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Seismic Velocities and Thicknesses of Alluvial Deposits along Baker Creek in the Great Basin National Park, East-Central Nevada

Open-File Report 2009-1174

U.S. Department of the Interior
U.S. Geological Survey

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U.S. Geological Survey
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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
foot per second (ft/s)	0.3048	meter per second (m/s)
mile (mi)	1.609	kilometer (km)
square mile (mi^2)	2.590	square kilometer (km^2)

Datums

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).
Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).
Altitude, as used in this report, refers to distance above the vertical datum.
Elevation, as used in this report, refers to relative vertical distances between points along profiles.

Seismic Velocities and Thicknesses of Alluvial Deposits along Baker Creek in the Great Basin National Park, East-Central Nevada

By Kip K. Allander and David L. Berger

Abstract

To better understand how proposed large-scale water withdrawals in Snake Valley may affect the water resources and hydrologic processes in the Great Basin National Park, the National Park Service needs to have a better understanding of the relations between streamflow and groundwater flow through alluvium and karst topography of the Pole Canyon Limestone. Information that is critical to understanding these relations is the thickness of alluvial deposits that overlay the Pole Canyon Limestone.

In mid-April 2009, the U.S. Geological Survey and National Park Service used seismic refraction along three profiles adjacent to Baker Creek to further refine understanding of the local geology. Two refractors and three distinct velocity layers were detected along two of the profiles and a single refractor and two distinct velocity layers were detected along a third profile.

In the unsaturated alluvium, average velocity was 2,000 feet per second, thickness ranged from about 7 to 20 feet along two profiles downstream of the Narrows, and thickness was at least 100 feet along a single profile upstream of the Narrows. Saturated alluvium was only present downstream of the Narrows—average velocity was 4,400 feet per second, and thickness ranged from about 40 to 110 feet. The third layer probably represented Pole Canyon Limestone or Tertiary granitic rock units with an average velocity of 12,500 feet per second. Along the upstream and middle profiles (profiles 3 and 1, respectively), the depth to top of the third layer ranged from at least 60 to 110 feet below land surface and is most likely the Pole Canyon Limestone. The third layer at the farthest downstream profile (profile 2) may be a Tertiary granitic rock unit.

Baker Creek is disconnected from the groundwater system along the upstream profile (profile 3) and streamflow losses infiltrate vertically downward to the Pole Canyon Limestone. Along the downstream and middle profiles (profiles 2 and 1, respectively), the presence of a shallow water table indicates that low permeability Tertiary granitic rock may extend across the Baker Creek Drainage intersecting the Pole Canyon Limestone. The Tertiary granitic rock may be acting as a barrier to groundwater flow within the Pole Canyon Limestone.

Introduction

Great Basin National Park encompasses about 120 mi^2 of the highest parts of the southern Snake Range in east-central Nevada (fig. 1). The park is near the Nevada-Utah border in White Pine County, and is bounded by Spring Valley on the west and Snake Valley on the east. The Baker Creek Cave System in the Baker Creek drainage basin on the eastern edge of the park is the longest known cave system in Nevada (Pease and others, 1969).

