US Army Corps
of Engineers®
Los Angeles District

Little Colorado River

Feasibility Study Report

APPENDIX F

Geotechnical

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US Army Corps
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Los Angeles District
Geotechnical Branch

Geotechnical Appendix: Geotechnical Study Report

Little Colorado River at Winslow Feasibility Study

Winslow, AZ, and vicinity, Navajo County

Winslow Levee, near McHood Rd. View to E. Sept. 2013

US Army Corps of Engineers
Geotechnical Branch, Los Angeles District
915 Wilshire Blvd., Ste. 930
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Updated 11-5-2015 and 12-9-2015 to include additional information on underground and through-going utility lines, and other data and changes.
Updated 4-21-2016 to reflect Corps Office of Counsel review.

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1.0 INTRODUCTION

This geotechnical report conveys observations, data, and recommendations on geology and geotechnical engineering issues pertinent to the 'Little Colorado River at Winslow' feasibility study, Navajo County, Arizona. The feasibility study is a cooperative effort by the U.S. Army Corps of Engineers (USACE) and Navajo County. The current study focus is on improving flood protection for Winslow, AZ, and adjoining parts of Navajo County through various combinations of enhancements to Winslow Levee and the downstreammost part of conjoined Ruby Wash Diversion Levee (RWDL). The existing Levees and the primary concepts studied as part of the levee improvements are shown on Figure 1. The Levee systems were built to protect the vicinity from overbank flooding by the Little Colorado River and several tributaries, including Ruby Wash.

1.1 Available Information

Much geotechnical and geologic information is available as part of this study. The USACE has developed several geotechnical documents as part of current feasibility study (initiated in 2008), and earlier work by the Corps. RWDL was designed by the Corps, completing the work in the early 1970s. The USACE documents include:

- Summary of Winslow Levee and Ruby Wash Diversion Levee (USACE, 2010)

  Report on as-built condition and past performance of the Winslow and RWDL Levees. This work included compilation and evaluation of available documentation regarding exploration, foundation conditions, applied construction methods, materials used, design parameters applied, and improvements made to Winslow Levee and RWDL; performance history also was reported, along with identification of past failure points on Winslow Levee. The work was done in 2009 and 2010 (US Army Engineer District, Los Angeles, 2010).

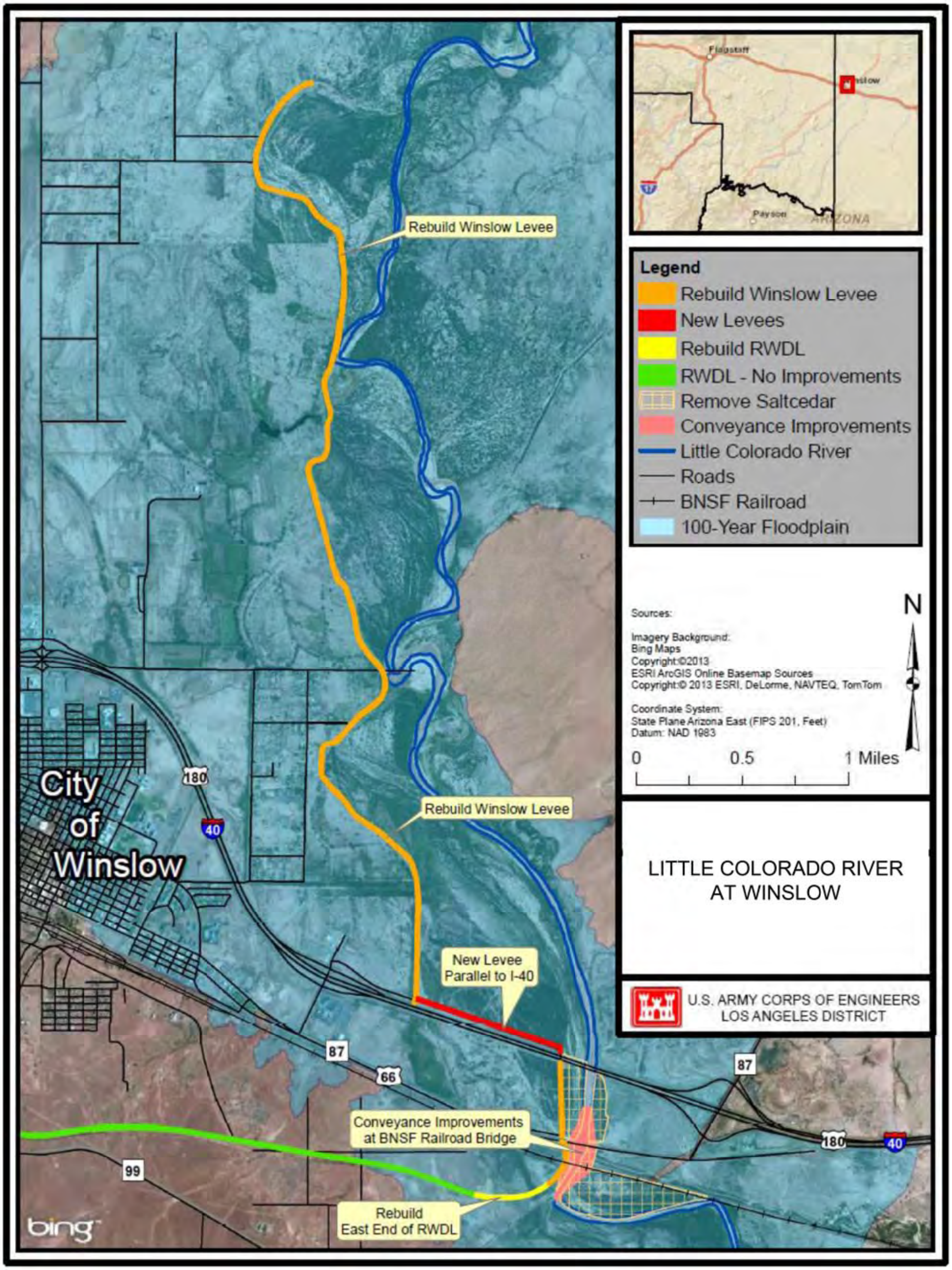
- Geotechnical Evaluation of Levee Fragility (USACE, 2012)

  The Los Angeles and San Francisco Districts collaborated to perform work which involved identification of locations and means through which the Levees are most anticipated to provide unsatisfactory performance under flood conditions, and to determine the probability of that unsatisfactory performance actually occurring. The work was performed in 2011 and 2012.

- Phase I Environmental Site Assessment (ESA) (USACE, 2013)

  This report, completed in 2013 by the USACE Los Angeles District, is one part of the set of technical appendices that support and are compiled with the LCR at Winslow main feasibility study report, which is a Planning Division document.

- Winslow Flood Control Project, Winslow, Arizona and vicinity, Design Memorandum No. 1 (USACE, 1969)



VARIOUS CONCEPTUAL LEVEE IMPROVEMENTS ELEMENTS (RED, BROWN, YELLOW, ORANGE LINES) AND CHANNEL CAPACITY IMPROVEMENTS SCENARIOS (ORANGE AND HACHURED POLYGONS) RECEIVE GEOTECHNICAL ASSESSMENT VIA THIS REPORT. OTHER ALTERNATIVES ARE LESS COMPREHENSIVE OR HAVE DIFFERENT ELEMENTS (SEE TABLE 1).

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY LEVEE IMPROVEMENTS, REALIGNMENTS, AND CHANNEL WORK UNDER CONSIDERATION AT THE FEASIBILITY STUDY TSP PHASE	FIGURE 1

FILE NAME: WINSLOWFIG01.DGN

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In addition, numerous other reports are available pertaining to the subject levee system:

- ADWR (Arizona Dept. of Water Resources), 1980, Feasibility report, Little Colorado River flood control project, Winslow, Arizona: report prepared for Navajo County Flood Control District, November 1980, 35 pp, 7 plates, plus appendix.
- Cella Barr Associates, 1994, Revised Winslow levee repair project alternative repair schemes report for Navajo County Public Works Department: consultation report , CBA file no. 106889-01-0300 WRB 00372.03R, dated 25 April 1994, by Cella Barr Associates, 4911 E. Broadway Blvd., Tucson, AZ 85711.
- Cella Barr Associates, 1995, Engineer's report, Winslow levee final report: consultation report for Navajo County, AZ, and FEMA, CBA file no. 106889-02-0280 KAD 00128.02R, dated 20 April 1995, by Cella Barr Associates, 4911 E. Broadway Blvd., Tucson, AZ 85711.
- Dames and Moore, 1980, Conceptual design, proposed levees near Winslow, Arizona, for Arizona Department of Water Resources: consultation report; could not be located for the current paper but this citation was found in an older geotechnical report on the proposed Levee rebuilt that eventually resulted in the current Winslow Levee.
- Kleinfelder West, Inc., 2009, Final geotechnical evaluation report, FEMA Certification, of Ruby Wash Diversion Levee West, station 163+80 to 381+30, Winslow, AZ: a consultation report prepared for Woodson Engineering & Surveying, Inc., 124 N. Elden St., Flagstaff, AZ, 86001, by Kleinfelder West, Inc., 1335 W. Auto Dr., Tempe, AZ, 85284.
- SHB Agra, Inc., 1994, Geotechnical investigation report, Winslow Levee repair, Navajo County, Arizona: consultation report for Cella Barr Associates, Tucson, AZ, by SHB Agra, Inc., Engineering and Environmental Services, 3232 W. Virginia Ave., Phoenix, AZ, 85009, 12 April 1994.
- Tetra Tech, Inc., 2009, Little Colorado River at Winslow Feasibility Study Baseline and Future Without-Project-Conditions Hydrology Report.
- Western Technologies, Inc. (WTI), 1982, Final evaluation of Little Colorado River Flood Control Project, Winslow, Arizona: consultation report for Navajo County Dept., of Public Works by Western Technologies, Inc., Phoenix, AZ, 9 Sept. 1982, WT no. 2212J282.
- Western Technologies, Inc. (WTI), 1982, Levee extension, Little Colorado River Flood Control Project, Winslow, Arizona: consultation report; could not be located for the current paper but this citation was found in an older geotechnical report on the proposed Levee rebuilt that eventually resulted in the current Winslow Levee; it is presumed the WTI 1982 borings found on the as-builts are a part of this report, since they all are in the Levee extension zone.
- Western Technologies, Inc. (WTI), 1987, Materials sources report for Winslow Levee Improvement Project: consultation report for Navajo County Dept., of Public Works project no. 429-45, by Western Technologies, Inc., job no. 2526JW108.
- Western Technologies, Inc. (WTI), 1993, Subsurface exploration and testing, Winslow Levee,
  Navajo County, Arizona: consultation report for Navajo County Dept., of Public Works by Western Technologies, Inc., 2400 E. Huntington Dr., Flagstaff, AZ, 86004, 2 Sept. 1993, WT no. 2523JW228.

1.2 Proposed Improvements

Individual flood risk management measures were first developed as part of the brainstorming process and screened for merit. Measures were then used in various combinations to come up with an array of alternatives. Alternatives were then further screened to create a “focused array of alternatives.” Information regarding the measures, alternatives, and screening criteria/process is presented in detail in the main feasibility report, but is summarized herein for good measure. The flood risk management measures included:

A. Non Structural:

1. Buy out properties
2. Ring levee/floodwall at individual structures as appropriate
3. Improve existing flood warning and evacuation system
4. Elevate homes
5. Relocate structures out of flood prone properties
6. Floodplain regulations (elevations)

B. Structural:

1. Upstream detention on the LCR and/or tributaries (i.e., Clear Creek and Chevelon Creek)
2. In-Channel Measures (in channel measures are ineffective as stand-alone alternatives, do not meet objectives, but can be combined with other measures)
   - Sediment removal
   - Invasive removal
   - Channelization
   - Concrete-lined channel
   - Channel training structures
   - Improve conveyance at bridges
   - Grade control structures
   - Diversion upstream of bridges
3. Levee Measures
   - Bank armoring (e.g., Soil cement, Riprap/Gabions, Articulated concrete blocks)
   - Sheet piles
   - Sand filter
   - Extend bentonite core
   - Toe drain
   - Raise levee height
   - New levee (current alignment)
   - Realign levee to remove impingement points
   - New setback levee
   - Floodgates at underpasses

The focused array of alternatives considered during this geotechnical assessment is summarized in Table 1.

Table 1.—Summary of alternatives considered during this geotechnical assessment. ***As of April 2016. See main feasibility report for maps and more in-depth discussion of each alternative and the most current iteration and detail on each alternative. All Alternatives include the nonstructural measure of improving the flood warning system.***

Alternative name	Important elements of the alternative
Alternative 1.1 *Rebuild levees* (this is Figure 1)	Rebuild entire Winslow Levee, most of it in place; relocate one Levee segment to eliminate I-40 embankment from being part of the Levee; rebuild east end RWDL in place; excavate sediment and clear tamarisk beneath & between bridges, southern end of study area.
Alternative 3.1 *Setback levees*	Rebuild entire Winslow Levee, the northern 1/3 of levee length in place and the southern approximately 2/3 setback to the west along French Rd.; relocate one Levee segment to eliminate I-40 embankment from being part of the Levee; rebuild east end RWDL in place; excavate sediment and clear tamarisk beneath & between bridges, southern end of study area.
Alternative 7 *Nonstructural measures*	No levee or river channel improvements. Elevate residences north of I-40 and west of Winslow Levee that would receive more than 0.5 feet of inundation from estimated flood event.
Alternative 8 *FEMA levee acceditation*	Same as Alternative 1.1 except include a setback levee between N Rd. and Prosperity Dr.
Alternative 9 *Levee increment 1*	Same as Alternative 7 except add Rebuild east end RWDL in place ("Levee increment 1").
Alternative 10 *Levee increments 1 and 2*	Apply Alternative 8 measures along southern half of Levee system (incl. RWDL segment) and Alternative 7 features along northern half.
Alternative 10.1	Apply Alternative 8 measures but only along southern half of Levee system (incl. RWDL segment). Levee height to provide freeboard against 1% ACE flood.
Alternative 10.2	Similar to Alternative 10.1, but with these major differences: 1) Levee would be designed to provide three feet of height above the 4% ACE water surface elevation; 2) neither salt cedar eradication nor river sediment removal are a part of this alternative.
Alternative 10.3	Same as Alternative 10.1 except Levee height to provide freeboard against 2% ACE flood.
Alternative 10.4	Same as Alternative 10.1 except Levee height to provide freeboard against 0.5% ACE flood and river sediment removal is considerably more extensive, continuing north of the I-40 bridges.

1.3 Scope of Work

The USACE Geotechnical Branch, Los Angeles, has supported this project through various phases of study from May 2008 through 2011, then more extensively during 2012 through 2014. The Geotechnical Branch objectives are to advise and support the planning process, preparation of civil design concepts, preliminary engineering, and cost determination; which are efforts of various USACE technical branches. During the feasibility process, the focus of geologic and geotechnical engineering evaluations is on the viability of conceptual levee improvements, development of geotechnical constraints and considerations that may impact these designs, assessment of potential materials sources (including material for both fill and slope protection), evaluation of relevant geotechnical hazards, and providing information that will assist in project cost estimates. Work included performance of these specific tasks:

A. Review of previously prepared geotechnical and geologic information
B. Performance of seismic refraction surveys
C. Participation in scoping meetings, development of measures and alternatives
D. Evaluation of levee performance and mitigation measures
E. Evaluation of geologic and groundwater conditions
F. Development of constraints that will impact proposed alternatives
G. Preparation of this written report documenting the geotechnical and geologic studies

2.0 FIELD STUDIES

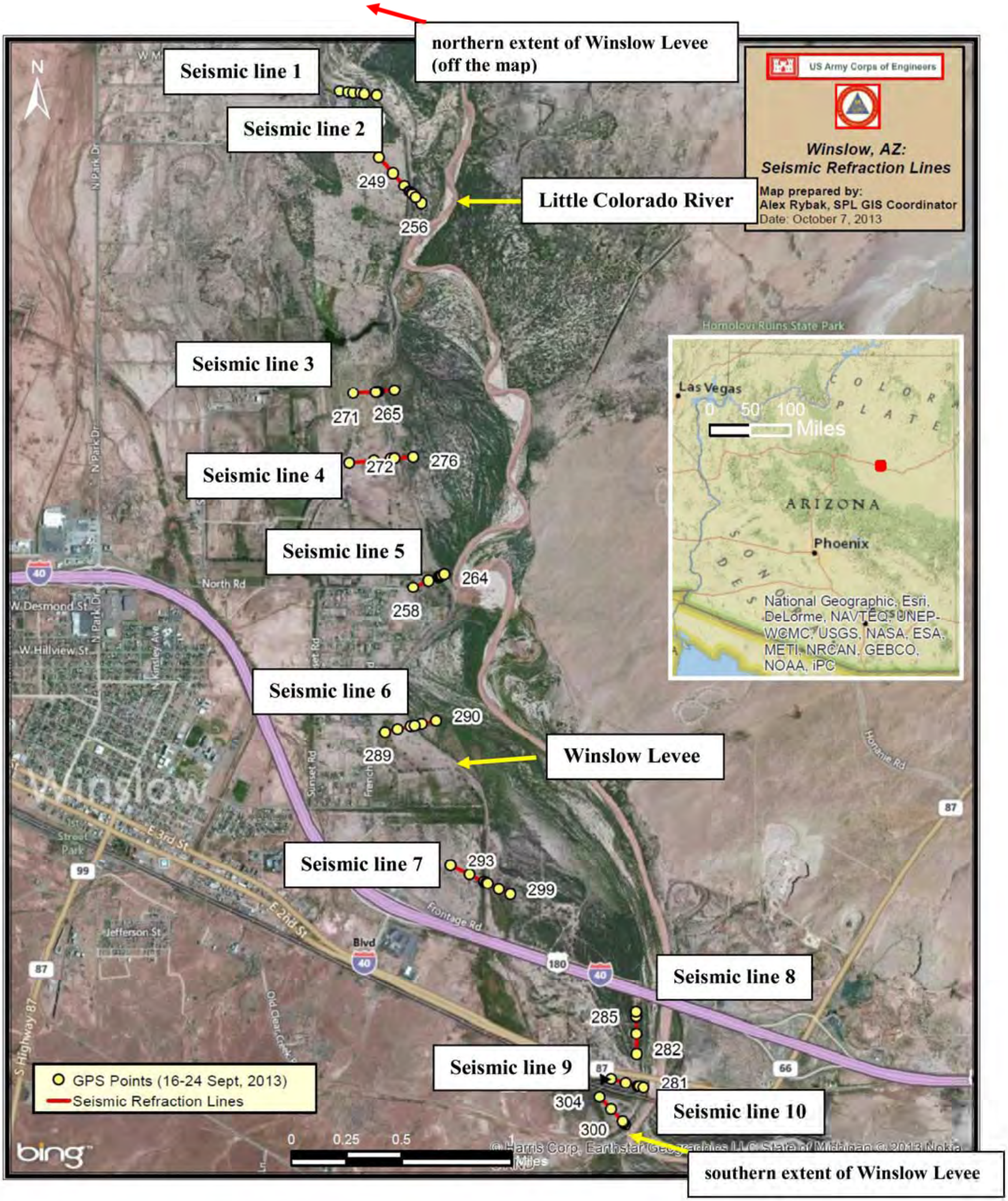
2.1 USACE 2013

While published and unpublished information is available for reference of project site conditions, the data is sparse and conflicting. In order to provide for a minimum of detail regarding the stratigraphy at the project site, a seismic refraction survey investigation was chosen as the means to both obtain information on depth to competent bedrock beneath the Levees, and to search for high permeability zones below the Levees. Advanced Geoscience, Inc., Torrance, CA, won a competitive bid process and subsequently, under contract to the USACE Geology & Investigations Section, Los Angeles, conducted a seismic refraction investigation along ten lines arrayed across the Winslow Levee. The approximate locations of the surveys are shown on Figure 2. The findings are discussed where they are most applicable in various subsequent sections of this report. See Appendix A for the seismic report prepared by Advanced Geoscience, Inc.

2.2 Previous Studies

Previous field studies are relatively minimal but are documented in several different reports as well as the as-built plans. These documents are attachments to Appendix B. In summary, previous studies included:

- The 1971 USACE As-built Plans for Winslow Flood Control Project, Winslow, Arizona contain foundation exploration information for RWDL, including six (6) test trenches. Five (5) of the trenches encountered bedrock and less than 1 foot below ground surface, and the sixth test trench (TT4) encountered silt and silty sand to a depth of 10 feet before becoming unstable due to groundwater. Lastly, 52 auger probes less than 6 feet deep recorded only depth to refusal; refusal is assumed to mean bedrock was located.
- The 1989 PRC Engineering As-built Plans for the Construction of Winslow Flood Control Project, Winslow, Arizona provide relatively sparse soils classification stick logs on the drawing profiles.
- In 1993, Western Technologies, Inc. drilled a total of 6 borings at pre-selected locations along a 600 foot portion of the Winslow Levee. All of the borings were advanced to a depth of about 30 feet. Sandy lean clay fill was encountered in all the boring to depths ranging from 13 to 28 feet below existing grade. Underlying native materials generally consisted of silty and clay sands. Groundwater was encountered in three of the boring at a depth of approximately 29 feet. Bulk samples were collected. The laboratory testing program included gradation, Atterberg Limits, and remolded permeability.
- In 1994, SHB Agra, Inc. drilled two exploratory hollow-stem auger borings to depths of about 50 and 40 feet through the levee. The deeper boring was drilled through the breach repair and the other through undamaged levee. Additionally, a 2-inch diameter well was installed in the deeper boring to a depth of about 27 feet below the levee crest. The screened interval was placed with the asphalt millings and a constant head, isolated interval permeability tests was performed in the well; the well was completed as a permanent piezometer at the request of Navajo County. Lastly, fourteen (14) backhoe test pits were excavated to depth of 10 to 12 feet along the slope erosion repair section on



NOTES:

1. AERIAL IMAGE SHOWS THE LOCATIONS OF THE TEN WINSLOW LEVEE SUBSURFACE SEISMIC REFRACTION INVESTIGATION LINES OF SEPTEMBER 2013 AND ONLY LINE 8 PARALLELS THE LEVEE.
2. THE WHITE NUMBERS IN THE 200s AND 300s ARE GPS POINT DESIGNATIONS AND ARE NOT PERTINENT TO THIS DISCUSSION.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY LOCATIONS OF 10 WINSLOW LEVEE SUBSURFACE SEISMIC INVESTIGATION LINES SEPTEMBER 2013	FIGURE 2

FILE NAME: WINSLOWFIG02.DGN HERNANDEZ (F): \DATA\SPL\DOCUMENTS\GEOTECH\CHATMAN\WINSLOW

both landside and riverside of the levee; in-place density tests were performed to evaluate the compaction of the erosion repair.

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3.0 SITE CONDITIONS

3.1 Surface Conditions and Topography

The Levees and surrounding lands that are the subject of this report are in westernmost Navajo County, close to the Coconino County line, a desert area characterized by low topographic relief, broad and flat mesas with remnants of smaller, eroded mesas on top of them. Refer to the local topographic maps located on Figure 3. The larger and more extensive mesas, such as Ives Mesa, which comprises the eastern bank of the Little Colorado River on the opposite side of the river from Winslow Levee, typically are at an elevation of 5,000 feet above sea level, while other, smaller mesas on top of them reach as much as 5,040 feet.

The primary drainage is the Little Colorado River, which has a system of highly mature river meanders, with switchbacks and cut offs, and which follows a low-gradient, north-northwest trend on the way to the confluence with the Colorado River, over 100 river miles farther to the north from the subject area. The Little Colorado River bed elevation at the south extent of Winslow Levee is approximately 4,850 feet; at the northern extent of the Winslow Levee, about nine miles away, elevation drops to approximately 4,820 feet. The Little Colorado River at Winslow is an ephemeral stream, as shown on the U.S Geological Survey topographic maps of the area, and recent field observations by the USACE, reports from local residents, and from the historical record, for example, Gregory (1916, p. 43), as cited in SWCA, Inc. (1996, p. 82), which notes that below Winslow, the riverbed is dry for "several months in the year." The Little Colorado River at Winslow is susceptible to large-volume flows of short duration, and it is those flow events that are the main impetus to this study. The flows from the Little Colorado River are increased considerably just before this watercourse reaches the Winslow Levee by tributary flow contributions from Clear Creek, Jacks Canyon, and Cottonwood Wash, and, another 8.6 straight-line miles to the southeast, flows of Chevelon Creek.

Some small stream courses that comprise part of the River's tributary system also deserve discussion. These northeast flowing tributaries to the Little Colorado River, some named, and some un-named, are braided, ephemeral stream courses that once naturally joined the Little Colorado River about 2-½ miles north of the Winslow Levee. The two named drainages of this tributary group are Ice House Wash and Ruby Wash. That natural, collective path of the streams, as seen in Figure 4, directs the flows of each through the main part of City of Winslow, thereby creating a flood risk. For that reason, the course of each of these streams was altered substantially, by constructing the RWDL in 1971. That diversion levee is oriented east-to-west, and thus is perpendicular to the flows of these tributary washes. RWDL stops the north-trending flows of these streams, diverts them through a constructed channel to the east, guiding them into the Little Colorado River immediately upstream and southeast of Winslow, as can be discerned in Figure 4. On the north side (*downstream* side) of RWDL, these tributaries resume their courses through Winslow, but convey only local runoff, and thus, have much reduced flows.

