FUGRO WEST, INC.

July 19, 2010
Project No. 3000.025

4820 McGrath Street, Suite 100
Ventura, California 93003-7778
Tel: (805) 650-7000
Fax: (805) 650-7010

Las Virgenes Municipal Water District
4232 Las Virgenes Road
Calabasas, California 91302

Attention: Mr. John Zhao, P.E.

Subject: Preliminary Geotechnical and Geophysical Evaluations, and Discussion of Potential Rock Excavation Methods, Proposed Las Virgenes Water Storage Tank Site A, Westlake Village, California

Dear Mr. Zhao:

INTRODUCTION

This report presents the results of our preliminary geotechnical and geophysical evaluations of the proposed Las Virgenes Water District (LVMWD) Storage Tank Site A in Westlake Village, California. The purpose of the geotechnical and geophysical evaluations was to provide preliminary evaluations of the rock excavation characteristics and generalized discussion of potential rock excavation methods for the new tank site. Tank Site A is located on the north side of a ridge near the northwestern portion of the Las Virgenes Reservoir, south of the "saddle dam." The topography across the tank site ranges in elevation from about 1060 to 1100 feet above mean sea level, and descends in a northerly direction.

The proposed tank site will be located on hard volcanic (basalt andesite and diabase) rock of the Conejo Volcanics that we understand was excavated to the current configuration during the grading of the existing reservoir embankments.

SCOPE OF WORK

The scope of work consisted of performing preliminary geotechnical and geophysical evaluations of the rock excavation characteristics and summarizing potential excavation methods that might be used for construction of the tank site.

TASK 1 - PRELIMINARY GEOTECHNICAL AND GEOPHYSICAL EVALUATION

Task 1 consisted of mapping geologic conditions at the site, performing geophysical surveys, interpretation, and evaluation of the findings.

Task 1a - Geologic Mapping

Site Reconnaissance and Mapping. The site was visited to observe and map existing geologic conditions and lay out the backhoe test pit locations and the geophysical survey lines.

Backhoe Mapping. Four shallow backhoe trenches were excavated and logged. The trench data were used to supplement the geologic mapping, geophysical evaluation, and the excavation evaluation. Trench locations are shown on Plate 3 - Site Geologic Map. The logs of the exploratory trenches are presented on Plates 4a through 4d - Trench Logs. The trench excavation and logging are discussed further in Appendix A- Field Exploration.

Task 1b - Seismic Refraction Surveys

Six seismic lines were performed across the tank site to help characterize the conditions. The geophone/seismic line locations were located using DGPS survey techniques. The locations of the seismic lines are indicated on Plate 5 - Seismic Line Location Map

Several compressional (P) wave seismic refraction surveys were performed across the proposed tank area. We utilized linear arrays of twenty-four, 10 Hz, vertical geophones connected to a DAQLINK II seismograph. The input energy was created using a 20-pound sledge hammer striking an aluminum plate at the ground surface. Both interior and off-end shot points were used. Repeated blows at each shot point were stacked to improve the signal-to-noise ratio. The resulting field data were processed using tomographic methods (Rayfract™ and SeisOpt 2D) and the General Reciprocal method (IXrefraX). The results of the seismic refraction surveys are displayed as profiles of P-wave velocity versus depth on Plates 6 through 11.

For all six of the lines, we also gathered passive surface-wave data so that we could estimate the 1-D building code site classification. Those surface wave data were processed using Refraction Microtremor (ReMi) methodology (SeisOpt ReMi) (Plates 10a through 10f and 11).

TASK 2 - SUMMARY OF POTENTIAL ROCK EXCAVATION METHODS

Based on our previous experience in the Conejo Valley area with excavations within rocks of the Conejo Volcanics, the most common excavation methods are: 1) hoe ramming/breaking, 2) blasting, 3) non-explosive excavation methods, and 4) ripping with a large dozer (D9, D10, or larger, if conditions permit).

To evaluate the potential excavation methods, we have reviewed the preliminary geotechnical data (Fugro, 2009) and preliminary grading/excavation plans by AECOM, reviewed findings from Task 1, and then evaluated and summarized some of the potential excavation methods. We have compared and contrasted factors such as: 1) relative excavation rate (slow, moderate, fast), 2) ground motion/vibration/noise that could impact adjacent improvements and residences, and 3) specialized construction considerations required for blasting, such as pre- and post-blast surveys. The potential rock excavation methods are summarized in this report.

TASK 3 - GEOTECHNICAL AND GEOPHYSICAL EVALUATIONS AND REPORTING

The results of the Task 1 geologic mapping and geophysical surveys are evaluated and presented in this written report documenting the findings, opinions, and conclusions developed for this study.

FINDINGS

GEOLOGIC SETTING

Regional Geology

Tank Site A is located in the Transverse Ranges geologic/geomorphic province of California. This province is characterized by generally east-west-trending mountain ranges composed of sedimentary and volcanic rocks ranging in age from Cretaceous to Recent. Major east-trending folds, reverse faults, and left-lateral strike-slip faults reflect regional north-south compression and are characteristic of the Transverse Ranges. The regional geology of the area in the vicinity of the site is portrayed in Plate 2- Regional Geologic Map.

The site is not located within an Alquist-Priolo Fault Rupture Hazard zone and no known active or potentially active faults trend toward or transverse the site.

Site Geology

The site is underlain by volcanic rocks of the Conejo Volcanics. On their regional geologic map, Dibblee and Ehrenspeck (1993) indicate that the site is underlain by massive to vaguely bedded flow basalt and breccia. Based on our surface mapping and observations of earth materials exposed in trench bottoms and sidewalls, the site is underlain by interbedded hard to extremely hard igneous volcanic rocks, including basalt, vesicular basalt, diabase, and agglomerate. The rock units exposed at the surface and in the trench excavations vary from moderately weathered to slightly weathered. Exposure of the earth materials and unit contacts was limited due to the hardness of the rock with depth. In some areas, the extent of weathering of the volcanic rocks made rock identification difficult. In addition to the volcanic-bedrock units, colluvium mantles the site and has filled in local topographic depressions and swales.

For site characterization, the volcanic rocks at the site have been grouped into six simplified map units based on color, lithology, and/or rock characteristics. The distribution of the geologic units is presented on Plate 3 - Site Geologic Map. The zone that could be excavated with the backhoe is generally classified as moderately weathered ("Rock hammer does not ring when rock is struck, Body of rock is slightly weakened." [Caltrans, 2010]). The thickness of the moderately weathered zone is indicated on the trench logs as the depth that could be excavated (Plates 4a through 4d). Slightly weathered (rock "hammer rings when crystalline rocks are struck" (Caltrans, 2010)) volcanic rocks are exposed at, or near, ground surface in the southern, eastern, and southeastern portion of the site.

The geologic units encountered in the trenches excavated on the site (their descriptions are summarized below) are applicable only to those materials observed to the depths penetrated:

Orange Diabase: This unit is gray diabase weathered to a brownish yellow ("orange" in appearance) diabase with strong brown, and dark reddish brown mineralization/alteration products. The upper 2 to 2.5 feet is generally moderately weathered. The moderately weathered unit is hard to moderately hard, and intensely to moderately fractured (1 inch to 1 foot spacing).

Dark Gray Diabase: This unit consists of dark gray to black phaneritic diabase with reddish brown to weak red banding. Brownish yellow alteration/weathering products were observed on fracture/shear surfaces. A dark gray welded ash(?) layer was observed within the unit in Trench 3. The upper 1.5 to 2 feet is generally moderately weathered. The moderately weathered unit is hard to moderately hard, and intensely to moderately fractured (1 inch to 1 foot spacing).

Platy Diabase: This unit is very hard black porphyritic diabase, which breaks into platy to prismatic fragments due to jointing and fracturing. The joint and fracture spacing is very intense to moderate (chips to 1 foot). The unit is generally slightly weathered. Trench depths, in this unit, varied from 1 to 2.5 feet.

Purple Basalt: This unit is weak red to dusky red vesicular to scoriaceous basalt, and basalt breccia with a weak red aphanitic matrix. The upper 1 to 2 feet is generally moderately weathered. The moderately weathered unit is hard to moderately hard, and very intensely to slightly fractured (chips to 3 foot spacing). Within about 1 foot of shear zones, the rock borders on intensely weathered, and is very intensely to intensely fractured (chips to 4 inch spacing). Outcrops of hard to very hard, slightly weathered, basalt are present in the southwestern portion of the site and were encountered in Trench 3.

Agglomerate: The agglomerate consists of gravel-to cobble-size volcanic rock clasts/fragments in a gray to dark gray andesitic basalt matrix. Where altered and/or weathered the unit is yellow with brownish yellow, yellowish brown, and dark reddish brown mineralization/alteration products. The moderately weathered zone varies in thickness from none to four feet and is generally intensely to slightly fractured (1 inch to 3 foot spacing). Slightly weathered agglomerate is present at the ground surface down to within 0.5 feet of ground surface in the central portion of Trench 2 and western half of Trench 4. The slightly weathered agglomerate is generally hard to very hard, with unfractured znes and areas that have moderate fracture spacing (4 inch to greater than 3 foot). Shears traverse the northwestern portion of this unit (see Plate 3 - Site Geologic Map). Within about 1 foot of shear zones, the rock borders on intensely weathered, and is moderately hard to hard and very intensely to intensely fractured (chips to 4 inch spacing).

Reddish Purple Diabase: This unit consists of gray to dark gray phaneritic diabase with dusky red to weak red banding. The upper 2 to 3 feet is generally moderately weathered. The moderately weathered unit is hard to moderately hard, and intensely to slightly fractured (1 inch to 3 foot spacing).

Colluvium: The colluvial unit is commonly a massive, nonindurated, loose to medium dense, brown clayey sand (SC) with scattered gravel and cobbles. The east end of Trench 1 encountered a foot of colluvium. Three and a half feet of colluvium was encountered at the west end of Trench 4.

The mapped rock units generally appear to have a north-south strike. It was generally difficult to determine the dip of the contacts due to the limited exposure and degree of weathering. A measurement of the bedding orientation was obtained from the contact between the Platy Diabase and Purple Basalt units in Trench 2. That measurement suggests that the units dip gently (about 10 to 12 degrees) to the southeast, at that location, which is consistent with nearby bedding measurements shown on the regional geologic map (Plate 2).

Tectonic shears and highly weathered (moderatetly weathered bordering on intensely weathered (Caltrans, 2010)) zones were observed to cut diagonally through the site, traversing from the southwest to the northeast, as shown on Plate 3 - Site Geologic Map. The brownish-yellow stained thin shears with associated 1 to 2 foot-thick moderately, bordering on intensely, weathered zones are near vertical and generally have an east-west to northeast-southwest orientation.

SEISMIC REFRACTION SURVEY

Six P-wave seismic refraction surveys were performed at the site, at the locations shown on Plate 5. A 24-channel digital seismograph was used to acquire the data and the results were processed and interpreted using three different refraction methods. The three interpretation methods that were used for each line are: 1) tomographic interpretation using SeisOpt-2D, 2) tomographic interpretation using Rayfract^{TM}, and 3) GRM layer interpretation using IXrefraX. The procedures used for performing and interpreting those seismic refraction surveys are described in

Appendix B. The Westlake Reservoir tank site subsurface velocity profiles developed using seismic refraction methods are shown on Plates 7 through 9. The following summaries provide a general discussion of each line.

Refraction Line 1 is oriented approximately east-west and is located in the topographically lower (northern) portion of the site. Each of the three interpretation methods suggests that high-velocity rock materials are likely to be present within a few feet of the ground surface in the area from about geophones 11 through 16 and from about geophones 20 through 24. The IXrefraX program estimated the P-wave velocity of those near-surface materials at over 8000 feet per second (fps). The SeisOpt-2D and Rayfract™ programs estimated similarly high velocities, but they suggest a slightly deeper depth, however, that may be an artifact of the smoothing process used in their modeling techniques. The velocity profile interpreted using Rayfract™ appears to show an eastward inclination of a low-velocity zone, which may be the result of the eastward dip of the bedrock strata observed in our trenches. The higher velocities appear to be associated with the volcanic agglomerate bedrock.

Refraction Line 2 is oriented approximately northwest-southeast and extends from the topographically lower (northern) portion of the site into the topographically higher portion. Each of the three interpretation methods suggests that high-velocity rock materials are likely to be present within a few feet of the ground surface in the area from about geophones 7 through 10 and from about geophones 14 through 19. The IXrefraX program estimated the P-wave velocity of those near-surface materials at over 5000 fps. The SeisOpt-2D and Rayfract™ programs estimated similarly high velocities. The hard materials that are located in the vicinity of geophones 14 through 19 are exposed as a resistant rock outcrop at the ground surface. The higher velocities appear to be associated with the volcanic agglomerate bedrock.

Refraction Line 3 is oriented approximately east-west and is located in the topographically lower (northern) portion of the site. The location of Line 3 approximately coincides with the location of Trench 1. Each of the three interpretation methods suggests that high-velocity rock materials are likely to be present within a few feet of the ground surface in the area from about geophones 14 through 18 and from about geophones 22 through 24. The two tomographic interpretations also suggest a near-surface high-velocity zone in the area of geophones 1 and 2. The IXrefraX program estimated the P-wave velocity of the near-surface materials at over 8000 fps in the area of geophones 14 through 18 and at over 5000 fps in the area of geophones 22 through 24. The SeisOpt-2D and Rayfract™ programs estimated similarly high velocities. The backhoe trenching encountered hard basalt and agglomerate in the area of geophones 14 through 18 and geophones 22 through 24. The backhoe trench exposed colluvial material near the eastern end of the trench that appears to be associated with low-velocity near-surface materials observed on the eastern end of refraction Line 3.

Refraction Line 4 is oriented approximately northwest-southeast and extends from the topographically lower (northern) portion of the site into the topographically higher portion. The location of Line 4 approximately coincides with the location of Trench 3. Each of the three interpretation methods suggests that high-velocity rock materials are likely to be present within a few feet of the ground surface throughout most of the length of the line. An exception is the area from about geophones 19 through 22, where a near-surface colluvial zone is present near the surface, as observed in Trench 3. The IXrefraX program estimated the P-wave velocity of the near-surface materials at over 5000 fps throughout most of the length of the line. The SeisOpt-2D and Rayfract™ programs estimated similarly high velocities. Along Line 4, we observed hard rock outcrops in the area of geophones 10 through 13, 16 through 19, and 21 through 24. The velocity profile interpreted using Rayfract™ appears to show a southeastward inclination of a low-velocity zone, which may be the result of the eastward dip of the bedrock strata observed in our trenches.

Refraction Line 5 is oriented approximately northwest-southeast and extends from the topographically lower (northern) portion of the site into the topographically higher portion. Each of the three interpretation methods suggests that there is a relatively thick zone (perhaps up to about 10 feet thick locally) of lower velocity colluvial and weathered bedrock material along the length of most of refraction Line 5. Near the southern end of Line 5 (in the topographically higher area of the site), the high-velocity rock materials appear to be closer to the ground surface (which is consistent with rock outcrops observed near the line in that area). The IXrefraX program estimated the P-wave velocity of the materials that are below the colluvial/weathered zone at over 5000-6000 fps. The SeisOpt-2D and Rayfract™ programs estimated similarly high velocities.

Refraction Line 6 is oriented approximately east-west and is located in the topographically higher (southern) portion of the site. The location of Line 6 approximately coincides with the location of Trench 2. Each of the three refraction interpretation methods suggests that high-velocity rock materials are likely to be present within a few feet of the ground surface throughout most of the central portion of the line. However, on both the eastern and western ends of Line 6, the near-surface materials appear to consist of lower-velocity colluvial/weathered rock materials, as observed in Trench 2. The IXrefraX program estimated the P-wave velocity of the near-surface materials at about 5000 fps throughout most of the central portion of the line. The SeisOpt-2D and Rayfract™ programs estimated similar or somewhat higher velocities. Along Line 6, we observed hard rock outcrops in the area of geophones 9 through 11 and 14 through 16, and trenching with the backhoe was nearly impossible through those areas. The higher velocities appear to be associated with the volcanic agglomerate bedrock.

On the basis of the seismic refraction results, the onsite bedrock velocities are generally high in the areas surveyed, and the lateral and vertical distribution of the high-velocity materials appears to be variable. In general, we suspect bedrock materials that will be difficult to excavate (and may require blasting or similar treatment) are likely to be encountered. Some scatter was observed in the seismic-refraction first-arrivals indicating the presence of inhomogeneities in the subsurface materials. Accordingly, significant variability in the excavatability (including excavation depth) of the surface materials should be expected across the project site. Velocities and subsurface geometry interpreted from refraction survey data may be more or less than actual, and estimated values should be considered only as a guide. Verification of the seismic depth sections is typically done using boring and/or test-pit data, and full-scale field tests of rippability using actual production equipment. A contractor with excavation experience in similar conditions should be consulted for expert advice on excavation methodology, equipment, production rate, and potential for oversized materials.

SHEAR WAVE VELOCITY SURVEY (ReMi)

To estimate the shear wave velocity of the earth materials in the area of the proposed Westlake Reservoir tank, we utilized the proven, non-destructive, passive surface-wave analysis technique referred to as ReMi (Refraction Microtremor) (Louie, 2001; Stephenson et al., 2005; Jaume et al., 2005). The technique uses surface waves generated by noise (e.g., traffic, equipment, wind, footsteps, etc.) to estimate subsurface soil characteristics. A description of the technique is provided in Appendix C.

The results of the ReMi analysis are presented on Plates 10a through 10f and summarized on Plate 11. On the basis of those results, we obtained V_{S100} (V_{S30}) results for the site that ranged from about 2280 to 2897 ft/sec (695 to 883 m/sec), with an average of about 2,590 ft/sec (about 790 m/sec). The range of results spans the boundary between the B and C site classifications (2,500 ft/sec; 760 m/sec) and the average is near the lower limit of the B site classification. Assuming that excavation and removal of near-surface low-velocity material is likely to accompany development of the site, it seems reasonable to utilize a site classification of B for design purposes.

SUMMARY OF POTENTIAL ROCK EXCAVATION METHODS

The excavation of hard rock materials, such as those encountered on the proposed tank site, may require the use of heavy ripping, blasting, or other specialized techniques. For over a century, explosive blasting has been an important method used to excavate hard rock. However, blasting has specialized permit requirements (due to the use of explosives) and can cause excessive noise, vibration, collateral damage, and fly-rock. Heavy ripping, using large excavation equipment, or mechanical methods such as hoe-rams are commonly used, but their success can depend on local rock characteristics and operator experience. Significant noise and vibration may accompany such mechanical excavation methods. In recent years, a number of small-scale methods that use small explosive or propellant charges, or specialized mechanical and hydraulic loading means have been proposed as alternatives to conventional blasting.

Efforts to develop alternatives to conventional explosive excavation have included water jets, firing high-velocity slugs of water or foam into pre-drilled holes, loading pre-drilled holes with viscous expansive chemicals, rapidly pressurizing pre-drilled holes with water or propellant-generated gases, mechanically loading pre-drilled holes with specialized splitters, various mechanical impact devices, and a broad range of improvements on mechanical cutters (Young, 1999). A search of the Internet, encounters many different products that appear to fit into those categories. A complete discussion of all of the various products/methods that have been developed is beyond the scope of this report, but a few selected types are discussed further below.

Expansive Viscous Chemical Agents

There are a number of rock-fracturing methods that utilize expansive viscous chemical agents. These chemicals are sometimes called "soundless chemical demolition agents" (SCDAs) or "non-explosive demolition agents." The process can be done on a small scale with a boulder, or on a large scale with a massive rock formation. It is controllable by the user, who decides where to drill the holes in order to achieve the desired effect.

For these SCDA methods, a pattern of holes is drilled partially through the rock materials to be fractured and a viscous fluid that commonly consists of powdery chemicals mixed with water is poured into the holes and allowed to setup. As the grout-textured fluid solidifies, significant expansion pressures are exerted on the rock materials, causing the development of tension fractures. Because the expansion takes place over the course of minutes to hours, flying rock debris, adverse vibrations, and noise are generally avoided. There are still vibration and noise concerns associated with the process of drilling the initial grout holes, but those typically are comparatively smaller than those associated with blasting or hoe-ram-type mechanical techniques. Products that are in this category include: Dexpan, RockFrac, Sylentmite Pour 'N Crack, Betonamit, DEMOSOL Type III, Bustar, and Crack.Ag. Under certain circumstances, the expansive grout-like mixture can be ejected from the filled hole, sometimes at high velocity, and may be referred to as a "blow out." Therefore, manufacturer safety precautions should be followed to protect workers when using these methods.

Non-Explosive Pyrotechnics

There is a class of rock-fracturing methods that utilize non-explosive pyrotechnical materials. These methods use combustible agents in conjunction with some type of igniter to generate significant expansion pressures within holes drilled into the rock material. These methods commonly use cartridges that contain a propellant, which when ignited produce high volumes of gas (such as nitrogen and carbon dioxide), to provide a pressure increase inside the sealed drill hole. The gas spreads through fissures and microcracks in the rock and breaks the rock in tension, rather than in compression as with explosives. Much less energy is required to break the rock in tension; therefore less energy needs to be dissipated on breakage. Although the propellants burn rapidly, they do not oxidize as rapidly as common explosives, thereby potentially reducing the noise and vibration effects that commonly accompany explosives. Products that are in this category include: Nonex, RocKracker, and PCF (Penetrating Cone Fracture), A similar process that uses liquid carbon dioxide that is converted to high-pressure carbon dioxide gas with ignition is referred to as the Cardox system.

Controlled-Foam-Injection Method

The Controlled-Foam-Injection (CFI) method is a proprietary technique that utilizes high-pressure foam as the fracturing medium to significantly reduce air-blast, fly rock, and toxic fume problems that are associated with explosive-based techniques. An injection barrel, with a proprietary hole-bottom seal, is used to inject high-pressure foam into the bottom of a pre-drilled hole in the rock to be broken. The hardware can be mounted on a conventional articulated boom for application to excavation and/or demolition operations. A percussive drill may be incorporated on the same boom, so that hole-drilling, indexing for injection barrel placement, and breakage can be carried out in a systematic and semi-automatic manner. This technology has been developed by Chapman Young and is available through his company Applied Geodynamics (Colorado), although there appears to be a limited number of rigs available at this time.

The following table provides a general qualitative comparison of some of the available methods for rock excavation.

METHOD	RELATIVE EXCAVATION RATE	POTENTIAL FOR GROUND VIBRATION/NOISE	NEED FOR SPECIALIZED PRE- AND POST-CONSTRUCTION DAMAGE SURVEYS
Heavy Ripping (D9, D10, etc.)	Reasonable rates possible if rocks are rippable; may not be possible to rip some very hard or un-fractured rocks	Relatively minor ground vibration and noise potential.	Pre- and post-construction damage surveys not typically performed. Vibration and noise monitoring may be advisable, if there are nearby receptors.
Blasting	Relatively slow process that requires shot-hole drilling, setting of charges, detonation, and removal of broken material.	Significant ground vibration and noise likely.	Pre- and post-construction damage surveys are commonly performed. Also, vibration and noise monitoring usually performed during drilling and blasts.
Non-explosive pyrotechnics	Relatively slow process that requires hole drilling, placement of pyrotechnics, detonation, and removal of broken material.	Noise and vibration potential associated with hole-drilling process. Slight to moderate potential for vibration and noise associated with rock-splitting process.	Pre- and post-construction damage surveys not typically performed. Vibration and noise monitoring may be advisable, if there are nearby receptors.
Mechanical Hoe-Ram	Moderate-speed process that requires breaking of localized hard-rock areas commonly accompanied by ripping and material removal using dozers.	Significant potential for noise accompanied by low-amplitude repetitive vibrations.	Pre- and post-construction damage surveys are advisable. Also, vibration and noise monitoring is recommended.
Expansive Chemical Agents	Relatively slow process that requires chemical-hole drilling, mixing and placement of chemicals, waiting for expansion, and removal of broken material.	Noise and vibration potential associated with hole-drilling process. Low potential for noise and vibration associated with rock-splitting process.	Pre- and post-construction damage surveys not typically performed. Vibration and noise monitoring may be advisable for drilling, if there are nearby receptors.
Controlled Foam Injection	Relatively slow process that requires hole drilling, indexing of injection device, pressurization, and removal of broken material.	Noise and vibration potential associated with hole-drilling process. Slight to moderate potential for vibration and noise associated with rock-splitting process.	Pre- and post-construction damage surveys not typically performed. Vibration and noise monitoring may be advisable, if there are nearby receptors.

CONCLUSION

We encountered fresh, hard, unfractured volcanic rock in the bottoms of the back-hoe trenches and in the seismic refraction profiles. Bedrock P-wave velocities in the upper 20 feet range from 5000 to over 9000 feet per second. Rocks with those properties typically require alternative excavation methods. Blasting was required to excavate the rock during construction of the existing dam. Contractors should make an initial site visit to observe rock and make an evaluation of the appropriate excavation methods. If blasting is used, the program will need to include a plan to mitigate velocities to an acceptable level offsite, and include blasting mats and other mitigations to prevent fly-rock.

Velocities and subsurface geometry interpreted from refraction survey data may be more or less than actual, and estimated values should be considered only as a guide. Verification of the seismic depth sections is typically done using boring and/or test-pit data, and full-scale field tests of rippability using production equipment.

CLOSURE

We have appreciated this opportunity to provide geotechnical services to LVMWD. Please call me at (805) 650-7000 if you have any questions.

Sincerely,

FUGRO WEST, INC.

Thomas F. Blake
Principal Engineering Geologist/Geotechnical Engineer

Attachments:

- Plate 1 - Location Map
- Plate 2 - Regional Geologic Map
- Plate 3 - Site Geologic Map
- Plates 4a through 4d - Trench Logs #1 through 4
- Plate 5 - Seismic Line Location Map
- Plates 6a through 6f - Travel Time Curves Line 1 through 6
- Plates 7a through 7f - Refraction Tomographic Profile Refraction Lines 1 through 6
- Plates 8a through 8f - Refraction Tomographic Profile Refraction Line 1
- Plates 9a through 9f - Refraction Profile - Layered Method Refraction Line 1 through 6
- Plates 10a through 10f - ReMi Line 1 through 6
- Plate 11 - ReMi Line Comparison
- Appendix A - Field Exploration
- Appendix B - Seismic Refraction Survey
  - Plate B-1 - D9T
  - Plate B-2 - D10T
  - Plate B-3 - D11T
  - Plate B-4 - D11T CD
  - Plate B-5 - Estimated Ripper Production Graphs
- Appendix C - Refraction Microtremor Analysis (ReMi)

REFERENCES

ASTM (2006) Standard Guide for Using the Seismic Refraction Method for Subsurface Investigation, Designation D-5777-00 (Reapproved 2006), ASTM International, 14 pp.

CDMG (2000), State of California, Department of Conservation, Seismic Hazard Zone Report for the Thousand Oaks 7.5-minute Quadrangle, Ventura and Los Angeles Counties, California, Seismic Hazard Zone Report 042.

CDMG (1997), Seismic Hazard Zone Report for the Calabasas 7.5-minute Quadrangle, Los Angeles and Ventura Counties, California, Seismic Hazard Zone Report 06.

Caltrans (California Department of Transportation) (2010), Soil and Rock Logging, Classification, and Presentation Manual., 82p.

Dibblee, T.W. (1992), *Geologic Map of the Calabasas Quadrangle, Los Angeles and Ventura Counties, California,* T.W. Dibblee Foundation, Map DF-37*.*

Dibblee, T.W. and H.E. Ehrenspeck (1993), *Geologic Map of the Thousand Oaks Quadrangle, Ventura and Los Angeles Counties, California,* T.W. Dibble Foundation, Map DF-49*.*

Jaume, S.C., Levine, N., Brown, C.H., and Cooper, S.L. (2005), "Shallow Shear Wave Velocity Structure of the Charleston Historical District, South Carolina: Comparison of Surficial Methods and Borehole Results," USGS Grant 05HQGR0072.

Louie, J.N. (2001), "Faster, Better: Shear-Wave Velocity to 100 Meters Depth from Refraction Microtremor Arrays," Bulletin of the Seismological Society of America, Vol. 91, No. 2, pp. 347-364.

Palmer, D. (1980), The Generalized Reciprocal Method of Seismic Refraction Interpretation, Society of Exploration Geophysicists, Tulsa, Oklahoma.

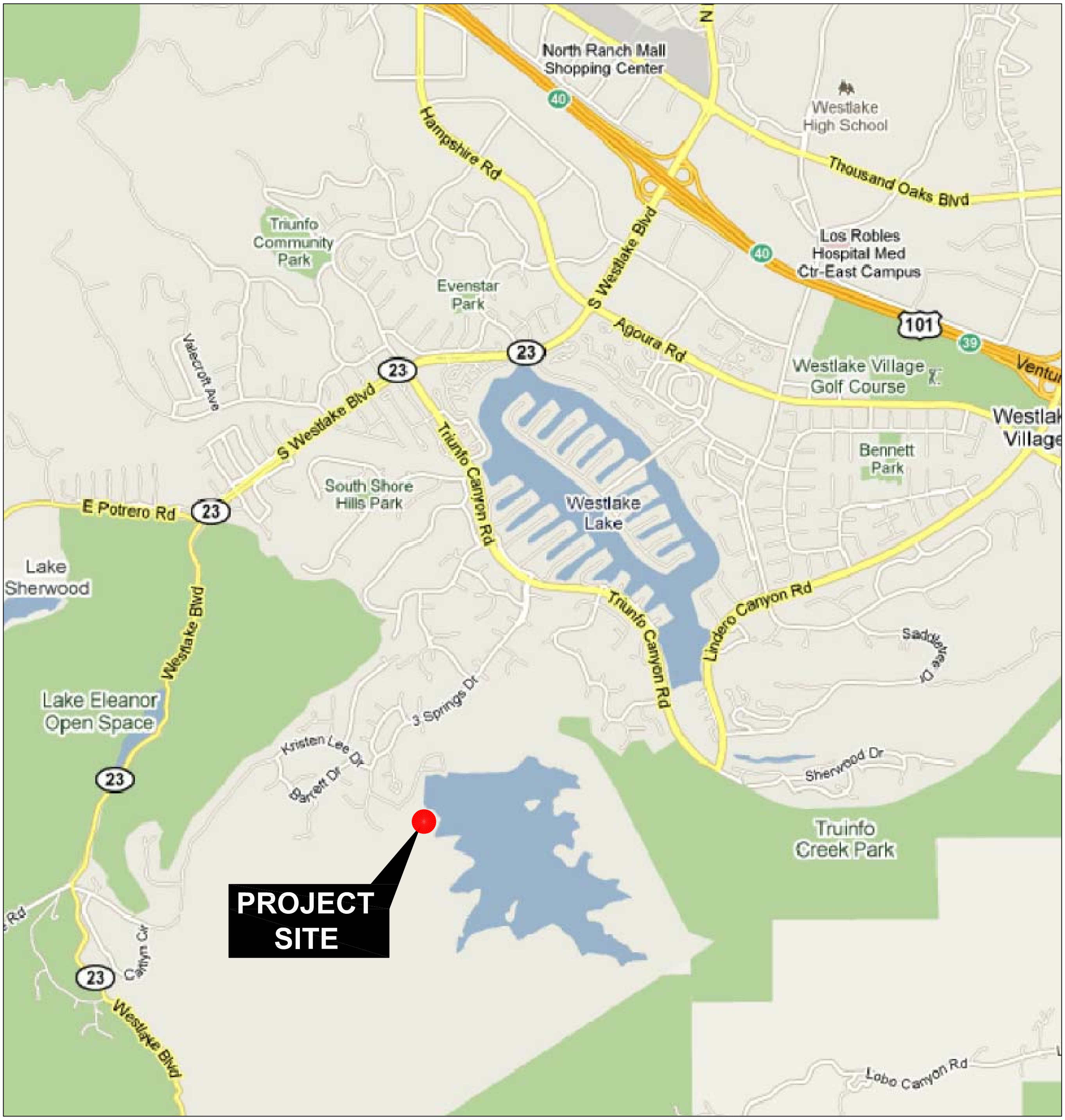
Schuster, G.T. and Quintus-Bosz, A. (1993) *Wavepath Eikonal Traveltime Inversion: Theory*, Geophysics, Vol. 58, pp. 1314-1323.

Stephenson, W.J., Louie, J.N., Pullammanappallil, S., Williams, R.A., and Odum, J.K. (2005), "Blind Shear-Wave Velocity Comparison of ReMi and MASW Results with Boreholes to 200 m in Santa Clara Valley: Implications for Earthquake Ground-Motion Assessment," Bulletin of the Seismological Society of America, Vol. 95, No. 6, pp. 2506-2516.

Weber, F.H., Jr. (1984), Geology of the Calabasas-Agoura-Thousand Oaks Area, Los Angeles and Ventura Counties, California Division of Mines and Geology Open-File Report 84-1-LA.

Young, C. (1999), "Controlled-Foam Injection for Hard Rock Excavation," *Proceedings of the 37th U.S. Rock Mechanics Symposium*, Vail, Colorado.

