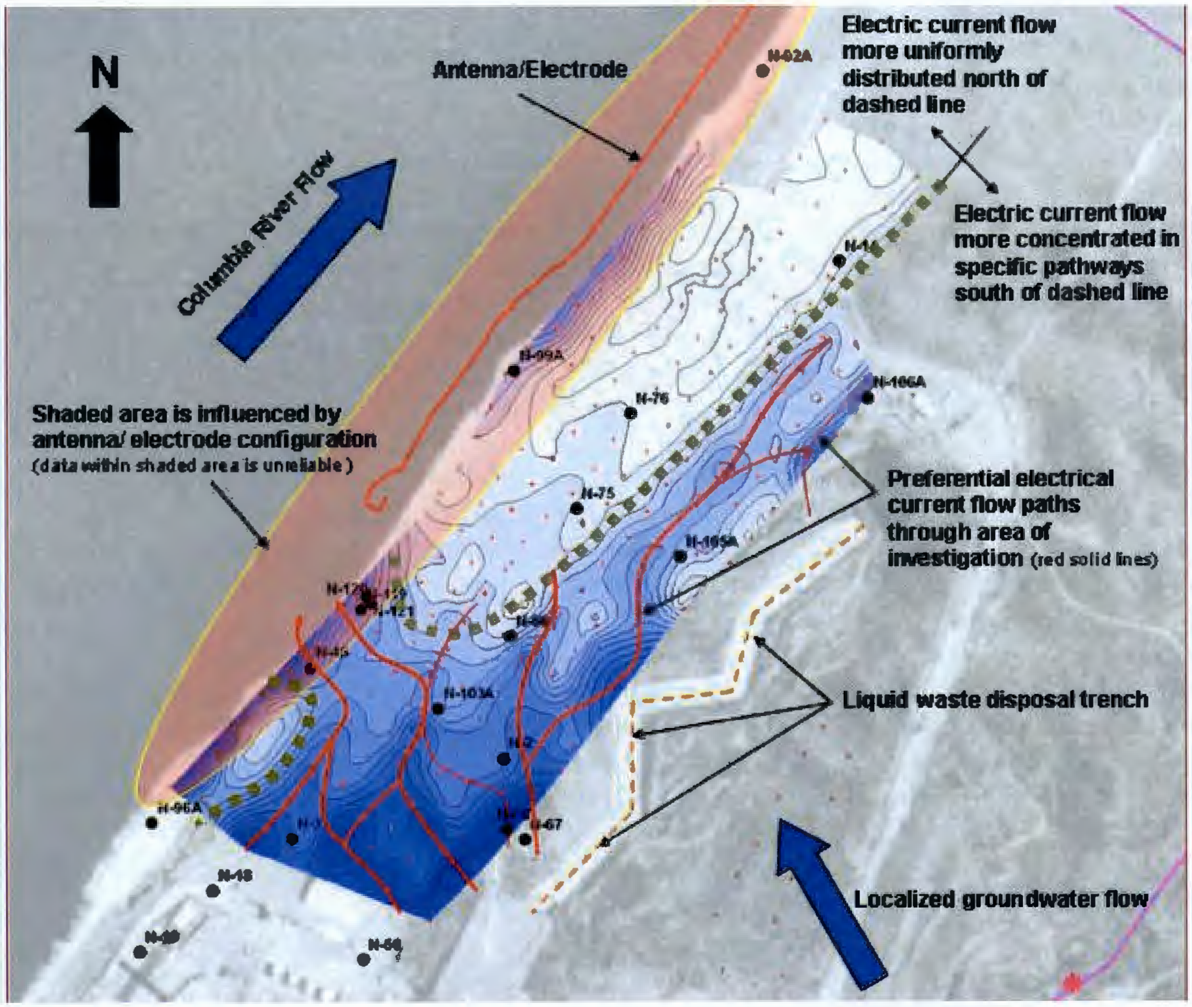

Figure 5.2 Interpretation of Preferential Flow

The semi-transparent pink circle centered over the electrodes shown in Figure 5.2 denotes the interference from the concentration of current flow into and out of the electrodes. The magnetic field contour map generated from the magnetic field readings showed a very strong contrast between areas of high electrical conductance (current concentration or flow) and areas of low electrical conductance. The areas of high electrical conductance are interpreted as areas where disposed wastewater (high in ion concentration) is likely concentrating in the saturated subsurface down-gradient of the LWDF. An important point of interest observed in the magnetic field data is the sharp drop-off of concentrated electrical current flow about halfway between the LWDF and the river in the northern part of the survey. As electrical current flowed northwestward toward the river, it appears that there is an edge to where the highly ionized groundwater begins to terminate (denoted with a thick green dashed line in Figure 5.2). This edge appears to dissipate the electrical current flow more uniformly toward the river. It is important to understand that if no anomalies are found between high and low areas of conductance, then it is because electrical current in the energized space disperses uniformly through the saturated formation. Because of the contrast observed between high and low conductive zones, there appears to be an edge of the elevated or highly ionized groundwater.

Note the tight contours or steep gradient that defines the edges of the high ionized groundwater and uniform spacing of contour lines northwest of this area which indicate weaker and more uniform electric current flow.

The red lines shown in Figure 5.2 is the interpretation of the centers of preferential flow paths where the magnetic signal is most prominent within the area of investigation. The steep gradient between high and low conductive areas defines the approximate edge of saturation zones and/or highly ionized saturated soils (the green dashed thick lines in figure 5.2). In this particular survey, it should be noted that the results of the AquaTrack™ investigation is likely a more generalized picture of the total subsurface flow. Actual subsurface groundwater flow may be more complex than that shown in the AquaTrack™ data. This is because the magnetic field emanating from the groundwater between the strategically placed electrodes is likely a mixing of dominate and less dominate groundwater flow paths. As a result, a generalized but accurate characterization of the groundwater is presented. Also, the results as shown here are a representation of groundwater conditions observed at the time of completing the fieldwork survey. It should be noted that different or additional groundwater flow paths may be activated under different hydrologic conditions (e.g., increase or decrease in flow in Columbia River and or runoff from storm water).

