Preliminary Hydrogeologic Analysis of the Mayfield Area, Ada and Elmore Counties, Idaho

John A. Welhan

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Idaho Geological Survey
Morrill Hall, Third Floor
University of Idaho
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CONTENTS

TABLES

ILLUSTRATIONS

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EXECUTIVE SUMMARY

The East Ada ground water system is recharged by three sources: (i) infiltration of seasonally warmed surface water into shallow aquifers near local streams, (ii) meteoric recharge into both the perched and deep aquifers derived from local watersheds, and (iii) a deep source of geothermally heated water rising along faults of the Boise Front.

Meteorically recharged ground water in the study area reflects local mean annual air temperature 50-54 ^{o}F (10-12 ^{o}C). However, drillers report temperatures up to 96 ^{o}F (35.5 ^{o}C) and two-thirds of wells are in the 66-71 ^{o}F (19-22 ^{o}C) range. The presence of widespread elevated water temperatures across this part of the WSRP indicates that mixing of meteoric recharge and geothermally heated water (not conductive heat flow) accounts for elevated temperatures in wells deeper than 200 feet. Systematic seasonal and pumping-induced temperature fluctuations of up to 4 ^{o}F in the Danskin and Stage Stop deep wells indicate that both natural seasonal factors and pumping-induced hydraulic stresses can affect mixing proportions and temperatures in the East Ada deep aquifer.

The elemental composition and ionic proportions in East Ada well water suggest that geothermal recharge originates from the same source that supplies the Boise geothermal system and the hot springs of the Idaho Batholith. This end member has a surface temperature of 60-90 ^{o}C and is characterized by elevated fluoride, lithium and boron concentrations derived from deep circulation through felsic rocks under an elevated geothermal gradient. Assuming that the temperature of the thermal end member is similar to hot springs in the Idaho Batholith and wells in the Boise geothermal system (160 ^{o}F, 70 ^{o}C), the fraction of geothermal recharge to parts of the deep East Ada aquifer may exceed 20%. However, such mixing proportions should not create a water quality problem due to high fluoride concentrations because dissolved fluoride appears to behave non-conservatively and is likely limited by fluorite (CaF_2) solubility.

One or more perched zones occur above the deep aquifer in the vicinity of the range front and are likely recharged from nearby watersheds and by infiltration from streams. Nearest the

range front, the hydraulic gradient of the deep aquifer is 0.011, reflecting the movement of recharge derived from local catchments. The gradient steepens to 0.027 four to five miles (6-8 km) from the range front, either because of additional recharge or a zone of lower transmissivity, either or both of which would result in a mounding effect. This change in hydraulic gradient allows constraints to be placed on the magnitude of recharge fluxes to the deep aquifer.

Based on two published well tests and specific capacities reported by drillers in the East Ada area, the average transmissivity of the deep aquifer is of the order of 7000 gpd/ft. Estimates of total recharge to the deep aquifer range from 7,000 to 12,600 acre-ft/year. The minimum estimate was obtained by assuming that the water table mound represents an influx of additional recharge to the deep aquifer (geothermal fluid rising along buried faults and / or drainage from the overlying perched zone). In that case, the amount of meteoric recharge that enters the deep aquifer from the Upper Indian Creek, Sand Hollow Creek, and Bowns Creek watersheds above 3,700 ft (an area of about 35 square miles) is about 3,000 acre-ft/year with an additional 4,000 acre-ft/year derived from geothermal inputs and possibly drainage of the overlying perched aquifer. The maximum recharge estimate was obtained on the assumption that a zone of decreased transmissivity is responsible for steepening the hydraulic gradient in the vicinity of I-84. In that case, the aquifer transmissivity near the range front could be as high as 18,000 gpd/ft and meteoric recharge from local watersheds could be as high as 12,600 acre-ft/year. Under this scenario, additional perched-zone or geothermal inputs would be negligible.

The above results suggest that previous estimates of recharge to the East Ada aquifer system may be overly optimistic and that the long-term safe yield of the system is quite uncertain. More work is needed to better define the fraction of geothermal recharge and the actual meteoric recharge potential in the highlands. In particular, fundamental estimates of precipitation, runoff and evapotranspiration are needed to evaluate aquifer recharge independently of aquifer transmissivity estimates and to help settle the question of whether recharge from a geothermal source as well as indirect recharge from the perched aquifer(s) represent significant components of the ground-water budget.

RECOMMENDATIONS

Additional work is needed to define the principal water-bearing zones in the East Ada aquifer system and to segregate water level information into shallow and deep subsets so that piezometric surfaces can be constructed separately for the perched and deep water-bearing zones.

More controlled pumping tests are needed in the deep aquifer to define its average transmissivity, to identify possible systematic spatial trends in transmissivity, and to better constrain the fluxes of cold, thermal and vertical recharge components.

