RGDSS Memorandum
Final

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Subject:	RGDSS Peer Review: Saguache / Gunbarrel area: Hydrogeologic Review of Confined Aquifer	
Date:	June 22, 2015	

Introduction

HRS was asked by the RGDSS peer review team (PRT) to review the hydrogeology of the area generally between Saguache and Center to determine if there were any discernible changes in the lithology of RGDSS model layers 3 and 4 that were not represented in the RGDSS model. This request was made initially in early 2013, and was complied with. Recent calibration efforts resulted in the PRT requesting that HRS review the question once again. In addition, HRS was asked to review the pumping assignment by layer for multi-aquifer well completions. We have addressed this topic also, using typical aquifer values for the Saguache region.

This memorandum describes our review.

Approach

The approach to this review assignment from the RGDSS PRT included our evaluation and, where appropriate, review and re-evaluation of the following:

1. HRS's cross sections B-B'[1]
2. Saguache County well logs from Brendle, 2002[2]
3. Driller's logs from the State Engineer's Office well permit database.
4. Review of the lithologic logs from RGDSS confined aquifer piezometers no. 1 (SE of Saguache) and no. 2 (near Center).

[1] HRS, 2001, RGDSS Ground Water Component, Task 7 Report, Hydrogeologic Data Review and Database Development, Appendix C

[2] Brendle, Daniel L., 2002, Geophysical Logging to Determine Construction, Contributing Zones, and Appropriate Use of Water Levels Measured in Confined-Aquifer Network Well, San Luis Valley, Colorado 1998-2000, USGS Water Resources Investigations Report 02-4058

5. Development of a new hydrogeologic cross section NW to SE across the Saguache / Werner Arroyo region.
6. Review of RGDSS' current layer by layer pumping assignments in multi-completion wells, which are common in irrigation wells in the Saguache region of the SLV.

Hydrogeologic Review and Evaluation

Brendle (USGS, 2002) classified the aquifer materials in the stratified sediments that are encountered in most confined aquifer wells into four categories (page 5 of Brendle):

1. Permeable (keyed in his graphics as dark blue): sand, gravel, and cobbles
2. Mostly permeable with some nonpermeable character (light blue): mainly sand and gravel with a nondominant clay component
3. Mostly nonpermeable with some permeable character (light gray): mostly clay with a nondominant sand and gravel component
4. Nonpermeable (dark gray): clay

Using this same general convention for approximate categorizing of permeable / nonpermeable sediments, HRS constructed two cross sections, SAG A-A' and SAG B-B', using the Saguache County logs from Brendle. Figure 1 shows the location of the two SAG sections. One cross section, SAG A-A' (Figure 2), was constructed in a north to south direction and the other, SAG B-B' (Figure 3) was constructed in a west to east direction. The model layers as shown on the sections were obtained from the Rio Grande Water Conservation District (RGWCD) database maintained by Principia Mathematica, which reflect model layer tops and bottoms recommended by HRS in a set of confined aquifer maps included in RGDSS Tasks 7 and 32 (HRS 2000 and 2002, respectively), as interpolated at specific monitoring well locations. Cross section SAG A-A' is located approximately 6 miles east of Highway 285 starting at well SAG 18 and progressing southward. Cross section SAG B-B' is located approximately halfway between Saguache and Center starting at SAG 1 and progressing eastward to end at SAG 2 which is the tie point to SAG A-A'.

Cross Section B-B' from the RGDSS Task 7 Report was constructed from drillers' logs located within one mile of Highway 285 (see Figure 4 for a location map and Figure 5 for Section B-B'). Using the cross section B-B' drillers well logs, we have classified the reported sediments per the Brendle classification with the exception of adding a classification for volcanic rocks (orange). This classification is shown on the attached cross section B-B'. One additional well, permit no. 5104-F, was added to the section to fill in a gap between well permit numbers R900-RF and 5016-F. There are no other wells between R900-RF and 5016-F that are deep enough to have penetrated through layer 3 into layer 4.

HRS also reviewed the Russell Springs / Russell Lakes area to determine the depth to the first volcanic rock layer, as we suspected that the presence of fractured volcanic rocks may have an effect on transmittal of pumping effects in the confined aquifer. Figure 6 shows the location of wells with reported volcanic rocks. Figure 6 shows the well permit, total depth of the well and

the depth to the top of the first reported volcanic rocks. On driller's logs, the volcanic rocks are variously described as: malipie, malpie, volcanic, solid rock, fractured rock, rock (may be large boulders), or hard malpie gravel. West of Russell Springs, volcanic rocks are penetrated at shallow depths below surficial soils or unconsolidated alluvial material. In places, the volcanic rocks are exposed at ground surface. The volcanic rocks dip steeply to the east such that at Highway 285 they are at depths ranging from 300 to greater than 500 feet below ground level. Not all of the confined aquifer wells, even in the Russell Lakes area, reported penetrating rocks that can be interpreted as volcanic rocks. A case in point is permit no. WCB 45, SW ¼ SW ¼ Sec. 31, T43N, R8E, which was drilled to 1,347 feet without describing any rocks that can be interpreted as volcanic rocks. This may be correct, or it may simply illustrate the variability in driller's interpretations as reported on completion reports.

The locus of the wells that report volcanic rocks in the subsurface in the Russell Springs / Russell Lakes region indicates a roughly lobate subsurface volcanic deposit, possibly one or several lava flows of the Rawley andesite (a Conejos Formation subgroup whose source was nearby in the La Garita Hills to the west of Russell Springs). This is shown by the red dashed outline on Figure 7. This figure also shows an interpretation of potential subsurface vertical offsets or lava flow edges on the upper surface of the volcanic rocks, as interpreted by the stepwise nature of the upper depth to volcanic rocks, from driller's reports.