In the southern/central extent of the survey area, there are some fairly well defined channels where groundwater and the highly ionized wastewater preferentially flow toward the Columbia River (see area between the two thick green dashed lines centered over monitoring well N-46). This portion of the survey area is the area where highly ionized wastewater appears to be most concentrated and encroaching into the Columbia River.

5.3 Signal-to-Noise Map

As referenced several times in this report, the signal-to-noise is computed for each measurement as the ratio of the 400-Hertz signal to the mean ambient field noise, which is determined from a sampling of several other frequencies in the spectrum.

Based on the signal-to-noise ratios (see Figure 5.3), the quality of the data collected during the AquaTrack™ investigation was excellent in most areas of the survey, exceeding 5+ times the noise floor. In the very southeastern corner of the study area the signal-to-noise ratio dropped to 2 to 3 times the noise floor. Although less, the signal strength (compared to the noise floor) was acceptable providing reliable data. This is the area closest to the reactor and power sources.

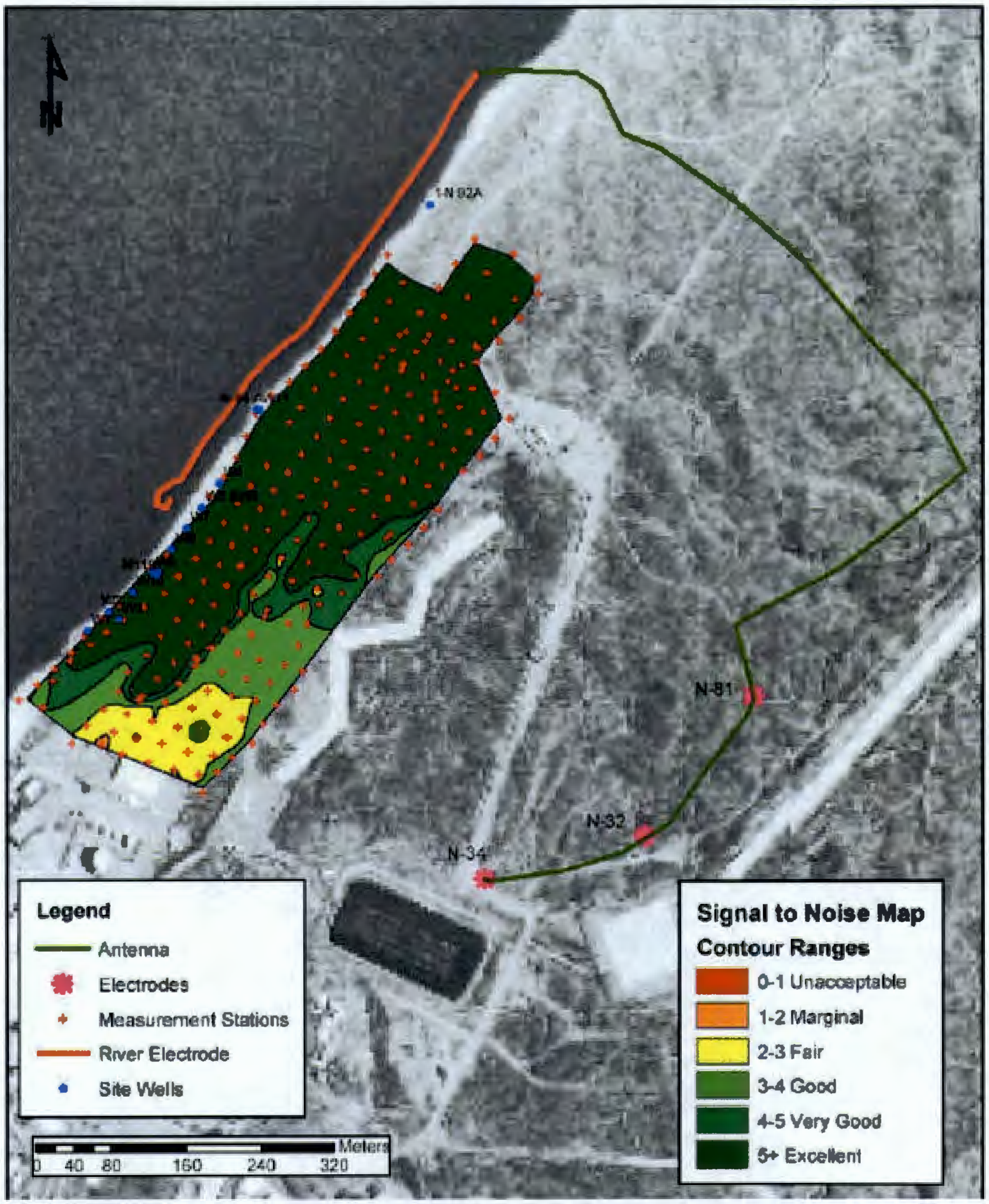

Figure 5.3 Signal to Noise Ratio Map

5.4 60 Hertz Noise Map

In some cases, the AquaTrack™ data can be influenced by noise generated by the regional power grid operating at 60 Hertz (i.e. overhead power lines, underground power lines, generators, motors, substations, etc.). Fortunately, the effects of this noise can be monitored and filtered out if necessary.

Figure 5.4 highlights the 60 Hertz signals observed in the survey area. Note, there is no influence from 60 hertz signals in the data.