Additional geologic data on the region’s basalts is needed to refine volcanic stratigraphy and deep aquifer architecture. More deep wells should be monitored during drilling by at least a student geologist and more chip samples collected for major and trace element chemistry.

One or more test wells, appropriately logged and monitored, in the vicinity of I-84 would help determine whether the steepening of the deep aquifer’s hydraulic gradient is due to a systematic decrease in the transmissivity of the sedimentary aquifer away from the range front or if it reflects drainage of the perched zone(s) above the deep aquifer in that area.

Additional water chemistry and temperature data are needed to characterize the geothermal signature in the deep aquifer, to estimate the temperature of the geothermal end-member, and to constrain its relative importance in the aquifer's water balance. Several data collection activities are recommended in this regard:

- Monitor and evaluate transient, pumping-induced changes in water chemistry due to mixing of geothermal water for possibly excessive transient fluoride concentrations.
- Conduct a one-time temperature survey of water pumped from deep wells in the study area to define the average temperature of the deep aquifer and estimate the proportion of geothermal recharge in its water balance.
- Well drillers should be required to provide water temperature information as part of their reporting obligations for wells drilled on the western Snake River Plain.
- Transcribe water temperature information from drillers' reports into IDWR's on-line database to make temperature information more accessible and searchable.

SCOPE AND OBJECTIVES

RATIONALE AND OBJECTIVES

The East Ada area's groundwater resources are facing increased development pressure and may have limited capacity. Arguing on the basis of the geographic proximity of the Mountain Home Ground Water Management Area (GWMA) and Cinder Cone Critical Ground Water Area (CGWA) and the WSRP's ground water flow budget, Tesch and Vincent (2009) estimated aquifer recharge in the East Ada area relative to pending water rights applications for diversion and concluded that "aquifer mining is a possibility if proposed development proceeds." Recent hydrogeologic evaluations of local ground water conditions by SPF Engineers (2007a, 2007b) concluded that recharge is sufficient to meet a portion of developers' needs.

Fewer than 150 drillers' reports on wells deeper than 450 feet are available for the region. IDWR has recently initiated a program of hydrologic monitoring in a number of water wells in the area and has commissioned several studies, including this one, to objectively review and evaluate the hydrogeologic characteristics of this aquifer system. Specific objectives were to:

- evaluate existing data and hypotheses regarding hydrogeologic conditions in East Ada
- integrate existing and recently acquired information and identify alternative hypotheses
- synthesize a testable hydrogeologic conceptual model of the East Ada area to guide further analysis, data collection and decision making.

STUDY AREA

Figure 1 shows a shaded relief map of the study area and environs, with areas proposed for development, the locations of wells and monitoring data that were considered in this analysis, and the area recently mapped by the Idaho Geological Survey (Phillips et al., 2012). The study area is situated on parts of three local watersheds: Upper Indian Creek, Sand Hollow Creek and Bowns Creek (**Figure 2**).

INTRODUCTION

REGIONAL HYDROGEOLOGIC SETTING

Southeast of the study area, shallow and perched aquifers in the Mountain Home area are hosted in alluvial sand and gravel units on the flanks of the Boise Front (Bendixsen, 1994). Most deep wells in that area encounter water more than 300 ft below land surface (bls), with local hydraulic gradients sloping to the south-southwest (toward the valley axis) at approximately 200 ft / 6 miles (0.0063). The deep regional flow system within the valley axis is largely hosted within basalts of the Bruneau Formation, with a regional hydraulic gradient that is roughly perpendicular to the range front that bounds the WSRP. The hydraulic gradient in the Mountain Home area is about 300 ft / 6 miles (0.0095), shallowing to 100-150 ft / 6 miles (0.0032 - 0.0047) to the southwest. Regional gravity data suggest that the WSRP graben may be 10,000 feet deep in this area, so that much deeper water-bearing zones are likely to exist.