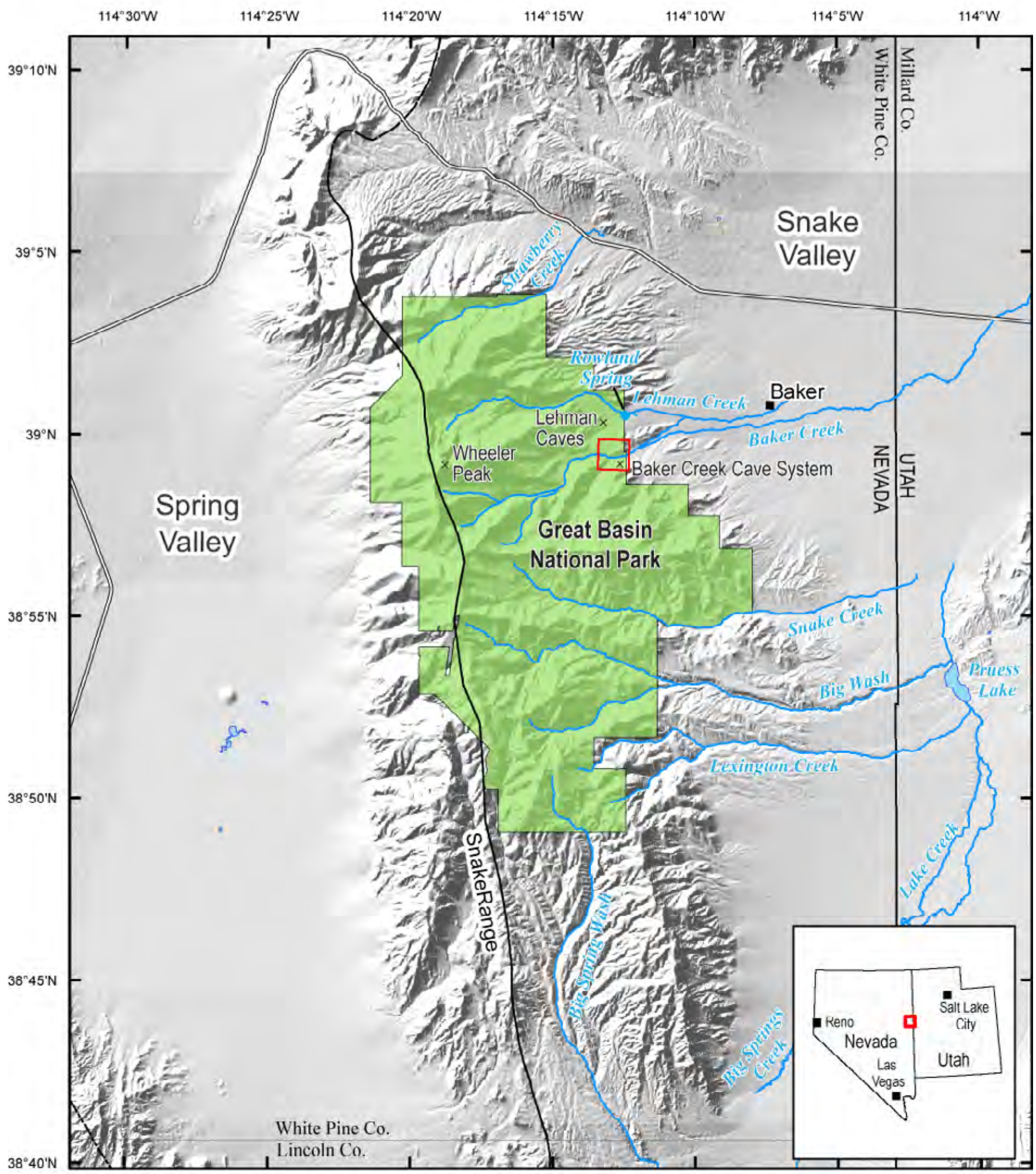
The National Park Service (NPS) has a mandate to preserve and protect the natural hydrologic processes that continue to form caves and support water-dependent flora and fauna in the park. The continued formation of caves is dependent on perennial streamflow in Baker Creek and groundwater. Due to increased demand for water supplies in the Las Vegas area, the Southern Nevada Water Authority has applied for rights to withdraw large quantities of groundwater from Snake Valley adjacent to the park. A recently completed U.S. Geological Survey (USGS) study indicates that streamflow, springs, and water in caves in the area of Baker Creek Cave System likely or potentially is susceptible to groundwater withdrawals from Snake Valley (Elliott and others, 2006). However, the degree of susceptibility of the water resources around the Baker Creek Cave System is largely dependent on the local geology and the interaction of Baker Creek with the groundwater system.

The geology of the lower Baker Creek drainage system within the park boundary generally consists of three geologic units (fig. 2; Whitebread, 1969; McGrew and others, 1995; Miller and others, 1995; Elliott and others, 2006). Underlying and adjacent to the main channel of Baker Creek are alluvial deposits of Quaternary age (Qa), which readily transmit water. One of the principle carbonate rocks that make up the Baker Creek Cave System is the Pole Canyon Limestone (Єpc) of Cambrian age. The Єpc outcrops adjacent to Baker Creek along much of the lower part of the drainage within the park and can transmit large quantities of water where fractures and dissolution have increased permeability. An intrusion of Tertiary granite (Tgr) intersects the Єpc in a few outcrops adjacent to Baker Creek just upstream of the park boundary. The Tgr generally acts as a confining unit but may transmit some water when highly fractured or weathered (Elliott and others, 2006, p. 5).

Results from multiple seepage investigations in 1992 and 2003 indicate that nearly one-half of the flow of Baker Creek infiltrates the underlying alluvium and caves along reaches adjacent to the Єpc (Elliott and others, 2006). Some of the water lost to the subsurface returns to the surface in Baker Creek drainage as springs and seeps, and supports a riparian zone downstream along Baker Creek. Some of the flow of Baker Creek is thought to be naturally diverted from the Baker Creek drainage through karst conduits in the Pole Canyon Limestone into the Lehman Creek drainage and discharges at Rowland Spring (Elliott and others, 2006, p. 32).

In order to better evaluate the relation between streamflow in Baker Creek and groundwater flow in the alluvium and through caves and fractures in the Pole Canyon Limestone, more information is needed about the thickness of the alluvial and possible Tertiary units overlying the limestone. Accurately delineating the thickness of these deposits will aid in the assessment of the hydraulic connection between aquifers and surface-water resources along Baker Creek, and thus assist in studies to determine the extent to which adjacent large-scale groundwater withdrawals would adversely affect water-resource features and cave forming processes in the park. In April 2009, the USGS, in cooperation with the NPS, collected seismic-refraction data along three profiles in the Baker Creek drainage to estimate thicknesses of geologic units overlying the carbonate rock.

The purpose of this report is to briefly describe the seismic-refraction method and results of its application to estimating the thickness of alluvial deposits overlying the carbonate rock along the Baker Creek drainage. Seismic-refraction data were collected along three profiles on April 14–16, 2009.



Shaded relief base derived from 30 meter USGS National Elevation Dataset, 1999. Hydrology sourced from 1:24,000-scale National Hydrography Dataset, 1974-2009. Place names sourced from USGS Geographic Names Information System, 1974-2009. great Basin National Park boundary sourced from Bureau of Land Management Surface Management Agency dataset, 2003. Universal Transverse Mercator Projection, Zone 11, NAD83.

