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Appendix C. 2007 Geophysical Study Report

July 2020

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Geomatrix

Memorandum

TO:	Groundwater/Surface Water Interaction Modeling Subcommittee	**DATE:**	June 18, 2007
FROM:	Tim Keuscher	**PROJ. NO.:**	10354.000.0
CC:	Jeff Weaver	**PROJ. NAME:**	USCR Chloride TMDL Support
SUBJECT:	**Surface Geophysics Program in the Vicinity of Blue Cut**		

Geomatrix Consultants, Inc. (Geomatrix) has prepared this memorandum to summarize results of the surface geophysics program performed in the vicinity of Blue Cut. Data collected during this surface geophysics program will support development of the Groundwater/Surface Water Interaction (GSWI) Model for the Upper Santa Clara River (USCR) TMDL Study. Field work was conducted between February 12 and 27, 2007 and on March 20, 2007.

Purpose

The purpose of this task was to evaluate the depth to bedrock, thickness of alluvium, and thickness of saturated alluvium along the Santa Clara River (SCR) in the Blue Cut area by collecting data using a combination of spectral analysis of surface waves (SASW) and multi-channel analysis of surface wave (MASW) geophysical survey methods. The bedrock in this area is known as the Pico Formation shale. The results of the surface geophysics program will be and have been used for the project in two primary ways. First, the geophysical data will be used to incorporate the subsurface alluvial geometry of the Blue Cut area into the groundwater-surface water interaction model being developed by CH2MHill and HydroGeoLogic (HGL). Second, the data has been used to develop final locations, drilling depths, and well construction details for the proposed groundwater monitoring wells in the Blue Cut area. Locations of the four surface geophysical profiles (Lines 1 through 4), along with Array profiles A, B, and C in the Blue Cut area, are shown on Figure 1.

Background

Characterizing groundwater flow in the alluvial system through Blue Cut was recognized as a key data gap in the GSWI study by the modeling team and GSWI Modeling Subcommittee.

With concurrence of the GWSI Modeling Subcommittee, Geomatrix is addressing this data gap using a three-phased field program. In the first phase, Geomatrix drilled exploratory borings in the Blue Cut area to gain a better understanding of the nature and extent of alluvium and depth to bedrock in this area. This work is summarized below and described in more detail in a previous

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memorandum. The second phase included performing the surface geophysical surveys described in this memorandum. The third phase (to be completed) will involve installing three groundwater monitoring wells in the Blue Cut area. Tentative locations for the three monitoring wells were selected before commencing the first and second phases of the field program. It was anticipated that these locations could be revised based on the results of the first and/or second phases.

Geomatrix conducted an exploratory soil boring program from October 30 through November 3, 2006, which consisted of drilling four soil borings (designated GSWI-SB01, GSWI-SB02, GSWI-SB03, and GSWI-SB04) to total depths ranging from 17.5 feet (ft) below ground surface (bgs) to 90 feet bgs. The exploratory borehole locations are shown on Figure 1. Results of the exploratory soil boring program were discussed in detail in a Geomatrix memorandum dated December 22, 2006. In general, bedrock appears to be shallow in the Blue Cut area, with estimated top of bedrock in the four borings being about 5 to 10 feet below the elevation of the river bottom.

As part of the exploratory soil boring program, Geovision Geophysical Services (Geovision) of Corona, California performed geophysical P-S suspension logging in exploratory borehole GSWI-SB03 to collect in-situ shear wave (S-wave) and compressional wave (P-wave) velocities of the alluvium and bedrock. Geovision used the results from the geophysical logging to evaluate the applicability of surface geophysical methods as an aid in further estimating the depth to bedrock and how it varies in the Blue Cut area.

Results of P-S Suspension Logging

P-wave velocities in the alluvium and bedrock were shown to range from approximately 1,150 to 2,000 feet per second (ft/s) and 6,000 to 6,750 ft/s, respectively. The large contrast in P-wave velocities for the alluvium and bedrock indicate that P-wave seismic refraction techniques would be effective at mapping depth to Pico Formation shale bedrock. However, the P-wave velocity of saturated alluvium is expected to be approximately 6,000 ft/s and, therefore, P-wave seismic refraction techniques could not distinguish between saturated alluvium and bedrock.

S-wave velocities in the alluvium and bedrock were shown to range from 550 to 800 ft/s and 950 to 1,700 ft/s, respectively. The S-wave velocities in bedrock increase with depth as weathering decreases. Unlike P-wave velocity, S-wave velocity does not increase significantly at the water table. Geovision indicated that there is sufficient difference in S-wave velocities between alluvium and bedrock that one-dimensional (1-D) or two-dimensional (2-D) surface wave geophysical techniques would be effective to help estimate approximate depths to bedrock in the Blue Cut area.

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Geophysics Scope of Work

The surface geophysical program consisted of a combination of MASW and seismic refraction surveys along four profiles (Lines 1 to 4) totaling approximately 9,000 linear feet as shown on Figure 1. In addition, SASW and/or MASW and seismic refraction soundings were conducted at the original three proposed monitoring well locations (Arrays A, B, and C on Figure 1). Geovision performed the surface geophysical work with oversight by Geomatrix. Representatives of Geomatrix and CH2MHill initially selected surface geophysical profile locations. These locations were selected based on site access, identifying subsurface conditions in the vicinity of the original proposed monitoring well locations, and providing CH2MHill with several cross sections in the Blue Cut area for the GSWI model. Attachment 1 to this memorandum is a detailed discussion of the methodology, instrumentation, field measurement procedures, data reduction and modeling, and results of the surface geophysical investigation. The following paragraphs provide a summary of this information.

The initial task of the surface geophysics program consisted of conducting SASW and/or MASW and seismic refraction soundings at the three proposed monitoring well locations (Arrays A, B, and C), one of which had a known depth to bedrock (GSWI-SB02). The primary purpose of this initial task was to evaluate whether: 1) surface wave techniques could provide reliable estimates of depth to bedrock, 2) saturated alluvium was present at these locations, and 3) the proposed monitoring well locations are appropriate for the subsurface conditions identified. Results from the initial task also helped select the most appropriate surface wave technique for the surface geophysics program (i.e., 1-D SASW soundings or 2-D MASW imaging). The subsequent task of the geophysics program was to conduct 1-D or 2-D surface wave surveys along four profiles (Lines 1 to 4 on Figure 1) to estimate the approximate depth to bedrock along these profiles.

The initial task indicated that active surface wave techniques (SASW and MASW) would provided a reasonable estimate of depth to bedrock at the control location (Array A located adjacent to GSWI-SB02). Additionally, the combined surface wave and seismic refraction soundings found that two of the proposed monitoring well locations (Array A and Array B) did not have saturated alluvium overlying bedrock. As such, alternative locations for these two monitoring wells needed to be evaluated. The absence of saturated alluvium at two of the three proposed monitoring well locations made it important to develop a cost-effective means to estimate both depth to groundwater and bedrock along the four profiles. A decision was made to conduct 2-D MASW soundings along the four profiles and also acquire seismic refraction data using the same geophone array. A total of 52 combined seismic refraction and surface wave soundings (MASW) were performed as part of the geophysics program.

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Technical Approach

Seismic refraction and MASW equipment consisted of two Geometrics Geode signal enhancement seismographs, 4.5-Hz vertical geophones, seismic cable, and two accelerated weight drop (AWD) energy sources. Each station consisted of a single spread of 48 geophones spaced 3.3 ft apart along a linear array for a length of 154 ft. The geophones were mounted on Kevlar reinforced webbing (landstreamer) so they could be towed from station to station using a utility vehicle. Four or more shot point locations were occupied at each station: an end shot 3.3 ft from geophones numbered 1 and 48; a center shot (Arrays A, B, and C only), and one or more off-end shots. An AWD was used as the energy source for each shot point. Seismic refraction and MASW data were acquired at all geophysical stations shown on Figure 1. By utilizing a 1-second record length and a 0.125-millisecond sample rate, it was possible to acquire both seismic refraction and MASW data, simultaneously.

SASW data were collected at Array A with base receiver spacings of 6.6, 13.1, 26.2, 39.4, and 65.6 ft. SASW data were monitored by two Oyo Geospace 1-Hz or 4.5-Hz geophones and recorded by an HP 35670A dynamic signal analyzer. Rock hammers, 3-lb hammers, 12- and 20-lb sledgehammers and an AWD were used as energy sources.

Geovision established the surface geophysical survey stations and then surveyed them using a Nikon total station system. At a minimum, geophysical stations were established at 197 ft intervals along each profile. Psomas, a licensed surveyor from Santa Clarita, California, surveyed the ends of the geophysical profiles to tie the survey to the state plane coordinate system.