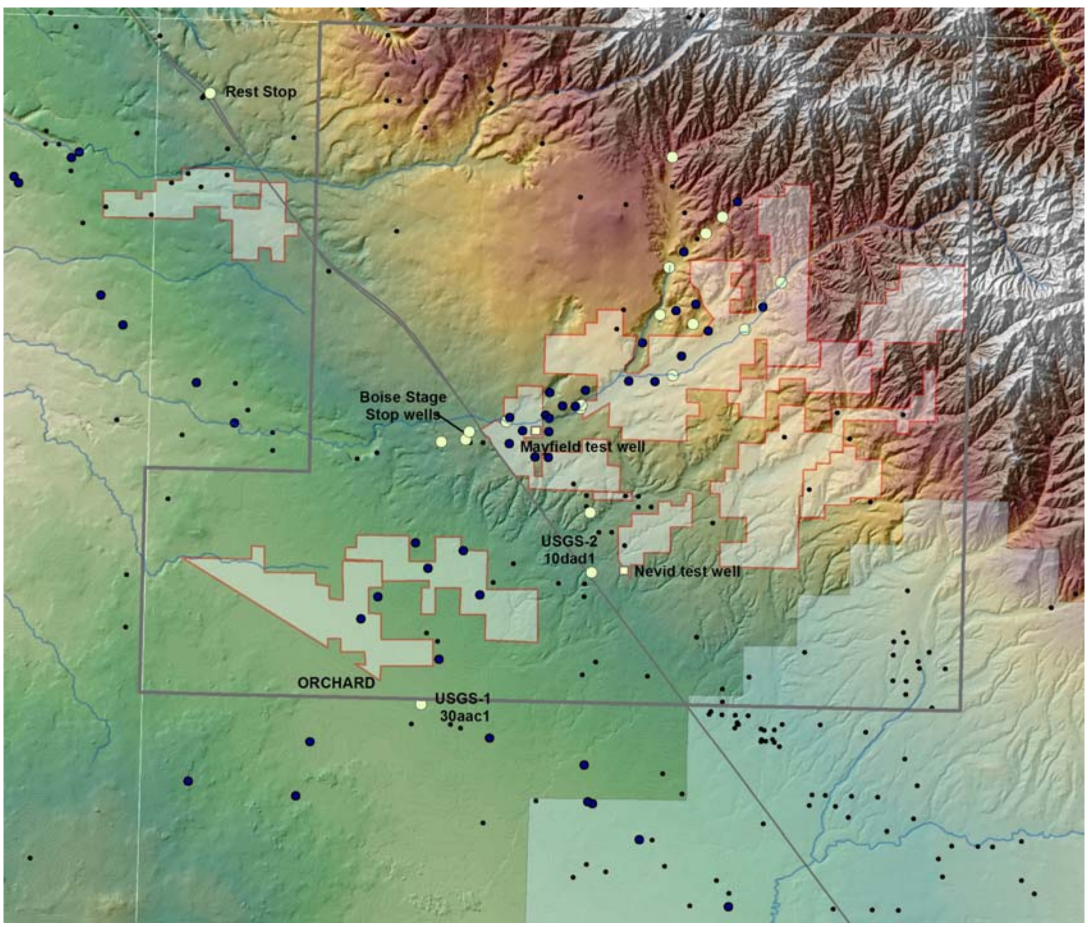

Figure 1 - Map of the general study area indicating locations of all wells in the IDWR well construction database (small black symbols). Wells used to construct hydrogeologic cross sections are shown as large black and white symbols, the latter also indicating water-level and temperature monitoring locations established by IDWR and USGS. Shaded area in southeast corner of map area is Mountain Home Ground Water Management Area and polygons outlined in red indicate areas proposed for future development. The gray polygon indicates the area recently mapped by Phillips et al. (2012).

Northwest of the study area, in the Boise Valley, the Boise aquifer system is hosted in sandy units confined by fine-grained lake sediments, but it is unknown whether this aquifer has any connection to the East Ada aquifer system.

Between 1976 and 1990, water levels in perched aquifers of the study area varied 10 to 30 feet or more in response to annual changes in recharge. In comparison, water levels in the regional aquifer north and northwest of Mountain Home were stable or rising between about 1970 and 1990, whereas water levels to the south had declined up to 30 feet or more (Bendixsen, 1994). Very few wells show any correlation to climatic-induced changes in precipitation. Wells in the southern part of the CGWA have shown declines of 40-80 feet between 1980 and 2005, whereas wells to the north and west have displayed relatively stable water levels.

LOCAL HYDROGEOLOGIC SETTING

The recent mapping by the Idaho Geological Survey has provided valuable information that constrains the subsurface hydrogeologic picture in the East Ada area (Phillips et al., 2012). Additional information relevant to the subsurface that was compiled by the IGS during the

