



**Golder Associates Inc.**  
18300 NE Union Hill Road, Suite 200  
Redmond, Washington 98052  
Telephone: (425) 883 0777  
Fax: (425) 882 5498



## **WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY FEASIBILITY REPORT**

*Submitted to:*

*Utilities Division, Water Resources Program  
Public Works Department  
Spokane County, Washington*

*Submitted by:*

*Golder Associates Inc.  
Redmond, Washington  
18300 N.E. Union Hill Road, Suite 200  
Redmond, Washington 98052*

*Funded by:*

*Washington State Department of Ecology  
Grant No. G0800330*

Matthew A. Benson, L.G.

Richard Sylwester, L.E.G, L.G.

June 2009

083-93096.400

## TABLE OF CONTENTS

1.0	INTRODUCTION.....	1
1.1	Project Background.....	1
1.2	Project Description.....	2
1.3	Project Schedule.....	2
2.0	SITE SELECTION.....	3
2.1	Line 1 - Craig Road and Highway 902 to Hayford Road.....	3
2.2	Line 2 - Ventura Road.....	4
2.3	Line 3 - Craig Road (Highway 902 to Four Lakes).....	4
3.0	GEOPHYSICAL METHODS.....	6
3.1	Seismic Reflection.....	8
3.1.1	Seismic Reflection Survey Design.....	8
3.2	Electrical Resistivity Imaging (ERI).....	8
3.2.1	Electrical Resistivity Imaging Survey Design.....	9
3.3	Gravity.....	9
3.3.1	Gravity Survey Design.....	9
3.4	Transient Electromagnetics.....	9
3.4.1	Transient Electromagnetics Survey Design.....	10
4.0	FIELD TRIAL RESULTS.....	11
4.1	Line 1: Craig Road and Highway 902 towards Hayford Road.....	11
4.1.1	Electrical Resistivity Imaging.....	11
4.1.2	Gravity.....	12
4.1.3	Transient Electromagnetics.....	12
4.1.4	Seismic Reflection.....	12
4.2	Line 2 - Ventura Road.....	13
4.2.1	Electrical Resistivity Imaging (ERI).....	13
4.2.2	Gravity.....	13
4.2.3	Transient Electromagnetics.....	14
4.2.4	Seismic Reflection.....	14
4.3	Line 3 - Craig Road (Highway 902 to Four Lakes).....	14
4.3.1	Electrical Resistivity Imaging.....	14
4.3.2	Gravity.....	15
4.3.3	Transient Electromagnetics.....	15
4.3.4	Seismic Reflection.....	15
5.0	MONITORING WELL INSTALLATION.....	16
5.1	Objectives of the Monitoring Well.....	16
6.0	FEASIBILITY OF GEOPHYSICAL METHODS.....	17
7.0	REFERENCES.....	19

## LIST OF TABLES

Table 1	Project Budget
Table 2	Project Schedule
Table 3	Matrix of Geophysical Methods and Applications
Table 4	Comparison of Acquisition Costs and Benefits of Seismic Reflection and Gravity

## LIST OF FIGURES

Figure 1	West Plains Study Area
Figure 2	Line 1 – Craig Road and Highway 902 to Hayford Road
Figure 3	Line 2 – Ventura Road
Figure 4	Line 3 – Craig Road (Hwy 902 to Four Lakes)

## LIST OF APPENDICES

Appendix A	Well Logs
	A1 Line 1 – Craig Road and Highway 902 to Hayford Road
	A2 Line 2 – Ventura Road
	A3 Line 3 – Craig Road (Hwy 902 to Four Lakes)
Appendix B	Geophysical Results of Orientation Survey
Appendix C	Monitoring Well Construction

**APPROVAL SHEET**

\_\_\_\_\_  
Mike Hermanson  
Spokane County

\_\_\_\_\_  
Date

\_\_\_\_\_  
Robert Lindsay  
Spokane County

\_\_\_\_\_  
Date

\_\_\_\_\_  
John Covert  
Washington Department of Ecology

\_\_\_\_\_  
Date



**DISTRIBUTION LIST:**

Mike Hermanson, Spokane County  
Robert Lindsay, Spokane County  
John Covert, Washington Department of Ecology  
Bryony Stasney, Golder Associates Inc.  
Richard Sylwester, Golder Associates Inc.

## 1.0 INTRODUCTION

The West Plains area is located west of the City of Spokane, at the boundary of WRIA 54 (Lower Spokane River Watershed), WRIA 56 (Hangman Creek Watershed) and WRIA 34 (Palouse River Watershed) and includes land within these three Water Resource Inventory Areas (WRIAs) (Figure 1). The study objective was to determine the feasibility of various geophysical methods to delineate the top of the crystalline basement rocks across the West Plains.

The project is funded by the Washington Department of Ecology (Ecology) as Grant No. G080030. Funding for drilling of confirmation borehole was provided by Supplemental Environmental Project No. 4018 between Ecology and Goodrich Corporation. Table 1 presents the project budget.

**TABLE 1. Project Budget**

Budget	Task
\$1,700.00	Project Management
\$28,100.00	Project Work Plan and Quality Assurance Project Plan
\$61,100.00	Geophysical Orientation Survey
\$40,000.00	Installation of Confirmation Borehole
\$13,100.00	Orientation Survey Report
\$144,000.00	Total Project Budget

This Feasibility Report documents the results of the geophysical orientation survey and present recommendations for future geophysical investigations based on land use, depth to basement, presence of overlying basalt group, size of the survey area, and cost of various methods.

### 1.1 Project Background

The West Plains area is located west of the City of Spokane and includes the Cities of Airway Heights, Medical Lake, and Four Lakes, and Fairchild Air Force Base (Figure 1). A formal boundary for the West Plains does not exist. However, the West Plains is generally considered as the relatively low lying land that is located west of the Spokane River that is surrounded by low lying hills and buttes that occur north of Cheney, east of Reardan and south of Four Mound Prairie. Two primary drainages, Deep Creek and Coulee Creek, flow in an easterly direction across the northern portion of the West Plains and discharge into the Spokane River.

The geology of West Plains is comprised of, from the youngest to the oldest units,

- Sand and gravel deposits that occur within palaeochannels;
- Columbia River Basalt Group; and,
- Crystalline basement rocks (such as granite and quartzite).

The crystalline basement rocks are exposed on a number of topographic highs such as Olson Hill (just north of Medical Lake), Booth Hill and Fancher Butte (west of Medical Lake) and McDowell Hill (south of Coulee Creek and north of Deep Creek). The crystalline basement also underlies the basalts and the sand and gravel deposits. Recent geologic mapping by Washington State Department of Natural Resources (DNR) and by Eastern Washington University (EWU) has improved the understanding of the distribution and occurrence of geologic units; however, the depth and topography of the contact between the crystalline basement rocks and overlying basalts and sediments are not well understood.

The primary aquifers in the West Plains area occur within the paleochannel deposits and within the Wanapum and Grande Ronde Basalt flows. The basement rocks, defined as metamorphic and intrusive igneous rocks, have low permeability and provide poor yield to wells and are considered to be an aquitard (i.e., barrier to groundwater flow). Recharge to the West Plains aquifers from precipitation (rain and snowmelt) totals about 15 to 19 inches annually. The Washington State Department of Ecology (Ecology) has compiled groundwater level information for a number of wells located across the West Plains and has concluded that in some areas groundwater levels within the basalt aquifers are declining (Covert, 2007). Between 2001 and 2003 documented declines in groundwater level range from about 15 feet in a Medical Lake well and approximately 120 feet in a Four Lakes well between 1997 and 2005 (TetraTech and GeoEngineers, 2007). Aquifer testing data also suggests that well interference occurs between some of West Plains municipal wells (Covert, 2007).

The conceptual model for the West Plains hydrogeology suggests that the depth and topography of the top of basement controls groundwater flow and that the basalts are divided into small, compartmentalized aquifers. Geophysics (primarily seismic reflection) has been used across the West Plains to delineate the configuration of the Deep Creek, Airport and Airway Heights palaeochannels (McCollum, 2009; Budinger, 2001; GeoEngineers, 2002; GeoEngineers, 2007). However, this investigation did not identify deeper reflectors that may be associated with the basalt – crystalline basement contact.

## 1.2 Project Description

The purpose of this project was to evaluate several geophysical methods in order to identify one or more methods that can be used to determine the depth to basement beneath unconsolidated sediment and to delineate the contact between the basalt and the crystalline basement rock. The geophysical investigation (including equipment, field operations and processing) needed to consider interference associated with cultural development (e.g., roads, power lines and buried utilities), depth to the crystalline basement contact, and the geophysical properties of various geologic units.

## 1.3 Project Schedule

Field activities began in March 2009 and were completed in June 2009. The table below summarizes the schedule of project activities.

**TABLE 2. Project Schedule**

Date	Monitoring Activities
March 2009	Submission of Quality Assurance Project Plan and Work Plan
March 2009	Begin geophysical field trials at select locations
April 2009	Complete geophysical field trials at select locations, process data from all field trials and prepare orientation survey draft report.
May 2009	Drill confirmation borehole, prepare orientation survey final report
July 2009	Submit final project deliverables

## 2.0 SITE SELECTION

Figure 1 shows the location of the geophysical lines for the five proposed field trials. However, budget constraints limited field trials to the first three lines. No field trials were conducted along proposed Lines 4 and 5. Additional information in the immediate vicinity of the first three lines, e.g. the approximate location of nearby wells, is included in Figures 2 through 4. Lithologic logs for wells associated with each of the lines are included in Appendix A and summarized in the following section that describes each of the sites.

The three lines, their location, and order of priority as determined with Spokane County, are:

- Line 1: Craig Road and Highway 902 towards Hayford Road
- Line 2: Ventura Road
- Line 3: Craig Road

The following section provides a brief description of the lines completed, including the general geology and the specific objective or objectives associated with each line.

### 2.1 Line 1 - Craig Road and Highway 902 to Hayford Road

This line ran in a northeasterly direction from the Delegans well (166859), also known as the Airway Heights Park West well, through a significant exposure of granite that is located about 3,000 feet south of Thorpe Road (Figure 2). This line was 5,000 feet (1,525 m) long (Figure 2).

The granite exposure located approximately three-quarters of the way along the line has been recently mapped by the Washington State Department of Natural Resources (DNR) as basement rock. However, in the three wells closest to this outcrop there is no evidence of crystalline basement at a depth shallower than 300 feet. Below is a summary of the geology in the three wells.

Mayhan well (166590).

0 to 9 feet	overburden
9 to 105 feet	basalt
105 to 145 feet	scoria
145 to 260	basalt, medium hardness
260 to 303 feet	scoria

Delegans well (166859).

0 to 42 feet	gravel, sand and clay
42 to 301 feet	basalt

Medical Lake well (417068).

0 to 64 feet	gravel and sandy clay
64 to 805 feet	basalt
805 to 1301 feet	clay
1301 to 1404 feet	quartzite / granite

Geophysical surveys were conducted to determine if the top of basement rock, noted in the Medical Lake well (417068) log, could be detected with geophysical methods, and to determine if the granite located at the northeast end of the line is a basement outcrop or glacial erratic.

## 2.2 Line 2 - Ventura Road

The Ventura Road line (Figure 3) ran northwards through an open field, crossed Highway 2, and then extended along Ventura Road. This line was 4,250 feet long.

Several of the logs from wells north of Highway 2 and in the vicinity of Ventura Road indicate the basalt – granite contact occurs at a depth between 90 and 543 feet (Figure 3). Based on well log data, the contact with basement rock is clay in the north that transitions to basalt near the center of the line. The Fairchild Air Force Base well (371438) did not encounter basement rock in the upper 439 feet. Below is a summary of the geology of two wells close to the line.

### Harding well (170106).

0 to 5 feet	sand and clay
5 to 55 feet	basalt
55 to 182 feet	clay
182 to 205	granite

### Audett well (173290)

0 to 9 feet	sand and clay
9 to 190 feet	basalt
190 to 260 feet	clay
260 to 543 feet	basalt
543 to 600 feet	granite

Geophysical data was acquired along this line to attempt to map the depth and topography of the top of basement. Data obtained on this line will also be used determine the maximum depth to which the top of bedrock can be detected.

## 2.3 Line 3 - Craig Road (Highway 902 to Four Lakes)

Line 3 was 6000 feet long and ran north from near the Four Lakes well (468689) to White Road (Figure 4). The Four Lakes well (468689) located just north of Interstate 90, logged the basalt-basement contact at a depth of 285 feet. Below is a summary of the geology in two wells located close to the geophysical transect.

The approximate location of the Keys well, which was drilled to a depth of 225 feet, is based on information available from the Ecology's on-line well viewer (Figure 2).

### Keys (170665) well

0 to 17 feet	gravel, sand and clay
17 to 225 feet	basalt

### Southern Four Lakes well (468689)

1 to 178 feet	basalt
178 to 198 feet	clay and sand
198 to 234 feet	basalt
234 to 244 feet	clay
244 to 285 feet	basalt
285 to 300 feet	decomposed granite

## Northern Four Lakes well (164483)

0 to 18 feet	sand and gravel
18 to 8 feet	clay
28 to 664 feet	basalt
664 to 775 feet	clay

Geophysics was conducted on Line 3 to attempt to map the top of the basement rock from the Four Lakes well (468689) north to White Road where it is expected to be between 285 feet and 1,000 feet below the ground surface.

### 3.0 GEOPHYSICAL METHODS

The selection of the geophysical methods used for the West Plains study was based on published method selection guides and a pilot test conducted in December of 2008. The geophysical method selection criteria for this study included the potential to detect the contact between different rock types, e.g. basalt over granite, and the potential to determine the depth to the top of competent rock covered by unconsolidated overburden, e.g. sand and gravel over basement. Also of importance were the estimated maximum depth of subsurface penetration and the resolution of each method.

Table 3, summarizes the methods that were considered and their application. Based on the stated criteria the geophysical methods that are the most appropriate for the West Plains study area are: seismic refraction, seismic reflection, GPR, ERI, gravity, and TEM. GPR, IP, SP, VLF, frequency domain electromagnetics, and magnetic were not considered because they were either a secondary choice or they were not applicable to the survey objectives. The selected methods, refraction, reflection, ERI, and TEM were evaluated during a pilot phase completed to support the Work Plan and QAPP.

**Table 3. Geophysical Methods and Applications**

(Adapted from ASTM Guide D 6429-99 Standard Guide for Selecting Surface Geophysical Methods)

	Rock Layers	Depth to bedrock	Depth to water table	Fractures and fault zones	Voids and sinkholes	Soil and rock properties	Dam and lagoon leakage	Salt water intrusion	Utility location	Abandoned wells
Seismic refraction	S	P	P	S	C	S				
Seismic reflection	P	P	P	S	S					
Ground penetrating radar (GPR)	S	P	P	S	P		S	S	P	
Electrical resistivity imaging (ERI)	S	S	S	S	S	P	S	P		
Induced polarization (IP)			S	S	S			S		
Spontaneous potential (SP)							P			
Very low Frequency EM (VLF)		S	S	P						
Frequency domain EM		S	S	P	S	S	S	P	S	S
Transient Electromagnetics (TEM)	S	S	S	S				P	P	P
Gravity		P		S	P					
Magnetics				S						S

P. Denotes primary choice of method for application.

S. Denotes secondary choice of method for application.

#### Seismic Methods

There is an increase in velocity with depth and a significant acoustic impedance contrast between basalt and granite suggesting seismic methods, reflection and/or refraction, are appropriate methods for most geologic conditions on the West Plains.