A. Saguache / Werner Arroyo cross section

To better assess the Saguache / Werner Arroyo area HRS constructed a cross section (see Figure 6 for the location of the cross section and Figure 8 for the cross section) from northwest to southeast across the Saguache/Werner Arroyo area using existing drillers' logs found in the States well database. The reported sediments from the drillers' logs were classified per the Brendle classification as discussed above with the addition of a volcanic designator. The majority of the wells in this area are less than 300 feet deep. The northwestern most well, Permit No. 900-RF, is also in the HRS B-B' cross section discussed above. The southeastern most well is Colorado Water Conservation Board Piezometer No. 1 (P-1), Permit No. 223817, drilled as part of Phase 1, Task 10 of the Ground Water component of the RGDSS. This monitoring well bottomed at 580 feet in a lava flow. Only one other well on the cross section, Well Permit No. 4524-F, penetrated what is a possible volcanic rock interval. The possible volcanic material is described as sandstone with gravel streaks. This is possibly one of the ash flow tuff units that exist in the subsurface, and are generally contemporaneous with later Conejos Formation volcanic rock deposition.

Also shown on this cross section are the screened intervals for each well. This was done to determine if the well was screened / slotted in the unconfined aquifer, the confined aquifer or whether it is screened or slotted in both aquifers. Water is produced from sand and gravel intervals within the confined and unconfined aquifers commonly throughout this region.

Review of the pumping tests and/or the pump installation forms for the dual completed wells shows that the pumping water level generally is near or below the bottom of the unconfined aquifer. As can be seen from the cross section, a number of the wells are screened over both

aquifers. Based on the available well logs in this area it would appear that the volcanic rocks visible on the surface on the west side of the area do not extend into the subsurface for any distance to the east of the outcrop area. Thus the volcanic rocks do not contribute any significant amount of water production to the wells in the Saguache / Werner Arroyo area.

B. Review of RGDSS layer pumping assignment in multi-completion wells

As part of this review, HRS has considered the weighting of pumping as assigned in the RGDSS model in the multi-completion wells that are common in some areas of the San Luis Valley, including the Saguache / Werner Arroyo area. We suspect that the weighting of pumping as currently configured may be too high in the confined and too low in the unconfined, in instances where drawdown is moderate so that there would still be substantial saturated thickness in the unconfined aquifer during pumping. Where drawdown is large, so that T is low in the unconfined aquifer near the well, weighting of the unconfined aquifer pumping is likely to be more in line with the current RGDSS pumping assignment.

Here is a hypothetical example using representative depths and aquifer parameter values. This is a preliminary evaluation, and refinement is needed with actual well data.

Typical aquifer characteristics in the Saguache / Werner arroyo area are:

	Kh (ft/d)	S or Sy	Pre-Pumping Msat (ft)	Total Thickness (ft)	SWL (ft)	T ft^2/day
L1	100	0.15	70	80	10	7,000
L2	20	1.00E-04	100	100	10	2,000
L3	50	5.00E-04	130	130	10	6,500

For example: one pumping well with L1, L2, and L3 all 100% screened; and if this one well pumps 1,000 gpm; and the pumping is distributed by layer according to the current RGDSS method, then the assigned pumping by layer is:

Q total (gpm)	Saturated screened interval	Layer Weighting	Layer & screen combined weighting	Percent weighting by Layer	Assigned Pumping (gpm)	Assigned pumping (ft^3/day)
1000	70	100%	70	28.0%	280.0	53,904
	100	50%	50	20.0%	200.0	38,503
	130	100%	130	52.0%	520.0	100,107
Total	300		250	100.0%	1,000.0	192,513

If this well is pumped at 1,000 gpm total, and we use the Cooper-Jacob linearization of Theis to estimate the drawdown layer by layer (assume pumping steadily for 150 days) then the assigned drawdown by layer is as shown in the tabulation below. (Note, this is a simplified scenario, and assumes no vertical leakance or other interactions vertically through the aquifers or the annulus between casing and borehole.)

	u ($r^2S/4Tt$)	Drawdown at Assigned Q after ***t*** days (feet)	% of total drawdown
L1	3.571E-08	10.2	14%
L2	8.333E-11	34.7	48%
L3	1.282E-10	27.2	38%
Total DD		72.0	100%

The current RGDSS pumping assignment would assign about 28% of pumping and 14% of the drawdown, and thus presumably any gradient change and depletions to L1, and the rest to L2 and L3.

However, the current RGDSS pumping assignment does not account for the decrease in well efficiency with depth (due to slot plugging, decreasing uphole velocity with depth, fines accumulating in bottom of well, and sometimes smaller borehole/casing sizes at greater depth) that we typically see in layered sedimentary aquifer wells.

If we estimate that there is maximum efficiency of transfer of water into the well at the top of screen (100%) and virtually zero transfer of water into the well at the bottom, and if we further estimate a linear change in well efficiency between these extremes, for the example well the result is:

	Top of Screen	Bottom of Screen	Highest Efficiency	Lowest Efficiency	Average Efficiency
L1	20	80	100%	79%	90%
L2	80	180	79%	45%	62%
L3	180	310	45%	0%	22%

This translates to a different weighting of pumping by layer, as follows:

Q total (gpm)	Saturated screened interval	**Efficiency Weighting**	Layer Weighting	Layer, efficiency, & screen combined weighting	Percent weighting by Layer	Assigned Pumping (gpm)	Assigned pumping (ft^3/day)
1000	70	90%	100%	63	51.1%	510.5	98,282
	100	62%	50%	31	25.2%	252.5	48,601
	130	22%	100%	29	23.7%	237.0	45,631
Total	300			123	100.0%	1,000.0	192,513

And a different drawdown in each layer, as follows:

	u ($r^2S/4Tt$)	Drawdown at Assigned Q after ***t*** days (feet)	% of total drawdown
L1	3.571E-08	18.5	25%
L2	8.333E-11	43.8	59%
L3	1.282E-10	12.4	17%
Total DD		74.7	100%

These hypothetical calculations are a simplification of actual conditions, but are intended to provide sufficient information to allow the PRT to consider refining the layer by layer assignment of pumping in multi-completion wells. It would be necessary to take into account the layer interactions to see where this might lead; either by modeling using, for example, the USGS MODFLOW Multi-node well package or empirically by testing a well and running a spinner (downhole flowmeter) log while testing to measure the layer by layer contributions.