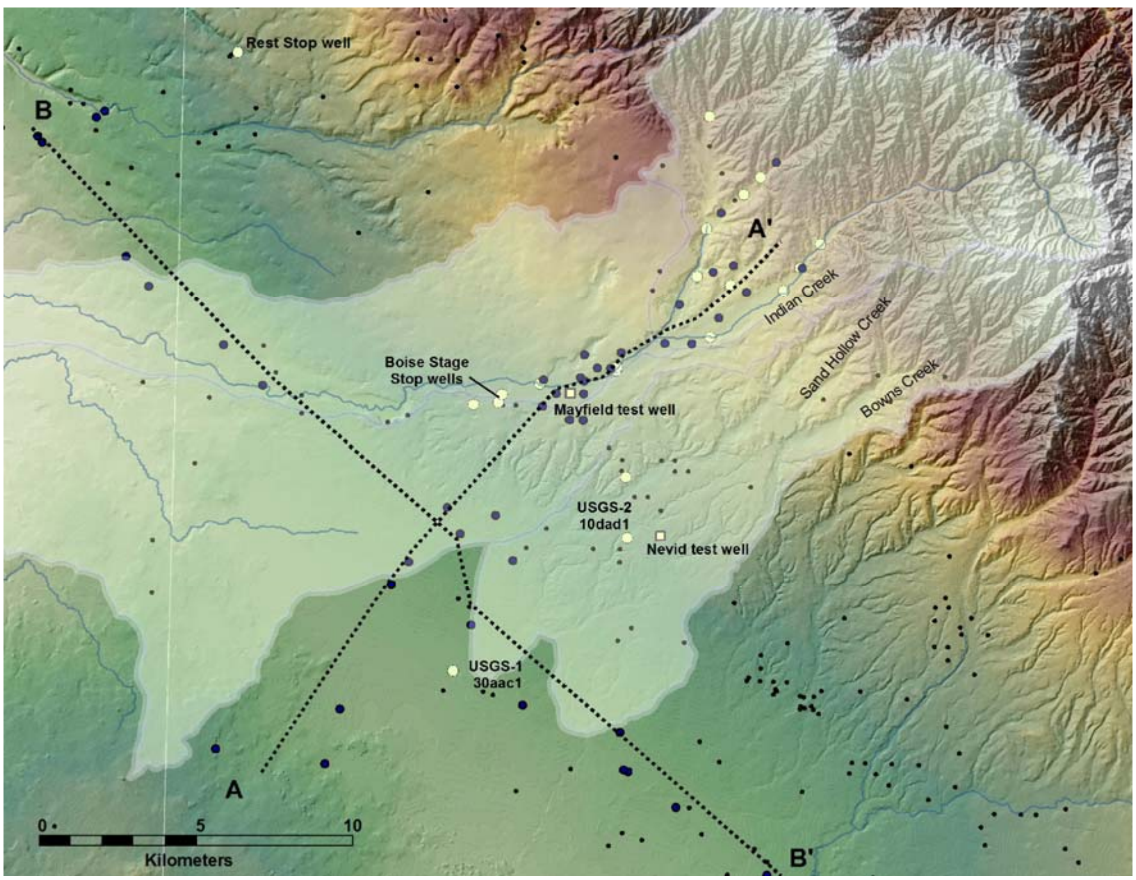

Figure 2 - Locations of cross-sections A-A' and B-B' and the areal extent of the Upper Indian Creek, Sand Hollow Creek, and Bowns Creek watersheds (lightly shaded area) indicating the length of the Boise Front over which ground water recharge to the aquifers in the study area is assumed to occur and the high-altitude catchment area of these watersheds.

course of surface mapping is provided in Appendix I (lithologic interpretations and stratigraphic syntheses based on chip samples from the Mayfield and Nevid test wells; V. Gillerman, written comm., 2011) and in Appendix II (additional geologic notes and observations gleaned from IDWR drillers' reports; W. Phillips, written comm., 2011).

Bedrock in the study area consists of granitic rock (Kbgd) locally overlain by patches of Eocene rhyolitic tuff and lava (Trv), with outcrops of Miocene(?) basaltic tuff and tuffaceous sandstone (Ttss) near the northern map boundary (Phillips et al., 2012). Whether these units are widely present at depth in the central and southern part of the study area is speculative. Granitic bedrock is intruded by Eocene northeast-trending and north-south trending Miocene (14 Ma) rhyolite dikes. The Miocene dikes' north-south orientation is consistent with emplacement into an east-west (Basin and Range) extensional field.

Basaltic units in the study area include the late-Pleistocene Slaters Flat shield volcano (K-Ar age of 907 ± 280 Ka; Othberg et al., 1995) and Pleistocene and older basalt flows that originated from vents nearer the central rift zone of the Western Snake River Plain (QTb). These are exposed on the surface and also interfinger with the deeper sediments to the north, as in the Nevid and Mayfield wells (basaltic tuff at about 200 ft depth). Basalts in the southwest corner of the map area are considered the most northerly of the central rift zone basalts (QTbor and Qbph). The older QTbor basalt has a duripan 1.5-2 m thick that is developed in thick loess cover and may represent a local barrier to recharge.

Sedimentary overburden in the northwest corner of the East Ada map area is dominated by gravels of Bonneville Point (Tgbp) representing the ancestral Boise River drainage. The bulk of the sedimentary material in the rest of the study area is a fine sand (Ts) that presumably correlates with Pliocene lacustrine sediments of the Idaho Group and hosts the deep aquifer of the East Ada study area. These sediments presumably interfinger with and underlie the Tgbp gravels to the northwest. Overlying the Ts sediments is a relatively thin granule sand unit with minor gravel (QTs) representing mostly decomposed granite (Kbgd that has been transported from the range front). Some evidence exists for a grain-size progression in surficial materials away from the range front (and hence a possible spatial control on aquifer transmissivity), but the alluvial fan-dominated nature of the QTs unit cannot be considered an analog for the lacustrine-dominated nature of the Ts unit (Phillips, W., written comm., 2011).