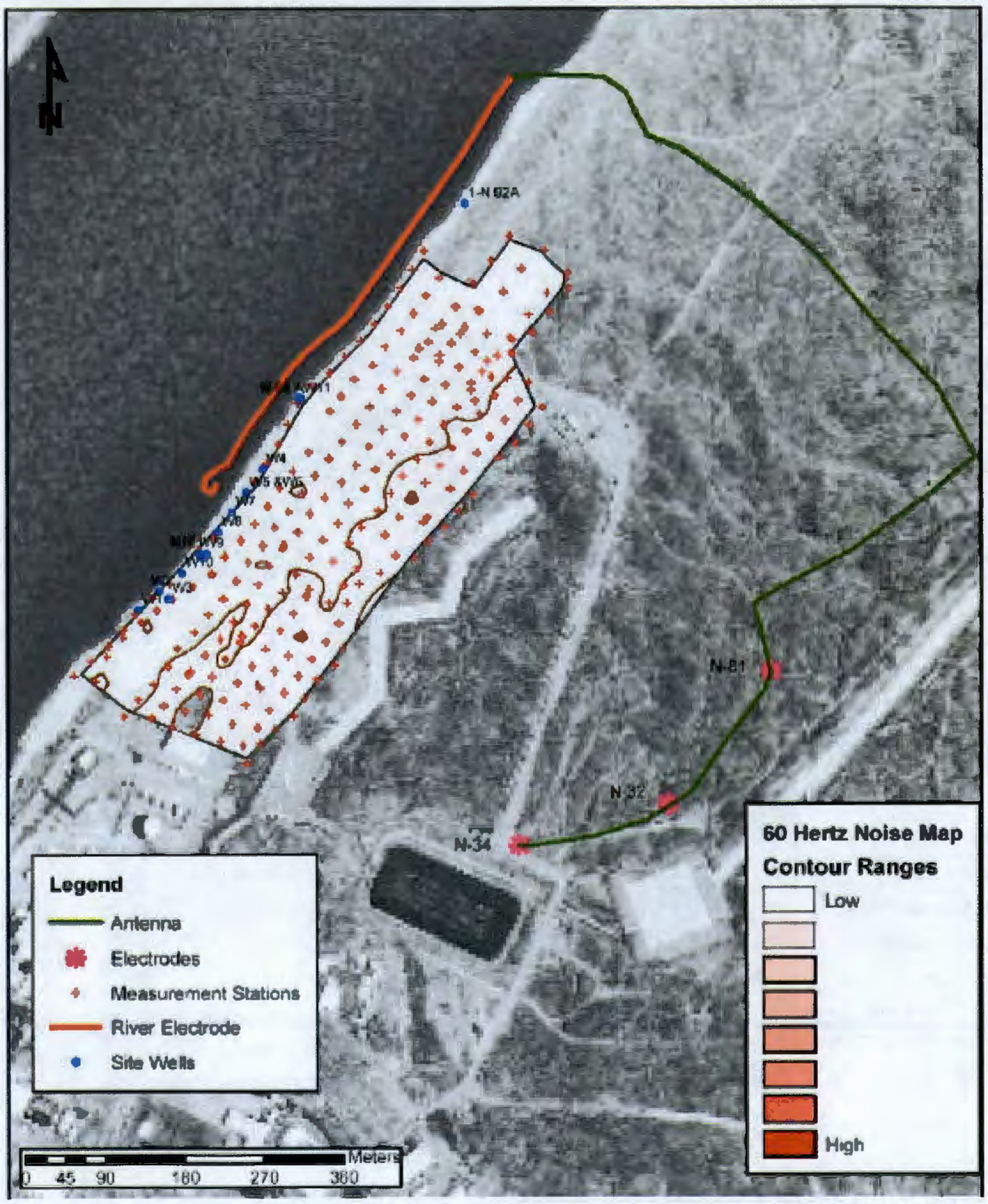

Figure 5.4 60 Hertz Noise Map

5.5 Spheric Noise Map

The Spheric Noise Map, shown in Figure 5.5, demonstrates and delineates areas in the shallow subsurface that are influenced by ambient and surface sources of noise (i.e., electric storms, ionosphere activity, etc.). It can also be influenced by local cultural features. Values of the measured and monitored spheric noise were generally low to medium and indicate that no significant interference from ambient magnetic fields, atmospheric fluctuations or other natural sources was experienced during the survey.