Figure 1. Location of Baker Creek and Great Basin National Park, east-central Nevada. Red box indicates extent of figure 2.

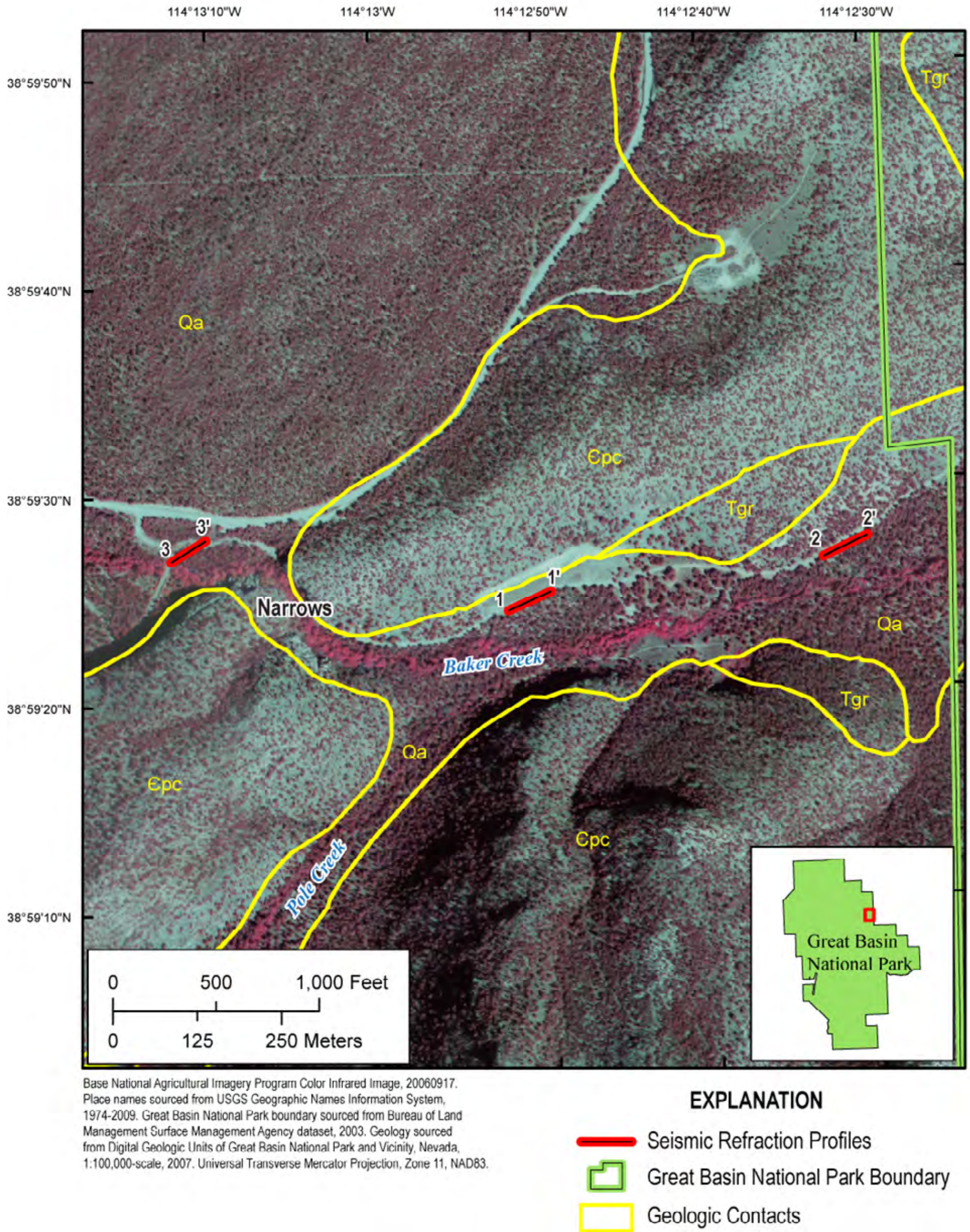


Figure 2. Location of seismic refraction profiles and general geology along Baker Creek in the Great Basin National Park, east-central Nevada.

Seismic-Refraction Method

The seismic-refraction method is based on measured traveltimes of artificially generated waves of elastic energy as they propagate through the subsurface. Seismic velocity is the speed at which energy propagates through the subsurface. Seismic velocity depends on a large number of factors, including mineralogical composition, grain size, cementation, pressure, and slope and direction with respect to bedding. Because seismic velocity depends on these factors, when seismic energy travels from one deposit type to another, there is often a rapid change in seismic velocity. This difference of seismic velocity between types of deposits is known as velocity contrast and is the essential property used by the seismic-refraction method to explore depths of subsurface deposits. Because seismic velocity is influenced by the slope and bedding properties of the deposit creating the velocity contrast, the observed seismic velocity is only an apparent velocity. A true seismic velocity is determined by averaging the apparent seismic velocity across the contrast in a given direction with the apparent seismic velocity across the contrast in the opposite direction. When seismic waves encounter a velocity contrast in the subsurface, such as the water table or carbonate rock, they refract according to Snell's Law (Telford and others, 1976, p. 245). The refracting interface represents an increase in seismic velocity and the depth of this interface can be determined using wave-path geometry and recorded traveltimes. The objective of a seismic-refraction survey is to profile the velocity contrasts within the subsurface on the basis of depth and dip of each refractor encountered. For the seismic-refraction method to be successful, each successively deeper refractor must have a higher seismic velocity along with a considerable velocity contrast.