Conclusions and Recommendations

Based on all of the well logs reviewed for construction of the four cross sections presented, with the exception of the surface and subsurface volcanic rocks in the U.S. 285 roadcuts a few miles south of Saguache, and in the Russell Springs area, there are no significant stratigraphic or lithologic changes seen in the RGDSS model layers 3 and 4 in a north-south direction from the Saguache Creek area to the south, toward the Rio Grande or across the Werner Arroyo area. Although it is possible that there are changes in lithology that limit the subsurface extent of confined aquifer potentiometric surface drawdown due to pumping, any such changes are not indicated in the available database of USGS logs and driller's logs from the SEO well permit database. We conclude that the stratigraphy of the aquifer layers is appropriately represented in the RGDSS model.

The presence of subsurface volcanic rocks with evident fracturing based on driller's descriptions, generally coincident with Russell Springs and several large capacity and also small capacity flowing wells in the Russell Lakes area (see Figure 7) suggests that there is enhanced vertical leakance between the RGDSS model layers present in this area. This was discussed with the PRT, and adjustments to the model were made as a result of this part of the review in 2013.

Overall, except for enhanced Kv in the local Russell Springs / Russell Lakes area as shown in Figure 7, we do not find that there is a hydrogeologic rationale, based on existing data, to make changes to Kh or Kv in the area between Saguache vicinity confined aquifer well pumping and the Rio Grande.

HRS recommends that the topic of layer / pumping assignment refinements be taken up in the next phase of RGDSS. This would involve reviewing the amount of water pumped from a well versus depth due to decreasing well hydraulic efficiency, and possibly also decreasing porosity and hydraulic conductivity with depth and between various layers in multiply-completed wells. Another factor may be plugging of well screens with greater plugging with depth. An empirical test of this hypothesis would involve the testing of one or more wells using spinner logs.

In our opinion a full review of multi-completed well pumping assignment; testing, and implementation of refinements now would be inadvisable, given the possible time line and the activities that may be needed. Activities may involve modeling, new data collection, or both, that may need to be done to test, verify, and peer-review this concept. Also, this concept first would need to be weighed against other new or revised concepts that the PRT may feel have higher priority for the next phase of enhancements.

Comments and Concerns

None.