PLATES



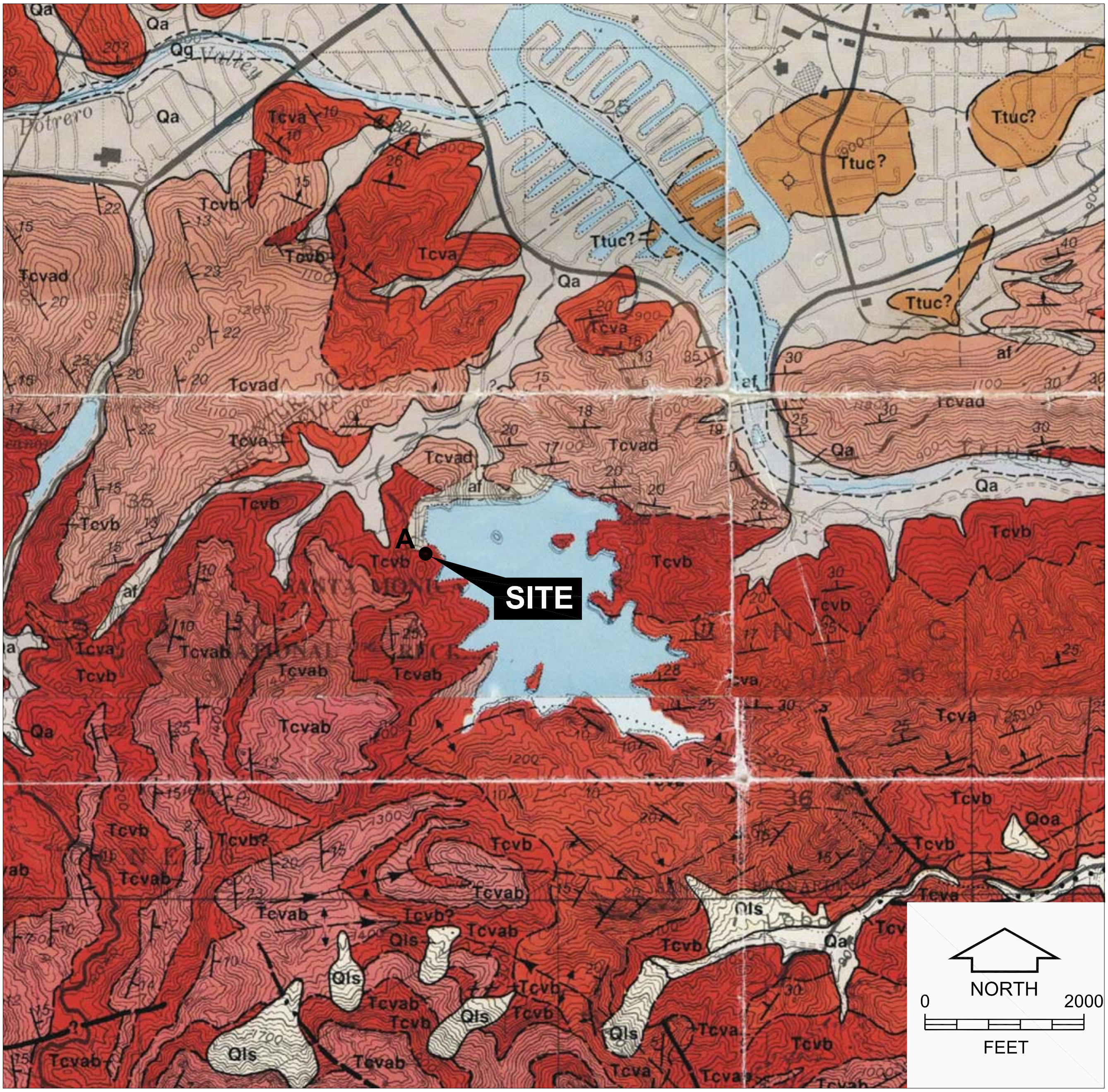
BASE MAP SOURCE: Google Maps 2010

NORTH
0 2400
FEET

LOCATION MAP
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 1

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-01 Location.dwg 07-15-2010 - 9:55am



BASE MAP SOURCE: Geologic Map of the Thousand Oaks and Point Dume Quadrangles (Dibblee & Ehrenspeck, 1993).

LEGEND

Qa	Alluvium
Qls	Landslide debris
Qoa	Older surficial sediments
Tm	Monterey Formation
Tmss	Monterey Formation, light gray to tan, semi-friable bedded sandstone
Tml	Monterey Formation, lower part
Tcvab	Conejo Volcanics, andesitic beccia with cobble to boulder-size inclusions
Tcva	Conejo Volcanics, andesitic flows, fine grained
Tcvb	Conejo Volcanics, basalt flows and breccia massive to vaguely bedded
Tcvad	Conejo Volcanics, andesite-dacite breccia with cobble to boulder-size angular inclusions
Tls	Detrital sediments of Lindero Canyon, sandstone
Tlsc	Detrital sediments of Lindero Cyn., conglomerate of granitic detritus
Tlvc	Detrital sediments of Lindero Cyn., basal epiclastic conglomerate
Ttuc	Upper Topanga Formation, clay shale and siltstone
Kcs	Chatsworth Formation, light gray to light brown sandstone

Formation contact

Member contact

Contact between surficial sediments

Anticline, dashed where approximate, dotted where concealed, arrow on axis indicates direction of plunge

Syncline, dashed where approximate, dotted where concealed, arrow on axis indicates direction of plunge

Strike and Dip of Beds:

20 inclined

inclined (approx.)

cv White calcite or travertine vein

Sandstone marker bed

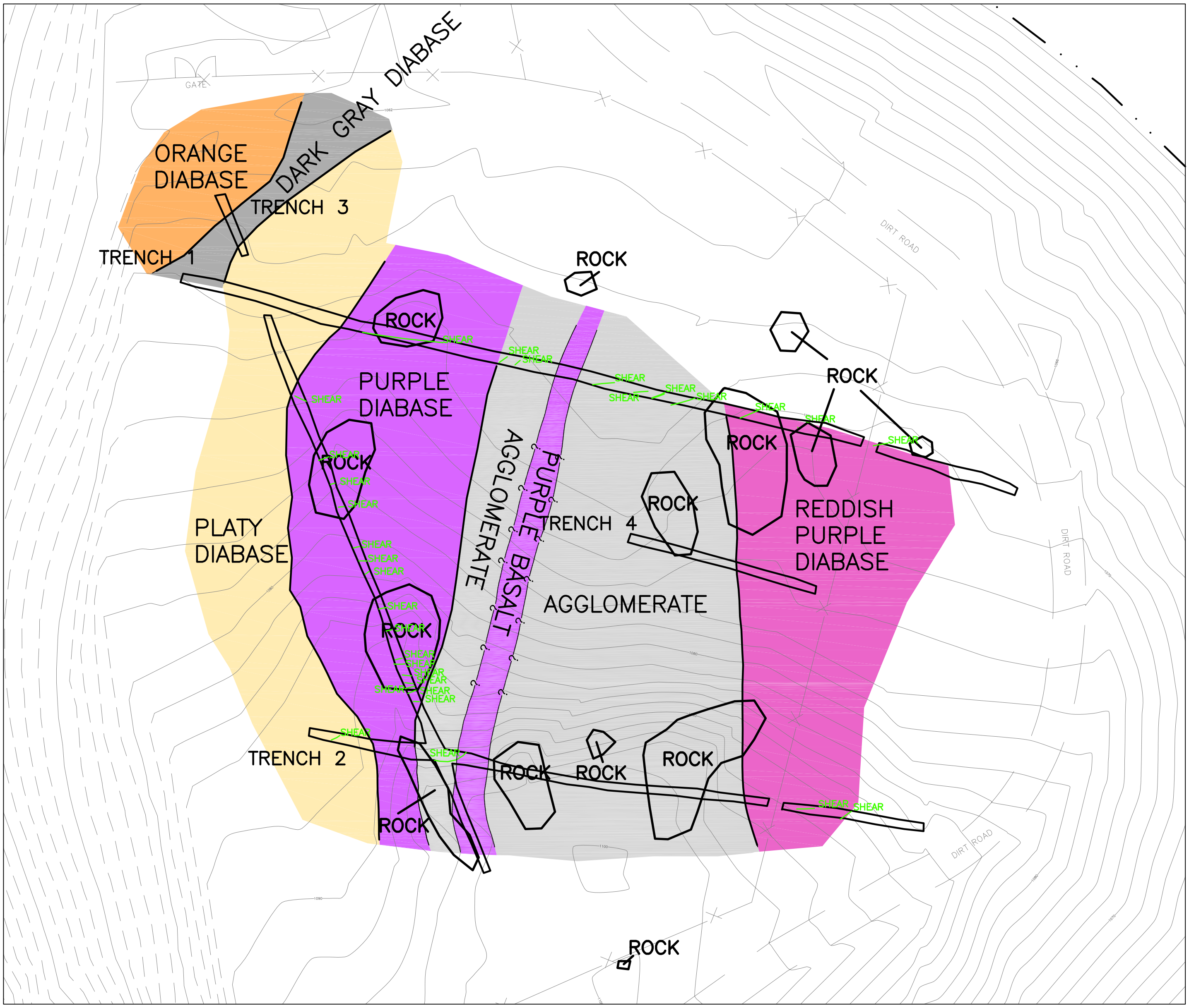
A Approximate location of tank site

REGIONAL GEOLOGIC MAP

Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 2

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-02 geomap.dwg 07-15-2010 - 9:56am



BASE MAP SOURCE: Topographic base map provided by AECOM.

LEGEND

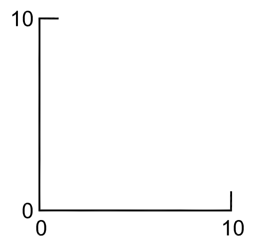
	Reddish purple diabase
	Agglomerate
	Purple basalt
	Platy jointed diabase
	Dark gray diabase
	Orange diabase
TRENCH 3	Backhoe trench location
ROCK	Approximate location of surface rock outcrop
SHEAR	Shear zone

NORTH
0 50
FEET

SITE GEOLOGIC MAP
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 3

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-03 Site Map.dwg 07-15-2010 - 4:41pm

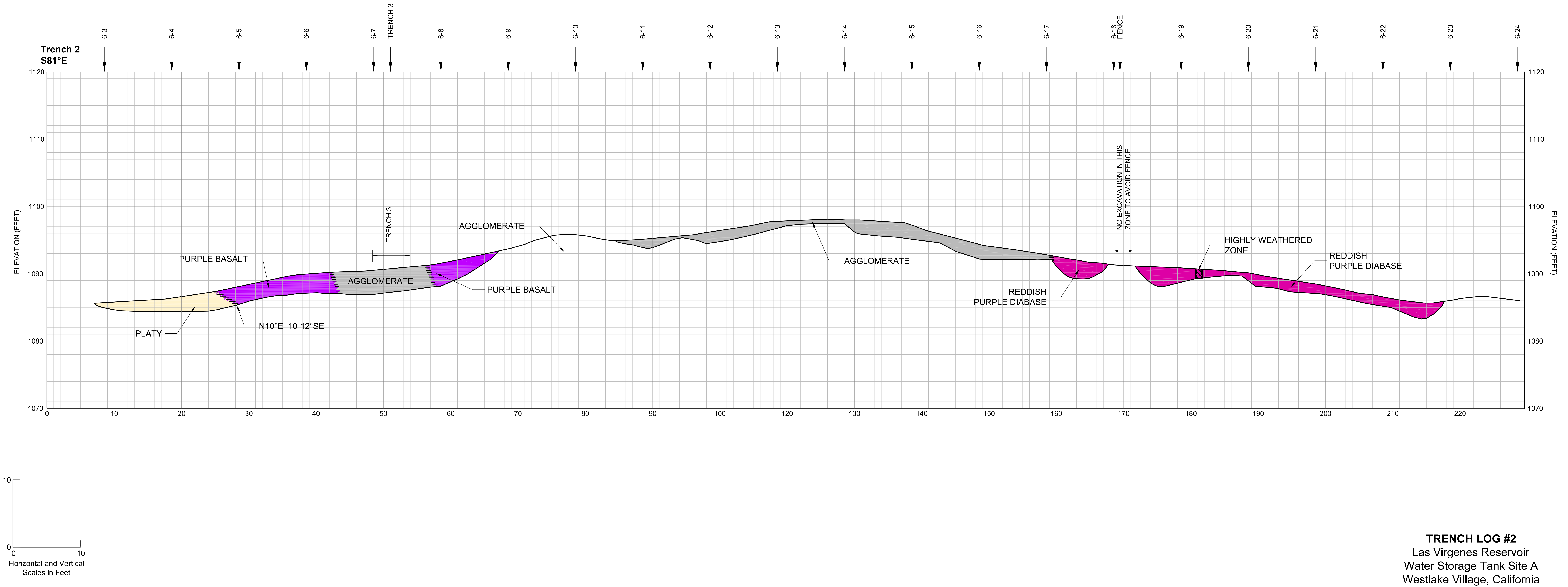


Horizontal and Vertical
Scales in Feet

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\C3000.025-04 Trench Logs.dwg 07-15-2010 - 4:31pm

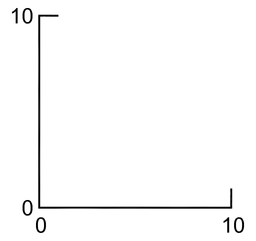
TRENCH LOG #1
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 4a



M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\C3000.025-04 Trench Logs.dwg 07-15-2010 - 9:59am

TRENCH LOG #2
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

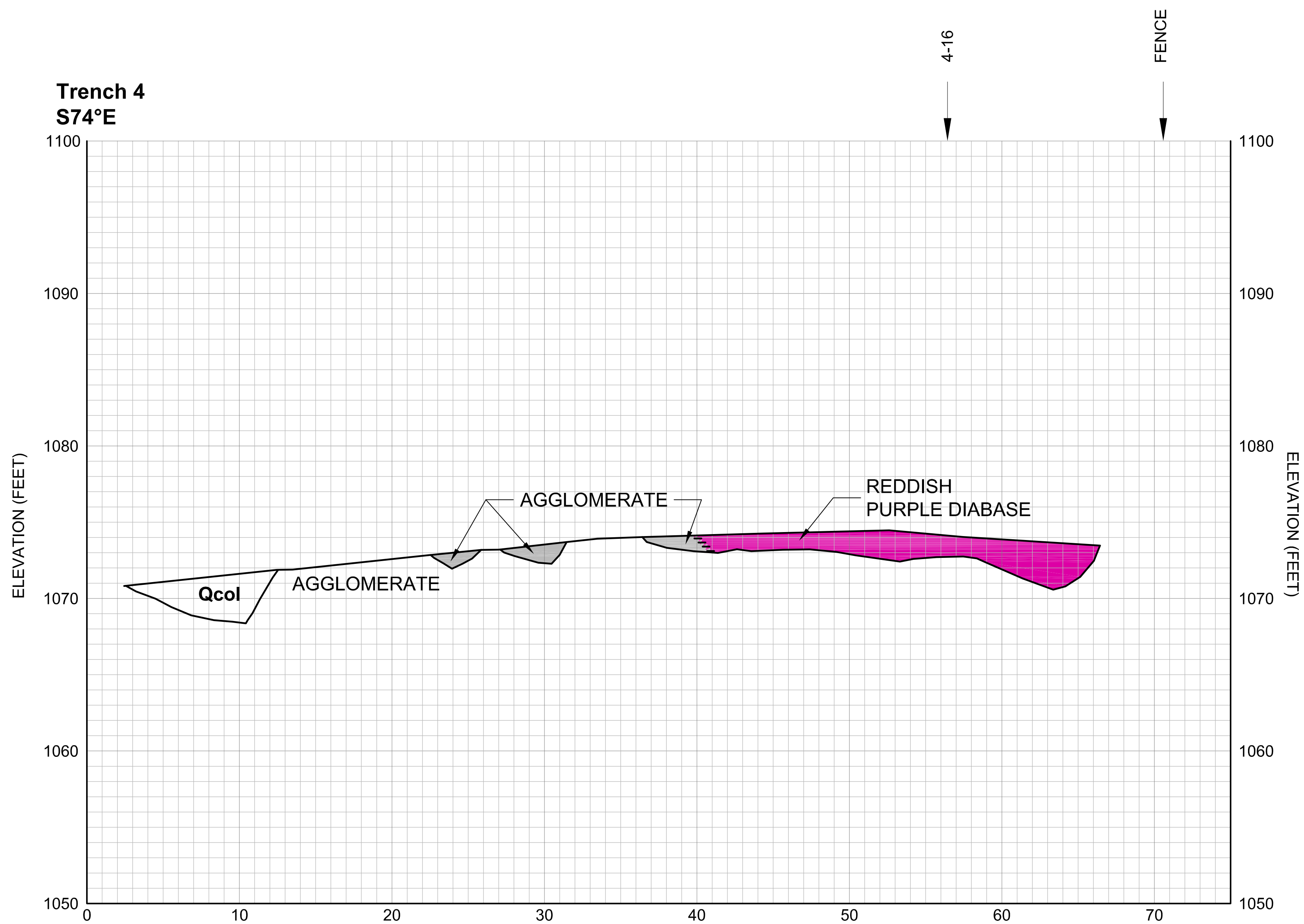


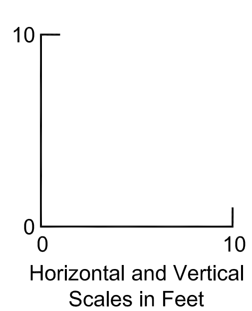
Horizontal and Vertical Scales in Feet

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\C3000.025-04 Trench Logs.dwg 07-15-2010 - 10:00am

TRENCH LOG #3
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 4c

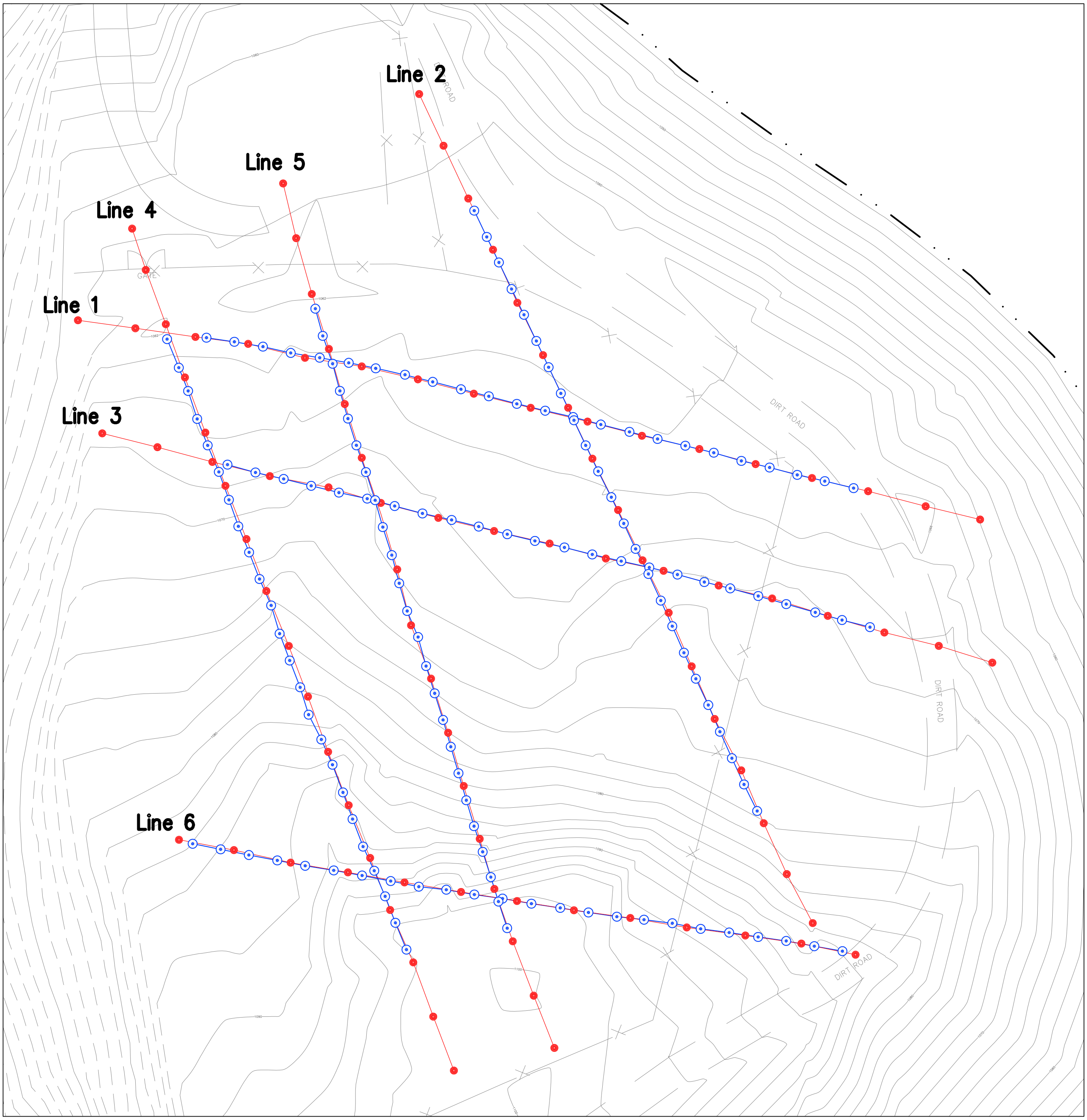




M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\C3000.025-04 Trench Logs.dwg 07-15-2010 - 4:32pm

TRENCH LOG #4
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

FUGRO



LEGEND

Approximate location of geophone

Approximate location of shotpoint

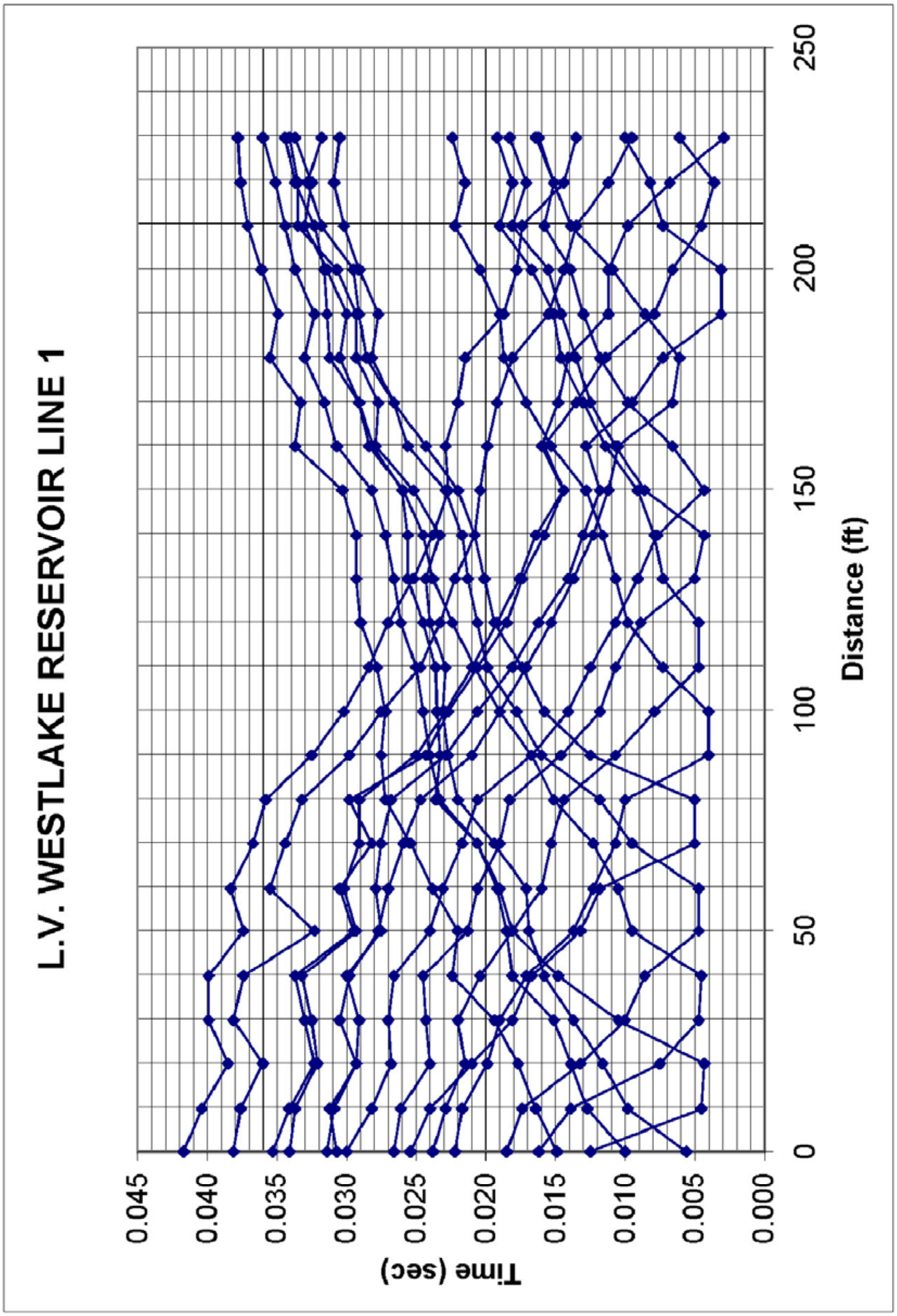
NORTH
0 50
FEET

SEISMIC LINE LOCATION MAP

Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

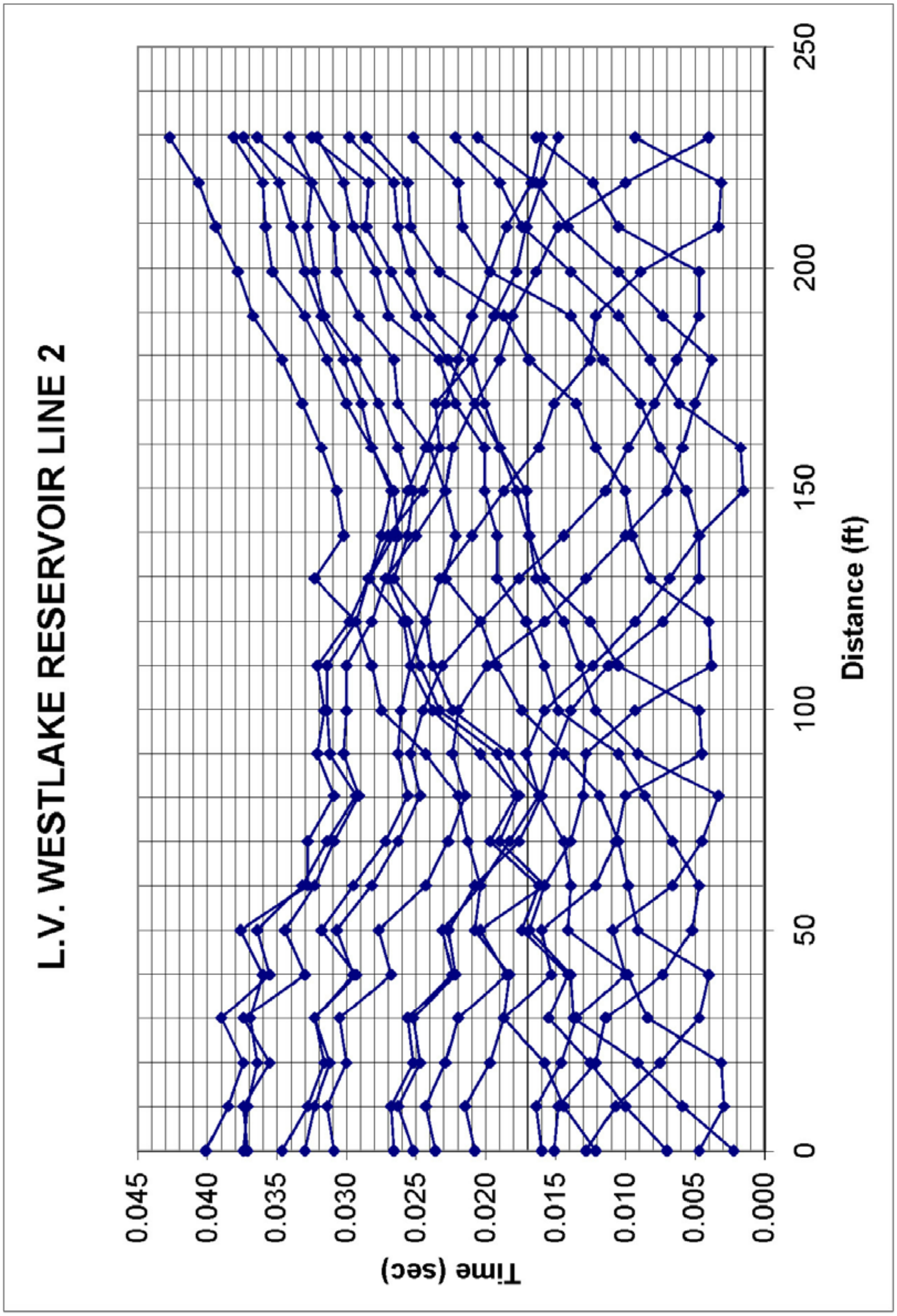
PLATE 5

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-05 Seis Loc.dwg 07-15-2010 - 10:08am



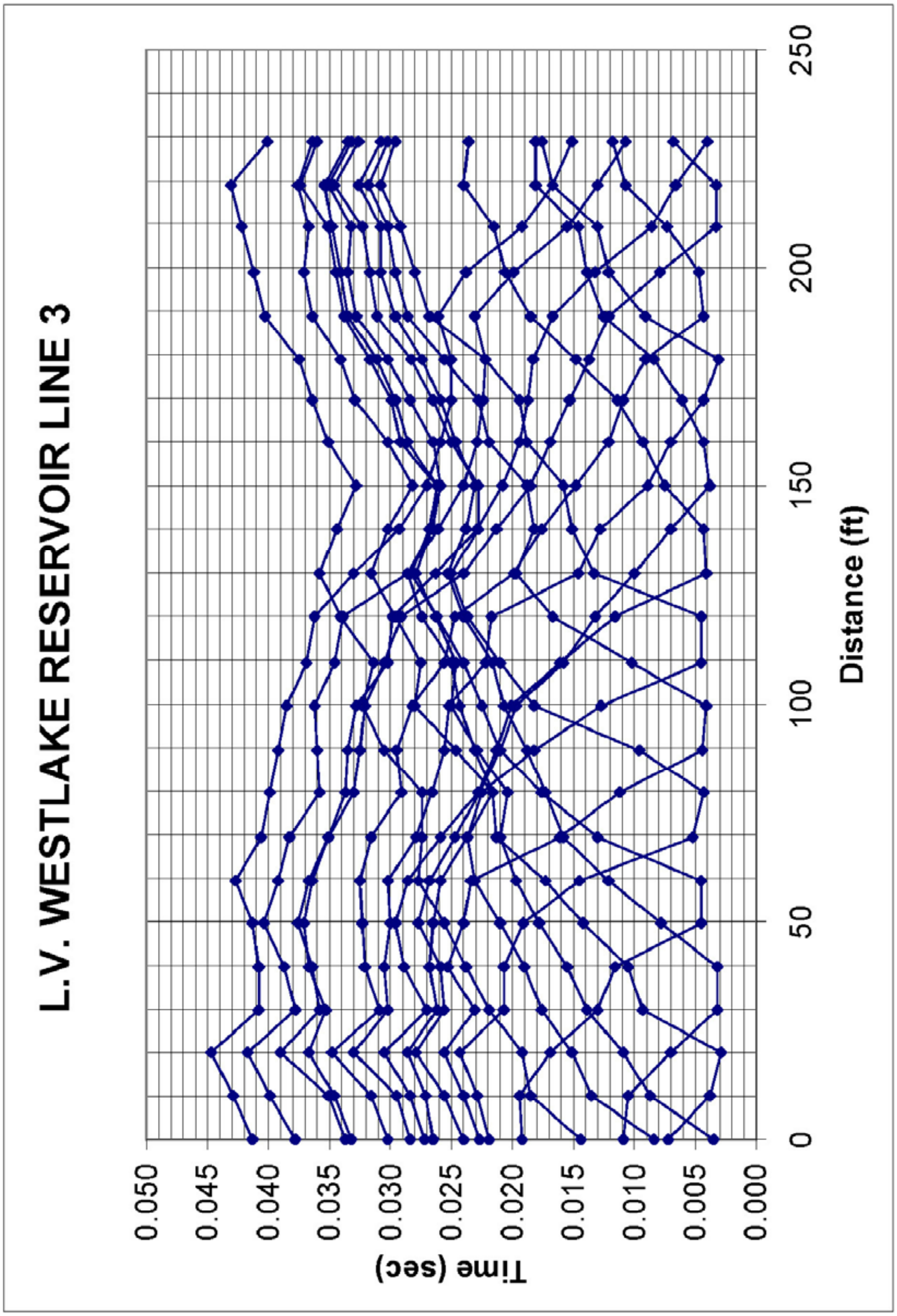
TRAVEL TIME CURVES (LINE 1)
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-06 TT Curves.dwg 07-15-2010 - 10:19am