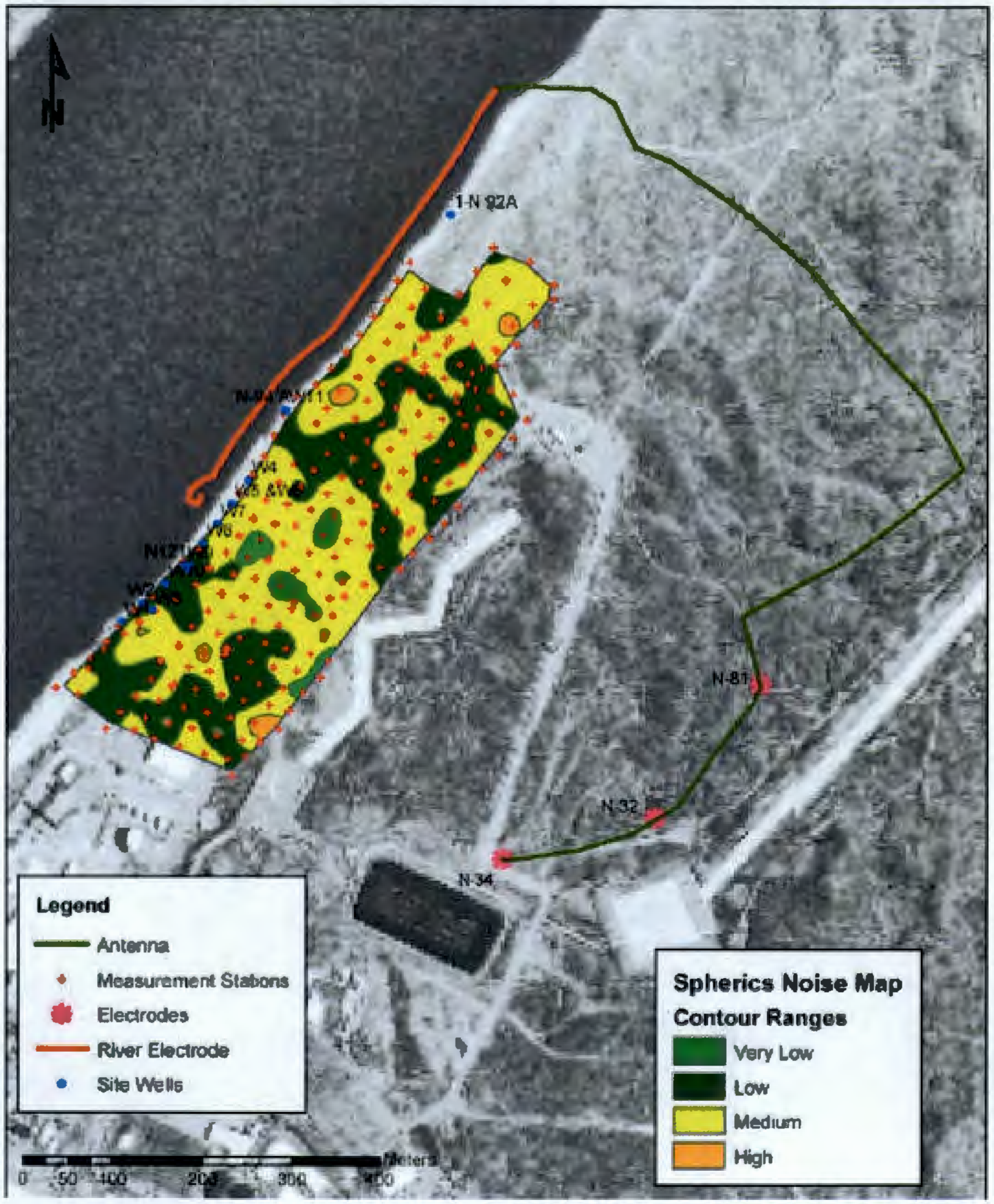

Figure 5.5 Spherics Noise Map

5.6 Measurement Repeatability

Measurement repeatability is determined from base stations readings or repeat station readings taken at random through out the survey process. Base stations are established in the survey and read and recorded several times per day (morning, mid-day, and evening). Repeat stations are read at the start and end of each new line. Also, in cases where additional data were requested after reduction and interpretation of the initial data, many stations were re-measured. The base stations and the repeat stations were compared to one another. In every case, repeat measurements consistently fell within acceptable deviations (determined by WillowStick™), generating confidence in the final recorded data sets. Figure 5.6 represents a sampling of base station readings taken on March 12^{th} which demonstrates repeatability of the AquaTrack™ data during the fieldwork.

BASE STATION READINGS ON 12-MAR-2006		
DATE	TIME	AquaTrack signal
3/12/06	8:08:55	3.608
3/12/06	8:12:03	3.844
3/12/06	8:23:36	3.745
3/12/06	10:42:21	3.731
3/12/06	10:48:53	3.610
3/12/06	10:52:25	3.660
3/12/06	12:27:51	3.628
3/12/06	12:31:50	3.646
3/12/06	13:15:55	3.704
3/12/06	13:19:22	3.687
3/12/06	16:21:14	3.863
3/12/06	16:25:12	3.761
3/12/06	17:47:31	3.810
3/12/06	17:57:36	4.009