Results and Interpretations

In general, results from the surface geophysical profiles included estimated depths to bedrock from the MASW soundings, and to groundwater or bedrock from the seismic refraction soundings. The travel time data, velocity model, and depth sections for the seismic refraction soundings at Arrays A, B, and C are presented in Figures 2 through 4. In general, two layers are interpreted in the depth sections; low velocity unsaturated alluvium and high velocity saturated alluvium or bedrock. The fit of the theoretical dispersion curve to the field data collected at Arrays A, B, and C along with the modeled shear wave velocity profiles are presented in Figures 5 through 7. There is excellent agreement between the dispersion curves (red, blue, and green dots) generated from the SASW, MASW, and passive surface wave data and the theoretical dispersion curves (black circles). Geologic cross-sections showing interpreted depth to saturated alluvium and bedrock along the surface geophysical profiles (Lines 1 through 4; Figure 1) are presented in Figures 8 through 11. Accuracy of the interpreted saturated alluvium, layer thickness, and bedrock depths provided in this memorandum and shown on figures are expected

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to be about 2.5 feet plus 10% of total depth. Subsurface conditions at Arrays A, B, and C and along surface geophysical profile Lines 1 through 4 are discussed and interpreted in greater detail below.

Array A

The shear wave velocity profile for Array A (Figure 5) indicates that shear wave velocity increases with depth from approximately 525 feet per second (ft/s) near the surface to 623 ft/s at a depth of 9.8 ft below ground surface (bgs). A higher velocity layer of approximately 1,230 ft/s was modeled at a depth of 15.6 ft bgs. The shear wave velocity profiles used to match the field data are provided in the table below.

Depth to top of layer (ft)	Layer Thickness (ft)	Shear Wave Velocity (ft/s)
0.0	3.3	525
3.3	6.6	476
9.8	5.7	623
15.6	32.8	1,230
48.4	>50.0	2,297

These results indicate unsaturated alluvium in the shallow depths down to 15.6 ft. The higher velocity layer below 15.6 ft is interpreted as weathered bedrock. The increase in shear wave velocity at a depth of 48.4 ft bgs is likely due to bedrock becoming more competent with depth.

Bedrock was modeled at a depth of 15.6 ft bgs at Array A (proposed monitoring well GSWI-MW01) using both seismic refraction (Figure 2) and MASW techniques. Bedrock was encountered at 16 ft bgs during the advancement of exploratory borehole GSWI-SB02 (located adjacent to Array A; see Figure 1). Both the seismic refraction and MASW soundings modeled depth to bedrock at 15.6 ft bgs; therefore, saturated alluvium does not appear to exist in the vicinity of Array A.

Array B

The shear wave velocity profile for Array B (Figure 6) indicates that shear wave velocity increases slightly with depth from approximately 591 ft/s near the surface to 623 ft/s at a depth of 18.0 ft bgs. A higher velocity layer of approximately 1,148 ft/s was modeled at a depth of 27.9 ft bgs. The shear wave velocity profiles used to match the field data are provided in the table below.

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Depth to top of layer (ft)	Layer Thickness (ft)	Shear Wave Velocity (ft/s)
0.0	6.6	591
6.6	11.5	558
18.0	9.8	623
27.9	16.4	1,148
44.3	>54.1	2,789

These results indicate unsaturated alluvium in depths down to 27.9 ft. The higher velocity layer below 27.9 ft is interpreted as weathered bedrock. The increase in shear wave velocity at a depth of 44.3 ft bgs is likely due to bedrock becoming more competent with depth.

Bedrock was modeled at a depth of 27.1 ft bgs and 27.9 ft bgs at Array B (proposed monitoring well GSWI-MW03) using seismic refraction (Figure 3) and MASW techniques, respectively. Because MASW and seismic refraction soundings are within 0.8 ft of each other, it appears both geophysical methods modeled depth to bedrock; therefore, saturated alluvium does not appear to exist in the vicinity of Array B.

Array C

The shear wave velocity profile for Array C (Figure 7) indicates that shear wave velocity increases with depth from approximately 361 ft/s near the surface to 705 ft/s at a depth of 12.3 ft, likely due to increase in moisture content and/or density of sediments. A higher velocity layer of approximately 1,148 ft/s was modeled at a depth of 37.7 ft bgs. The shear wave velocity profiles used to match the field data are provided in the table below.

Depth to top of layer (ft)	Layer Thickness (ft)	Shear Wave Velocity (ft/s)
0.0	3.3	361
3.3	9.0	509
12.3	25.4	705
37.7	55.8	1,148
93.5	>4.9	2,297

These results indicate unsaturated alluvium in the shallow depths down to 12.3 ft, with increasing saturation with depth. Saturated alluvium extends to a depth of 37.7 ft. The higher velocity layer below 37.7 ft is interpreted as weathered bedrock. The increase in shear wave velocity at a depth of 93.5 ft is likely due to bedrock becoming more competent with depth.

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Bedrock was modeled at a depth of 37.7 ft bgs bgs at Array C (proposed monitoring well GSWI-MW02) using MASW techniques. Groundwater was modeled at a depth of 9.8 feet bgs using seismic refraction techniques. Results of these soundings indicate there is approximately 18 feet of saturated alluvium in the vicinity of Array C.

Line 1

The scaled interpreted 2D geologic cross-section for Line 1 is presented as Figure 8. Seismic refraction and MASW soundings were collected along Line 1 at fifteen locations. Results of the seismic refraction and MASW soundings conducted along Line 1 are provided in the table below.

Station ID	Bedrock Depth (ft) MASW	Bedrock OR Groundwater Depth (ft) Seismic Refraction
L1-30	19.7	23.0
L1-90	16.4	18.0
L1-150	18.0	17.2
L1-210	14.8	11.5
L1-270	9.8	4.9
L1-360	6.6	2.5
L1-510	24.6	23.8
L1-570	31.2	18.9
L1-630	30.3	16.4
L1-703	36.1	21.3
L1-747	41.0	28.7
L1-810	55.8	41.8
L1-870	55.8	39.4
L1-930	55.8	44.3
L1-990	55.8	50.9

These results indicate three distinct layers; alluvium, saturated alluvium, and bedrock (Figure 8). Saturated alluvium does not appear to exist north of the river along Line 1 (stations L1-30, L1-90, and L1-150). There appears to be a thin layer of saturated alluvium beneath the present day river between stations L1-150 and L1-510. The thickest section of saturated alluvium appears to be in the vicinity of Salt Creek (between stations L1-630 and L1-703).

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Line 2

The scaled interpreted 2D geologic cross-section for Line 2 is presented as Figure 9. Seismic refraction and MASW soundings were collected along Line 2 at nine locations. Results of the seismic refraction and MASW soundings conducted along Line 2 are provided in the table below.

Station ID	Bedrock Depth (ft) MASW	Bedrock OR Groundwater Depth (ft) Seismic Refraction
L2-30	52.5	49.2
L2-90	45.9	44.3
L2-150	37.7	36.1
L2-204	36.1	36.9
L2-266	32.8	32.8
L2-293.5	32.8	31.2
L2-371.5	18.9	10.7
L2-390	19.7	9.8
L2-421.5	15.6	9.8

These results indicate three distinct layers; alluvium, saturated alluvium, and bedrock (Figure 9). There appears to be a thin layer of saturated alluvium near the southern end of Line 2 between stations L2-371.5 and L2-421.5.

Line 3

The scaled interpreted 2D geologic cross-section for Line 3 is presented as Figure 10. Seismic refraction and MASW soundings were collected along Line 3 at thirteen locations. Results of the seismic refraction and MASW soundings conducted along Line 3 are provided in the table below.

Station ID	Bedrock Depth (ft) MASW	Bedrock OR Groundwater Depth (ft) Seismic Refraction
L3-0	24.6	25.4
L3-30	24.6	23.8
L3-90	20.5	21.3
L3-150	19.7	18.0
L3-210	10.7	12.3
L3-270	9.8	13.1
L3-330	9.0	9.8

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Station ID	Bedrock Depth (ft) MASW	Bedrock OR Groundwater Depth (ft) Seismic Refraction
L3-390	8.2	7.4
L3-559	12.3	11.5
L3-600	13.1	9.8
L3-660	14.8	9.0
L3-720	15.6	9.8
L3-780	19.7	8.2

These results indicate three distinct layers; alluvium, saturated alluvium, and bedrock (Figure 10). There appears to be a thin layer of saturated alluvium north of the river between stations L3-559 and L3-780 (southern portion of Line 3); however, saturated alluvium does not appear to exist in the northern portion (L3-0 through L3-390) of Line 3.

Line 4

The scaled interpreted 2D geologic cross-section for Line 4 is presented as Figure 11. Seismic refraction and MASW soundings were collected along Line 4 at thirteen locations. Results of the seismic refraction and MASW soundings conducted along Line 4 are provided in the table below.