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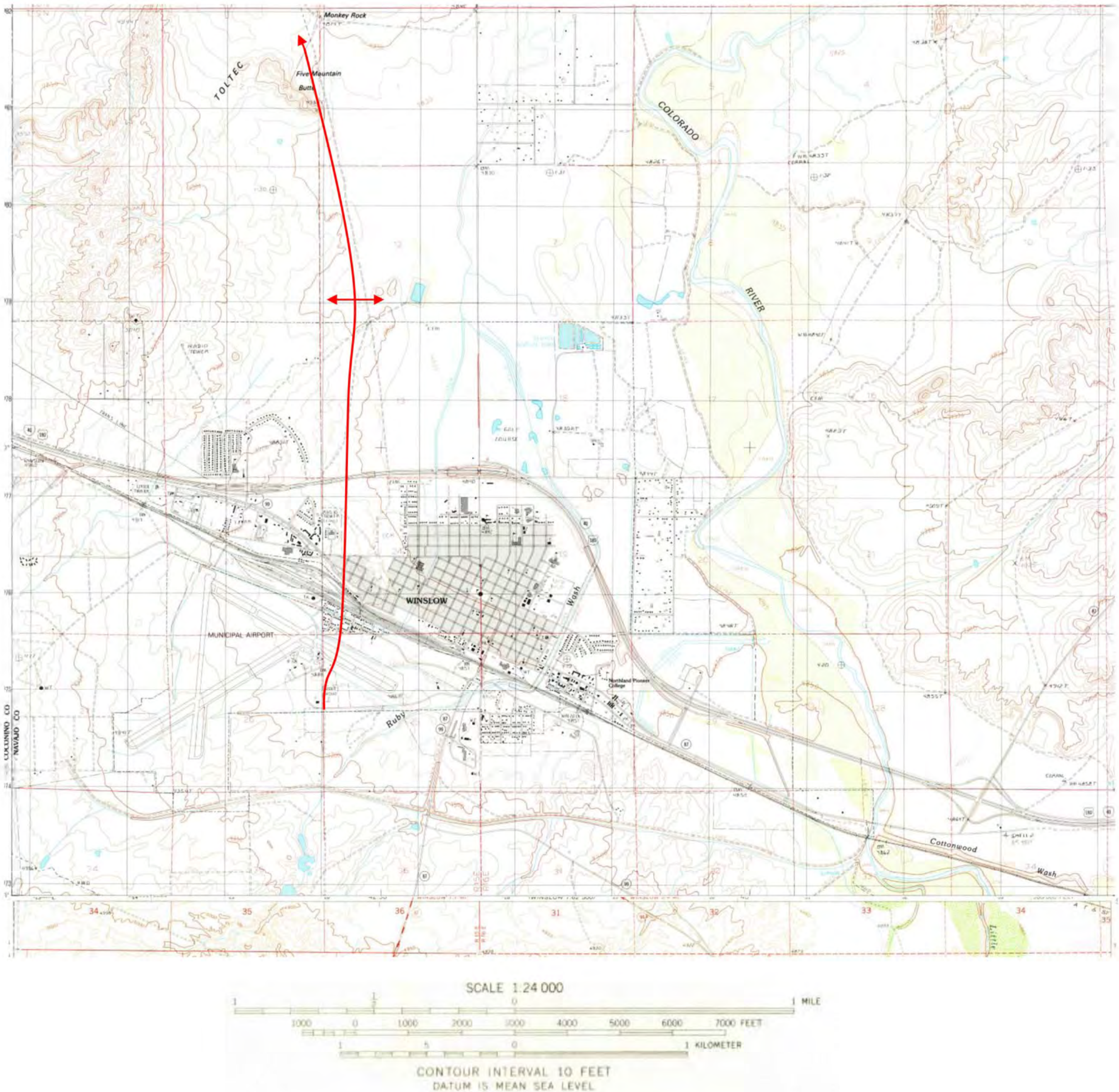
FIGURE
3



TOPOGRAPHIC MAP COVERAGE OF THE WINSLOW AND RDWL LEVEES AND VICINITY. IT CAME FROM THE U.S. GEOLOGICAL SURVEY DIGITAL FILES OF THE WINSLOW AZ (1986) AND CLEAR CREEK RESERVOIR (1970) 1:2400 SCALE MAPS. THE READER IS ADVISED TO USE THE ZOOM FEATURE ON THE DOCUMENT VIEWER. YOU WILL BE ABLE TO EXPAND THE SIZE OF THIS MAP AND SEE THE DETAILS MORE CLEARLY.

THE RED LINE IS A GEOLOGIC STRUCTURE: A NORTHWARD-PLUNGING ANTICLINE MAPPED BY ULRICH AND OTHERS (1984). IT IS A RIDGE-LIKE FLEXURE IN BEDROCK, WITH THE LONG RED LINE DRAWN DOWN THE CENTER OF THE "RIDGELINE". THE SHORT EAST AND WEST TRENDING RED ARROWHEADS INDICATE THE DIP OF THE SLOPES OFF THE "RIDGELINE". THE SHORT NORTH TRENDING RED ARROWHEAD SHOWS THE DIRECTION OF THE PLUNGE OF THE STRUCTURE (IT IS DEEPING TO THE NORTH).

LITTLE COLORADO RIVER
WINSLOW, ARIZONA

WINSLOW FEASIBILITY STUDY

TOPOGRAPHIC MAP WITH GEOLOGIC STRUCTURE

US Army Corps of Engineers
Los Angeles District

FILE NAME: WINSLOWFIG03.DGN

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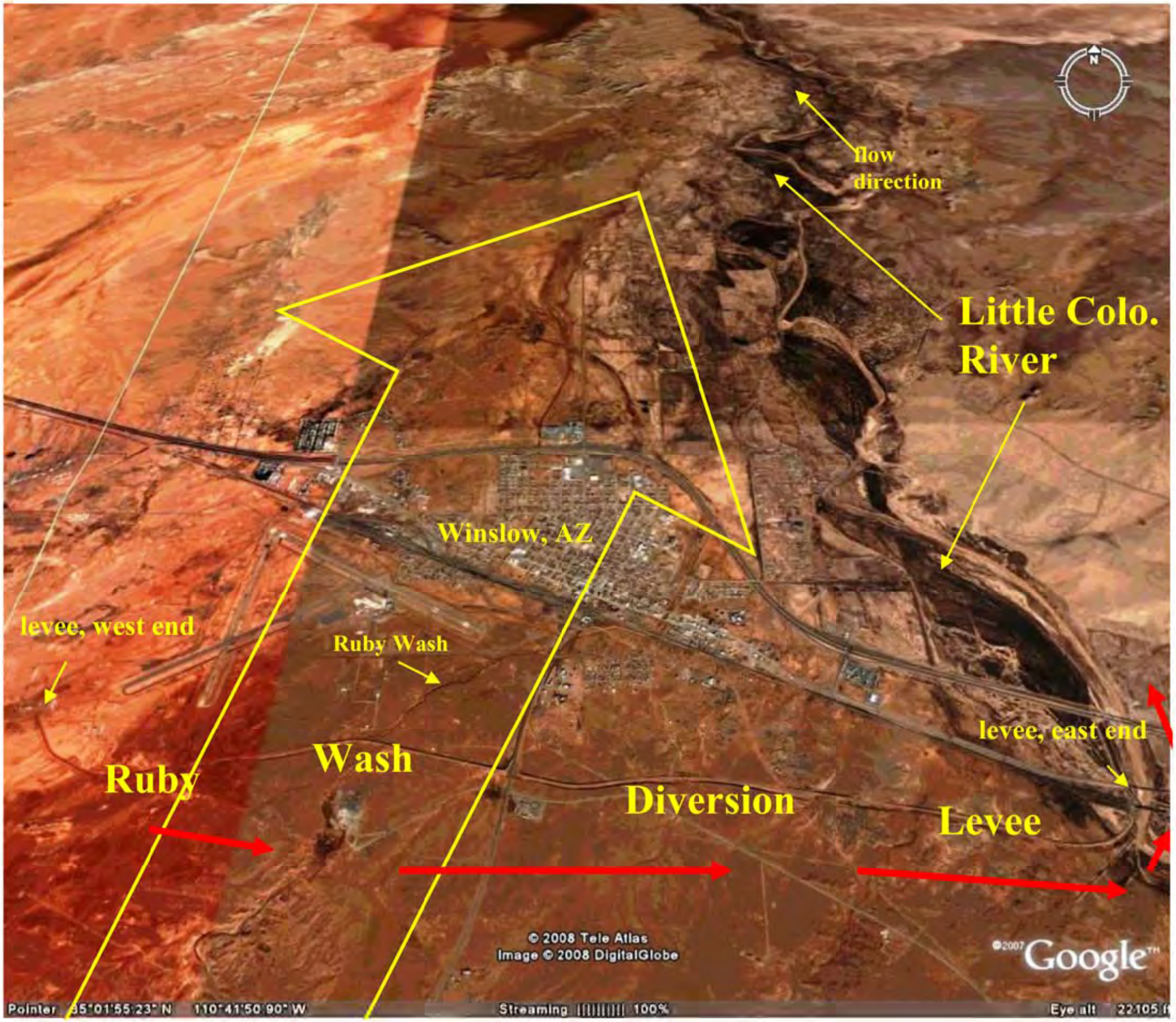


THE ALIGNMENT OF RUBY WASH AND RUBY WASH DIVERSION LEVEE, RELATIVE TO WINSLOW, AZ. THE RUBY WASH DIVERSION LEVEE IS LABELED. THE LARGE YELLOW ARROW COVERS THE APPROXIMATE LENGTH AND WIDTH OF RUBY WASH BRAIDED CHANNEL FLOWS, AND THOSE OF SEVERAL UNNAMED, AFFILIATED PARALLELING, WASHES AND SHOWS THE DIRECTION OF THIS COMPOSITE FLOW, PRE-LEVEE. THE SPECIFIC CHANNEL DELINEATED AS "RUBY WASH "WAS FOUND IN THE CITED REFERENCE KLEINFELDER WEST (2009, pl. 1).

NOTE THE IMPACT, PRE-LEVEE, OF THE COMBINED NORTHEASTERLY FLOWS OF THESE EPHEMERAL WASHES, ON THE LOCATION OF WINSLOW, AZ. THE CITY IS ESSENTIALLY "IN THE CHANNEL". THE DIRECTION OF RE-DIRECTED RUBY WASH FLOWS IS SHOWN BY SERIES OF RED ARROWS.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY RUBY WASH DIVERSION LEVEE	FIGURE 4

3.2 Geomorphology

Flows of the Little Colorado River and its tributaries are the primary agents that formed the site geomorphology, including the wide, aggrading river channel, and the mesas. Eolian forces too had a role shaping the exposed bedrock in the mesas. Eolian forces continue to modify the geomorphology of the site, mainly by depositing dune fields of silt and sand, brought into the area by strong and persistent winds that move from southwest to northeast. Transverse dunes commonly are the resulting landform; they are found on both sides of Winslow Levee (Figure 5, plate 2) and are major features on the leeward side of the Levee, adjoining the active LCR channel there. Crescent dunes form at the base of the large vegetation stands, particularly tamarisk. The prolific tamarisk growth appears to have both augmented dune deposition and also semi-stabilized the dunes, maintaining them east of Winslow Levee in the Little Colorado River floodplain, such that they continue to grow taller. Some of the dune crests were observed to be taller than the Levee and taller than the structures that the Levee is designed to protect. This phenomenon does not occur at RWDL, due to no water, no tamarisk, and a different levee orientation.

3.3 Regional Geology

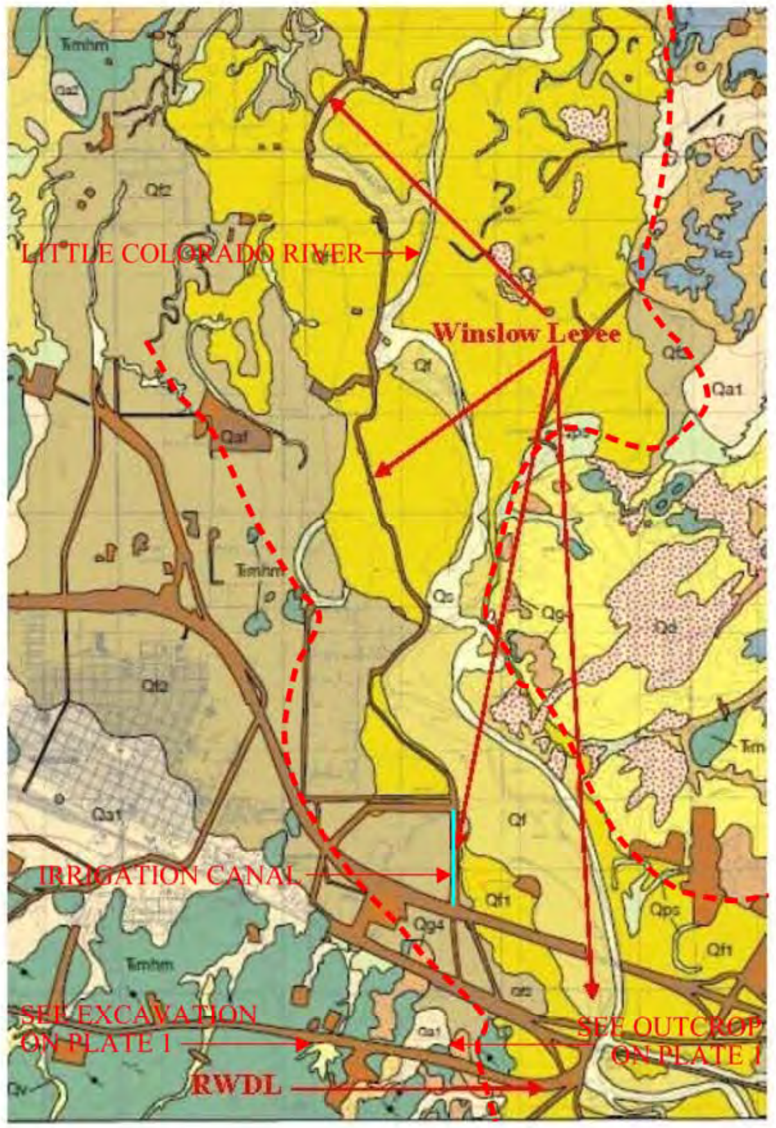
The area studied is part of the Colorado Plateau physiographic feature, which, in its uppermost parts, is characterized by uniform, thick, nearly flat-lying, mostly clastic rocks of late-Paleozoic- to early-mid Triassic-ages. The Plateau, through its geologic history, has experienced different periods of tectonic uplift, and corresponding stream downcutting and erosion. These erosional cycles have alternated with depositional periods (stream aggradation). Volcanic vents cut through the layered sedimentary rocks, bringing basalts to the surface, primarily in Miocene time. Slightly younger basaltic volcanic eruptions of the San Francisco volcanic field to the west formed large mountains around Flagstaff, AZ. Basaltic flows have impacted drainage patterns in the Little Colorado River, and at one point, well north of the LCR at Winslow, blocked the river, resulting in flows bypassing part of the established river channel. The Grand Falls geomorphic feature formed as a result. The Little Colorado River is thought by many researchers to have been reversed from southeast direction of flow, to its current northwest direction of flow (north-northwest immediately at the study area) via stream capture, as the Colorado River began deeply eroding the Grand Canyon and its tributaries also began severe downcutting with headward erosion. Around Miocene or Pliocene time, one of those tributaries is thought to have eroded sufficiently far from west to east that it captured the Little Colorado River and thus reversed its course, making it a tributary of the Colorado River (Hinchman, 1992, Graf and others, 1987, Childs, 1948, all cited in SFC Engineering Co., 1997, pp. 7- 8).

3.4 Site Geology

Winslow Levee and easternmost RWDL, in addition to the conceptual realignments of part of Winslow Levee and most potential sources of borrow for levee fill, are all entirely founded on alluvium deposits of the Little Colorado River (Figure 5). Bedrock under the north half of the Winslow Levee occurs beneath the river alluvium in the depth range of 50 to 100 feet, slowly deepening on a 1 to 3 degree dip to the north. The 2013 seismic investigation Line 8 (Figure 2, Figure 6, and Appendix A), which is oriented south to north, verifies the shallow dip and

Descriptions of geologic units most pertinent to Winslow Levee and RDWL areas.

[from US Geological Survey mapping (Billingsley and others, 2013, phamphlet)]



SURFICIAL DEPOSITS

- Qaf — **Artificial fill and quarries (Holocene)**
- Qs — **Stream-channel deposits (Holocene)**
- Qf — **Modern flood-plain deposits (Holocene)**
- Qps — **Ponded sediments (Holocene)**
- Qd — **Dune sand and sand-sheet deposits (Holocene)**
- Qa1 — **Young alluvial fan deposits (Holocene)**
- Qf1 — **Young flood-plain deposits (Holocene)**
- Qf2 — **Intermediate-age flood-plain deposits (Holocene)**
- Qg4 — **Older terrace-gravel deposits (Pleistocene)**

SEDIMENTARY ROCKS

- Tcs — **Shinarump Member (Upper Triassic)**

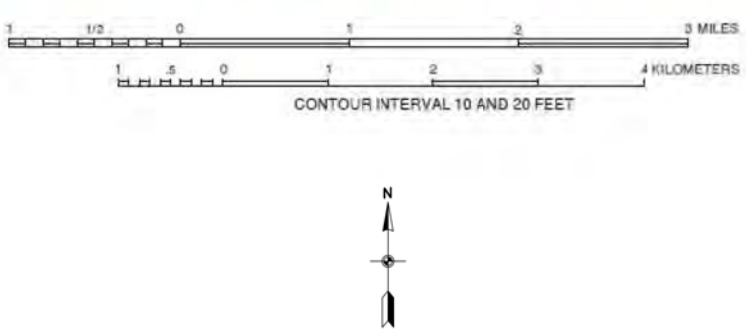
Moenkopi Formation (Middle? and Lower Triassic)

- Tmhm — **Holbrook and Moqui Members, undivided (Middle? and Lower Triassic)**

EXPLANATION OF MAP SYMBOLS

Strike of vertical and subvertical joints—Interpreted from aerial photographs; symbol placed where joints are most visible on aerial photographs

Approximate maximum width of Little Colorado River Canyon (between the two red dash lines), prior to it's current in-filled, aggraded condition, based on field observations. Base is USGS Geologic Map (Billingsley and others, 2013).



Qaf Artificial fill and quarries (Holocene) Alluvium and bedrock material removed from barrow pits and trench excavations and used to build livestock tanks, drainage diversion dams, roads, and other man-made construction projects (not all highway road excavations are mapped). No distinction between cut or fill excavations is made on map. Agricultural fields are not shown

Qs Stream-channel deposits (Holocene) White to light-red and gray, interbedded silt, sand, and clay, mixed with gravel, pebbles, and cobbles; poorly sorted. Pebbles and cobbles dominantly are angular to rounded, red, white, gray, and black chert clasts; subrounded to rounded red sandstone clasts; and angular to subrounded mafic monchiquite and basanite clasts in Hopi Buttes area. Deposits intertongue with, overlap, or are inset against adjacent surficial deposits (Qa1, Qa2, Qa3, Qv, Qg1, Qg2, QTdi), and they overlap or erode into flood-plain deposits (Qf, Qf1, Qf2, Qf3), ponded sediments (Qps), and mixed alluvium and eolian deposits (Qae). Stream channels subject to high-energy flows and flash-flood debris flows. Little or no vegetation in stream channels except for salt cedar (tamarisk), russian olive, and cottonwood trees along Little Colorado River and several large washes. Contacts with other alluvial deposits are gradational and approximate. Stream-channel deposits of Little Colorado River are mapped as shown on 1:24,000-scale color aerial photographs flown in 2005 (Block and others, 2009). Channel of Little Colorado River meanders within its floodplain valley between Winslow and Leupp. Downstream (northwest) of Leupp, Little Colorado River channel is confined within narrow bedrock strata of the Moenkopi and Kaibab Formations. Thickness, 2 to 9m (6 to 30ft)

Qf Modern flood-plain deposits (Holocene) Gray-brown to light-red clay, silt, and fine-grained sand; weakly consolidated by clay and calcite cement. Deposits include some lenticular gravel, subangular to rounded pebbles, and cobbles; intertongue with or are overlapped by adjacent fluvial or eolian surficial deposits (Qs, Qv, Qa1, Qps, Qd, Qes). Forms shallow flats 0.5 to 1m (2 to 3ft) above stream-channel deposits (Qs). Subject to overbank flooding in lateral and vertical sense along Little Colorado River and larger tributary valleys. Sup- ports sparse to light growths of sagebrush, grass, tumble weed, and thick growths of salt cedar (tamarisk) trees and other high-desert shrubs that trap and accumulate more recent eolian-sand deposits. Thickness, 0.05 to 2m (2 to 6ft)

Qps Ponded sediments (Holocene) Gray to brown clay, silt, sand, and thin gravel lenses along margins; weakly consolidated by clay, calcite, and gypsum cement. Locally includes small chert and limestone fragments or pebbles derived from nearby bedrock outcrops. Deposits commonly occupy man-made or natural internal drainage depressions. Desiccation cracks commonly form on dry hardpan surfaces that often restrict plant growth. Sandy ponded areas support growths of seasonal grass, especially downwind (northeast) of local parabolic dunes below and on Newberry, Ives, and Marcou Mesas. Thickness, 1.5 to 9m (5 to 30ft)

Qd Dune sand and sand-sheet deposits (Holocene) Hopi Buttes area (sheet 2): Light-red and white, fine-grained quartz sand; locally derived mainly from other surficial units whose sediments are easily eroded by wind (Qs, Qf, Qf1, Qf2, Qf3, Qg1, Qg2, Qg3, Qa1, Qa2, Qa3, Qae, QTdi). Originally those sand grains were derived from erosion of nearby bed- rock outcrops of the Moenave, Kayenta, and Bidahochi Formations and include fragmented grains of volcanic rock (Tm, Tmt, Tmu). Forms lumpy, undefined sand-dune or sand-sheet deposits often concealed beneath moderate growths of grass, sagebrush, and pinyon pine and juniper woodlands at higher elevations of volcanic mesas and buttes. Little Colorado River area (sheet 1): White to light-red, fine- to coarse-grained, windblown sand; composed primarily of quartz, chert, and some feldspar grains locally derived from other surficial deposits eroded by wind (Qs, Qf, Qf1, Qf2, Qf3, Qa1, Qa2, Qa3, Qg1, Qg2, Qg3, Qae). Contacts are approximate and subtly gradational with adjacent alluvial deposits and bedrock and are likely to change on yearly basis under influence of variable weather conditions such as strong windstorms and sheet-wash erosion associated with local severe thunderstorms. Locally includes topographically controlled climbing and falling sand-dune and sand-sheet ramp accumulations on gentle slopes or steep bedrock terrain northeast of Little Colorado River Valley. Contacts between young sand-dune and sand-sheet deposits (Qd, Qes) and old sand-dune and sand-sheet deposits (QTd, QTes) are difficult to constrain by empiricalobservation but, as mapped, show boundaries that illustrate potential differences between young and old sand accumulations on Ives Mesa, on Marcou Mesa, and in some areas of Hopi Buttes. Supports moderate growths of grass and high-desert shrubs that help stabilize all eolian-sand accumulations during wetter conditions. Thickness, 1 to 61m (3 to 200ft)

Qa1 Young alluvial fan deposits (Holocene) Southwest of Little Colorado River Valley (sheet 1): Gray-brown silt, sand, gravel, pebbles, cobbles, and boulders; weakly consolidated by calcite, gypsum, and minor amounts of salt cement. Silt and sand is derived primarily from eroded outcrops of the Kaibab and Moenkopi Formations that also supply dissolved cal- cite, gypsum, and minor amounts of salt that precipitates as cement. Pebbles, cobbles, and boulders are subangular to rounded limestone, chert, and sandstone clasts locally derived from bedrock. Also includes small, subrounded to rounded pebbles and cobbles of basalt, andesite clasts, and pyroclastic fragments derived from San Francisco Volcanic Field west and southwest of quadrangle. Supports light to moderate growths of sagebrush, cactus, and grass. North and northeast of Little Colorado River Valley (sheet 2): Gray, light-brown, and light-red clay, silt, sand, pebbles, and cobbles of chert, limestone, and sandstone; derived from local Mesozoic sedimentary rocks and monchiquite, basanite, and decomposed tuff from local outcrops of the volcanic rocks of Hopi Buttes Volcanic Field. Commonly is overlapped by or intertongues with various Quaternary surficial deposits (Qs, Qps, Qf, Qd, Qes, Qv, Qg1, Qae). Clay, silt, and sand are derived primarily from local outcrops of the Chinle, Moenave, Kayenta, and Bidahochi Formations; also derived from Cretaceous rocks north and northeast of quadrangle that commonly supply cementing ingredients of clay, cal- cite, gypsum, and minor amounts of salt for all surficial alluvial deposits north and northeast of Little Colorado River. Subject to extensive sheet-wash erosion, wind erosion, flash-flood debris flows, and minor arroyo erosion. Thickness, 1 to 6m (3 to 20ft)

Qf1 Young flood-plain deposits (Holocene) Gray-brown clay, silt, and fine- to coarse grained sand; weakly consolidated by clay content. Forms benches 1 to 3m (3 to 10 ft) above stream- channel (Qs) or modern flood-plain (Qf) deposits. Subject to cut-bank channel erosion in Little Colorado River Valley and local streams in large tributary washes. Overlapped by thin accumulations of young surficial deposits (Qd, Qes, Qps, Qa1). Supports thick growths of salt cedar (Tamarisk) trees, grass, tumble weed, camel thorn bush, and various other high-desert shrubs. Often subjected to overbank flooding by Little Colorado River and local tributary streams. Thickness, 1 to 6m (3 to 20ft)

Qf12 Intermediate-age flood-plain deposits (Holocene) Gray-brown clay, silt, and fine-grained sand; weakly consolidated by clay and calcite cement. Lithologically similar to young flood- plain deposits (Qf1) but forms flat benches 3 to 4.5m (10 to 15ft) above stream-channel (Qs) or modern flood-plain (Qf) deposits. Subject to cut-bank and headward erosion by local stream channels. Overlapped by various accumulations of thin surficial deposits (Qd, Qes, Qps, Qa1). Supports sparse to moderate growths of grass, tumble weed, and other high- desert shrubs in north half of quadrangle (sheets 1, 2); thick to moderately thick growths of grass, camel thorn bush, tumble weed, salt bush, and other desert shrubs along with scattered cottonwood, salt cedar (tamarisk), and willow trees in Little Colorado River Valley (sheet 1). Eolian-sand accumulations commonly cause temporary blockage of local runoff that forms ponded sediments (Qps) on flat flood-plain deposits (Qf2, Qf3) in Little Colorado River Valley and in wide, principal-tributary washes. Subject to overbank flooding in Little Colorado River Valley and along local washes. Thickness unknown but may exceed 30m (100ft) in some areas; visible thickness, 3 to 9m (10 to 30ft)

Qg4 Older terrace-gravel deposits (Pleistocene) Gray and light-brown clay, silt, sand, gravel, cobbles, and boulders; weakly cemented by clay, calcite, and gypsum; poorly sorted. Includes abundant rounded and well-rounded clasts of quartzite, quartz, chert, and assorted metamorphic crystalline rocks derived from scattered Tertiary rocks south, southeast, and southwest of quadrangle; also includes well-rounded white chert, gray limestone, and red sandstone clasts locally eroded from Permian and Triassic strata south of Little Colorado River Valley, as well as well-rounded clasts of yellow, red, gray, and brown quartzite, black chert, and subrounded clasts of petrified wood locally derived from the Shinarump Member of the Chinle Formation. Forms terrace deposits about 17 m (55 ft) above stream-channel deposits (Qs) along principal tributary washes near Little Colorado River and as much as 25m (80ft) above stream-channel (Qs) and flood-plain (Qf, Qf1, Qf2, Qf3) deposits of Little Colorado River. Commonly covered by thin deposits of subrounded to rounded, wind-polished pebble and cobble clasts that form thin veneer of desert pavement on surface of deposits near Little Colorado River Valley. Unit is about 12 to 30 m (40 to 100 ft) below oldest terrace-gravel deposits (QTg4) of Little Colorado River at Tucker Mesa and Toltec Divide west of Winslow (fig. 1; see also, sheet 1). Thickness, 2 to 25m (6 to 80ft)