The typical depth of penetration for the seismic refraction method is less than 100 feet unless explosives are used as the source. This limits its applicability within the West Plains area, although refraction data, collected simultaneously with seismic reflection data with some limitations, could be used to map the alluvial-bedrock contact at depths less than 100 feet. The typical depth of penetration for seismic reflection measurements ranges between 50 and 1,000 feet; measurement at depths beyond 1,000 feet require seismic sources not common to hydrogeologic investigations.

**GPR Method**

The effective depth of the GPR method in most soil and rock is generally less than 30 feet, and often less than 3 feet in mineralogical clays or materials containing conductive pore fluids. The depth limitation of GPR indicates that this method would only be useful for rapid reconnaissance mapping of the top of shallow bedrock.

**ERI Method**

Electrical resistivity is a secondary choice to map rock layers and the depth to bedrock. The depth of subsurface penetration and resolution of ERI measurements are a function of the electrode spacing. This method is a good choice to use in areas where the top of basement rock is in contact with unconsolidated sediments at depths less than 200 feet.

**TEM Method**

The TEM is a secondary choice to map rock layers and the depth to bedrock. The depth of measurements can be as shallow as 20 feet and as great as 3,000 feet. Measurements at depths greater than 500 feet require a large loop size. Horizontal resolution can be problematic because large loops often cross lateral discontinuities, such as dramatic increase in the depth to bedrock, which produces erroneous measurements. TEM could be a good choice for mapping depths to deeper rock layers and basement in most areas in the West Plains.

**Gravity Method**

Gravity measurements are primarily used to map regional geologic structure including the depth to bedrock. Vertical resolution is a function of the accuracy of density estimates for the geologic units. Lateral resolution is a function of station spacing. Because there is a large contrast in the density of unconsolidated sediments and granitic basement rocks, as well as good density estimates for the basalt and granite, gravity is a good choice for the West Plains area.

**Test of Geophysical Methods**

A pilot geophysical study was conducted by Golder in December 2008 as the first phase of the project. At the pilot site the depth to basement rock ranged from zero at an outcrop to greater than 220 feet below the ground surface at a well located 250 feet to the north. The site provided fairly representative conditions for evaluating the effectiveness of various geophysical methods including seismic refraction, seismic reflection, time-domain electromagnetics, electrical resistivity imaging, and gravity methods. However, it was expected that it would be difficult to image the top of basement rock since it dips steeply to the north.

Seismic refraction, ERI, and gravity methods proved successful for mapping the overburden-basement rock contact and seismic reflection and gravity proved successful for mapping the basalt-basement rock contact. The following is a summary of the results from the pilot study (line P1 on Figure 1).

- Seismic refraction successfully imaged the soil overburden-basement contact, but did not image the basalt-basement contact. There is such a large contrast in velocity and density between the overburden and the basalt that very little seismic energy was transmitted through the basalt to the basalt-basement contact.
- Seismic reflection also imaged the overburden-basement contact, but did not detect the basalt-basement contact with certainty. The depth to basement rock on the south end of the test line was too shallow and dips to steeply on the south end of the line, based on the well log data, to be detected by the seismic reflection method.
- ERI imaged the overburden-basement contact along the south end of the line, but did not image the basalt-basement contact in the middle and northern areas of the line. One possible explanation is that there is insufficient contrast between the basalt and the basement rock.



- TEM did not work well for detecting the basalt-basement contact. There appeared to be a sharp lateral variation in the electrical resistivity data coincident with the locations of the TEM loops. This could lead to TEM data that is noisy and inconclusive results. It is also possible the electrical conductivity of basalt is not sufficiently different from the basement rock, and consequently not detectable.
- Gravity successfully imaged the overburden-basement contact and the basalt-basement contact. However, because the density contrast between the basalt and the basement rock is less than between the overburden and the basement rock, the model for the basalt-basement contact has more uncertainty than the model for the overburden-basement contact.

The geophysical methods selected as the most appropriate to investigate the West Plains area include gravity, seismic reflection, TEM, and ERI. Because the depth of interest along Lines 1-3 is greater than the practical limit of seismic refraction, this method was not evaluated during the orientation survey. Because the TEM results from the Pilot Test were inconclusive, this method was evaluated as part of the evaluation survey.

### **3.1 Seismic Reflection**

Seismic reflection is the method commonly used to map stratigraphic or geologic contacts that are greater than 100 feet below the ground surface. This method uses a seismic energy source to create a seismic or acoustic wave, which travels through the subsurface. At interfaces that have an acoustic impedance contrast (related to velocity and density), a portion of acoustic energy is reflected back to the ground surface, and a portion is transmitted through the interface to be reflected at the next interface or contact. Geophones on the ground surface detect the reflected arrivals which are then recorded on a seismograph and eventually processed to produce a model of the subsurface geology or stratigraphy.

#### **3.1.1 Seismic Reflection Survey Design**

Seismic reflection data were collected with a 96-channel Geometrics GEODE seismic system. Geophones were spaced at 3 meter intervals. A 16-lb sledge hammer and a PEG-40 elastic weight drop were used as the seismic sources. Shot points were recorded every two geophone intervals along the line.

### **3.2 Electrical Resistivity Imaging (ERI)**

Electrical resistivity imaging is used to map changes in subsurface soil conductivity or resistivity. The resistivity values are used to interpret geologic features such as lithology, structure, fractures, and geology.

In an electrical resistivity imaging survey, a direct current is injected into the ground through electrodes. Because of soil resistance the current produces a voltage, and the resulting voltage drop is measured across a pair of potential electrodes. There are several electrode configurations commonly used to map geologic features. The dipole-dipole array is used most commonly to map lateral changes, but is also effective when mapping vertical changes in resistivity. The measurement of the current from the energy source and the voltage across potential electrodes are used to compute electrical resistance. The electrical resistance is multiplied by a geometric factor, associated with the particular electrode configuration, to derive apparent resistivity values that represent bulk average resistivities for the volume of earth being sampled. Representative resistivity values for various geologic layers are interpreted from the apparent resistivity values. The resistance of the alluvium

and/or soil is expected to be considerable greater than basalt, particularly if the basalt is fractured and has weathered to clay.

### 3.2.1 Electrical Resistivity Imaging Survey Design

Electrical resistivity data were collected with a 96-channel IRIS Syscal PRO system using a dipole-dipole electrode configuration with an electrode spacing of approximately 20 feet.

## 3.3 Gravity

Gravity is a method that measures small spatial differences in the gravitational pull of the Earth and is commonly used to map the depth and topography of basement rock. The method involves measurement of the gravitational attraction exerted by the earth at a measurement station on the surface. If the bedrock and overburden have different densities the gravity will change over a bedrock topographic feature. The instrument does not measure the absolute value of gravity, but the spatial differences in gravity i.e. lateral density changes in the subsurface cause a change in the value of gravity at the surface. The anomalous gravitational field over a bedrock structure (depression or mound) depends on the amplitude of the depression, its width and depth, and the density contrast between the overburden and the bedrock. Significant bedrock topography with large density contrasts will produce large gravitational anomalies. Conversely, small amplitude structures at depth, even with large density contrasts, may only produce relatively small anomalies.

Gravity data were collected using a LaCoste and Romberg gravimeter using a station spacing of 50 feet. Each station consisted of two consecutive measurements to ensure repeatability.

### 3.3.1 Gravity Survey Design

At the start of each day, a measurement was recorded at the gravity base station located at the downtown Spokane Post Office. The field crew then drove to the survey line and established a local base station. They then recorded gravity data along the line at stations spaced 50 feet apart. After approximately 50 measurements, or three hours, gravity measurements were obtained once again at the local base station. After the last measurement of the local base station, the field crew returned to the gravity base station to record the final measurement of the day. The latitude, longitude and elevation of each gravity station were recorded using a Trimble R7 Real Time Kinematic GPS.

## 3.4 Transient Electromagnetics

Transient electromagnetic surveying (TEM) is used to measure vertical changes in subsurface electrical properties by recording the decay rate of an induced electromagnetic signal as it propagates through the earth. Changes in the decay rate are used to model the electrical properties of the subsurface. This model is then used to infer the subsurface soil conditions and stratigraphy.

TEM surveying requires a transmitter, square loop transmitter coil, a receiving unit and receiver coil. The transmitter sends an electrical current through the transmitter coil, which is turned off after a very brief time producing an EM field. This EM field induces eddy currents in the ground, which in turn, produce a secondary magnetic field. As the eddy currents propagate downward and away from the transmitter coil, the secondary magnetic field loses strength (decays) at a rate proportional to the electrical conductivity of the subsurface. A receiver measures the decaying secondary magnetic field at different points in time (record length). One sequence of secondary magnetic field measurements at a particular location is called a sounding. In a homogenous earth, the secondary magnetic field will

decay at a predictable rate. Deviations from this decay rate correspond to changes in subsurface electrical properties. The TEM method takes advantage of these properties by correlating both the magnetic field strength and measurement time with changes in the electrical properties of the subsurface.

During the TEM sounding, the transmitter and receiver are synchronized via a reference cable. The receiver instructs the transmitter to turn on and off at predetermined measurement intervals (time gates), and then measures the strength of the decaying secondary magnetic field at up to 30 time gates during the transmitter off period. The signal is enhanced by taking multiple sets of readings and averaging them during a user-determined measurement period (from 2 to 64 seconds in length). The total number of measurements available for averaging per measurement period is determined by the repetition frequency, with higher frequencies giving a larger sample set at the expense of a shorter record length.

The depth of penetration of the TEM signal depends on the subsurface electrical properties, current strength and the area (size) of the transmitter antenna. For a given antenna size and current, a greater depth of investigation is achieved in areas underlain by relatively resistive material. A larger antenna size and larger transmitter current are required to investigate to greater depths. Transient Electromagnetics Survey Design

#### 3.4.1 Transient Electromagnetics Survey Design

TEM soundings were collected using a Zonge TEM system with a 300-foot square loop transmit coil and TEM/3 receiver. The presence of cultural features such as roads, driveways, fencing, pipelines, and power lines restricted the use of TEM to areas of open agricultural fields. TEM soundings were acquired at stations nominally spaced at 500 feet.

## 4.0 FIELD TRIAL RESULTS

Electrical resistivity imaging, gravity, transient electromagnetics, seismic reflection and seismic refraction methods were primary choices for the varying geologic and land use conditions present across the West Plains area. Because the depth to basement rock is known to range between approximately 300 feet and 1,300 feet below the ground surface, methods such as electrical resistivity and seismic refraction which are best suited for mapping at shallow target were given a lower priority than methods such as gravity, transient electromagnetics, and seismic reflection which are well suited for mapping targets to depths greater than 1,000 feet. Electrical resistivity imaging was chosen over seismic refraction because it was the only direct-current resistivity method listed as a primary choice.

The geophysical results for the test study are presented in Appendix B. In general, electrical resistivity and transient electromagnetics proved to be of limited use for mapping the basalt-basement contact. The gravity and seismic methods appeared to be appropriate for the full range of land uses and to achieve the expected depths to basement rock in West Plains.

Gravity surveys are less expensive than seismic reflection surveys. Seismic reflection surveys require long lines that often cross property boundaries, requiring access agreements. However, gravity data is collected at stations typically on 50 to 100 foot intervals. Often these measurements are obtained along county roads with minimal impact to property owners.

### 4.1 Line 1: Craig Road and Highway 902 towards Hayford Road

Line 1 is located in an open agricultural field where there was very little cultural interference. The geophysical data was collected and evaluated with respect to the following criteria.

1. The depth to basement rock on the west end of the line, 1,300 feet, is believed to be near the maximum known depth on the West Plains. This line was selected to help determine the most suitable methods for mapping a relatively deep basalt-basement contact.
2. There has been some question as to whether or not granite boulders on the east end of the line are an outcrop of basement rock or glacial erratic. This line was selected to help answer this question.

#### 4.1.1 Electrical Resistivity Imaging

ERI data acquisition was designed to address the second criteria - Is the outcrop shallow granite basement exposure or an erratic float? The ERI model for Line 1 is shown in Figure B-1. A 19.7 foot (6 meter) electrode spacing was used to provide high-resolution mapping of the shallow electrical properties. The depth of penetration was approximately 130 feet (40 meters), significantly shallower than the depth to granite at the western end of the line. A dipole-dipole array was used to map lateral variations in the shallow subsurface, e.g., a transition from basalt to granite as the line approached the area thought to be a granite exposure.

Electrical resistivity values ranged from 20 to 2,035 ohm-meters. These values are consistent with the clay and basalt described in lithologic log for the Delegans well located on the west end of the line. There are no apparent high resistivity zones in the model for Line 1 that would suggest the presence of massive granite basement rock. This supports the concept that the granite present on the east end is an erratic and not an exposure of basement rock. Drilling results confirmed the ERI interpretation that no granite is present in the upper 450 feet (137 meters) at the east end of the line.

#### 4.1.2 Gravity

Gravity data acquisition was designed to address the first criteria, .i.e. mapping the depth to the top of the granite. The gravity model for Line 1 is shown in Figure B-2. The blue dots represent observed values of gravity. The red dashed line represents the expected values that would be recorded for the geologic model presented in the lower panel. The close fit between the observed values and the expected values suggests that the geologic model in the lower panel represents the geologic conditions in the field.

Regional gravity trends, mapped west and east of the line by others, were incorporated into the model to help constrain the interpretation on Line 2. Gravity measurements were recorded between 0 and approximately 5100 feet (1550 meters) along the line, but the model incorporates the influence of regional gravity values to help ensure a model consistent with regional geology. The residual gravity anomaly ranges from -1 to -6 milligals. Gravity values for station between 0 and 1,890 feet (0 and 575 meters) fit poorly to the model values whereas values from stations between 1890 and 5,085 feet (575 and 1550 meters) show a tight fit to the modeled gravity values. Adjusting the thickness of the interpreted wedge of sediment doesn't change the goodness of fit between the observed and modeled gravity values between 0 and 1890 feet (0 and 575 meters), but does negatively impact the goodness of fit for values between 1890 and 5,085 feet (575 and 1550 meters). This is an indication that the measured field data between 0 and 1,890 feet (0 and 575 meters) is likely poor quality data resulting in an incorrect geologic model.

Additionally, observed gravity values and the corresponding geologic model on the east end of the line support an interpretation that granite boulders present on the surface are glacial erratics rather than a basement rock outcrop.

#### 4.1.3 Transient Electromagnetics

TEM data acquisition was designed to address the first criteria, mapping the depth to the top of the granite. The TEM model for Line 1 is shown in Figure B-3. A 300-foot square transmitter loop was used with a TEM/3 receiver antenna to maximize the sounding depth. A station spacing of 500 feet was chosen to optimize horizontal resolution and rate of data acquisition.

Based on nearby well control the depth to bedrock as determined from the TEM did not agree with the expected depth to basement rock along Line 1. It is likely that TEM results are unreliable because of insufficient contrast between the electrical conductivity of the basalt and the basement rock.

#### 4.1.4 Seismic Reflection

The seismic reflection model for Line 1 is shown in Figure B-4. Seismic reflection data acquisition was designed to address the first criteria, mapping the depth to the top of the basement rock.

In general, the data along this line are of good quality. The top of basement rock is interpreted as the bottom of the sequence of continuous reflectors at a depth of almost 1,500 feet in the center of the section. Towards the east end of the line, at a distance of approximately 4,000 feet, the reflector interpreted as representing the top of basement rock rises steeply before leveling off at a depth of approximately 750 feet below the ground surface.

In summary, the seismic reflection data has proven viable to map the top of basement rock at depths greater than 1,300 feet. The seismic reflection section also confirmed that the exposure of granite boulders are apparently glacial erratic.