Station ID	Bedrock Depth (ft) MASW	Bedrock OR Groundwater Depth (ft) Seismic Refraction
L4- -105	31.2	15.6
L4- -60	32.8	11.5
L4-0	39.4	9.8
L4-30	37.7	9.8
L4-90	37.7	9.0
L4-120	37.7	6.6
L4-180	31.2	1.6
L4-287	32.0	3.0
L4-330	29.5	5.7
L4-390	28.7	9.8
L4-450	26.2	9.8
L4-510	24.6	10.7
L4-570	16.4	13.1

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These results indicate three distinct layers; alluvium, saturated alluvium, and bedrock (Figure 11). There appears to be a thin layer of alluvium along the entire length of Line 4. There also appears to be a thick section of saturated alluvium along the entire length of Line 4.

Summary of Geophysical Results

Geophysical results confirm that bedrock is relatively shallow in the Blue Cut area, and that saturated alluvium is locally isolated, with thicknesses ranging from 0 to a maximum of approximately 30 feet in the areas investigated. The shallow depth to bedrock in the Blue Cut area is consistent with findings from the exploratory boring program. Geomatrix and Geovision have evaluated the results from the surface geophysics to estimate saturated alluvial thickness at the original locations for the proposed monitoring wells. Based on the results of the surface geophysics, saturated alluvium does not appear to exist in the vicinity of two of the three originally proposed monitoring well locations (GSWI-MW01 and GSWI-MW03). However, areas where some saturated alluvium likely exists were identified along the profiles that coincide with the original locations for the proposed monitoring wells. Therefore, new locations are proposed for monitoring wells GSWI-MW01 and GSWI-MW03 as shown on Figure 1. Recommendations for the new proposed well locations and well construction details will be provided in a separate memorandum.

Enclosures:

Figure 1	Surface Geophysical Profiles in Blue Cut Area
Figure 2	Seismic Refraction Model – Array A
Figure 3	Seismic Refraction Model – Array B
Figure 4	Seismic Refraction Model – Array C
Figure 5	Velocity Model for Active and Passive Surface Waves – Array A
Figure 6	Velocity Model for Active and Passive Surface Waves – Array B
Figure 7	Velocity Model for Active and Passive Surface Waves – Array C
Figure 8	Geologic Cross Section – Line 1
Figure 9	Geologic Cross Section – Line 2
Figure 10	Geologic Cross Section – Line 3
Figure 11	Geologic Cross Section – Line 4
Attachment 1	Geovision Draft Report – Geophysical Investigation, Blue Cut Area

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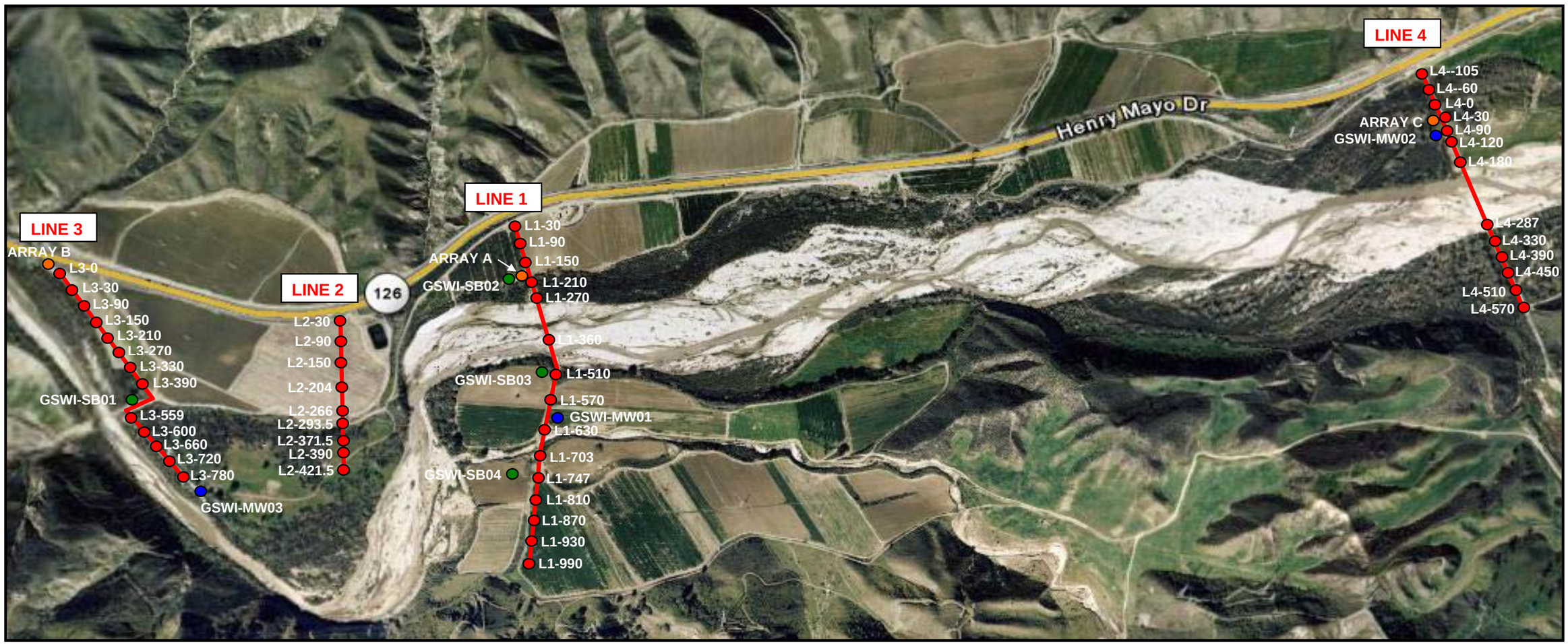

Explanation

- Surface Geophysical Profile
- Seismic Refraction and Surface Wave Sounding
- Exploratory Surface Geophysical Array
- Exploratory Borehole
- Proposed Monitoring Well Location (subject to change)

Note: Aerial photo not to scale

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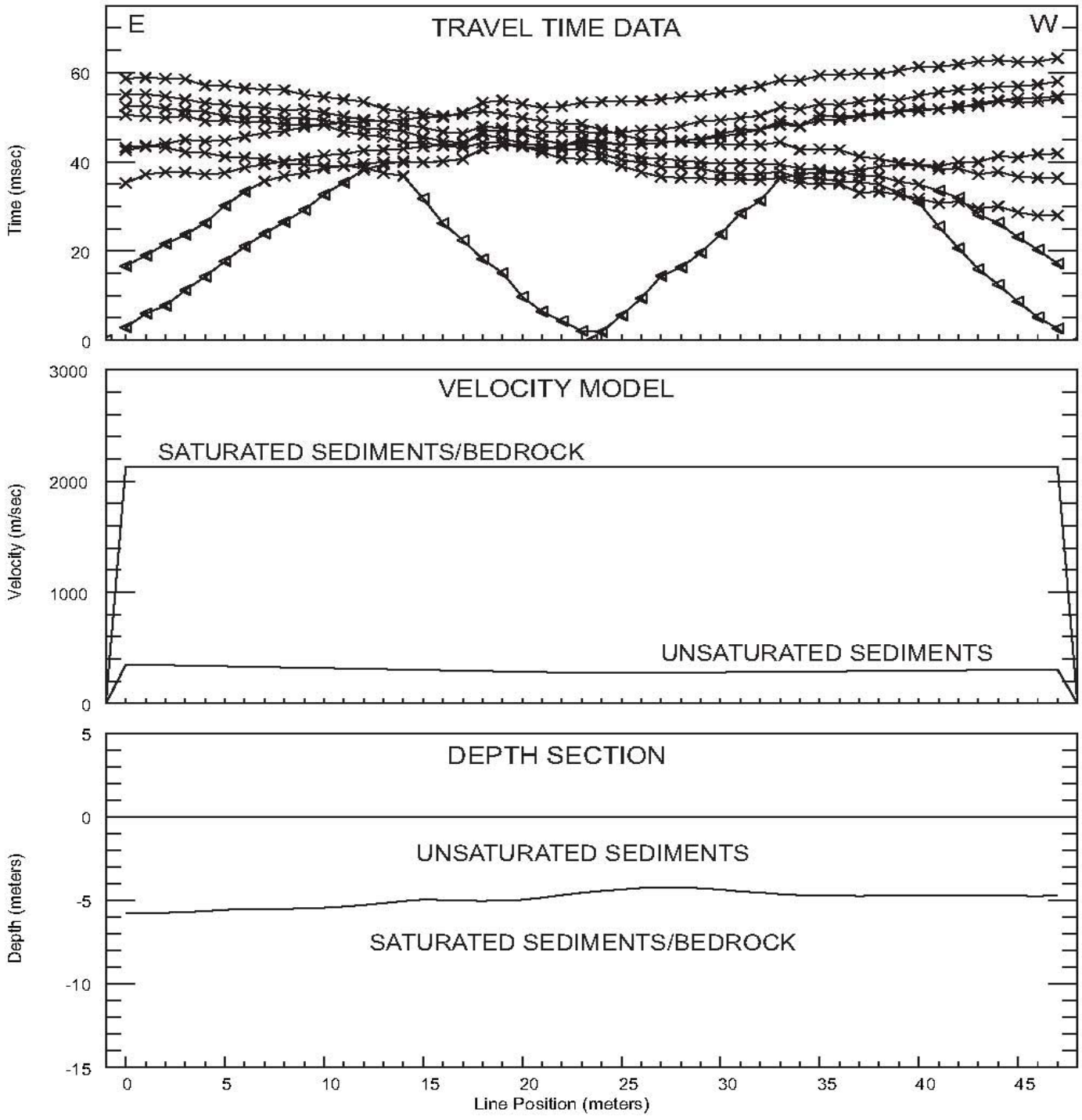
SURFACE GEOPHYSICAL PROFILES IN BLUE CUT AREA