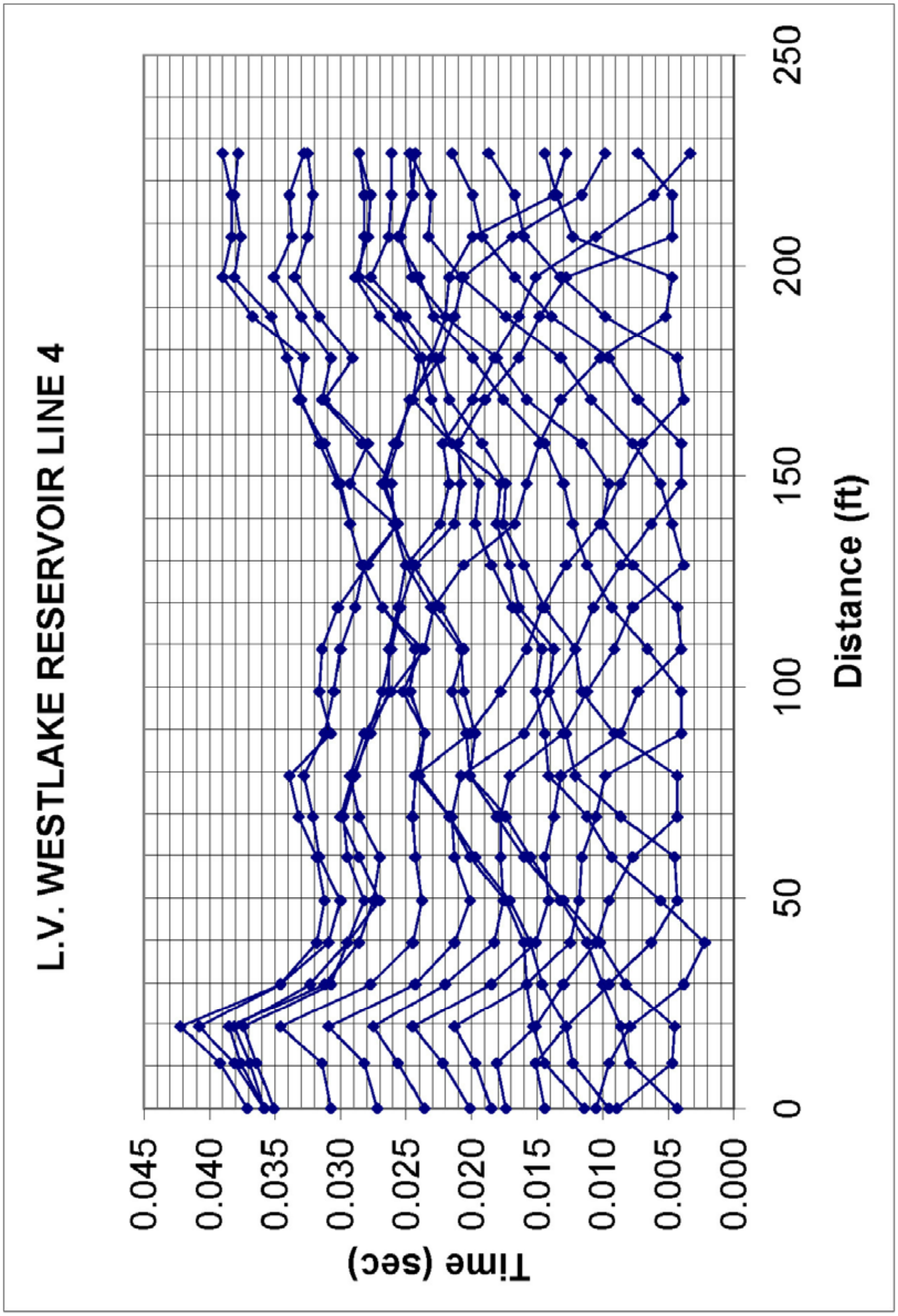


TRAVEL TIME CURVES (LINE 2)
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-06 TT Curves.dwg 07-15-2010 - 10:23am

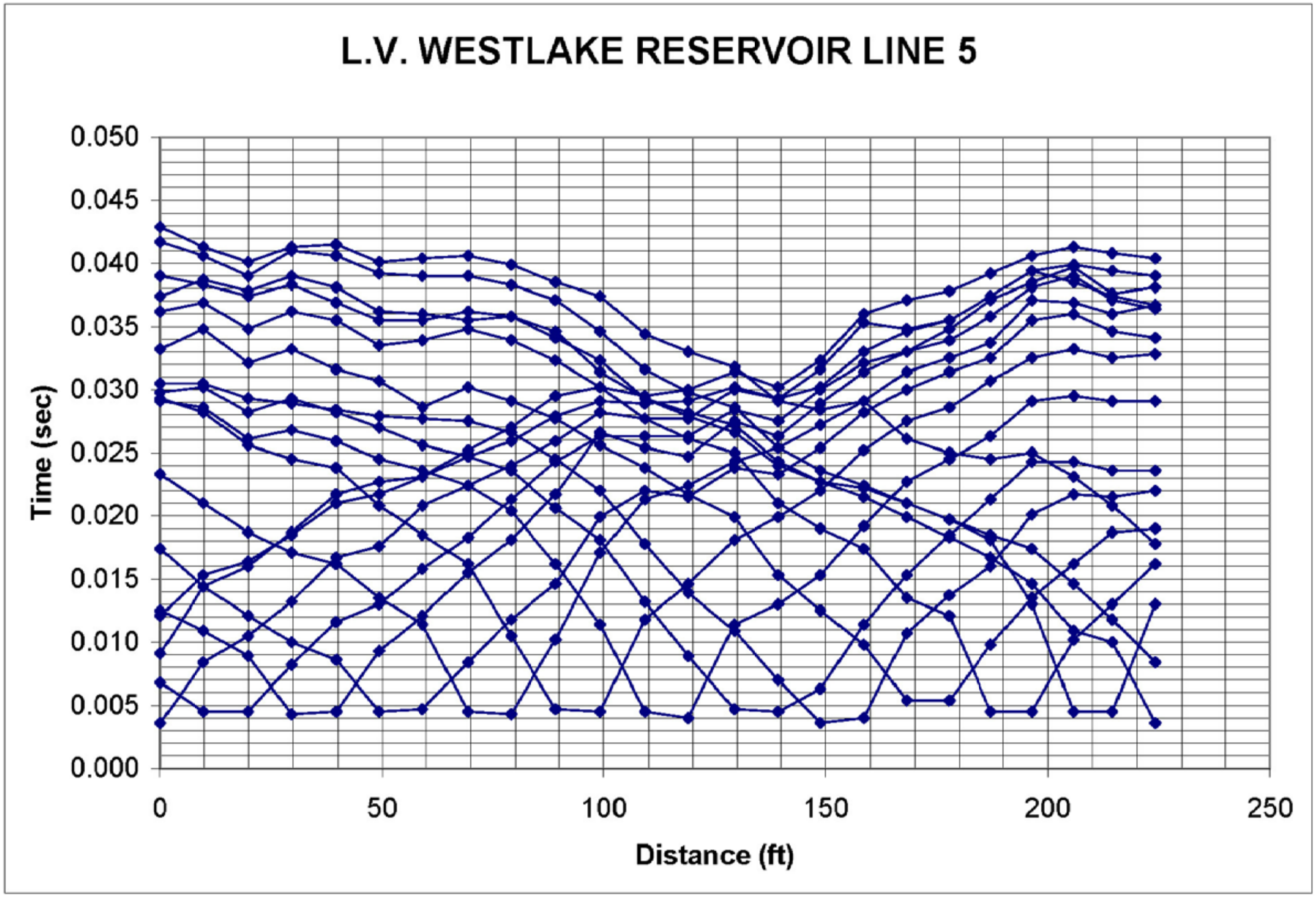


TRAVEL TIME CURVES (LINE 3)
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California



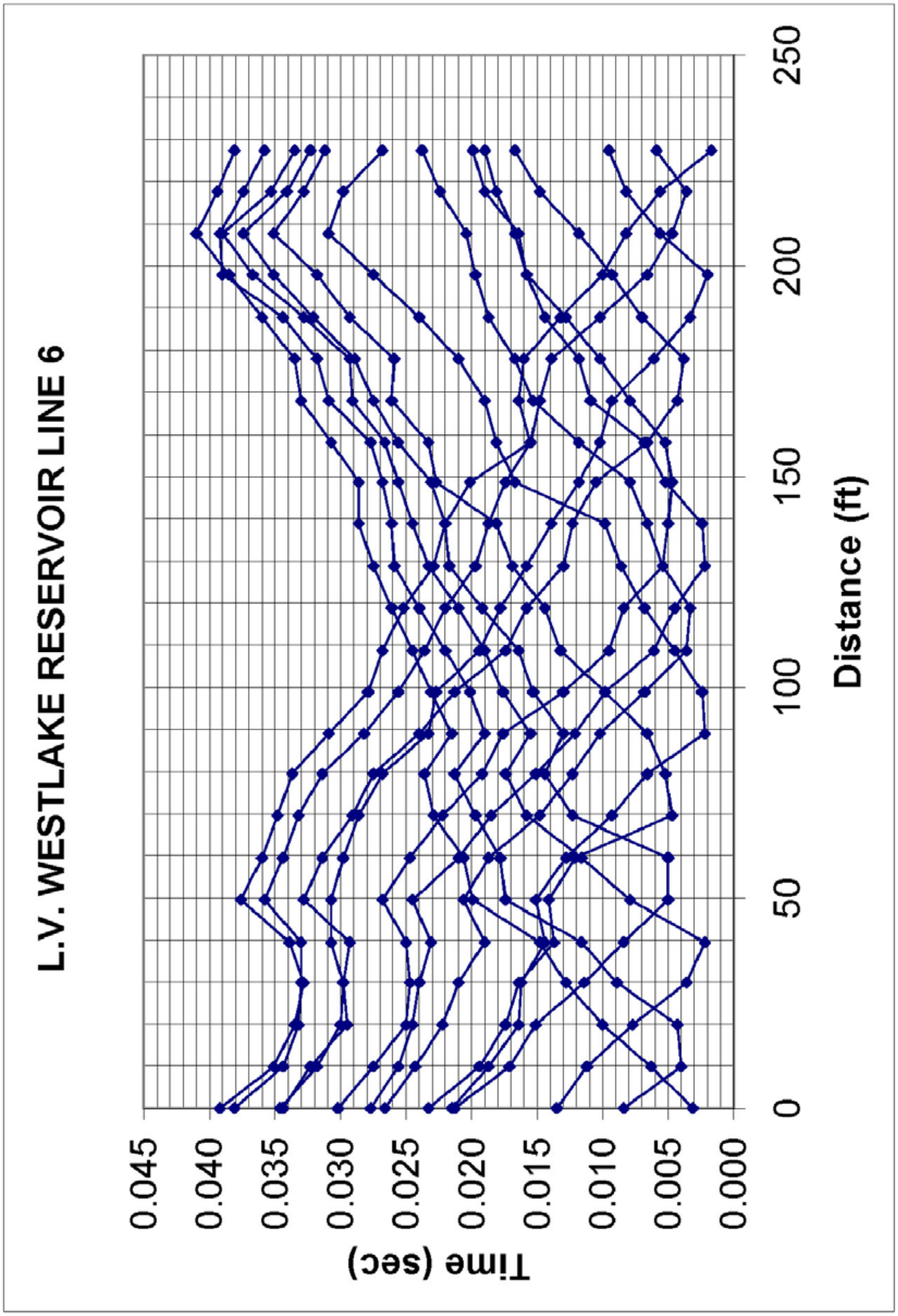
TRAVEL TIME CURVES (LINE 4)
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-06 TT Curves.dwg 07-15-2010 - 10:25am

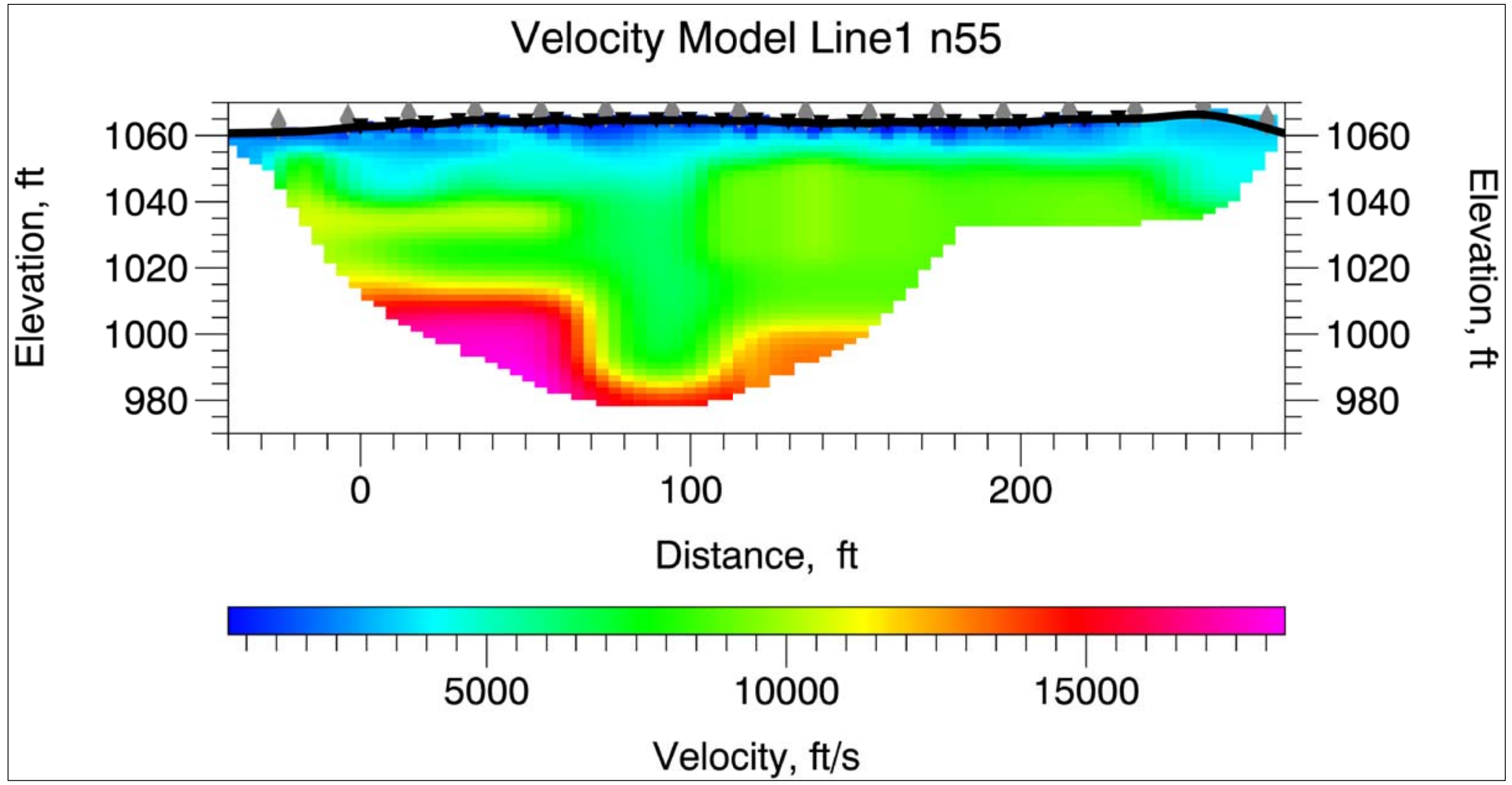


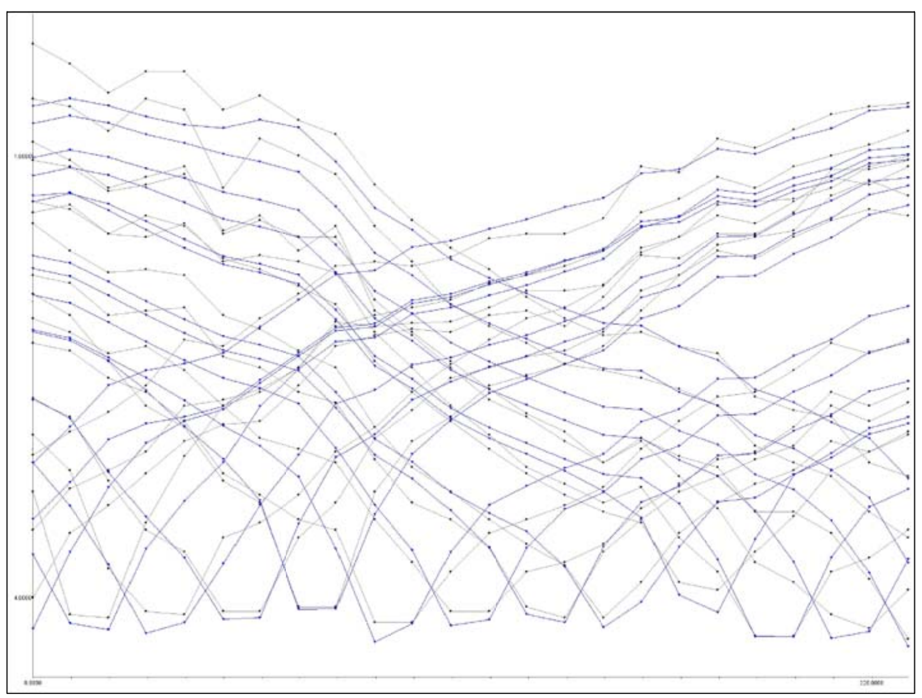
TRAVEL TIME CURVES (LINE 5)
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-06 TT Curves.dwg 07-15-2010 - 10:25am

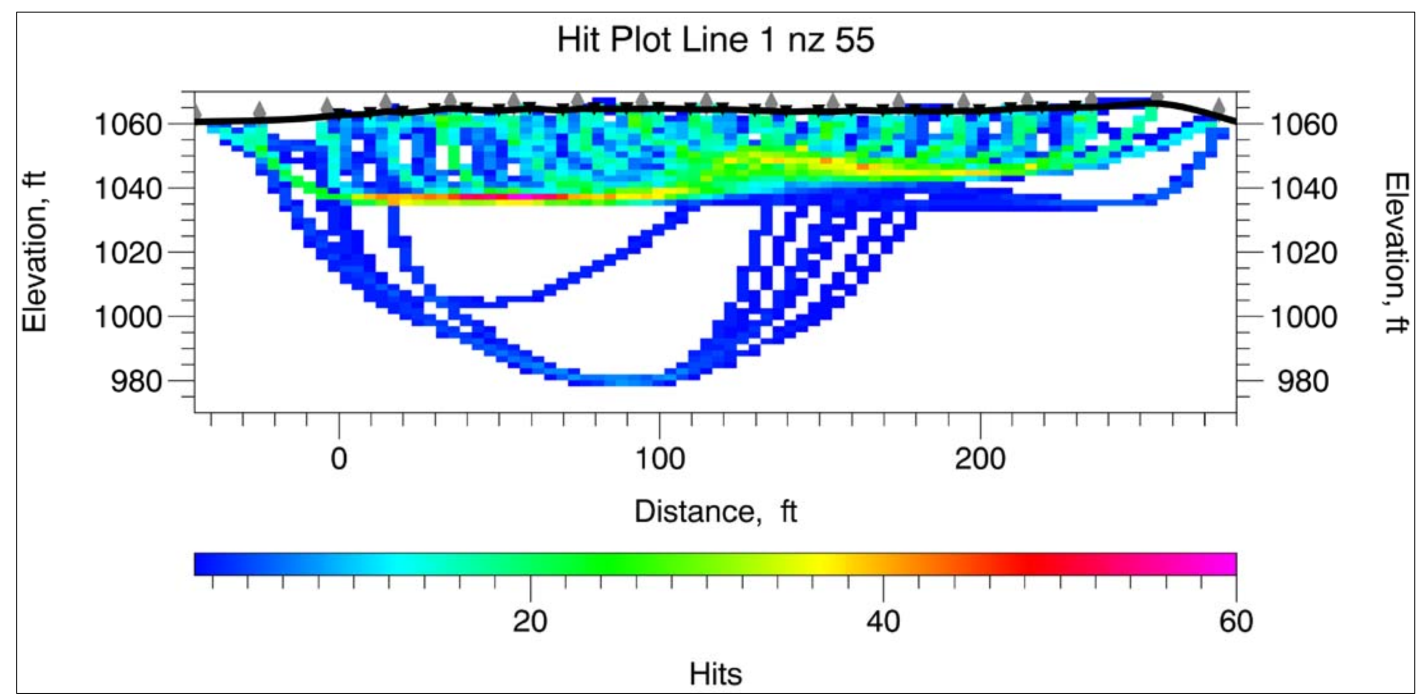


TRAVEL TIME CURVES (LINE 6)
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

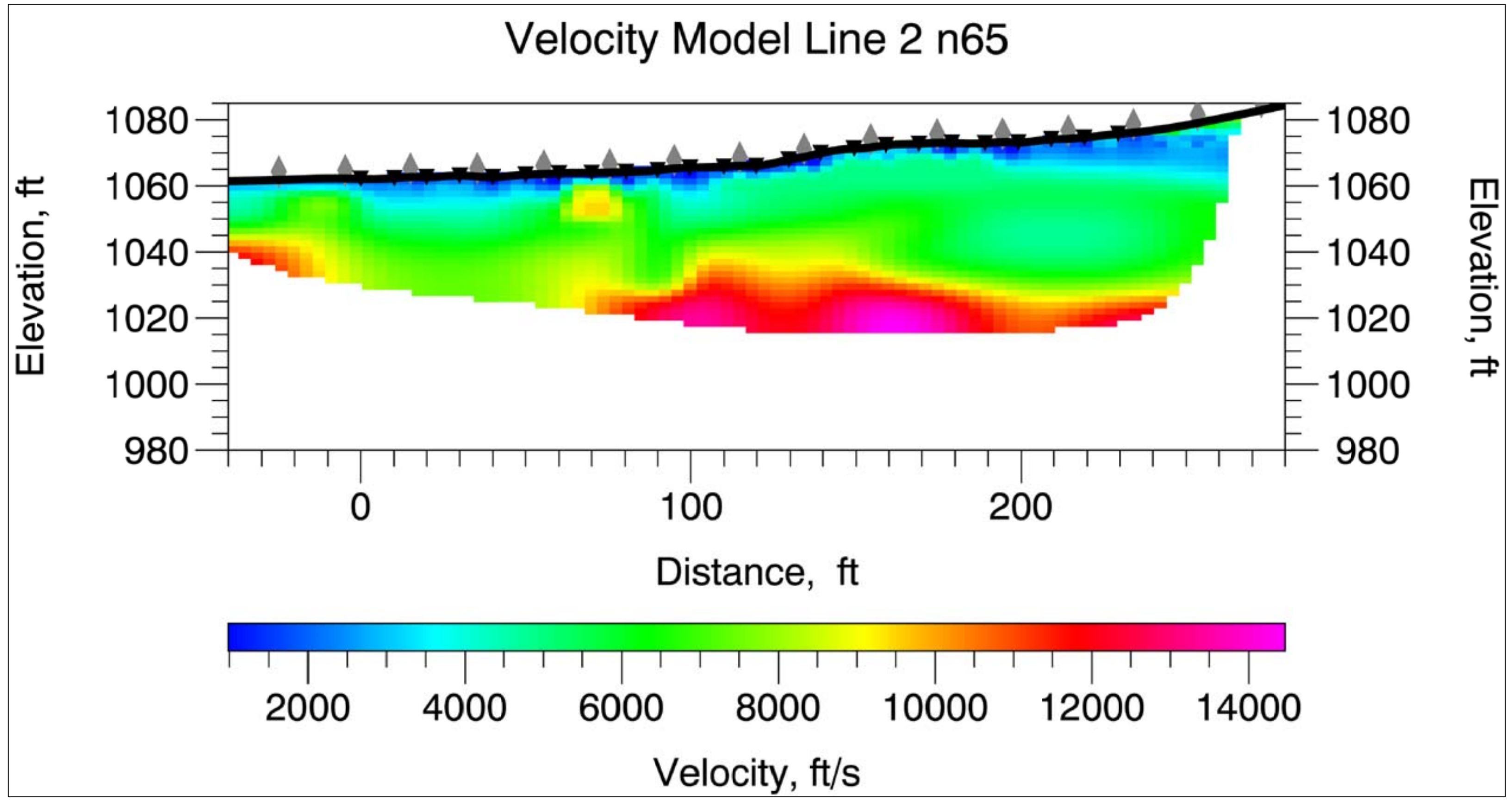


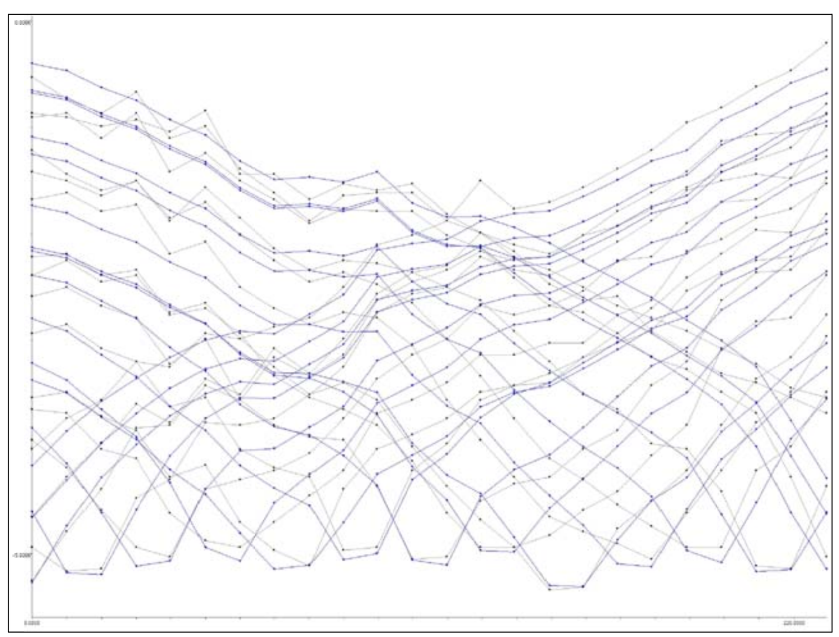


Travel-Time Plot

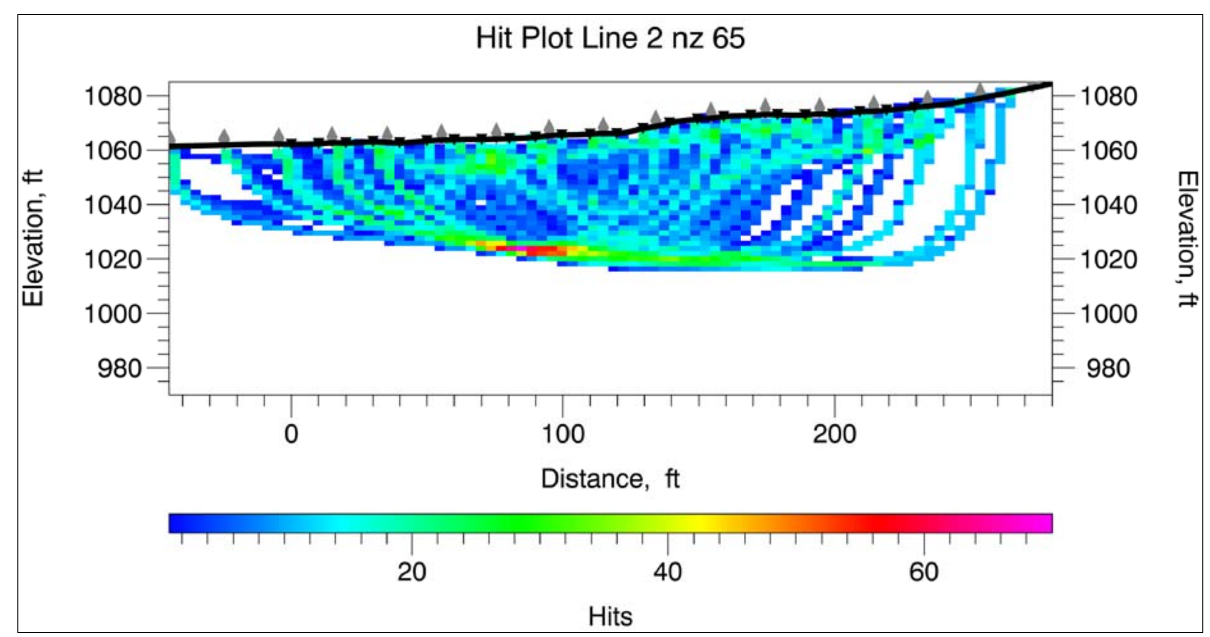


REFRACTION TOMOGRAPHIC PROFILE (SEIS OPT - 2D)
REFRACTION LINE 1
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California



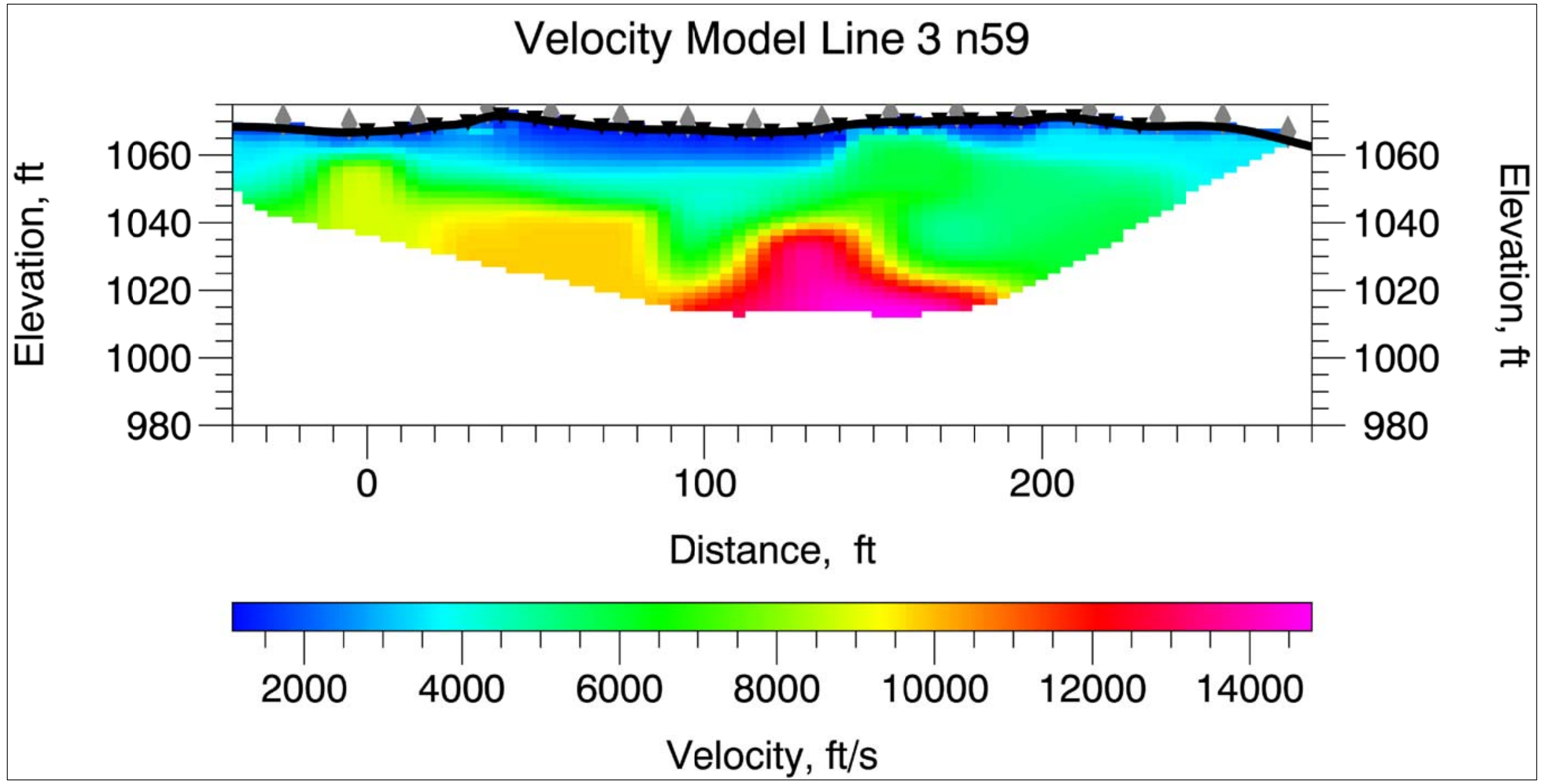


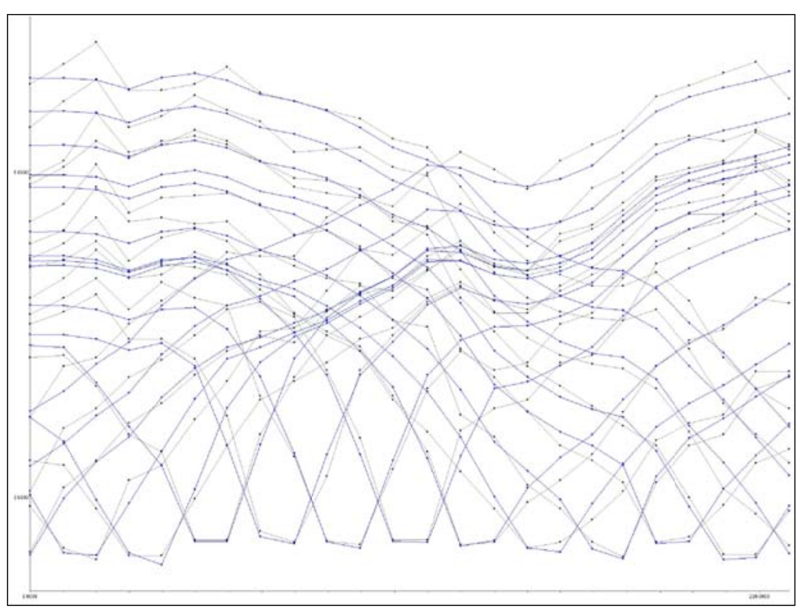
Travel-Time Plot



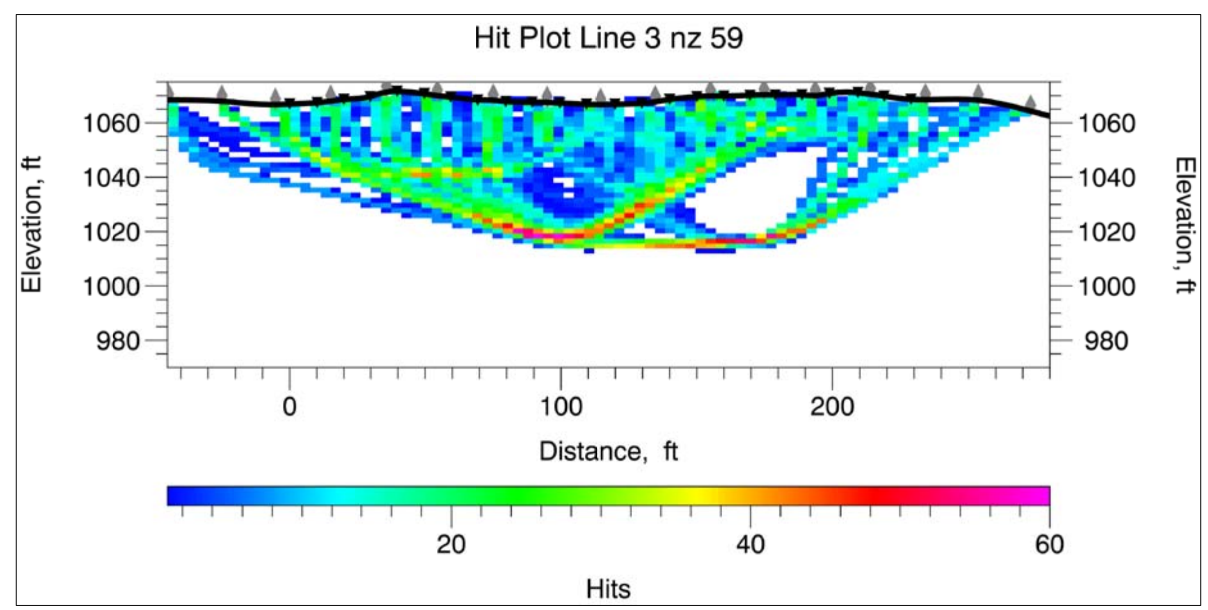
REFRACTION TOMOGRAPHIC PROFILE (SEIS OPT - 2D)
REFRACTION LINE 2
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-07 seis opt.dwg 07-15-2010 - 10:56am