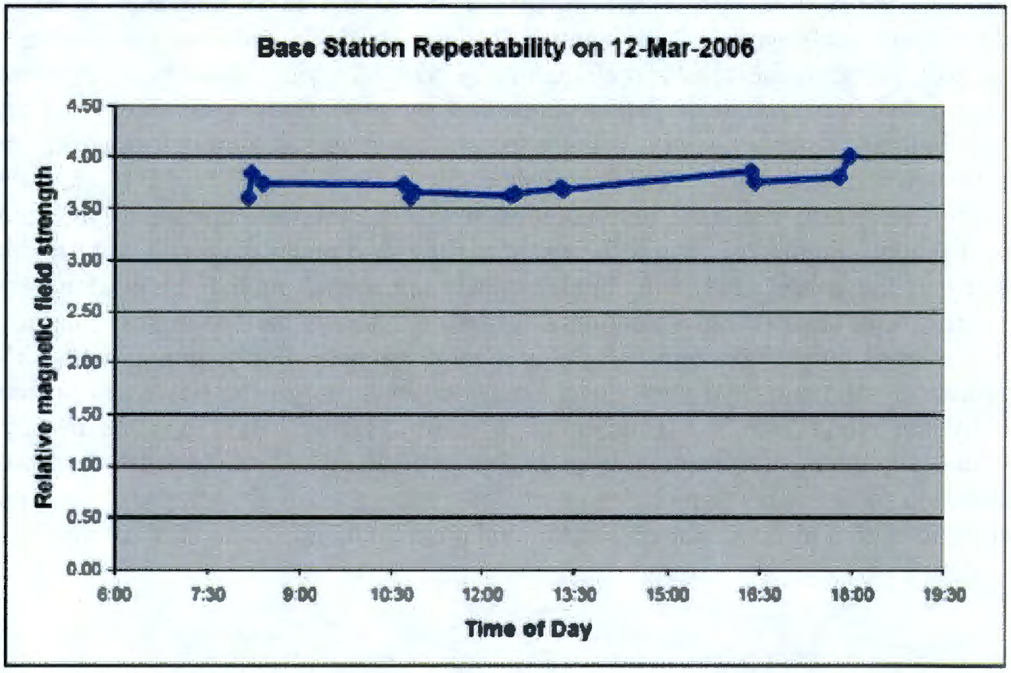

Figure 5.6 Repeatability of AquaTrack™ Signal

6.0 Modeling

To confirm that the interpretation of the AquaTrack™ magnetic field data is reasonable and probable, a simple theoretical electric current flow model was created for the survey based upon the findings and observations found in the AquaTrack™ data. By definition, a "forward model" consists of the determination of the data that would be recorded for a given subsurface configuration and under the assumption that given laws of physics hold (Treitel, et al, 1999). The purpose of using forward modeling is to arrive at a better interpretation of field data by comparison to computational data. Figure 6.1 represents the results of a finite element model of probable groundwater flow paths constructed in the MATLAB™ programming environment. The electrical current flow paths (simplified, smoothed, and interpreted as probable groundwater flow paths and shown as red lines in Figure 5.2) were used to create the model. This model consists of a set of finite element "wires" placed in the subsurface and represent the spreading and likely flowpaths of electrical current radiating outward from the electrodes through the area of investigation. A simulated electrical current, similar in magnitude to that applied to the electrodes in the AquaTrack™ survey, was applied to the wire flow model to simulate geo-electrical current flow through the subsurface aqueous system. Varying amounts of electrical current are concentrated into each flow path (represented by a wire and wire thickness) and moves along the indicted path for some distance before dispersing into the formation and migrating back toward the electrodes. A theoretical magnetic field, based on the model, was computed at each measurement station. The theoretical magnetic contour map was then created from this forward model. Figure 6.1 shows the results of the theoretical magnetic field for the flow paths created in the model (magnetic field contours are shown in red for contrast and comparison with the AquaTrack™ blue contours). Figure 6.2 shows the theoretical magnetic field contour map placed directly on top of the AquaTrack magnetic field contour map. The shape of the theoretical magnetic field very closely matches the shape of the physical magnetic field measured by the AquaTrack™ instruments. The AquaTrack™ data appears to have identified horizontal alignment of current flow paths very effectively. To determine depths of flow paths, the pseudo model wires (which represent flow paths) are adjusted vertically (up and down) in model depth until a match of the theoretical and physical magnetic fields are made.