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/11/07	Project No. 10354.000
Geomatrix		**Figure** 1



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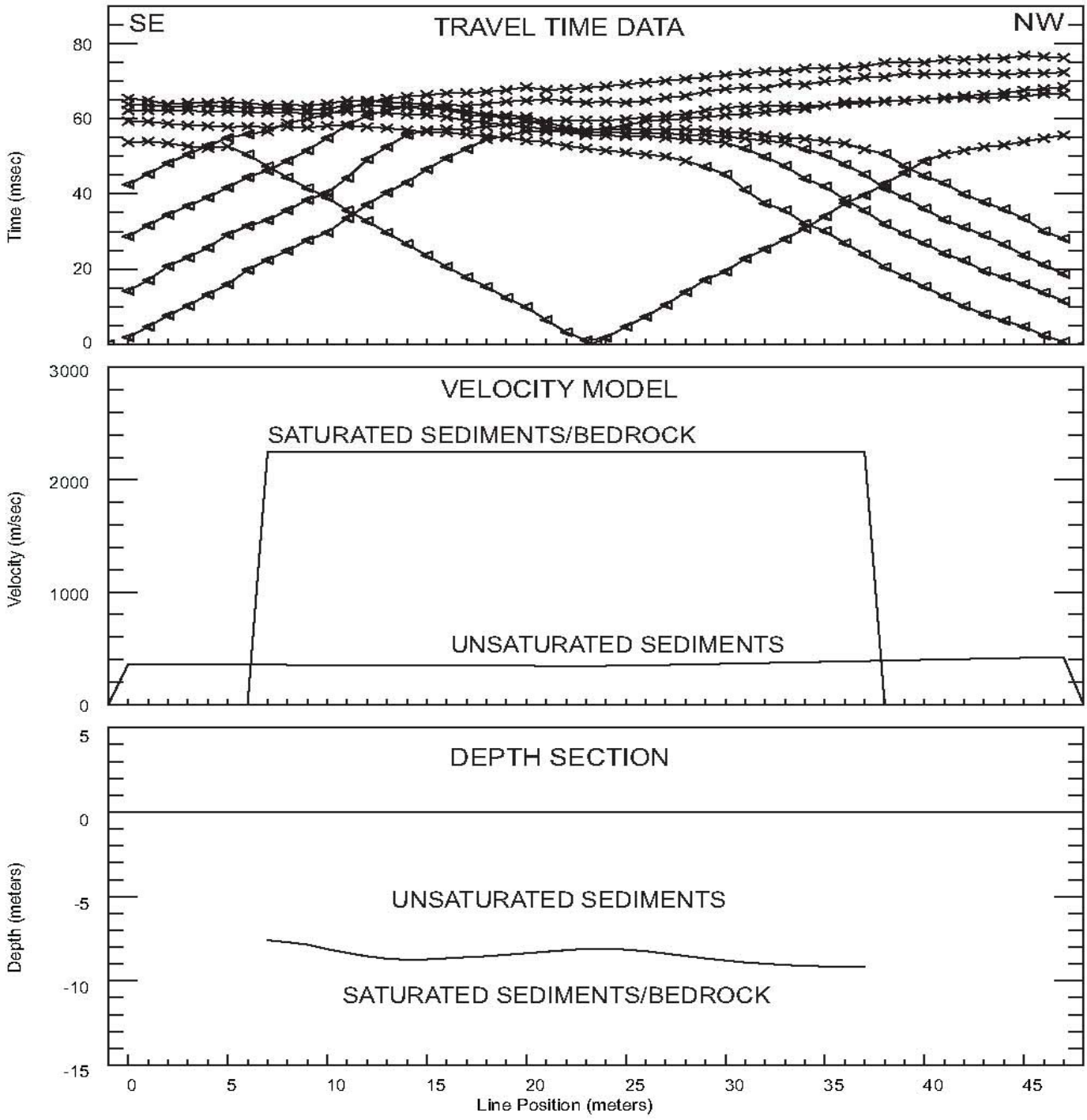
SEISMIC REFRACTION MODEL

ARRAY A

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/15/07	Project No. 10354.000
Geomatrix		**Figure 2**



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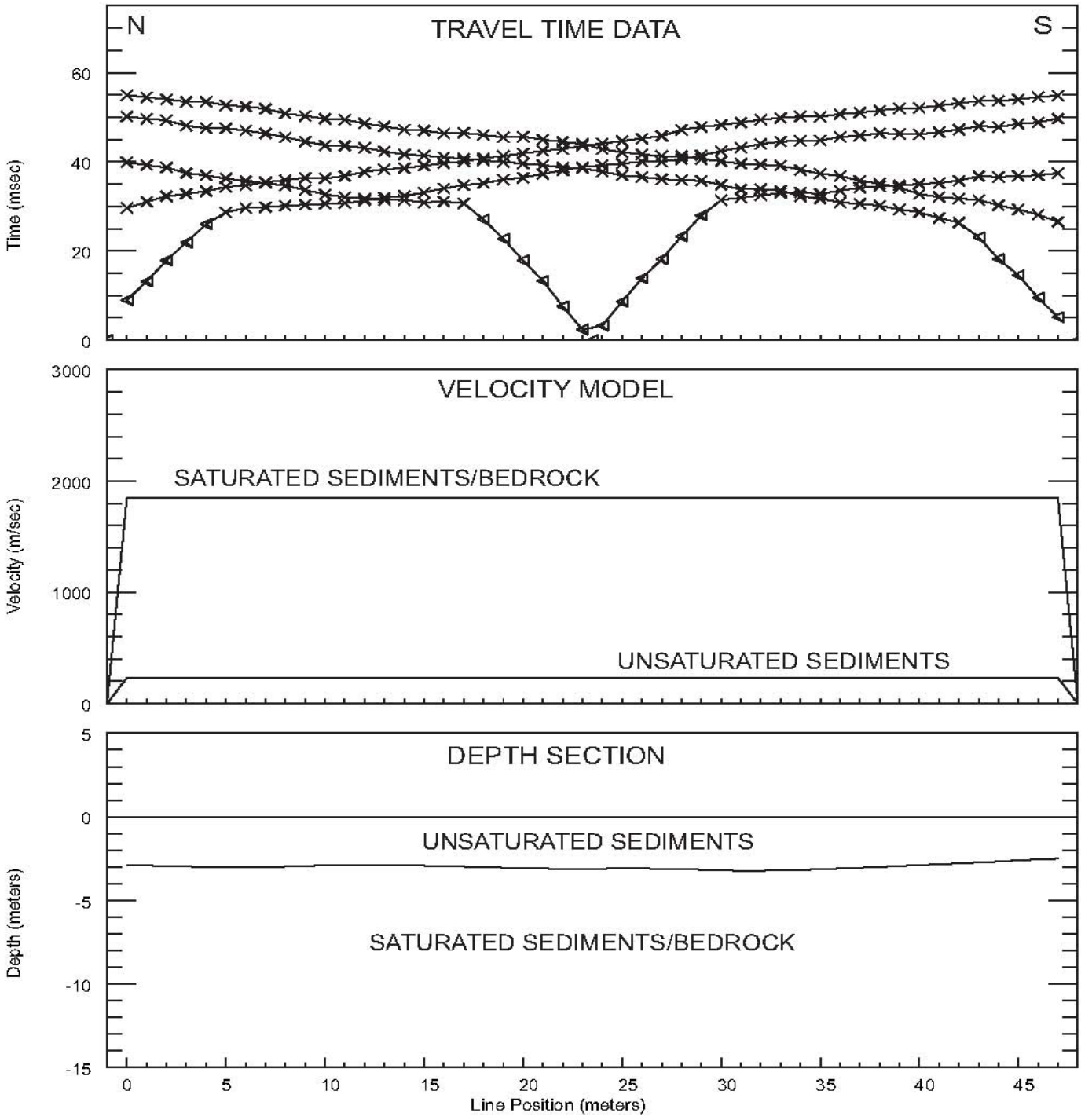
SEISMIC REFRACTION MODEL