Depth to most geologic units can be inferred from seismic velocities, although many ambiguities exist. Seismic velocity in basin-fill deposits of Nevada and Utah tends to increase with depth primarily due to compaction and partial cementation of the deposits. Seismic velocities in unsaturated basin-fill deposits typically range from 1,200 to about 3,000 ft/s (Berger and others, 2001, p. 8). When a seismic wave encounters the water table, the velocity can increase as much as 150 percent and creates a considerable contrast between unsaturated and saturated basin fill (Berger and others, 2001, p. 8). Seismic velocities in saturated basin fill can range from as low as 4,000 ft/s to as high as 8,000 ft/s, depending on the depth and induration of the basin-fill deposits (Haeni, 1988, p. 41; Berger, 2001, p. 8). Seismic velocities in consolidated rocks, such as granite or carbonate rock, range from 7,000 to more than 20,000 ft/s (Haeni, 1988, p. 41; Berger, 2001, p. 8) depending on the degree of karstification and extent of weathering and fracturing of the rock encountered.

Seismic-refraction data were collected along three profiles in the Baker Creek drainage (fig. 2) on April 14–16, 2009. Each profile consisted of 24 vertical-component geophones, spaced 10 ft apart along a 230 ft array. Energy sources (shot points) generally were located between 10 and 250 ft from the last geophone on each side of the arrays in addition to a single shot point near the center of the arrays. The energy source primarily was generated by striking a 10-pound sledge hammer on a metal plate on the ground surface. However, some shot points on profile 1 required the use of explosives buried between 1 and 2 ft below land surface in order to generate sufficient energy. Between 5 and 7 shot points were used for each seismic profile. The precise surface elevation of each geophone and shot point in an array was determined using a total station survey instrument. The accuracy of the surface elevations of each point within an array relative to each other is ±0.1 ft. Altitude of a single point in each array was determined using USGS 7.5-minute topographic maps and then was used to convert surface elevations from the rest of the array points to altitudes. The accuracy of the altitude of the array is one-half the contour interval for this area, and is ±20 ft. Each profile was collected on top of alluvial deposits at a minimum distance from the nearest rock outcrop of about 150 ft.

The seismic-refraction data were initially interpreted in the field from traveltime curves using the intercept-time formula (Dobrin, 1976). Subsequent interpretation was guided by a computer-modeling procedure based on a delay-time technique developed by Barthelmes (1946), modified by Pakiser and Black (1957) and further developed by Scott and others (1972), Scott (1973, 1977a, 1977b, and 1993), and Rimrock Geophysics Inc. (1995). The inversion algorithm used by the program creates an initial two-dimensional depth model using the delay-time method. Refinement of the depth model is accomplished by a series of ray-tracing iterations until a minimum difference between the measured traveltime and the corresponding times traced through the depth model was achieved.

Seismic Velocities and Thickness of Alluvial Deposits

Two refractors were detected for the seismic sections in the Baker Creek drainage indicating presence of three distinct velocity layers: a low velocity layer (layer 1), a moderate velocity layer (layer 2), and a high velocity layer (layer 3). Layer 2 was only present at profiles 1 and 2 and was not detected at profile 3.

Apparent seismic velocities for layer 1 of all profiles ranged from 1,200 to 3,400 ft/s (table 1) The overall average velocity of layer 1 is about 2,000 ft/s, which is consistent with seismic velocities in unsaturated alluvium (Haeni, 1988). Apparent seismic velocities for layer 2 of all profiles ranged from 2,900 to 6,400 ft/s. The overall average velocity of layer 2 is about 4,400 ft/s, which is consistent with seismic velocities in saturated alluvium (Haini, 1988). Apparent seismic velocities for layer 3 of all profiles ranged from 7,900 to 20,700 ft/s. The overall average velocity of layer 3 is about 12,500 ft/s, which is consistent with seismic velocities in consolidated rock (Haeni, 1988). Estimated depths to consolidated rock units represent minimum estimates of depth directly beneath the seismic profiles and thicknesses of alluvial deposits represent minimum estimated thicknesses. This is due to the proximity of nearby rock outcrops to the seismic profiles and an assumption that consolidated rock units are relatively flat surfaces that slope from nearby outcrops to beneath the seismic profiles.