## 4.2 Line 2 - Ventura Road

Two land uses common to the West Plains area were encountered along Line 2, open agricultural fields and rural residential development. There was very little cultural interference present along the southern half of the line in the agricultural field while there was considerable interference on the northern half of the line near the residential development. Geophysical data was collected and evaluated with respect to the following criteria.

1. The depth to basement rock was expected to be relatively shallow, less than approximately 300 feet. This line was selected to help determine suitable methods for mapping a relatively shallow contact.
2. There was a combination of agricultural field and rural residential development and this line was selected to help evaluate methods with regards to the effect of land use issues on geophysical methods.

### 4.2.1 Electrical Resistivity Imaging (ERI)

ERI data acquisition was designed to address a shallow granite contact and varying land use conditions. The ERI model for Line 2 is shown in Figure B-5. A 20 foot (6-meter) electrode spacing was used to provide high-resolution mapping of the shallow electrical properties. The depth of penetration was approximately 150 feet (50 meters), was substantially deeper than the reported 90 feet (27 meters) to top of granite reported in the Harding well. A dipole-dipole array was used to map lateral variations in the shallow subsurface, e.g., a transition from basalt to granite as the line approached the area thought to be a basement exposure.

Electrical resistivity values on Line 2 ranged from 20 to 5,550 ohm-meters. These values are consistent with the rock described in lithologic logs for the Audett, Harding, and Stevens wells located on the north end of the line. Resistivity values for granite can be as low as 450 ohm-meters, consistent with the values mapped at the depth granite is known to exist on the north segment of the line. However, on the south segment of the line, resistivity values of 450 ohm-meters are mapped above the zone of resistivity values interpreted to be basalt, indicating the material is not basement rock (which would occur below the basalt). This relatively low resistivity zone is likely clay-rich sediment. On this line the ERI results suggest that there is too much ambiguity in electrical resistivity values to use this method to reliably map the depth and topography of the top of basement rock.

### 4.2.2 Gravity

Gravity data acquisition was designed to address both criteria, mapping the depth to the top of the granite, and mapping in areas with varied land use. The gravity model for Line 2 is shown in Figure B-6. The blue dots represent observed values of gravity. The red dashed line represents the expected values that would be recorded for the geologic model presented in the lower panel. A close fit between the observed values and the expected values indicates the geologic model in the lower panel is likely to accurately reflect geologic conditions in the field.

Gravity measurements were recorded between 0 and 4,430 feet (0 and 1350 meters) along the line. The residual gravity anomaly ranges from 0.2 to -0.5 milligals. Gravity values for the entire 4,430 feet (1350 meters) show a relatively close fit to the modeled gravity values. This indicates the gravity method is a suitable method to map the depth and topography of the basement surface in areas ranging from agricultural to rural residential land use.

#### 4.2.3 Transient Electromagnetics

TEM data acquisition was designed to address the first criteria, mapping the depth to the top of the basement rock. The TEM model for Line 2 is shown in Figure B-7. A 300-foot square transmitter loop was used with a TEM/3 receiver antenna to maximize the sounding depth. A station spacing of 500 feet was chosen to optimize horizontal resolution and rate of data acquisition.

Based on nearby well control the TEM results match poorly with the expected depth to basement rock along Line 2. It is likely that there is insufficient contrast between the electrical conductivity of the basalt and that of the basement rock to clearly detect the contact..

#### 4.2.4 Seismic Reflection

The seismic reflection model for Line 2 is shown in Figure B-8. Seismic reflection data acquisition was designed to address the first criteria, mapping the depth to the top of the granite. A station spacing of 10 feet was chosen to optimize horizontal resolution and rate of data acquisition.

In general, the data along this line are of good quality. The top of basement rock is interpreted as the bottom of the sequence of continuous reflectors located in the upper 500 feet of the subsurface. At a distance of 3,200 feet along Line 2, the Harding wells provide excellent calibration for the seismic reflection interpretation. The interpreted depth to the top of the basement rock corresponds well to the known depth to granite observed in the nearby wells. As such, seismic reflection is an appropriate method to map the top of the basement rock in locations where the basalt – basement contact is shallow, in areas of agricultural farm fields and rural residential development along county roads.

### 4.3 **Line 3 - Craig Road (Highway 902 to Four Lakes)**

Geophysics was conducted at this location to attempt to map the top of the basement rock from the Four Lakes well (468689) north to White Road where it is expected to be 1,000 feet below the ground surface.

#### 4.3.1 Electrical Resistivity Imaging

ERI data acquisition was designed to help determine if the top of basement rock became shallower than 285 feet north of the Four Lakes well. The ERI model for Line 3 is shown in Figure B-3. A dipole-dipole electrode array with a 19.7 foot (6 meter) electrode spacing was used to provide high-resolution mapping of the shallow electrical properties. The depth of penetration is approximately 180 feet (55 meters), significantly shallower than the known depth to basement rock.

Electrical resistivity values range from 100 to 9,100 ohm-meters. These values are consistent with expected values for the clay and basalt described in lithologic log for the Four Lakes well located on

the north end of the line. There are no resistivity values that are interpreted as representing basement rocks.

#### 4.3.2 Gravity

Gravity data was collected to help determine if gravity is a suitable method to map the depth and topography of the top of the basement when this surface is greater than 1,000 feet below the ground surface. The gravity model for Line 3 is shown in Figure B-11. The blue dots represent observed values of gravity. The red dashed line represents the expected values that would be recorded for the geologic model presented in the lower panel. A close fit between the observed values and the expected values indicates the geologic model in the lower panel is likely to accurately represent geologic conditions in the field.

Regional gravity trends south and north of the line are incorporated into the model to help constrain the interpretation on Line 3. Gravity measurements, recorded between 0 and 5,825 feet (0 and 1775 meters), but the model incorporates the influence of regional gravity values to help ensure a model consistent with regional geology. The residual gravity values range from 0.1 to -1.2 milligals. Generally, gravity values for the entire line showed reasonable fit to the modeled gravity values indicating the gravity method is suitable to map the basalt-granite contact at depths greater than 1,000 feet below the ground surface.

#### 4.3.3 Transient Electromagnetics

TEM data acquisition was designed to address the first criteria, mapping the depth to the top of the granite. The TEM model for Line 3 is shown in Figure B-11. A 300-foot square transmitter loop was used with a TEM/3 receiver antenna to maximize the sounding depth. A station spacing of 500 feet was chosen to optimize horizontal resolution and rate of data acquisition.

Based on nearby well control the TEM results did not match with the expected depth to basement rock. It is likely that there is insufficient contrast between the electrical conductivity of the basalt and that of the basement rock to detect the contact.

#### 4.3.4 Seismic Reflection

The seismic reflection model for Line 3 is shown in Figure B-12. Seismic reflection data acquisition was designed to address the first criteria, mapping the depth to the top of the granite. A station spacing of 10 feet was chosen to optimize horizontal resolution and rate of data acquisition.

In general, data along Line 3 are of good quality and shallow reflections are distinct and continuous across much of the section. The top of basement rock is interpreted as the bottom of the package of continuous reflectors to a depth of almost 1,400 feet in the center of the section. At the south end of the line, the top of granite is mapped at a depth of 300 feet. Near the center of the line, at a distance of 3,100 feet, the basalt-granite contact is interpreted at a depth of 1,375 feet. These results indicate that seismic reflection has proven feasible for use in areas where the top of basement rock is between 500 and 1,000 feet below the ground surface.



## **5.0 MONITORING WELL INSTALLATION**

From June 25-30, 2009, H2O Well Services, Inc. drilled two boreholes to augment the geophysical program. A 6-inch diameter borehole was drilled at a distance of 4,950 feet along Line 1 using an air-rotary rig. A second borehole was drilled at a distance of 5,050 feet along Line 1 with an offset of approximately 175 feet to the north. These locations were determined in consultation with the County.

The first borehole was drilled to help calibrate geophysical results along Line 1. This borehole, drilled to a depth of 450 feet, encountered only basalt, with a small zone of clay between 280 and 300 feet. Water was first encountered at a depth of 260 feet with some perched groundwater at a depth of 12 feet. However, on June 30, 2009 the depth to water was reported to be at 198 feet bgs.

The second borehole was drilled to help determine if the granite boulders found on the ground surface represent a basement exposure or glacial erratic. This borehole was drilled to a depth of 50 feet and encountered only basalt. This verifies the geophysical results that the granite is not an exposure of basement rocks.

### **5.1 Objectives of the Monitoring Well**

The objectives of the monitoring well are as follows:

1. Provide information to support interpretation of the geophysical data.
2. Provide information on the nature and depth of geologic units down to the crystalline basement.
3. Provide a location to obtain groundwater level monitoring data.
4. Help determine if granite boulders on the ground surface at the east end of Line 1 represent a local granitic basement high or are glacial erratic.

The first borehole was converted to a monitoring well by installing 2-inch PVC casing. The well was installed in the borehole with 60 feet of 10-slot screen placed between 250 and 310 feet below the ground surface. Figure C-1 shows the schematic of the monitoring well installed along Line 1.

## **6.0 FEASIBILITY OF GEOPHYSICAL METHODS**

Based on the result of this geophysical investigation the seismic reflection and gravity methods have shown to be the best suited for mapping the depth and topography of the top of the basement rocks when in contact with overlying basalt. The gravity method also successfully mapped the overburden-basement contact where it occurs at a relatively shallow depth. However, seismic reflection offers better vertical resolution than the gravity method.

The accuracy of the results from the seismic processing and subsequent interpretation is dependent on an accurate seismic velocity profile. With good velocity profile data the interpreted depths can often be less than 5 percent of the true depth. Vertical seismic profile data can be collected in borehole to the velocity profile.

The accuracy of the gravity model is dependent on an accurate profile of density values with depth. This data is difficult to obtain, particularly when there are no rock samples available for density testing. Alternating layers of clay and basalt produce varying bulk density values used in modeling, especially in areas with little borehole control. The vertical accuracy of gravity models often ranges between 10 and 20 percent, but with reliable density values the accuracy can be less than 10 percent.

The TEM and ERI methods were not successful in detecting the overburden-basement rock contact. The electrical properties of the basalt and the basement rock are likely too similar to be detected with these methods.

The tables below compares the costs and the benefits for the two methods best suited for mapping the top of basement rock in the West Plains area. Gravity has the most widespread applicability for mapping the top of basement rock in the West Plains area. This method is less expensive and more versatile than seismic reflection, particularly with respect to data collection. Even a short (less than 500 feet long) seismic reflection profile will have an approximate minimum cost of \$8,500.00, whereas funding amounts as low as \$4,000.00 could provide the same coverage with gravity measurements.

**Table 4. Comparison of Acquisition Costs and Benefits of Seismic Reflection and Gravity.**

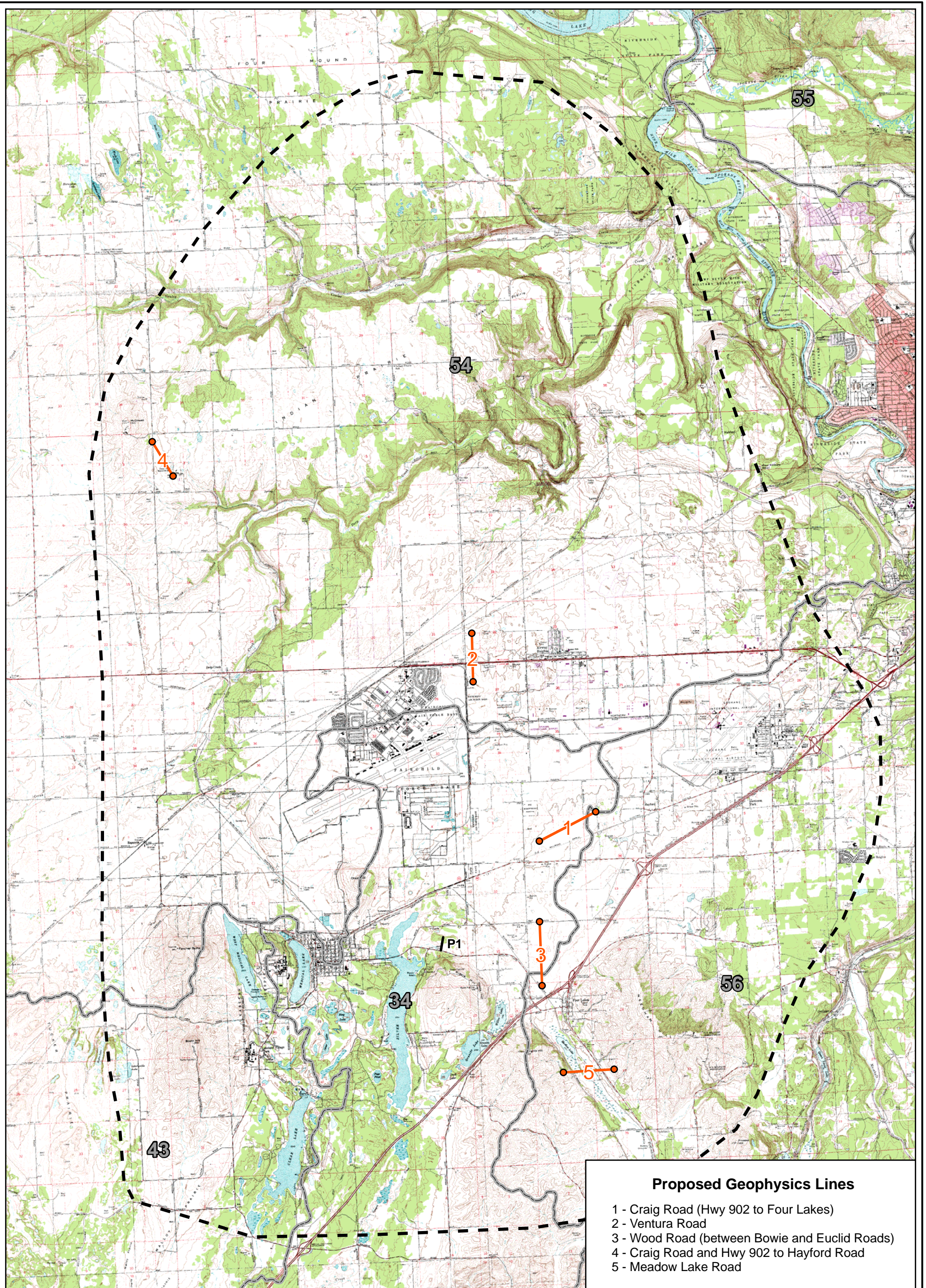
Method	Measurement Spacing	Unit	Cost per Unit of Coverage	Benefits
seismic reflection	10 foot geophone spacing	14,000 lineal feet	\$2.61 per lineal foot	<ul style="list-style-type: none"> <li>• Works well in open agricultural fields</li> <li>• Provides continuous coverage along long lines</li> <li>• Good vertical resolution</li> <li>• Velocity contrast is greater than the density contrast</li> <li>• May be able to map layers within the basalt that are important to the hydrogeologic model</li> <li>• Base of basalt has characteristic reflection signature</li> </ul>
gravity	50 foot station measurements	298 measurements	\$15.90 per gravity station \$0.31 per lineal foot	<ul style="list-style-type: none"> <li>• Works well in rural residential areas</li> <li>• Doesn't require long, continuous lines</li> <li>• Requires just 1 field geophysicist as opposed to a crew of 3 for seismic reflection</li> <li>• Logistically easier to collect field data</li> <li>• Data processing is a less complicated effort than processing reflection data</li> </ul>

## 7.0 REFERENCES

- Budinger & Associates, Inc., 2001, Results of seismic refraction survey, paleo-channel investigation, Airway Heights, WA: Report by Budinger & Associates, Inc., Spokane, Wash. for URS Consultants, Inc., Spokane, Wash., April 27, various pages.
- Covert, J., 2007. West Plains Aquifer System – Groundwater Resource Issues. Presentation at West Plains Informational Meeting in Cheney, WA. February 1, 2007.
- GeoEngineers, Inc., 2002, Report, Hydrogeologic Study, Pacific Northwest Technology Park, Spokane, Washington: Report by GeoEngineers, Inc., Spokane, Wash., for Vandervert Construction, Inc., Spokane, Wash, January 10, various pages.
- GeoEngineers, Inc., 2007, Report-Revision 2, Hydrogeologic Evaluation, Proposed Water Reclamation Plant, City of Airway Heights,” Airway Heights, Washington: Report by GeoEngineers, Inc., Spokane, Wash., for City of Airway Heights, Wash, September 26, various pages.
- Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies, Washington State Department of Ecology, Environmental Assessment Program, Publication No. 04-03-030, July 2004. Revision of Publication No. 1-03-003, February, 2001.
- McCollum, L., 2009. Verbal communication between Linda McCollum (Eastern Washington University) and Bryony Stasney (Golder). January 19, 2009.
- Standard Guide for Use of the Time Domain Electromagnetic Method for Subsurface Investigation, ASTM Designation: D6820-02, American Society for Testing and Materials, 2007.
- Standard Guide for Using the Gravity Method for Subsurface Investigation, ASTM Designation: D6430-99, American Society for Testing and Materials, 2005.
- Standard Guide for Using the Seismic-Reflection Method for Shallow Subsurface Investigation, ASTM Designation: D7128-05, American Society for Testing and Materials, 2005.
- TetraTech and GeoEngineers, 2007. Water Resource Inventory Area (WRIA) 54 Multi-Purpose Water Storage Assessment. October, 2007.