ARRAY B

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/15/07	Project No. 10354.000
Geomatrix		**Figure 3**



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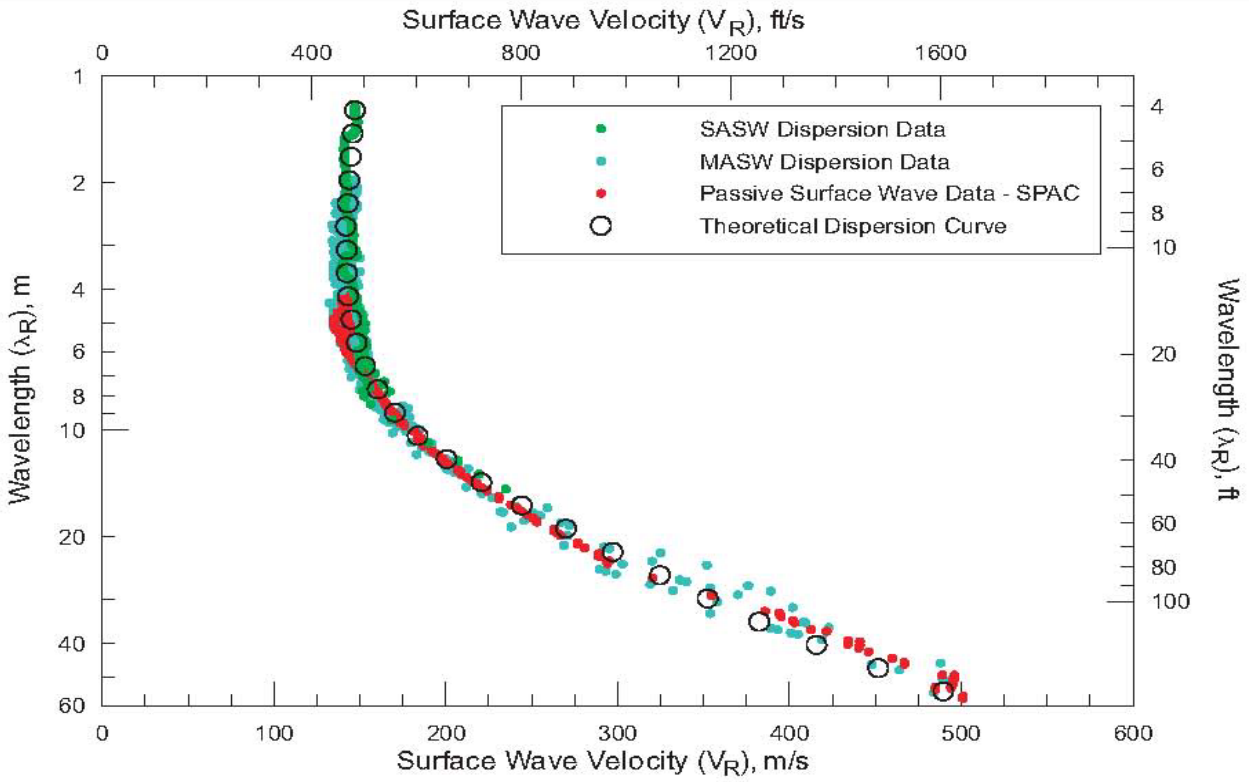
SEISMIC REFRACTION MODEL

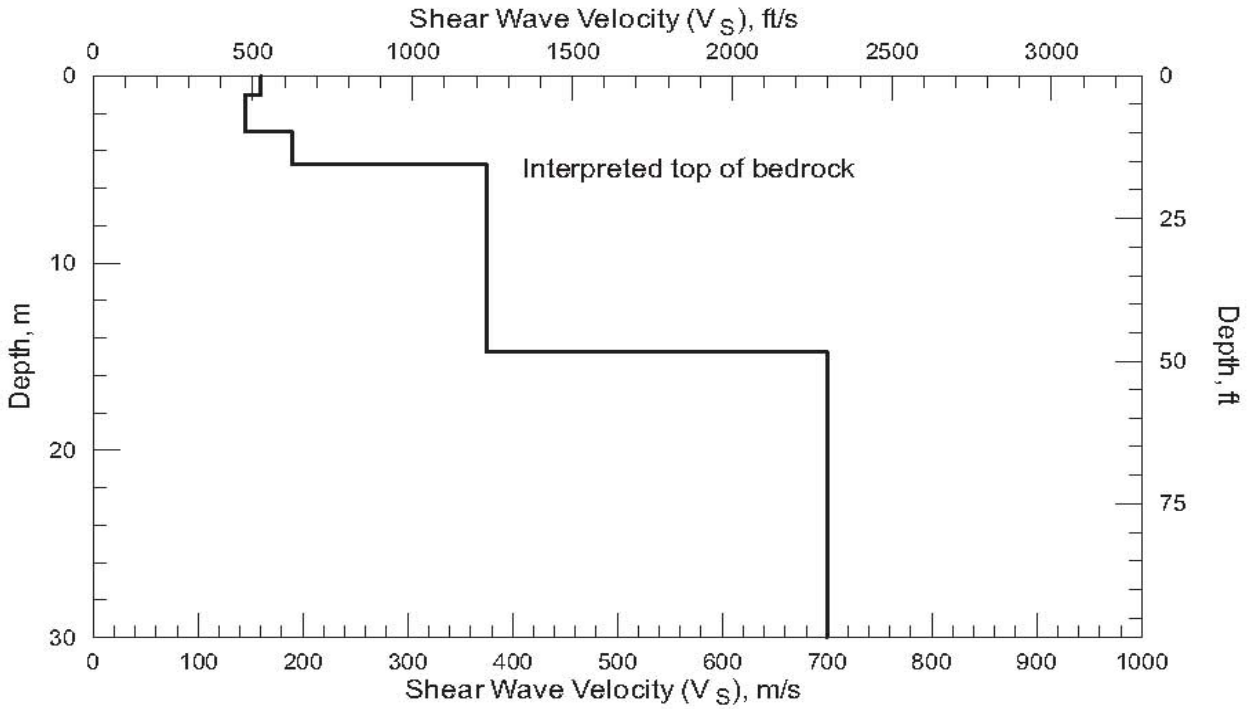
ARRAY C

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/15/07	Project No. 10354.000
Geomatrix		**Figure 4**



Comparison of Field Experimental Data and Theoretical Dispersion Curve from Active and Passive Surface Wave Array A (next to GSWI-SB02)



V_S Profile from Active and Passive Surface Wave Array A (next to GSWI-SB02)