FIGURE 5

LITTLE COLORADO RIVER
WINSLOW, ARIZONA
WINSLOW FEASIBILITY STUDY
GEOLOGIC MAP

US Army Corps of Engineers
Los Angeles District

HERNANDEZ (F): \DATA\SPL\DOCUMENTS\GEOTECH\CHATMAN\WINSLOW

FILE NAME: WINSLOWFIG05.DGN

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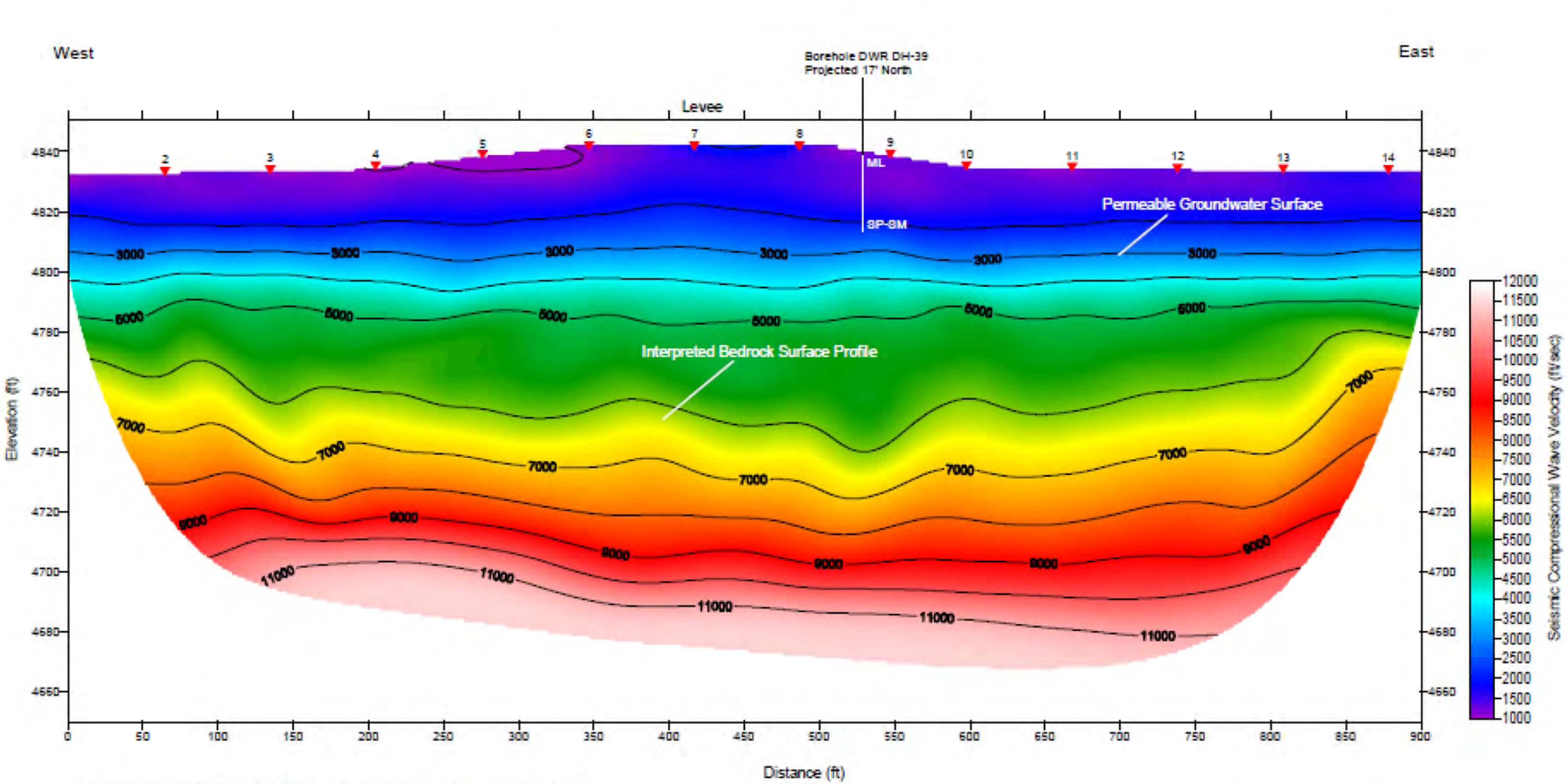
Line 1- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

0 50 100

Horizontal Scale 1 inch= 60 Feet
Vertical Scale x2 1 inch= 30 Feet

Line 1 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

NOTES:

1. BEDROCK IS SHOWING AT 90ft+ DEEP BELOW THE LEVEE CREST.
2. REFER TO FIGURE 2 FOR LOCATION.

US Army Corps of Engineers
Los Angeles District

LITTLE COLORADO RIVER
WINSLOW ARIZONA

WINSLOW FEASIBILITY STUDY

SEISMIC REFRACTION VELOCITY DEPTH PEOFILE

FIGURE 6

FILE NAME: WINSLOWFIG06.DGN

HERNANDEZ (F): \DATA\SPL\DOCUMENT\GEOTECH\CHATMAN\WINSLOW

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direction. Both west and east of the Levee foundations and outside of any conceptual realignment of Winslow Levee, bedrock becomes much shallower, occurring at depths of a few inches to a few feet, under thin, overbank flood and windblown deposits, many of which are fine grained. In some locations lateral from the Levees, bedrock is exposed at the surface, although these rock outcrops are no closer than 1,000 feet to the Levee. Near the southern end of the Levee, bedrock is exposed, but the Levee footprint remains on relatively deep alluvium; typically 30 to 40 feet of sediment remain there beneath the Levee and above the bedrock. The cause of this difference in depths to bedrock is the fact that Little Colorado River once had eroded a 30- to 100-foot-deep canyon through the area, but subsequently backfilled that canyon with alluvium, after the local depositional environment changed from an eroding one to an aggrading one. The cause of the change in depositional regime likely was the repeated tectonic fluctuation impacting the Colorado Plateau over time (tectonic-scale uplift promotes erosion and canyon deepening along existing river courses, while tectonic-scale subsidence can result in aggrading river conditions).

The USACE geologist mapped probable maximum width of this eroded canyon on Figure 5, based on field observations and study of aerial photographs. It has long been recognized that after infilling its canyon, the Little Colorado River meandered many times back and forth across the width of its floodplain, with several such progressions being recorded just in the time that the area has been settled (Kolbe, 1991). It is widely held that this meandering is evidence that the river has reached base level (i.e., has reached ‘hard’ bedrock that is sufficiently indurated that it cannot be eroded and down cut with the river forces available), and thus it meanders instead of downcutting.

In contrast, the 2013 seismic refraction investigation suggests that if the river is at base level, it is not because further downcutting has been stopped by bedrock. The original Winslow Levee construction in the 1960s occurred at a time when the river happened to have meandered over to its far eastern bank, a location from which it could not meander farther to the east due to the presence of Ives Mesa, a bedrock mesa comprised of Moenkopi Formation, and which is substantially higher in elevation that the typical river water surface level. After construction of the Levee, local interests have maintained the Levee on its original footprint, and so the Levee has continued to constrain the Little Colorado River close to its eastern bank and Ives Mesa. As long as this Levee continues to stand, it will not allow the River to meander back to its western lateral extent. Bedrock on the eastern and western extents of the maximum natural river path of lateral migration is much shallower than it is along the axis of the former deeply eroded river valley. The River currently flows close to this axis line, based on the USACE seismic investigation. There is much shallower bedrock on the buried west toe of Ives Mesa (which is the eastern lateral extent of the River meandering), per the seismic investigation data. It subsequently can be understood that the ‘shallow bedrock’ in the current river course is probably the buried western toe of Ives Mesa, and thus, if the River were freed to meander across its full natural floodplain, and once again cross areas of deep sediment, the potential exists that the River could erode more deeply into accumulated alluvium, in places not reaching bedrock to depths of over 90 feet (Figures 5 and 6). Of course, the base level of a River is impacted by many other factors, chief among them regional tectonics and weather patterns. But the sum of the data available suggests that shallow bedrock is not stopping such downcutting along this reach of this River. The railroad bridge geotechnical investigation, performed by BNSF Railway Co., shows deep bedrock across the entire width of the span over full width of the Little Colorado River. Historical references suggest that at some point such shallow rock exists. None of the USACE 2013 seismic profiling located it, but instead suggests rock is moderately to very deep, end to end under the Winslow Levee footprint.

3.5 Stratigraphy

The most recent geologic mapping that included the Levees and surrounding lands was done by the US Geological Survey (Billingsley and others, 2013). The parts of the USGS findings most pertinent to this USACE feasibility study are on Figure 5. With the exception of small areas near the southernmost extent of the Winslow Levee and easternmost RWDL, no bedrock is exposed near the Levees. All bedrock exposed in the vicinity and all bedrock that could possibly underlie Levee improvements and other construction is limited to the Moenkopi Formation.

3.5.1 Moenkopi Formation

In the general vicinity of Winslow, the Moenkopi Formation is characterized as “dark red sandstone and mudstone,” which can include gypsum beds and that was “deposited on a low-relief coastal plain.” The age of this deposition is estimated to be possibly Middle to Early Triassic, which was 230 to 245 Ma (million years ago) (Richard and others, 2000, map legend).

At the site of the southernmost part of Winslow Levee, the Formation is a thinly bedded, fissile, moderately to weakly cemented, fine- to medium-grained, red- to rust-colored sandstone (Plate 1). At least one thick-bedded sandstone layer does exist in the Formation, at the western extent of the part of RWDL that is of interest to this study (Plate 1), as can be seen in a channel cut made as part of the RWDL Levee system. The thick bed of sandstone is within 10 feet of the surface, and underlain by fissile sandstone. Its lateral extent is not known.

3.5.2 Chinle Formation

Bedrock along the east and northwest parts of the area studied is a younger formation, known as the Shinarump Member of the Chinle Formation, and it too is shallowly buried by alluvial and eolian deposits. Richard and others (2000, map legend) characterize the Shinarump Conglomerate Member in this area as “basal conglomerate and pebbly sandstone,” which is “relatively resistant to erosion and forms extensive benches in some parts of the Colorado Plateau.” The age of the Chinle Formation is reported as Late Triassic, 210 to 230 Ma (million years ago). Low mesas on the east and northwest parts of the area studied are composed of the Shinarump member, with Moenkopi Formation below. The Chinle Formation is not present anywhere beneath the Winslow or RWDL Levees, having been eroded from those locations.

3.5.3 Older Sedimentary Rock Formations

Older rocks, primarily the Permian-age Kaibab Formation, are at depth below the Moenkopi Formation, but no Permian-age rocks are exposed in the area studied and none will be encountered in any project-related excavations.

3.5.4 Soils

Fine-grained, silty soils generally comprise the most recent deposits in the area of interest, and are the material deposited in local dust storms, which are so intense they at times require closing of Interstate 40 in both directions, due to visibility issues. Fine-grained deposition from floods also is to be expected (Gregory, 1916, p. 93, as cited in SWCA, Inc., 1996, p. 82), along with ½ -inch to 3-inch-diameter gravels, cobbles, sand, and silty sand at shallow depths, and over a wide area. The existence of shallow fine grained (silt and clay) blankets is likely in some areas based on the minimal available boring information shown on as-built plans. The thickness, continuity, and extent of such layers cannot be accurately determined with the lack of currently available soils information.

3.5.5 Fill

The Winslow Levee and RWDL structures comprise the artificial fill most pertinent to the study area. Roadway embankments of Interstate 40, State Route 87, and the BNSF Railway Co. embankment are the other locations of artificial fill in the study area.

Based on examination of exposed materials on the outer part of the structure, Winslow Levee fill was derived from mining sand and gravel, and silty sand deposits, and cobbles from adjoining Little Colorado River alluvium. Likely the fill source was taken all along the alignment as the Levee was built and extended northward. The largest particle size seen exposed is about 6 inches. Construction documentation and exploration data further characterize other types of fill in the structure. Bentonite for a bentonite-slurry levee core was imported and added after the Levee was completed, as were cement for a small cement-slurry repair section of the core, and riprap slope protection stone. None of the levee core material is exposed so it cannot be further described. Additional riprap was added as recently as 2012 to extend the amount of Levee surface protected by stone. Flood-fight material stockpiled along the Levee crest consists of sand (possibly crusher fines), soil, concrete debris, broken sandstone (derrick stone and large riprap size), and additional imported basalt (riprap), all brought on site from external locations and strategically placed for fast application to anticipated river impingement points on the structure. At the McHood Rd. intersection, masses of vegetation and some automobile hulks can be seen in use as artificial fill within Winslow Levee, but the sum total of available information suggests these unsuitable materials are the exception to the character of typical artificial fill used in Winslow Levee. Levee composition is further described in another report done for this feasibility study (US Army Engineer District, Los Angeles, 2010), which is Appendix B to the current report.

According to Corps design documents, fill that comprises the RWDL also is local on-site material, but quite different than what was used to build Winslow Levee. RWDL was built of material excavated from the adjacent RDWL channel, so the fill source was taken all along the alignment of the structure as it was built and extended along its east-to-west alignment. Based on knowledge of the source material, the fill was anticipated in the design documents to be rocky, which it is. Exposures of the Levee and the concurrently built diversion channel suggest the bulk of the Levee is composed of broken, crushed, and weathered Moenkopi Formation sandstone and siltstone, and that the far lesser quantity of RWDL fill is comprised of alluvium mined from the small ephemeral stream channels that the structure intersects and diverts. Riprap on this Levee represents additional fill but riprap on RWDL also is nearly all local broken Moenkopi Formation sandstone, with the exception of very small quantities of imported Kaibab Formation stone and small amounts of imported basalt. These final two stone types are limited to the easternmost part of RWDL, which is the part of this Levee within the study area. Levee composition is further described in another report done for this feasibility study (US Army Engineer District, Los Angeles, 2010), which is Appendix B to the current report.

No information was gathered regarding the fill that comprises the Interstate and State Route roadway embankments because those structures are to be protected in place. Their composition and fill sources are unknown.

Based on exposures, the BNSF Railway Co. embankment is primarily broken and crushed basalt and volcanic cinders, with a lesser amount of sandstone and alluvium. This structure too is to be left in place during any levee improvement work that may occur.

3.6 Structural Geology

There are no major geologic structures present beneath the Levees. Structural orientation of the local bedrock follows the regional trend of low-angle dip of 1 to 3° to the north. One shallow, northward plunging, anticline has been mapped west of Winslow Levee by Ulrich and others (1984). It forms a divide between two of the parallel tributaries that flow northward into and through Winslow. A similar, subparallel, shallow-angle, north-oriented anticlinal deformation was seen to the east (Plate 1).

3.7 Faulting and Seismicity

There are no mapped faults in or near the Levees. There are no major regional faults in the vicinity.

The seismic risk in the study area is low, as the area is not considered active seismically. Yet, the area did experience an earthquake in January 2012 (Holland, 2012), although the epicenter was far away and unrelated to site geologic conditions. The 3.1 magnitude temblor occurred on 8 January 2012, from an epicenter 21 miles to the southwest, at the margin of the Mogollon Rim and the Colorado Plateau. An earthquake of such a small magnitude produces no dangerous or damaging shaking at such distances from the epicenter, and possibly may not have been felt or noticed by all who were in Winslow during the event.

The Arizona Geological Survey assigns a shaking risk from seismic events of “5” (on the Modified Mercalli sale) to the study area and all of Winslow, AZ. Shaking intensity of “5” on the Modified Mercalli sale is “very light shaking.” The seismic risk to any structures built in Winslow should be quite low.

3.8 Groundwater

Groundwater is approximately 30 feet beneath the Winslow Levee, based on the seismic exploration. This is consistent with water well data posted on the Arizona Department of Water

Resources (ADWR) web site as of late 2011, which show 14- to 30-foot depths with seasonal fluctuation.

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4.0 GEOTECHNICAL CONSTRAINTS AND CONSIDERATIONS

The geotechnical evaluation of site conditions identified several potential geologic issues that warrant further consideration during the evaluation and development of measures and alternatives. These constraints and considerations, as well as those measures expected to be impacted are discussed in detail in the following text.

4.1 Depth to Bedrock

The top of ‘competent’ (= “not deeply weathered”) Moenkopi Formation bedrock is about 90 feet deep (or deeper) below the Levee base in the northern half of the structure, and becomes more shallow in the southern part, with depths about 40 to 60 feet deep below the Levee base. Projected width and depth of the former canyon eroded by Little Colorado River leads to the conclusion that no lateral realignment of Winslow Levee will permit tying into bedrock while still protecting areas the Levee is intended to protect. Based on seismic refraction analysis and older boring logs, the Levee, no matter where it is realigned in this study, will be founded on permeable, relatively recent Little Colorado River alluvium, including many channel-fill wedges of sediment. Relocation of the Levee farther from the River, which would help lower water surface profiles in flood stages by giving the flows a wider area in which to flow, would not change the foundation conditions significantly. Shallow bedrock is too far west of the Levee to tie into, and still has a Levee that performs its intended function (protecting the structures and ranch land). A Levee constructed sufficiently west to tie into bedrock would leave most of the structures it is designed to protect on the riverside. Levee designs potentially could be adjusted to tie into and utilize a continuous clay or silt layer in the foundation, as a seepage cutoff layer, should such a layer exist and be found through exploration. But the depositional regime of this river (multiple cut off meanders and aggrading conditions) suggests that such a layer, where found, would not have sufficient lateral continuity. Some of the RWDL could be tied into bedrock.

It should be reiterated that, except for the seismic refraction and limited boring from the as-built plans and bridge plans, there is very little geotechnical information currently available for the subsurface. As part of the accelerated “SMART Planning” directive, subsurface investigations have been delayed to future phases of the project. As a result, the study will carry increased project risk and cost contingencies going forward, until such investigation is performed.

4.2 Levee Construction and Performance

The as-built plans indicate that most of the Winslow Levee, which dates from 1989, was built on top of older, apparently un-engineered levee that was left in place, and there is no report or other evidence, such as test data, to suggest that the foundation beneath this older levee was processed (compacted or otherwise treated) prior to levee fill placement. The foundation most likely consists of unprocessed desert surface. Limited anecdotal evidence suggests that no foundation processing took place. There is no documentation or testing to describe the as-built condition of the contact between the older, underlying levee and the engineered 1989 Winslow Levee that was built on top. Finally, no test data can be located for any of the materials or structures of the 1989 Levee fill, despite extensive search. All the above raise concern regarding Levee performance, particularly from the perspective of seepage risk. The Levee performance history raises that risk because the history reveals that such seepage has occurred and at one point nearly led to failure of the structure. Documented seepage initiated deeper than the base of the structure's end-to-end bentonite slurry cutoff, installed through both original and overlying 1989 levees and was arrested only via a flood fight. In addition, uncorroborated information from local ranchers indicates multiple seepage events have taken place over time, initiating specifically at the base of the Levee. Whether those events occurred pre- or post-bentonite core installation is not known. It is possible that the un-prepared foundation may have contributed to and may have been a locus of this underseepage. Some original Levee sections were built under emergency flood-fight conditions, further increasing the chances that non-compacted, dump fill levee composed of random materials was placed and remains. Car bodies and masses of vegetation found in the northern part of the Levee further support such concerns. Levee composition and foundation conditions are described in more detail in another report done for this study (US Army Engineer District, Los Angeles, 2010), which is Appendix B to the current report.

Seepage also is anticipated at the contact of differing levee fills (upper engineered fill and underlying, non-engineered fill). The contact between the differing fills is not uniform throughout the Levee. This suggests widespread and unpredictable seepage paths in areas beyond where documented seepage events occurred. Consequently, the feasibility team has suggested conceptual models based on levee reconstruction as opposed to enhancement of the existing structure. Direct investigation of the fill and foundation have not occurred to this point in the feasibility study. Even if densely spaced (and costly) geotechnical investigation of the existing Levee were to be done in the future, the risk is considered high that undetected flaws still would remain and pose a threat to the future performance of the Levee. See also "existing utilities" section, below, for other potential seepage pathways.

4.3 Freeboard

The easternmost RWDL and conjoined southernmost Winslow Levee will be overtopped by 5 feet at the 100-year flood event and floodwaters would break out and travel westward to inundate more than half of central Winslow. If the Levees in this area were to be raised in height to provide sufficient freeboard, the BNSF railroad track, which currently crosses the crest of the Winslow Levee, would remain as a point with insufficient freeboard, and hydraulic modeling indicates the resulting breakthrough, flood and damage would be identical to Levee overtopping or failure in this vicinity, causing extensive flooding in Winslow. The feasibility study team proposed the solution of building a stop log across the railroad track at the low elevation point. The railroad rejected the solution. As a result, sufficient freeboard cannot be attained solely by raising the Levees in this area.

4.4 Channel Capacity at BNSF Railroad Bridge

The low-elevation bridge deck of the BNSF railroad bridge over Little Colorado River at the southern end of the area studied (Plate 1) is an obstruction to river flow. Precise height above the river invert is not known. The locally narrow river channel and prolific tamarisk vegetation serve to exacerbate the water surface elevation here during floods. It was recognized well in advance of this study that the existing railroad bridge deck could be raised in elevation only by incrementally raising the railroad grade and replacing the bridge; costs were determined to be prohibitive to this study. The locally narrow river channel and prolific tamarisk vegetation serve to exacerbate the water surface elevation here during floods.

4.5 Existing Utilities

Existing underground utility lines in the Winslow Levee foundation and utilities through the Levee embankment fill are important considerations because they could be seepage paths, and because in most instances they will need to be protected in place or relocated in conjunction with any Levee reconstruction that may occur. Some underground lines may be so shallow that protect-in-place is not a viable option. Relocations quickly can reach or exceed six figures in cost. The utility locations reported here are based primarily on as-built and other plan sheets. In cases of locations determined via the summer 2015 Navajo County field survey for utility lines, locations are based additionally on surface markers observed at that time. *No* potholing was done in 2015 to verify location of utility lines, so it should be expected that small station location corrections eventually will be made regarding specific levee under-crossing points. Such work is not expected to be done in the feasibility phase of this study.

4.5.1 Natural Gas Line

Kinder-Morgan's 4.5-inch-diameter (O.D.) high-pressure natural gas line, formerly a possession of El Paso Natural Gas, is under the Winslow Levee foundation at three separate locations, according to the 1989 Levee as-built sheet no. 6, and as verified by the 2015 Navajo County field survey of utilities. From downstream to upstream, the gas line undercrossing points are: Levee Station 6+45 (upstream of State Route 87); Levee Stations 50+00 and 53+25 (beneath Interstate 40 embankment on the upstream and downstream sides, respectively, with Stations reflecting the oblique angle of the undercrossing relative to embankment orientation); and Levee Stations 79+00 and 81+00 (on the riverside and landside of the Levee, respectively, with Stations reflecting the oblique angle of the undercrossing relative to Levee orientation). Overall the gas line bearing beneath the Levee foundation is approximately N. 30° W. Depths to the line are reported only at Levee Stations 6+45 and 78+40, where it is at approximately elevations 4,849 feet and 4,846 feet, respectively, or about 6 feet deeper than the base of Winslow Levee. During construction of the gas line, a cutoff wall for seepage control was built around the line where it is beneath the Levee but no details of this measure are known. More precise control on depth and information regarding pipe composition, trench fill, if any, and sequencing of construction are important characteristics that are not known. The line is older than the Levee, so the Levee was built on top of it. Nevertheless, conceptual ideas to rebuild a levee, and possibly a larger, more massive levee, overtop of this utility line requires engineering review of stresses that the gas line would have to bear. Possibly the gas line or Levee will have to be relocated. The preliminary assessment of the Corps lead Design Engineer on this study, as of late 2015, is that the Kinder-Morgan line will have to be relocated, considering the deep toe down of scour protection that will be designed into the new levee. Preliminary costs for relocation of this segment of the gas line are approximately $250,000 as of late 2015. If the line or its utility trench were to be left in place, measures to address the potential for seepage will have to be evaluated.

4.5.2 Fiber Optic Line, Electrical Line, and Telephone Cable

Based on information and the survey provided by Navajo County in mid 2015, a 4-in.-diameter fiber optic conduit was microtunneled beneath Winslow Levee in the foundation at approximately at levee Station 6+60. Within the conduit is a half-inch-diameter "50-pair" fiber optic line. The utility line orientation at the Levee undercrossing point is approximately N. 85° W. Depth to the conduit is 8.65 feet below the existing ground surface, as observed in a manhole approximately 390 feet northwest of Winslow Levee, but depth precisely at the Levee undercrossing point is not known but assumed to be no less than 8.65 feet. At such a shallow depth, assuring adequate protect-in-place procedures for this line may be difficult but as of late 2015, the Corps conceptual plans are to protect the line in place rather than relocate it.

A 3-ft-deep, buried, 12 KV electrical conduit that pre-dates the Levee is shown on as-built drawing 9 beneath Winslow Levee at Levee Station 232+40. The conduit has been de-energized, according to a Navajo County survey of underground utilities for this study that was conducted in summer 2015, but the conduit remains in place, and as such continues to be a potential seepage conduit. A cutoff wall was constructed around this line according to notes on as-built drawing 9, but no other details on the seepage-control measure are known. Considering its shallow depth it likely would be excavated and removed during any levee reconstruction work that may occur.

A buried telephone cable that pre-dates the Levee is shown on as-built drawing 5 beneath Winslow Levee at Levee Station 6+10, which is on the north side of and nearly adjacent to the State Route 87 roadway embankment. At the time of Levee construction, depth to this cable was not known, nor were any of the details of its construction, or seepage cutoff features, if any. All remains unknown at this time. The location has to be considered a potential seepage path.

4.5.3 Irrigation Canal and Siphons, and Drainage Culverts

An active, flowing irrigation canal parallels Winslow Levee north of Interstate 40 for a length of 2,700 feet (Figure 5). The 7-foot-wide canal is an open, concrete-lined, trapezoidal channel. Adjoining to the north are 300 feet of irrigation pipe that connect to the canal and convey the water further to the north. This canal is 60 to 75 feet west of the landside toe of the Winslow Levee. The canal is fed by water that flows northwest beneath the segment of RWDL that is included in this study, via two inverted siphons at RWDL Station 108+40. These siphons are twin pipes, approximately 3 ft in diameter, buried below the pre-Levee ground surface to a depth a 12 inches. Burial was by protection stone, of an undefined size and gradation. During RWDL construction these siphons were protected in place and covering with an additional 1.5 ft thickness of protection stone. This protection stone layer detail can be found on RWDL as-built drawing 11. It is possible to rebuild Winslow Levee without the need for levee through-crossings or undercrossings of this irrigation flow because all is currently routed west of the 'Interstate 40' segment of Winslow Levee and is directed into pastureland on the landside of Winslow Levee, not into the LCR channel.