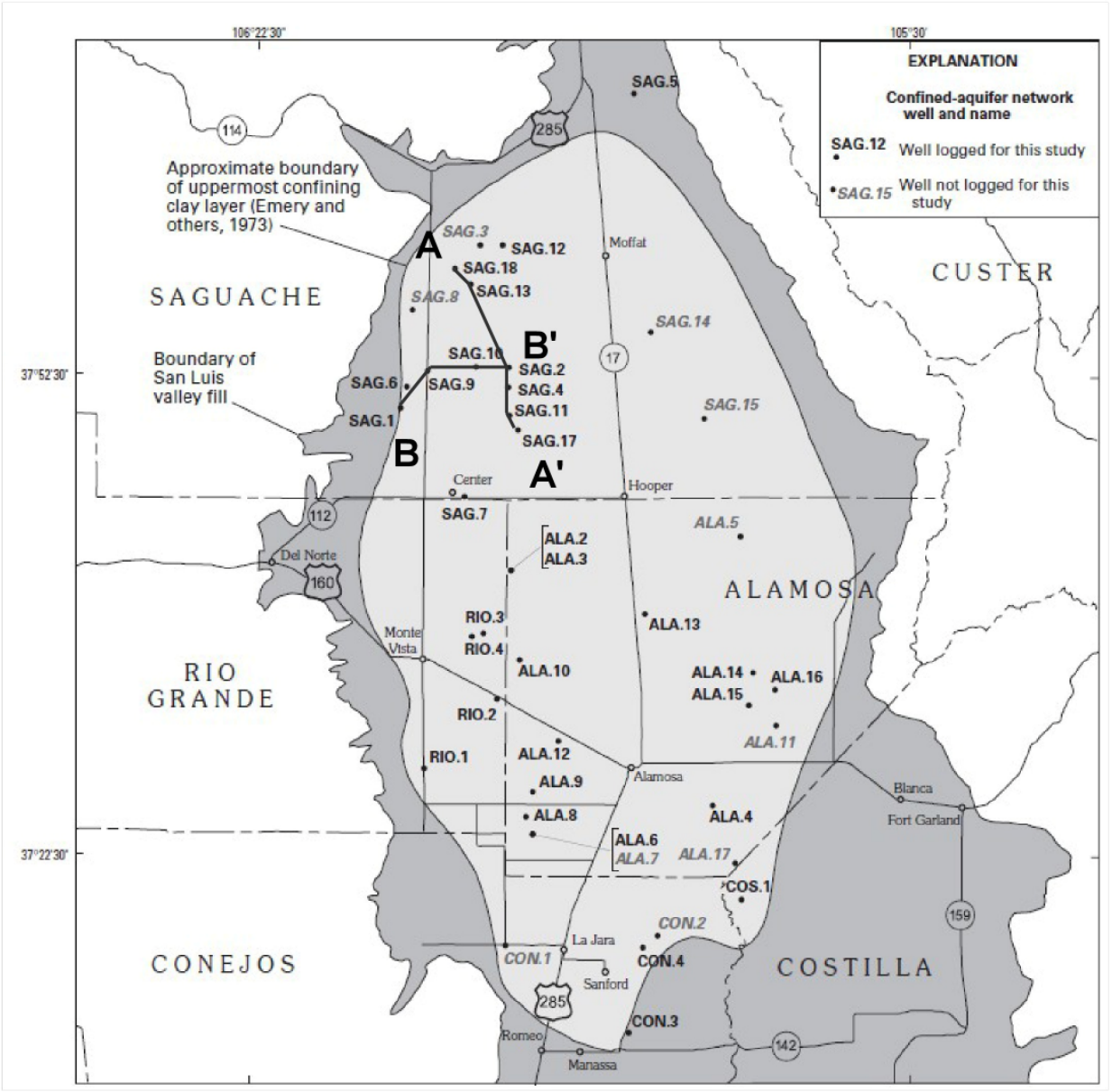

Figure 1: Location map for geologic cross sections SAG A-A' and B-B'

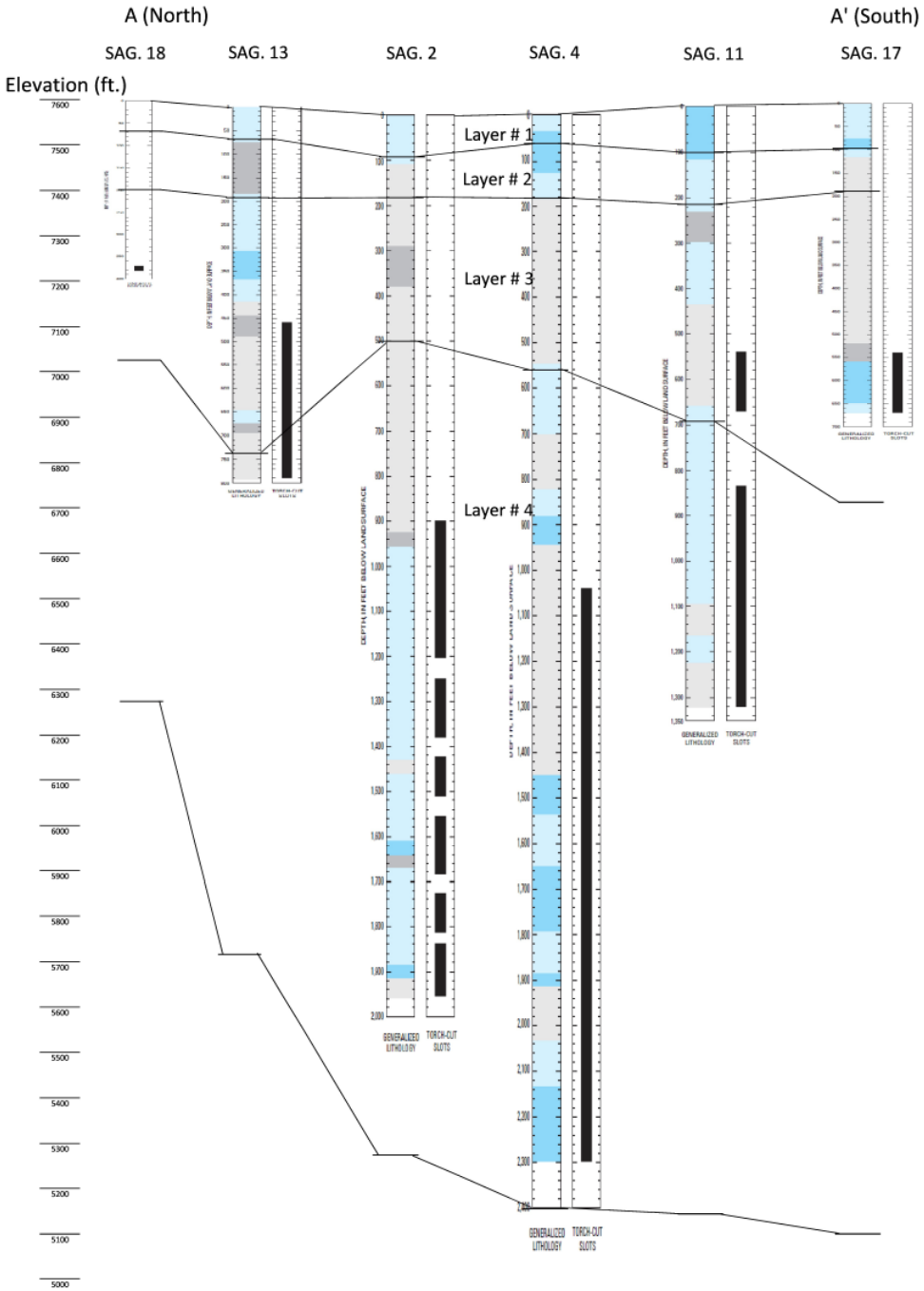

Figure 2: Geologic Cross Section SAG A-A'