## **FIGURES**





- Proposed Geophysics Lines**
- 1 - Craig Road (Hwy 902 to Four Lakes)
  - 2 - Ventura Road
  - 3 - Wood Road (between Bowie and Euclid Roads)
  - 4 - Craig Road and Hwy 902 to Hayford Road
  - 5 - Meadow Lake Road

**LEGEND**

- Proposed Geophysics Line
- West Plains Study Area
- WRIA Boundary

0 1.5  
Scale in Miles

Map Projection:  
Washington State Plane  
North Zone NAD 1983

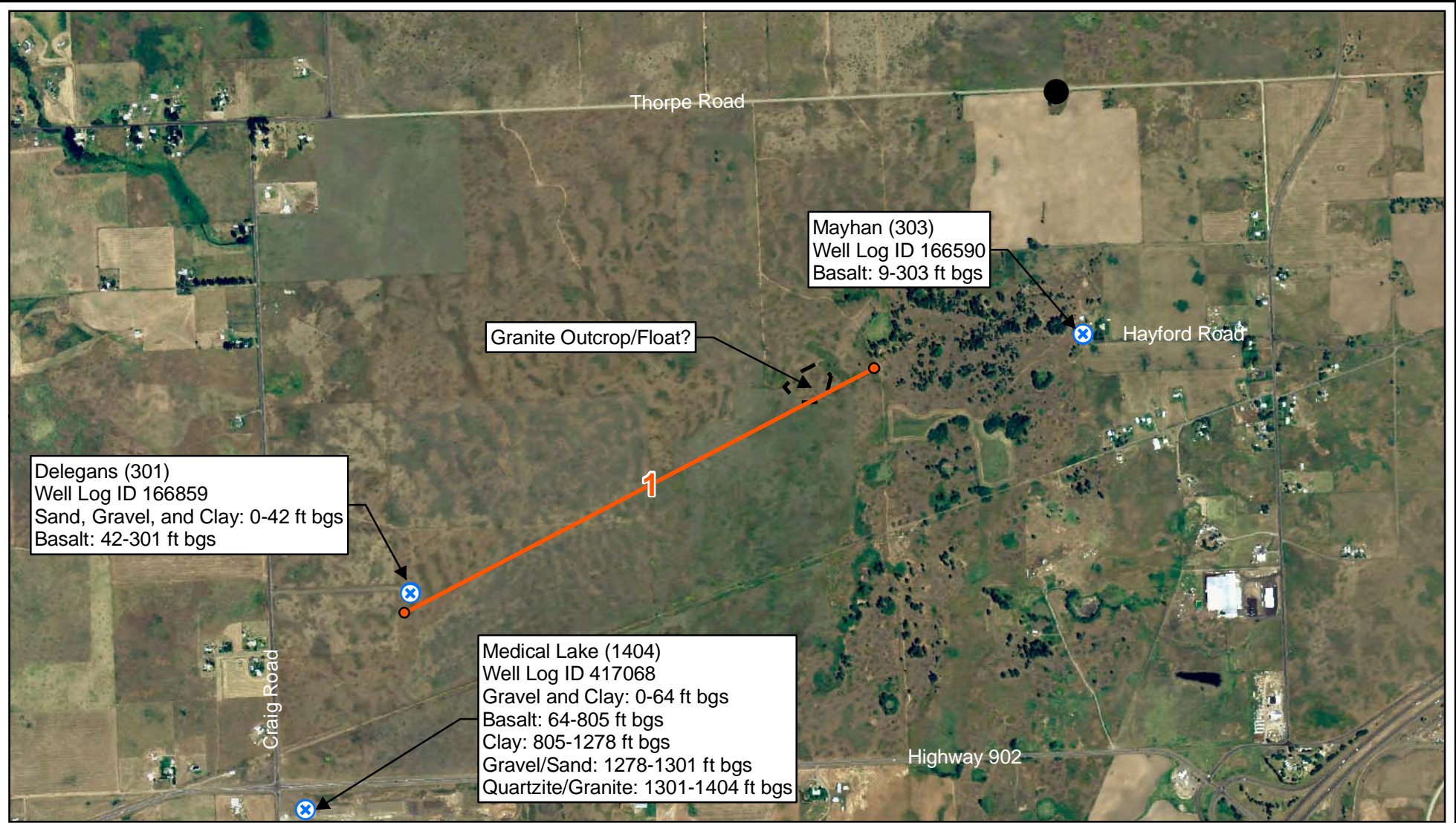
Source:  
USGS (24k quadrangle map mosaic),  
WA Dept. of Ecology (WRIA boundaries),  
Golder Associates Inc. (study area, geophysics lines)






This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

**FIGURE 1**  
**STUDY AREA**  
SC/WEST PLAINS GEOPHYS SURVEY/WA





**LEGEND**

-  Existing Well (well depth in feet)
-  Potential Monitoring Well Location
-  Proposed Geophysics Line

Note: Location of Mayhan well is approximate and based on information from WA Dept. of Ecology's online Well Log Viewer.



Map Projection:  
Washington State Plane  
North Zone NAD 1983

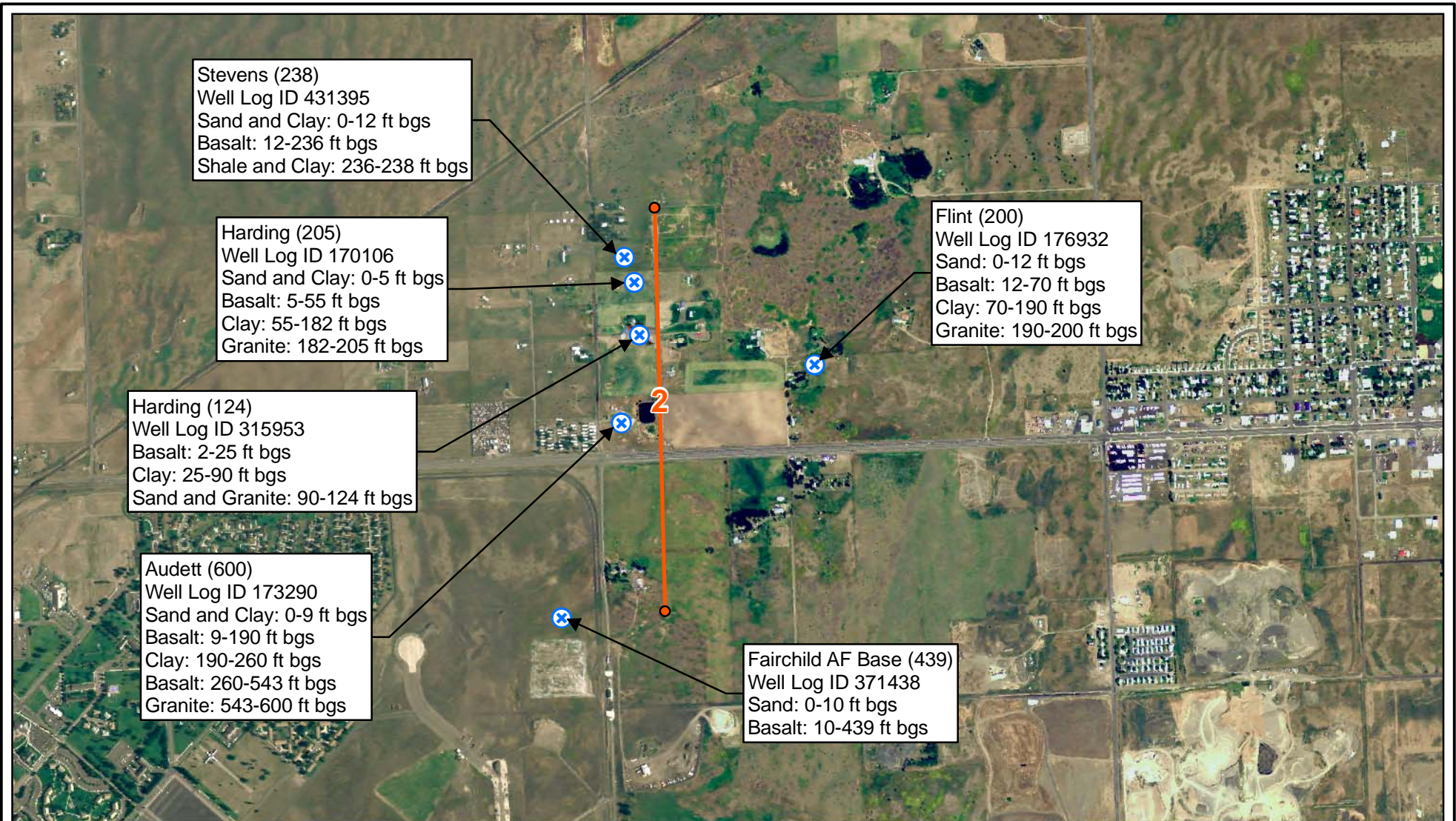
Source:  
WA Dept. of Ecology (wells),  
USDA (NAIP, 2m, 2005),  
Golder Associates Inc. (geophysics lines, monitoring well)



This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

**FIGURE 2**  
**LINE 1:**  
**CRAIG ROAD AND**  
**HWY 902 TO HAYFORD ROAD**  
SC/WEST PLAINS GEOPHYS SURVEY/WA





Stevens (238)  
Well Log ID 431395  
Sand and Clay: 0-12 ft bgs  
Basalt: 12-236 ft bgs  
Shale and Clay: 236-238 ft bgs

Harding (205)  
Well Log ID 170106  
Sand and Clay: 0-5 ft bgs  
Basalt: 5-55 ft bgs  
Clay: 55-182 ft bgs  
Granite: 182-205 ft bgs

Flint (200)  
Well Log ID 176932  
Sand: 0-12 ft bgs  
Basalt: 12-70 ft bgs  
Clay: 70-190 ft bgs  
Granite: 190-200 ft bgs

Harding (124)  
Well Log ID 315953  
Basalt: 2-25 ft bgs  
Clay: 25-90 ft bgs  
Sand and Granite: 90-124 ft bgs

Audett (600)  
Well Log ID 173290  
Sand and Clay: 0-9 ft bgs  
Basalt: 9-190 ft bgs  
Clay: 190-260 ft bgs  
Basalt: 260-543 ft bgs  
Granite: 543-600 ft bgs

Fairchild AF Base (439)  
Well Log ID 371438  
Sand: 0-10 ft bgs  
Basalt: 10-439 ft bgs

**LEGEND**

Existing Well (well depth in feet)

Proposed Geophysics Line

0 1500

Scale in Feet

Map Projection:  
Washington State Plane  
North Zone NAD 1983

Source:  
WA Dept. of Ecology (wells),  
USDA (NAIP, 2m, 2005),  
Golder Associates Inc. (geophysics lines)



This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

Note: Existing well locations are approximate and based on information from WA Dept. of Ecology's online Well Log Viewer.

**FIGURE 3**  
**LINE 2:**

**VENTURA ROAD**  
SC/WEST PLAINS GEOPHYS SURVEY/WA





**LEGEND**

- Existing Well (well depth in feet)
- Proposed Geophysics Line

Note: Location of Mayhan well is approximate and based on information from WA Dept. of Ecology's online Well Log Viewer.



Scale in Feet

Map Projection:

Washington State Plane

North Zone NAD 1983

Source:

WA Dept. of Ecology (Wells),

USDA (NAIP, 2m, 2005)

Golder Associates Inc. (geophysics lines)



This figure was originally produced in color. Reproduction in black and white may result in a loss of information.

**FIGURE 4**  
**LINE 3:**

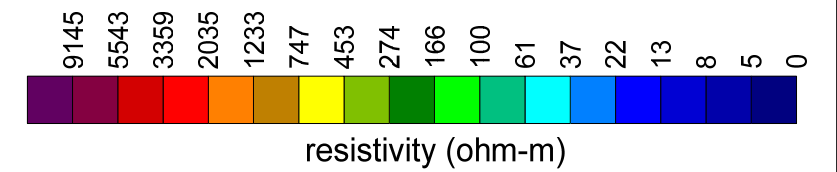
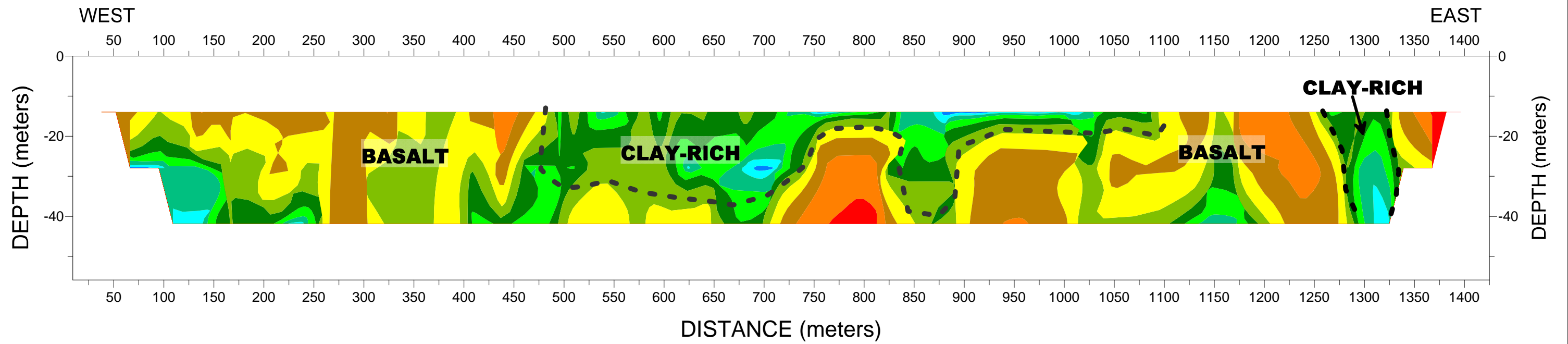
**CRAIG ROAD (HWY 902**  
**TO FOUR LAKES)**