Surface runoff and Little Colorado River tributary channel drainage collect on the upstream (south) side of the Interstate 40 embankment and are passed through the embankment via ADOT's large 'K-3', six-barrel box culvert system that is built through the interstate highway embankment, Levee Stations 24+78 through 46+75. The interstate highway embankment, currently part of the Winslow Levee, would *not* be used as a part of any Corps-redesigned or improved Winslow Levee, but this tributary drainage and surface runoff still will have to be accounted for in any Corps design as water will continue to collect south of I-40, be conveyed through I-40, and will have to be provided with outlet to the Little Colorado River channel. The K-3 structure is by far the largest size utility that intersects either the Winslow or RDWL systems, and it should be expected that outlet for K-3 drainage through any new or redesigned Winslow Levee will have to accommodate a similar, large capacity.

Surface runoff and east-flowing City of Winslow collected storm drainage are conveyed through Winslow Levee via ADOT's "I-4" box culvert and gate system which intersects the Levee at Levee Station 91+24.410 on the west side of the Levee and Levee Station 93+10 on the downstream side. The structure is built through the levee embankment fill but no cutoff wall was built with this box culvert system and cutoff was considered "not necessary" according to engineer notes on as-built drawing 6. Any Corps-redesigned or improved Winslow Levee will have to provide for outlet of this water to the Little Colorado River channel and it appears unlikely that this can be done without leaving the existing culvert system in place and reconstructing new levee around it, or else building a very similar structure at a different location.

Outfall from the Winslow Wastewater Treatment Plant, a facility owned, operated, and maintained by City of Winslow, undercuts Winslow Levee at Levee Station 223+00. The penetration is a 12-in.-diameter ductile iron pipe. The pipe outlet is approximately 100 ft east of the riverside Levee toe. Means of installation, depth of burial, and type of utility trench backfill, if any, were not reported and it is not known if the penetration is through Levee embankment or foundation.

4.5.4 Homolovi Water Line

City of Winslow's Homolovi Water Line, a potable water supply line that apparently comprised of 6-in.-diameter PVC pipe, undercuts Winslow Levee at Levee Station 158+00, then crosses the Little Colorado River to supply Homolovi State Park on the opposite river bank. The system also includes, on the landside of the Levee, a gate-valve box and buried water line that extends for some 1,000 ft within the Levee right-of-way, all beginning east of the far eastern end of Prosperity Ave. Precise stationing of these landside features is not known; refer to the utility lines map in the Asset Management Appendix to the Integrated Feasibility Report for more location information. Means of installation, depth of burial, and type of utility trench backfill, if any, were not reported and it is not known if the penetration is through Levee embankment or foundation.

4.6 Groundwater and Dewatering

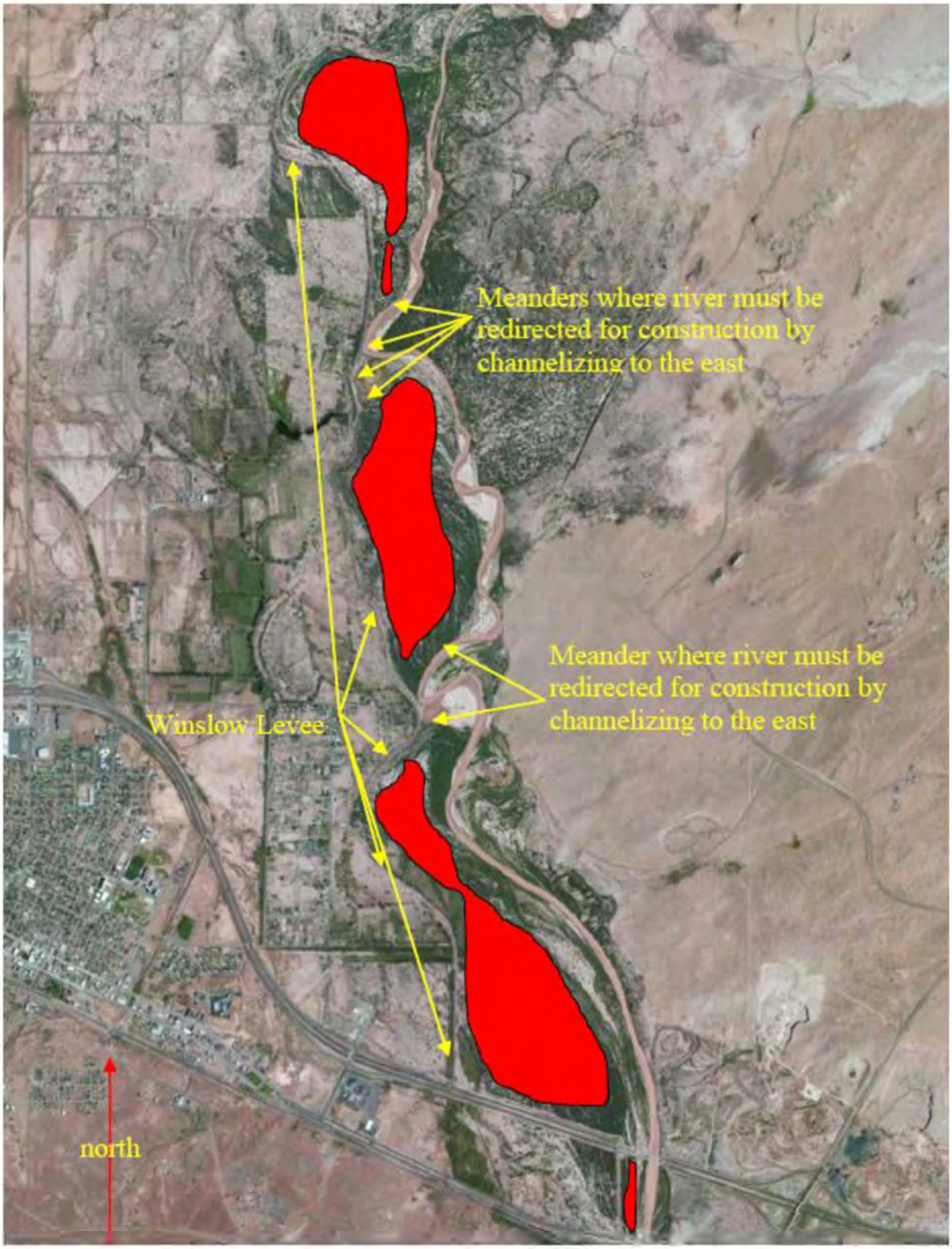
Existing well logs suggest that groundwater in the floodplain of the Little Colorado River occurs in the depth range of 14 to 30 feet below the ground surface. Seasonal records cannot be discerned from the available data. Groundwater was found by all ten seismic refraction investigation lines of 2013, and was consistently shallow. Groundwater would have to be lowered to excavate alluvium from the active river channel beneath the BNSF Railway Co. bridge. That condition could impact the alternative of permanently lowering the grade underneath the rail road bridge. There may be places where Levee fill reconstruction may force either dewatering or diversion of the LCR in order to undertake construction activities on the Levee. Such locations are the two existing river meanders that impinge on the Levee (Figure 7). If the river is not diverted there for construction, the levee toe will be impacted by river flows. For the southern of those two locations, channelization was done in years past by Levee stakeholders who were attempting to make a permanent solution and end river impingement on the Levee there. The results were short lived, as the river filled in the artificial channel and migrated elsewhere. A construction method under consideration by the team that would circumvent this problem is leaving the existing Levee in place, and building a set-back Levee for that segment, then demolishing the existing Levee. It is also possible that excavation for a trench drain near the landside toe of the levee could encounter groundwater if groundwater is shallow in certain areas or where the active river is close to or impinging upon the levee. During the design phase of the project, alternative design measures should be considered in these select areas to determine the most cost effective solution; however, there is currently a lack of sufficient geotechnical and groundwater information available to accurately define these areas. No pumping test data are known for the active Little Colorado River channel in the vicinity of the levee.

4.7 Borrow

If the Winslow Levee is rebuilt, additional fill may be required. Reuse of much of the existing Levee fill as well as use of material from required excavations is assumed, including material excavated from the potential trench drain and also from the vicinity of the BNSF bridge. The Geotechnical Branch observations from the field suggest that the potential, nearby fill sources (Figure 7) are composed of eolian and river run materials, including alluvial sand, fines, and coarse gravel, the same as was used to build the original Levee. Borrow sources will need to be identified for each measure and alternative for levee embankment materials, drain materials, riprap, and soil cement.

4.8 Eolian Deposits

In three specific locations near Winslow Levee on the riverside, dune height exceeds the levee crest and the tops of houses protected by the levee. Observing dust storms in the area revealed that the tamarisk is acting as a wind break, causing additional silt to deposit during dust storms, further raising the dunes. Tamarisk was observed rooted on top of many of these dune crests (Plate 2); suggesting a rapid succession occurs from dune height increase with new windblown deposition, to stabilization of the new crest elevation with tamarisk. Tamarisk, which is very common in the river floodplain and beyond, is known for rapid and aggressive re-rooting when shoots are cut or the plant is uprooted. Thick, dense tamarisk growth occurs on both sides of the levee but is largely not present in active cattle pasture lands on the landside.



NOTES:

1. RED POLYGONS SHOW AREAS WHERE RIVER RUN MATERIALS READILY COULD BE MINED AS SOURCES OF LEVEE FILL, BASED ON CORPS OBSERVATIONS AND STUDY OF AERIAL PHOTOGRAPH.
2. ALL ARE HEAVILY GROWN WITH TAMARISK.
3. MOST ARE EXPECTED TO INCLUDE SOME FINE GRAINED, WIND BLOWN DEPOSITS. NONE HAVE BEEN SAMPLE OR TESTED. MOST LIKELY IT WAS USED TO BUILD EXISTING LEVEE.
4. PHOTO CAME FROM GOOGLE EARTH BASE MAP OF 2013.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY RIVER RUN MATERIALS	FIGURE 7

4.9 Riprap

Large-sized, high-quality, durable, basalt riprap with a D_{50} of approximately 10 inches has been placed on both sides of Winslow Levee along approximately half of the Levee. The placement on the riverside is slightly more extensive than landside coverage. This stone is dense and is well interlocked as placed. Durability testing of the stone was done previously and included in the Levee construction record (see Appendix B). Past experience in this region indicates no local or even moderately close sources of durable and dense riprap. The riprap is Bidahochi formation basalt mined from a mesa over 40 miles northeast of Winslow Levee (a 60 mile one-way haul distance along existing, but indirect roads).

The Geotechnical Branch understands that the feasibility team's preliminary Levee re-design calls for grouted stone slope protection to be used in various strategic places along the rebuilt Levee, so as to resist the points of higher projected flow velocity and the likely points of River impingement on the Levee. As of mid-2014, that design calls for a total of 74,000 cubic yards of 24-inch stone for grouted stone and 26,000 cubic yards of 36-inch stone for grouted stone. An estimated 25,000 cubic yards of salvageable basalt riprap, which could be used as stone for grouted stone, exists on the Winslow Levee, although the gradation is much smaller than would be needed to construct either the 24- or 36-inch stone for grouted stone. Nevertheless, this smaller on-site stone could be used to fulfill some of the smaller gradation fractions in a 24- or 36-in. protection stone layer.

Very little salvageable riprap exists on the short segment of RWDL that is within this study. That which can be re-used is limited to the basalt.

4.10 Lack of Subsurface Information

The USACE planning process generally delays geotechnical and other investigation work until after the feasibility phase of the study. Thus, there has been no direct geotechnical sampling of the Levees, the foundation, or any potential borrow sources. As a result, the study will carry increased project risk and cost contingencies going forward, until such investigation is performed.

4.11 Existing Debris

Notable debris in the Winslow Levee consists of some automobile hulks and vegetation. What is known occurs near McHood Rd. Descriptive information and recommendations are in USACE, Los Angeles (2013).

5.0 CONCLUSIONS AND RECOMMENDATIONS

The proposed measures and alternatives developed for improvement of the existing levee systems require differing levels of consideration of existing geotechnical and geologic conditions. The following recommendations need to be accounted for in preliminary design drawings, cost estimates, and development of future scopes of work.

5.1 General

For feasibility-level planning enhancements to Winslow Levee and RWDL, the following should be considered and incorporated into conceptual designs, planning, and cost estimates, including cost-risk analysis. Detailed discussions are further presented later in the text of this report.

- Assume the existing Winslow Levee has multiple potential seepage paths (one at the contact of unprocessed foundation and base of the levee, another at the internal contact between original levee fill and 1989 levee fill, and one at the upper contact of the unprocessed and non-engineered pre-1989 fill. Dumped emergency flood fighting materials (car bodies, masses of cut vegetation) offer additional seepage paths.
- Assume the existing Winslow Levee fill, which is natural river-run deposition derived from locations adjacent to the Levee, and fine grained windblown material in the vicinity, both will be suitable for use in Levee reconstruction, while recognizing that none of these materials have been tested. Also assume that suitable fill for use in soil cement will be available from borrow sources, while recognizing that no testing has been performed to confirm this assumption.
- Assume that the local-sponsor-proposed off-site borrow sources, the O'Haco no. 1 and O'Haco no. 2 pits, and Dyna sand and gravel site, and the adjoining, unnamed floodplain deposit site, all are suitable for use in Levee reconstruction, while recognizing that none of these materials have been tested. The four borrow locations represent four different geologic deposit types. Assume the levee design and fill specification can accommodate each of these different deposit types. Materials costs would be associated with hauling material from these off-site potential borrow sources.
- Recommend salvaging the existing, suitable basalt riprap that is on Winslow Levee for reuse in any Levee reconstruction scenario. Reuse of this material will be economically beneficial to the project. Hauling costs associated with stone salvage will be minimized but existing quantities are insufficient and existing gradations are too small to satisfy current conceptual redesign of the Levee; soil cement could be considered for the remaining portions of the levee, for economy, since building soil cement with local materials likely is less expensive than hauling additional riprap from the far-away stone sources.
- Recommend wasting all of the non-basalt riprap on site (this includes sandstone, very small amounts of limestone, and waste concrete). It will not pass the Corps stone durability criteria for riprap; the sandstone, additionally, will not pass the Corps stone density requirements. Wasted rock materials should be considered for miscellaneous fill areas such as fill on top of the riprap toe down. This could be a cost effective method of disposable and there may be other opportunities to waste these materials on-site.

- No testing of the potential borrow material has been done to verify its suitability for soil cement.
- Much greater precision regarding exact depth to the natural gas line beneath Winslow Levee will have to be obtained before any actions can be decided upon, including protect-in-place or relocation.

In addition, it is recommended to do the following:

- Obtain data on the SR-87 bridge construction, particularly information on the bridge piers. This will be important in conceptual design and for post-sediment-removal stability analysis.
- Develop a plan for test excavation, sampling, and testing of potential levee fill, including large-scale sorting and gradation, and blending with sources of fine material.
- Examine, map, sample, and test all potential borrow sources.
- During future study and design, recommend evaluation of the existing bentonite slurry core and cement slurry core to determine potential re-use opportunities during reconstruction. After existing Levee demolition, the material no longer will be suitable to serve as an impermeable zone, but depending on the degree of cementation, the material may be suitable for use in levee fill, miscellaneous fill (perhaps to bury the riprap toe down), or even for soil cement. Re-use of this material may require minimal to substantial processing depending on its strength and cementation (i.e. basic blending if the material is weakly cemented or perhaps pulverization if the material is strong and highly cemented).
- Soils beneath the former BNSF alignment will need to be tested for hazardous substances, excavated and hauled to a suitable treatment and storage facility. It is recommended to avoid the alignment if possible with new levee, and thus to avoid this expense.
- Remain aware of the need to perform tamarisk removal to utilize the potential fine-grained borrow sources that are expediently located near or adjacent the existing Winslow Levee. All such areas are heavily vegetated with tamarisk. The Corps biological survey for this study determined there are no species of concern in this vegetation as of 2015 (refer to the Integrated Feasibility Report, environmental sections). If that condition were to change in the future, and / or if regulatory approval of tamarisk removal could not be attained due to some other issue, more distant sources of similar fine-grained material would have to be used. Those sources exist. The difference in distances is not extreme and will not translate into a large construction cost increase. Cost increases relate to increased transportation distances.
- Remain aware of the fact that LCR channel conveyance capacity has decreased from combined impact of dense tamarisk growth, dune deposition, and the promotion of additional sedimentation as flood waters are slowed by the existing sedimentation and vegetation. This concept has been utilized in hydraulic modeling done for this study and the results are conveyed in the Hydraulics Appendix.
- Evaluate and address the potential for seepage along the natural gas line and other utility line penetrations which pass under the levee alignment in the foundation, as well as seepage potential around drains that pass through the levee prism.

5.2 Levee Seepage Control

Seepage control at the Winslow Levee is considered a significant issue due to past seepage events as well as preliminary analysis which indicates the potential for high exit gradients, especially in areas where thin, landside blanket layers exist (see Geotechnical Evaluation of Levee Fragility, USACE 2012).

Potential seepage control measures have been evaluated based on the understanding that bedrock is located at a depth of approximately 50 to 100 feet below ground surface along the northern half of the levee alignment and at a depth of at least 30 feet along the southern half. Additionally, there are no indications to suggest that a continuous, relatively impermeable layer of alluvium exists beneath the levee, although such a layer may exist in some areas over limited distances. It is also assumed that permeable foundation soils are exposed in much of the river channel, and that, on the landside, the permeable foundation soils are overlain in some areas by a fine-grained blanket layer at ground surface.

In general, there are three methods of seepage control: 1) control seepage at the entrance (riverside), 2) control seepage beneath the levee, and 3) control seepage at the exit (landside). Given the foundation characteristics and broad width of the active floodplain, thousands of feet wide in many areas, riverside seepage control measures such as impermeable blankets would be costly, impractical, and relatively ineffective. Further consideration was given only to control measures which could potentially cutoff (or lengthen) the seepage path below the levee or control the seepage at the exit.

5.2.1 Cutoff Walls

Cutoff walls (e.g. bentonite slurry trench and/or sheetpile) constructed at either the middle of the levee alignment or near the upstream toe were considered as a means of cutting off or lengthening the seepage path. The seismic refraction survey performed in 2013 indicated that bedrock was 50 to 100 feet deep in many areas; however, making a full cutoff unlikely to be cost effective. A partial cutoff (not tied into bedrock or a continuous relatively impermeable stratum) was also considered, but based on preliminary analysis using estimated parameters and the presence of permeable alluvial foundation materials (sands), even a relatively deep (40+ foot) partial cutoff is not expected to significantly reduce exit gradients. Given the high costs associated with cutoff wall construction and ineffectiveness of partial cutoffs in permeable soils, landside seepage control measures are expected to be more cost effective.

5.2.2 Seepage-Control Toe Drain

Seepage control at the landside toe was considered primarily in the form of a trench drain which would be constructed using filter compatible sands and gravels. While minimal foundation data is available, it is anticipated such a drain could be constructed and could be effective at this site. Natural semi-impermeable blanket layers on the landside of the levee are expected to exist and are anticipated to be thin enough such that they can be penetrated with a trench drain excavation prior to encountering groundwater (without requiring dewatering). It is generally important that a trench drain penetrate the less permeable surface layer and maintain intimate contact with the more permeable soils below in order to be effective. Given the relative lack of subsurface site data, the possibility exists for areas along the alignment where groundwater could limit the depth of excavation. In these cases, dewatering would be required or an alternative solution would be required.

Note that a trench drain, as opposed to relief wells, is currently the preferred landside seepage control measure due to several factors: relief wells are less verifiable during construction, relief wells require relatively increased maintenance to ensure functionality, and the effectiveness of relief wells is less predictable given the current lack of foundation data. Additional benefits associated with the use of trench drains include construction with standard earthwork equipment, ease of verification through observation during construction and soils testing during construction, and minimal operations and maintenance costs.

5.3 Potential Borrow Sources

Areas where potential fill exists are shown on Figure 7. Heavy tamarisk cover exists at most of these areas. The material has not been tested for the purposes of this feasibility study, nor is there a record of construction era testing from the Levee construction. Other borrow sources exist and are described below.

Windblown deposits brought to the Levee area by strong and consistently oriented dust storms are a potential source of Levee fill. The resulting dune deposits, composed mostly of silt and fine-grained sandy silt, are commonly found deposited adjacent and near the Winslow Levee, and in many locations have buried the levee toe. No sampling or testing of this material was done. It was observed that the dust dunes should be plentiful. The dust dune material represents a potential source of fines.

The feasibility team was asked to consider other, specific, more distant potential Levee fill borrow sources. All are privately owned. There is no testing record available for the materials. The local sponsor and study team interest in these more distant sites was initiated out of concern regarding potential mitigation issues that may have to be resolved if tamarisk is removed to access adjacent-to-Levee borrow. No geologic or geotechnical field studies were performed for these potential borrow sources. A ‘desk-top’ geotechnical assessment using limited available data was performed. What has been reported to the USACE by Navajo County and what can be discerned from existing aerial photos and geologic maps is discussed below. The two sites are shown on a map (Figure 8) and additional characteristics were gleaned from aerial photos of the deposits (Figures 9 and 10). There has been no testing of the materials by suppliers, users, or the USACE. Eventually, site examination, sampling, and testing will have to be done, should any of these materials be used for levee construction.

The O’Haco no. 2 pit (Figure 9) is 2.5 miles northwest of the northernmost part of Winslow Levee. It is approximately 12 miles north of the southern extent of the Levee. Only 1.5 acres of the 40-acre tract has been noted as available for mining. The deposit has been described as being as much as 40-feet thick and containing 50,000 tons of fill. The precise location of the 1.5 acres available for mining was not indicated to the USACE. No site geology has been provided. The site material is described as “silty sandy clay” by Navajo County personnel. The material was used to repair a breach in the Winslow Levee in 2006. No materials testing from that effort is known or thought to exist. The USACE examined available geologic maps, studied aerial photographs, and made conclusions regarding the likely site geology.

The O'Haco no. 1 pit (Figure 10) is, at the closest, approximately 5 miles due west of Winslow Levee. Average haul distances to Winslow Levee would exceed 10 miles, each way. Only 20 acres of the 77-acre tract has been noted as available for mining. The deposit of material has been described as being as much as 30-feet thick and containing 500,000 tons of fill. The precise location of the 20 acres available for mining was not indicated to the USACE. No site geology has been provided. Materials produced are described as "silty sandy clay" by Navajo County.

Near the southern end of Winslow Levee is an operating gravel and sand quarry, the Dyna Sand and Rock / Winslow Ready Mix site, owned by McCauley Construction, of Winslow. The site is approximately 0.7 miles east of the southern extent of Winslow Levee (Figure 11), and therefore, is approximately 9 miles south of the most distant, northern part of the Levee. It is the closest existing and operating commercial fill source to the Levee. Navajo County reported to the USACE that the site has 100,000 tons of fill available but that more could be mined from the property. A January 2014 estimate made by the owner and forwarded to the USACE via Navajo County indicates the operation could deliver fill to the potential Winslow Levee construction site for $6 to $7 per ton. One gradation test of material from the northern part of the property indicates it is a sand with gravel and 25 percent fines (Figure 12). That sample was described as "silty sand plus rock" and as "red material."

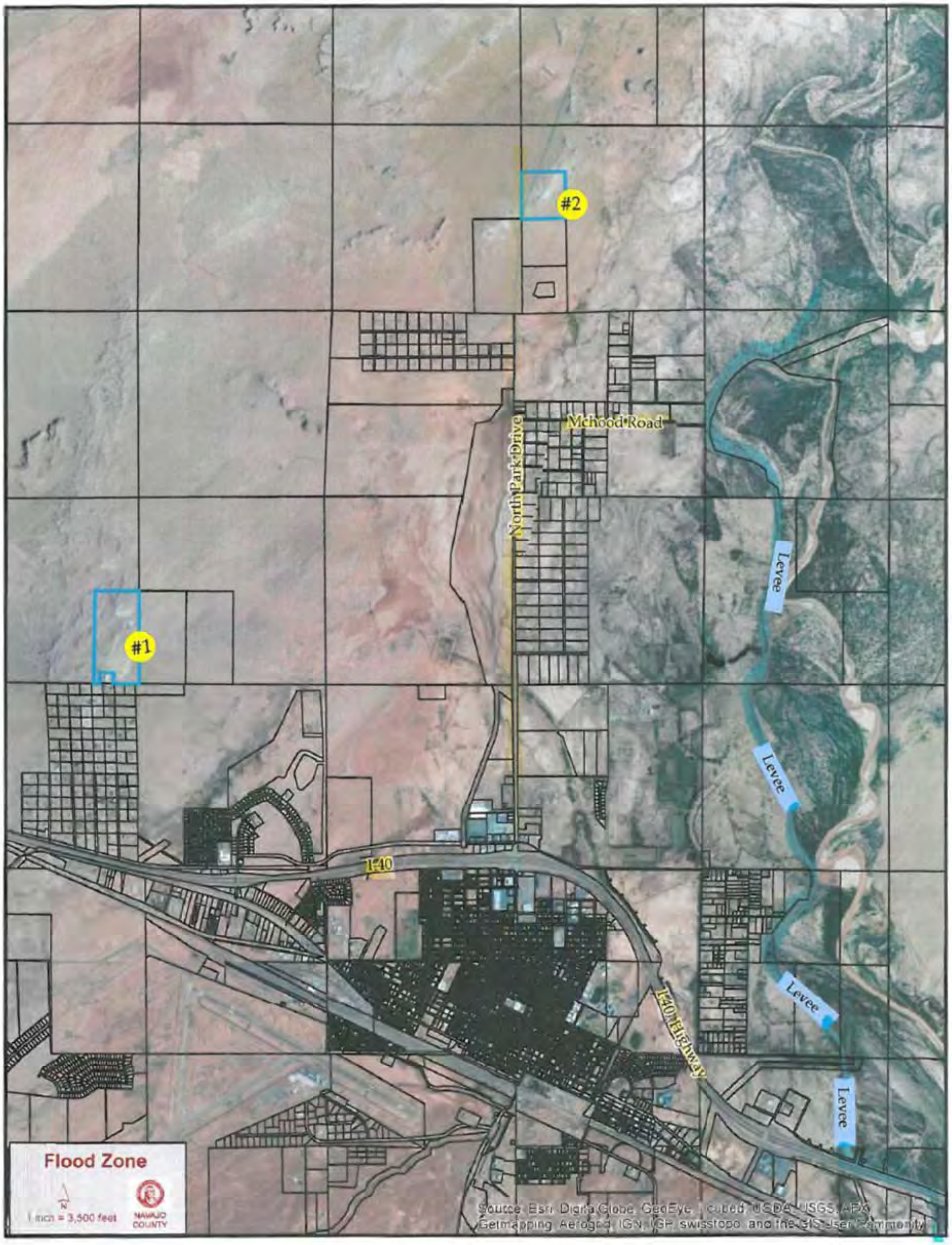
Another commercial operation adjoins the south side of Dyna Sand and Rock on a different land parcel (Figure 11). No specific information on that site was obtained, and it is not known to be operating, but the numerous materials pits and stockpiles visible on the site in aerial photographs are sufficient confirmation it has been mined in the recent past.