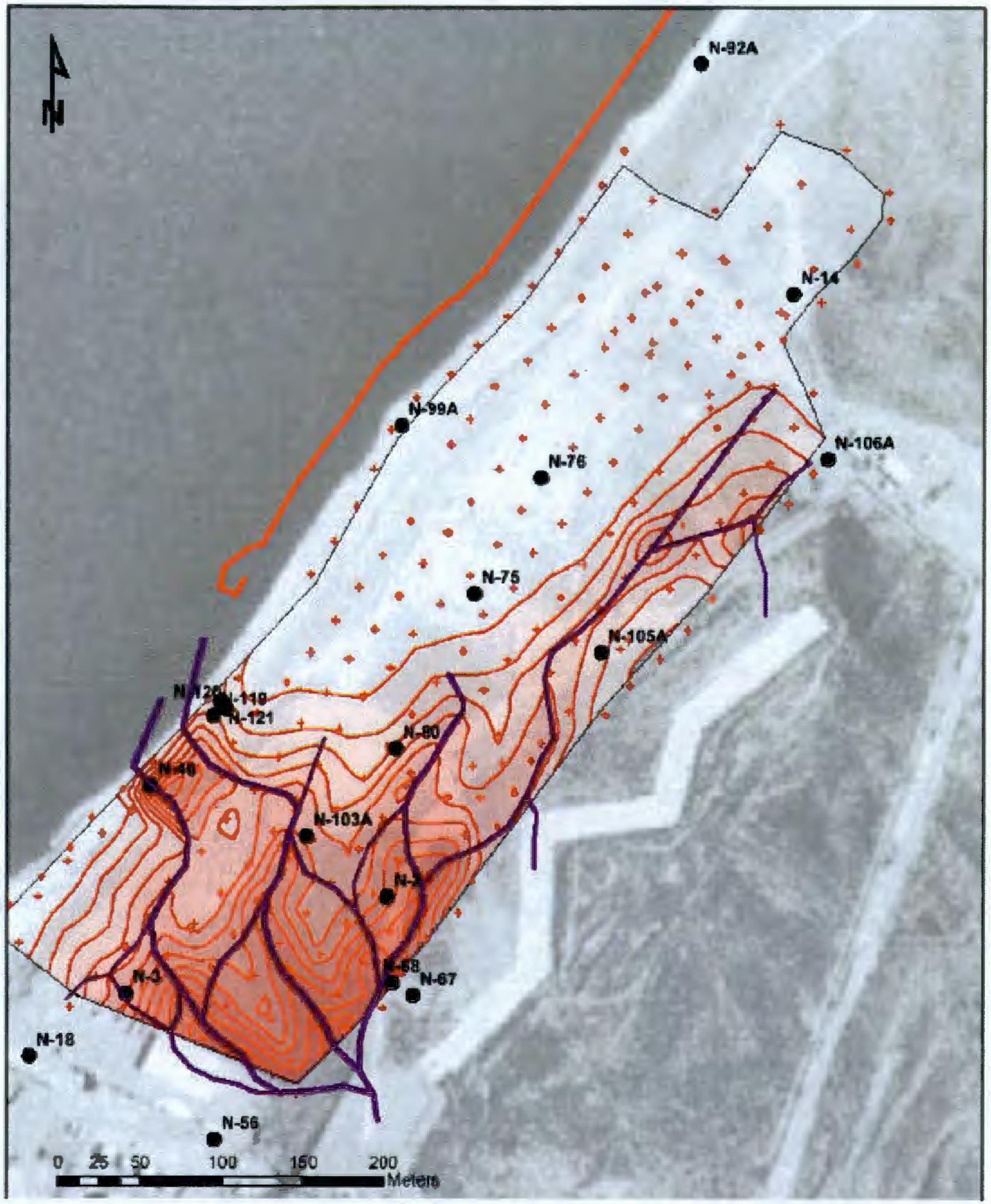

Figure 6.1 Theoretical Magnetic FieldModeled

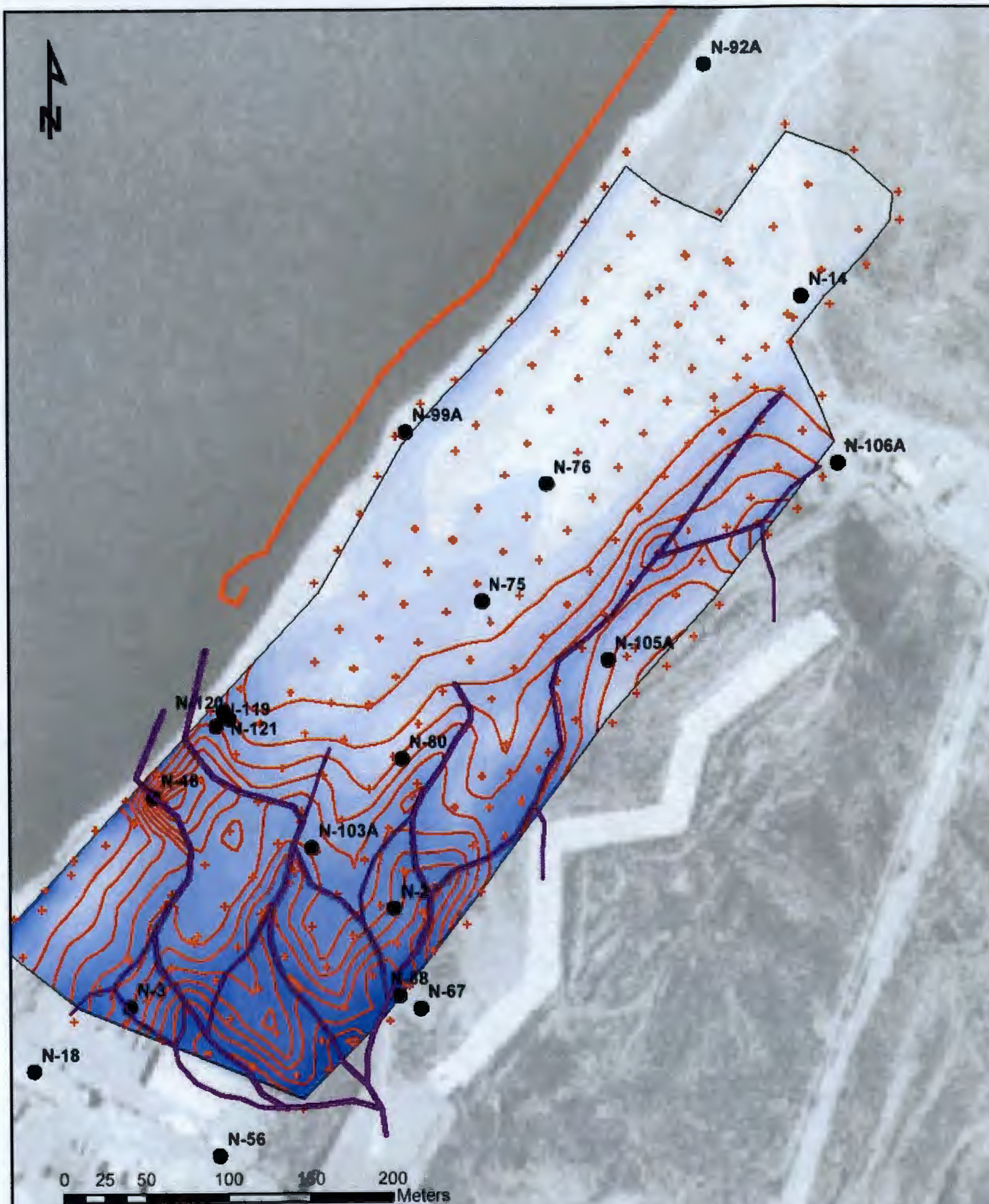

Figure 6.2 Comparison of Theoretical Model with AquaTrack™ Data. Red Contours Represent Theoretical Data Figure 6.1), Blue Shading Represents Collected AquaTrack™ Data (Figure 5.2).

Appendix A includes the model coordinates (easting, northing, and elevation) of each used to create the simplified subsurface current flow model. This model represents one possible solution of the subsurface flow beneath the site. As in all geophysical interpretations, it does not necessarily represent the only solution or the most probable solution. It is important to note that the information provided in Appendix A is a simplified model of water flow beneath the site and is based solely on the contractor's experience working with and developing the AquaTrack™ technology. The actual subsurface flow is likely to be much more complex than that shown in the model.

In addition, the GPS survey equipment used in the AquaTrack™ investigation generally does not provide sub-meter accuracy. Some location and elevation readings fluctuate by a meter or more, which is expected given the equipment used and site conditions. The AquaTrack™ survey method and grid spacing used in the investigation was intended to provide an accurate but general characterization of the groundwater and cannot provide sub-meter accuracy.

The results obtained from the theoretical modeling are provided to demonstrate and verify that the AquaTrack™ data is reasonable and a probable solution to the presence of highly ionized wastewater and/or preferential flow paths between the LWDF and the Columbia River.

7.0 Conclusions and Recommendations

The information gathered through the AquaTrack™ investigation suggests that the layout, including antenna/electrode configuration and data grid spacing were appropriately designed and that the findings of the demonstration project are reliable and accurate. The findings are supported by the following evidence:

- The magnetic contour map, generated from the AquaTrack™ geophysical survey method, showed an acceptable contrast between areas of high electrical conductance (current flow and concentration) and areas of low electrical conductance. The areas of high electrical conductance are interpreted as areas of greatest groundwater saturation and/or ion concentrations in the subsurface or a combination of both. The magnetic field survey has provided valuable horizontal resolution that defines the centers and approximate edges of highly ionized saturated zones beneath the area of investigation.

- Numerous and various measurements (signal repeatability, signal-to-noise ratios, 60 Hz noise, spheric noise, and magnetic field data) provided consistent and reliable information from which the interpretation was based. The measured and recorded data support, compliment, and confirm the final results.

- The data collected and the interpretation of the data were compared to other information known about the study area, e.g., location of liquid waste disposal trench, direction of groundwater flow, contaminant appearance in clam-shell data, etc. The AquaTrack information compares favorably with the current conceptual model of groundwater flow and existing geologic knowledge of the site. Other data deserving comparison include concentration of contaminants in trench and concentration of contaminants from monitoring wells.

- Theoretical electrical current flow modeling was performed with MATLAB™ software to compare theoretical magnetic contours and profiles with actual AquaTrack™ magnetic contours and profiles to estimate flow path depths as well as establish credibility of data. This theoretical model data matched closely with the actual field data.