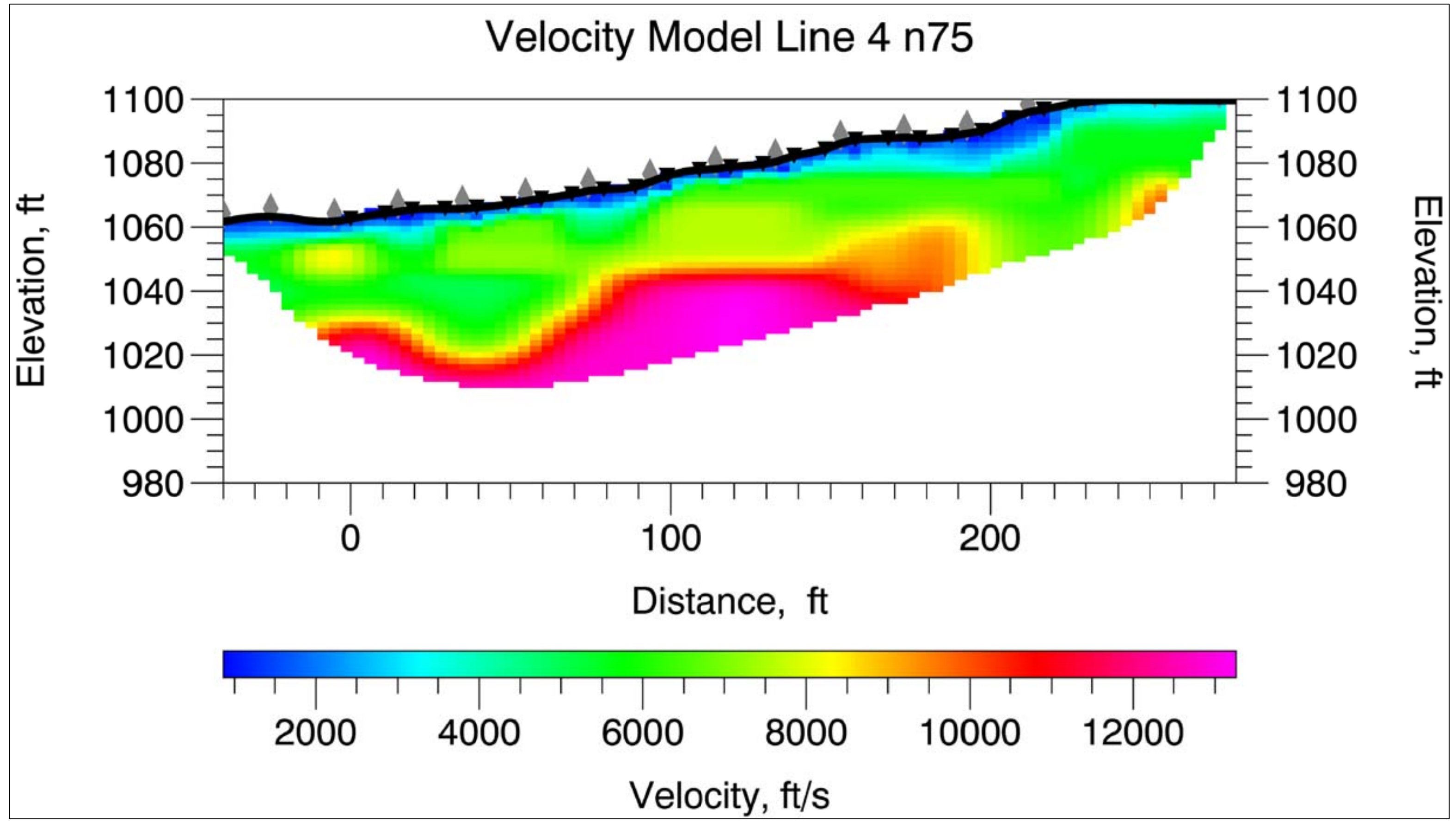


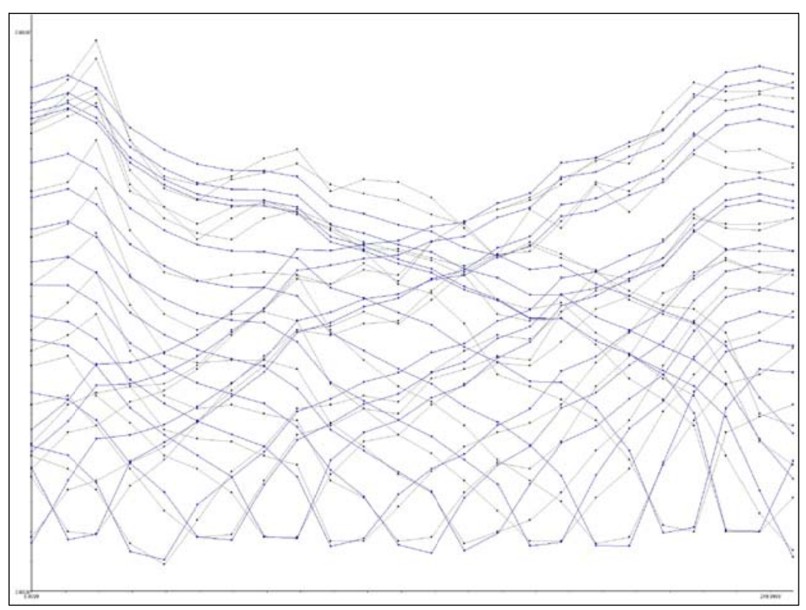
Travel-Time Plot



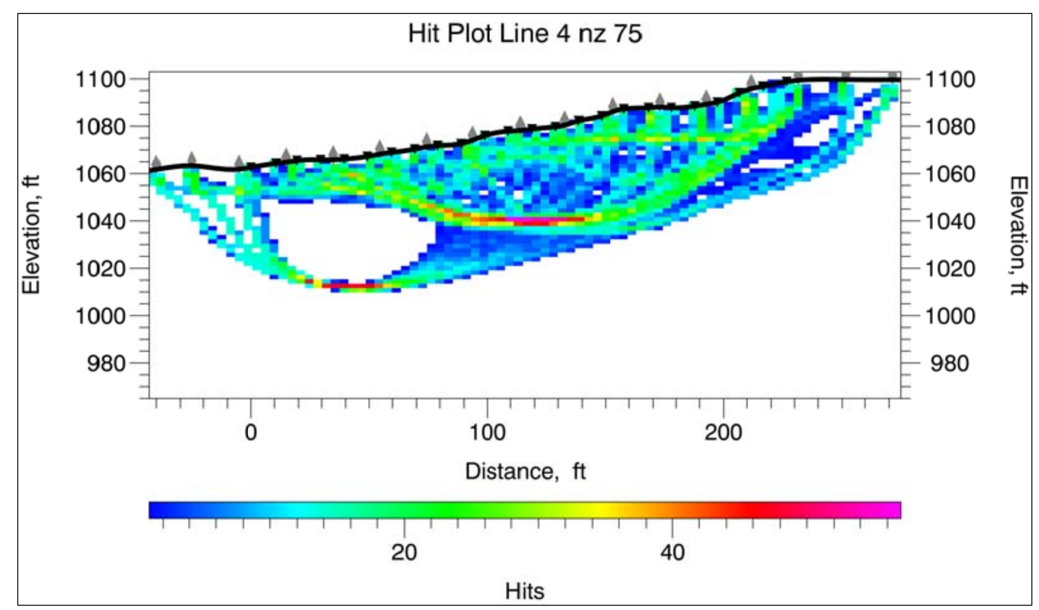
REFRACTION TOMOGRAPHIC PROFILE (SEIS OPT - 2D)
REFRACTION LINE 3
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-07 seis opt.dwg 07-15-2010 - 10:58am





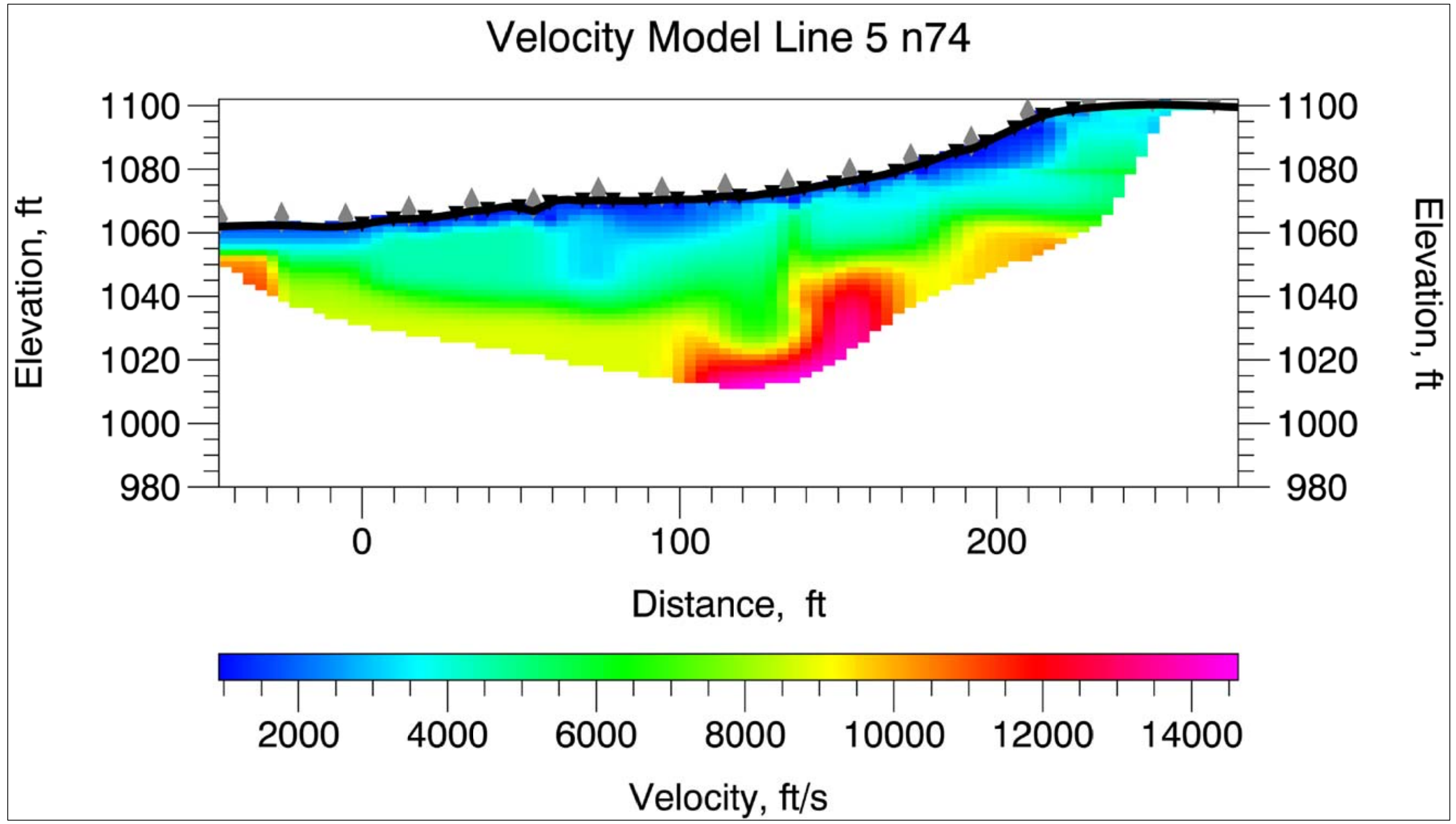
Travel-Time Plot

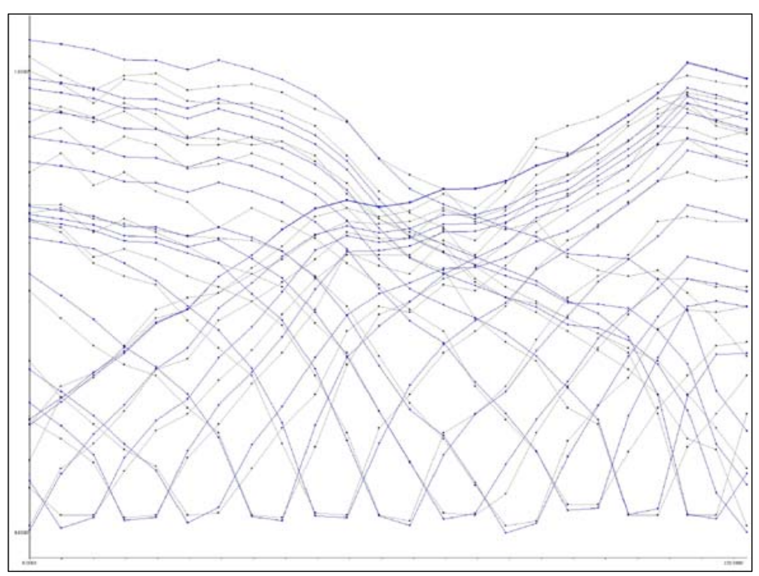


REFRACTION TOMOGRAPHIC PROFILE (SEIS OPT - 2D)
REFRACTION LINE 4
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

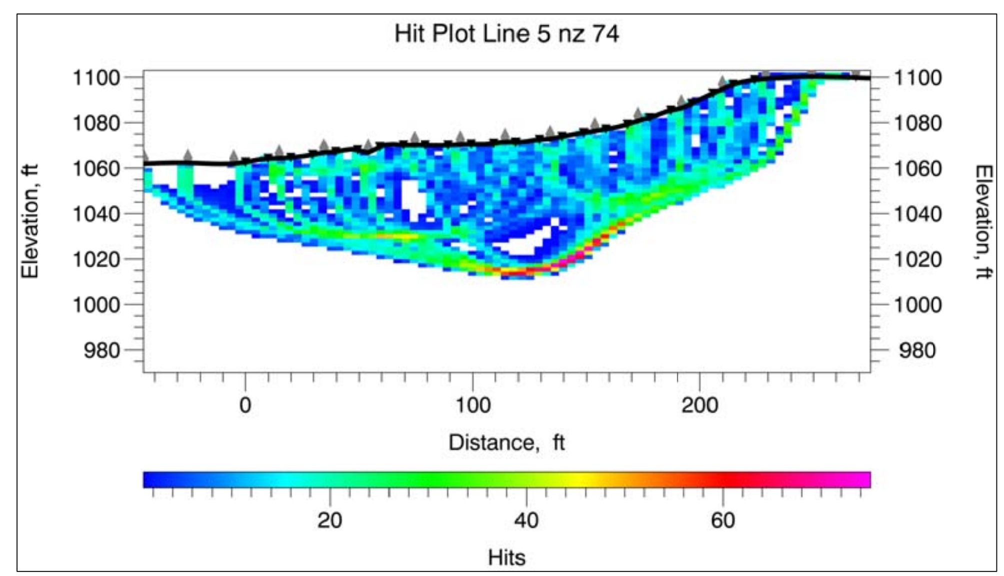
PLATE 7d

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-07 seis opt.dwg 07-15-2010 - 11:00am



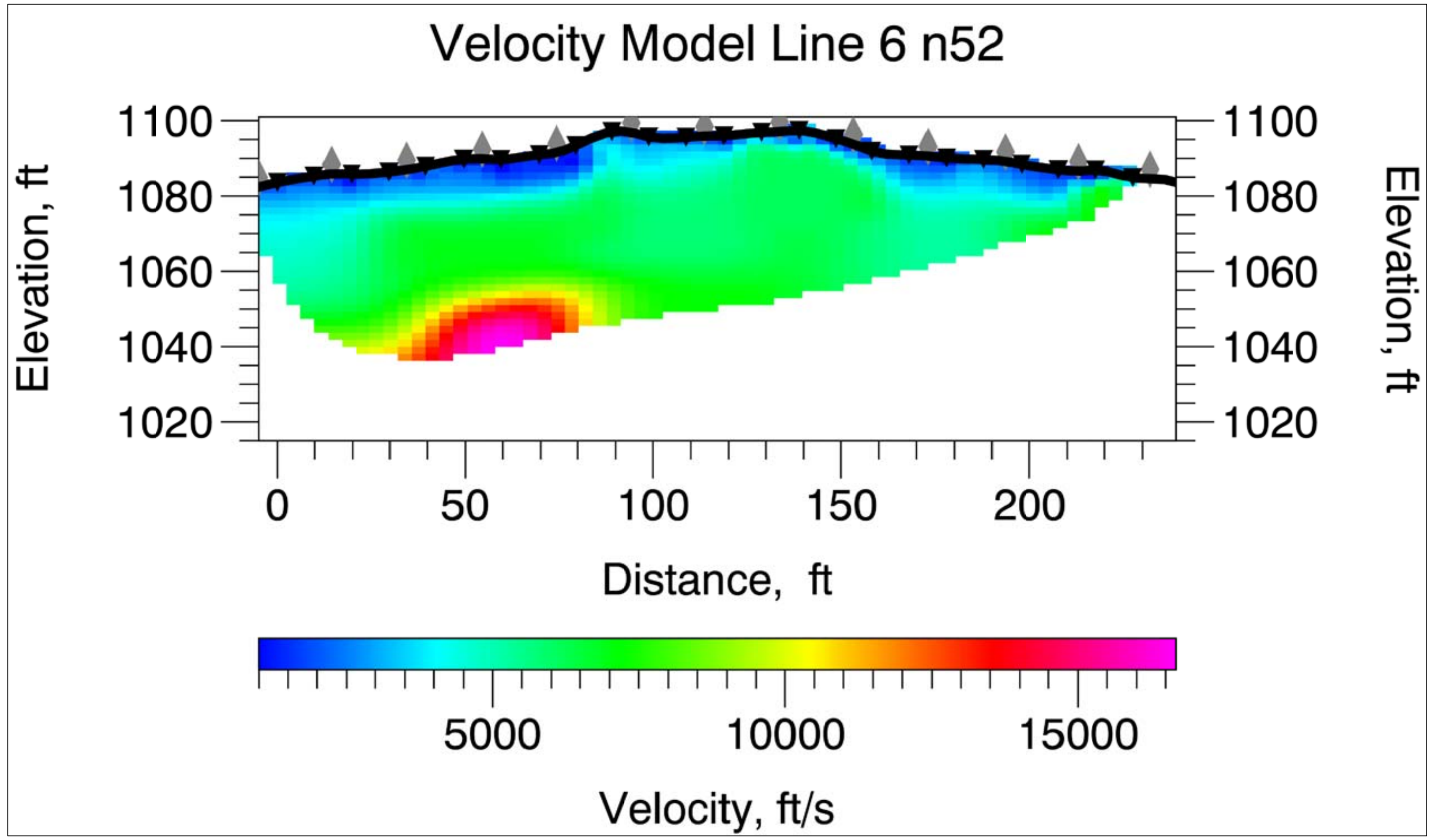


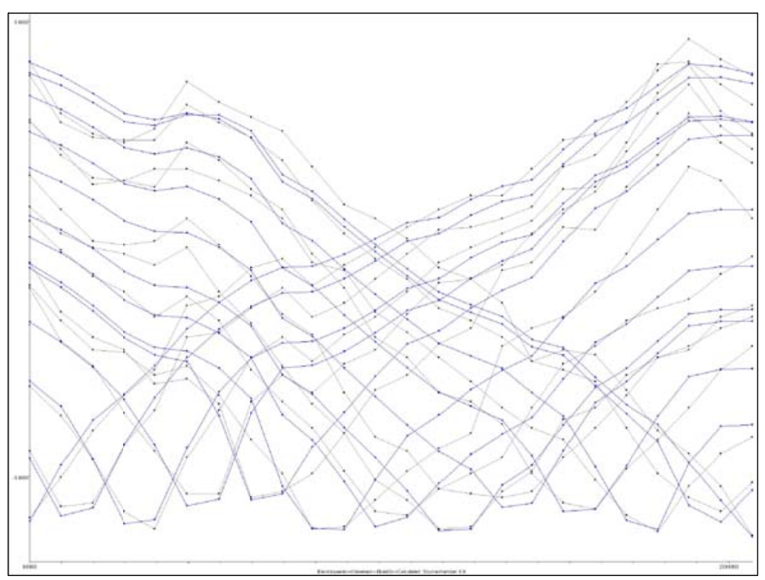
Travel-Time Plot



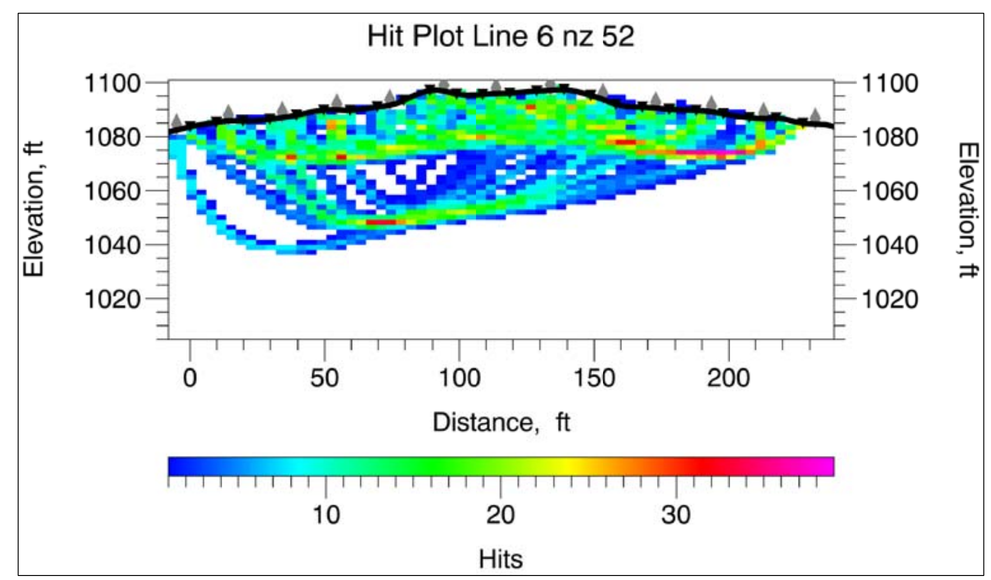
REFRACTION TOMOGRAPHIC PROFILE (SEIS OPT - 2D)
REFRACTION LINE 5
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-07 seis opt.dwg 07-15-2010 - 11:01am

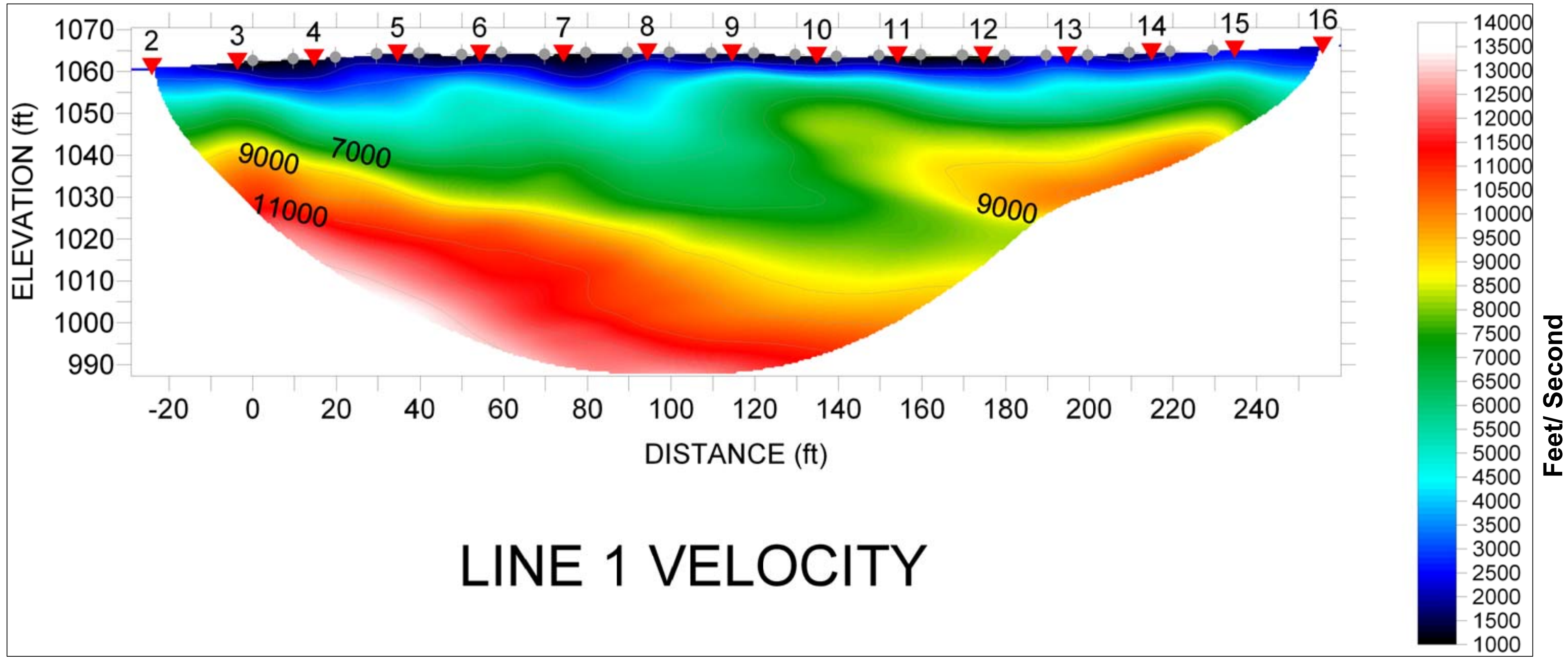


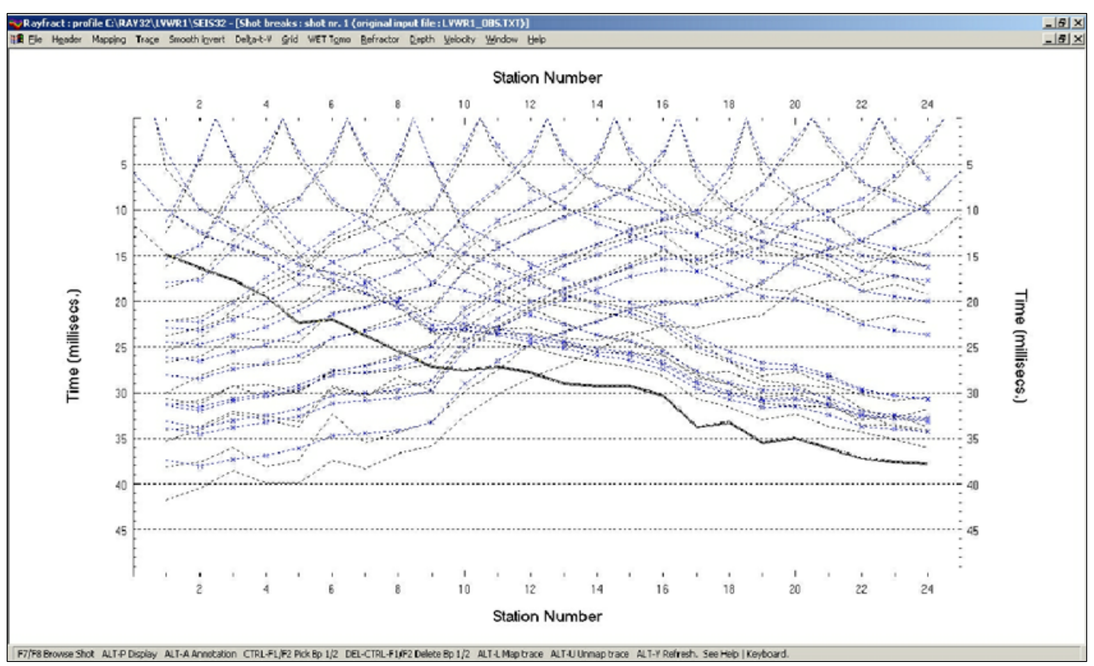


Travel-Time Plot

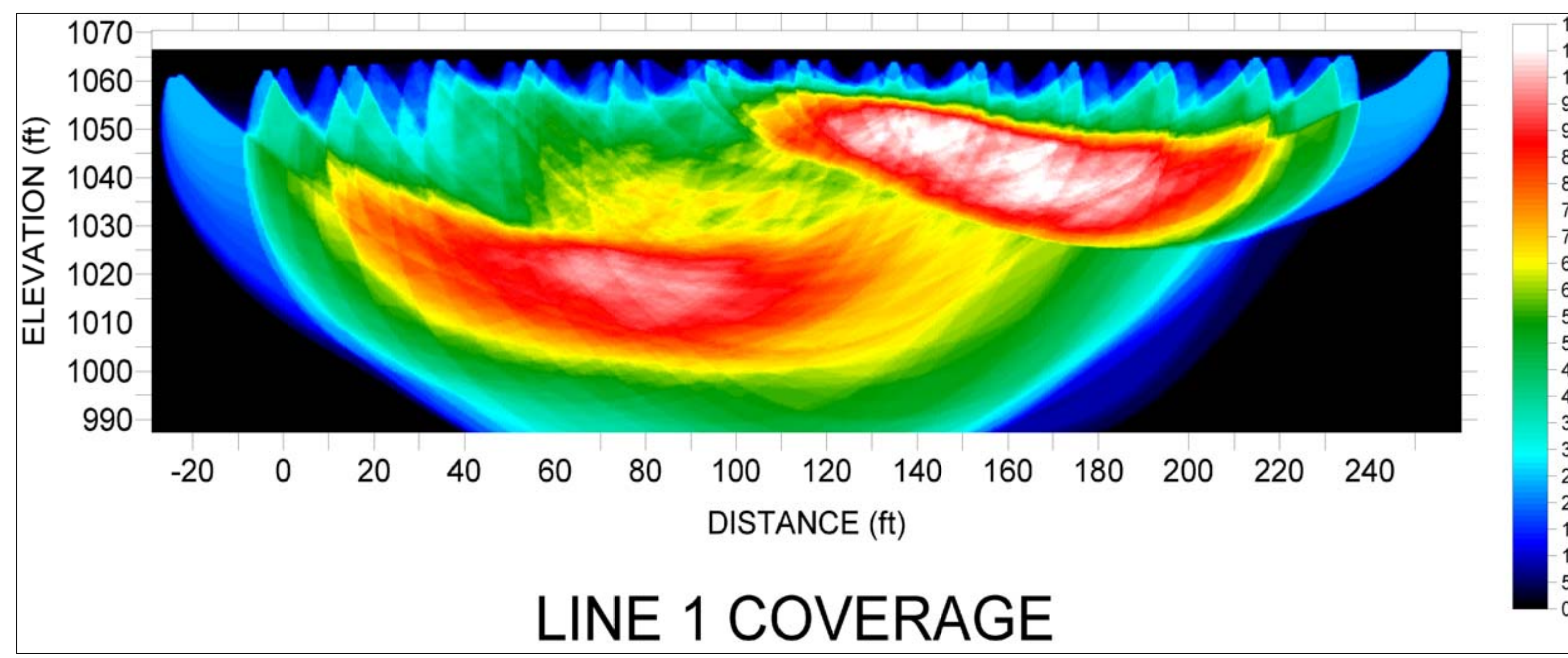


REFRACTION TOMOGRAPHIC PROFILE (SEIS OPT - 2D)
REFRACTION LINE 6
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California