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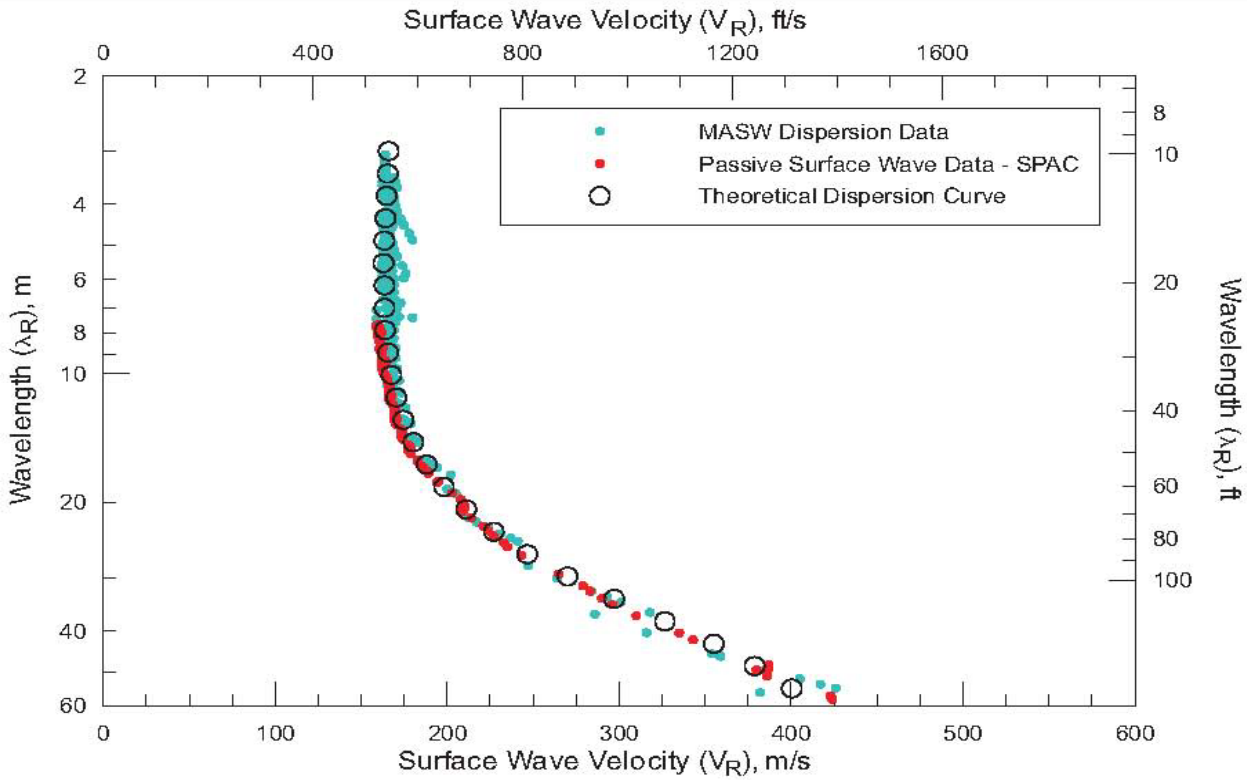
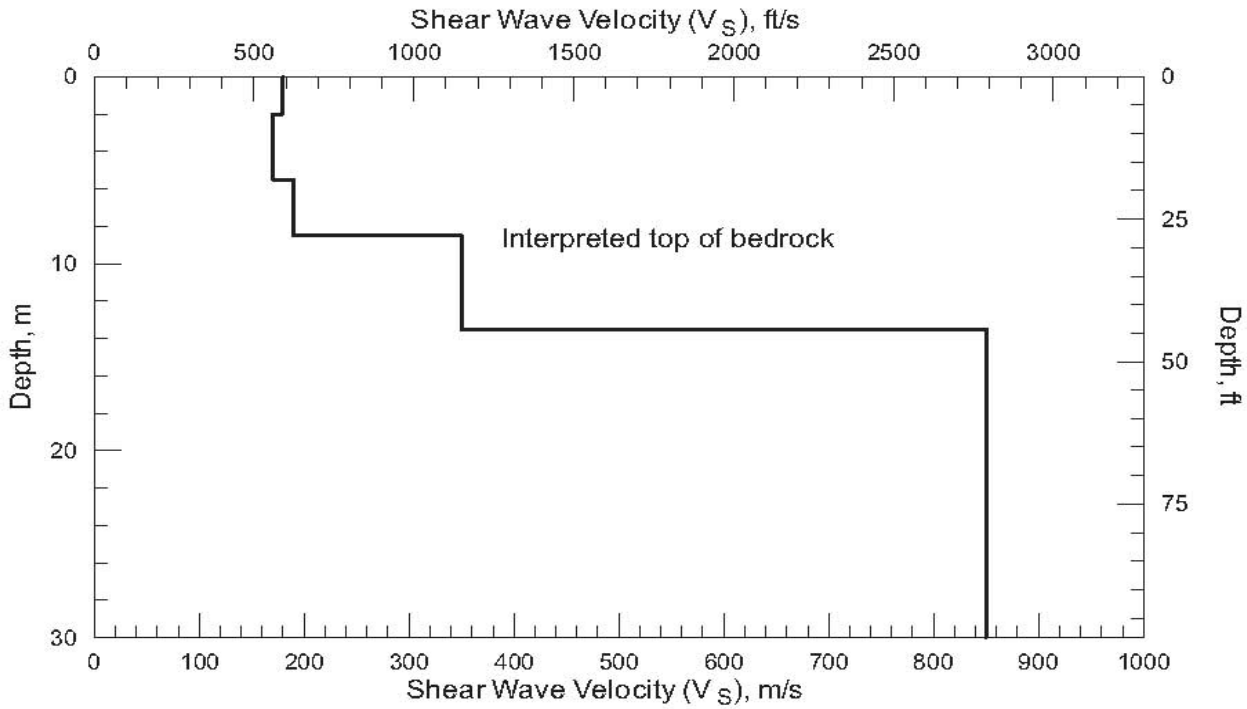
VELOCITY MODEL FOR ACTIVE AND PASSIVE SURFACE WAVES - ARRAY A

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/15/07	Project No. 10354.000
Geomatrix		**Figure 5**



Comparison of Field Experimental Data and Theoretical Dispersion Curve from Active and Passive Surface Wave Array B



V_S Profile from Active and Passive Surface Wave Array B

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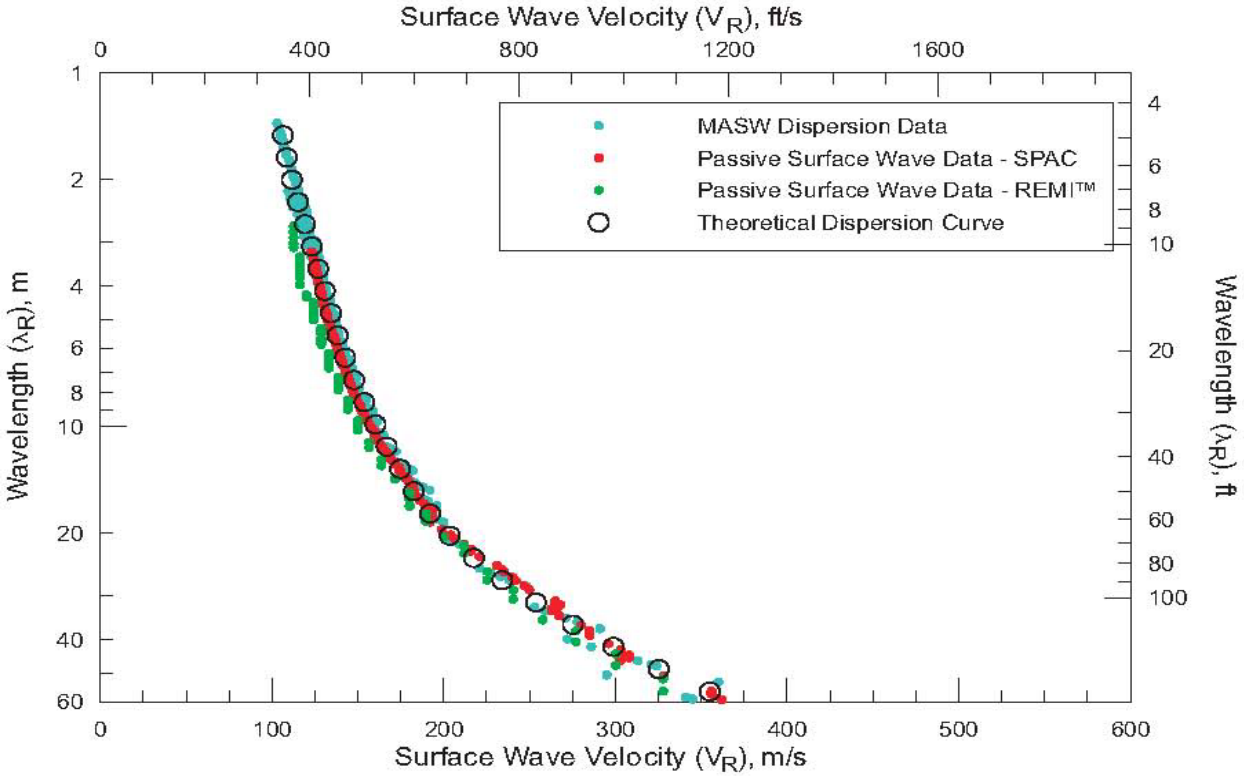
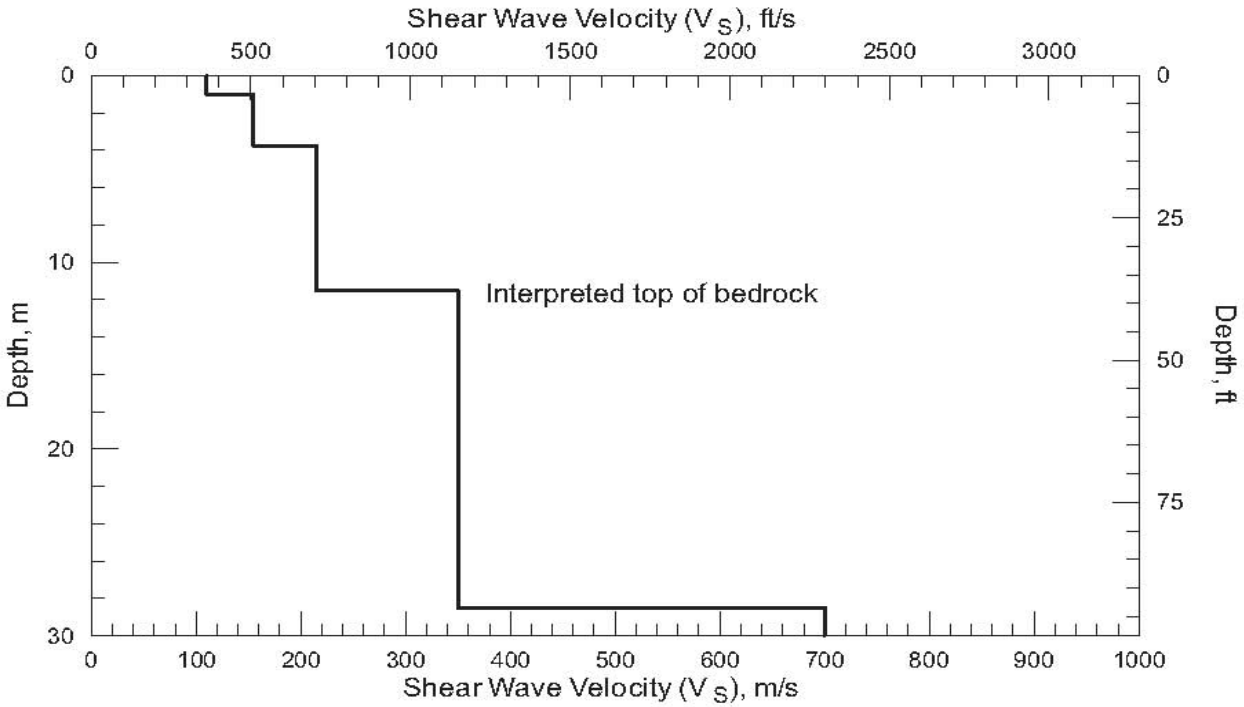
VELOCITY MODEL FOR ACTIVE AND PASSIVE SURFACE WAVES - ARRAY B