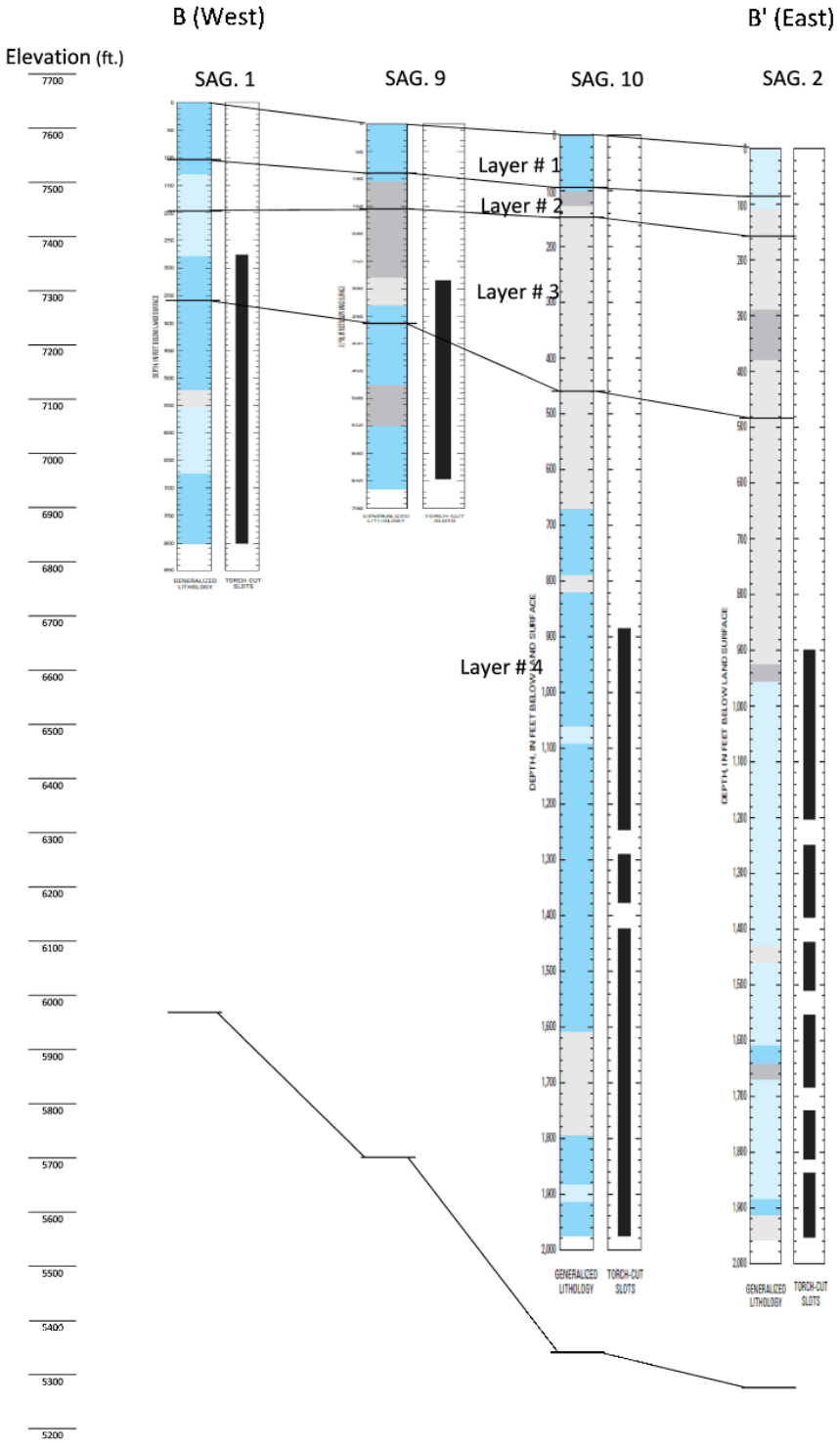

Figure 3: Geologic Cross Section SAG B-B'