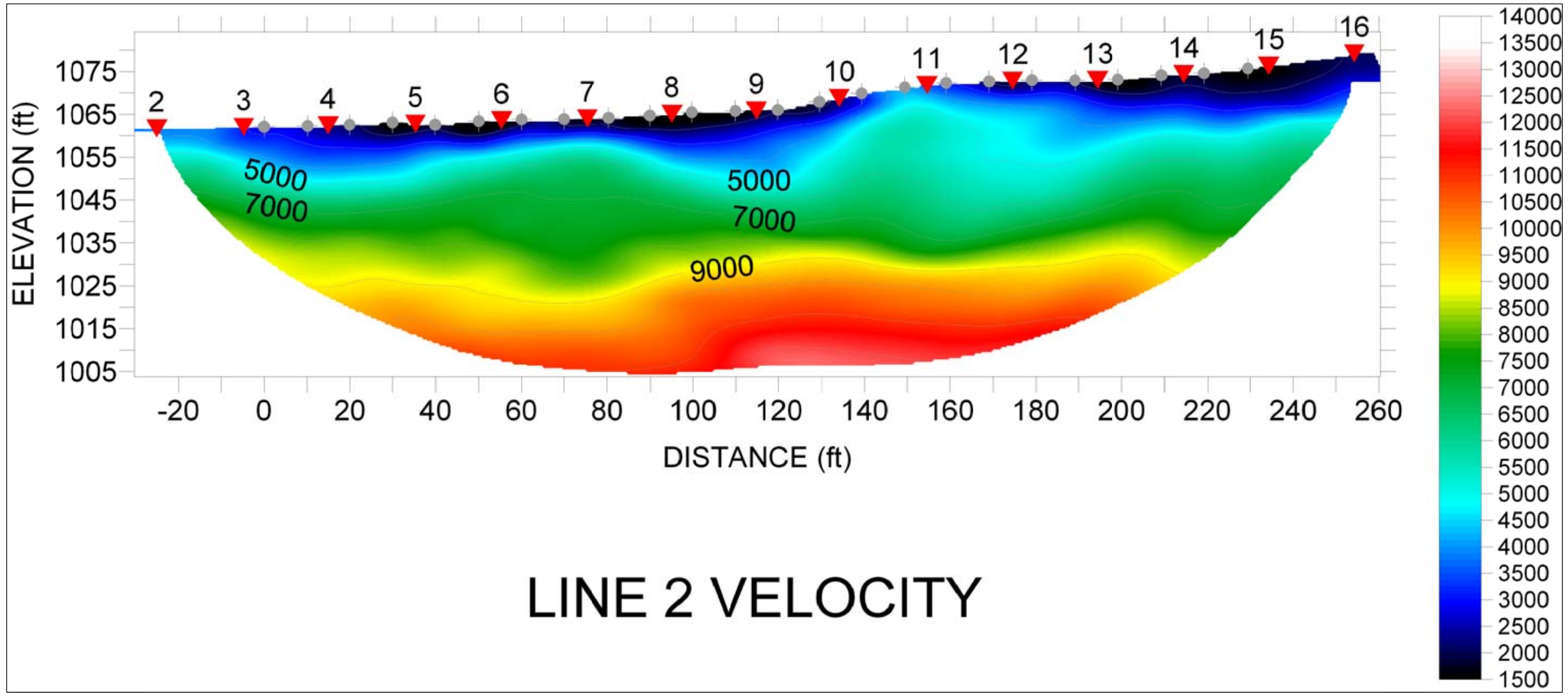
Travel-Time Plot

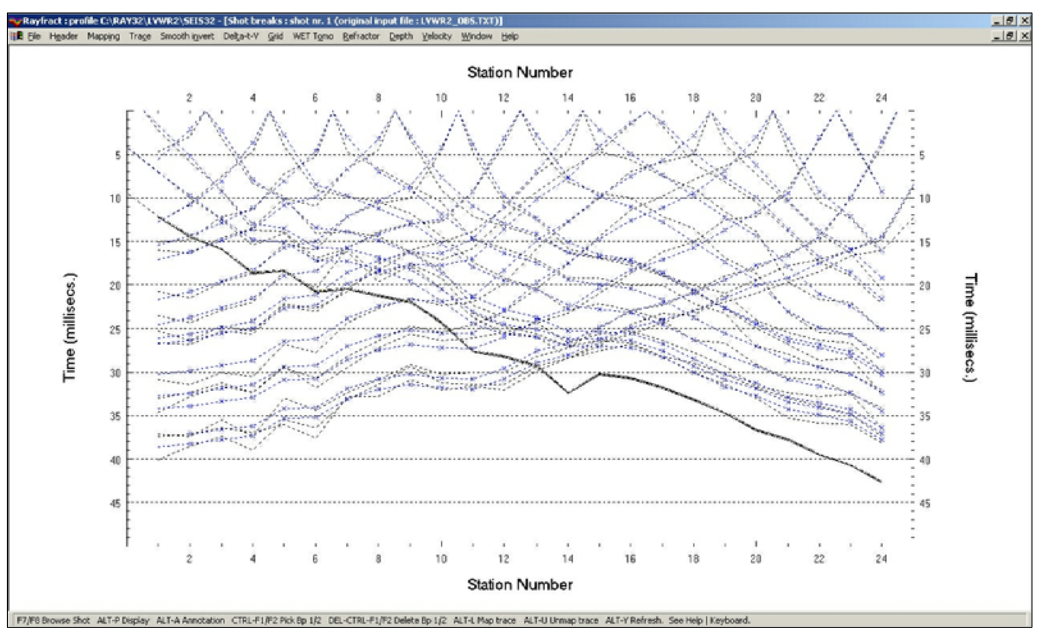


REFRACTION TOMOGRAPHIC PROFILE (RAYFRACT)
REFRACTION LINE 1
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

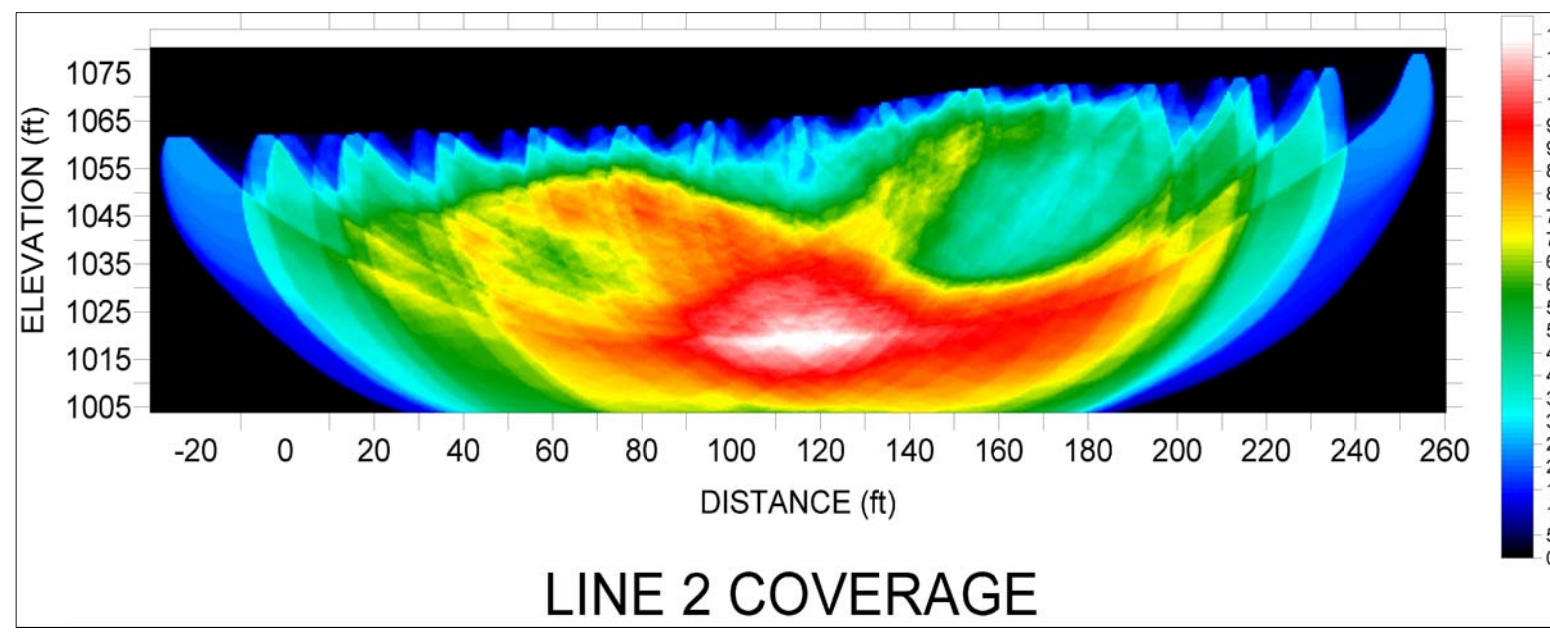
PLATE 8a

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-08a Rayfract Line 1.dwg 07-15-2010 - 10:52am



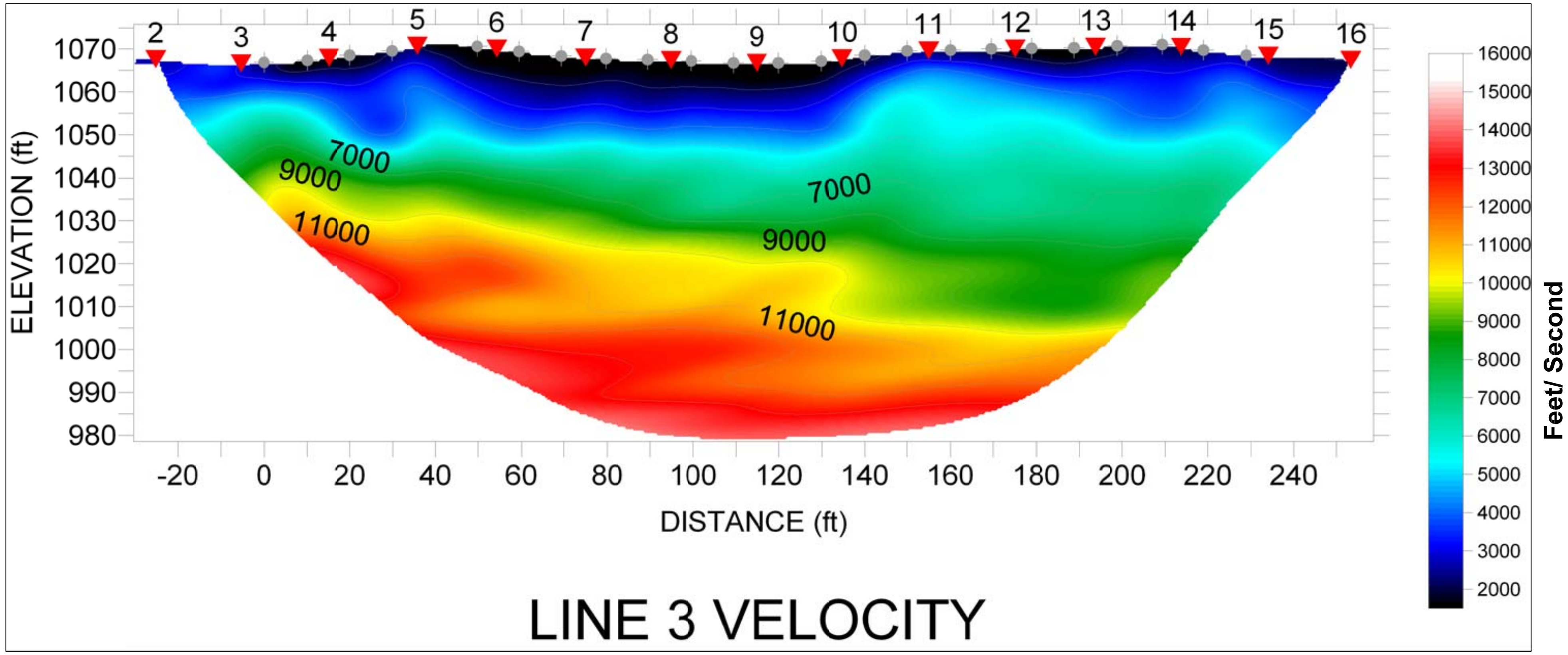


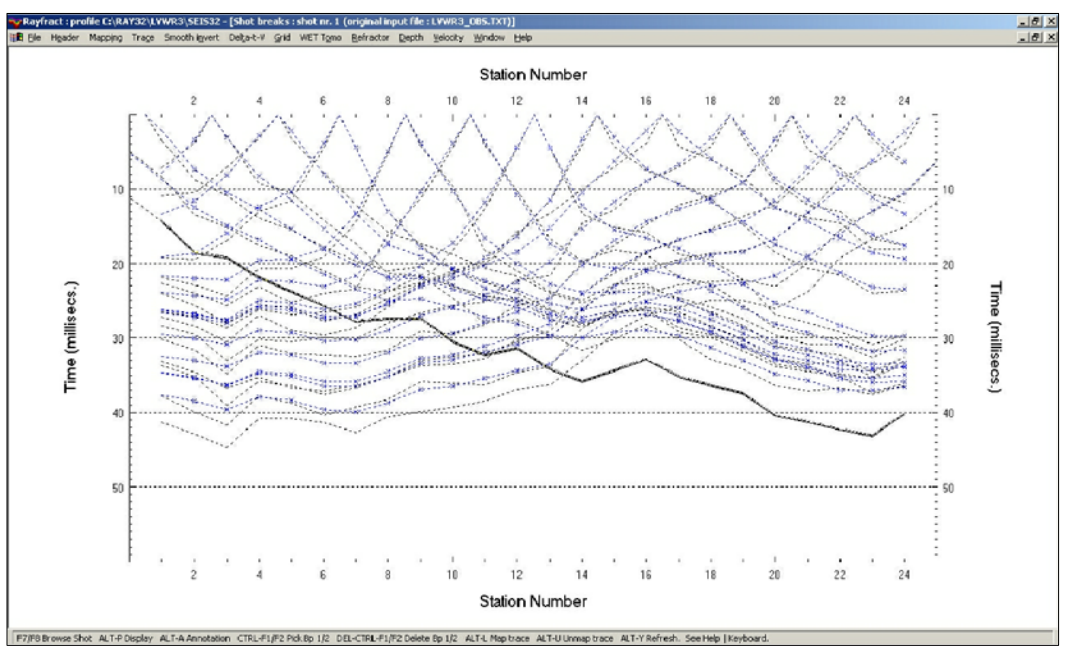
Travel-Time Plot



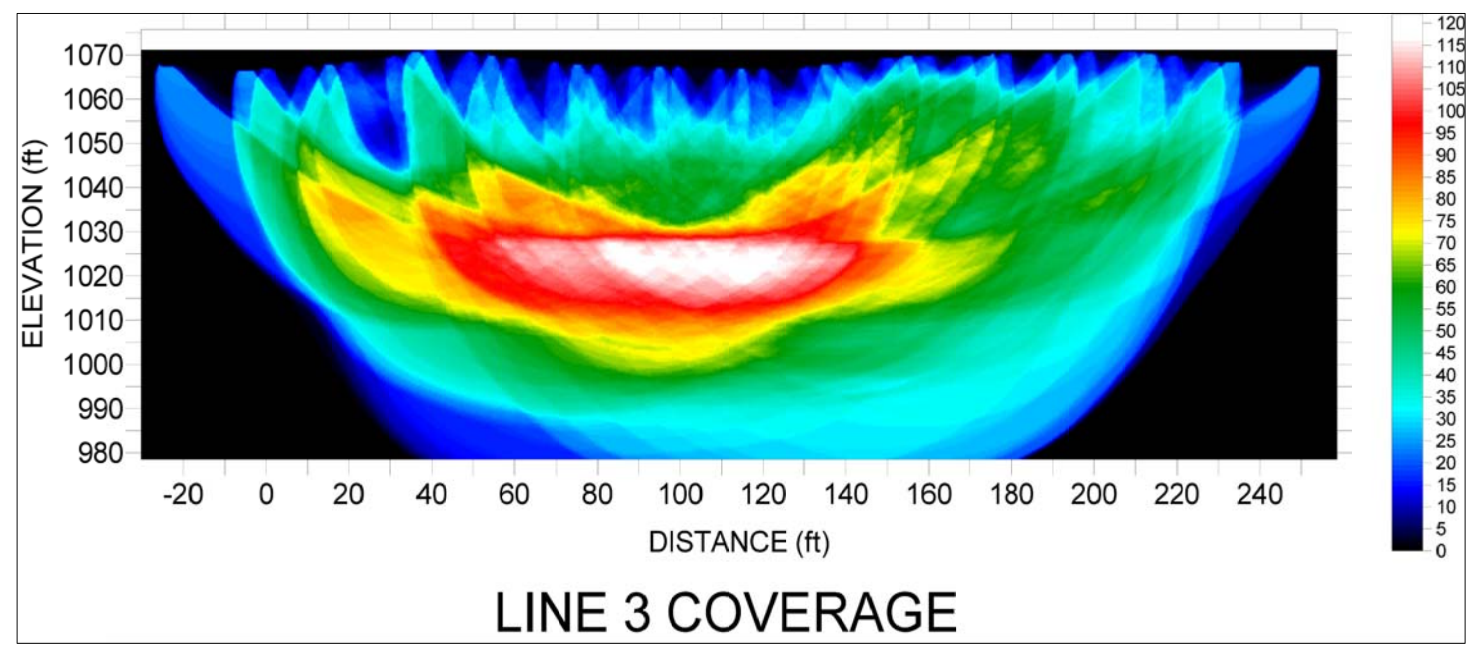
REFRACTION TOMOGRAPHIC PROFILE (RAYFRACT)
REFRACTION LINE 2
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-08b Rayfract Line 2.dwg 07-15-2010 - 11:21am

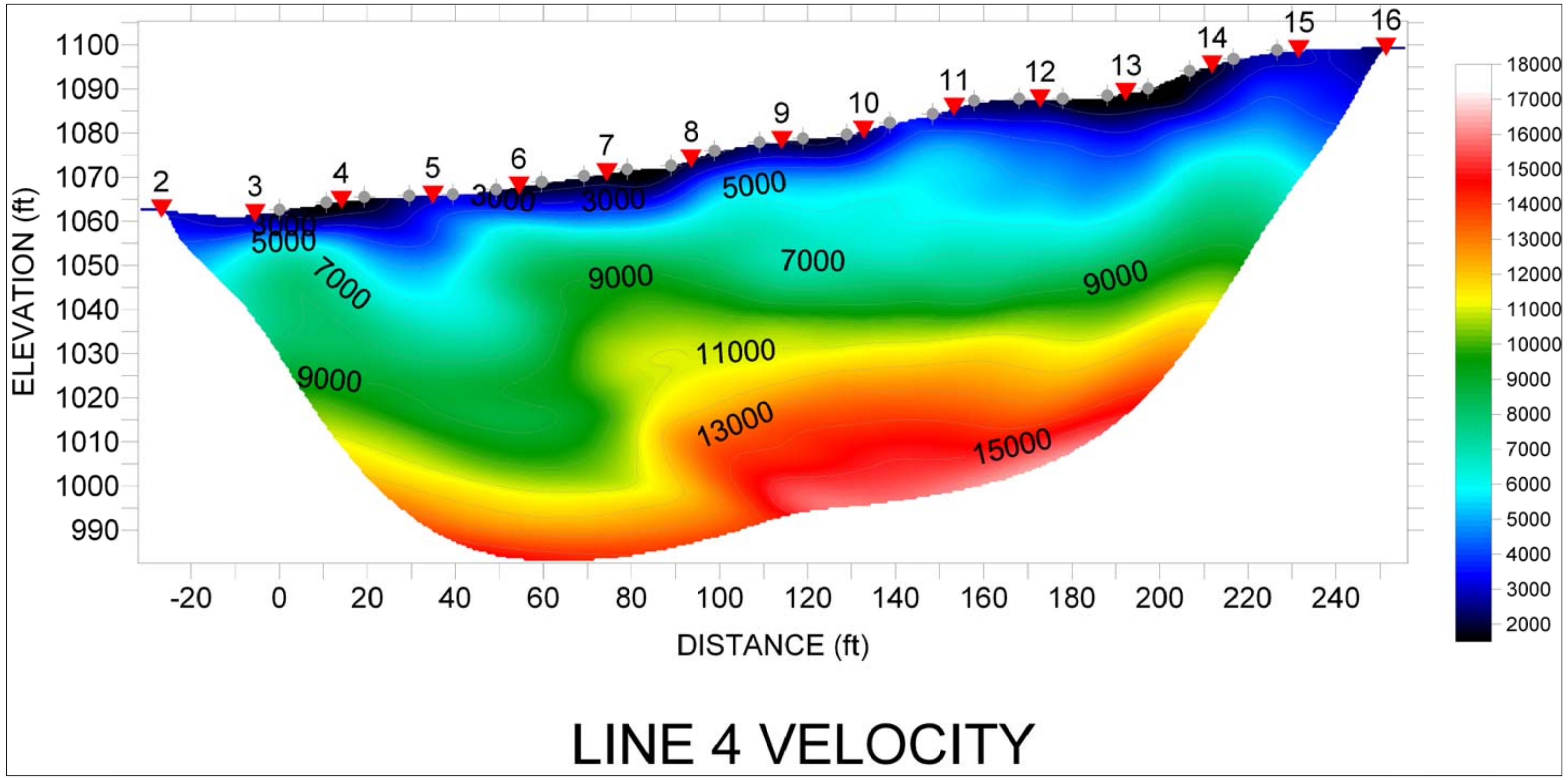


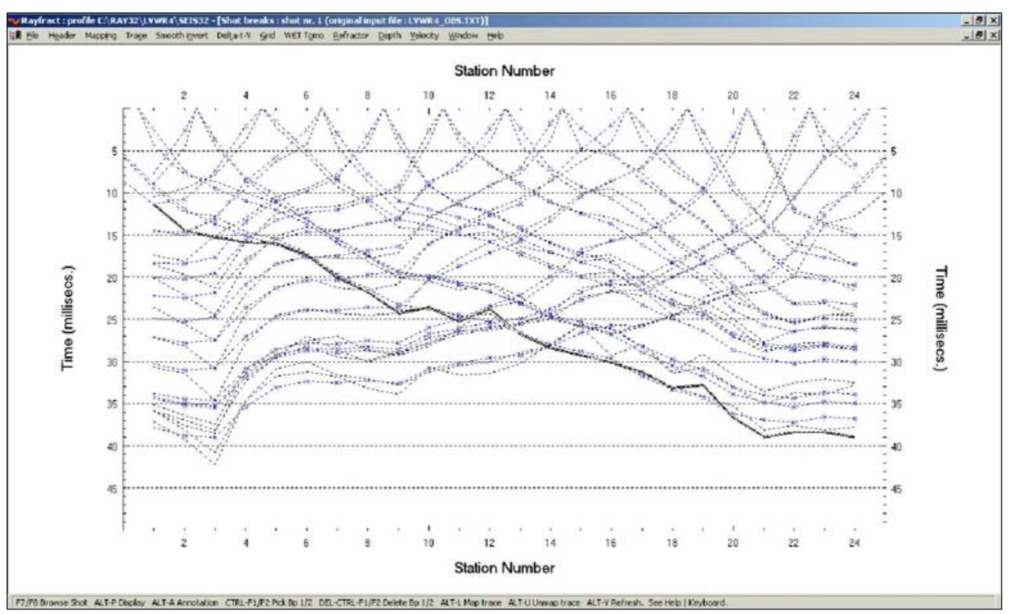


Travel-Time Plot

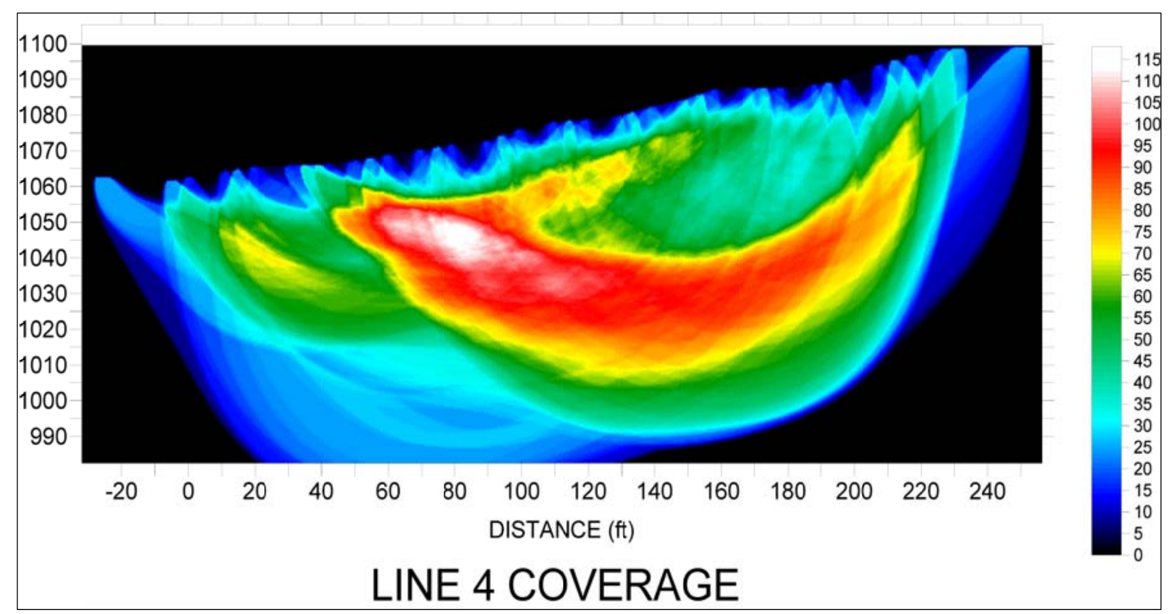


REFRACTION TOMOGRAPHIC PROFILE (RAYFRACT)
REFRACTION LINE 3
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

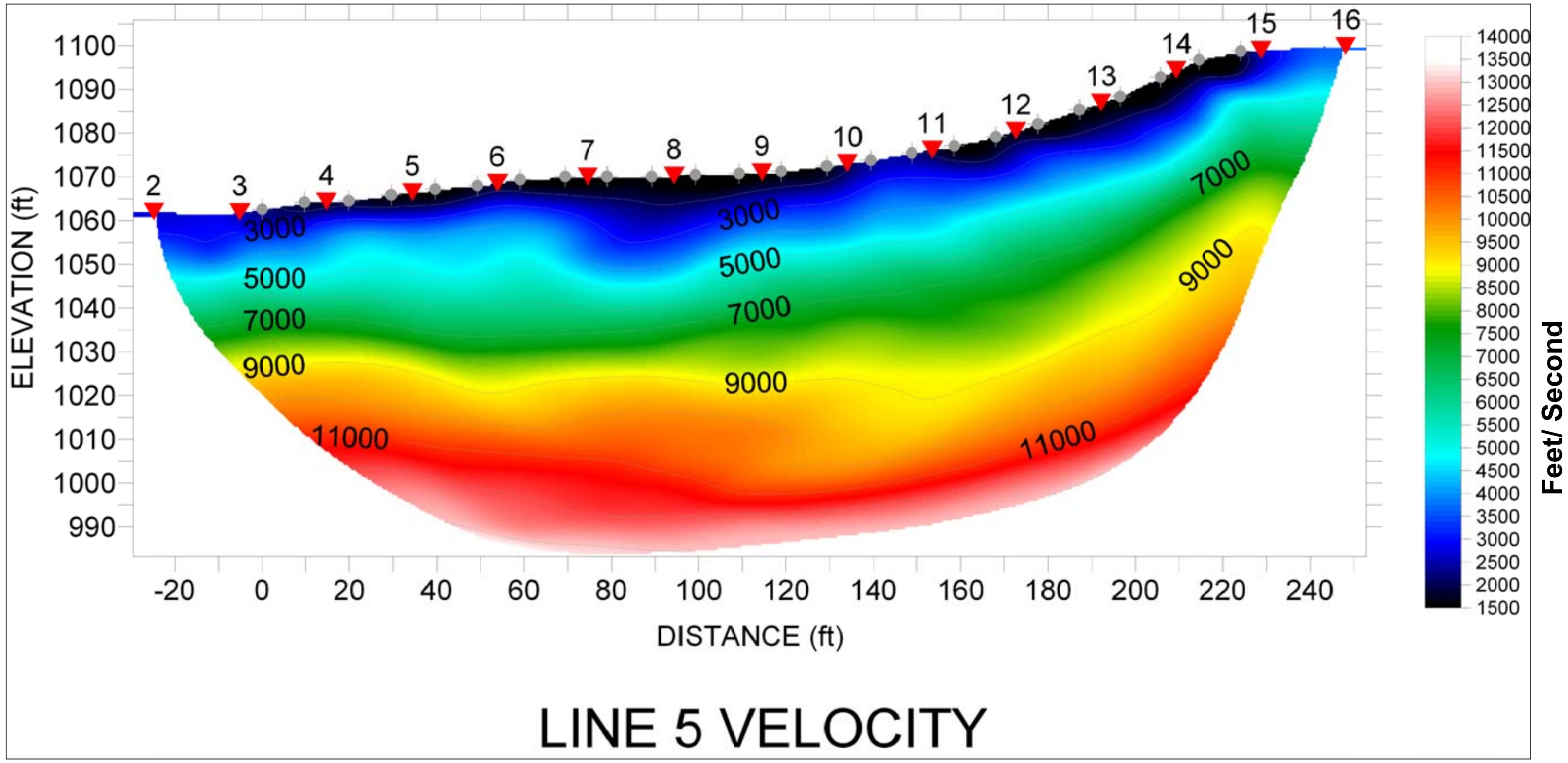


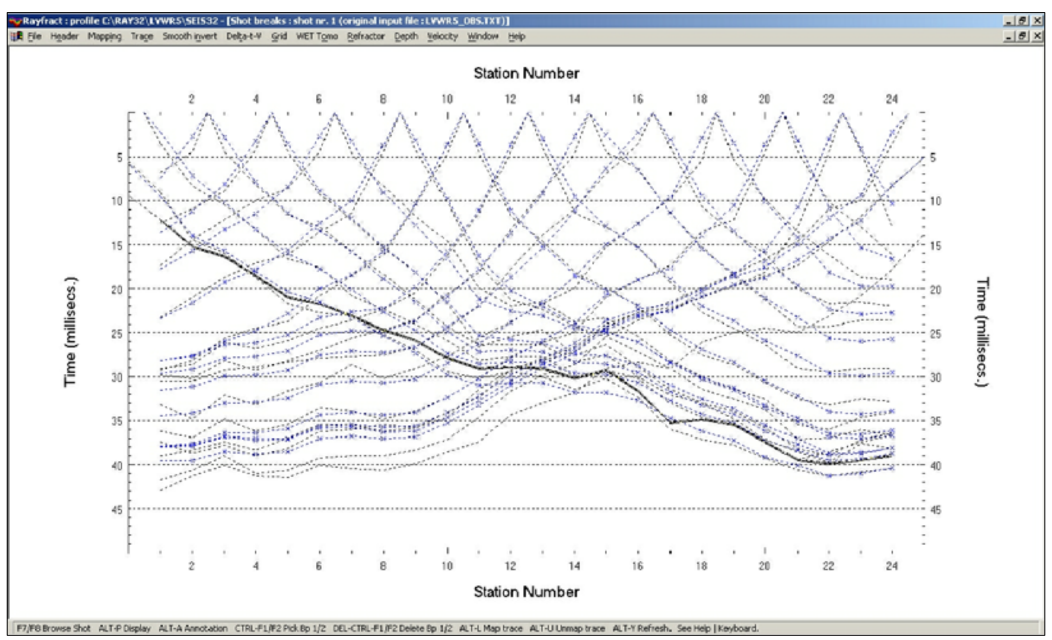


Travel-Time Plot

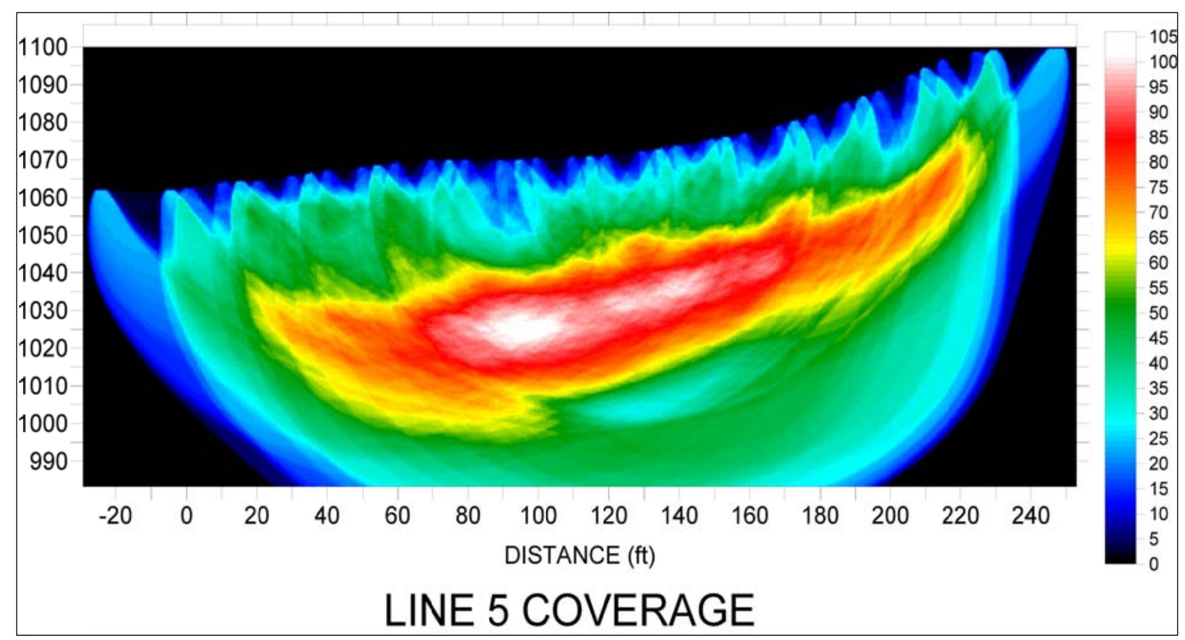


REFRACTION TOMOGRAPHIC PROFILE (RAYFRACT)
REFRACTION LINE 4
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California