SC/WEST PLAINS GEOPHYS SURVEY/WA

**Golder Associates**

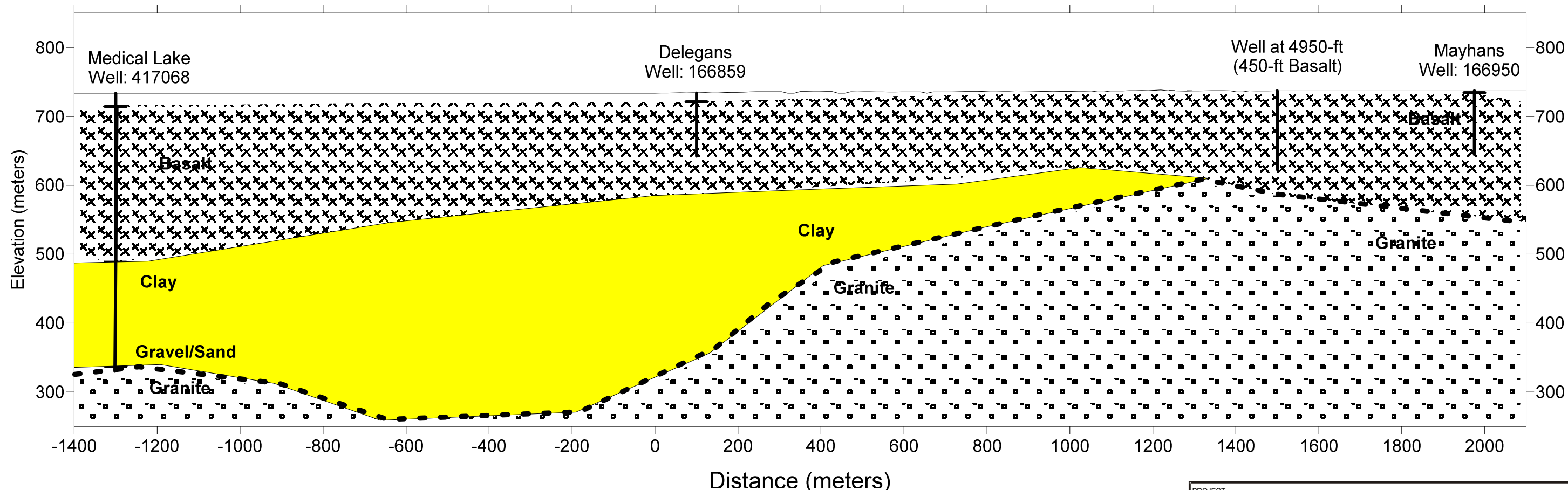
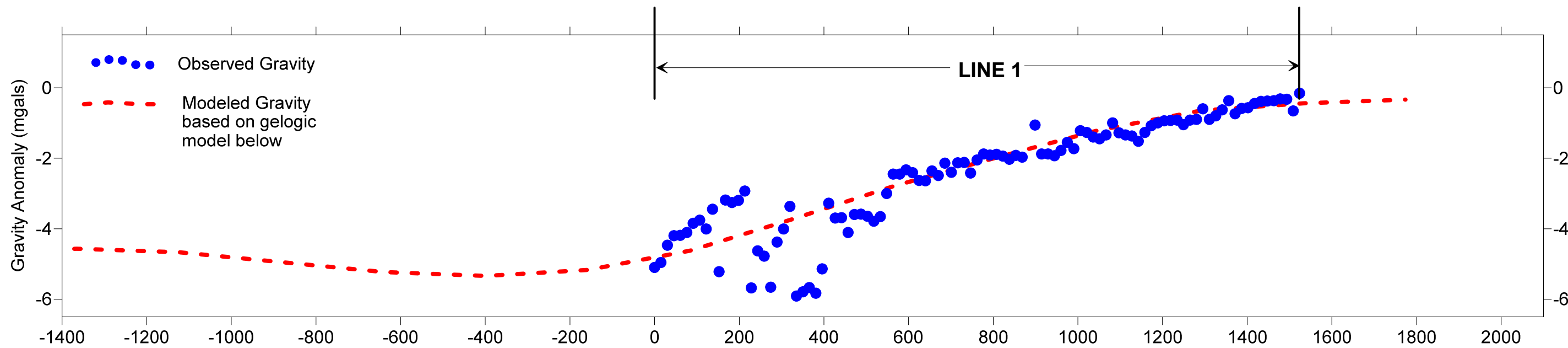
**APPENDIX A**

**WELL LOGS**



PROJECT					SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY				
TITLE					LINE 1 ELECTRICAL RESISTIVITY MODEL				
PROJECT No.			083-93096.400		FILE No.			---	
DESIGN	MB	JUNE 09		SCALE	AS SHOWN		REV.		
CADD	MB	JUNE 09		FIGURE B-1					
CHECK	DS	JUNE 09							
REVIEW	DS	JUNE 09							





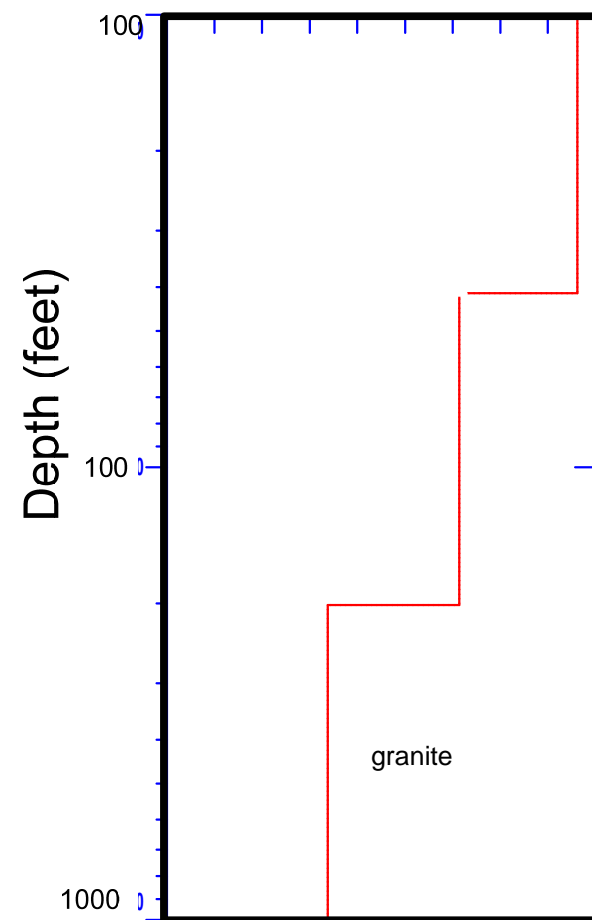
REVISION DATE: BY: SURFER FILE:

PROJECT		SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY		
TITLE		LINE 1 OBSERVED AND MODELED GRAVITY DATA		
PROJECT No.		083-93096.400	FILE No. ---	
DESIGN	MB	JUNE 09	SCALE	AS SHOWN
CADD	MB	JUNE 09	REV.	
CHECK	DS	JUNE 09	FIGURE B-2	
REVIEW	DS	JUNE 09		



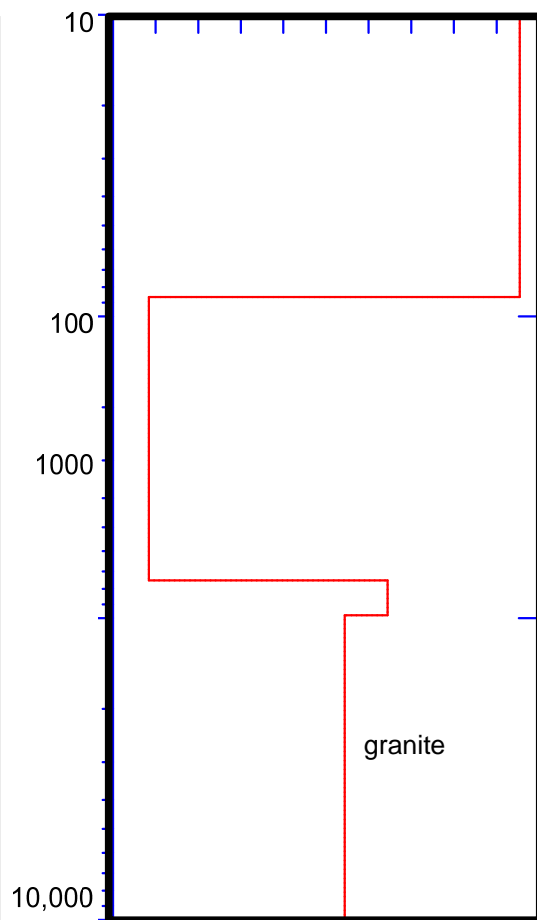


500 feet



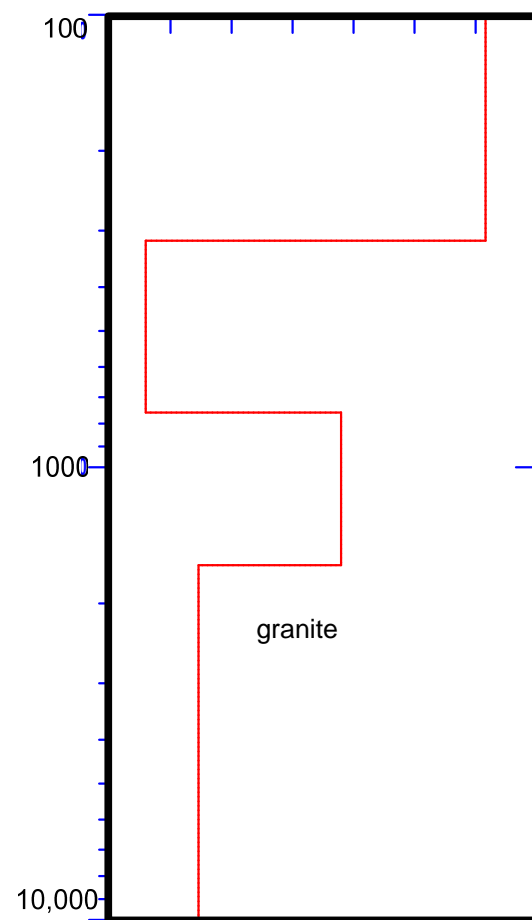
resistivity  
(ohm-m)

1000 feet



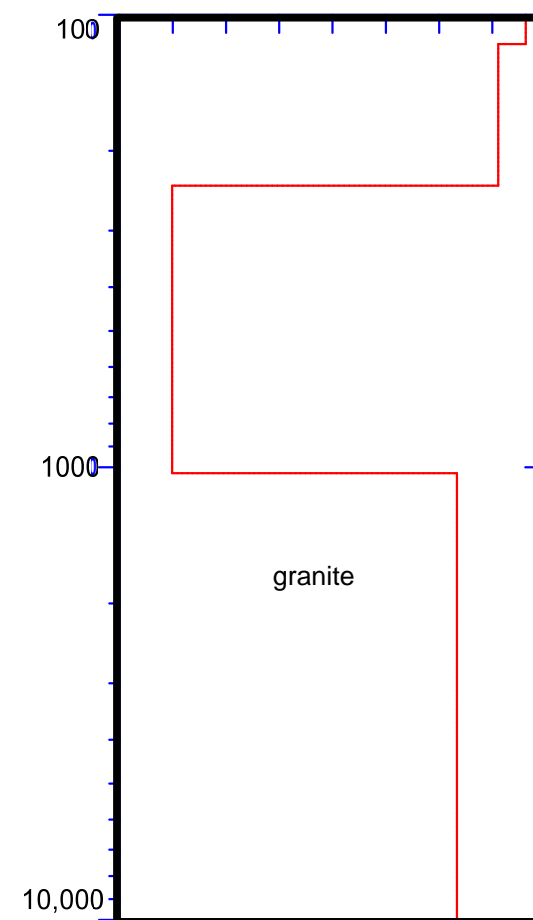
resistivity  
(ohm-m)

1500 feet



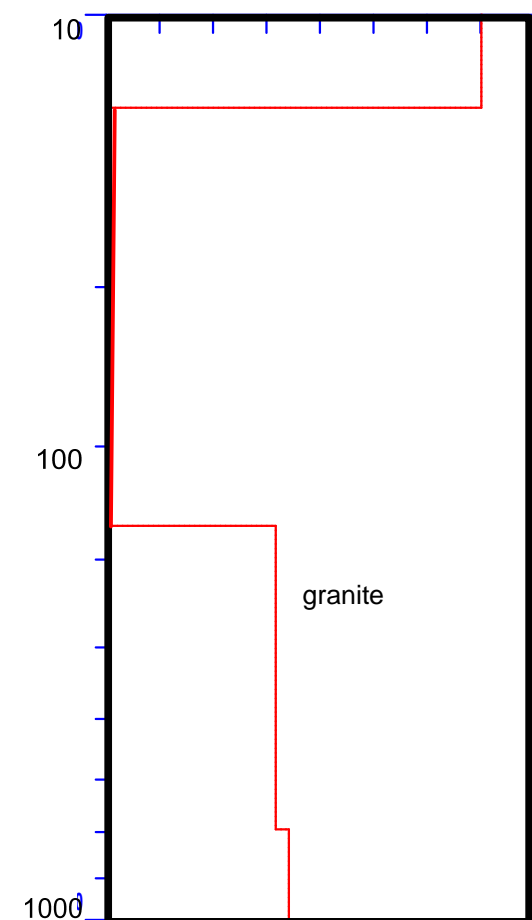
resistivity  
(ohm-m)

2500 feet



resistivity  
(ohm-m)

4000 feet

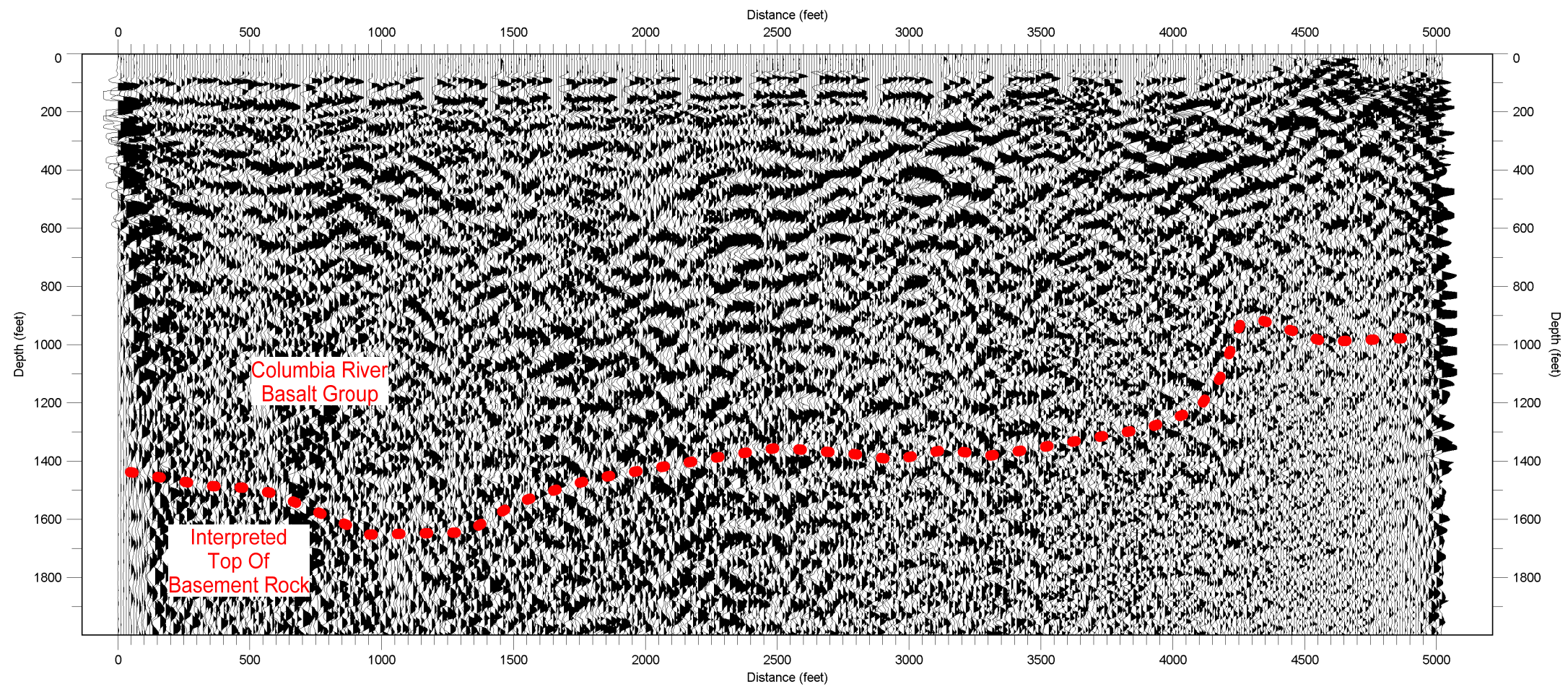


resistivity  
(ohm-m)