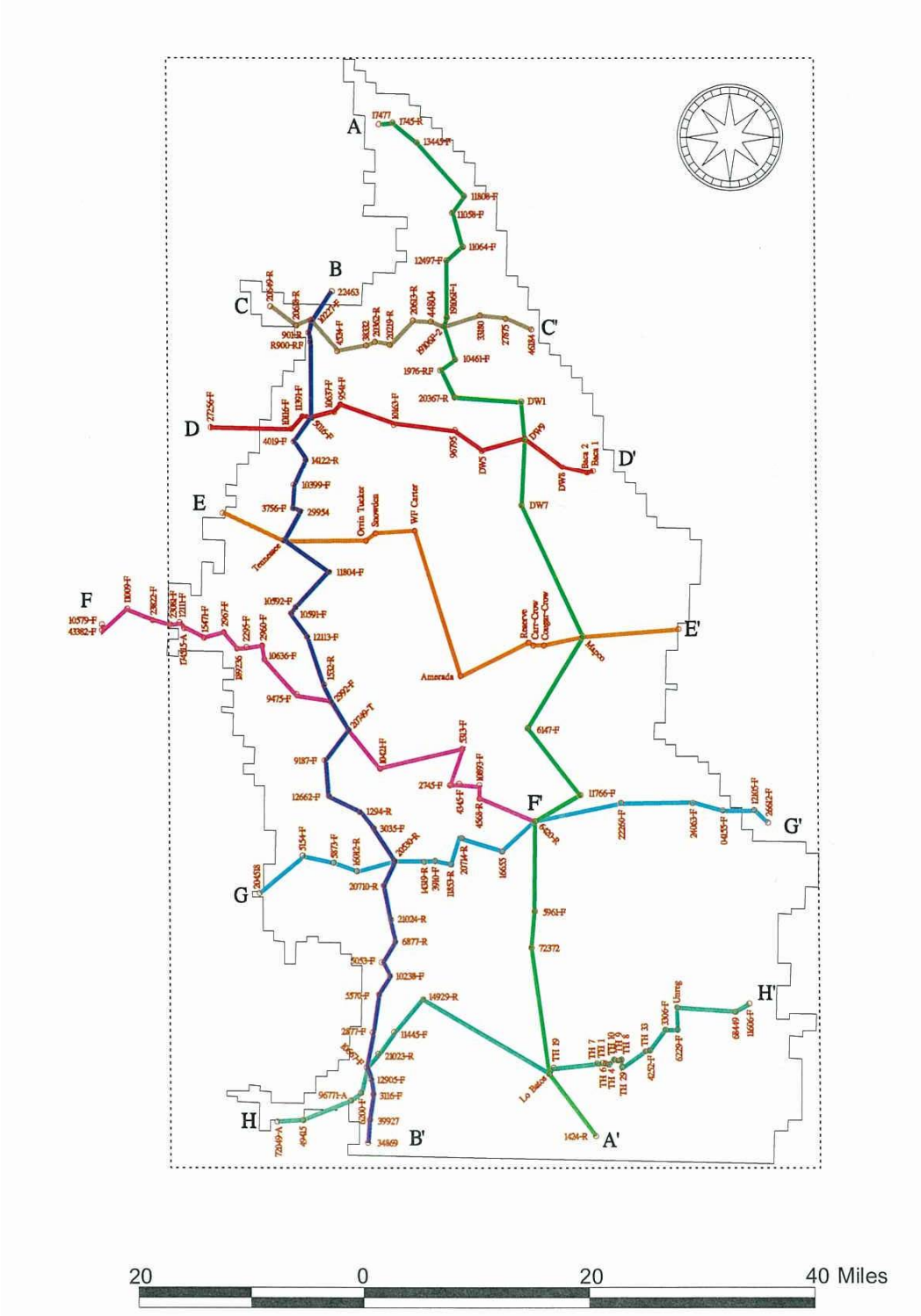

Figure 9. Location of Hydrogeologic Cross Sections

Figure 4: Location of B – B' Cross Section. (this was Figure 9 in RGDSS Task 7 Report, HRS 2002).

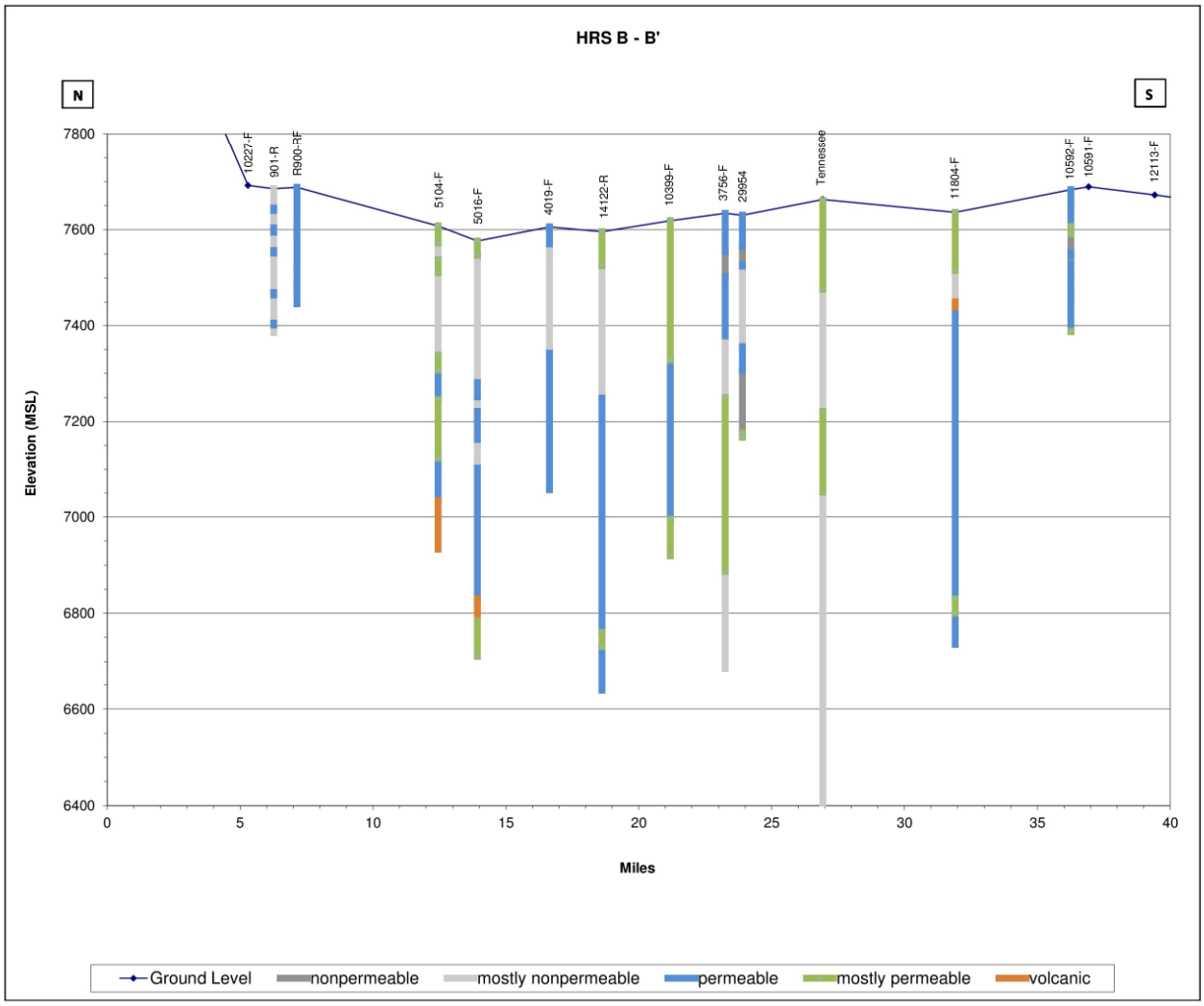

Figure 5: Cross Section B-B'