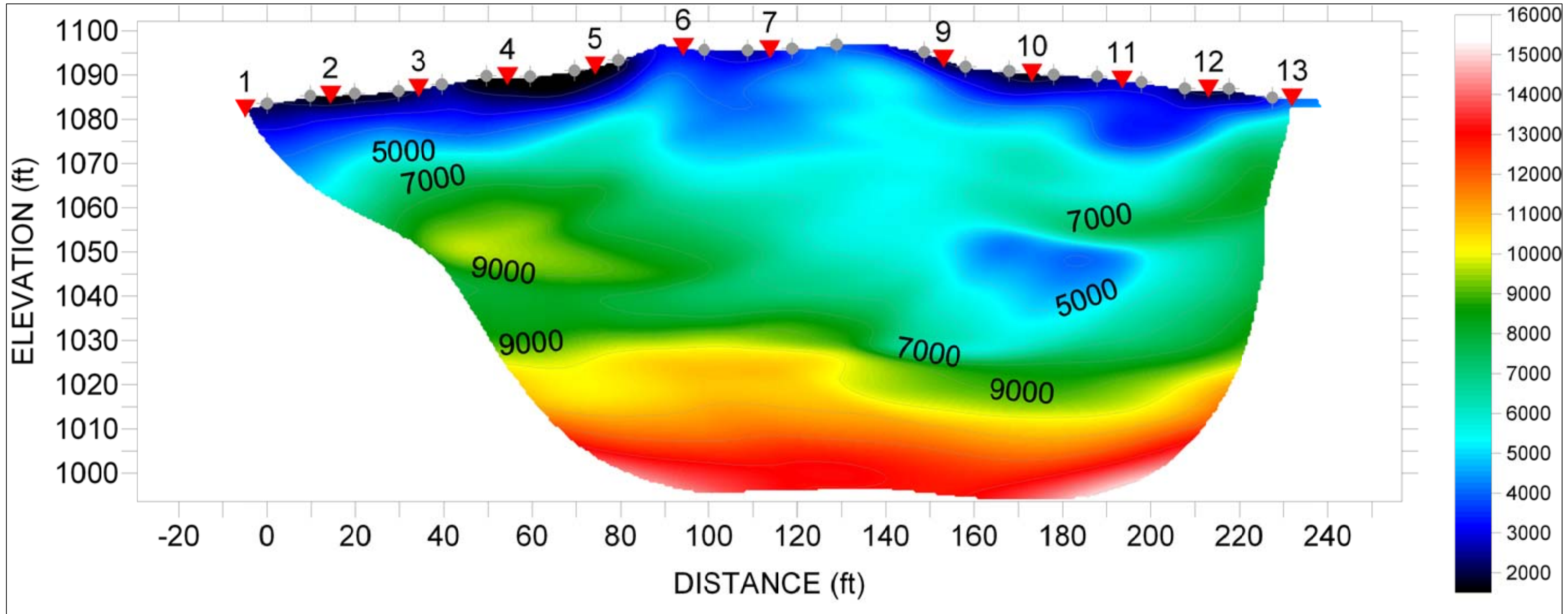


Travel-Time Plot

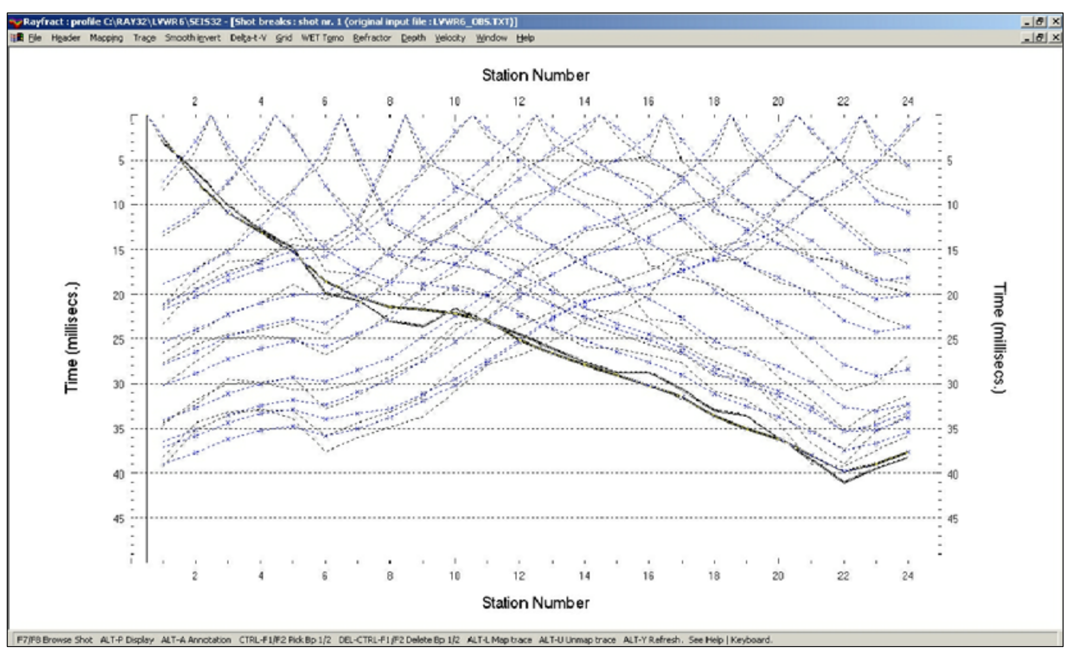


REFRACTION TOMOGRAPHIC PROFILE (RAYFRACT)
REFRACTION LINE 5
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

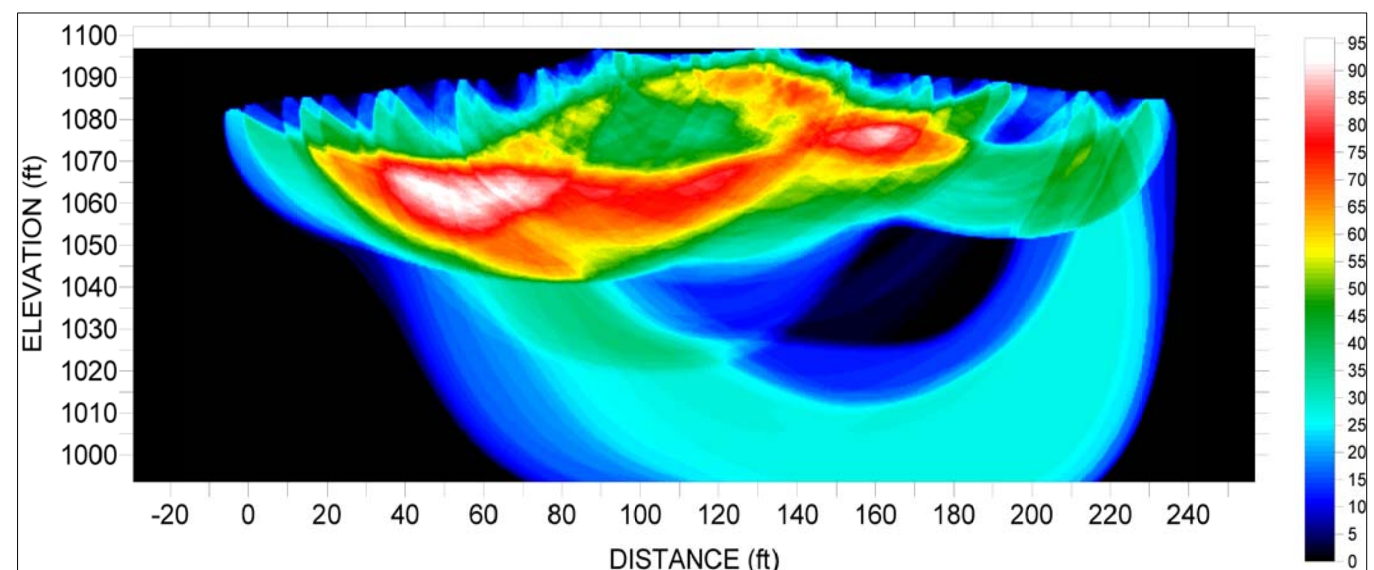
M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-08e Rayfract Line 5.dwg 07-15-2010 - 11:25am



LINE 6 VELOCITY

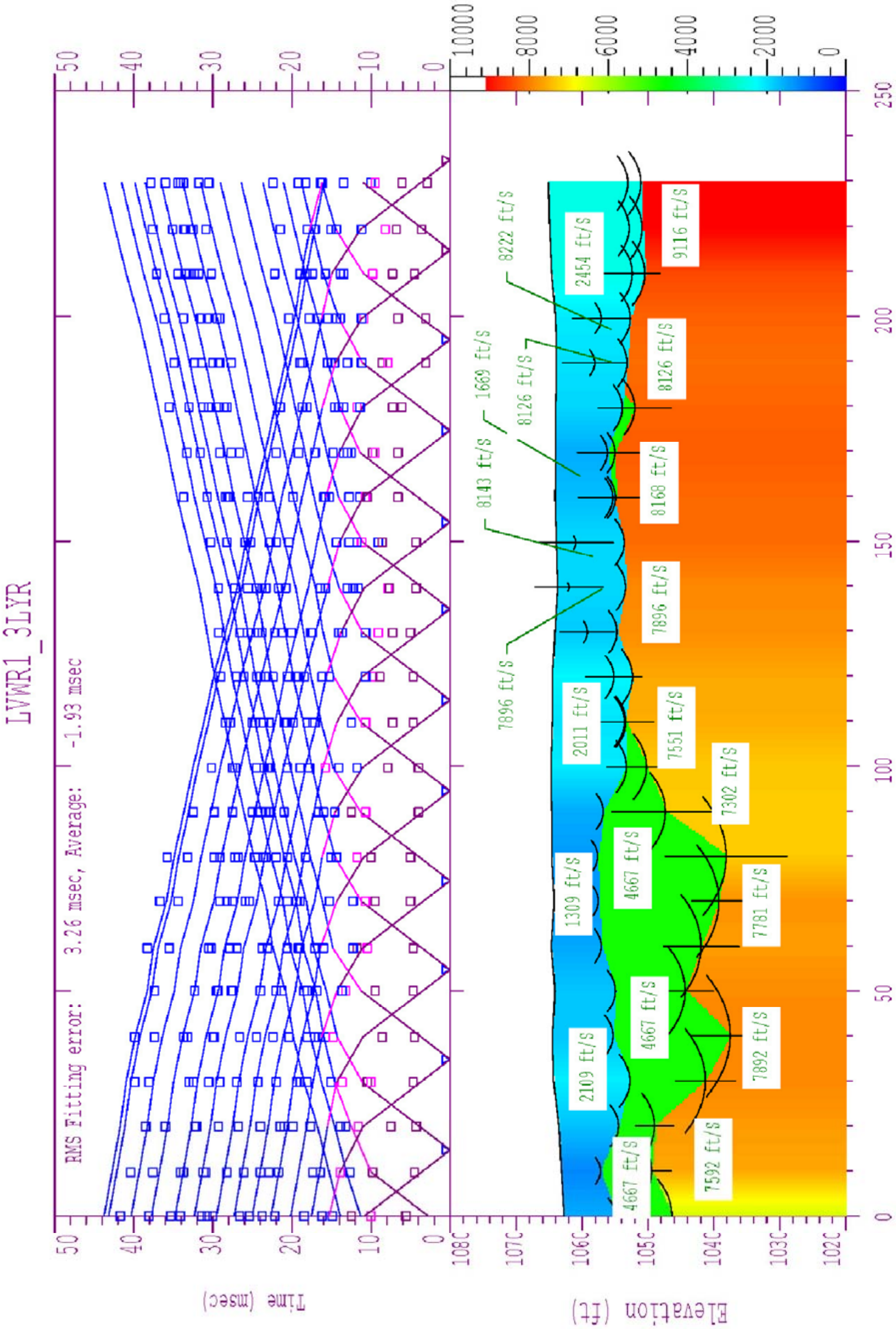


Travel-Time Plot



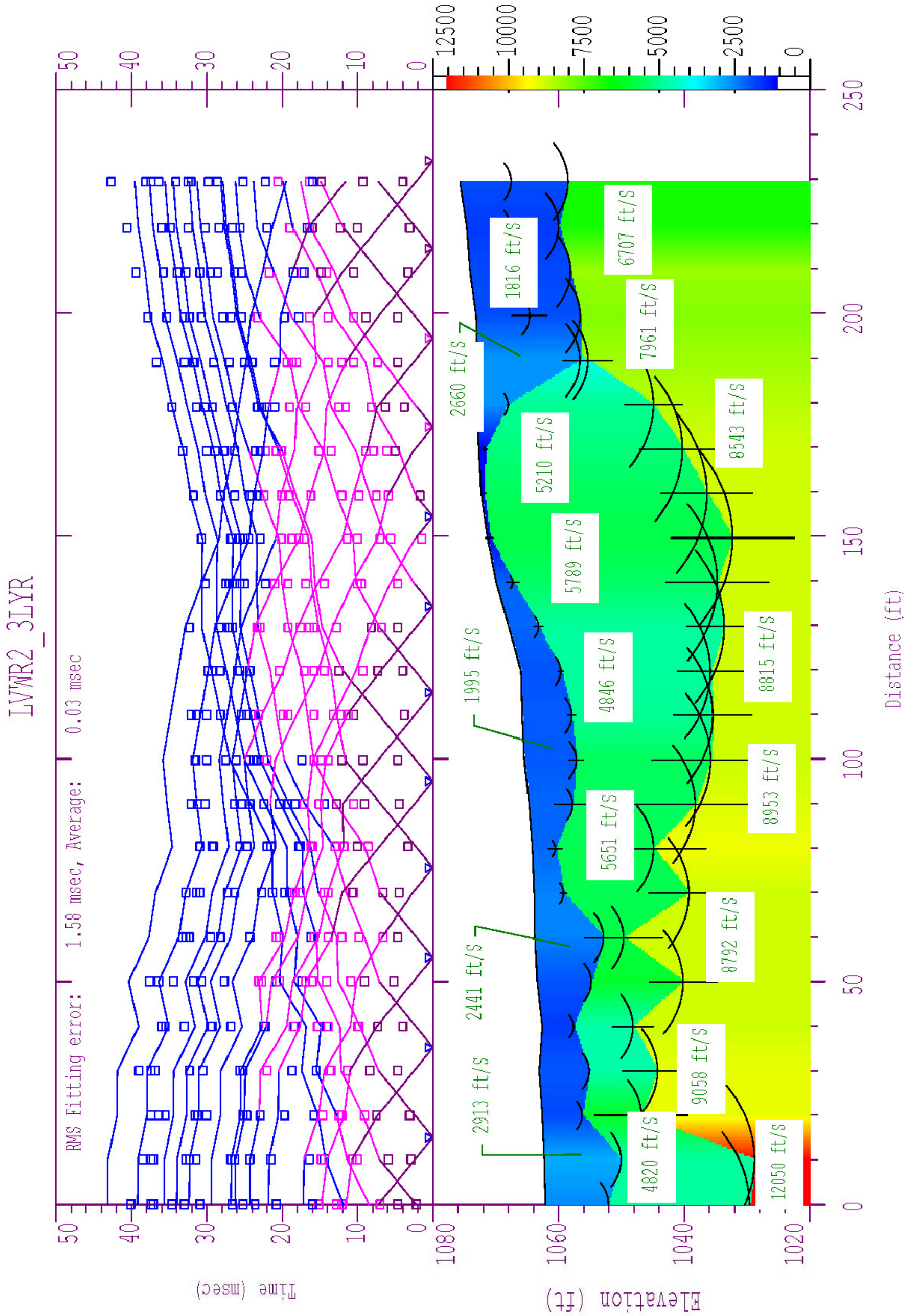
LINE 6 COVERAGE

REFRACTION TOMOGRAPHIC PROFILE (RAYFRACT)
REFRACTION LINE 6
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California



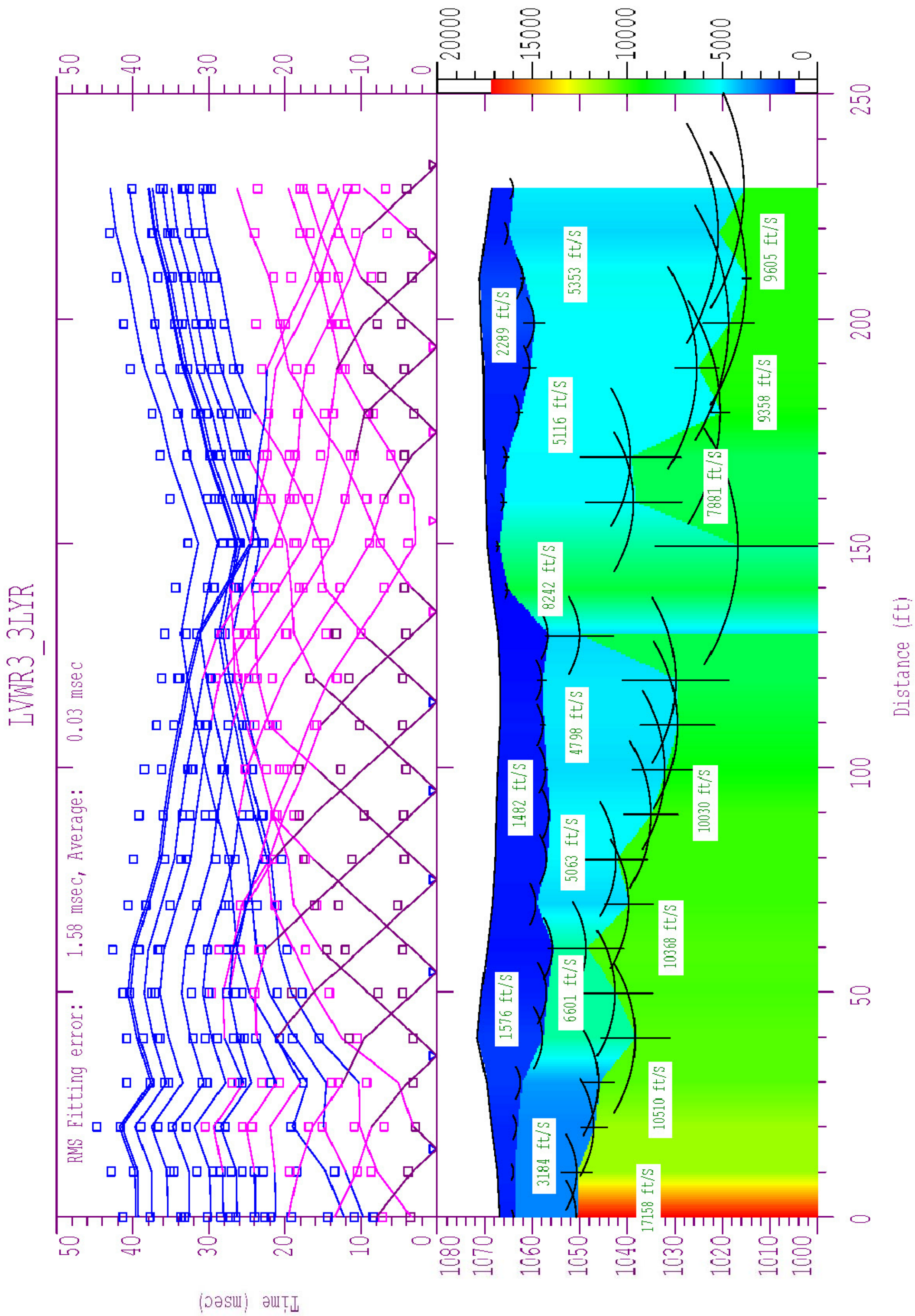
REFRACTION PROFILE - LAYERED METHOD (GRM)
REFRACTION LINE 1
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-09 GRM.dwg 07-15-2010 - 11:12am



REFRACTION PROFILE - LAYERED METHOD (GRM)
REFRACTION LINE 2
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-09 GRM.dwg 07-15-2010 - 11:13am



REFRACTION PROFILE - LAYERED METHOD (GRM)

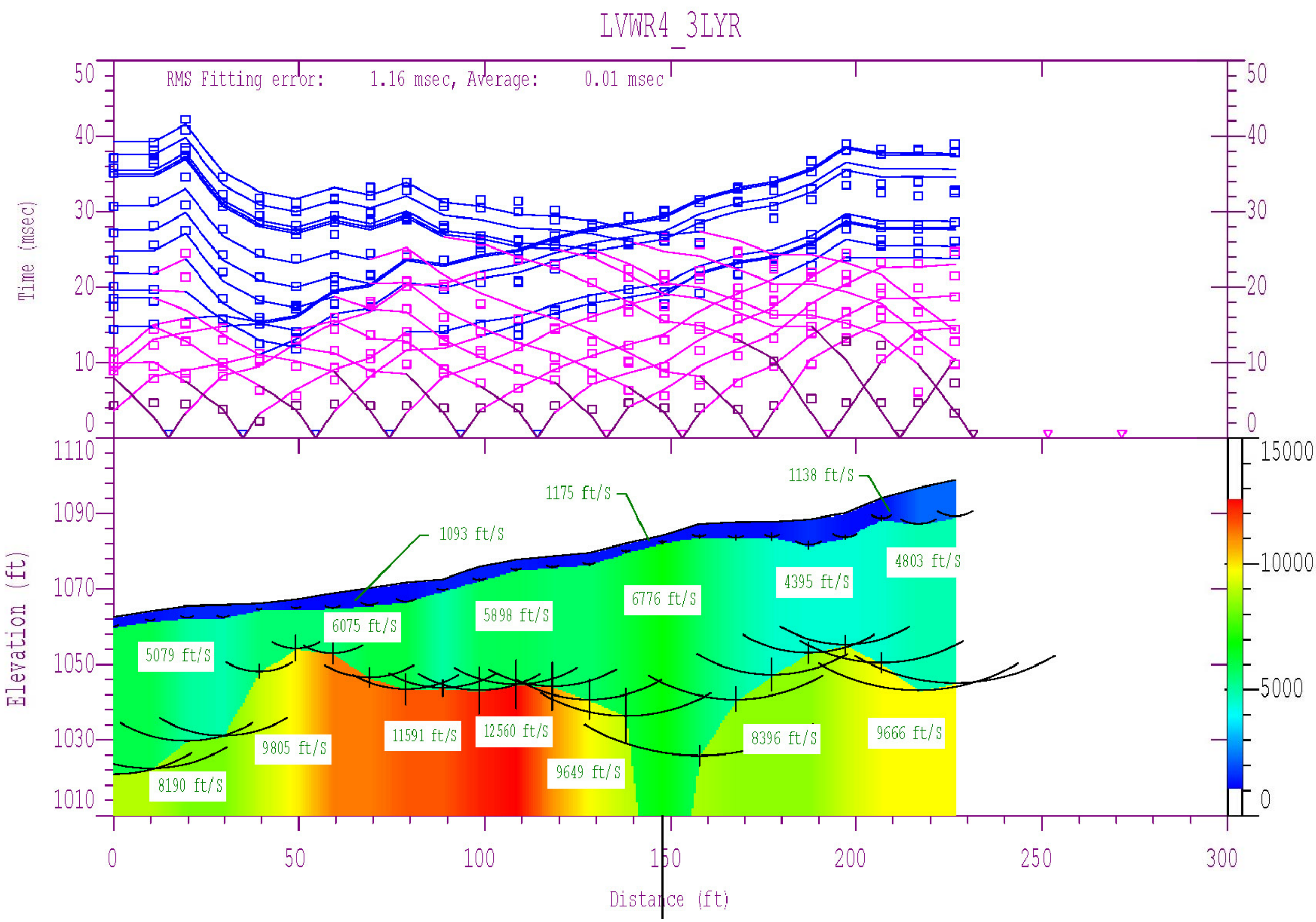
REFRACTION LINE 3

Las Virgenes Reservoir

Water Storage Tank Site A

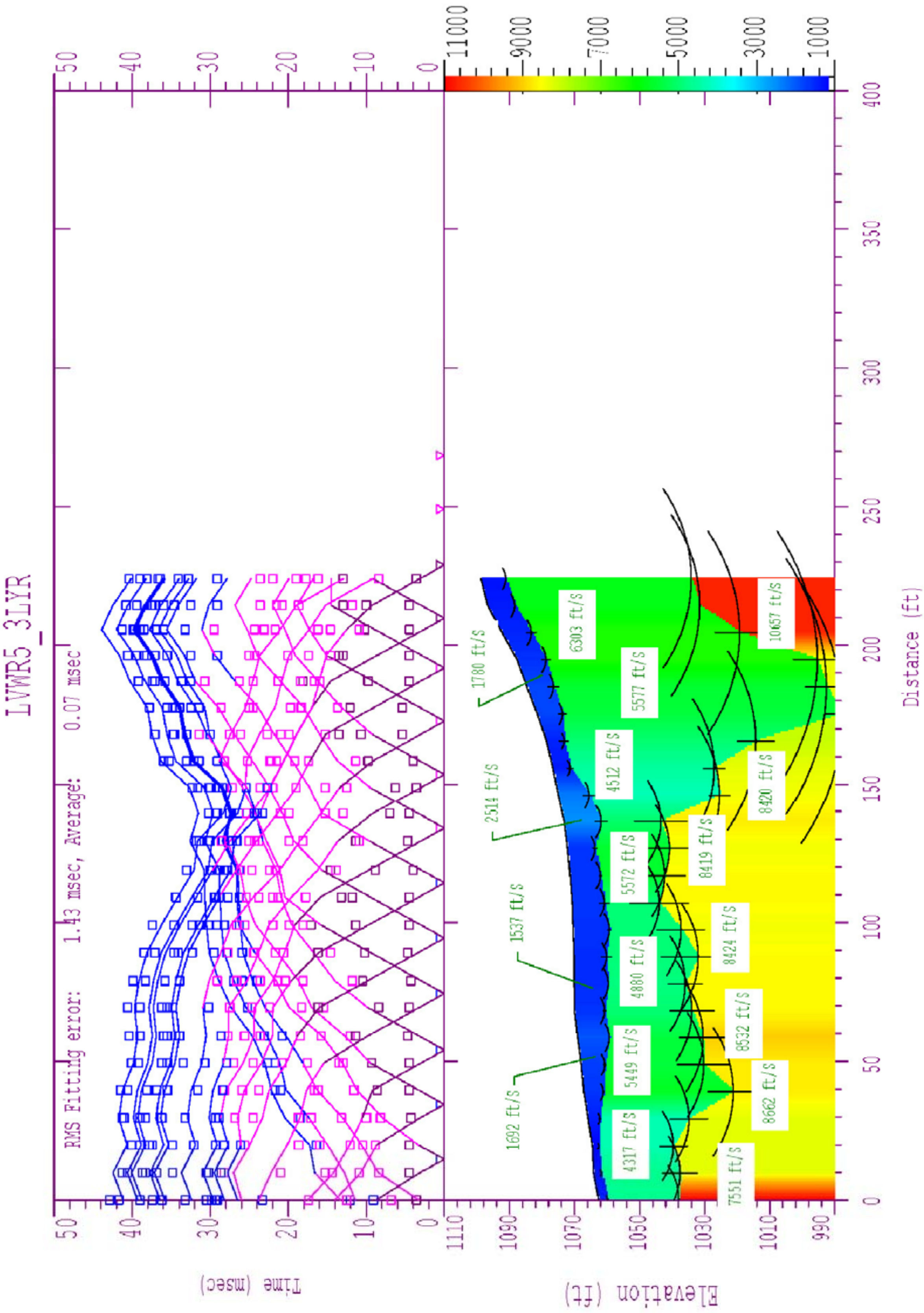
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-09 GRM.dwg 07-15-2010 - 11:33am



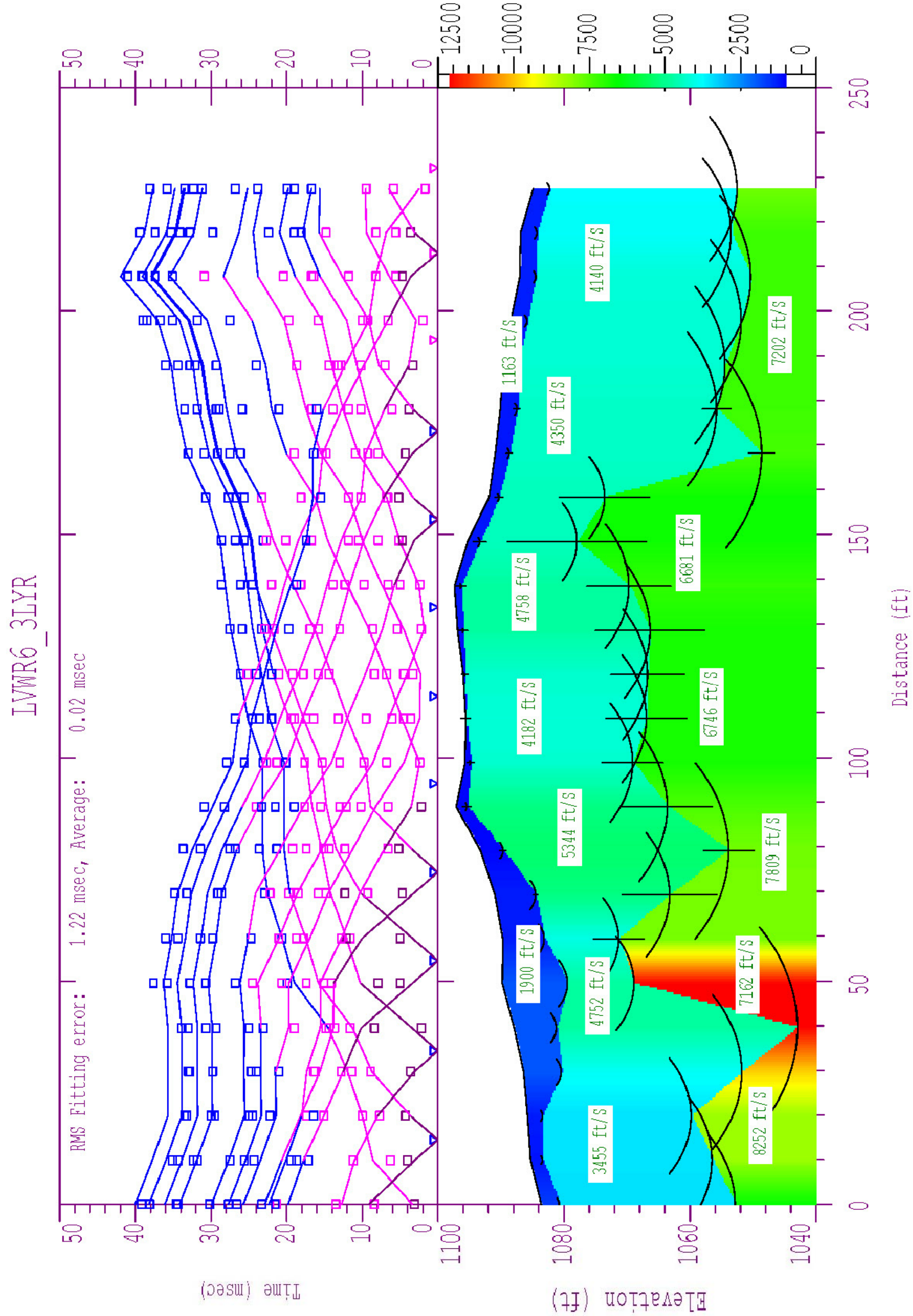
REFRACTION PROFILE - LAYERED METHOD (GRM)
REFRACTION LINE 4
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-09 GRM.dwg 07-15-2010 - 11:34am

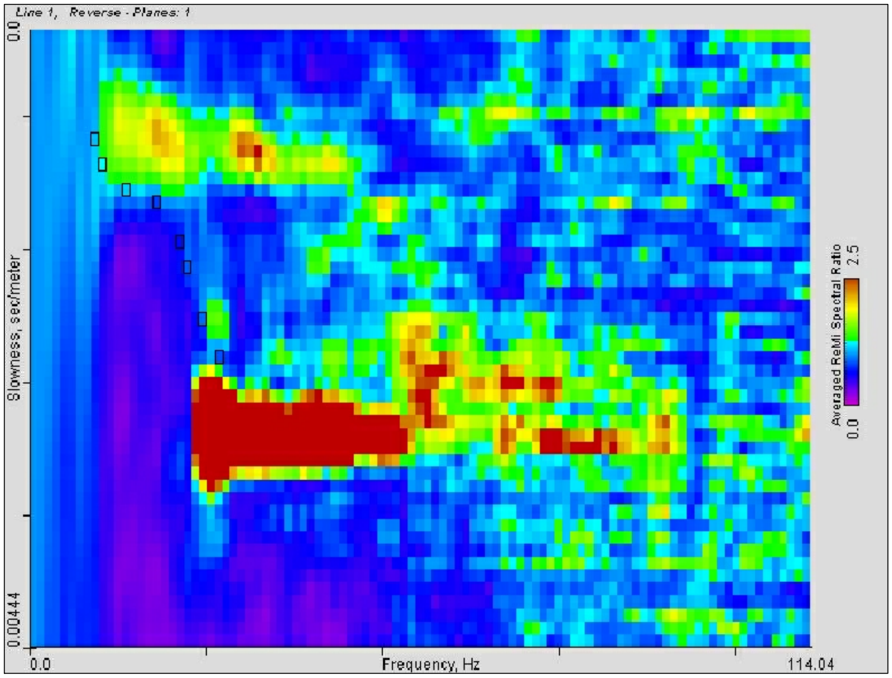


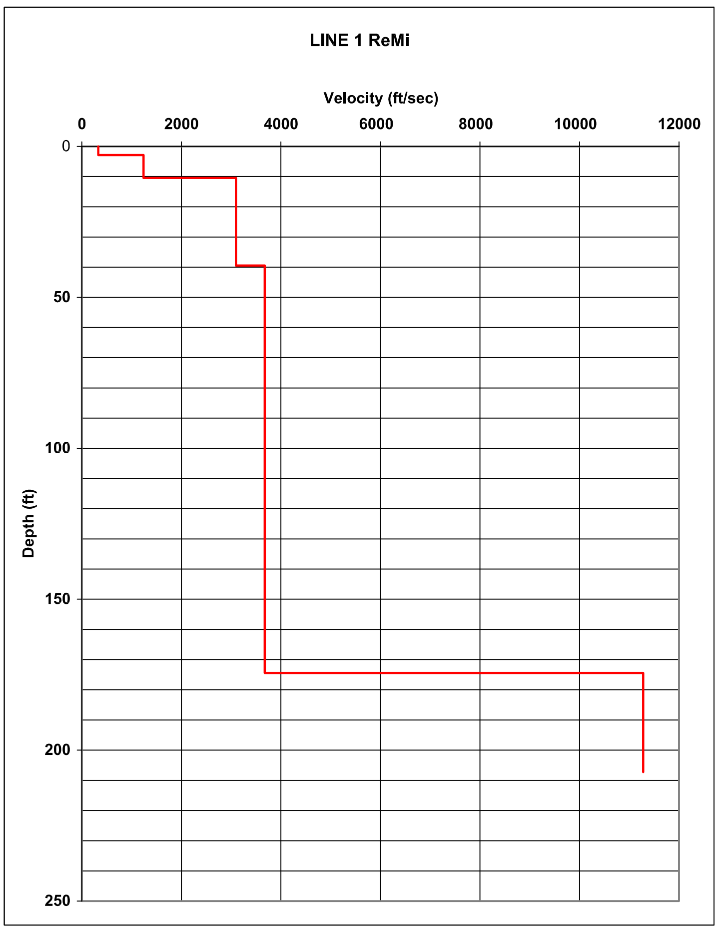
REFRACTION PROFILE - LAYERED METHOD (GRM)
REFRACTION LINE 5
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-09 GRM.dwg 07-15-2010 - 11:34am