Chip samples from the 1000-foot deep Mayfield and Nevid test wells are consistent with cross section A-A'" of Phillips et al. (2012). The water table in these wells stands at about 400 ± 50 feet depth and the principal water-bearing zone is between 700-800 ± 50 feet depth, apparently from a series of fine and medium-grained sands. Potential confining layers were not identified, although cementation (silica?) of some sand and gravel units was noted that, if laterally continuous, could serve as local aquitards. The driller's report for the Nevid well indicates a specific capacity of 3.5 gpm/ft, based on 8 hours of pumping.

Using lithologic logs of mostly deep wells, Wood (1996) constructed a cross-section through the East Ada study area that extends from the Boise Front along Indian Creek and through the town of Orchard. His cross section suggests an approximate hydraulic gradient of the order of 133 feet / mile (0.025) to the southwest, but it did not adequately differentiate between water levels in shallow and deep water-bearing zones. Wells completed in sedimentary materials have low specific capacities (< 2 gpm/ft). Two wells with depths of 900 and 940 ft and open intervals spanning a 40 ft thick coarse sand unit within finer-grained lacustrine sediments were pump-tested for 24 hrs and allowed to recover 72 hours. Their maximum specific capacity was no more than 1.7 gpm/ft (Wood, 1996).

Faulting undoubtedly plays an important role in the hydrogeology of the East Ada aquifer system. The northeast-trending Blacks Creek fault offsets the Miocene dikes and older units and apparently controls the Black Creek drainage (Phillips et al., 2012). Those authors also state that, "The northeast orientation of the East Fork of Slater Creek and Indian Creek is suggestive of similar structures," although no definitive surface evidence for such faults has been found.

One or more northwest-trending normal faults distributed over a several mile-wide zone along the range front comprise the Boise Front fault system (Wood, 1996), although surface evidence of them in the East Ada study area has not yet been found (Wood, 1996; Phillips et al., 2012). Liberty (written comm., 2011) identified several linear features northwest of Indian Creek that suggest these faults have been obscured by surficial processes. A series of seismic reflection profiles in the study area were collected and interpreted by Liberty (2010). The longest of these, the four mile-long Indian Creek profile, was run along Indian Creek Road between Mayfield and the Elmore and Ada County line. Granitic bedrock (Kbgd) outcrops approximately a mile north of the northeastern end of this profile, and the seismic results indicate that depth to bedrock varies from approximately 1000 ft bls at the northeastern end of the profile to more than 5000 ft bls east of the Boise Stage Stop. Although Liberty (2010) originally concluded that seismic evidence for buried faults along this profile was weak, his recent reinterpretation indicates that at least two probable normal faults offset granitic basement two and three miles southwest of the range front. These faults are indicated in Phillips' et al. (2012) cross-section A-A'".

DATA SOURCES AND METHODOLOGY

The data that were evaluated during this analysis included:

(i) subsurface lithologic descriptions, well open intervals, water-bearing zones, and water temperatures as summarized in IDWR's well construction database (http://www.idwr.idaho.gov/apps/appswell/searchwc.asp) and reported in the associated well drillers' reports;

(ii) water-level and temperature data collected by IDWR in selected wells in the study area using automated data loggers (C. Tesch, written comm., 2010, 2011);

(iii) USGS water-level data (http://www.idwr.idaho.gov/hydro.online/gwl/default.html) and well construction information for the two monitoring wells nearest the study area;

(iv) aquifer hydraulic characteristics and water quality information from hydrogeological reports on the immediate study area and surrounding areas, principally SPF (2007a, 2007b; Tesch and Vincent, 2009; C. Tesch, unpubl. data); and

(v) lithologic data and unpublished information on recently drilled wells (Nevid LLC and Mayfield test wells, C. Petrich written comm., 2011) including chip logging by IGS (V. Gillerman, written comm., 2011).

Information from IDWR's on-line database and well drillers' reports was evaluated following protocols developed in previous work on the eastern Snake River Plain (Phillips and Wellhan, 2011a, 2011b; Phillips et al., 2010; Welhan, 2009; Welhan, in prep.). The coordinates of a small number of wells in the database are mislocated, and to be safe, any wells with a County location other than Ada or Elmore were disregarded in the analysis. Drillers' descriptions of lithologic characteristics were utilized to the extent that the information has proven to be reliable in previous work. In the lithologic context of the WSRP, as in the eastern Snake River Plain (ESRP), three lithologic groups are most likely to be reported fairly reliably: (1) volcanic rock (generally “lava”, “basalt” or “cinders”); (2) clay-rich sedimentary units with sufficient cohesion to pose challenges during drilling (e.g., “clay”, “sticky clay”); and (3) undifferentiated and partially differentiated sedimentary materials with grain-size information of unknown accuracy (e.g., “fine sand and clay”, “sandy gravel”, “decomposed granite”, etc.).