Seismic profile 1 was collected along a dirt road adjacent to Baker Creek, approximately 0.2 mi downstream of the Narrows adjacent to an old gravel quarry (fig. 2), and is about midway between profiles 2 and 3. Two refractors were detected and three layers were interpreted for this profile (fig. 3A). Layer 1 is unsaturated alluvium with apparent seismic velocities ranging from 1,200 to 2,000 ft/s and an average velocity of 1,800 ft/s (table 1). Thickness of layer 1 ranged from 14 to 21 ft with an average of 18 ft. Layer 2 is saturated alluvium with apparent seismic velocities ranging from 2,900 to 6,400 ft/s and an average velocity of 4,300 ft/s. The top of the saturated alluvium is relatively smooth, generally parallels land surface, and is at an altitude similar to Baker Creek indicating that Baker Creek is connected with the groundwater system along this profile. The depth to the top of the saturated alluvium ranges from 14 to 21 ft with an average of 18 ft. The minimum thickness of saturated alluvium along this profile ranged from 42 to 69 ft with an average minimum thickness of about 59 ft. Layer 3 is consolidated rock with apparent velocities ranging from 9,600 to 13,600 ft/s with an average of 11,000 ft/s. The surface of layer 3 has a little more relief than layers 1 or 2 but generally parallels land surface. The minimum depth to the top of layer 3 ranges from 59 to 85 ft with an average minimum depth of 76 ft. With the presence of Єpc outcrops on either side of the Baker Creek drainage at this location (fig. 2), and with speleological accounts of caves beneath Baker Creek just upstream at the Narrows (Ben Roberts, Natural Resource Program Manager, Great Basin National Park, oral commun., April 2009), this high velocity layer likely represents the Єpc.

Seismic profile 2 was collected along a dirt road adjacent to Baker Creek approximately 0.5 mi downstream of the Narrows and 0.1 mi upstream of the park boundary (fig. 2) and is the most downstream of the three profiles. Two refractors were detected and three layers were interpreted for this profile (fig. 3B). Layer 1 is unsaturated alluvium with apparent seismic velocities ranging from 1,000 to 3,000 ft/s and an average velocity of 1,700 ft/s (table 1). Thickness of layer 1 ranged from7 to 16 ft with an average thickness of 12 ft. Layer 2 is saturated alluvium with apparent velocities ranging from 3,700 to 5,400 ft/s and an average velocity of 4,500 ft/s. The top of the saturated alluvium is relatively smooth, generally parallels land surface, and is at an altitude similar to Baker Creek indicating that Baker Creek is connected with the groundwater system along this profile. The depth to the top of the saturated alluvium ranges from 7 to 16 ft with an average of 12 ft. The minimum thickness of saturated alluvium along this profile ranged from 59 to 108 ft with an average minimum thickness of about 75 ft. Layer 3 is consolidated rock with apparent velocities ranging from 7,900 to 15,600 ft/s and an average of 13,900 ft/s. The surface of layer 3 has more relief than layers 1 or 2. The minimum depth to the top of layer 3 ranges from 75 to 115 ft with an average minimum depth of 87 ft. Tgr outcrops on either side of the Baker Creek drainage at this location (fig. 2). If Tgr is continuous across the Baker Creek drainage, then layer 3 along this profile is likely to be Tgr. However, if Tgr is not continuous across Baker Creek drainage, then layer 3 could be the Єpc.

Seismic profile 3 was collected along a dirt road about 0.1 mi upstream of the Narrows and at an angle of about 30 degrees off of Baker Creek (fig. 2) and is the most upstream of the three profiles. The west end of this array was within 100 ft of Baker Creek. Only one refractor was detected and only two layers are interpreted for this profile (fig. 3C). Layer 1 is unsaturated alluvium with apparent seismic velocities ranging from 1,600 to 3,400 ft/s and an average velocity of 2,500 ft/s (table 1). The minimum thickness of layer 1 ranged from 93 to 112 ft with an average of 102 ft. Average velocity for the unsaturated alluvium beneath profile 3 probably is higher when compared to the unsaturated alluvium beneath profiles 1 and 2 because of its greater thickness. Velocities in alluvium will tend to increase with depth due to compaction of sediments (Telford and others, 1976). Layer 2 (saturated alluvium) was not detected beneath seismic profile 3. Layer 3 was detected, but only from two shot points off the northeastern end of the profile. Because these shot points could not be reversed, the velocities obtained from the data are apparent velocities and may not reflect the actual velocity of the layer. However, the range of apparent velocities (11,200 to 20,700 ft/s) are similar to layer 3 velocities observed in the first two profiles indicating that this layer also is consolidated rock. The velocity used to interpret a depth to this unit was estimated using the average of layer 3 velocities in profiles 1 and 2 (12,500 ft/s). The minimum estimated depth to the top of the consolidated rock unit ranges from 93 to112 ft with an average minimum estimated depth of about 102 ft.

Results from profile 3 indicate that Baker Creek may be disconnected from the groundwater system in the area of profile 3, as evidenced by the lack of saturated alluvium beneath the seismic profile. Water lost to infiltration from the creek probably moves vertically through the alluvial deposits and into the underlying consolidated rock. Substantial losses in streamflow along this section of Baker Creek indicate the movement of water into the alluvial deposits (Elliott and others, 2006), which may be effectively drained by underlying karstic Єpc. Because of these multiple lines of evidence, layer 3 is likely the Єpc along this profile.

Table 1. Seismic velocities, depths, thicknesses, and lithology beneath seismic-refraction profiles along Baker Creek, Great Basin National Park, Nevada.