This information effectively characterized elevated ion concentrations and groundwater levels where contaminants from disposed wastewater is likely concentrating and flowing in the subsurface groundwater regime. The AquaTrack™ data, when combined and correlated with known geologic and hydrologic information helped to provide insight to groundwater flow paths and areas of concentration. It generated accurate and timely groundwater characterization maps of the unconfined water bearing zones within the Hanford and Ringold formations beneath the 100-N Area from which informative decisions can be made regarding clean up and remediation of the site from contaminated groundwater. It showed how the contaminated and highly ionized wastewater has been influenced by groundwater flow down-gradient of the LWDF in the unconfined water bearing formations beneath the site. This method can be utilized as an additional planning tool for the cleanup of the Hanford site. The information gathered and processed from the AquaTrack™ method can be done at a reasonable cost that is generally less expensive than other types of geophysics; thus saving DOE money by effectively characterizing a contaminated area and reducing uncertainty. This method is also a faster way to collect contamination data than other types of geophysics such as a resistivity survey.

This information could be compared with known information of the site to further characterize and substantiate subsurface conditions impacting groundwater contaminant levels through the unconfined water bearing zones of the Hanford and Ringold formations. The resulting maps clearly delineate magnetic anomalies that may be compared with results of other geophysical methods (such as electromagnetics) to accurately locate specific subsurface objects and conditions. Water from wells in the survey area should be collected and the ion concentrations of contaminants from these wells should be analyzed to see if they match the results from the survey. Additional verification of this method may be obtained with a pumping or tracer test to tell if ground water flow can be defined by preferential flow paths. However, in a contaminated zone, it may be difficult to dispose of water collected from a pumping test, and more wells may have to be drilled for both the pumping test and a tracer test. The AquaTrack™ system has been effectively used at other DOE sites despite the presence of cultural structures such as tanks and pipelines. One recommendation the CTUIR DOSE would like to make would be to test this method in or near a tank farm to see if it can delineate a leak that is reaching or soon to reach the ground water such as at the B-BX-BY tank farm

These surveys will help DOE focus cleanup activities to specific areas and help to cut costs in the overall cleanup effort. For example, the results from this survey show a possible location where DOE may focus cleanup activities to a narrow passageway of apparent ground water flow with higher concentrations towards the Columbia River. This would help in the construction of a narrower barrier wall to capture the Strontium-90 before it reaches the Columbia River.

7.1 Future Work

If DOE judges this work as valuable and important to the cleanup effort at Hanford, then other areas within the complex could also benefit from the use of this technology. Many areas within the Hanford complex are ideal for the use of this geophysical survey technology. For example, most of the monitoring wells are drilled with steel casings that are completed to the ground water. This would eliminate the need to send a probe down to the ground water directly since the well casing may be used as one end of the electrical circuit. The number of monitoring wells on-site would also help to assure that the electrical current is induced in the ground water at ideal locations. Further characterization of ground water and contaminate flow is essential to both speed up the cleanup process and to save costs. The CTUIR would like to submit additional proposals to characterize the preferential flow paths that waste water and highly ionized waste is taking in the subsurface unconfined formations.

Examples of additional areas that could benefit from this technology include:

- A survey in the 300 area to characterize the Uranium plume that has been moving towards the Columbia River. This area has proven difficult in the past to characterize the movement of the Uranium in the ground water.
- A survey in the 618-10 and -11 burial grounds would characterize the flow path that the high-concentration tritium plume that appear to be rapidly flowing towards the Columbia River. The survey may also help to locate the source of this plume.
- A survey in the Gable Mountain/Gable Gap area to determine how the Uranium plume from the 200 Areas is flowing towards the 100 BC area and eventually discharging towards the Columbia River. It is speculated that fractures within the basalt or buried flood channels may be controlling this flow. The AquaTrack™ system would be ideal to determine if there are preferential flow paths within the basalts carrying the contaminates to the northwest.
- A localized survey in the B-BX-BY tank farm under the 200 E area to plot out the overflow and leak from a tank that now appears as a narrow plume moving towards the Gable Gap area.
- A survey in the 100-KW area to map the chromium plume from the K-Basin moving towards the Columbia River. There is evidence that this plume may be reaching the shoreline. An early survey would help to control this plume before it spreads too far.
- Technetium-99 has been increasing at Waste Management Area T within the ground water at the highest technetium-99 concentration (181,900 pCi/L) on the Hanford Site in FY 2005. The AquaTrack™ system may help to delineate the contamination and to investigate sources, transport, and possible remedial alternatives for the contamination.
- 200 West Area. has a large plume of carbon tetrachloride that has been difficult to delineate in the past. A survey with a well completed within this plume may help to outline the plume.
- This method may be useful as a tool to locate the unidentified sources of plumes. A well located down-gradient of and within a plume of unknown origin could be used as one end of the circuit. Wells far up-gradient of potential sources would form the other end. As this "circuit" is energized, the strongest current would flow in the ionized fluids back to the potential source.

These are just a few suggested locations for the survey. Further consultation with DOE may reveal additional locations where a survey to determine ground water flow paths may be desirable.

8.0 References

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Appendix A
Model Coordinates

AquaTrack Geophysical Groundwater Investigation

Hanford Site 100-NR-2 Operable Unit
Water Model Coordinate System
Coordiante System is in WGS 1984, UTM Zone 11 N