Ultimately, material suitability for use as levee fill and overall material cost (including any required mitigation impacts, hauling, etc.) will be the primary determining factor for borrow source selection. Currently, minimal soils data exists for the borrow source material discussed above, so none of the sources have been ruled out based on material suitability. It is assumed at this point that suitable material could be mined from all proposed sources described above.

5.3.1 Embankment Fill - Levee

The existing levee was built of Little Colorado River river-run material (sand and gravel), based on observations of its content exposed on rain-washed slopes. No as-built testing of this material could be found, and no investigation sampling and testing was done as part of this feasibility study. Based on field observations of the Levee surface, the material is sandy, gravelly river-run material and should be suitable for re-use in a Levee rebuild scenario.

Should the Levees be increased in size or for other reasons need additional borrow material, the first source of levee fill is expected to be required excavations such as that required to construct the trench drain included in the recommended plan. Additionally, Little Colorado River river-run material, similar to the material used in previous levee construction, exists over extensive areas in the active river floodplain that are close to the existing levee on the riverside, outside of (west of) the active Little Colorado River channel (Figure 7). No as-built testing of this material



NOTES:

1. MAP SHOWS O'HACO MATERIALS BORROW PITS NUMBER 1 AND 2.
2. SEE FIGURES 9 AND 10 FOR AERIAL PHOTOS FOR DETAILS OF PITS.
3. NAVAJO COUNTY PROVIDED THIS MAP IN JANUARY OF 2014.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY LOCATION OF PITS 1 AND 2	FIGURE 8

FILE NAME: WINSLOWFIG10.DGN HERNANDEZ (F): \DATA\SPL\DOCUMENTS\GEOTECH\CHATMAN\WINSLOW

NOTES:

1. AERIAL IMAGE SHOWS DETAILS OF THE O'HACO MATERIALS BORROW PIT NUMBER 2 IN WINSLOW, AZ.
2. LOCATION OF OF THE 40 ACRE PROPERTY IS APPROXIMATELY MARKED IN YELLOW.
3. REFER TO FIGURE 8 TO GET AN IDEA HOW FAR AWAY IT IS FROM WINSLOW, AZ.
4. CORPS ESTIMATED MAXIMUM EXTENT OF THE LCR VALLEY WIDTH IS SHOWN IN RED (VALLEY TO THE RIGHT OF THE LINE).
5. AERIAL IMAGE CAME FROM GOOGLE EARTH PRO, JANUARY 2014.

US Army Corps of Engineers
Los Angeles District

LITTLE COLORADO RIVER
WINSLOW ARIZONA

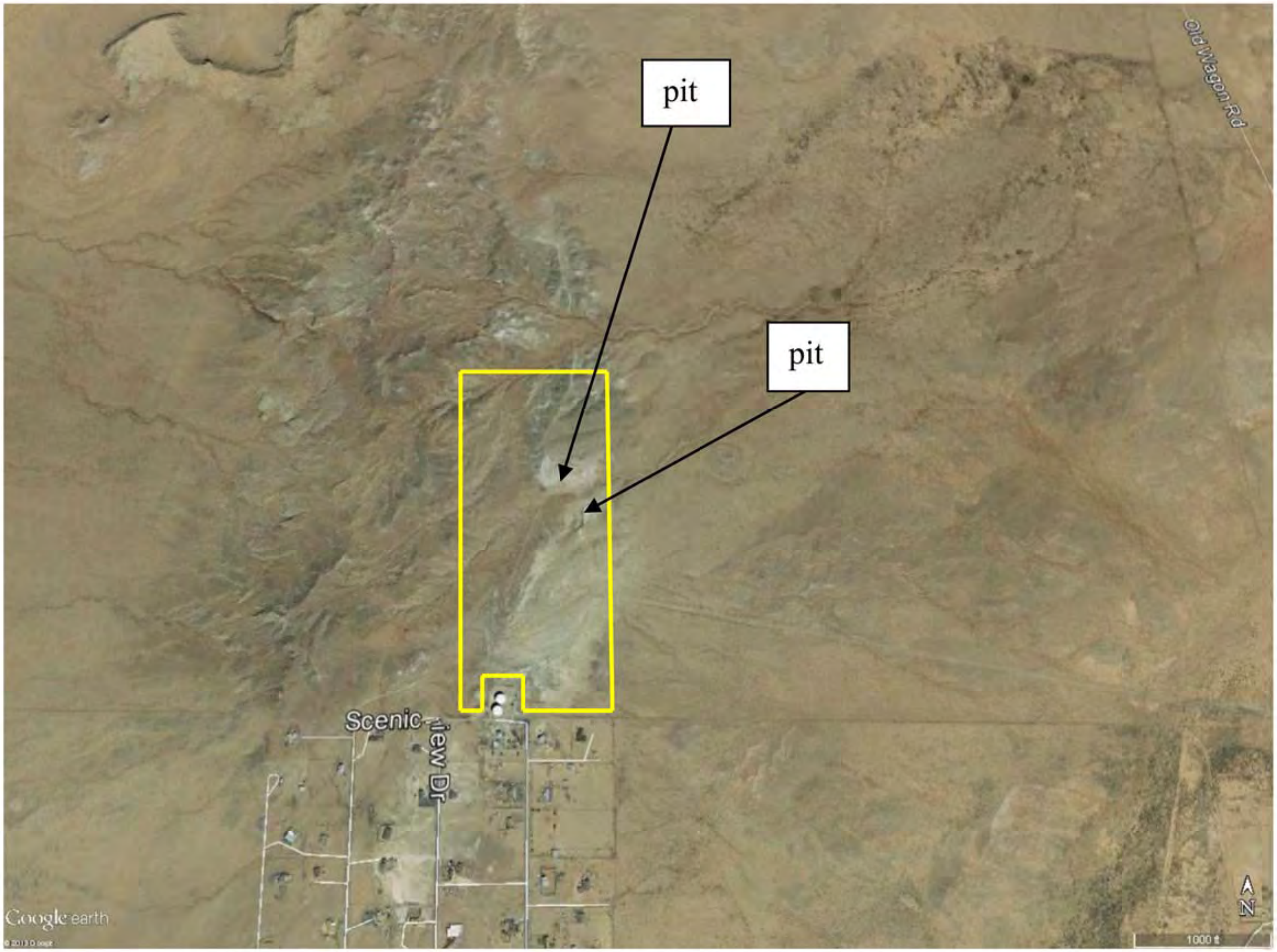
WINSLOW FEASIBILITY STUDY

AERIAL OF PIT 2

FIGURE 9

FILE NAME: WINSLOWFIG11.DGN

HERNANDEZ (F): \DATA\SPL\DOCUMENT\GEOTECH\CHATMAN\WINSLOW



NOTES:

1. AERIAL IMAGE SHOWS DETAILS OF THE O'HACO MATERIALS BORROW PIT NUMBER 1 IN WINSLOW, AZ.
2. LOCATION OF OF THE 40 ACRE PROPERTY IS APPROXIMATELY MARKED IN YELLOW.
3. REFER TO FIGURE 8 TO GET AN IDEA HOW FAR AWAY IT IS FROM WINSLOW, AZ.
4. AERIAL IMAGE CAME FROM GOOGLE EARTH PRO, JANUARY 2014.

500 250 0 500 1000ft
SCALE: 1"=1200'

US Army Corps of Engineers
Los Angeles District

LITTLE COLORADO RIVER
WINSLOW ARIZONA

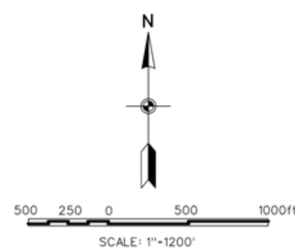
WINSLOW FEASIBILITY STUDY

AERIAL OF PIT 1

FIGURE 10

FILE NAME: WINSLOWFIG12.DGN

HERNANDEZ (F): \DATA\SPL\DOCUMENT\GEOTECH\CHATMAN\WINSLOW



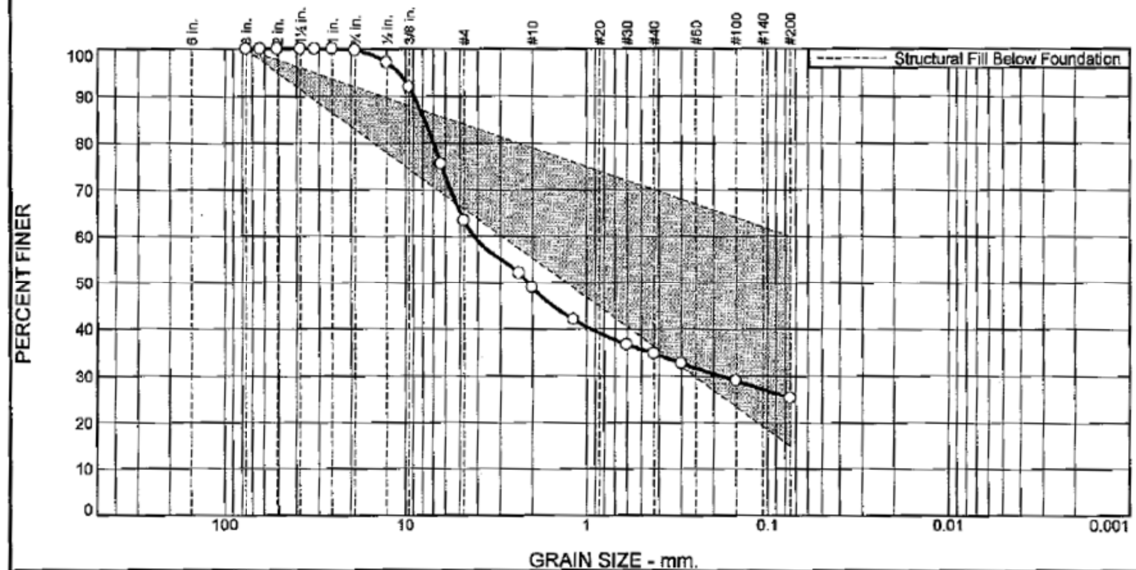
NOTES:

1. AERIAL PHOTOGRAPH SHOWS McCAULEY CONSTRUCTION'S BORROW PIT (YELLOW OVAL) AND ITS SPATIAL RELATION TO WINSLOW LEVEE.
2. WIND BLOWN DEPOSITS ARE NORTH OF THE RED LINE (PER GEOLOGIC MAPPING, BILLINGSLEY AND OTHERS (2013)).
3. FLOOD PLAIN DEPOSITS ARE SOUTH OF THE RED LINE (PER GEOLOGIC MAPPING, BILLINGSLEY AND OTHERS (2013)).
4. AERIAL IMAGE CAME FROM GOOGLE EARTH JANUARY 2014.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY AERIAL OF McCAULEY CONSTRUCTION'S BORROW PIT	FIGURE 11

FILE NAME: WINSLOWFIG13.DGN HERNANDEZ (F): \DATA\SPL\DOCUMENTS\GEOTECH\CHATMAN\WINSLOW

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0	0	37	14	14	10	25	

TEST RESULTS

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
3"	100	100	
2.5"	100		
2"	100		
1.5"	100		
1.25"	100		
1"	100		
3/4"	100		
1/2"	97		
3/8"	92		
1/4"	76		
#4	63		
#8	52		
#10	49		
#16	42		
#30	37		
#40	35		
#50	33		
#100	29		
#200	25	15 - 60	

* Structural Fill Below Foundation

Material Description

Silty, Clayey Sand with Gravel

Atterberg Limits (ASTM D 4318)

PL= 14 LL= 21 PI= 7

Classification

USCS (D 2487)= SC-SM AASHTO (M 145)= A-2-4(0)

Coefficients

D_{90}= 8.9397 D_{85}= 7.8330 D_{60}= 4.1966
D_{50}= 2.1153 D_{30}= 0.1820 D_{15}=
D_{10}= C_u= C_c=

Remarks

Import for [redacted] Construction Project

Date Received: 11-25-13 **Date Tested:** 11-26-13

Tested By: M. Rivera

Checked By: A. Capper

Title: Lab Supervisor

Source of Sample: Silty Sand with Rock - Sample #3 - Northeast Corner of Top Pit **Date Sampled:** 11-23-13

Sample Number: 13-091

ATL, INC. Phoenix, AZ	**Client:** Dyna Rock & Sand **Project:** Plant QC Testing **Project No:** 211149 **Figure**

NOTES:

1. GRADATION OF FILL MATERIAL SAMPLE FROM McCAULEY CONSTRUCTION'S BORROW PIT.
2. APPARENTLY FROM WIND BLOWN DEPOSITS BASED ON GEOLOGIC MAP FROM US GEOLOGICAL SURVEY.
3. SEE FIGURE 11 FOR LOCATION OF McCAULEY CONSTRUCTION'S BORROW PIT.
4. TEST RESULTS WERE SUPPLIED TO THE CORPS VIA NAVAJO COUNTY, JANUARY 2014.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY GRADATION SAMPLE FROM McCAULEY CONSTRUCTION'S BORROW PIT	FIGURE 12

FILE NAME: WINSLOWFIG14.DGN HERNANDEZ (F): \DATA\SPL\DOCUMENTS\GEOTECH\CHATMAN\WINSLOW

could be found, and no investigation sampling and testing was performed. Similar material also exists on the landside of the levee, an area of active ranching. It is presumed that the study objective should be to obtain borrow without disrupting any such existing land uses. The riverside locations are mostly covered by dense tamarisk growth, which would have to be removed to obtain the fill. Such removal of plant material may be subject to one or more of various levels of regulatory and environmental review, and that could very time consuming.

Ultimately, material suitability for use as levee fill and overall material cost (including any required mitigation impacts, hauling, etc.) will be the primary determining factor for borrow source selection. Currently, minimal soils data exist for borrow source material, so none of the sources have been ruled out based on material suitability. It is assumed at this point that suitable material could be mined from all proposed sources.

5.3.2 Drain Material - Toe Drain

The trench drain proposed in the recommend plan is expected to require highly permeable gravels and filter sand. The filter sand will be filter compatible with the foundation soils and the drain gravel; the filter sand will serve to keep fines from migrating out of the foundation and into the coarse drain gravel. It is possible that a single stage filter/drain will be adequate, but it has been assumed that a two-stage filter will be necessary given the high permeable that will be required for the drain to be effective. Additional geotechnical investigation including sampling and gradation testing will be required to determine the drain and filter gradation requirements. Current cost estimates have been based on drain and filter materials recently used on other USACE projects.

The source for the drain and filter materials has not been determined at this time due to lack of foundation data and lack of borrow source data. It is possible that these materials could be mined from the inactive portions of the river channel (between the levee and the active river), but it is also possible that these materials will have to be manufactured and/or imported. Material from the river channel, if suitable, may still require processing to meet specified gradation requirements, but it is expected that river channel material will be more cost effective than imported manufactured material, even if minimal processing is required. If the materials cannot be reasonably produced from the river channel or if the river channel is not available for borrow for other reasons, it is also possible that the local off-site borrow sources described in this section can produce the proposed drain and filter materials, but little to no information has been made available for these sources at this time. The filter sand will likely be similar to ASTM C33, Fine Aggregate or “concrete wash sand,” so it is likely that the off-site borrow sources can produce this material if they also produce concrete aggregates. The coarser drain gravel will likely be similar to one of the standard ASTM C33, Coarse Aggregate gradations, and it is also possible that this material could be produced by a local off-site borrow source, if necessary. It should be noted that if these materials cannot be mined from the river channel or produced locally, hauling costs (and associated material unit costs) would drastically increase due to the remote nature of the project.

5.3.3 Soil Cement

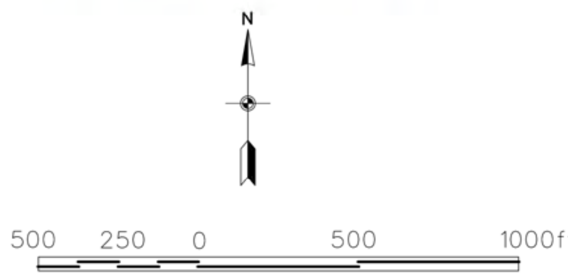
Successful soil cement materials sources are composed of both sand and also appreciable quantities of finer material, such as silt. Visual examination of the available borrow material and the material in the existing levees suggests that fines exist, although mixing may be needed. Some select mining of wind-deposited material may have to be done in order to increase the silt and other fines content of the soil cement material. Systematic sampling and testing of potential soil cement materials is necessary to verifying these visual observations and to have a complete Levee design.

5.3.4 Riprap Material

The vast majority of the existing riprap on the Levee is a hard, durable, and very dense basalt that would pass the USACE stone quality criteria testing for riprap for a Levee. This riprap should be salvageable and usable on a new Levee. Re-use, rather than waste of the stone, during reconstruction would offer a double cost benefit: the haul and disposal costs of a "waste" would be eliminated, and the reuse of riprap at strategic places would allow the elimination of some other levee-slope protection or hardening, such as soil cement.

There is essentially no salvageable riprap on RWDL, and there is an insufficient quantity of salvageable riprap on the Winslow Levee to meet the existing conceptual Levee redesign stone protection needs. What riprap is present is undersized compared to the grouted stone protection quantities needed in the current conceptual design: approximately 74,000 cubic yards of 24-inch stone for grouted stone and 26,000 cubic yards of 36-inch stone for grouted stone. Existing riprap is smaller than either of those gradations, but should be usable to meet some of the smaller and mid-range gradation segments for the 24-inch grouted stone and some of the smallest gradation ranges for the 36-inch grouted stone. Thus, existing, salvageable riprap on Winslow Levee should be usable in the conceptual rebuild design, while overall, there will be a shortage of stone for grouted stone of at least 75,000 cubic yards. There are only 25,000 cubic yards of salvageable riprap on the existing Levee. There are no suitable, nearby stone sources to make this type of riprap and grouted stone. The nearby sources are too low in density and durability to pass the USACE stone quality acceptance criteria. The lack of durability in local sandstone and limestone and the low density of local sandstones requires that basalt stone be sought for protection stone. The closest source for large basalt is the existing, operating Brimhall Hardluck Quarry (Figure 13), in Indian Wells, AZ, 40 miles north of Holbrook on SR 77. This location is 43 straight-line miles northeast of Winslow Levee, but alignment of existing roads will require actual hauling distances to be substantially longer: approximately 60 miles, one way, to the southern end of Winslow Levee.

This apparently is the same quarry that was used to supply the existing riprap on the Levee, albeit at a time when the quarry was operated under the name 'Bidahochi quarry' in 'Bidahochi, AZ'. A search of current aerial photographs finds that Indian Wells, AZ, and 'Bidahochi, AZ,' are the same place, and that there is only one quarry in the region west of SR 77 and southwest of Indian Route 15, not two. The conclusion is that Brimhall has to be mining the same deposit that was used for basalt stone on the existing Levee.



NOTES:

1. AERIAL PHOTOGRAPH SHOWS BRIMHALL HARDLUCK STONE QUARRY MINED INTO A MESA OF BIDAHOCHI BASALT. THEY ARE LOCATED 1.2 MILES NORTHEAST OF THE CENTER OF INDIAN WELLS, AZ.
2. BRIMHALL HARDLUCK STONE QUARRY IS A VIABLE SOURCE OF NEW BASALT STONE FOR GROUTED STONE ON WINSLOW LEVEE.
3. THIS IS THE SITE OF THE BASALT PROTECTION STONE THAT CURRENTLY IS ON THE LEVEE.
4. AERIAL IMAGE CAME FROM GOOGLE EARTH JANUARY 2014.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY AERIAL OF BRIMHALL HARDLUCK STONE QUARRY	FIGURE 13

The Brimhall Hardluck Quarry has been mined into a large basalt mesa, and the operations occupy approximately one square mile. Quantity of stone available should not be an issue. The material was tested prior to placement on the Levee, by Navajo County contractors, and although there are some slight variations from the standard Corps of Engineers test suite, all indications are that the stone would pass the USACE stone acceptance criteria suite. Further, the stone has been examined on the Levee by the USACE and passes all visual and field tests for stone durability, and now has a service record based on time in place on the Levee. It is not breaking down or otherwise weathering, and it is very dense. It is, therefore, reasonable to model this basalt deposit as the source for additional protection stone. It should be understood that prior to any use on a USACE levee, any stone would have to be subjected to a suite of current durability tests and other tests, and in this case, since it is to be used as grouted stone, subjected to a suit of silica reactivity tests to assure no unwanted reaction with the grout. These tests are expensive and beyond the scope of what is done in a feasibility study, so they have not and will not be done at this time.

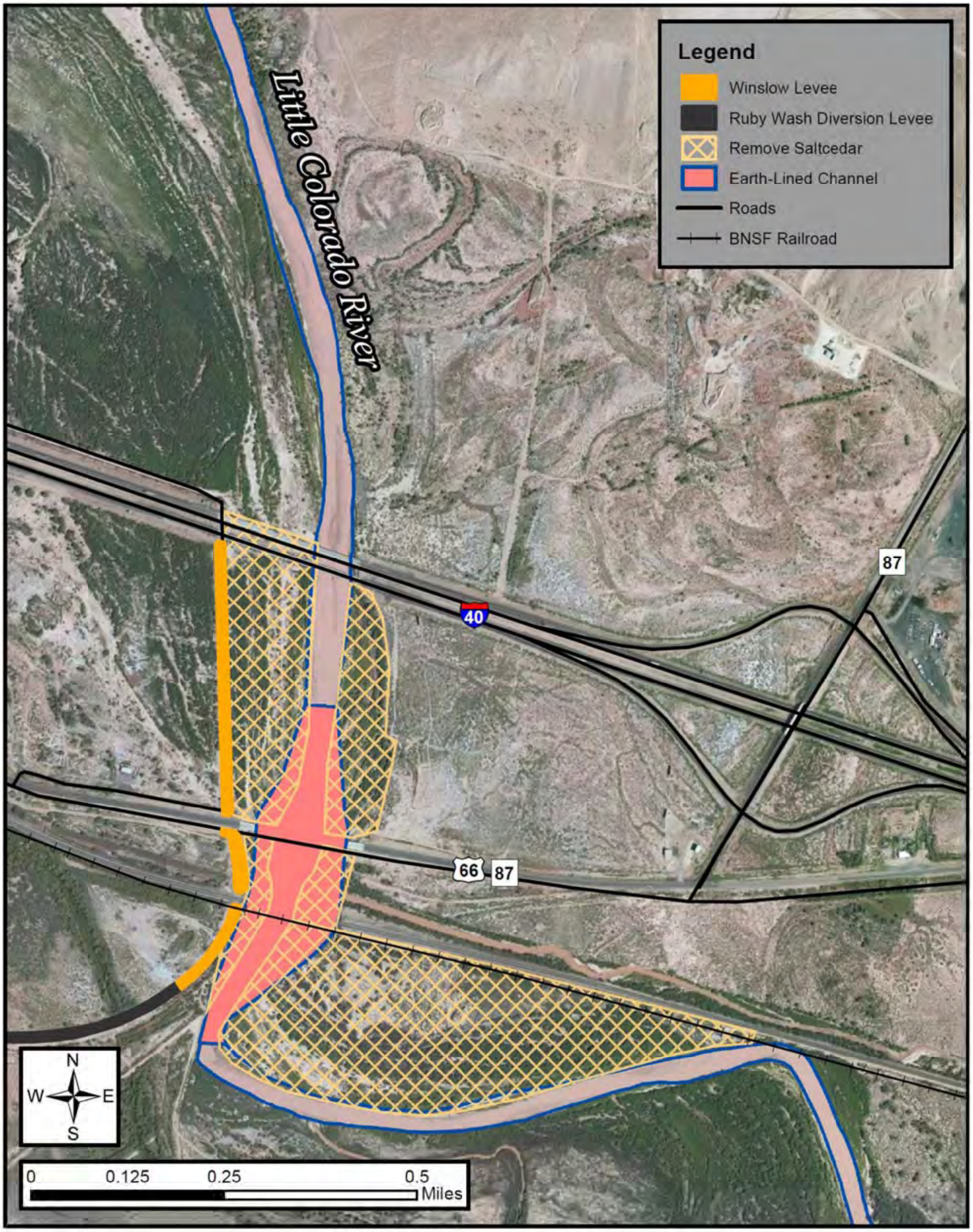
USACE observations of the existing sandstone and limestone riprap on the Levees indicate both of those stone types are deteriorating badly and would not pass the USACE stone durability test suite. In addition, the sandstone would be of too low a density to be considered. All should be expected to be wasted in a reconstruction effort, or else, crushed and mixed in with Levee fill.

5.4 Channel Capacity at BNSF Bridge

The feasibility team developed a concept to jointly address the lack of freeboard at the southern end of Winslow Levee and the low railroad bridge deck: remove extensive areas of tamarisk on the river banks and dredge under the bridge and in adjoining channel segments to increase channel capacity (Figure 14). The channel would be widened and deepened by this means, but not deepened beyond the current thalweg elevation, thus maintaining the current river gradient. USACE hydraulic modeling has demonstrated that the local water surface profile would be successfully lowered by this method, such that Levees would not be overtopped, the water surface would remain below the bridge deck, and there would be no breakout of floodwaters through the railroad track ‘low elevation’ point. Modeling shows all elements of the concept are needed in conjunction to achieve the result. This concept raises several geotechnical issues, discussed below.

5.4.1 Continued Channel Maintenance

Sediment removal from the river channel would include sediment removal from beneath both the Arizona State Route 87 (SR-87) bridge, and the BNSF bridge (Figure 14). Sediment has been deposited by the Little Colorado River beneath both bridges. The known record of river sedimentation is limited to ADOT biennial bridge inspection records for the I-40 bridge over the Little Colorado River, from 1977 through 1991. When comparing river thalweg elevation measurements to 1966 bridge design drawings, the data demonstrate sediment accumulated under the bridge at the thalweg to a depth of as much as 9 feet above the 1966 design thalweg elevation of 4,844 feet, and as little as 1 foot in other parts of the structure (under the easternmost span) (Geo. V. Sabol Consult. Eng., 1993, p. 19).