REVISION DATE: BY: SURFER FILE:

PROJECT					SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY				
TITLE					LINE 1 TEM MODELS				
PROJECT No.			083-93096.400		FILE No.			---	
DESIGN	MB	JUNE 09			SCALE	AS SHOWN		REV.	
CADD	MB	JUNE 09			FIGURE B-3				
CHECK	DS	JUNE 09							
REVIEW	DS	JUNE 09							




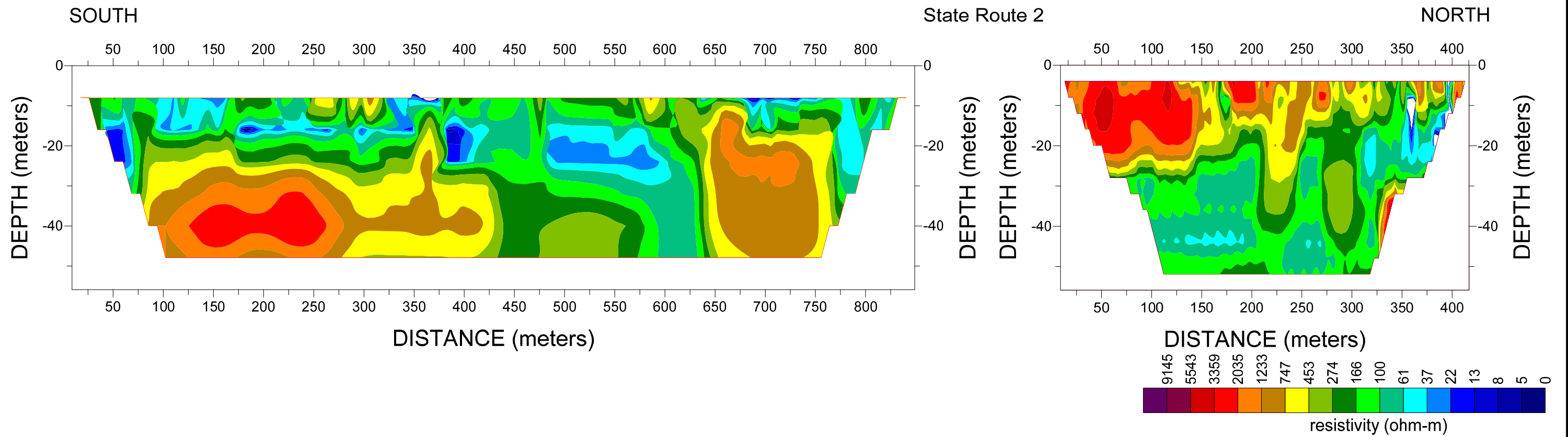


NOTES:

1. Geophysical survey performed May 13-21, 2009.
2. The primary objective of the seismic reflection survey was to determine if seismic reflection methods can detect the top of granitic bedrock.
3. Geometrics Inc. 96-channel GEODE seismic system was used to collect reflection data.
4. Data were processed using Seismic Processing Workshop software from Parallel Geosciences Inc.
5. See Figure 1 for line location.


REVISION DATE: BY: SURFER FILE:

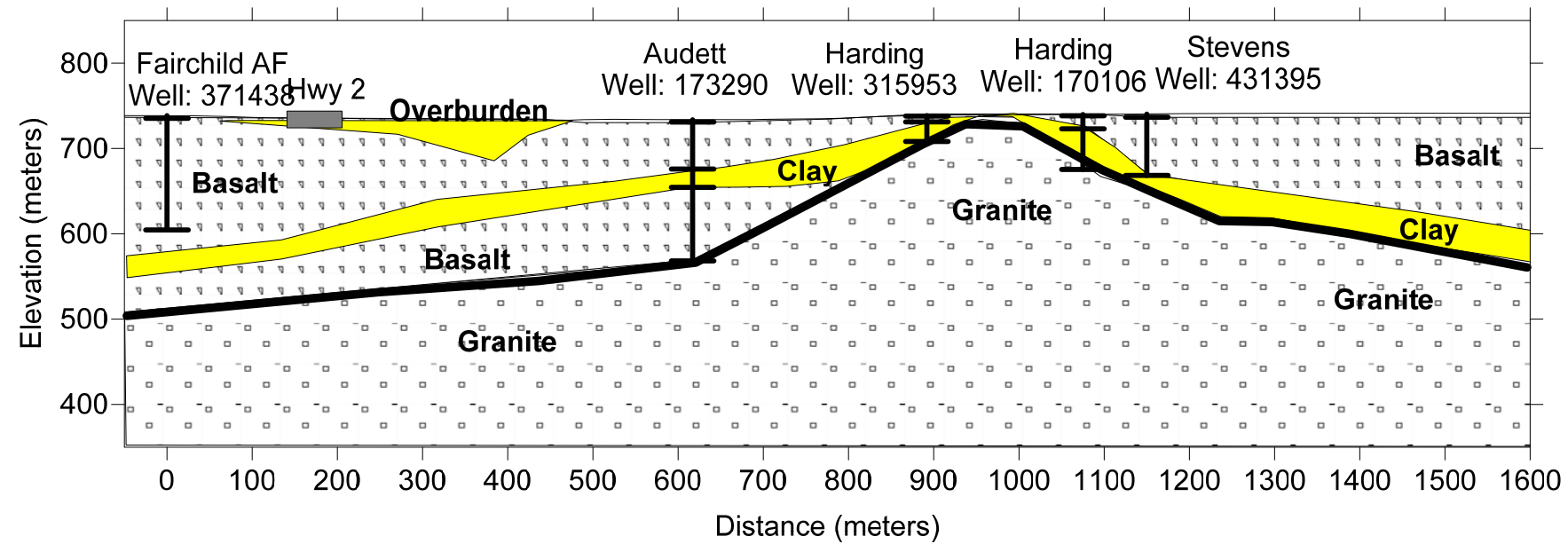
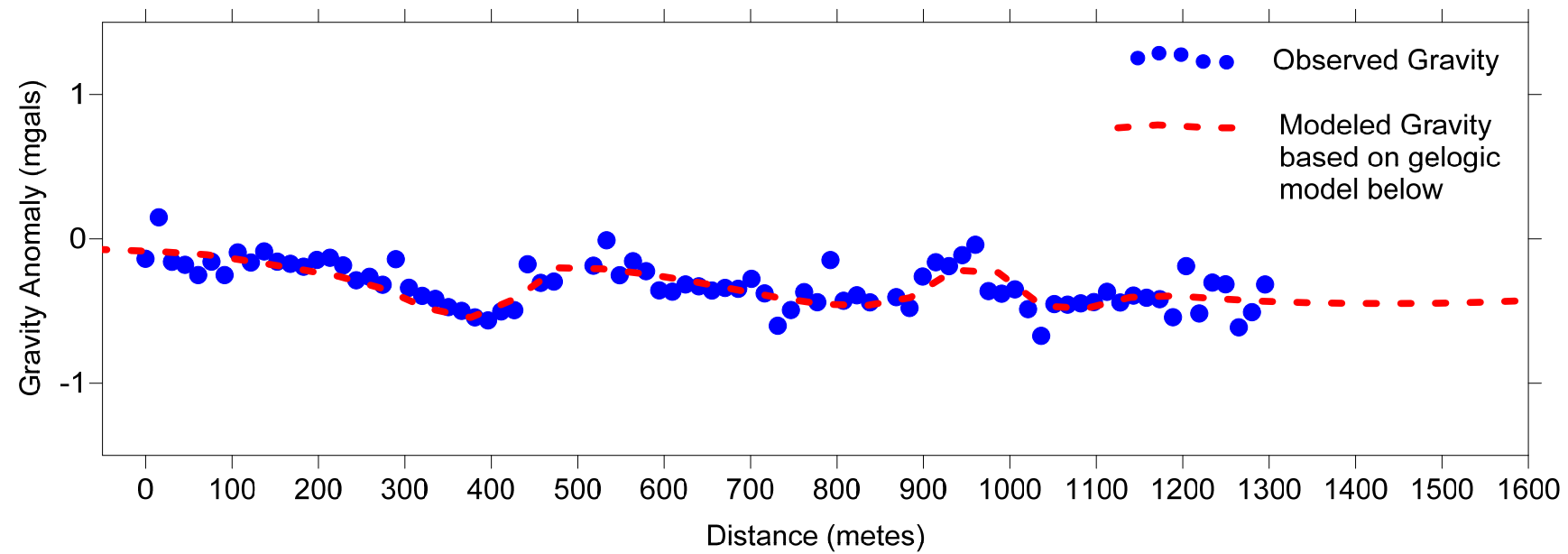
PROJECT		SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY			
TITLE		<b>LINE 1 SEISMIC REFLECTION</b>			
	PROJECT No.	083-93096.400		FILE No.	---
	DESIGN	MB	JUNE 09	SCALE	AS SHOWN
	CADD	MB	JUNE 09	REV.	
	CHECK	DS	JUNE 09	<b>FIGURE B-4</b>	
REVIEW	DS	JUNE 09			




PROJECT **SPOKANE COUNTY PUBLIC WORKS DEPARTMENT  
UTILITIES DIVISION, WATER RESOURCES PROGRAM  
WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY**

TITLE **LINE 2  
ELECTRICAL RESISTIVITY DATA**

	PROJECT No. 083-93096.400		FILE No. ---		
	DESIGN	MB	JUNE 09	SCALE AS SHOWN	REV.
	CADD	MB	JUNE 09	<b>FIGURE B-5</b>	
	CHECK	DS	JUNE 09		
REVIEW	DS	JUNE 09			

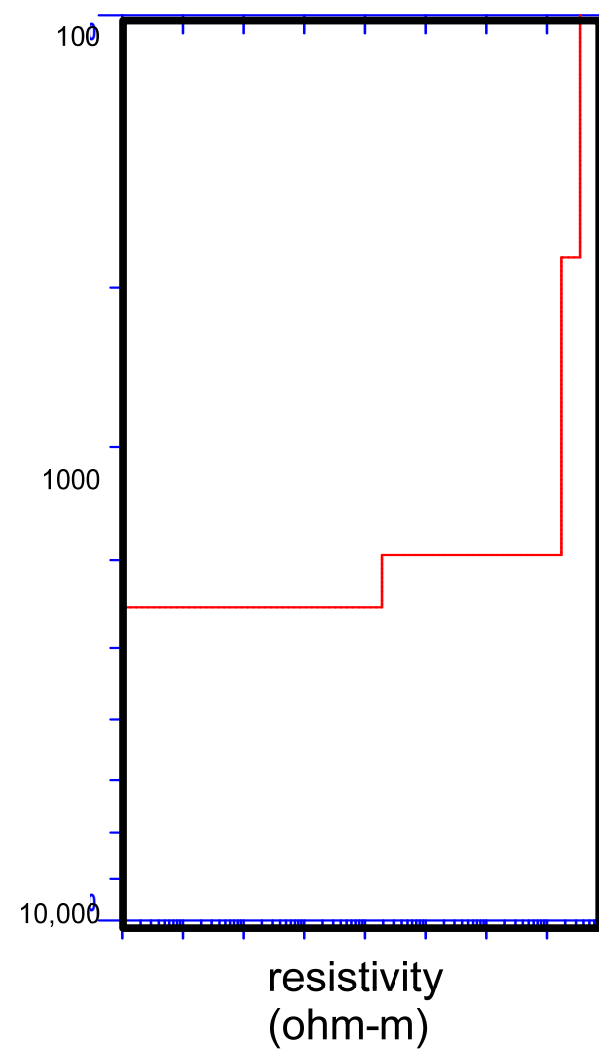
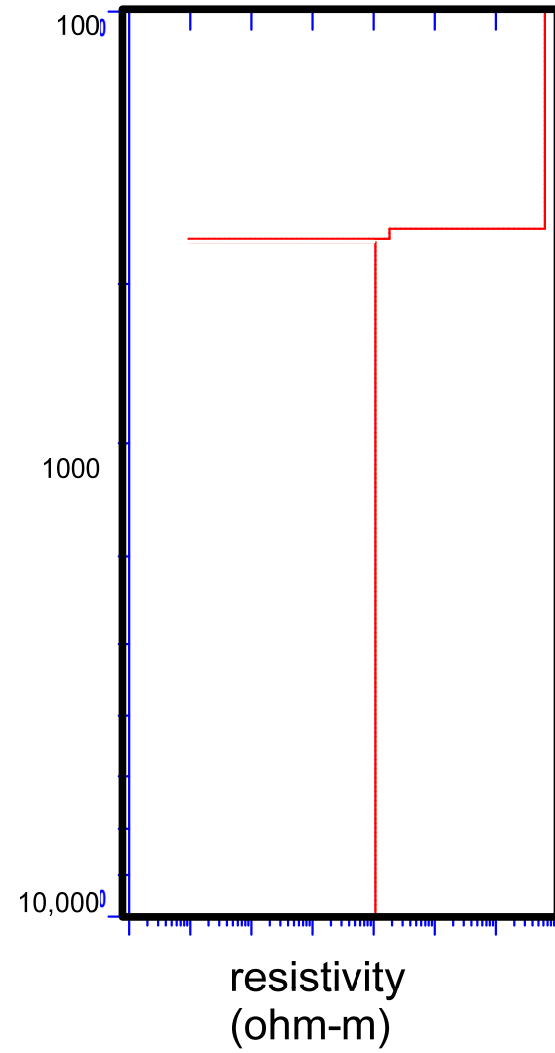
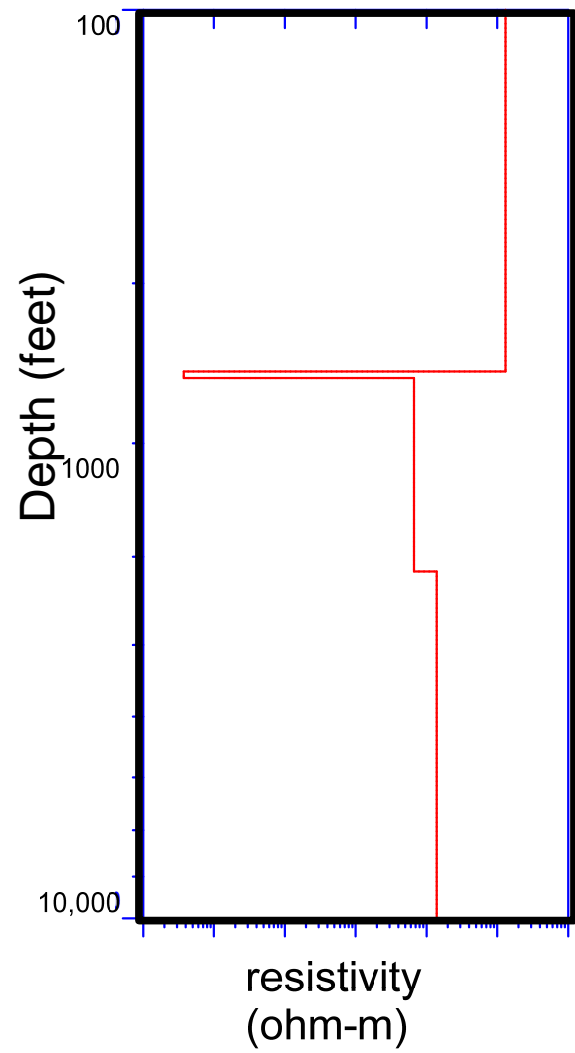