[Arrivals, number of arrivals used to estimate velocities; Apparent seismic velocity, in feet per second; depth, in feet; thickness, in feet; italicized numbers, represent estimated minimum depths or thicknesses; --, Not determined]

Profile and figure No.	Layer No.	Arrivals	Range in apparent seismic velocity	Average seismic velocity	Range in depth to top of layer	Average depth to top of layer	Range in layer thick-ness	Average layer thick-ness	Lithology type
1 fig. 3*A*	1	32	1,200-2,000	1,800	0	0	14-21	18	alluvium, unsaturated
	2	168	2,900-6,400	4,300	14-21	18	*42-69*	*59*	alluvium, saturated
	3	49	9,600-13,600	11,000	*59-85*	*76*	--	--	consolidated rock, probably Єpc
2 fig. 3*B*	1	14	1,000-3,000	1,700	0	0	7-16	12	alluvium, unsaturated
	2	139	3,700-5,400	4,500	7-16	12	*59-108*	*75*	alluvium, saturated
	3	32	7,900-15,600	13,900	*75-115*	*87*	--	--	consolidated rock, possibly Єpc or Tgr
3 fig. 3*C*	1	150	1,600-3,400	2,500	0	0	*93-112*	*102*	alluvium, unsaturated
	2[1]								
	3	10	11,200-20,700	12,500[2]	*93-112*	*102*	--	--	consolidated rock, probably Єpc

[1]Layer 2 was not detected on seismic profile 3.

[2]Layer 3 velocity on profile 3 was only detected in one direction and therefore average velocity was not computed. Velocity used was average of layer 3 velocities from profiles 1 and 2.

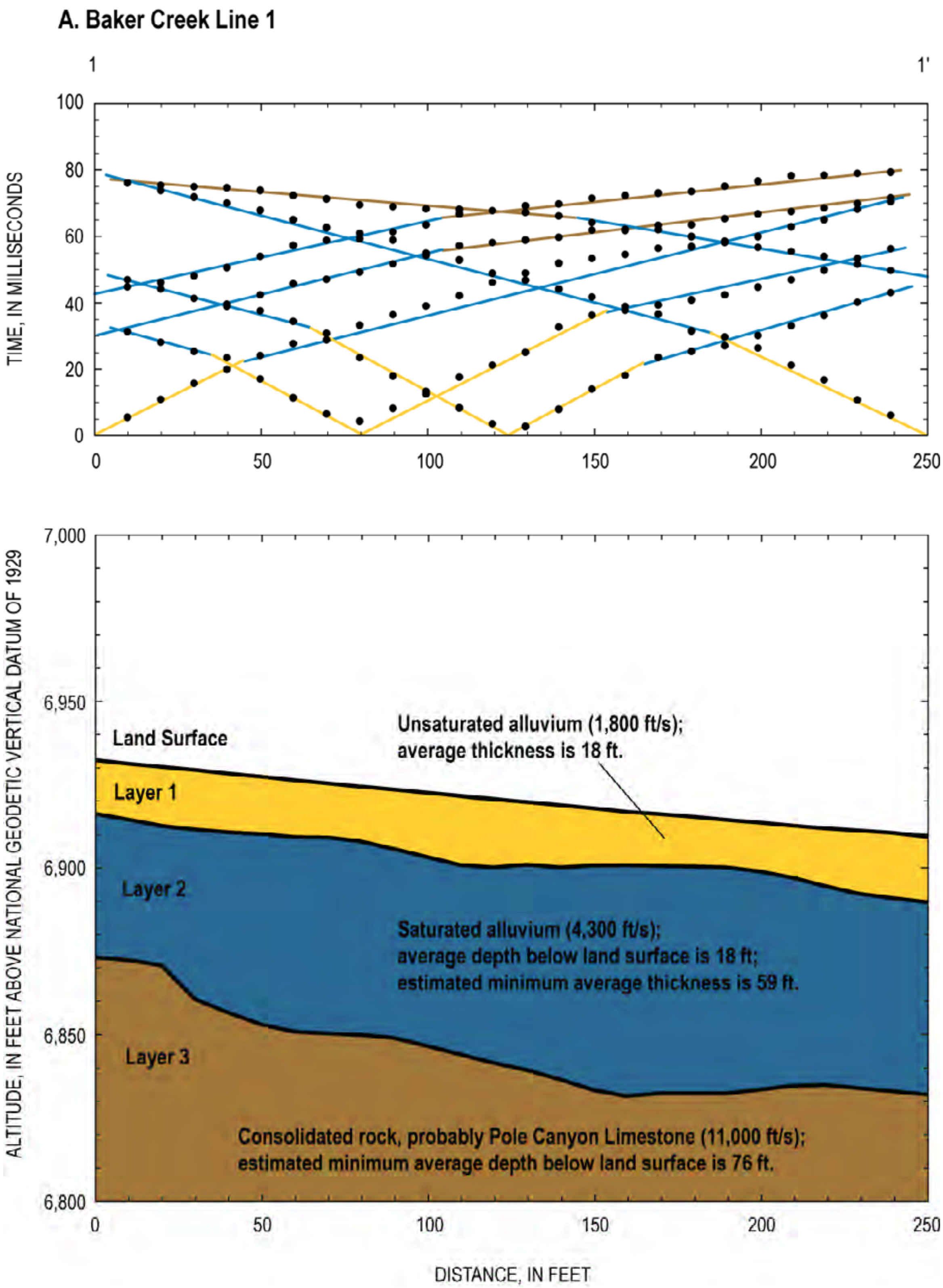


Figure 3. Seismic refraction first arrival data and interpreted depths to geologic units beneath seismic-refraction profiles for *(A)* Profile 1, *(B)* Profile 2, and *(C)* Profile 3.