NOTES:

1. CONCEPTUAL LCR CHANNEL EXCAVATION AND WIDENING ZONE (NOT DEEPENING OF CHANNEL) ARE SHOWN AS AN ORANGE POLYGON.
2. YELLOW HACHURING IS CONCEPTUAL AREA OF TAMARISK REMOVAL.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY CONCEPTUAL LCR CHANNEL EXCAVATION AND WIDENING	FIGURE 14

FILE NAME: WINSLOWFIG07.DGN HERNANDEZ (F): \DATA\SPL\DOCUMENTS\GEOTECH\CHATMAN\WINSLOW

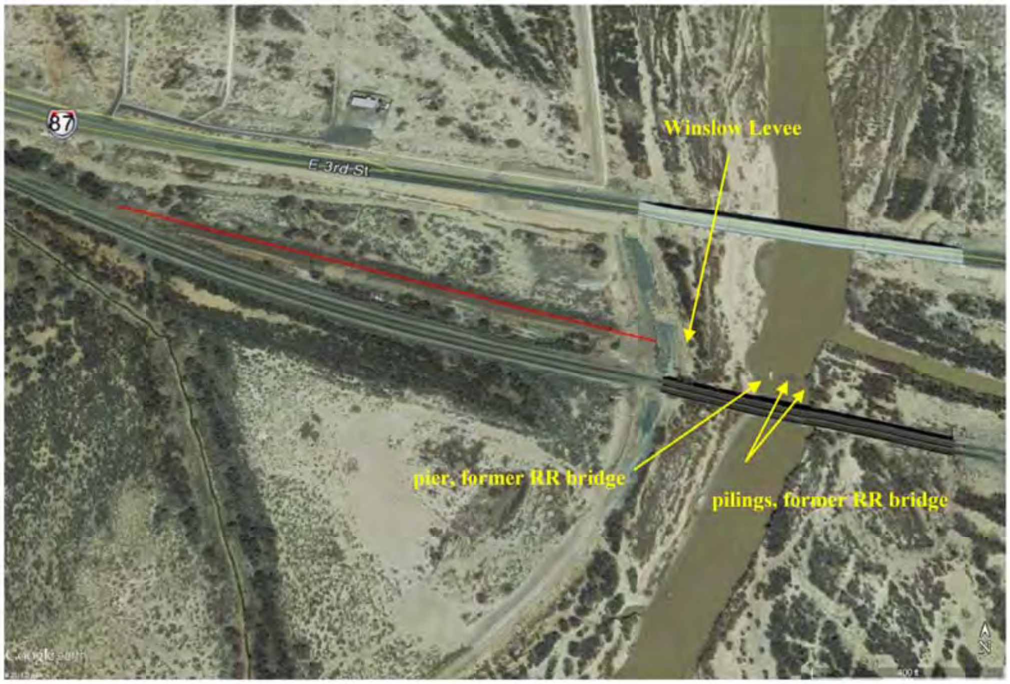
The USACE feasibility study hydraulic engineer modeled sedimentation under conditions of the conceptual channel dredging complete. That modeling predicts shallow sediment scouring would occur beneath the BSNF railroad and SR-87 bridges, and north of (downstream from) the Interstate 40 bridge, while a few feet of sedimentation are predicted beneath the Interstate 40 bridge. These modeling results conform with other sedimentation studies of the river, which indicate stream downcutting occurs in selected areas of the watershed (SFC Engineering Co., 1997, pp. 8-12), concurrent with on-going aggradation in other river segments.

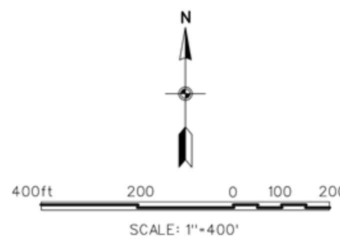
5.4.2 Removal of Channel Obstacles

Cut sandstone bridge piers and abandoned post-type bridge pilings are in the Little Colorado River immediately north of the existing BNSF railroad bridge. It is clear from study of aerial photography that they mark the former alignment of a railroad bridge (Figure 15). Abandoned post-type bridge pilings also exist immediately *beneath* the current BNSF bridge and can be seen at low water (Plate 1). To achieve the improved conveyance concept, sediment would have to be dredged or otherwise removed from around these obstacles or they would have to be demolished before or during excavation of sediment. Nothing is known of the emplacement or depth of the piers and pilings, or whether other buried obstacles will be encountered during sediment removal.

As an example of other obstacles that may be found if river sediment excavation is undertaken is the “Sunset Crossing” area of shallow bedrock in the Little Colorado River channel. Historical reports indicate Santa Fe Trail era wagon trains forded the Little Colorado River near what is now Winslow, AZ, on “a rocky ledge through a river bed” that elsewhere was known to contain numerous areas of quicksand. That site is ‘Sunset Crossing’ and reportedly, years later, the transcontinental railroad followed the same route at Winslow, as, did, eventually, SR-87 and Interstate 40) (Arizona Water Commission, 1980, p. 21). That information alone suggests the presence of very shallow bedrock, at the least, beneath all the area that would be dredged to increase channel conveyance for this feasibility study. Yet, in substantial contradiction to this implication historical record: a BNSF cross section of the existing railroad bridge shows bedrock is 45 to 70 feet deep, all the way across the river, and that bridge piers were sunk to those depths to tie into the bedrock. The shallow bedrock of ‘Sunset Crossing” is somewhere else. If encountered during sediment removal, it would not be a formidable or unduly costly object to remove because the local sandstone is not well cemented (not very hard) in the area.

River channel morphology, specifically the sharp 90° bend to the north at the Winslow Levee-RWDL junction, suggests a bedrock outcropping could be there and that the river turned sharply in response to intersecting it. If so, it is south of all the aforementioned bridges and south of all the conceptual dredging areas. Yet, USACE seismic refraction in this vicinity in 2013 did not indicate shallow bedrock there. All that can be concluded with assurance is that no precise location of Sunset Crossing is known to the feasibility team, but if present, it could limit channel capacity to less than what was modeled, and without exploration in the river, these unknowns will remain.





NOTES:

1. OBSTACLES TO RIVER SEDIMENT REMOVAL IN LITTLE COLORADO RIVER CHANNEL (SEE YELLOW ARROWS), NORTH OF EXISTING BNSF RAILROAD BRIDGE.
2. YOU CAN SEE FORMER RAILROAD ALIGNMENT (RED LINE) CROSSING WINSLOW LEVEE.
3. THE OLD PIER NOTED IN LITTLE COLORADO RIVER (LIGHT COLORED RECTANGLE) IS 20ft IN LONGEST DIMENSION.
4. PHOTO CAME FROM GOOGLE EARTH JUNE OF 2012.

US Army Corps of Engineers Los Angeles District	LITTLE COLORADO RIVER WINSLOW, ARIZONA WINSLOW FEASIBILITY STUDY RIVER SEDIMENT REMOVAL	FIGURE 15

FILE NAME: WINSLOWFIG08.DGN

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5.4.3 Bridge Stability

Increasing channel conveyance by removing river sediment brings the requirement to analyze bridge stability after excavation. No such analysis has been undertaken. Pertinent data known about the BNSF bridge useful to stability analysis include:

- Pier length and diameter, and depth to the base of each pier;
- Pier installation method (sunk by dredging, pneumatic hammering to final depth);
- One specific pier cracked during the pneumatic hammering installation and was repaired with steel band trusses.

In contrast, nothing known about the pier structure or installation for the SR-87 bridge, besides the number of piers and the widths of the spans between them. For excavation quantity determinations, and to acknowledge the need to maintain bridge pier stability during and following such excavation, USACE applied a basic, conservative, 10-foot lateral offset from each pier as the limit for river sediment excavation, with a 1:1 slope extending away from that offset to the base of the excavation. This is a first step in assuring bridge pier stability as river sediment excavation is occurring nearby and suffices to allow an initial sizing of the cut and calculation of the likely sediment removal quantity. Additional, detailed analysis for assuring pier stability will occur at the onset of project design.

5.5 Slope Stability

There have been no documented slope stability failures at Winslow Levee or RWDL. Preliminary slope stability analysis was performed for the Geotechnical Evaluation of Levee Fragility (USACE, 2012), and probabilities of slope stability failure at four cross-sections of the existing (un-improved) levee under loaded-to-the-top conditions ranged from 0 to 0.25, with three of the four cross-section coming in at less than 0.05 probability of failure. While foundation data is currently limited, it is anticipated that slope stability requirements for a new levee can be met using standard fill placement procedures and commonly used slope gradients (2H:1V to 3H:1V).

As discussed in this report, there is potential for liquefiable soils to exist in the project area, but the concern for this risk is minimal primarily due to the low probability of an earthquake occurring simultaneously with a significant river loading event. The Winslow Levee is generally unloaded (dry), and the active river is commonly hundreds or even thousands of feet from the levee. Two locations do currently exist in which the river is impinging upon the levee, and saturated foundation conditions can be expected at shallow depths in these locations. It is assumed, however, that there will be ample time to repair the levee in the event that an earthquake causes damage to the levee under “dry” conditions (i.e. no coincident river loading). Additional geotechnical investigation and analysis is required to evaluate the expected impacts of seismicity.

5.6 Seismic Design

As previously discussed in this report, seismic risk for the area is low. State shaking intensity data suggest low shaking intensity risk for the area, and modeling with US Geological Survey data suggest low ground acceleration would be experienced during an earthquake.

Liquefaction can occur during moderate to intense seismic shaking of saturated, granular soils in the foundation of a structure. Pore pressures rise in response to the seismic acceleration, causing momentary loss of soil strength and structure collapse or toppling can occur in that vulnerable time period. No liquefaction risk analysis has been done for Winslow Levee. No studies by others were encountered during the literature search. What is known and anticipated about the Levee foundation soils suggest that liquefiable layers probably exist in the Levee foundation, yet the seismic acceleration that could be generated by any earthquake impacting this site probably is too low to cause liquefaction.

5.7 Construction Considerations

5.7.1 Construction Easements

USACE modeling for excavation quantity determinations applied a 10-foot lateral offset from toes of the existing Levees (both Winslow Levee and RWDL) as the limit for river sediment excavation, with a 1:1 slope extending away from that offset to the base of the excavation. This was only a cursory first step to recognize the need to maintain Levees stability.

5.7.2 Equipment Mobility

The river bank (Plate 1) historically and recently is known to have very low strength areas, especially when wet ("quick sand"), and could be difficult to navigate through with construction vehicles in the dry due to deep, loose sand.

5.7.3 Site Access

The channel area that would be excavated and that also is not directly accessible by excavation machinery, without a crossing of the LCR, can be seen on Figure 14: it is the white hachured area south of the railroad tracks and north of the River. To work there, the Little Colorado River channel would have to be forded by the excavation equipment, a means of River diversion devised, or some other solution would have to be developed. Soft river bottom, quick sand, and varying water elevation in the River all could impact access and operation of sediment removal equipment.

5.7.4 Excavations

A means of excavation to increase capacity at the BNSF bridge has not been selected. To perform such work in the dry, the area would have to be dewatered and/or river diverted, and this could be difficult, due to the narrow channel in this area, lack of other places to relocate the river, close proximity of diverted channel flows to the work area, and high permeability of the sediments. At the least, a cofferdam and impermeable diversion channel lining would likely have to be built. It is anticipated that excavations associated with Levee construction will be constructible using typical heavy earthwork equipment (i.e. scrapers, dozers, and excavators).

5.7.5 Excavated Material Usage

The material to be excavated during channel capacity increase could encompass a large tonnage and could become a cost issue if treated as a waste to dispose. It will be river-run material. River-run material from the same river, at many locations, including, probably, this location, was used to build Winslow Levee. No testing of the material specifically in the channel capacity excavation area has been done to verify the material suitability for Levee construction. That it would be substantially different would be unexpected. Examination of the location suggests the material is uniform and with low fines content, and, consequently, may be low in strength, and likely somewhat difficult to compact. Blending is typically applied to alleviate such issues in levee construction.

Dune deposits composed mostly of silt and fine-grained sandy silt are commonly deposited adjacent and near the Winslow Levee, and in many locations have buried the levee toe. No sampling or testing of this material was done. This material appears to be valuable for blending, should other fill sources, through testing, be shown to be low in strength, low in fines content, difficult to compact, etc.

Materials exposed in the channel beneath the railroad bridge and one cross section developed from existing BNSF drill logs done on the bridge alignment suggest excavation will encounter river run material suitable for use and levee fill and similar to that found in the existing levee. No as-built testing of this material could be found and no investigation sampling and testing was done. In this vicinity, materials in the Little Colorado River at the surface include very loose surficial sands in the dry, which can become quick in the wet if water conditions are right.

5.7.6 Dewatering and Diversion

As stated earlier in this report, dewatering and/or diversion, to some extent, shall be anticipated in the area of the proposed channel excavation at the railroad bridge. Dewatering and/or diversion will likely be required to perform the excavation using typical earthwork equipment. Phasing of this portion of the project will be required to allow the river to flow through the area without interruption; it is anticipated that one side of the channel could be excavated while the river flow is diverted to the other side and vice versa.

No significant dewatering is anticipated along the alignment for levee construction, although it may be required in select areas such as locations where drainage structures convey surface flows through the levee and into the channel. Groundwater is generally expected to be between 14 and 30 feet deep in most areas, and this is expected to be deep enough to allow for construction of a trench drain without the need for dewatering. If groundwater is found to be significantly shallower than expected in certain areas, and significant dewatering is expected, the use of alternative designs which do not require dewatering should be re-evaluated.

5.8 Hazardous Wastes

No major environmental waste issues are anticipated during reconstruction and/or relocation of any segments of the Winslow Levee or RWDL, based on findings during the Phase I ESA (environmental site assessment) done for this job in 2013. Based on available information, the most likely location to encounter hazardous waste is along the abandoned BNSF Railway Co. alignment west of the Little Colorado River. That location is marked with a red line on Figure 15. It should be presumed, in the absence of testing, that at least some soil removal would have to occur here for hydrocarbons and possibly polychlorinated biphenyls (PCBs). Testing may show a simpler, or a more complex issue.

Buried vehicles in Winslow Levee are not thought to be common, and any fluid leaks likely represent only small soil cleanups that could be addressed during Levee reconstruction.

Out of any abundance of caution, more regulatory files data search has been recommended for several potential RECs (recognized environmental conditions) moderately close (within 1 mile) of the Levees and their potential realignments. Refer to the “HTRW” appendix to the main Planning Division report for this study, or to US Army Engineer District, Los Angeles (2013), for details.

6.0 ADDITIONAL RECOMMENDED STUDIES

Additional subsurface exploration should be conducted during the design phase to the level of detail necessary to perform design, minimize unnecessary assumptions, and to conform with the general requirements of EM 1110-2-1913. Geotechnical data is currently one of, if not the, greatest data gap on the project; therefore, a significant investigation effort should be anticipated moving forward. It is recommended that future investigation include detailed investigation of both the levee foundation and the existing levee (if necessary). It is expected that the scope of the investigation would generally include borings, test trenches/pits, index testing on bulk samples, strength and permeability testing of both in-situ and remolded, as well as field testing for permeability. Cone Penetration Testing (CPT) may also be a useful method for determining foundation properties and defining the foundation stratigraphy.

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Appendix A:
Seismic Refraction Profiling for Subsurface Investigation of Winslow Levee, Winslow, Arizona (Advance Geoscience, Inc., 2013)

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ADVANCED GEOSCIENCE, INC.
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Subsurface Exploration Non-Destructive Evaluation

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November 8, 2013

US Army Corps of Engineers
Geotechnical Branch
PO Box 532711
Los Angeles, California 90053-2325

Attention: Mr. James Farley

Re: **REPORT**
Seismic Refraction Profiling for Subsurface Investigation of Winslow Levee, Winslow, Arizona
US Army Corps of Engineers Contract: W912PL-13-P-0030

INTRODUCTION

This report summarizes the recent seismic refraction profiling completed for the subsurface investigation of the Winslow Levee. In accordance with our proposal dated July 15, 2013, seismic refraction surveys were conducted along ten survey lines positioned by the US Army Corps of Engineers across the levee embankment. These survey lines were positioned to investigate the depth profile of the bedrock surface and lithologic conditions within the alluvium and Moenkopi Formation bedrock unit.

The seismic refraction surveys were performed by Advanced Geoscience on September 16 through September 24, 2013. Refraction tomography data were recorded along the ten survey lines designated as Lines 1 through 10, shown on the topographic maps in Figures 1 through 4. These data were used to prepare subsurface profiles showing seismic compressional-wave velocity variations in the upper 120 feet.

The following sections provide a summary of our field survey procedures and methods of data processing and evaluation. A concluding section discusses the results of this seismic refraction profiling and our interpretation of subsurface conditions beneath Lines 1 through 10.

FIELD SURVEY

Advanced Geoscience arrived at the project site on September 16 and started the seismic surveys on Line 1 the northern-most survey line. The initial data recorded on Line 1 showed that the 90-pound, accelerated weight drop provided sufficient seismic energy to record longer geophone lines consisting of more than 100 geophone channels spaced 10-feet apart. Due to the more difficult terrain conditions, these longer geophone lines helped facilitate the data collection along Lines 1 through 10, which was completed on September 24.

The seismic refraction tomography data were recorded along each survey line using a multi-channel Seistronix EX-6 seismic data acquisition system. This recording system was connected to various "geophone lines" set up along the survey lines. Lines 1, 3, 5, 8, 9, and 10 were recorded using one geophone line consisting of 82 to 102 geophones spaced 10-feet apart. The longer-length, Lines 2, 4, 6, and 7 were recorded using two overlapping geophone lines consisting of 102 to 108 geophones spaced 10-feet apart. The geophones used were 14-Hertz (low-cut frequency), vertically-aligned velocity transducers. The total length of geophone coverage setup along each survey line is listed below.

Line 1	900 feet
Line 2	1,490 feet
Line 3	1,010 feet
Line 4	1,550 feet
Line 5	810 feet
Line 6	1,250 feet
Line 7	1,670 feet
Line 8	1,010 feet
Line 9	810 feet
Line 10	950 feet

The refraction data were recorded into each 82 or 108-channel geophone line from seismic energy "source points" positioned along the survey lines. The source points started at the west end of the geophone lines and continued to the east at 50 to 70-foot intervals between the geophone positions. Overlapping source points were recorded for the longer-length Lines 2, 4, 6, and 7 which were set up with two overlapping geophone lines. The last source point was positioned at the east end of the survey line.

The seismic energy source was generated using a 90-pound, accelerated weight drop mounted on a 4WD Polaris Ranger. This weight drop was used to impact a metal plate placed on the ground surface. To increase the signal-to-noise ratio several impacts were recorded at each energy source point and summed together to generate a single recording. At locations where the Polaris Ranger could not drive into a 20-pound sledge hammer was used to make multiple impacts on the metal plate. A two-man crew was used to deploy this equipment along the survey lines.

Line 4 was also used to record a small amount of data for multi-channel analysis of surface waves (MASW) near the center of this survey line. This data was used to prepare a one-dimensional shear-wave velocity profile to help interpret the alluvium-bedrock contact in this area. Active-source MASW data were recorded between stations 700 to 1,000 feet using a separate 28-channel geophone line set up with lower cut off frequency 4-Hertz geophones spaced 10-feet apart. These data were recorded with the accelerated weight drop in an "end-on" recording configuration. The first source point was positioned 20-feet west the first geophone position and recorded into 28 geophone positions from stations 720 to 990 feet. The second source point was positioned at station 710 feet and recorded in 28 geophone positions from stations 730 to 1,000 feet.

After the data recording was completed a DGPS survey was performed along each survey line to measure the coordinates and elevations of the starting and ending geophone positions. Additional geophone positions were also measured near the sharp breaks in topography along the survey lines.

DATA PROCESSING AND EVALUATION

The field record data quality for Lines 1, 2, 3, 4, 5, 7, 9, and 10 was mostly good to excellent. Lines 6 and 8, however, showed some noise interference in the longer-offset part of the field records which was caused by strong wind gusts on Line 6 and vehicle traffic from Interstate 40 on Line 8.

The field records from each survey line were input into the RAYFRACT seismic refraction tomography software developed by Intelligent Resources, Inc. (www.rayfract.com). RAYFRACT was used to generate seismic compressional-wave velocity depth profiles. This refraction tomography modeling procedure is generally more capable of imaging sharper lateral velocity variations due to bedrock channels than other refraction tomography methods and conventional two to four-layer refraction interpretation methods such as the Generalized Reciprocal Method (Sheehan et al., 2005).

RAYFRACT was first used to graphically pick first arrival times ("first breaks") for refracted waves traveling through the surface layer and into deeper higher-velocity layers. These time-distance data were used together with geophone station coordinates and elevations to conduct refraction tomography imaging of the shallow seismic velocity layering. RAYFRACT generated an initial velocity-depth model based on the Delta TV method. This initial model was then refined to produce a closer fit to the arrival time data using the Wavepath Eikonal Traveltime (WET) tomographic inversion method with 60 to 80 iterations with a maximum velocity 3,500 m/sec. The best-fit velocity-depth models were then gridded and color contoured with SURFER (written by Golden Software, Inc.) to show estimated vertical and lateral velocity variations.

Figures 5 through 12 show the resulting refraction velocity-depth profiles for Lines 1 through 10. These profiles are displayed at three different horizontal scales (1 inch= 60, 80, and 100 feet) with a 2:1 vertical exaggeration to show as much detail as possible. Each profile is also displayed with a similar color velocity spectrum.

The MASW data recorded on Line 4 was processed using the SurfSeis software Developed by the Kansas Geological Survey (www.kgs.ku.edu/software/surfseis/). The 28-channel field records from the two source points were used to generate surface-wave amplitude displays of phase velocity versus frequency. These displays were used to pick dispersion curves for the fundamental-mode, Rayleigh wave. The resulting curves were used to conduct a least-squares inversion to calculate one-dimensional models of shear-wave velocity layering near stations 840 to 850 feet on Line 4. Figure 15 displays these shear-wave velocity depth profiles.

DISCUSION OF RESULTS

The bedrock depth profile beneath Lines 1 through 10 is interpreted to follow the yellow-highlighted 6,000 to 6,500 ft/sec velocity contours shown in Figures 5 through 14. This interpretation is consistent the MASW shear-wave velocity profiles from Line 4 which show a higher-velocity, 1,550 to 1,600 ft/sec shear-wave velocity layer near the depth of this yellow-highlighted surface (Figures 8 and 15). No borehole information on depth to bedrock was available; however, boreholes DWR DH-39 and DWR DH-32 located near Lines 1 and 2 ended their total depth in alluvium and help to support the interpretation of a deeper bedrock surface in this area.

The yellow-highlighted depth profiles (in Figures 5 through 14) show that the bedrock surface generally deepens to the north between Lines 1 and 10. The depth profiles also reveal the locations of possible ancient river channels (“paleo-channels”). The locations of these channels are noted on the profiles.

The most prominent paleo-channel is located beneath Lines 3 and 4 west of the levee. This channel appears to be over 100 feet deep with a north-south orientation that may extend to the north beneath the levee. Beneath Line 3 this channel is filled with lower-velocity, saturated alluvium, with compressional-wave velocity of 5,000 ft/sec or less. This lower velocity alluvium extends beneath the levee and occurs in the area where the 1993 levee breach and 2004 piping failure occurred.

Another prominent paleo-channel is located beneath Line 7, about 150 feet east of the levee. This channel also appears to be over 100-feet deep. However, this channel is filled with higher-velocity, saturated alluvium, with a velocity of 6,500 ft/sec. Based on our experience, compressional-wave velocities of 6,500 ft/sec in saturated alluvium indicate deposits of cobbles or boulders.

The upper-most groundwater surface (free "water table") beneath Lines 1 through 10 occurs mostly in the finer-grained floodplain deposits with variable lateral permeability. For this reason this surface is mostly undetectable as a continuous layer on the refraction profiles. However, a separate analysis of the data on Line 1 made using a three-layer refraction model generated from the modified Generalized Reciprocal Method (GRM) in RAYFRACT shows a stronger refracting layer near the 3,000 ft/sec velocity contour in Figure 5. This indicates this mostly flat 3,000 ft/sec velocity horizon is probably near the upper part of the permeable groundwater layer beneath Lines 1 through 10.

Advanced Geoscience appreciates this opportunity to be of service to US Army Corps of Engineers. If you have any questions or additional requests concerning this seismic refraction profiling investigation please contact the undersigned.

Sincerely,

Advanced Geoscience, Inc.