REVISION DATE: BY: SURFER FILE:

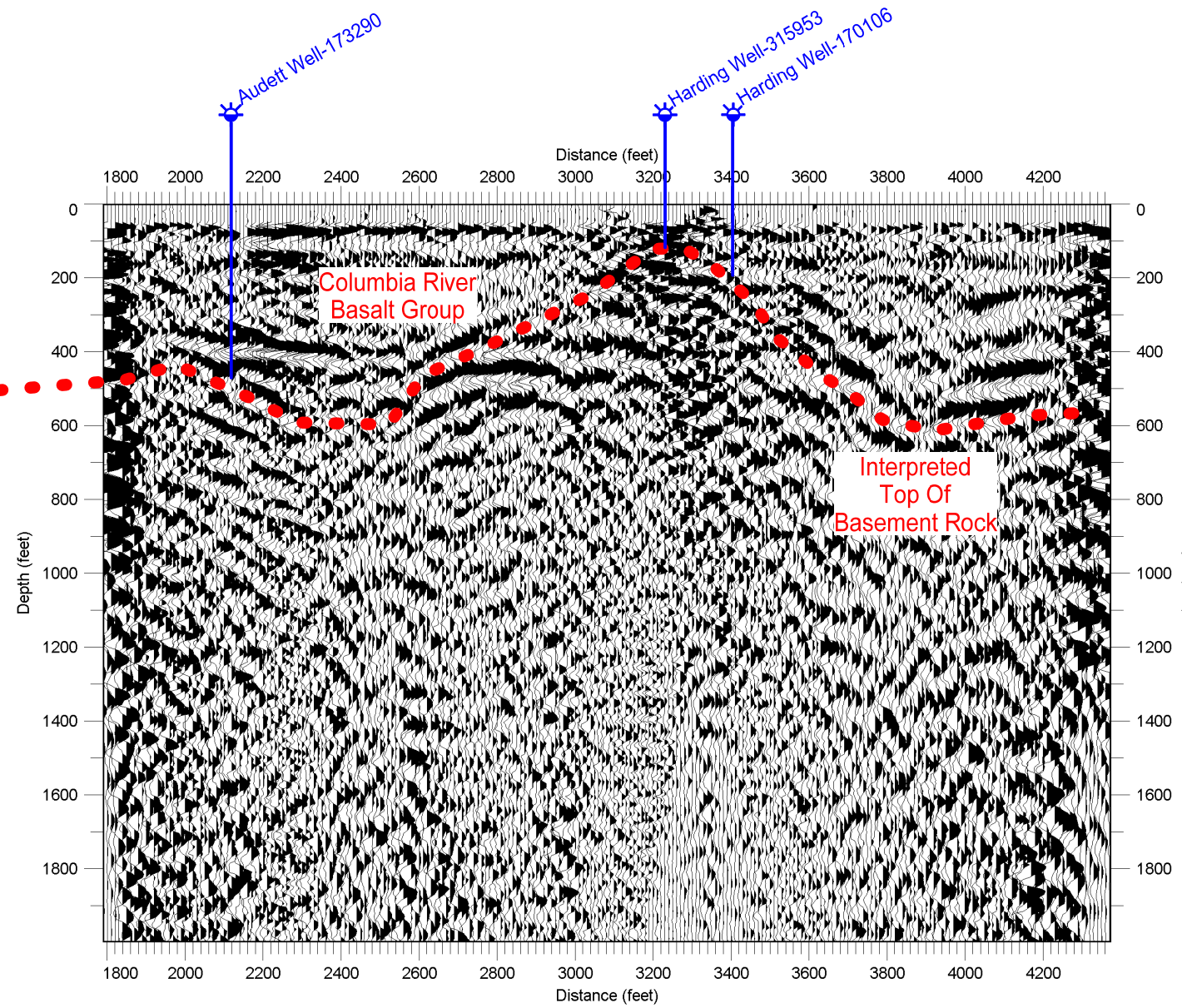
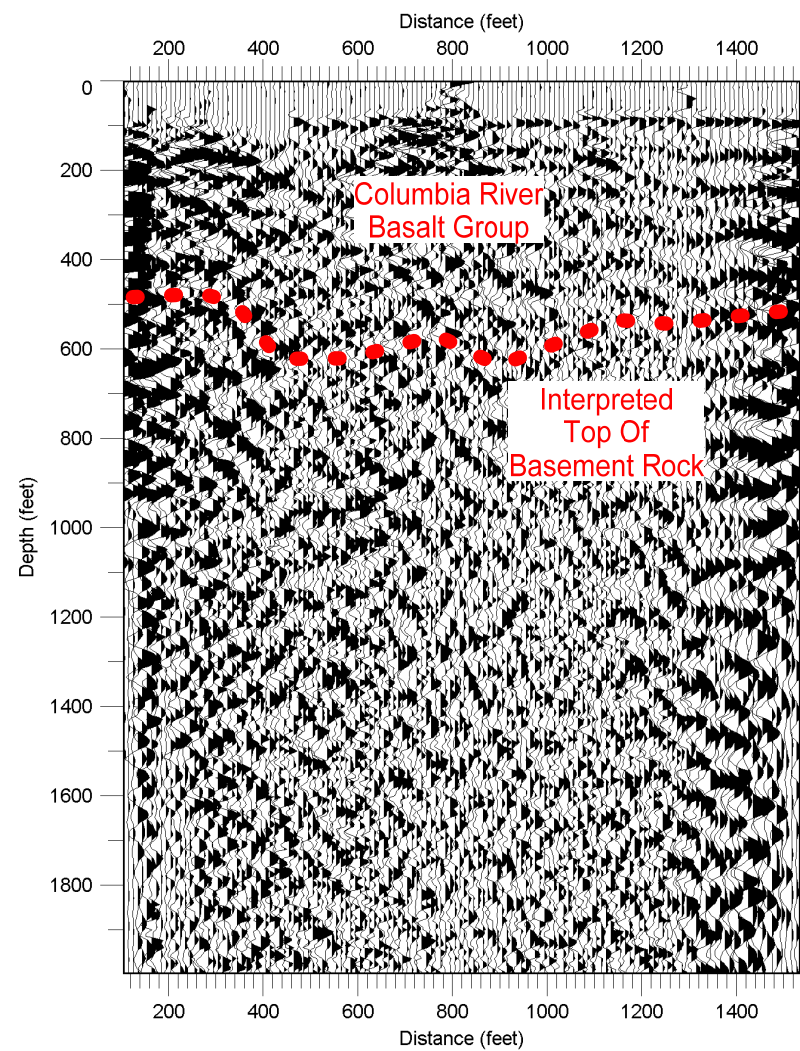
PROJECT: SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY				
TITLE: <b>LINE 2 OBSERVED AND MODELED GRAVITY DATA</b>				
	PROJECT No.	083-93096.400	FILE No.	---
	DESIGN	MB	JUNE 09	SCALE AS SHOWN
	CADD	MB	JUNE 09	REV.
	CHECK	DS	JUNE 09	<b>FIGURE B-6</b>
REVIEW	DS	JUNE 09		



REVISION DATE: BY: SURFER FILE:



PROJECT					SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY					
TITLE					LINE 2 OBSERVED AND MODELED TEM DATA					
		PROJECT No.		083-93096.400		FILE No.			---	
		DESIGN	MB	JUNE 09		SCALE	AS SHOWN		REV.	
		CADD	MB	JUNE 09		FIGURE B-7				
		CHECK	DS	JUNE 09						
REVIEW	DS	JUNE 09								



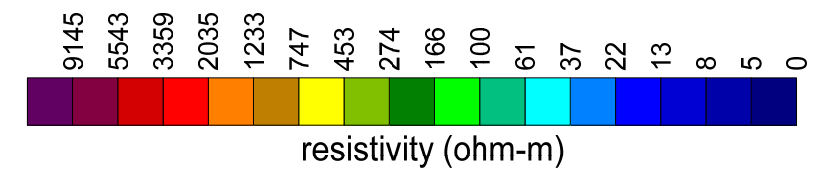
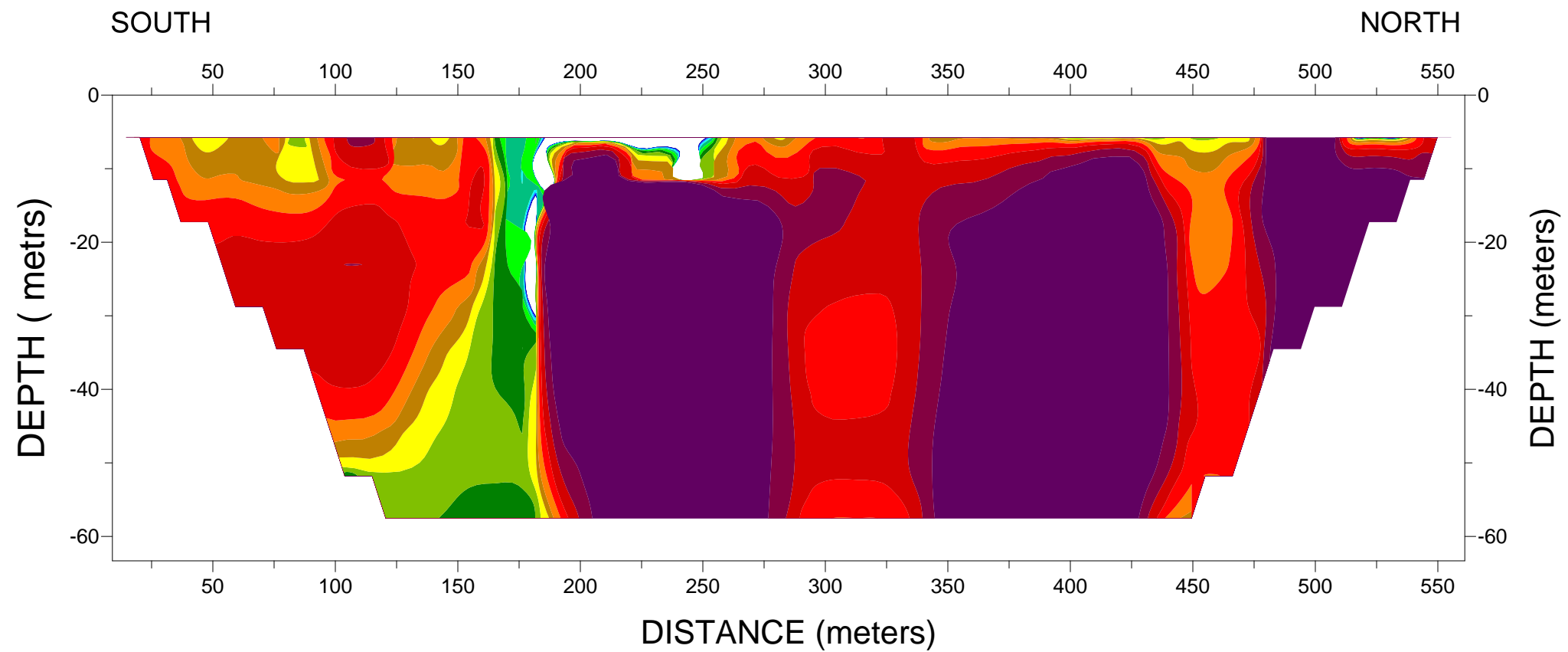
NOTES:

1. Geophysical survey performed May 13-21, 2009.
2. The primary objective of the seismic reflection survey was to determine if seismic reflection methods can detect the top of granitic bedrock.
3. Geometrics Inc. 96-channel GEODE seismic system was used to collect reflection data.
4. Data were processed using Seismic Processing Workshop software from Parallel Geosciences Inc.
5. See Figure 1 for line location.

REVISION DATE: BY: SURFER FILE:

PROJECT		SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY	
TITLE		<b>LINE 2 SEISMIC REFLECTION</b>	
PROJECT No. 083-93096.400		FILE No. ---	
DESIGN	MB	JUNE 09	SCALE AS SHOWN
CADD	MB	JUNE 09	REV.
CHECK	DS	JUNE 09	<b>FIGURE B-8</b>
REVIEW	DS	JUNE 09	

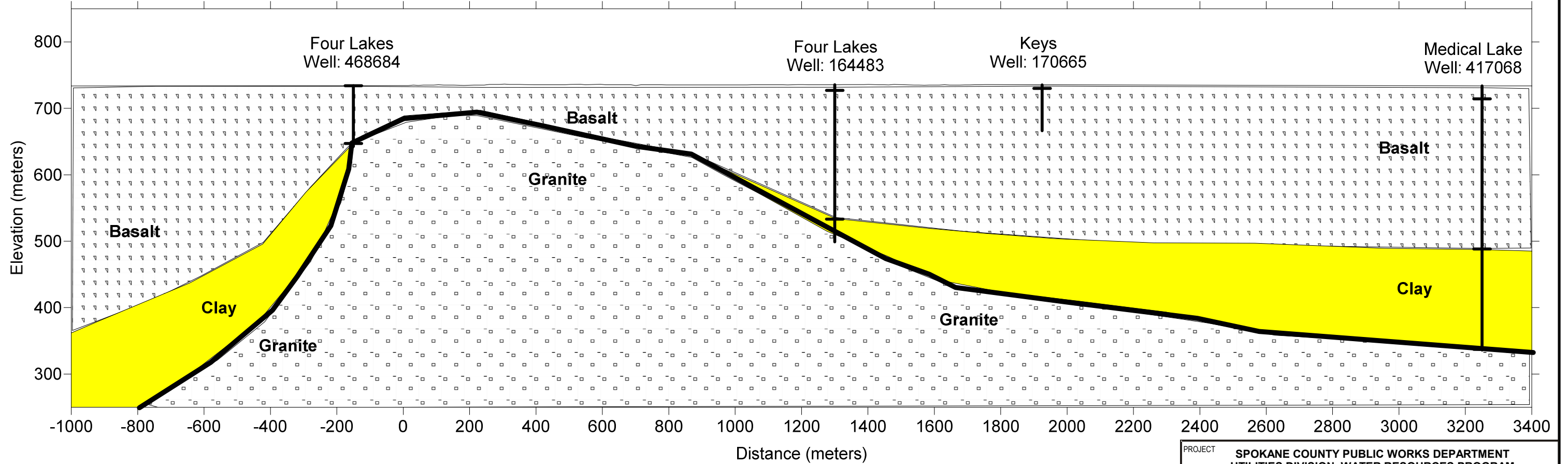
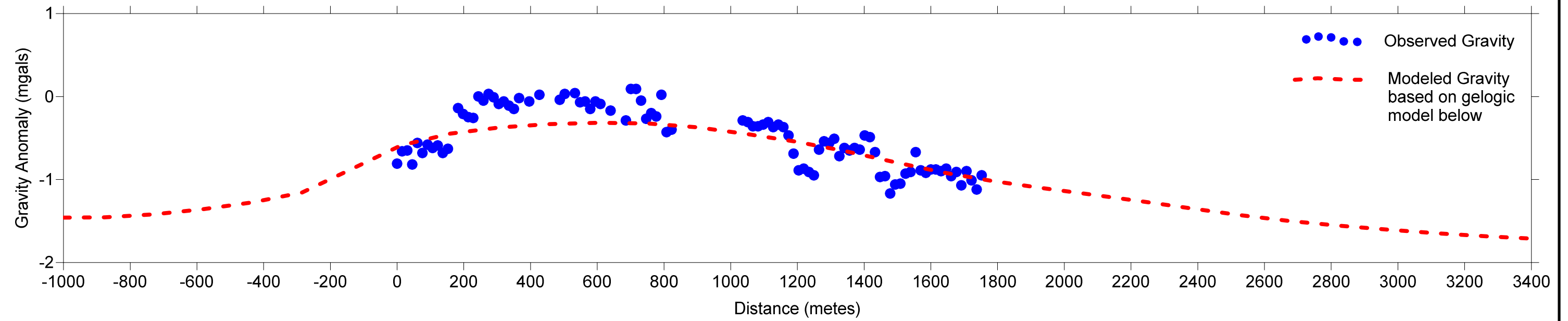