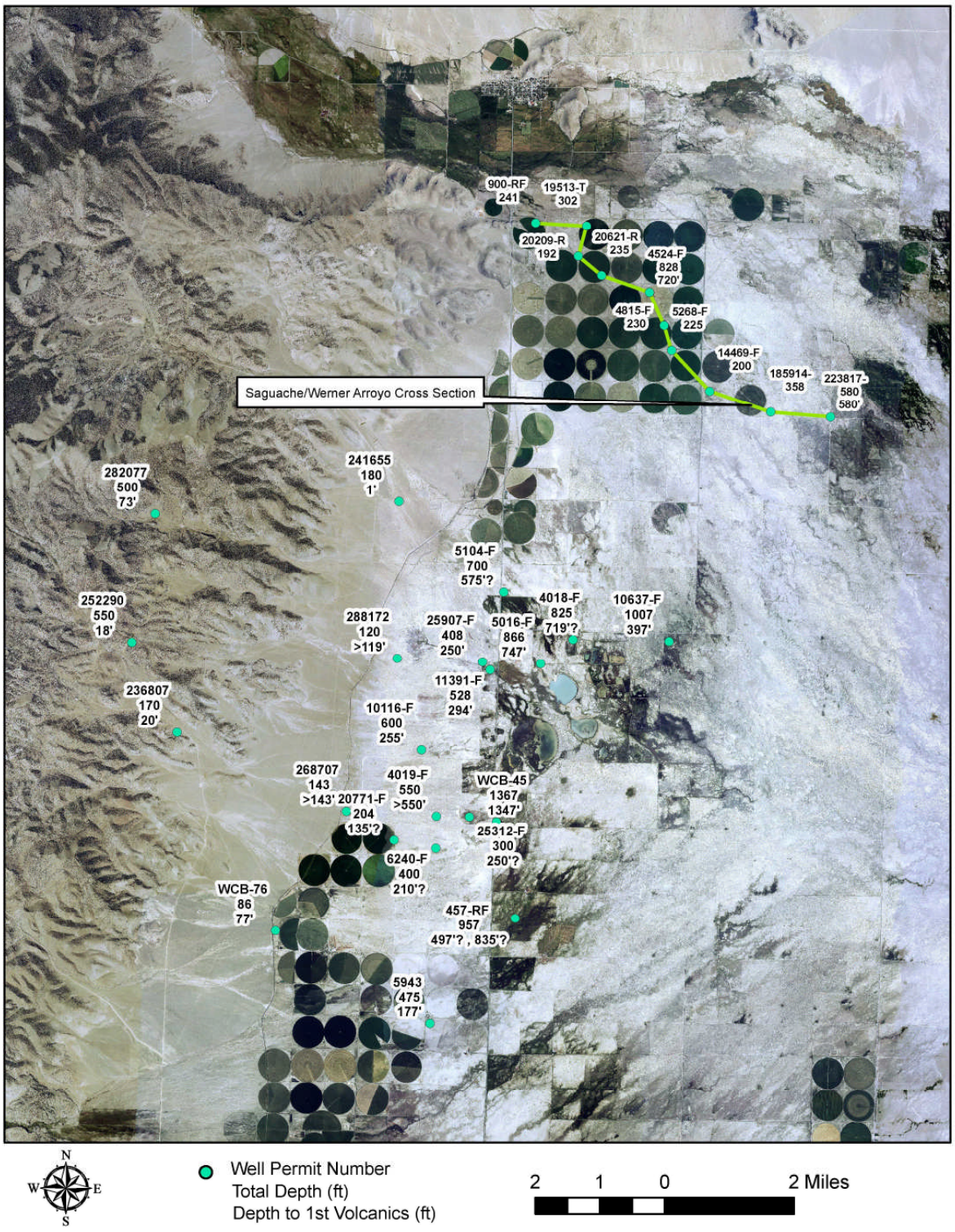

Figure 6: Well Locations with Permit No., Total Depth , and Depth to 1st Volcanic rocks listed on driller's reports in the Russell Lakes region.