Mark G. Olson
Principal Geophysicist
California Registered Professional Geophysicist No. GP970
California Registered Professional Geologist No. 6239

Attachments:

Figures 1-4	Maps Showing the Locations of Survey Lines 1 through 10
Figures 5-14	Seismic Refraction Profiles for Lines 1 through 10
Figure 15	Line 4 MASW Shear-Wave Velocity Profiling

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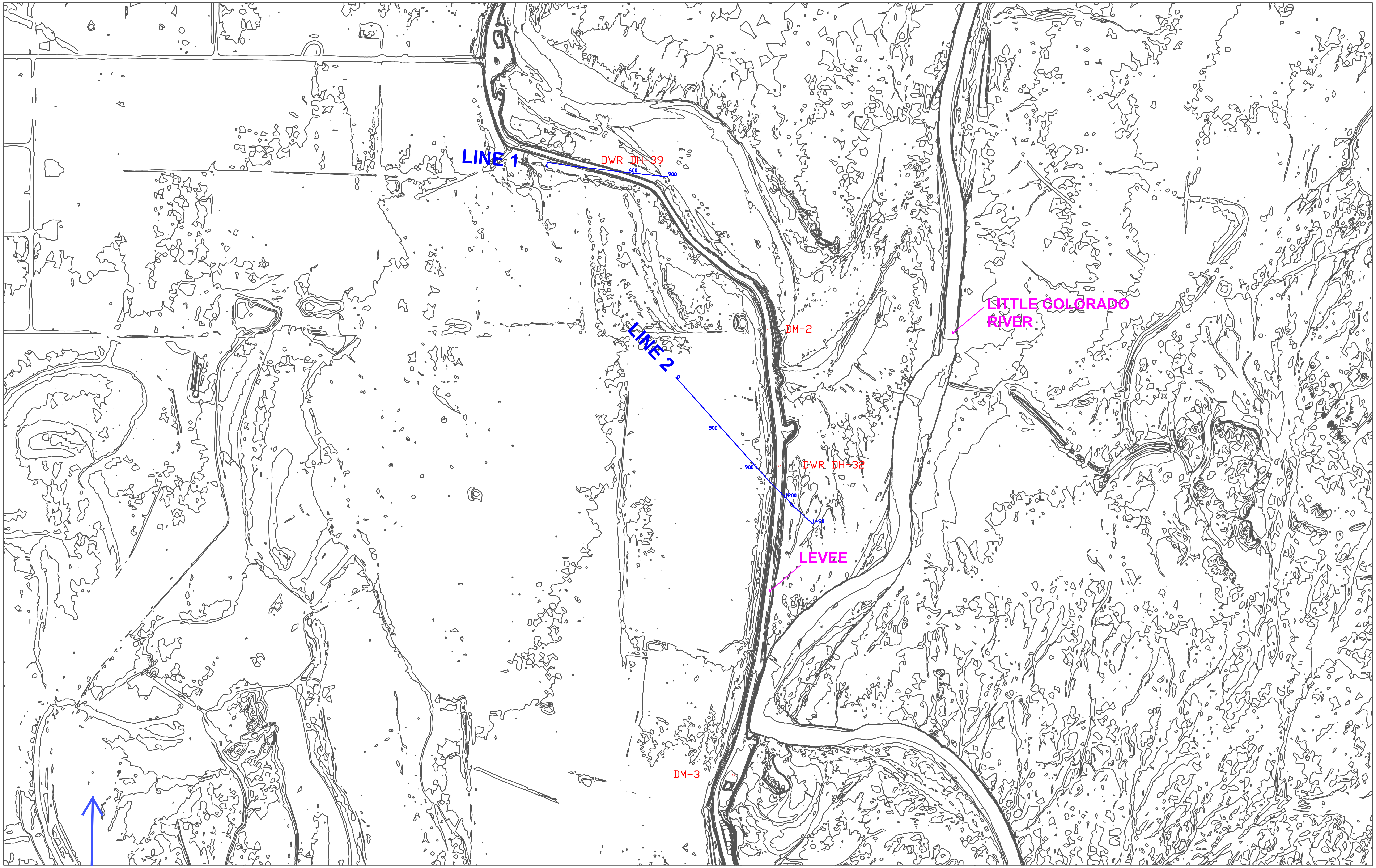
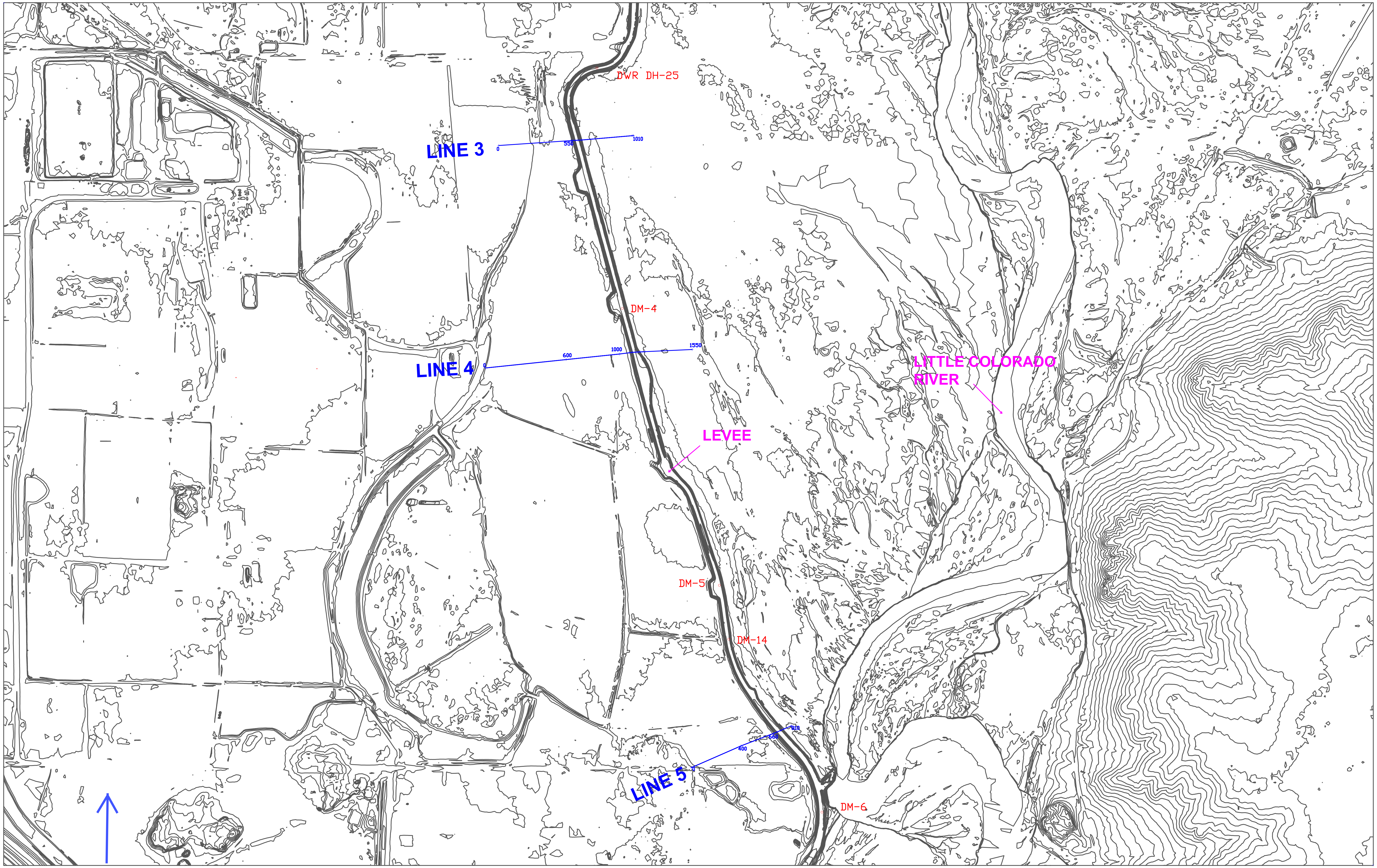


North

Scale 1 inch= 600 ft

Map Showing Location of Survey Lines 1 and 2
Winslow Levee Seismic Refraction Surveys
Winslow, Arizona

Figure 1
Advanced Geoscience, Inc.



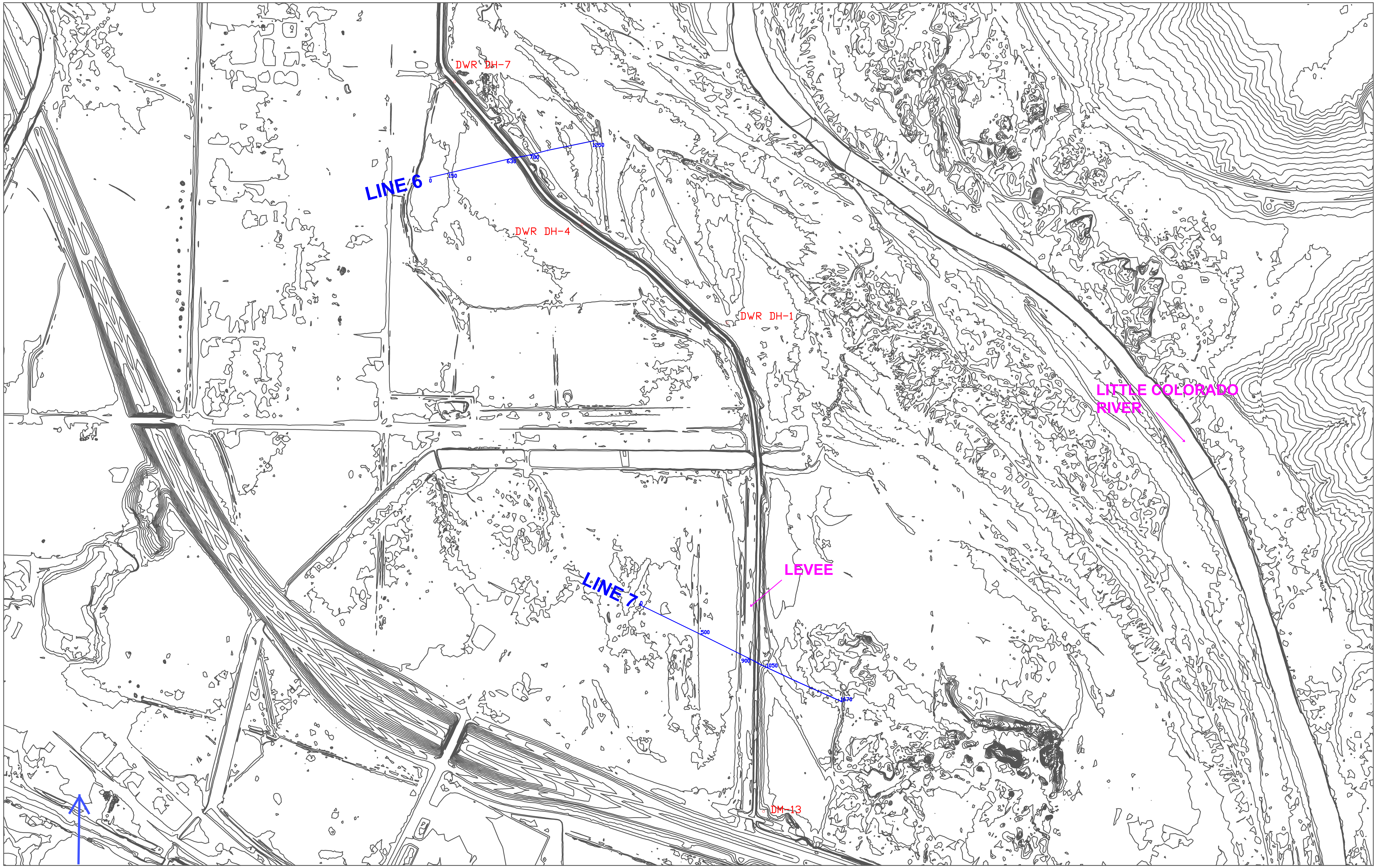
North

Scale 1 inch= 600 ft

Map Showing Location of Survey Lines 3, 4 and 5
Winslow Levee Seismic Refraction Surveys
Winslow, Arizona

Figure 2

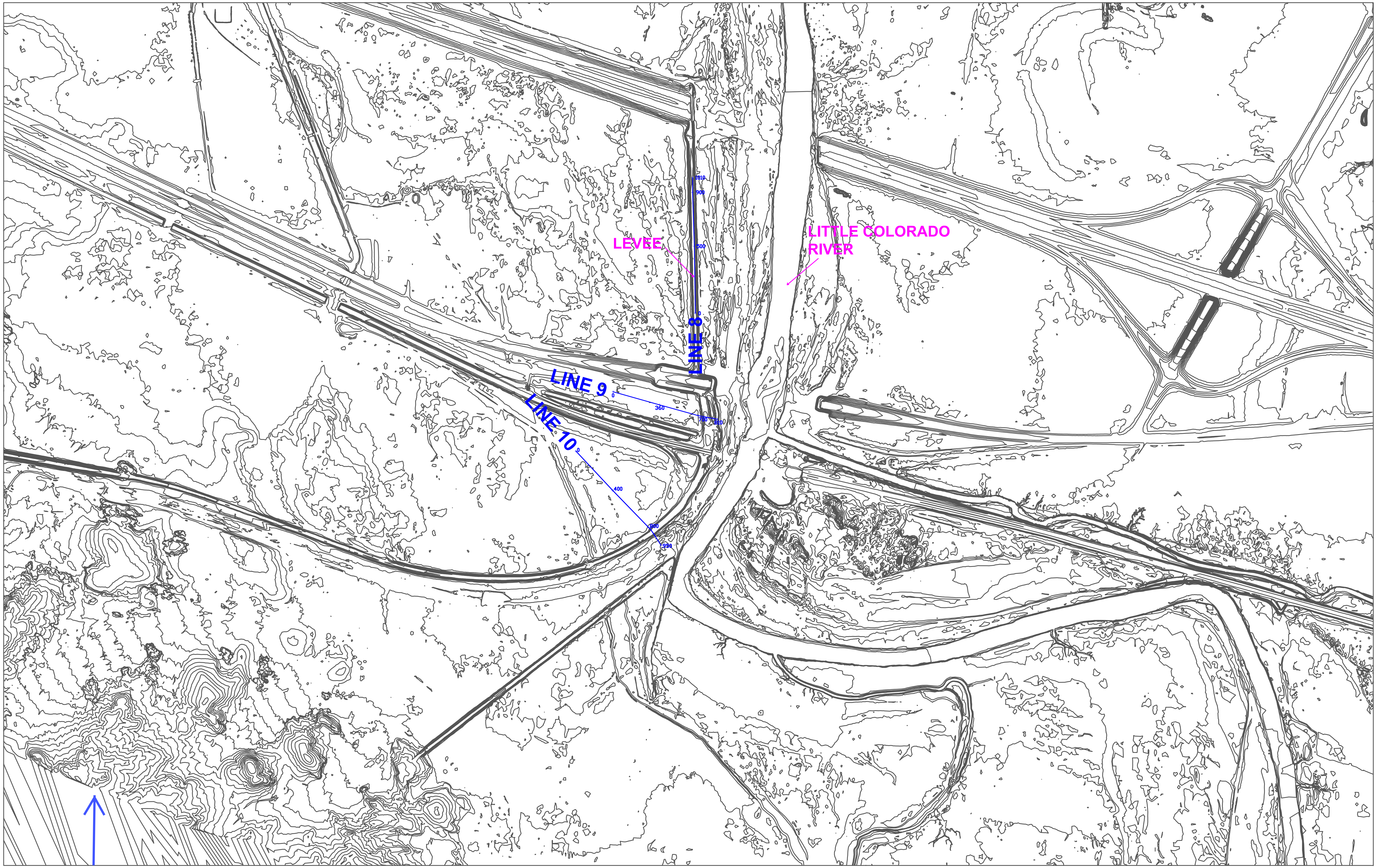
Advanced Geoscience, Inc.



North
Scale 1 inch= 600 ft

Map Showing Location of Survey Lines 6 and 7
Winslow Levee Seismic Refraction Surveys
Winslow, Arizona

Figure 3
Advanced Geoscience, Inc.



North

Scale 1 inch= 600 ft

Map Showing Location of Survey Lines 8, 9 and 10
Winslow Levee Seismic Refraction Surveys
Winslow, Arizona

Figure 4

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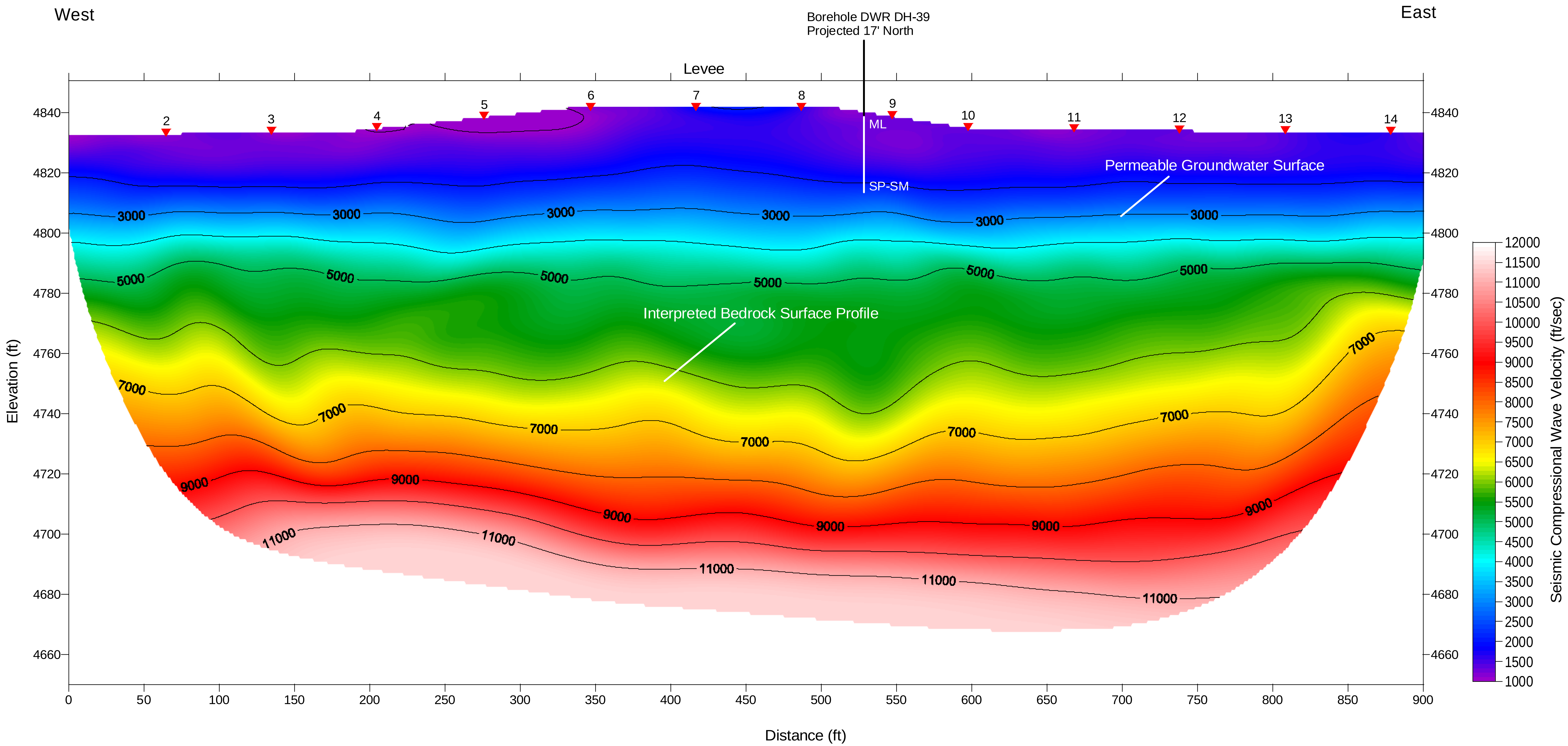
Line 1- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

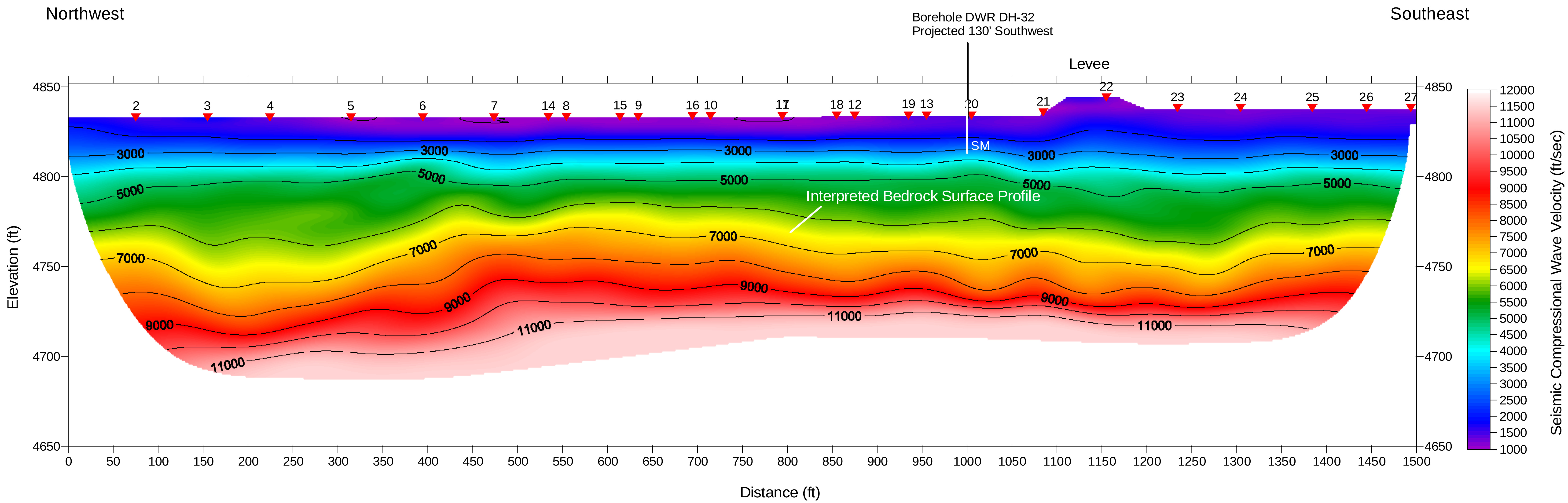
0 50 100

Horizontal Scale 1 inch= 60 Feet
Vertical Scale x2 1 inch= 30 Feet

Line 1 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 5
Advanced Geoscience, Inc.

Line 2- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

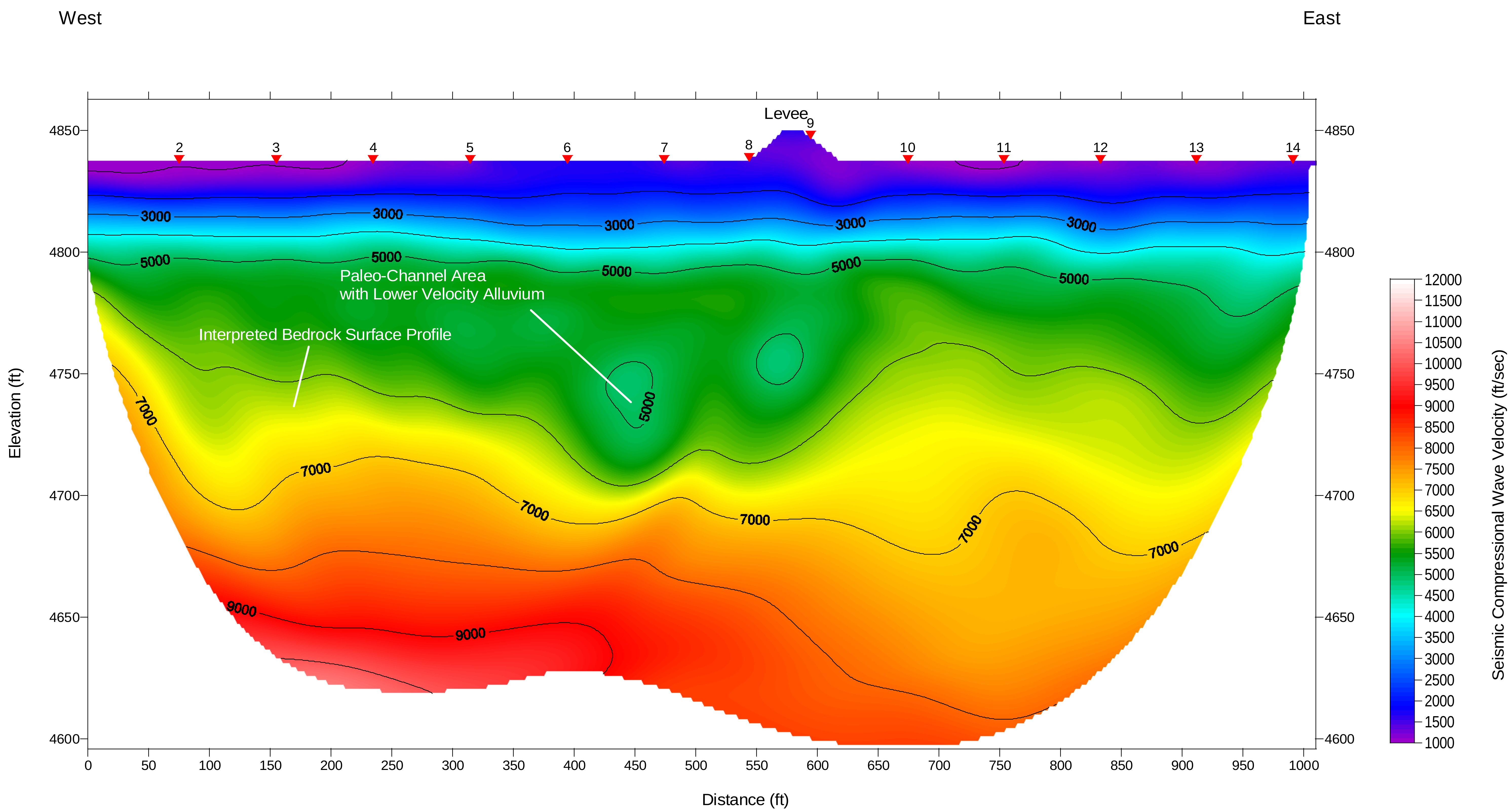
0 100 200

Horizontal Scale 1 inch= 100 Feet
Vertical Scale x2 1 inch= 50 Feet

Line 2 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 6
Advanced Geoscience, Inc.

Line 3- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

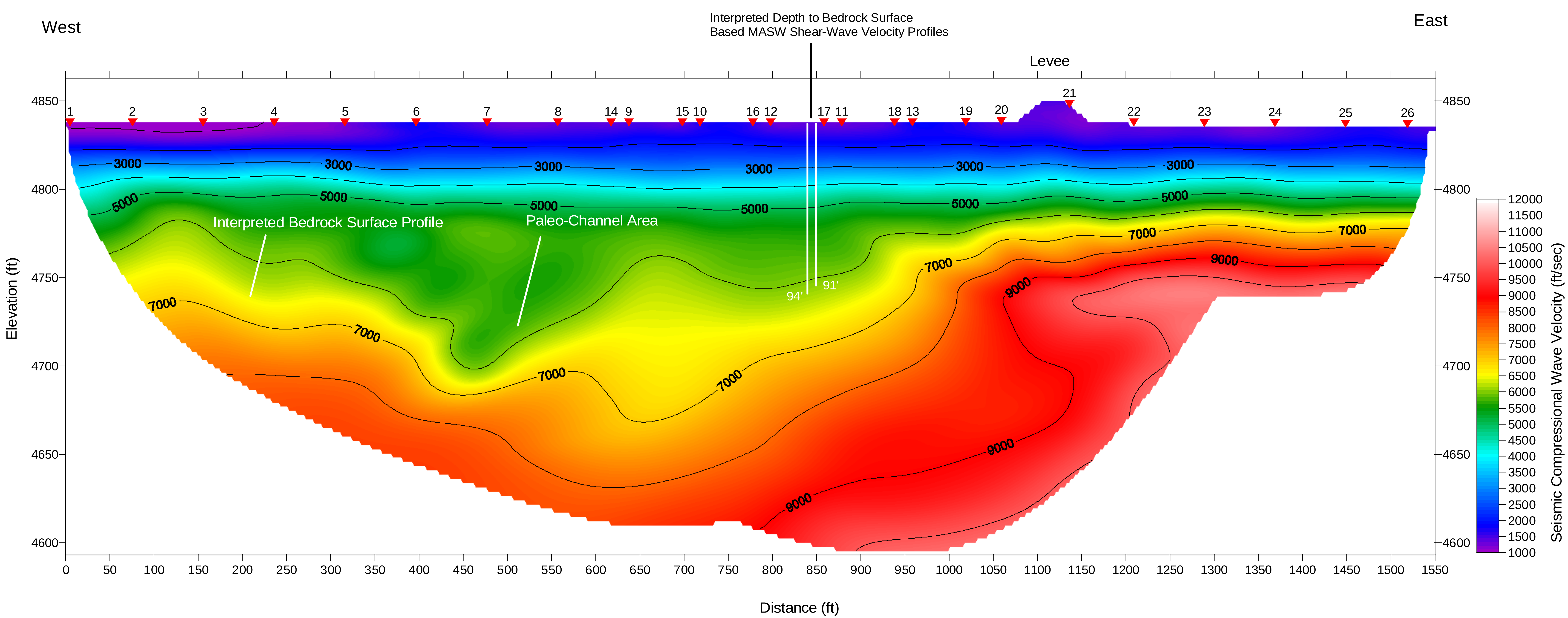
0 100 200

Horizontal Scale 1 inch= 80 Feet
Vertical Scale x2 1 inch= 40 Feet

Line 3 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 7
Advanced Geoscience, Inc.