As for water-level information, one of the advantages of IDWR’s on-line database is the sheer number of water-level records that are available to augment or “fill-in” interpretations gleaned from the USGS water-level monitoring network. In the East Ada study area, with so few water-level monitoring locations, the on-line database is indispensable in a preliminary analysis of the hydrogeology. The on-line water level data represent measurements made following well development and are available as an ESRI-compatible shapefile that IDWR updates periodically (http://www.idwr.idaho.gov/GeographicInfo/GISdata/wells.htm). The April, 2010 version of this shapefile was utilized in this analysis. Several important limitations constrain how these water-level data can be used (Welhan, in prep.), including (i) uncertainties introduced by seasonal and climatic variability; (ii) lack of specificity regarding the intake depth(s) of a well and hence the piezometric context of its water level; (iii) erroneous “static” water-level readings due to inadequate well development, insufficient equilibration time for stabilization of static water levels, or measurement and reporting errors. Despite these potential sources of uncertainty, experience in the ESRP has shown that static water level data in the IDWR database is reliable on a regional scale, providing a good approximation of average water levels. Gross errors in ESRP drillers’ reports occurred in fewer than 5% of reported water levels (Welhan, in prep.).

Long-term water-level data on the only two nearby monitoring wells in the USGS’s network were obtained from the HydroOnline website (http://www.idwr.idaho.gov/hydro.online/gwl/default.html). Well construction, completion and depth information was obtained from the Boise Water Resources Division (A. Campbell, written comm., 2011).

RESULTS AND DISCUSSION

SUBSURFACE LITHOLOGY

Figure 2 shows the area recently mapped by Phillips et al. (2012) as well as the locations of cross sections that were constructed from the lithologic descriptions in IDWR drillers’ logs. Cross-section A-A’ (**Figure 3**) is oriented perpendicular to the Boise Front in the area of greatest availability of well data. The northeastern third of the cross section was constructed along Liberty’s (2010) Indian Creek seismic profile. Based on drill cuttings and borehole geophysics, Wood (1996) concluded that sediments encountered below about 2800 ft amsl were of lacustrine origin and quoted Whitehead’s (1992) resistivity soundings as evidence that the basalt section extends to an elevation of 1200-2000 ft amsl in the southwest part of the study area.

No firm evidence for faults was identified during detailed mapping in the vicinity of the range front in this area (Phillips et al., 2012), but Liberty’s analysis of geomorphological linears and his re-interpretation of seismic evidence (written comm., 2011) suggest buried faults do exist near the range front. The geologic architecture in Figure 3 conforms to Liberty's (2010) data and depth to bedrock near the range front as interpreted by Phillips et al. (2012). The dip of the sediment / bedrock contact in section A-A' is greater than 5^{o}, based on where drillers report encountering competent granite, which is consistent with the approximately 10^{o} dip of the bedrock reflector detected by Liberty (2010).

Cross-section B-B' (**Figure 4**) helps to place section A-A' in a regional context. Except for a thin carapace of Qbsf in the northeastern part of the section, the remaining lavas can only be differentiated as QTb (Pleistocene-Pliocene?; Phillips et al., 2012).

STATIC WATER LEVELS

Water-bearing zones, well intake zones, static water levels reported at the time of drilling, and other hydraulically relevant information reported in drillers' logs are shown in **Figures 5 and 6**. **Table 1** summarizes specific capacity information for the wells in section A-A'. In previous work on the eastern Snake River Plain, this author documented that reliable information on average static water levels and hydraulic gradients can be derived from drillers' reports by analyzing the spatial ensemble of a number of wells; such an approach overcomes the statistical noise due to measurement errors and seasonal and annual water-level fluctuations (Welhan, in prep.). Although there a limited number of East Ada drillers' reports available, it is assumed that a similar approach can be applied, albeit with a corresponding lower degree of confidence in the conclusions.

The majority of wells shown in Figures 5 and 6 have low specific capacities (Table 1)[1], whether or not they were developed by pumping or by air lift. Excluding the four highest estimates, average air-lift and pumped specific capacities are 0.4 and 1.4 gpm/ft, respectively. Including the four highest estimates, the average of only pumped estimates is 5.5 gpm/ft whereas the average of all air-lift and pumped specific capacities is 4.1 gpm/ft. The small sample size makes it difficult to determine whether specific capacities show any systematic variation across section A-A'. The average of five shallow (<400 ft) wells in the perched zone is 0.8 gpm/ft, whereas the average of eight wells in the deep (>400 ft) sedimentary aquifer is 5.9 gpm/ft. However, two of the three highest values in the deep aquifer occur nearest the range front (Ark Properties LLC wells). It is not known whether the wide range of specific capacities reflects well construction practices, insufficient well development or a highly variable permeability distribution in the deep aquifer. The available data provide no compelling evidence for a systematic decrease in the deep aquifer's transmissivity away from the range front.