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/15/07	Project No. 10354.000
Geomatrix		**Figure 6**



Comparison of Field Experimental Data and Theoretical Dispersion Curve from Active and Passive Surface Wave Array C (Line 4, Station 30 m)



V_S Profile from Active and Passive Surface Wave Array C (Line 4, Station 30 m)

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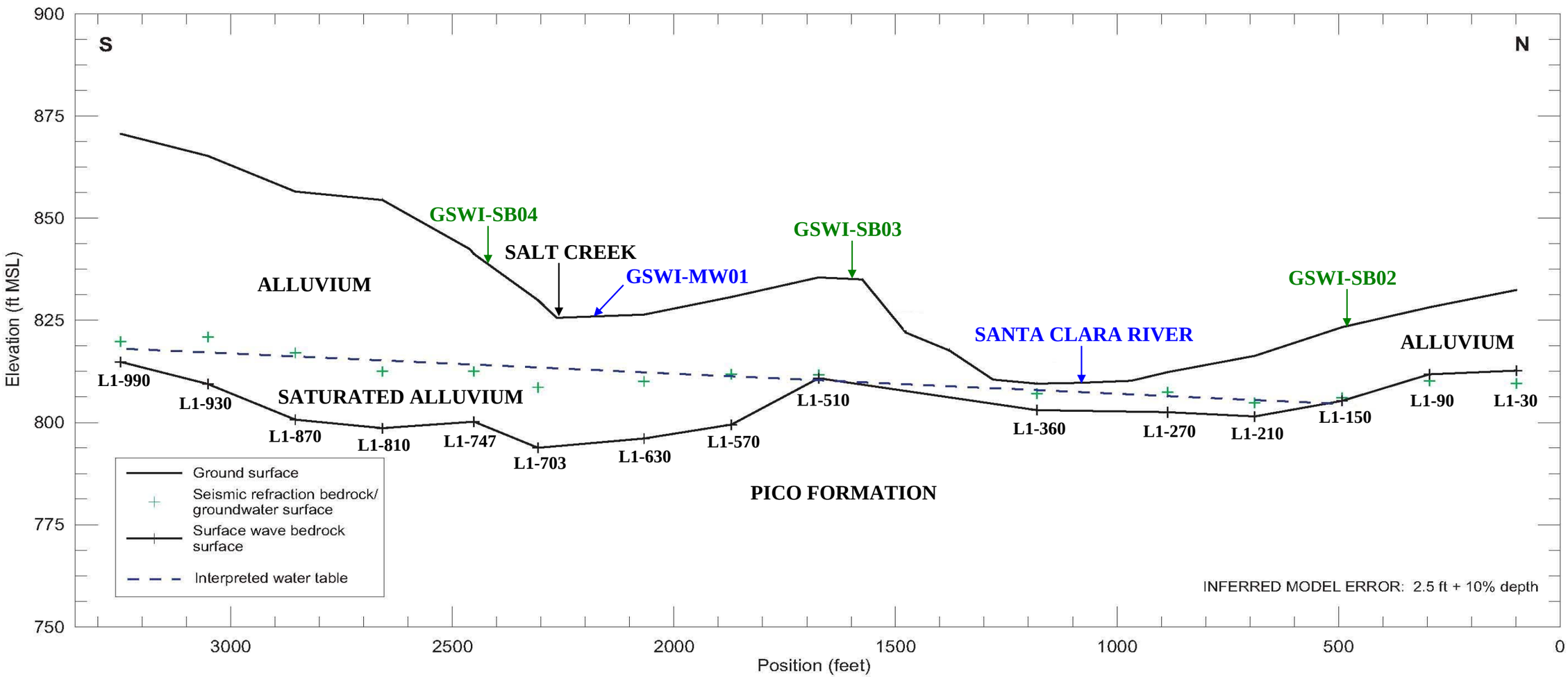
VELOCITY MODEL FOR ACTIVE AND PASSIVE SURFACE WAVES - ARRAY C

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/15/07	Project No. 10354.000
Geomatrix		**Figure 7**



Explanation

GSWI-SB02	Exploratory Borehole
GSWI-MW01	Proposed Monitoring Well Location (subject to change)
L1-990	Seismic Refraction and Surface Wave Sounding Station ID

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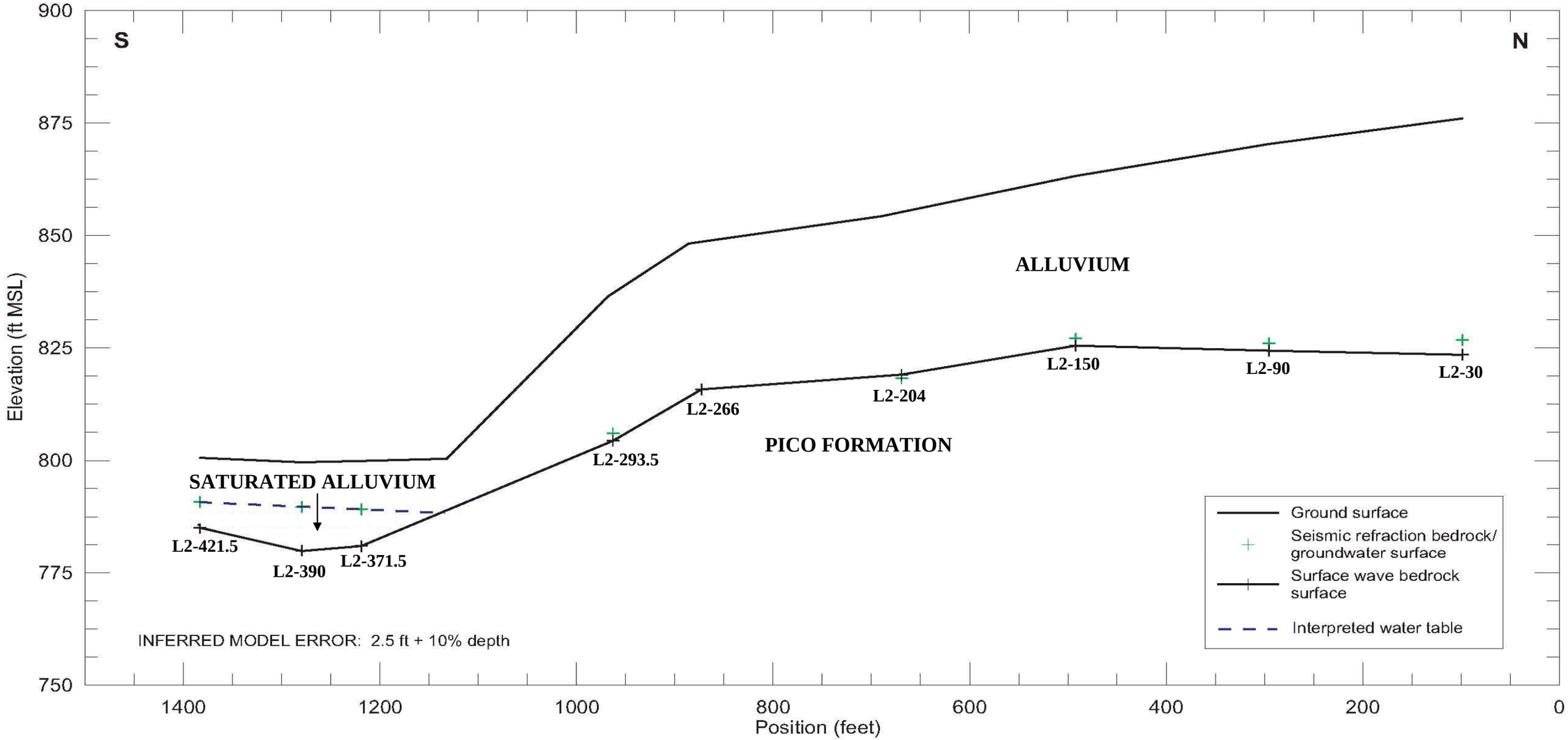
GEOLOGIC CROSS SECTION
LINE 1