Line 4- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

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Horizontal Scale 1 inch= 100 Feet
Vertical Scale x2 1 inch= 50 Feet

Line 4 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 8
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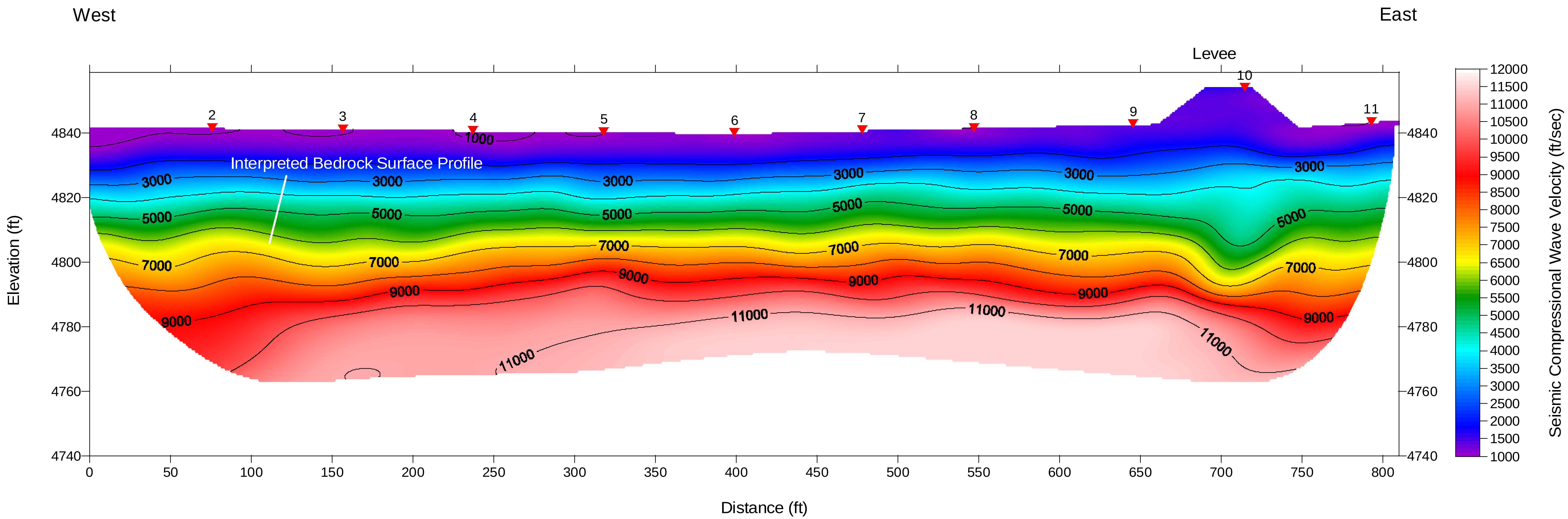
Line 5- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

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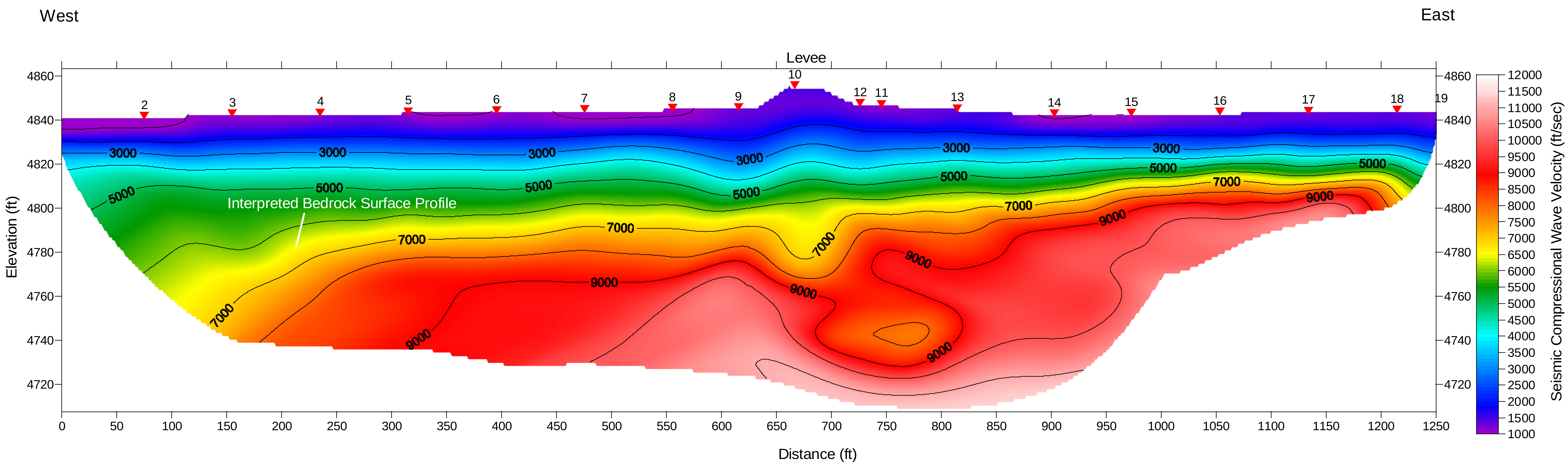
Horizontal Scale 1 inch= 60 Feet
Vertical Scale x2 1 inch= 30 Feet

Line 5 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 9
Advanced Geoscience, Inc.

Line 6- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

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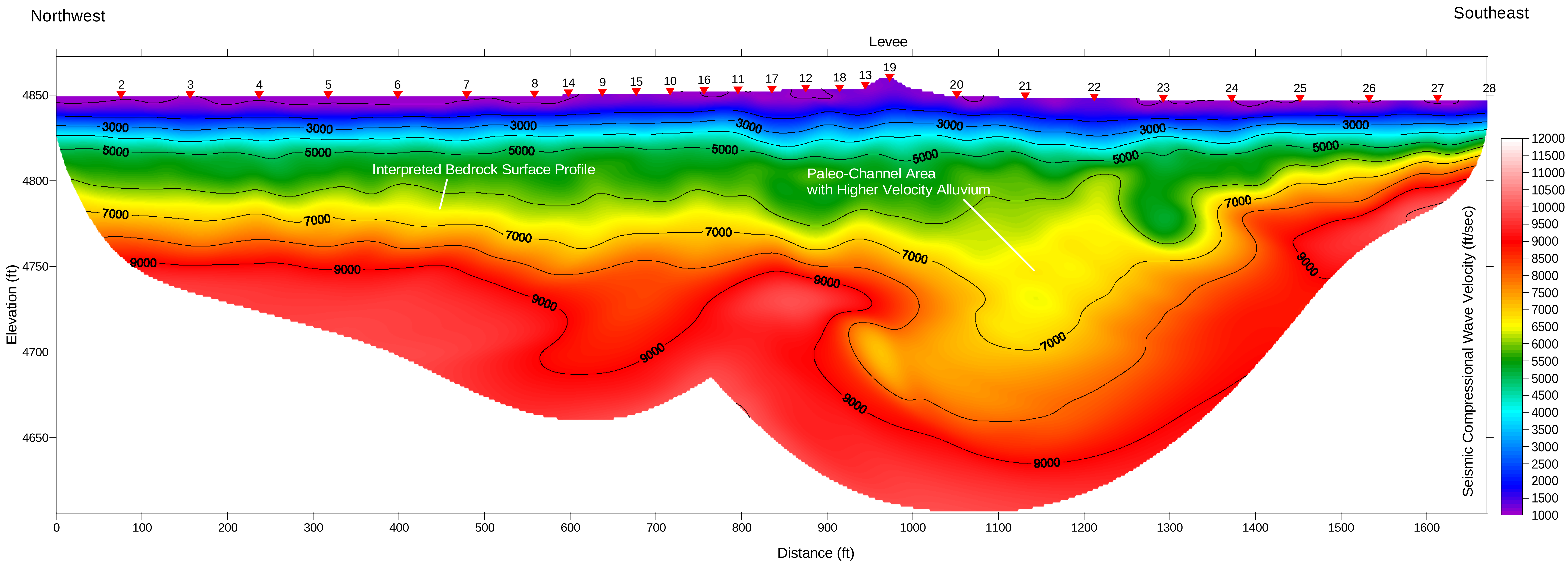
Horizontal Scale 1 inch= 80 Feet
Vertical Scale x2 1 inch= 40 Feet

Line 6 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 10
Advanced Geoscience, Inc.

Line 7- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

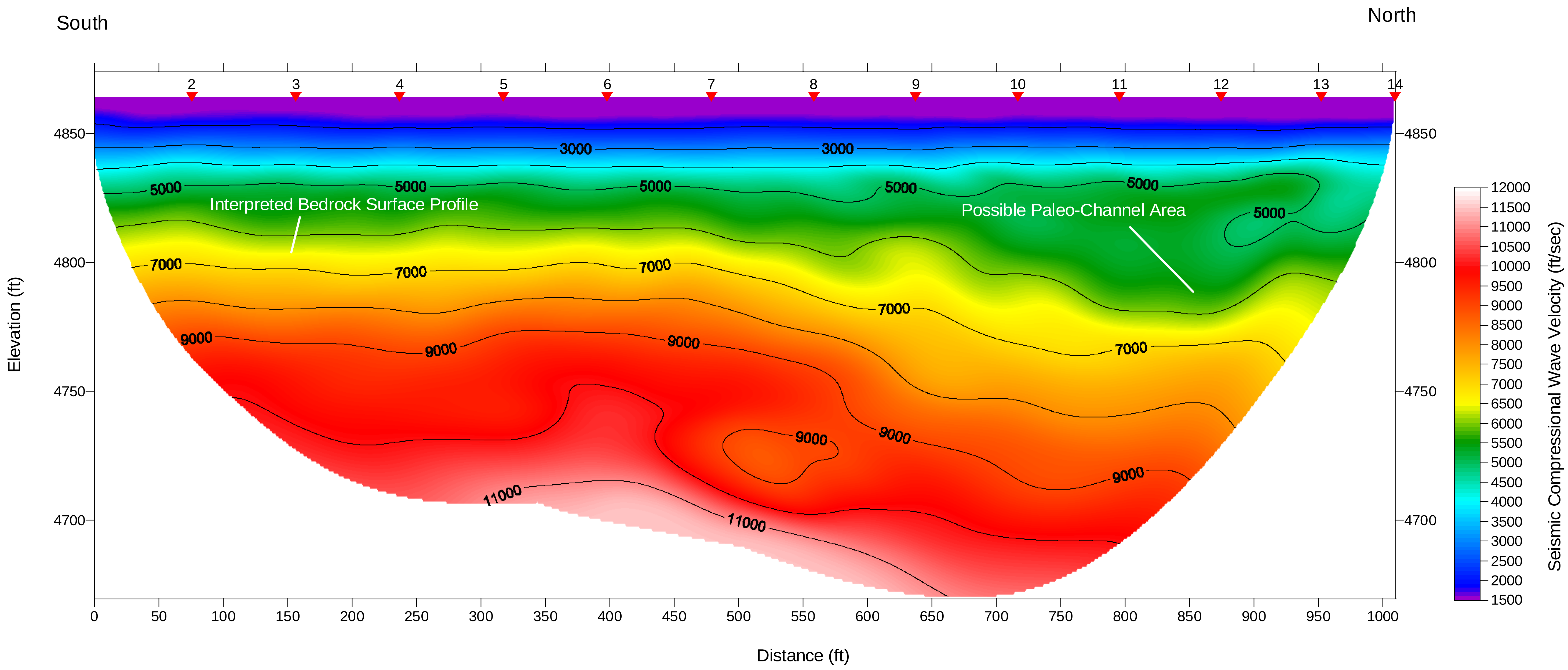
0 100 200

Horizontal Scale 1 inch= 100 Feet
Vertical Scale x2 1 inch= 50 Feet

Line 7 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 11
Advanced Geoscience, Inc.

Line 8- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

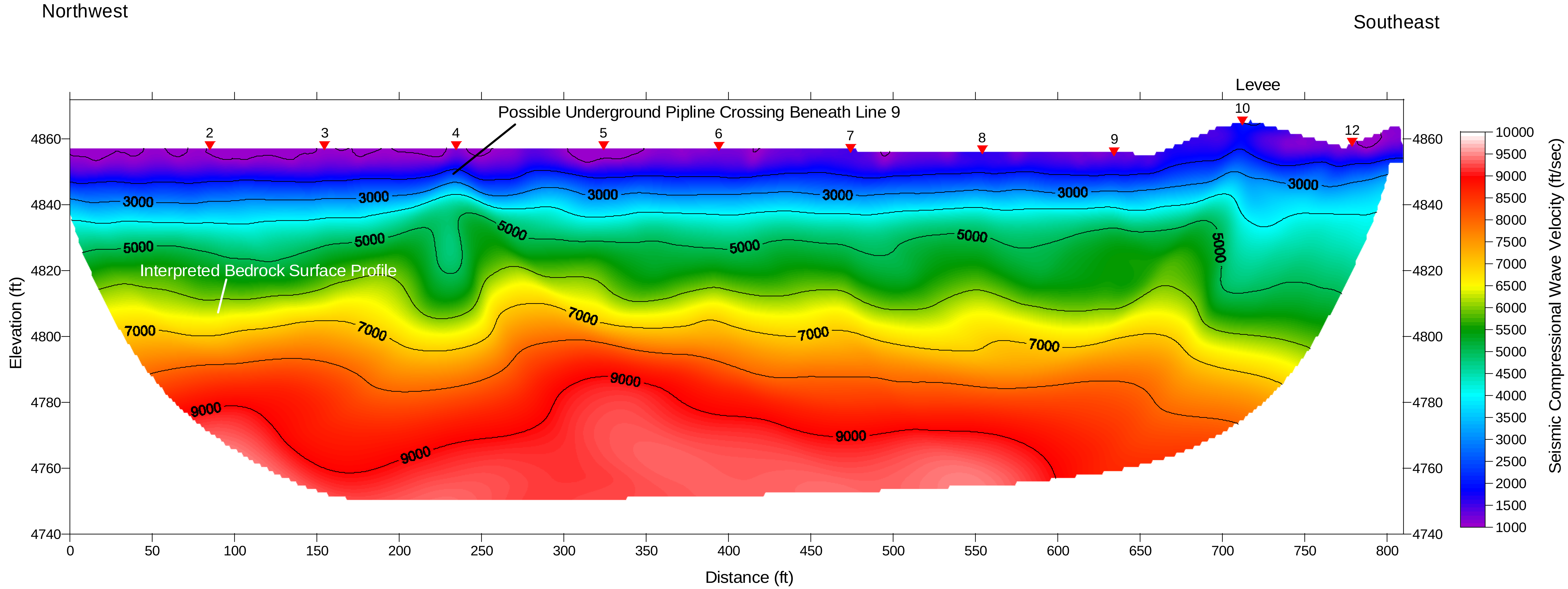
0 100 200

Horizontal Scale 1 inch= 100 Feet
Vertical Scale x2 1 inch= 50 Feet

Line 8 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 12
Advanced Geoscience, Inc.

Line 9- Seismic Refraction Velocity Depth Profile



RAYFRACT Initial Delta TV Velocity + WET Iterations w/Vmax=3500 m/sec

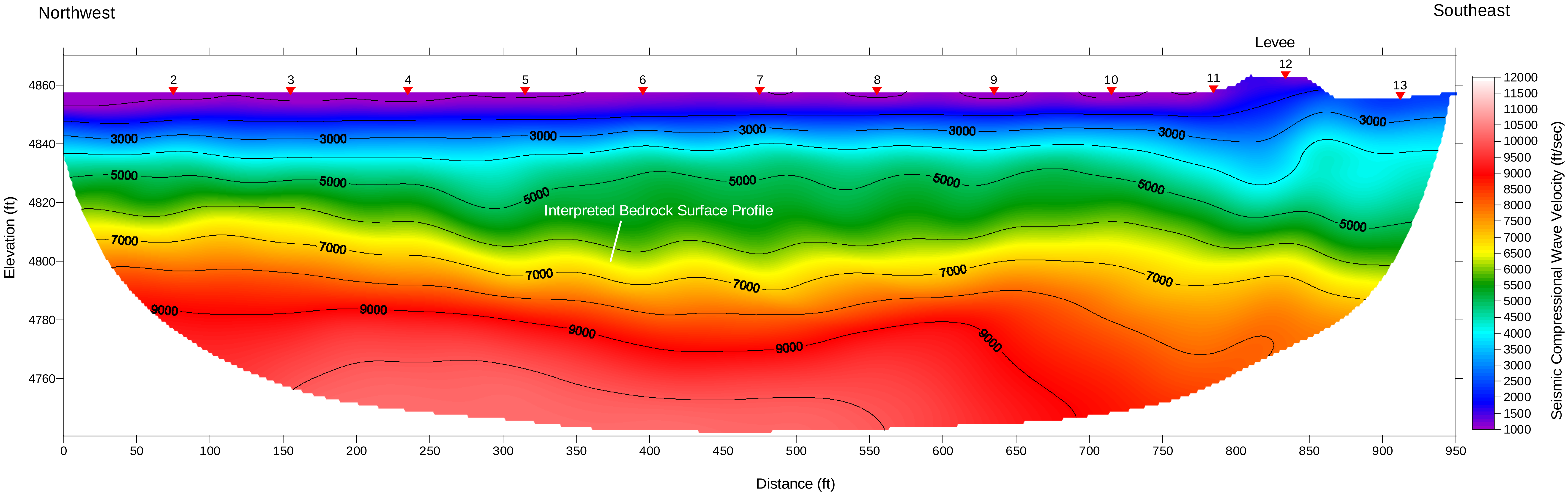
0 50 100

Horizontal Scale 1 inch= 60 Feet
Vertical Scale x2 1 inch= 30 Feet

Line 9- Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 13
Advanced Geoscience, Inc.

Line 10- Seismic Refraction Velocity Depth Profile



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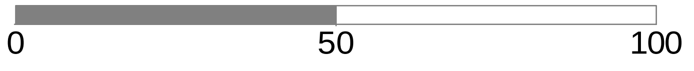


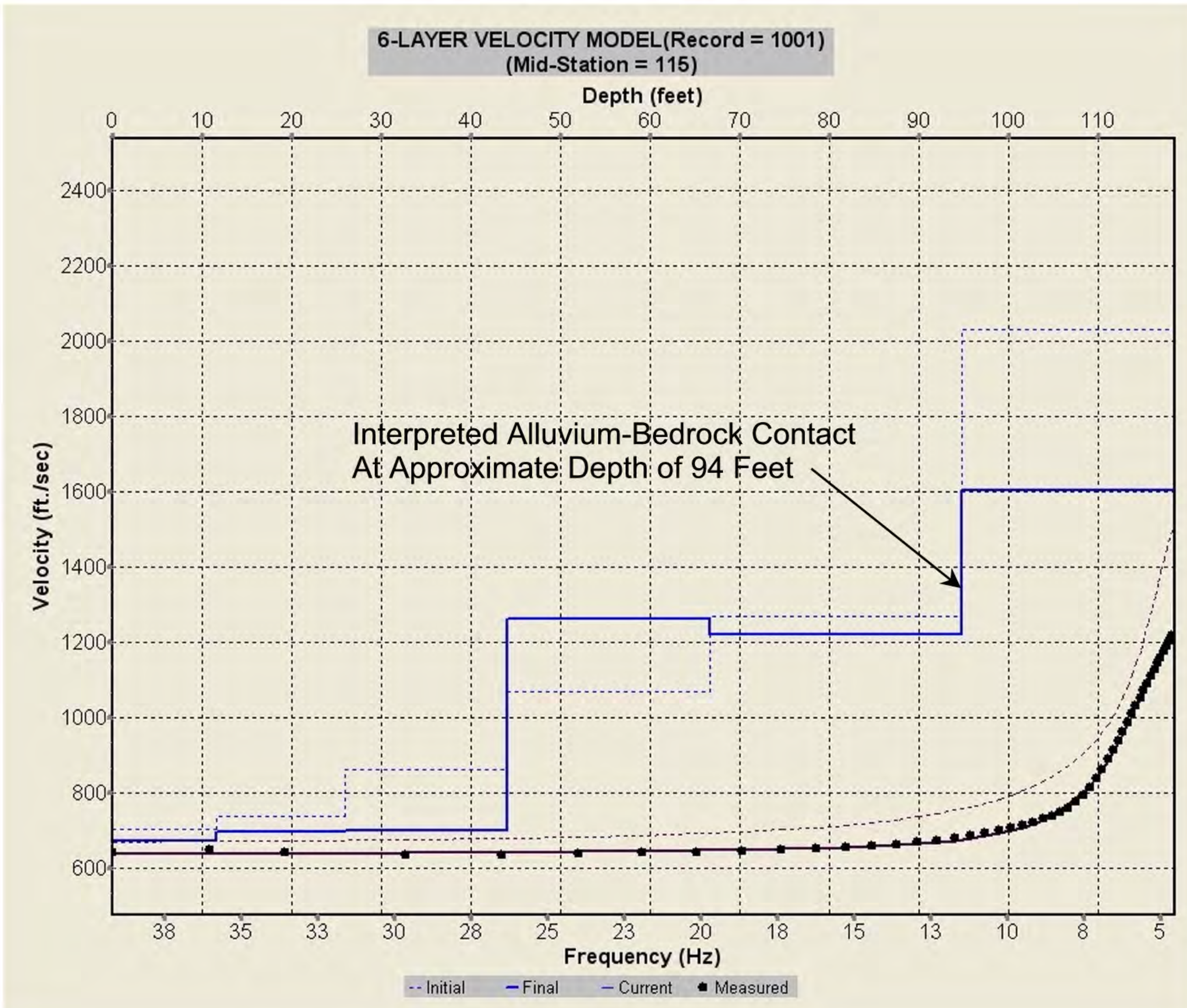
Horizontal Scale 1 inch= 60 Feet
Vertical Scale x2 1 inch= 30 Feet

Line 10 Seismic Refraction Profile for
Subsurface Investigation of Winslow Levee
Winslow, Arizona

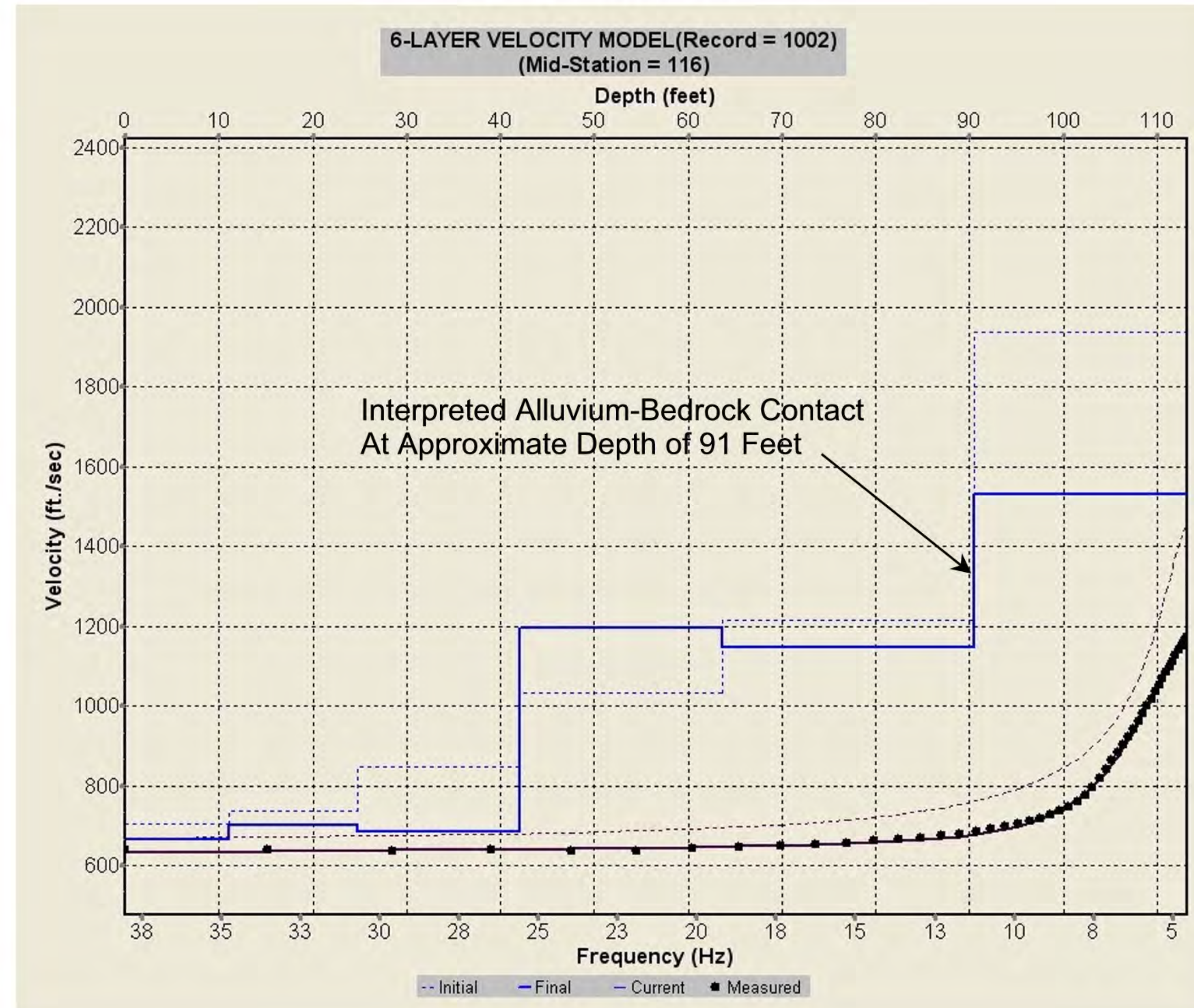
Figure 14
Advanced Geoscience, Inc.

Estimated Shear-Wave Velocity Depth Profiles

Line 4 Station 840 Feet



Line 4 Station 850 Feet



Line 4 MASW Shear-Wave Velocity Profiling
Subsurface Investigation of Winslow Levee
Winslow, Arizona

Figure 15
Advanced Geoscience, Inc.

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