Series ID	Point Number	Easting X	Northing Y	Elevation Z	(All coordinates in meters)
Series 1					
1	1	303766.8	5172419.0	118.0	
1	2	303764.5	5172435.2	118.0	
1	3	303755.3	5172450.2	118.0	
1	4	303740.3	5172464.1	118.0	
1	5	303733.3	5172479.1	118.0	
1	6	303721.8	5172495.2	118.0	
1	7	303709.1	5172509.1	118.0	
1	8	303701.0	5172522.9	118.0	
1	9	303696.4	5172539.1	118.0	
1	10	303697.6	5172557.6	118.0	
1	11	303705.6	5172570.3	118.0	
1	12	303707.9	5172580.7	118.0	
1	13	303711.4	5172596.8	118.0	
1	14	303717.2	5172610.7	118.0	
1	15	303711.4	5172619.9	118.0	
1	16	303695.2	5172624.5	117.0	
1	17	303679.1	5172629.2	117.0	
1	18	303662.9	5172638.4	117.0	
1	19	303653.7	5172649.9	117.0	
1	20	303645.6	5172661.5	117.0	
1	21	303639.0	5172678.0	117.0	
1	22	303654.3	5172718.7	117.0	
Series 2					
2	1	303764.5	5172435.2	118.0	
2	2	303746.5	5172440.1	118.0	
2	3	303726.1	5172437.2	118.0	
2	4	303705.8	5172435.8	118.0	
2	5	303691.3	5172444.5	118.0	
2	6	303682.6	5172459.0	118.0	
2	7	303668.1	5172469.1	118.0	
2	8	303657.9	5172479.3	118.0	
2	9	303650.6	5172492.4	118.0	
2	10	303640.5	5172506.9	118.0	
2	11	303628.9	5172522.9	118.0	
2	12	303626.8	5172542.1	118.0	

2	13	303636.1	5172560.6	118.0	
2	14	303647.7	5172576.6	118.0	
2	15	303649.2	5172594.0	117.0	
2	16	303640.5	5172614.3	116.0	
2	17	303627.4	5172626.0	115.0	
2	18	303611.8	5172640.6	115.0	
2	19	303628.9	5172681.8	116.0	
Series ID	Point Number	Easting X	Northing Y	Elevation Z	(All coordinates in meters)
Series 3					
3	1	303755.3	5172450.2	118.0	
3	2	303755.2	5172466.2	118.0	
3	3	303759.5	5172482.2	118.0	
3	4	303768.3	5172499.6	118.0	
3	5	303775.5	5172518.5	118.0	
3	6	303785.7	5172530.1	118.0	
3	7	303794.4	5172549.0	118.0	
3	8	303794.4	5172565.0	118.0	
3	9	303785.7	5172582.4	118.0	
3	10	303784.2	5172596.9	118.0	
3	11	303784.2	5172614.3	118.0	
3	12	303790.0	5172627.4	118.0	
3	13	303801.6	5172643.4	118.0	
3	14	303811.1	5172661.0	118.0	
3	15	303819.3	5172671.8	118.0	
3	16	303820.1	5172677.8	118.0	
3	17	303810.4	5172694.4	118.0	
Series 4					
4	1	303874.1	5172575.1	120.0	
4	2	303869.0	5172594.0	122.0	
4	3	303867.0	5172609.0	124.0	
4	4	303860.0	5172615.0	122.0	
4	5	303868.4	5172643.4	120.0	
4	6	303875.7	5172655.0	118.0	
4	7	303872.8	5172673.9	118.0	
4	8	303869.9	5172692.7	118.0	
4	9	303874.2	5172708.7	118.0	
4	10	303891.7	5172721.8	118.0	
4	11	303907.6	5172736.3	118.0	
4	12	303922.2	5172755.2	118.0	
4	13	303935.2	5172771.2	118.0	
4	14	303949.2	5172793.5	118.0	
4	15	303963.7	5172813.8	118.0	
4	16	303976.8	5172831.2	118.0	
4	17	303995.7	5172857.4	118.0	
4	18	304030.0	5172890.0	118.0	
Series 5					
5	1	304006.4	5172731.9	118.0	
5	2	304006.4	5172756.6	118.0	
5	3	304000.6	5172774.1	118.0	

5	4	303999.1	5172791.5	118.0	
5	5	304016.5	5172813.3	118.0	
5	6	304034.0	5172826.3	118.0	
Series 6					
6	1	303657.9	5172479.3	118.0	
6	2	303662.3	5172499.6	118.0	
6	3	303669.5	5172517.1	118.0	
6	4	303682.6	5172530.1	118.0	
6	5	303697.6	5172557.6	118.0	
Series ID	Point Number	Easting X	Northing Y	Elevation Z	(All coordinates in meters)
Series 7					
7	1	303717.2	5172610.7	118.0	
7	2	303723.2	5172627.4	118.0	
7	3	303727.6	5172640.5	118.0	
7	4	303733.4	5172655.0	118.0	
Series 8					
8	1	303935.2	5172771.2	118.0	
8	2	303962.8	5172779.9	118.0	
8	3	303983.1	5172785.7	118.0	
8	4	303999.1	5172791.5	118.0	
Series 9					
9	1	303768.3	5172499.6	118.0	
9	2	303763.9	5172528.7	118.0	
9	3	303753.7	5172547.6	118.0	
9	4	303740.7	5172562.1	118.0	
9	5	303721.8	5172572.2	118.0	
9	6	303711.4	5172596.8	118.0	
Series 10					
10	1	303794.4	5172565.0	118.0	
10	2	303808.9	5172579.5	118.0	
10	3	303830.7	5172588.2	118.0	
10	4	303848.1	5172601.3	118.0	
10	5	303860.0	5172615.0	118.0	
Series 11					
11	1	303753.7	5172547.6	118.0	
11	2	303751.8	5172565.8	118.0	
11	3	303761.0	5172588.2	118.0	
11	4	303771.2	5172601.3	118.0	
11	5	303784.2	5172614.3	118.0	
Series 12					
12	1	303705.8	5172435.8	118.0	
12	2	303690.0	5172437.3	118.0	
12	3	303679.6	5172442.5	118.0	
12	4	303666.1	5172445.1	118.0	
12	5	303651.2	5172452.3	118.0	
12	6	303640.8	5172464.4	118.0	
12	7	303638.8	5172474.7	118.0	
12	8	303644.3	5172484.9	118.0	
12	9	303643.7	5172501.9	118.0	

Series 13				
13	1	303638.8	5172474.7	118.0
13	2	303614.0	5172490.0	118.0
13	3	303601.3	5172509.0	118.0
13	4	303586.8	5172505.4	118.0
13	5	303575.1	5172493.8	118.0