REFRACTION PROFILE - LAYERED METHOD (GRM)
REFRACTION LINE 6
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

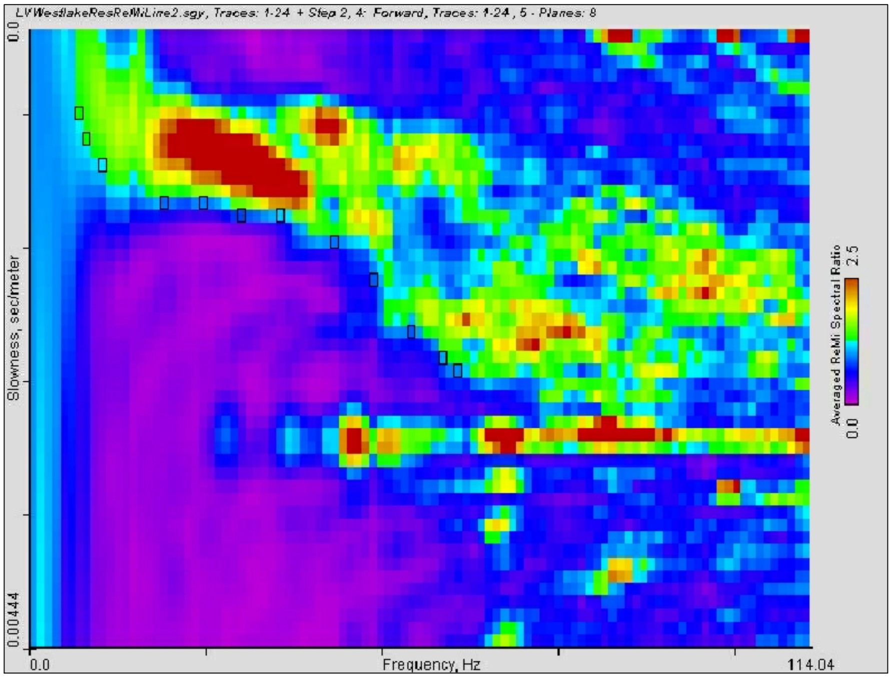


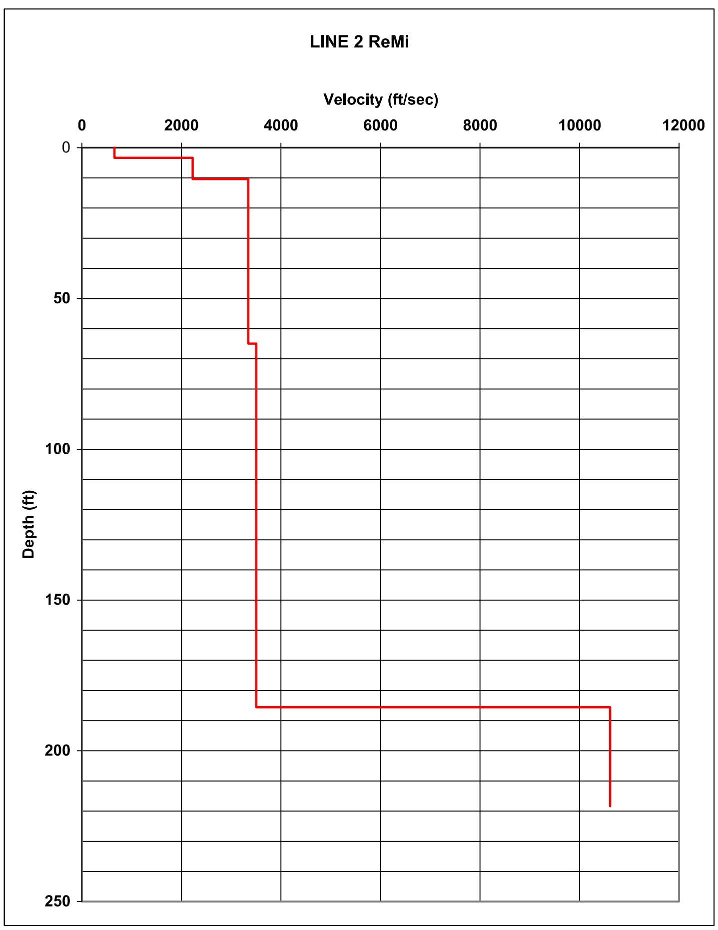


ReMi LINE 1
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

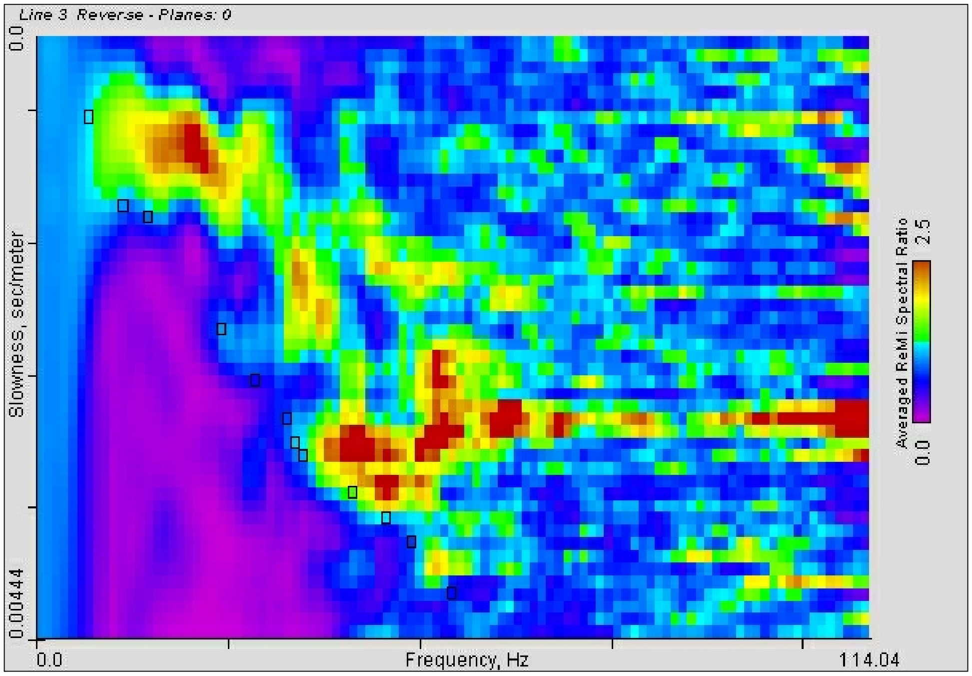
PLATE 10a

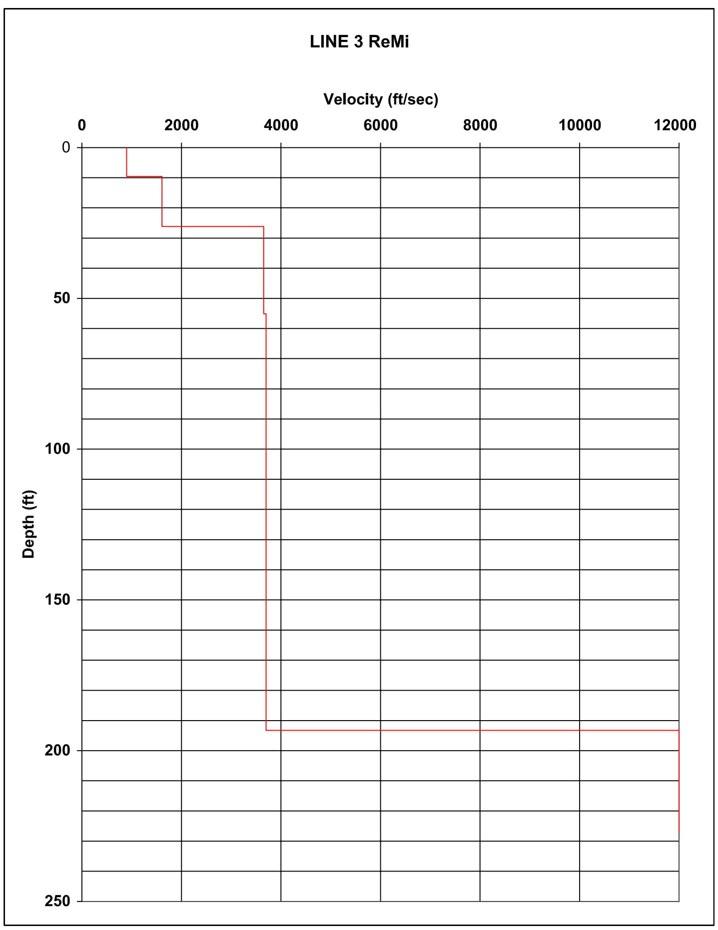
M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-10 ReMi.dwg 07-15-2010 - 11:29am





ReMi LINE 2
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

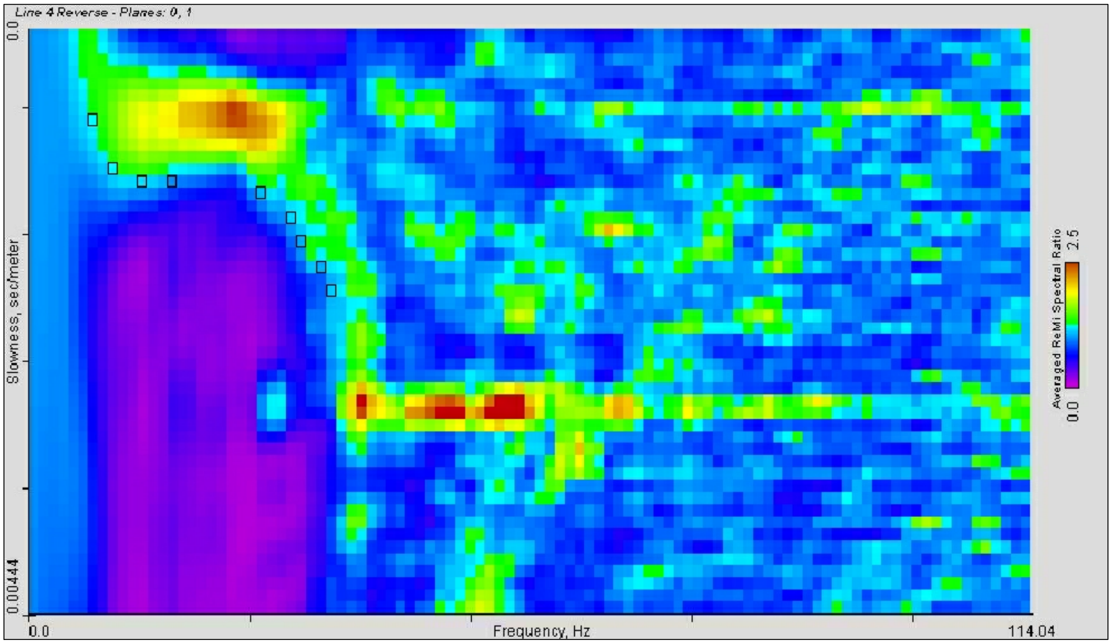


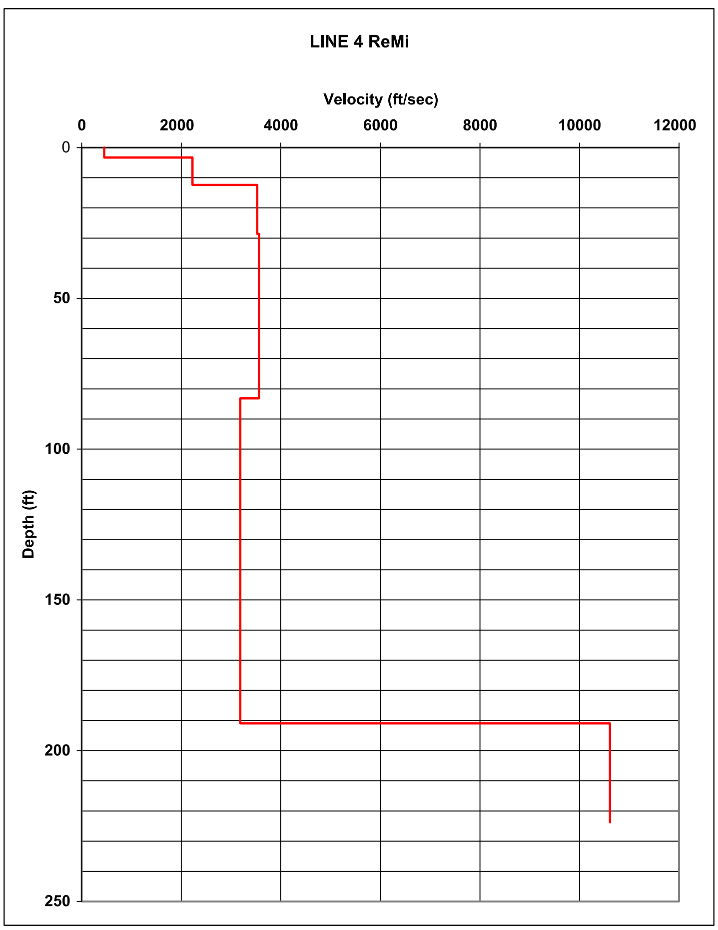


ReMi LINE 3

Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 10c

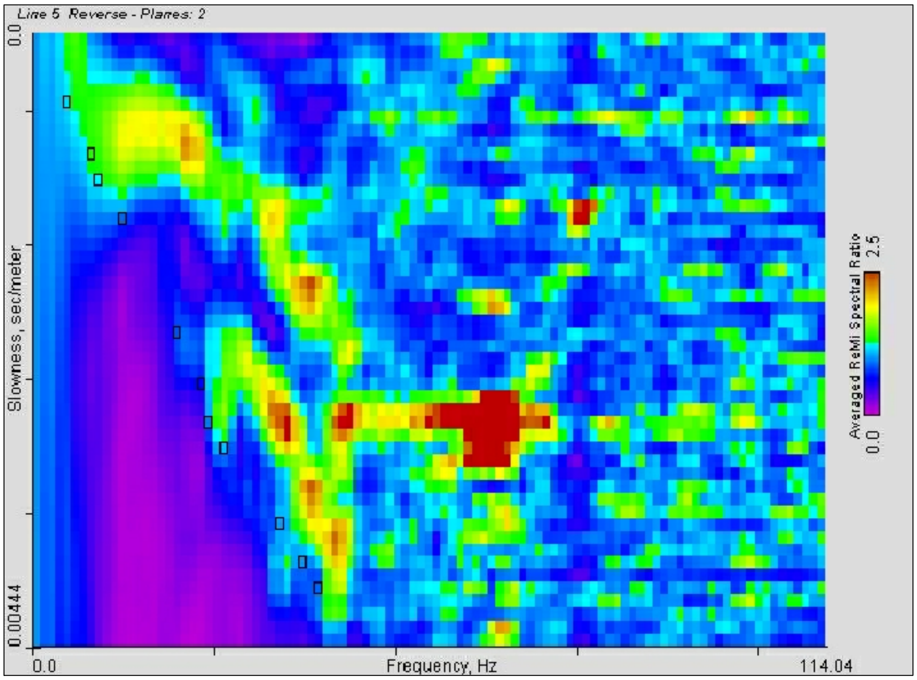


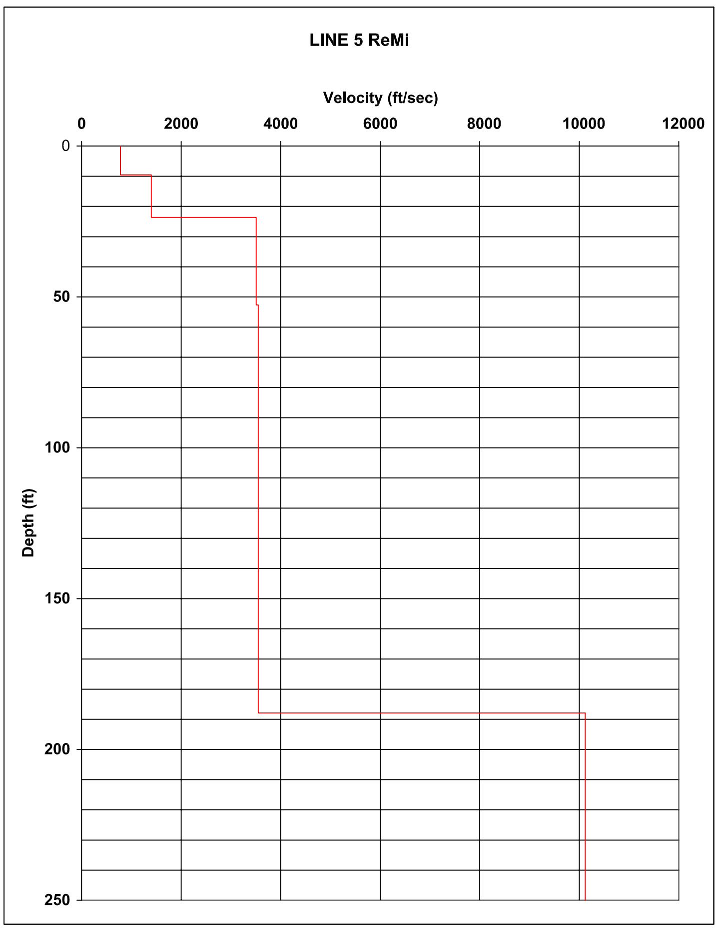


ReMi LINE 4
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

PLATE 10d

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-10 ReMi.dwg 07-15-2010 - 11:31am

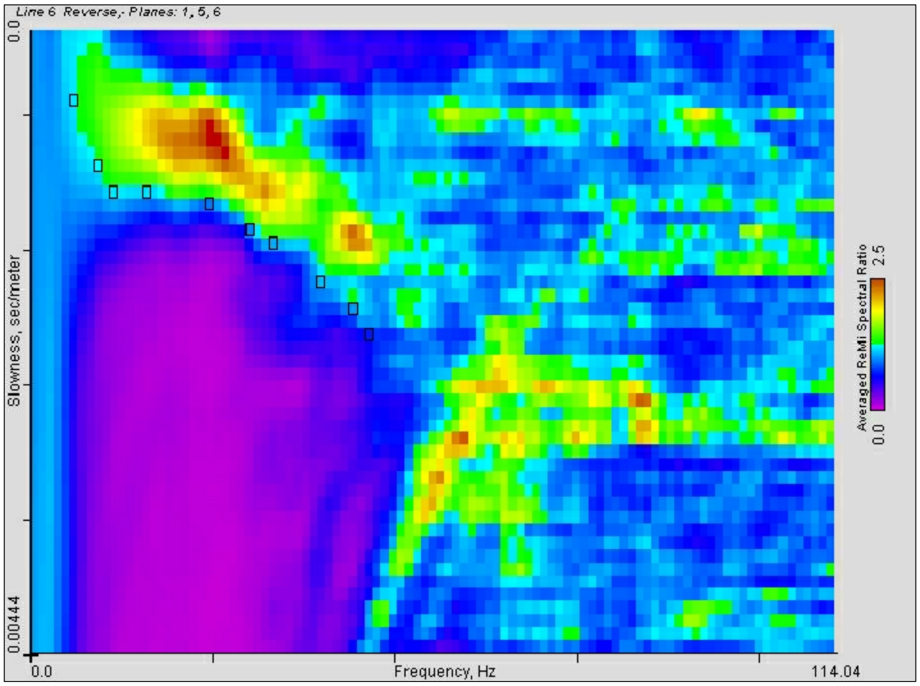


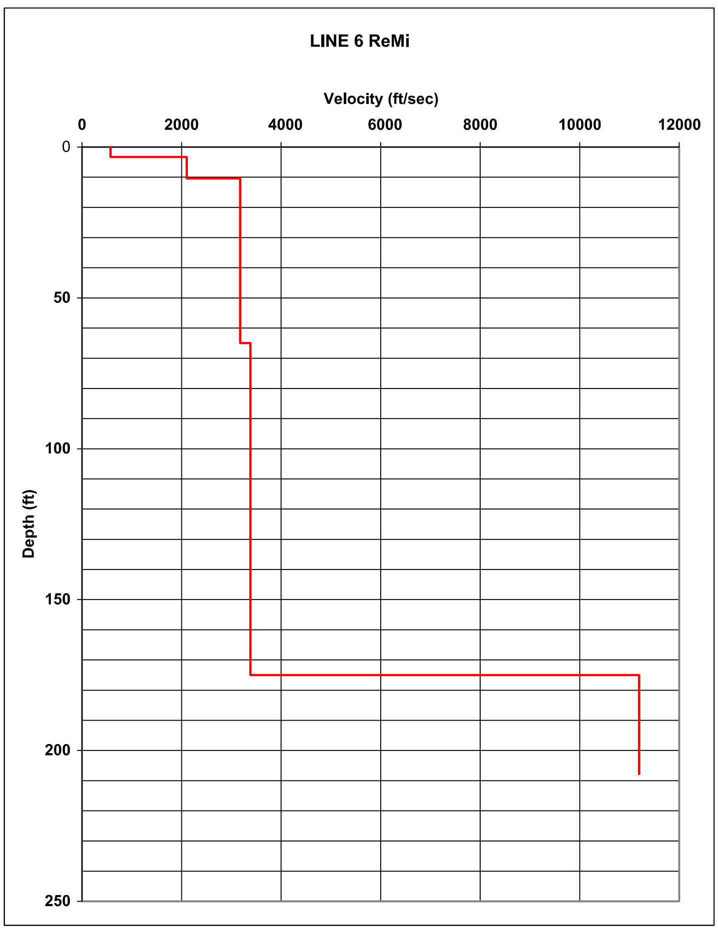


ReMi LINE 5
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

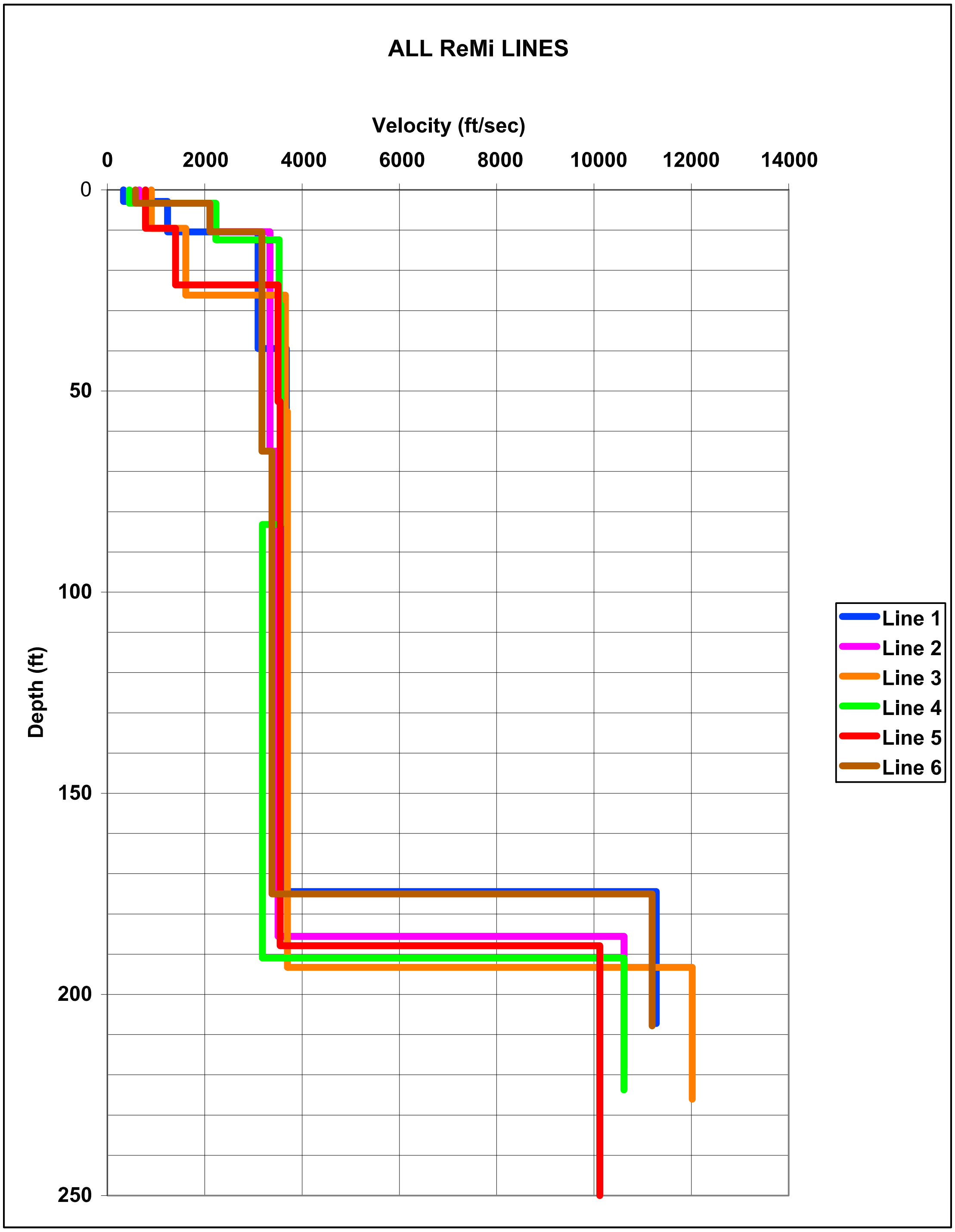
PLATE 10e

M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-10 ReMi.dwg 07-16-2010 - 3:40pm





ReMi LINE 6
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California



M:\Drafting\JOBFILES\2010\3000\3000.025\Drawings\A3000.025-11 ReMi Comparison.dwg 07-15-2010 - 11:37am

ReMi LINE COMPARISON
Las Virgenes Reservoir
Water Storage Tank Site A
Westlake Village, California

APPENDICES

APPENDIX A
FIELD EXPLORATION

Four trenches were excavated on May 28, 2010, using a Case 580SL tire-mounted backhoe operated by Buzza Backhoe Service. The trenches were logged on May 28, 2010, and June 2, 2010. Buzza Backhoe Service backfilled the trenches with cuttings on June 4, 2010. Trench locations are shown on Plate 3 - Site Geologic Map. The graphic depictions of the exploratory trenches are presented on Plates 4a through 4d - Trench Logs. The trench lengths varied from about 270 feet for Trench 1 to about 65 feet for Trench 4. The trenches were excavated to a depth at which excavating became difficult. Trenches 1 and 2 were discontinuous, so as to avoid and not undermine support for an existing chain link fence. Trench 3 was discontinuous in the proximity of the intersection with Trench 1. Trench depths varied from ground surface in areas of hard bedrock exposures, to a maximum of 4 feet. The exposed rocks were visually identified in the field. The project did not include rock identification based on microscopic study of rock thin sections.

APPENDIX B
SEISMIC REFRACTION SURVEY

APPENDIX B
SEISMIC REFRACTION SURVEY

SESIMIC REFRACTION

General Methodology. The seismic refraction geophysical survey technique is widely used as a non-destructive site characterization method. The method is commonly used for estimating the depth to bedrock and/or the water table, mapping faults, estimating formation thicknesses, measuring compressional wave (P-wave) or shear-wave (S-wave) velocities, and estimating rock rippability characteristics.

The seismic refraction method involves measuring the total time for P-waves to travel from a shot point through the subsurface to a set of geophones placed along the ground. The method is based on the general assumption that the compression-wave velocity of earth materials increases with depth. When that condition exists, seismic waves generated from the surface are refracted (bent) at higher velocity subsurface layers (producing plane-wave head-waves), so that first arrivals at distant geophones are from deeper (faster) layers instead of being from direct arrivals traveling through the lower-velocity surface layers. The first surge of energy that reaches a geophone is termed the "first arrival" and is depicted on the seismogram as a high-angle deflection along each trace. The seismic refraction technique measures arrival times of P (or S) body-waves produced by a near-surface energy source. Those waves travel from the source through the earth to a linear array of detectors (called a seismic spread) placed on the ground surface. The source positions typically are in-line within the seismic spread (between selected geophone locations). Depending on the subsurface conditions, the seismic body-waves travel directly to the seismic detectors (direct arrivals) or along critical and non-critical refraction paths at acoustic boundary interfaces (refracted arrivals). The refractor interfaces represent boundaries between earth layers that exhibit distinct P- or S-wave propagation velocity contrasts.

In practice, the desired depth of exploration and velocity contrasts determine the optimum survey parameters such as seismic refraction line length, number of detectors (geophones) on a line, and geophone spacing. For shallow refraction surveys, the typical number of geophones in a single spread ranges from 12 to 48. Geophones are placed in the ground and connected to a seismograph using a signal transmission cable. Down-going seismic energy commonly is generated by striking an aluminum plate on the ground with a sledgehammer or by the use of small explosives.

The geophones detect the critically refracted head-waves as vertical particle motion (P-waves) on the surface. The seismic refraction data are converted to electrical signals and transmitted through a seismic refraction cable (which is connected to all geophones along the seismic spread) and then recorded in the seismograph. Seismograph trigger timing is controlled by a trigger switch, which is mounted on or near the energy source so that zero time is known and the refraction arrival times for each multi-channel seismic record can be accurately measured.

In processing the refraction data, a time-distance relationship of the first arrivals is used to determine the depth and thickness of the layers, and the velocities. The data recorded on the seismograph system are processed and interpreted using computer software.

Site-Specific Data Acquisition. In general, the field acquisition of seismic refraction data followed ASTM 5777 guidelines. The seismic refraction surveys performed at the Westlake Reservoir tank site measured P-wave seismic velocities by modeling the first arrivals picked from plots of 24-channel geophone spreads. Twenty-four 10-Hz geophones were embedded in the ground surface at about 10-foot spacing along each survey line. The geophone spikes were pushed firmly into the surface of the native earth materials. Six lines were surveyed; three lines oriented in approximately an east-west direction (Lines 1, 3, and 6) and three lines oriented in approximately a north-south direction (Lines 2, 4, and 5). A DAQLink II 24-bit seismograph was used to collect and record the data. At the shot point locations, an aluminum plate was placed on the ground surface and struck repeatedly using a 20-pound sledgehammer. At each shot point location, at least 5 repeated hits from the sledgehammer were stacked (summed together), thus improving the quality of the signal over the ambient noise. Along survey Lines 1 through 5, 17 shot points were used, at approximately 20-foot spacing and approximately in line with the geophones. Along Line 6, 13 shot points, spaced at 20-foot intervals, were used. Shot points were positioned between every other geophone (with the middle shot point located mid-way between Geophones 12 and 13). For the spreads with 17 shot points, there were 3 offset shot points located off of each end of the geophone spread. For the spread with 13 shot points, there was one set of shot points located off of each end of the geophone spread.

Significant levels of ambient noise were encountered on this site, primarily caused by wind. Despite high levels of background noise, the multiplicity of shot stacks provided relatively good data. Geophone output was sampled at 0.125 milliseconds and recorded in SEG2 standard file format.

A Trimble Pro-XR, mapping-grade GPS receiver that collected 5-second synchronized carrier-phase kinematic post-processed differentially corrected data, was used to estimate the positions of the geophone receivers and shot points.

Data Interpretation. After gathering the field data, the refraction data were imported into the SEISOPT-Picker program developed by Optim Software and Data Solutions. In that program, first arrivals were picked for each shot and the resulting time-distance curves are shown on Plates 6a through 6f. The first-break pick data were then imported into three different computer programs, for profile interpretation: SeisOpt-2D, Rayfract™, and IXrefraX. Those three seismic refraction interpretation methods require a relatively large data set (geophones and shot points) and a relatively small geophone spacing to be effective. The methods also require that travel times be measured in both forward and reverse directions from many shot points per geophone spread. The seismic refraction survey field setup used for this project was designed to meet those data acquisition requirements.

The SeisOpt-2D and Rayfract™ programs use tomographic methods to provide relatively complex interpretations of subsurface refractor profiles. The IXrefraX programs a layered-method that attempts to characterize the subsurface profile as a series of two or three layers with lateral velocity variations (but no vertical velocity variation within each layer). An advantage of the tomographic methods over conventional layer-interpretation methods is their ability to estimate both lateral and vertical velocity variations throughout the subsurface profile. The results of tomographic analyses are velocity-depth profiles that estimate the interpreted distribution of seismic velocities in the subsurface beneath the geophone spread. Tomographic methods interpret a velocity gradient for each geophone spread. A significant limitation associated with tomographic methods is their inability to produce a unique subsurface model (i.e., multiple models are possible with a given set of observational data).