PROJECT		SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY			
TITLE		LINE 3 ELECTRICAL RESISTIVITY DATA			
PROJECT No.		083-93096.400		FILE No. ---	
DESIGN	MB	JUNE 09		SCALE	AS SHOWN
CADD	MB	JUNE 09		REVIEW	REV.
CHECK	DS	JUNE 09			
REVIEW	DS	JUNE 09			



FIGURE B-9

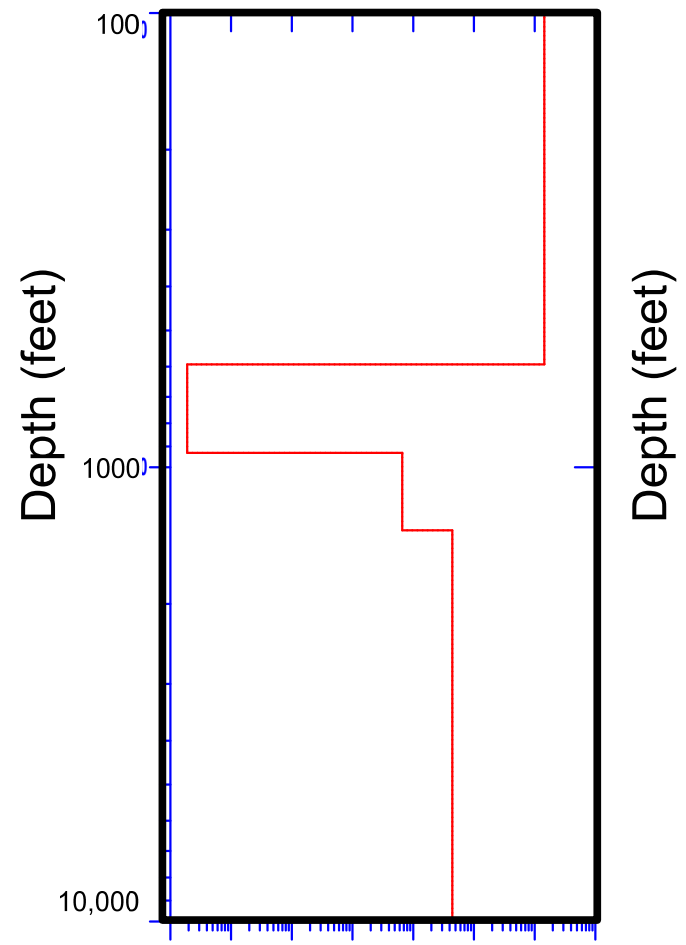



PROJECT					SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY				
TITLE					<b>LINE 3 OBSERVED AND MODELED GRAVITY DATA</b>				
PROJECT No. 083-93096.400			FILE No. ---						
DESIGN	MB	JUNE 09	SCALE	AS SHOWN	REV.				
CADD	MB	JUNE 09	<b>FIGURE B-10</b>						
CHECK	DS	JUNE 09							
REVIEW	DS	JUNE 09							



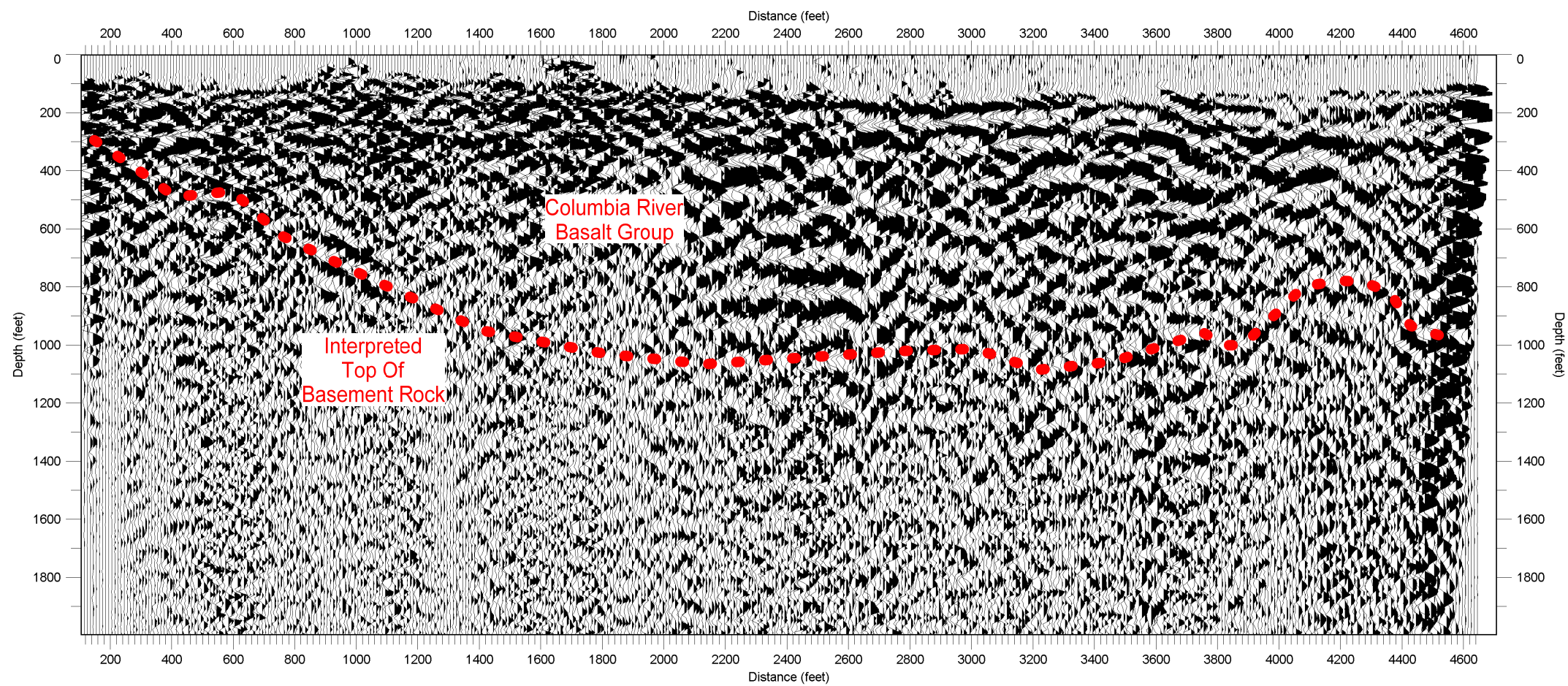
REVISION DATE: BY: SURFER FILE:

REVISION DATE: BY: SURFER FILE:



PROJECT		SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY		
TITLE		LINE 3 OBSERVED AND MODELED TEM DATA		
	PROJECT No.	083-93096.400	FILE No.	---
	DESIGN	MB	JUNE 09	SCALE AS SHOWN
	CADD	MB	JUNE 09	REV.
	CHECK	DS	JUNE 09	FIGURE B-11
REVIEW	DS	JUNE 09		






REVISION DATE: BY: SURFER FILE:

**NOTES:**

1. Geophysical survey performed May 13-21, 2009.
2. The primary objective of the seismic reflection survey was to determine if seismic reflection methods can detect the top of granitic bedrock.
3. Geometrics Inc. 96-channel GEODE seismic system was used to collect reflection data.
4. Data were processed using Seismic Processing Workshop software from Parallel Geosciences Inc.
5. See Figure 1 for line location.

PROJECT		SPOKANE COUNTY PUBLIC WORKS DEPARTMENT UTILITIES DIVISION, WATER RESOURCES PROGRAM WEST PLAINS GEOPHYSICAL ORIENTATION SURVEY		
TITLE		<b>LINE 3 SEISMIC REFLECTION</b>		
	PROJECT No.	083-93096.400	FILE No.	---
	DESIGN	MB	JUNE 09	SCALE AS SHOWN
	CADD	MB	JUNE 09	REV.
	CHECK	DS	JUNE 09	<b>FIGURE B-12</b>
REVIEW	DS	JUNE 09		

**APPENDIX B**  
**GEOPHYSICAL RESULTS OF ORIENTATION SURVEY**

**APPENDIX C**  
**MONITORING WELL CONSTRUCTION**



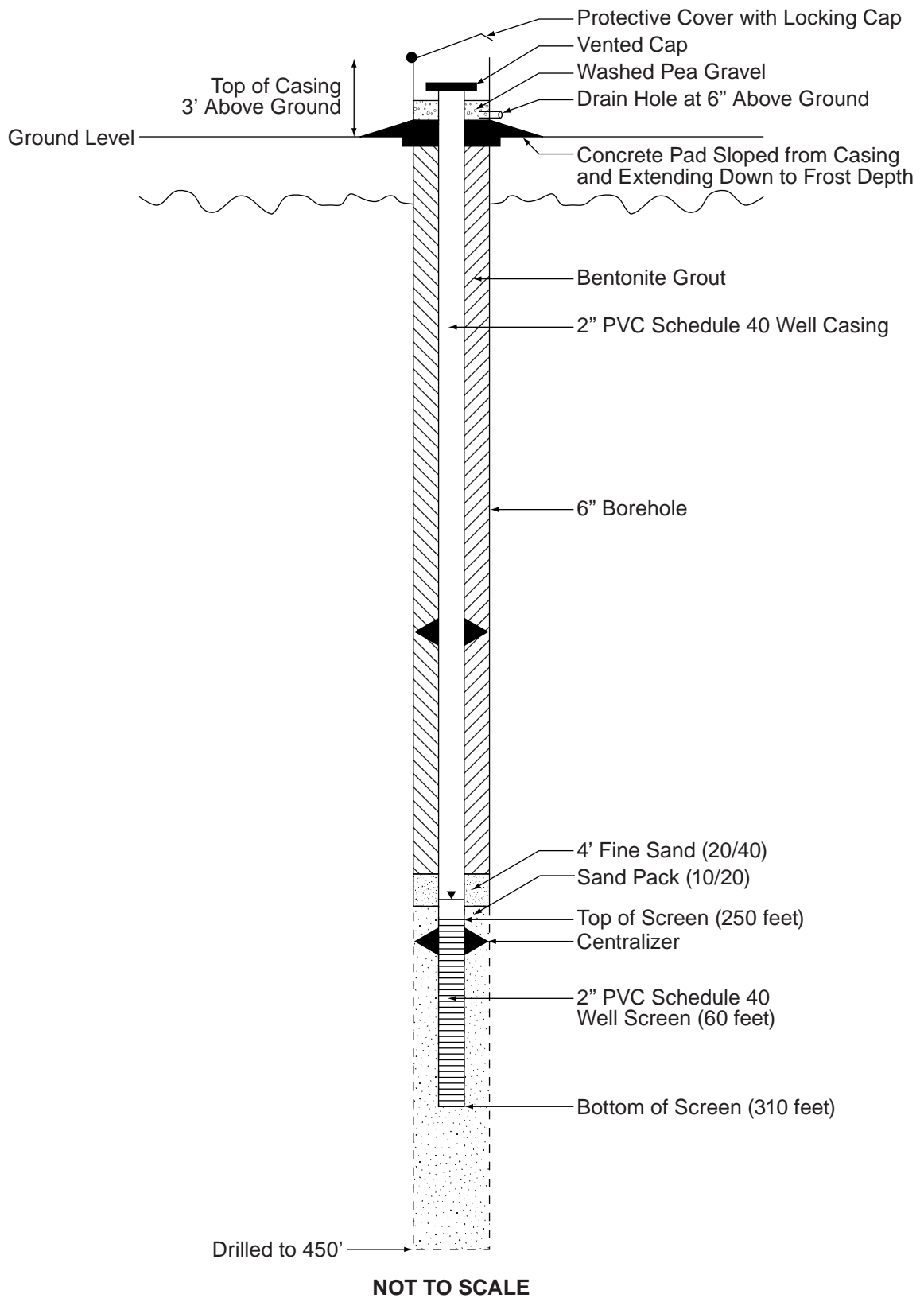


FIGURE **C1**  
**MONITORING WELL**  
**CONSTRUCTION DIAGRAM**  
 SC/WEST PLAINS GEOPHYS SURVEY/WA

# RESOURCE PROTECTION WELL REPORT

CURRENT Notice of Intent No. RE03508

(SUBMIT ONE WELL REPORT PER WELL INSTALLED)

Construction/Decommission (select one)

- Construction
- Decommission ORIGINAL INSTALLATION Notice of Intent Number \_\_\_\_\_

Type of Well (select one)

- Resource Protection
- Geotech Soil Boring

Consulting Firm \_\_\_\_\_

Unique Ecology Well ID \_\_\_\_\_

Tag No. APC-141

Property Owner SPOKANE INTL AIRPORT

Site Address OFF HAYFORD ROAD

City AIRWAY HEIGHTS County SPOKANE

Location SW 1/4-1/4 NW 1/4 Sec 01 Twn 24 R 41E  EWM  WWM

WELL CONSTRUCTION CERTIFICATION: I constructed and/or accept responsibility for construction of this well, and its compliance with all Washington well construction standards. Materials used and the information reported above are true to my best knowledge and belief.

Driller  Engineer  Trainee Name (Print) TODD MORGAN

Driller/Engineer /Trainee Signature \_\_\_\_\_

Driller or Trainee License No. 2383

Lat/Long (s, t, r still REQUIRED) Lat Deg \_\_\_\_\_ Lat Min/Sec \_\_\_\_\_

Long Deg \_\_\_\_\_ Long Min/Sec \_\_\_\_\_

Tax Parcel No. \_\_\_\_\_

Cased or Uncased Diameter 6" Static Level 180'

Work/Decommission Start Date 6/17/2009

Work/Decommission Completed Date 6/30/2009

If trainee, licensed driller's Signature and License No. 2383

Construction/Design	Well Data	Formation Description
	<p>30 gpm Static 180'</p>	<p>0 - 2 Top Soil 2-12 Broken Basalt 12-85 Med. Black Basalt 85-90 Basalt w/ Brown Clay 90-170 Med. Black Basalt 170-185 Basalt w/ Tan Clay 185-200 Med. Basalt 200-205 Basalt w/ Tan Clay 205-255 Basalt w/Fractures 255-280 Lg Fract. Basalt 280-285 Basalt, Small Gravels &amp; Sand 285-372 Broken Basalt 372-380 Hard Pan Green Clay 380-390 Hard Pan Brown Clay 390-450 Med. Black Basalt</p>