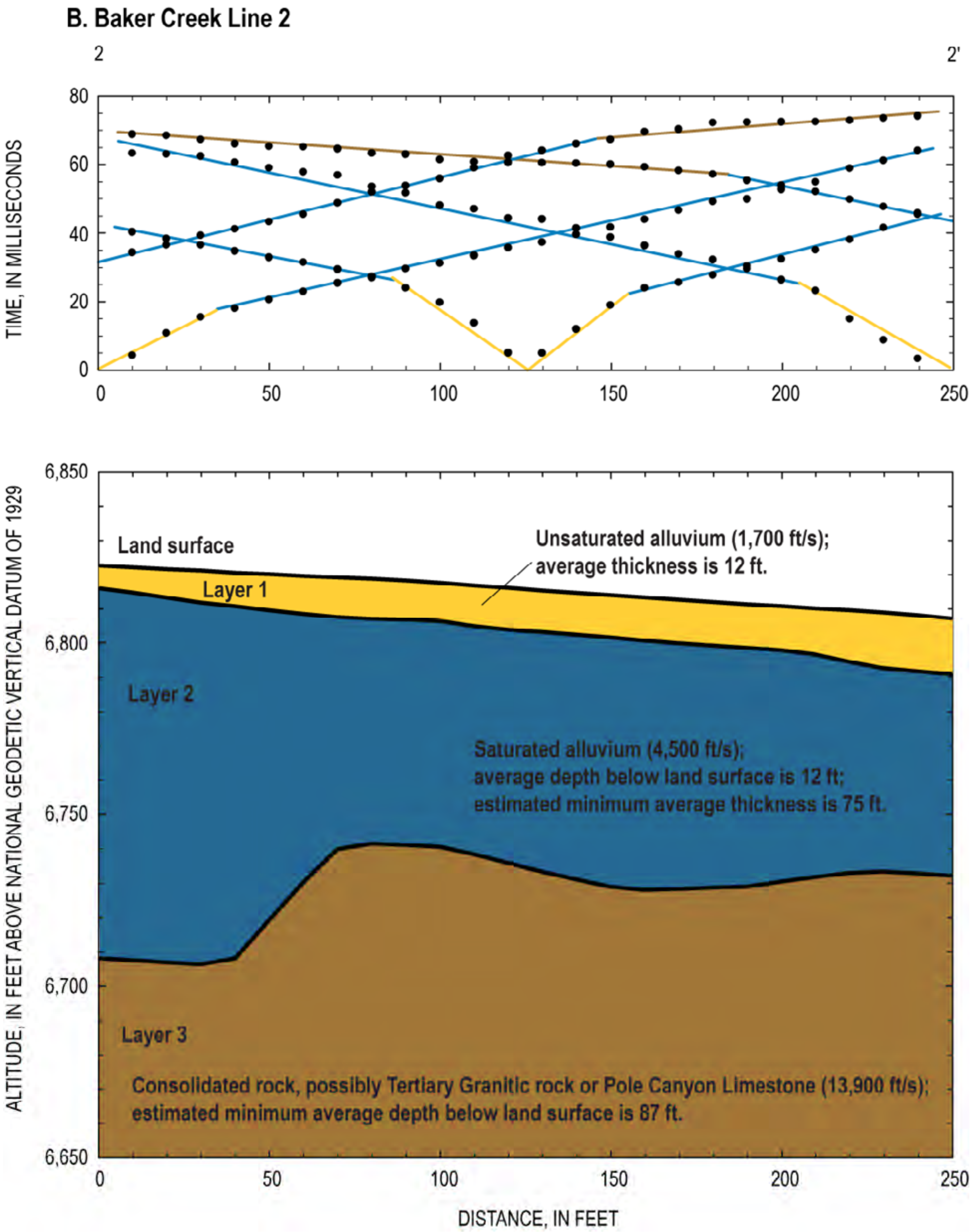


Figure 3. Continued.