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/11/07	Project No. 10354.000
Geomatrix		Figure 8



Explanation

L2-30 Seismic Refraction and Surface Wave Sounding Station ID

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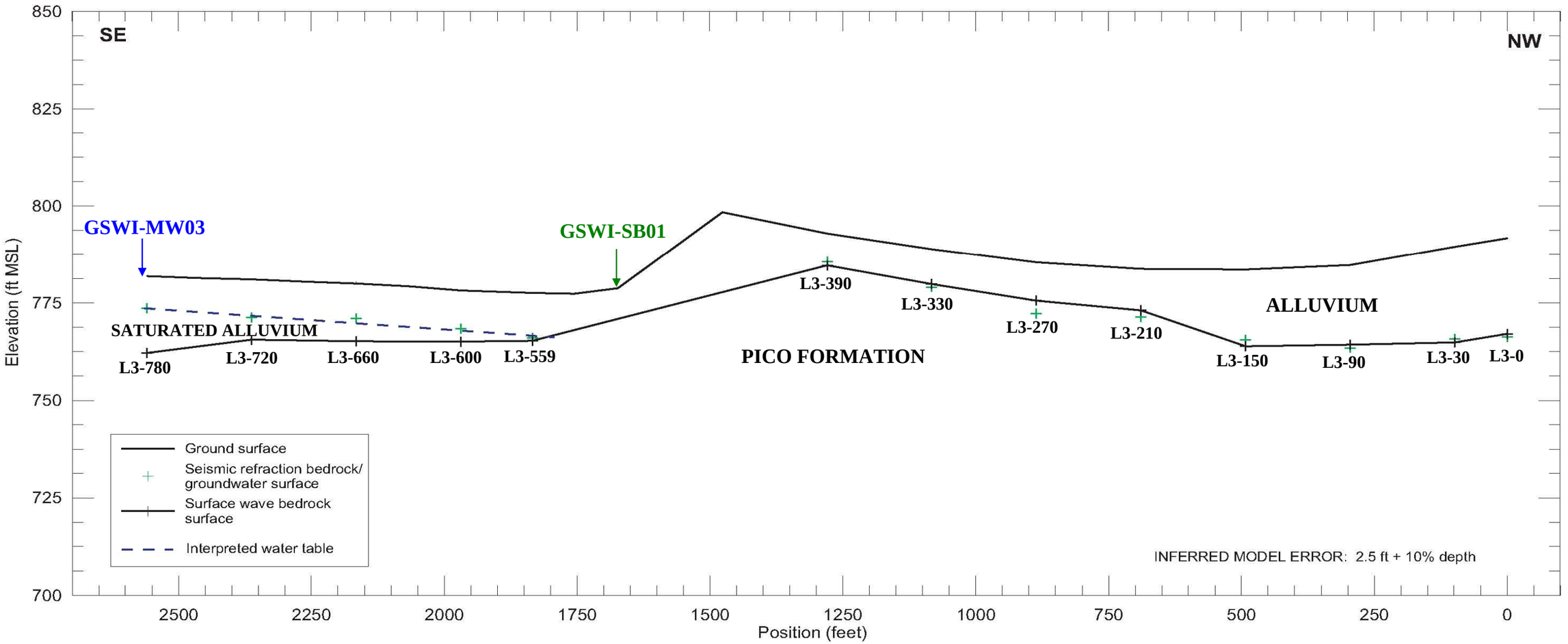
GEOLOGIC CROSS SECTION
LINE 2

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/11/07	Project No. 10354.000
Geomatrix		**Figure 9**



Explanation

GSWI-SB01	Exploratory Borehole
GSWI-MW03	Proposed Monitoring Well Location (subject to change)
L3-30	Seismic Refraction and Surface Wave Sounding Station ID

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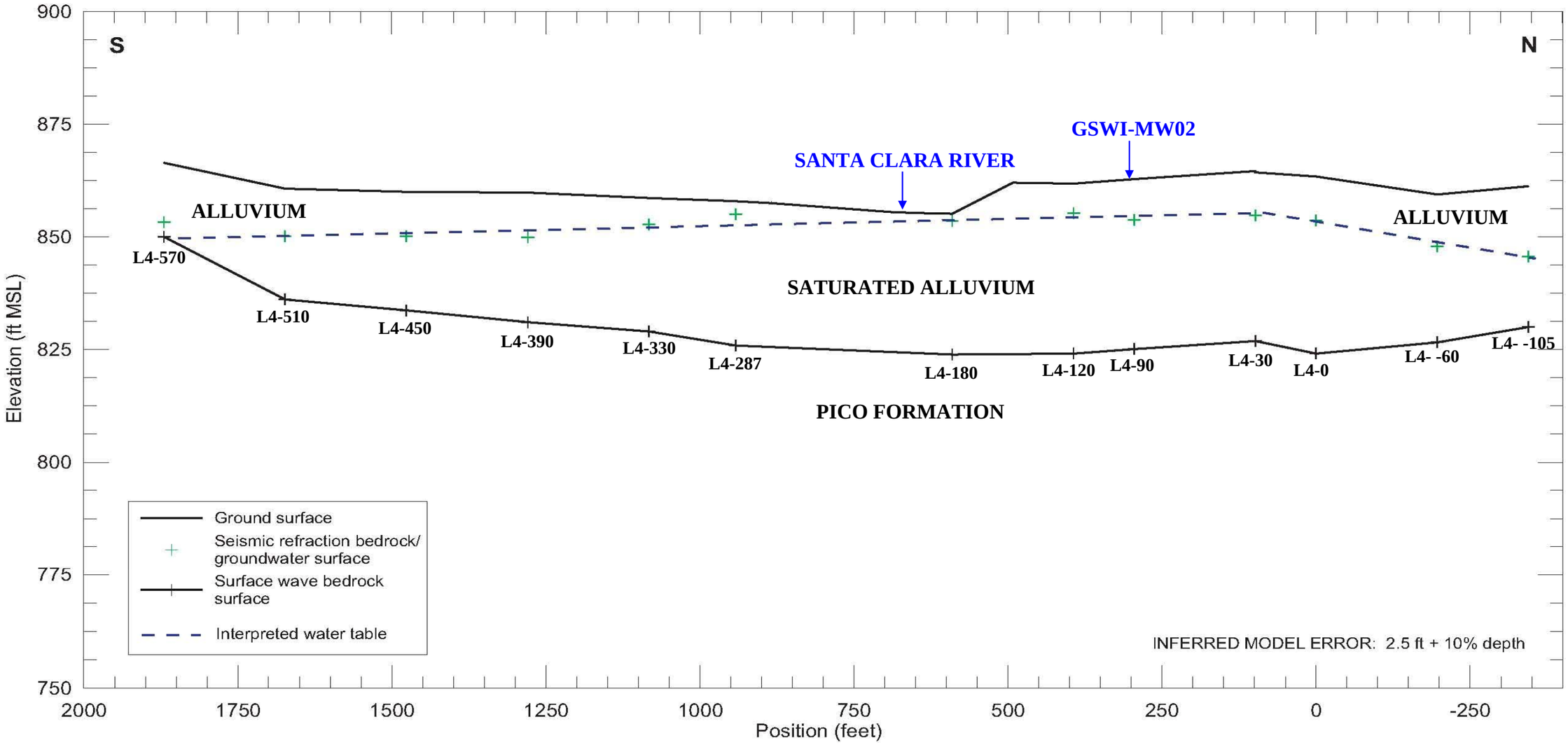
GEOLOGIC CROSS SECTION
LINE 3

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/11/07	Project No. 10354.000
Geomatrix		**Figure 10**



Explanation

GSWI-MW02 Proposed Monitoring Well Location (subject to change)

L4-30 Seismic Refraction and Surface Wave Sounding Station ID

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GEOLOGIC CROSS SECTION
LINE 4

Task 1B - Data Collection Upper Santa Clara River Chloride TMDL Collaborative Process

By: PRJ	Date: 05/11/07	Project No. 10354.000
Geomatrix		**Figure 11**