SeisOpt-2D. The SeisOpt-2D computer program (developed by Optim Software) interprets a velocity gradient by using a technique referred to as non-linear optimization. That technique utilizes a simulated annealing routine to calculate travel times through a finite-difference model mesh and create travel-time curves that are compared to the travel-time curves measured in the field. The software performs tens of thousands of iterations to obtain the best statistical matches between actual arrival times at each geophone and the calculated times based on ray paths through the finite-difference mesh. It is referred to as an optimization because it attempts to find the model that has the least minimum travel-time error between the calculated and the observed (field) measurements. Elements that are not parts of modeled ray paths do not have a velocity, so the extent of the investigated zone is the part of the finite-difference mesh with optimized velocities. The modeled line with the best statistical fit between observed and modeled arrival times, and/or best correlation with known or inferred geologic conditions is typically selected and processed to create a tomographic velocity profile in which different velocities are represented as different colors. The change in modeled velocity in the transition from one finite difference grid cell to the next is limited to about a factor of 3 to allow for numerical stability of the computations. As a result, abrupt transitions between areas of high- and low-velocity may be shown as more gradational in the modeled velocity profile than they actually are in the field. Consequently, velocity transitions shown on the profile should be considered approximate. To perform analyses for this site, we computed about 10 or 11 different models for each line and for each line, we have presented the model that produced the best statistical fit to the observed data. The resulting SeisOpt-2D tomographic velocity profiles are attached as Plates 7a through 7f. Because none of those models produced an exact match to the field data, the resulting profiles should not be considered to be exact images of the subsurface velocity conditions.

Rayfract™. The analyses performed using the computer program Rayfract™ are based on the Wavepath Eikonal Traveltime (WET) inversion of the travel-time data. Data were inverted for the subsurface velocity structure using the WET algorithm in the Rayfract™ software package. That algorithm is based on the procedure described by Schuster and Quintus-Bosz (1993). The method calculates the travel-time of wave paths through a regular grid of velocity values by using a finite difference solution to the Eikonal equation. The velocity grid is updated until the calculated travel-times match the observed travel-times. The method does not require the assignment of arrivals to layers and is suited to sites with vertical and lateral velocity gradients. In contrast to standard layer-methods of refraction interpretation or ray-path tomography, the WET inversion partially accounts for frequency-limited source and shadow effects in the data. Initial velocity models are constructed using a smooth, one-dimensional velocity gradient. Final two-dimensional velocity models for this site were created from 20 WET inversions of the initial starting models. Output from the algorithm is a subsurface velocity grid that is contoured using Golden Software's SURFER computer program. The Rayfract™ velocity grids for Lines 1 through 6 are presented as color-contour sections on Plates 8a through 8f.

The contoured velocity sections derived from the WET inversions provide for an evaluation of the overall velocity ranges and distributions, however, they should not be viewed as exact images of the velocity distribution of the subsurface. The inversion generates a velocity field that produces calculated arrival times that best fit the observed travel-time data. The algorithm generates a relatively smoothly varying velocity structure. Sharp boundaries between layers or regions of differing rock velocity are typically imaged by increased gradients in the velocity model that span the location of the discontinuity. For a sharp boundary between a low-velocity unit and a deeper high-velocity unit, the inversion velocity contour that corresponds to the high-velocity unit will generally be plotted below the depth of the actual boundary. The actual subsurface contact will be located at a shallower depth within the gradient. Consequently, the velocity contours derived from the WET inversions cannot be assumed to be the actual depth at which the indicated velocity value exists in the subsurface. The WET inversions are not able to utilize the arrival-time data from the off-end shots to calculate the velocity at depth beneath the ends of the lines. That produces the curved bottom on the velocity sections.

General Reciprocal Method (GRM). The first-break pick data were also imported into the IXrefraX Generalized Reciprocal Method (GRM) computer program developed by Interprex. IXrefraX provides a highly automated implementation of Palmer's (1980) GRM method of refraction data interpretation. The GRM method is regarded as one of the more robust seismic refraction interpretation layer-methods used to resolve complex subsurface conditions. The GRM method incorporates the strengths of most other seismic refraction layer-interpretation methods and can provide relatively detailed interpretations of refractor profiles. An advantage of the GRM method is its ability to estimate lateral velocity variations in the overburden materials as well as in the refracting materials (although it does not model vertical variations within each layer). The results of the GRM analyses are velocity-depth layered-profiles that estimate the interpreted lateral distribution of seismic velocities in each subsurface layer beneath the geophone spread (Plates 9a through 9f). Vertical velocity variations are averaged within each layer. Because none of those models produced an exact match to the field data and due to the simplifying assumptions inherent in the interpretation methodology, the resulting profiles should not be considered to be exact images of the subsurface velocity conditions.

Rippability Estimates. The determination of rock rippability is an imprecise science and is based on observational data correlating ease of excavation with compressional (P-wave) seismic velocities. In general, P-wave seismic velocities can be correlated to material density and/or rock hardness. The relationship between rippability and seismic velocity is empirical and assumes a homogeneous mass. Localized areas of differing composition, texture, cementation/mineralization, and /or structure (e.g., bedding, joints, or fractures), like those observed on this site, may affect both the recorded data and the actual rippability of the rock mass. The rippability of a rock material is also dependent on the excavation equipment used, and the skill and experience of the equipment operator.

The qualitative rippability classifications suggested in Table B-1 below are based on our experience with similar rock materials and assume that a Caterpillar D-9 dozer ripping with a single shank is used. It should be noted that the ranges used in that classification system are approximate and that rock characteristics, such as fracture spacing and orientation, play a significant role in determining rock rippability. The characteristics may also vary with location and depth.

For trenching operations, the rippability values should be scaled downward significantly. For example, velocities as low as about 3,500 feet/second may indicate extremely difficult ripping during trenching operations. In addition, the presence of boulders and hard zones, which can be problematic in a narrow trench, should be anticipated.

Table B-1 - Qualitative Rock Rippability Classifications

Seismic P-Wave Velocity (feet/second)	Qualitative Rippability Classification
1000 to 2,000	Readily rippable
2,000 to 3,500	Generally rippable
3,500 to 5,000	Ripping with considerable difficulty; possible local blasting
5,000 to 6,000	Ripping with great difficulty; probable local to general blasting
6,000 to 7,000	Ripping with extreme difficulty; probable local to general blasting
Greater than 7,000	Blasting generally required

It should be noted that the rippability classifications presented in Table B-1 are slightly more conservative than those published in the Caterpillar Performance Handbook. Consequently, the above classification system should be used with discretion, and contractors should be required to make their own independent evaluation of the rippability of the onsite materials prior to their bids.

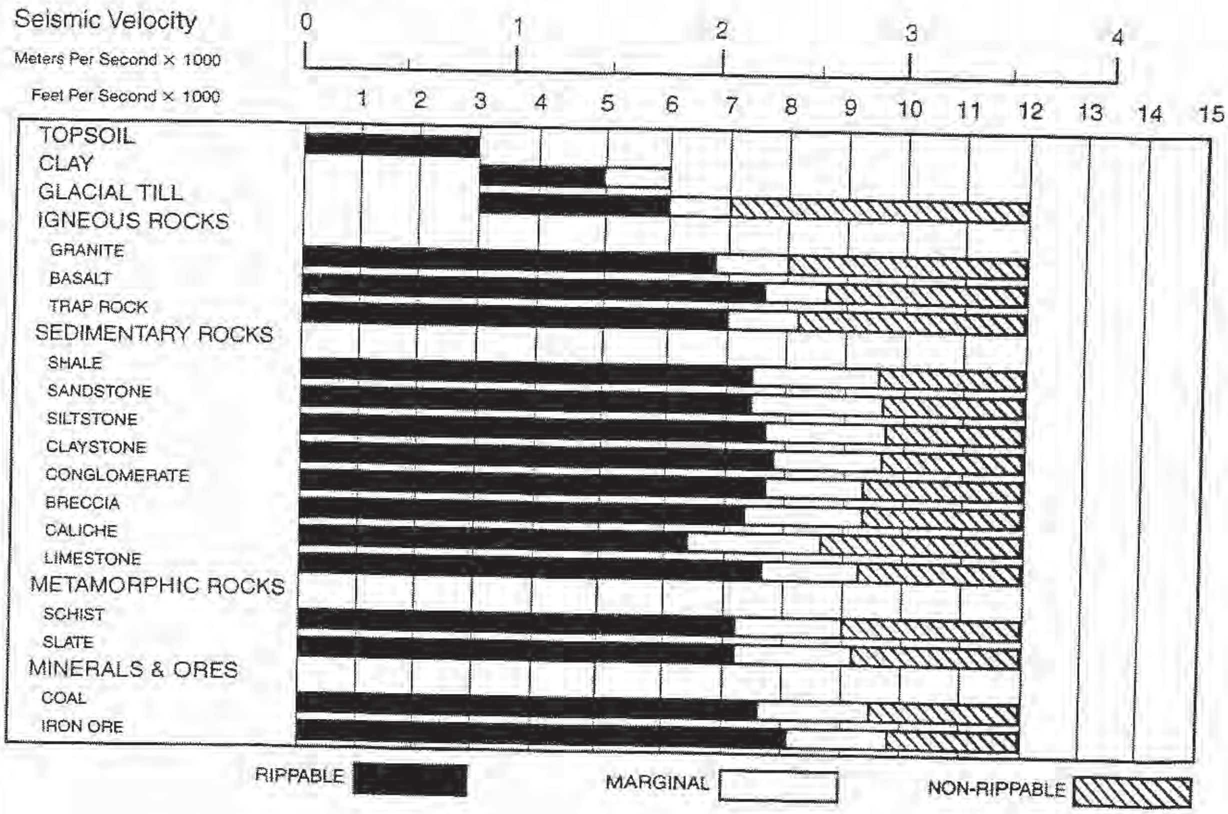
Ripper performance charts from Caterpillar are attached as Plates B-1 through B-5, and may be used in conjunction with Caterpillar's "Estimated Ripper Production Graphs 2," attached as Plate B-5. We note that Caterpillar indicates P-wave velocities should be, at best, used as only one indication of excavation potential. In addition to P-wave velocity, many other geologic factors (as noted above) influence bedrock rippability. The Caterpillar charts are provided only as a guide and should not be considered absolute. Although the Caterpillar charts are commonly used, in our experience, they may overestimate the ease of ripping and should only be used for initial provisional estimates.

Limitations. The objective of the geophysical survey was to estimate the geometry and velocities of the near-surface geologic units using seismic refraction methods within the resolution of the equipment. The results of our refraction survey are based on our interpretation of recorded geophysical data and should not be construed as absolute fact. The seismic refraction method may not be able to detect some subsurface velocity conditions and the unrecognized presence of those conditions can result in incorrect velocity cross-sections. The following considerations may account for differences between predicted and actual layer depths and velocities:

- Because the seismic refraction method is based on the general assumption that compression-wave velocity of earth materials increases with depth, this method may miss thin, intermediate velocity layers (blind zones) or lower velocity layers beneath higher velocity layers (hidden zones).
- Excavation potential (e.g., rippability) may gradually increase as a harder layer is approached or it may vary suddenly at a specific interface. Because of simplifications associated with refraction interpretation methods, the positions of layers and zones indicated on the velocity sections may be only generalized and the transitions from softer to harder units may be gradational.
- Third-dimensional effects may reduce the accuracy of layer depths because seismic waves travel not only vertically, but in all subsurface directions. This can result in out-of-plane effects, and cross-section depths may not always represent vertical depths.
- Localized lateral variations, such as soft or hard zones, may not be detected by the refraction survey method, and may result in misinterpreted subsurface conditions.
- Seismic waves may not generate a distinguishable head wave on a bedrock surface, and consequently, later arrivals may be selected as the first arrival, resulting in possible configuration and velocity errors.
- Velocities generally apply only along the survey line; hence localized conditions away from the lines may not be detected.

Therefore, velocities and subsurface geometry interpreted from refraction survey data may be more or less than actual, and estimated values should be considered only as a guide. Verification of the seismic depth sections is typically done using boring and/or test-pit data, and full-scale field tests of rippability using production equipment.

D9R/D9T
- **Multi or Single Shank No. 9 Ripper**
- **Estimated by Seismic Wave Velocities**



USE OF SEISMIC VELOCITY CHARTS

The charts of ripper performance estimated by seismic wave velocities have been developed from field tests conducted in a variety of materials. Considering the extreme variations among materials and even among rocks of a specific classification, the charts must be recognized as being at best only one indicator of rippability.

Accordingly, consider the following precautions when evaluating the feasibility of ripping a given formation:

— Tooth penetration is often the key to ripping success, regardless of seismic velocity. This is particularly true in homogeneous materials such as mudstones and claystones and the fine-grained caliches. It is also true in tightly cemented formations such as conglomerates, some glacial tills and caliches containing rock fragments.

— Low seismic velocities of sedimentaries can indicate probable rippability. However, if the fractures and bedding joints do not allow tooth penetration, the material may not be ripped effectively.

— Pre-blasting or "popping" may induce sufficient fracturing to permit tooth entry, particularly in the caliches, conglomerates and some other rocks; but the economics should be checked carefully when considering popping in the higher grades of sandstones, limestones and granites.

Ripping is still more art than science, and much will depend on operator skill and experience. Ripping for scraper loading may call for different techniques than if the same material is to be dozed away. Cross-ripping requires a change in approach. The number of shanks used, length and depth of shank, tooth angle, direction, throttle position — all must be adjusted according to field conditions. Ripping success may well depend on the operator finding the proper combination for those conditions.

D10T
- **Multi or Single Shank No. 10 Ripper**
- **Estimated by Seismic Wave Velocities**

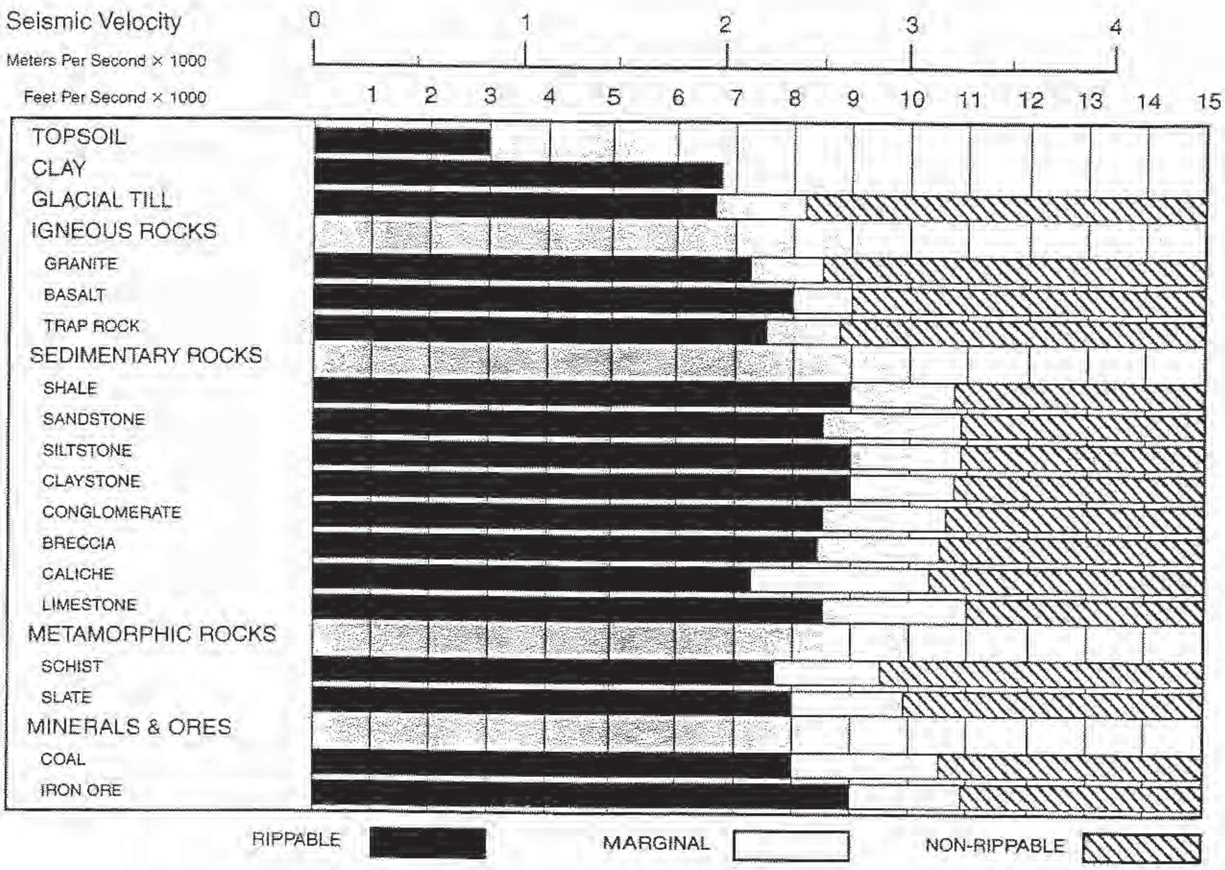


PLATE B-2

D11T
- **Multi or Single Shank No. 11 Ripper**
- **Estimated by Seismic Wave Velocities**

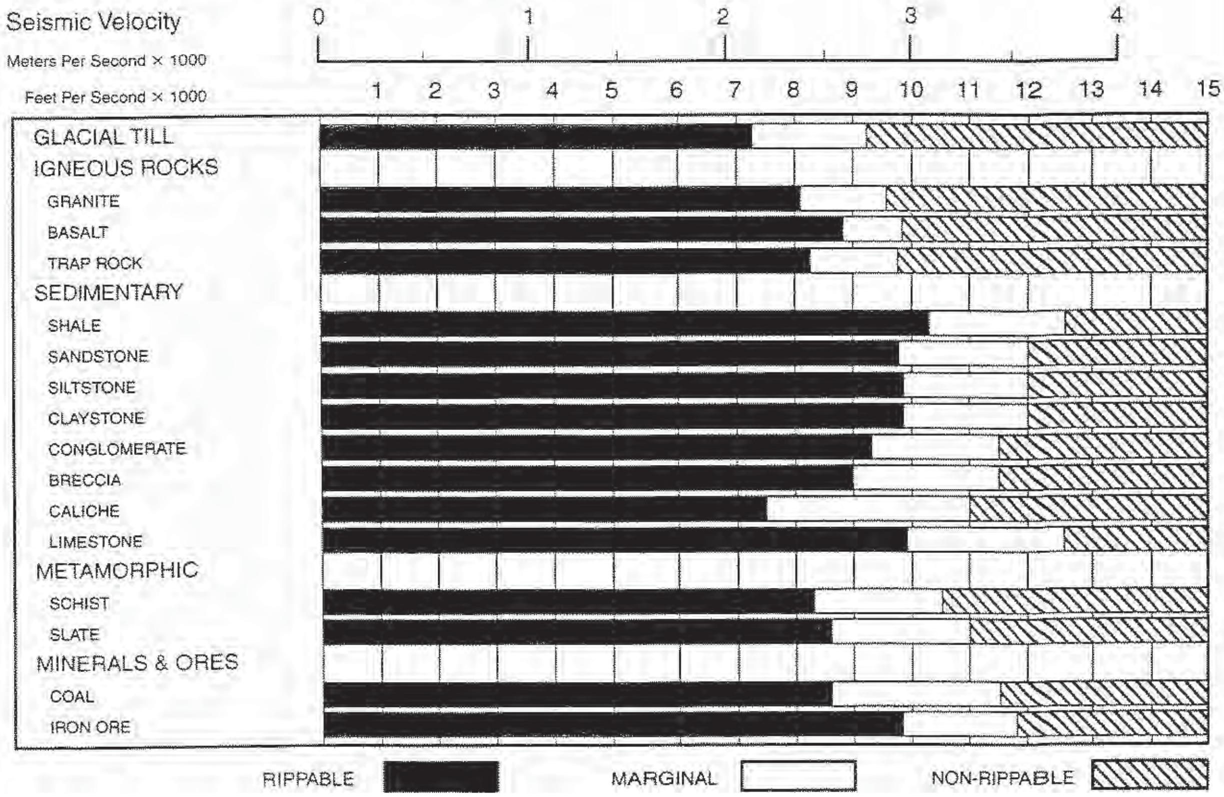


PLATE B-3

D11T CD
- **Single Shank No. 11 Ripper**
- **Estimated by Seismic Wave Velocities**

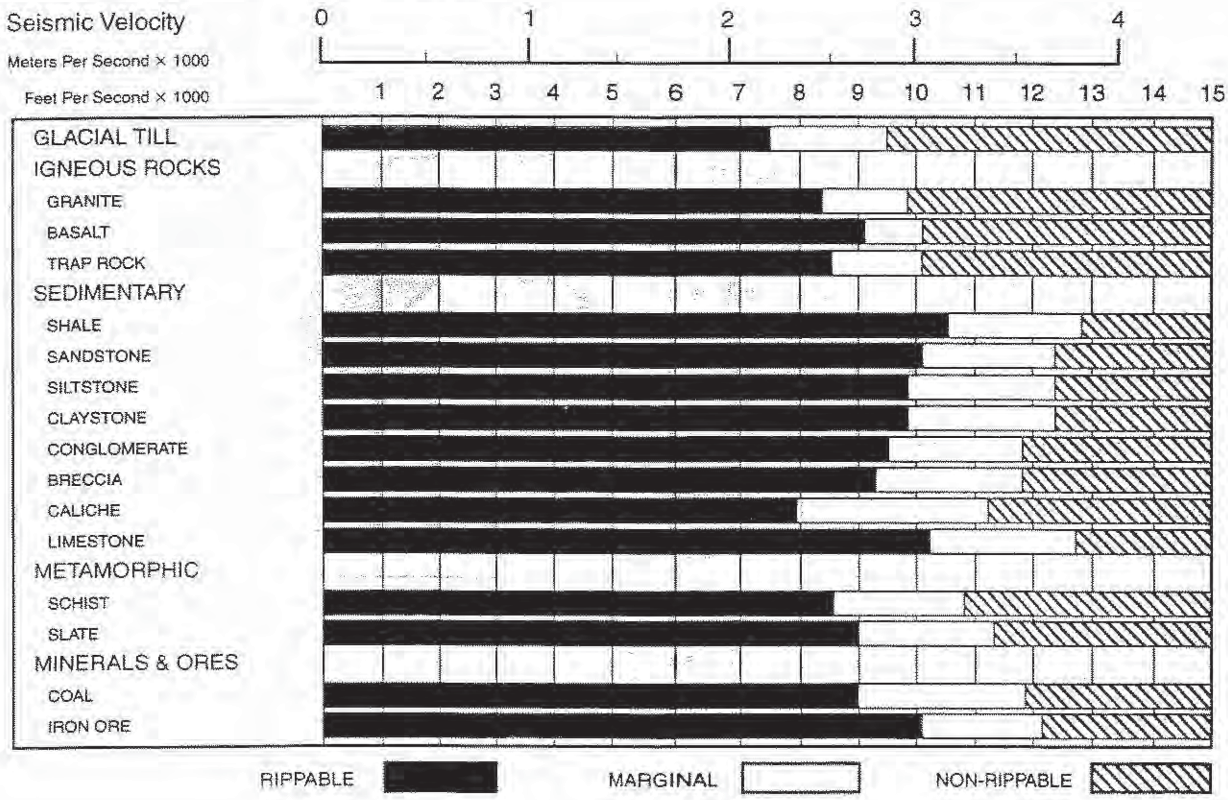
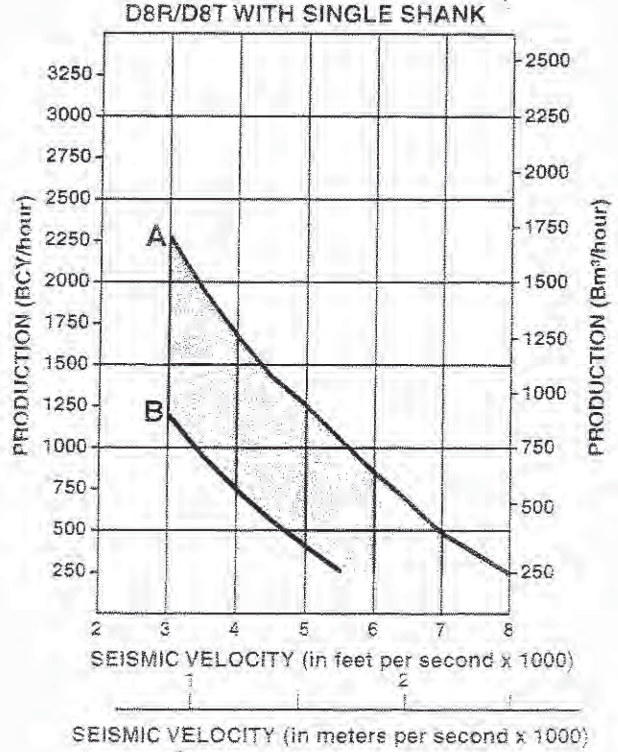


PLATE B-4

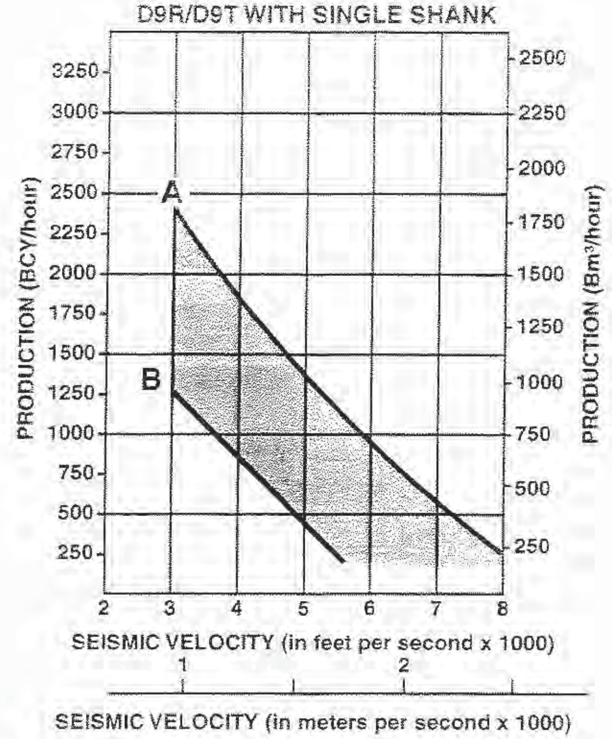
CONSIDERATIONS FOR USING PRODUCTION ESTIMATED GRAPHS:

- Machine rips full-time — no dozing.
- Power shift tractors with single shank rippers.
- 100% efficiency (60 min hour).
- Charts are for all classes of material.
- In igneous rock with seismic velocity of 8000 fps (2450 mps) or higher for the D11R, and 6000 fps (1830 mps) or higher for the D10T, D9R/D9T and D8R/D8T, the production figures shown should be reduced by 25%.
- Upper limit of charts reflect ripping under ideal conditions only. If conditions such as thick lamination, vertical lamination or any factor which would adversely affect production are present, the lower limit should be used.

D8R/D8T WITH SINGLE SHANK

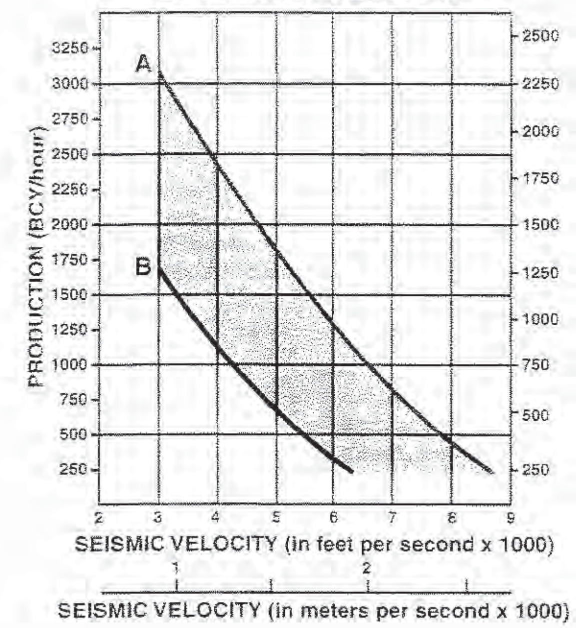


D9R/D9T WITH SINGLE SHANK

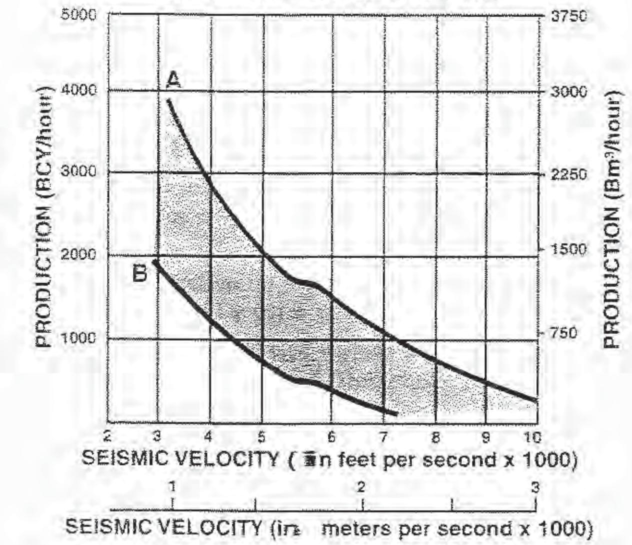


KEY
A — IDEAL
B — ADVERSE

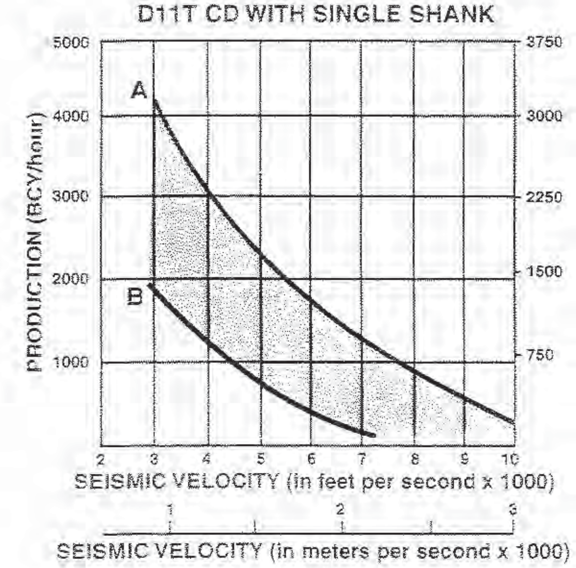
D10T WITH SINGLE SHANK



D11T WITH SINGLE SHANK



D11T CD WITH SINGLE SHANK



KEY
A — IDEAL
B — ADVERSE

APPENDIX C
REFRACTION MICROTREMOR ANALYSIS (ReMi)

APPENDIX C
REFRACTION MICROTREMOR ANALYSIS (ReMi)

SHEAR WAVE VELOCITY ESTIMATION USING REMI

To estimate the shear wave velocity of the earth materials in the area of the proposed Westlake Reservoir tank, we utilized the proven, non-destructive, passive surface-wave analysis technique referred to as ReMi (Refraction Microtremor) (Louie, 2001; Stephenson et al., 2005; Jaume et al., 2005). The technique uses surface waves generated by noise (e.g., traffic, equipment, wind, footsteps, etc.) to estimate subsurface soil characteristics. The basis of surface wave methods is the dispersive characteristic of Rayleigh waves when propagating in a layered medium. The Rayleigh-wave phase (propagation) velocity primarily depends on the material properties to a depth of about one wavelength (and is strongly influenced by soils within about one-half of a wavelength). Different phase velocities result as longer-period waves sample deeper soil layers. The variation of phase velocity with frequency (i.e., wavelength) is called dispersion.

For our ReMi analysis, we used the same geophone spreads that we used for seismic refraction Lines 1 through 6. Those lines consisted of arrays of 24 10-hz geophones that were arranged on the ground-surface with geophones spaced at 10-foot intervals along a linear spread. The spreads were oriented approximately north-south and east-west (Plate 5).

From 10 to 12, 30-second-long seismic records (each with a 2 millisecond sampling rate) were gathered for each line. For most of those records, a pickup truck was driven back and forth just off of the end of each geophone spread to generate broad-spectrum noise that helps model near-surface earth material characteristics. A slowness-frequency (p-f) wave-field transform was used to separate Rayleigh surface wave energy from that of other waves (slowness is the inverse of phase velocity). The wave-field transform is conducted for a range of velocity vectors through the geophone array, all of which are summed using the slant-stack technique. The dispersion curve picked to model the site was along the lower envelope of the summed Rayleigh wave energy in p-f space (Plates 10a through 10f). After picking the Rayleigh-wave dispersion curve, an interactive modeler was used to model a subsurface soil profile that provided a good fit to the dispersion curve (Plates 10a through 10f). A comparison plot of the ReMi results from all six lines is shown on Plate 11.

On the basis of our ReMi velocity survey of Lines 1 through 6, we obtained shear wave velocity for the upper 100 feet (V_{S100}) 30 meters (V_{S30}) results for the site that ranged from about 2,280 to 2,897 ft/sec (695 to 883 m/sec), with an average of about 2,590 ft/sec (about 790 m/sec). The range of results spans the boundary between the B and C site classifications (2,500 ft/sec; 760 m/sec) and the average is near the lower limit of the B site classification. Assuming that excavation and removal of near-surface low-velocity material is likely to accompany development of the site, it seems reasonable to utilize a site classification of B for design purposes.