C. Baker Creek Line 3

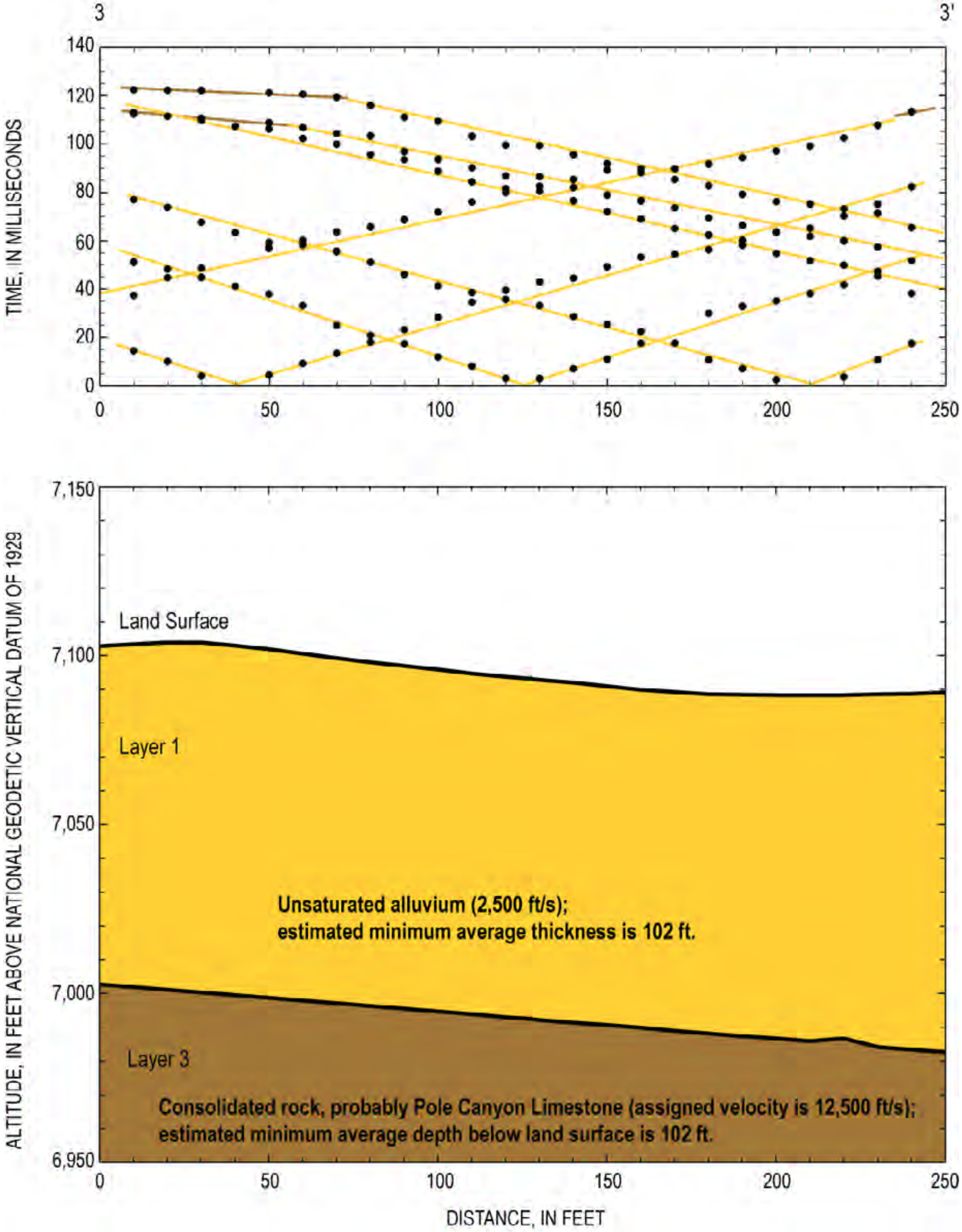


Figure 3. Continued.

Summary

To better understand how proposed large-scale water withdrawals in Snake Valley may affect the water resources and hydrologic processes in the Great Basin National Park, the National Park Service needs to have a better understanding of the relations between streamflow and groundwater flow through alluvium and karst topography of the Єpc. Information that is critical to understanding these relations is the thickness of alluvial deposits that overlay the Єpc. In mid-April 2009, the U.S. Geological Survey and National Park Service used seismic refraction along three profiles adjacent to Baker Creek to further refine understanding of the local geology.

A single refractor and two distinct velocity layers were detected along the profile upstream of the Narrows (profile 3), and two refractors and three distinct velocity layers were detected along the two profiles downstream of the Narrows (profiles 1 and 2). The top layer, encountered along all three profiles, had an average velocity of 2,000 ft/s and was unsaturated Qa. The second layer, only detected along the two downstream profiles, had an average velocity of 4,400 ft/s and was saturated Qa. The third layer, encountered along all three profiles, had an average velocity of 12,500 ft/s and was Єpc and possibly Tgr.

Upstream of the Narrows, Baker Creek is disconnected from the groundwater system and streamflow losses are moving vertically downward through a minimum of about 100 ft of alluvial deposits to the Єpc below. This interpretation is consistent with observations of substantial streamflow losses of nearly 50 percent along this reach by Elliott and others (2006).

Downstream of the Narrows adjacent to Baker Creek, there is a relatively shallow water table in the alluvial deposits with depth to water generally less than 20 ft. The total minimum thickness of alluvium in this area generally ranges from 60 to 120 ft and the thickness of the saturated alluvium ranges from 42 to 108 ft. Consolidated rock is beneath the saturated alluvium. Whether the consolidated rock detected using the seismic-refraction method is only the Єpc or if it also includes the Tgr unit is undetermined. If Tgr is continuous across the Baker Creek drainage between the outcrops near seismic profile 2, and it intersects the Єpc, then the presence of this unit could act as a barrier to downstream movement of water in the Єpc. This would potentially restrict flow to above the Tgr through the Qa. This interpretation would support the observed shallow water table along this reach of Baker Creek. If however, the Tgr is not continuous across the Baker Creek drainage, and the high velocity returns along profile 2 were refracting from the Єpc, then the shallow water table conditions observed would not be expected in this area unless one of the following conditions were met. Either the Єpc does not have the same degree of karstification as is characteristic of this unit elsewhere or if there is a low permeability unit between the saturated alluvium and the Єpc that did not have enough velocity contrast to be detected using the seismic-refraction method.

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