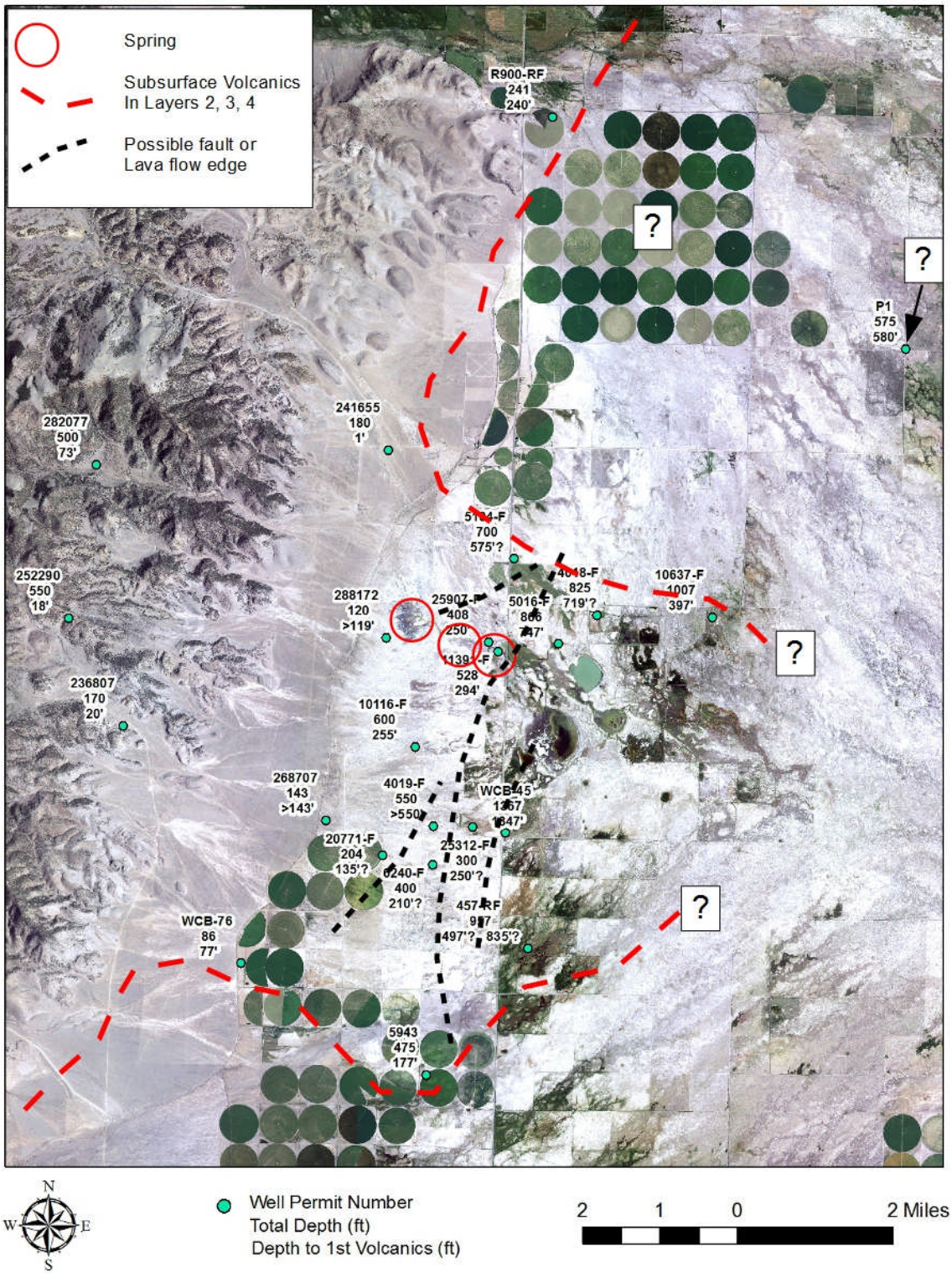

Figure 7: Interpreted subsurface geologic structure and subsurface extent of volcanic rocks in the Russell Lakes region.

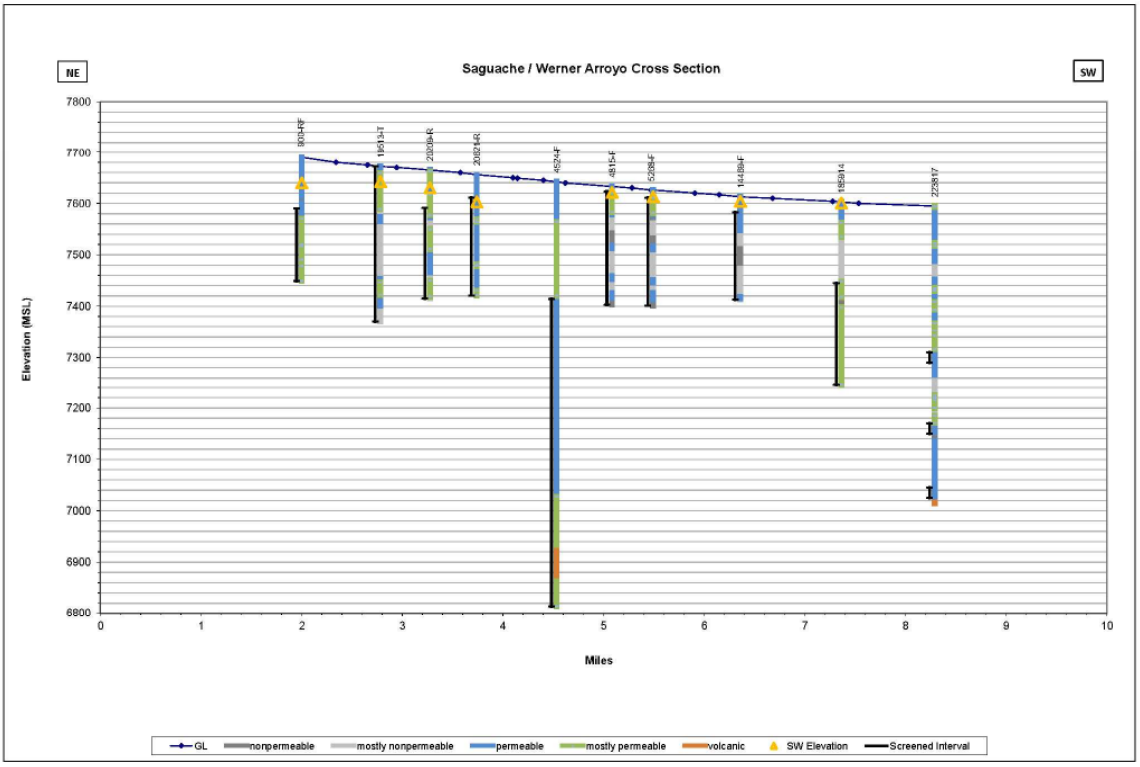

Figure 8: Saguache / Werner Arroyo Cross Section