Most but not all water-bearing zones encountered by wells evaluated in this study were completed as well intake zones. **Figure 7** summarizes depth information on the water-bearing zones and well intakes shown in cross-section A-A'. The conclusion to be drawn from this is that drillers in the East Ada area tended to report zones of significant water-bearing potential during drilling, including water-bearing zones that were not completed as well intake zones. Therefore, lacking more substantive information, it is concluded that the information provided in these drillers' reports can be used to infer locations of at least some of the principal water-bearing zones that exist in the subsurface.

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[1] *The exceptions are four wells (permit numbers 851081, 851510, 721893, 721391) with specific capacities of 7 to 15 gpm/ft.*

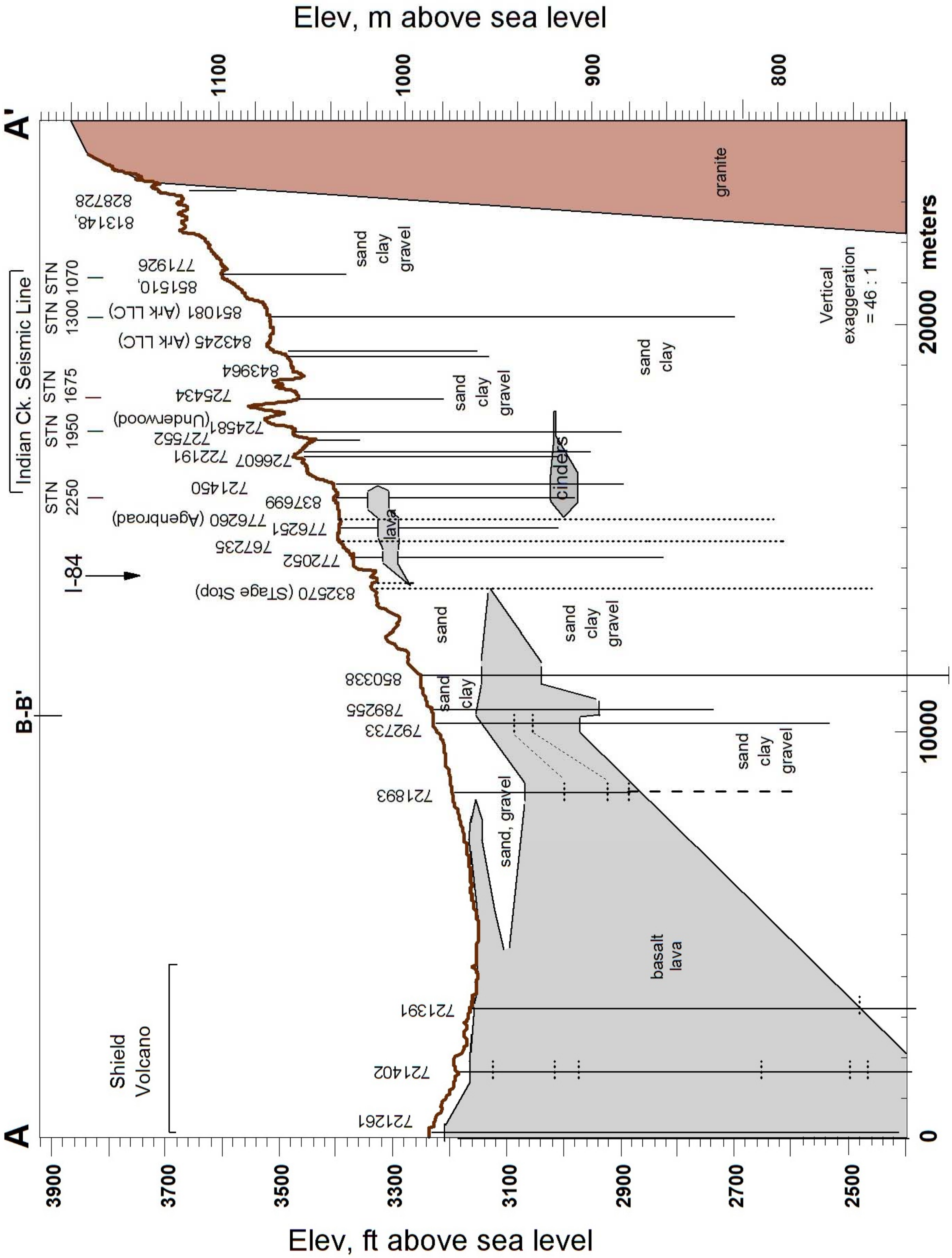


Figure 3 - Lithologic interpretation along cross-section A-A' in Figure 2. Locations of wells within 1 km of the section line are shown as solid lines; wells projected onto the section from greater than 1 km are shown as dashed lines. Well permit numbers shown for reference. Lithology is summarized from drillers' reports; dashed contacts within the basaltic lava section are locations of rubble, cinder, or other occurrences indicating contacts between lava flows. Location of Liberty's (2010) seismic Indian Creek seismic line is shown at the top, with some station numbers for reference.

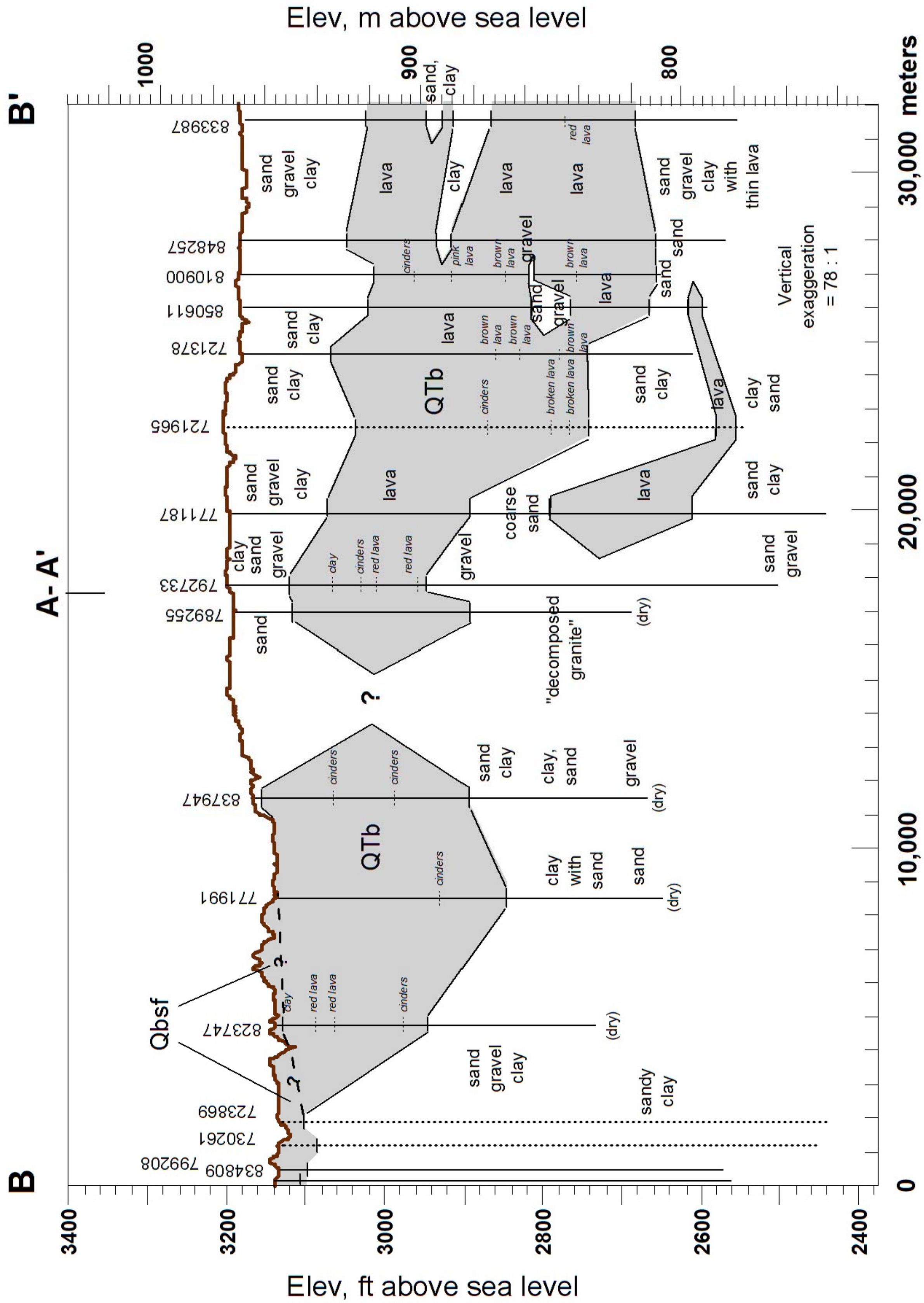


Figure 4 - Lithologic interpretation along cross-section B-B' in Figure 2. Symbolism, lithologic descriptions and well IDs are as described in Figure 3.

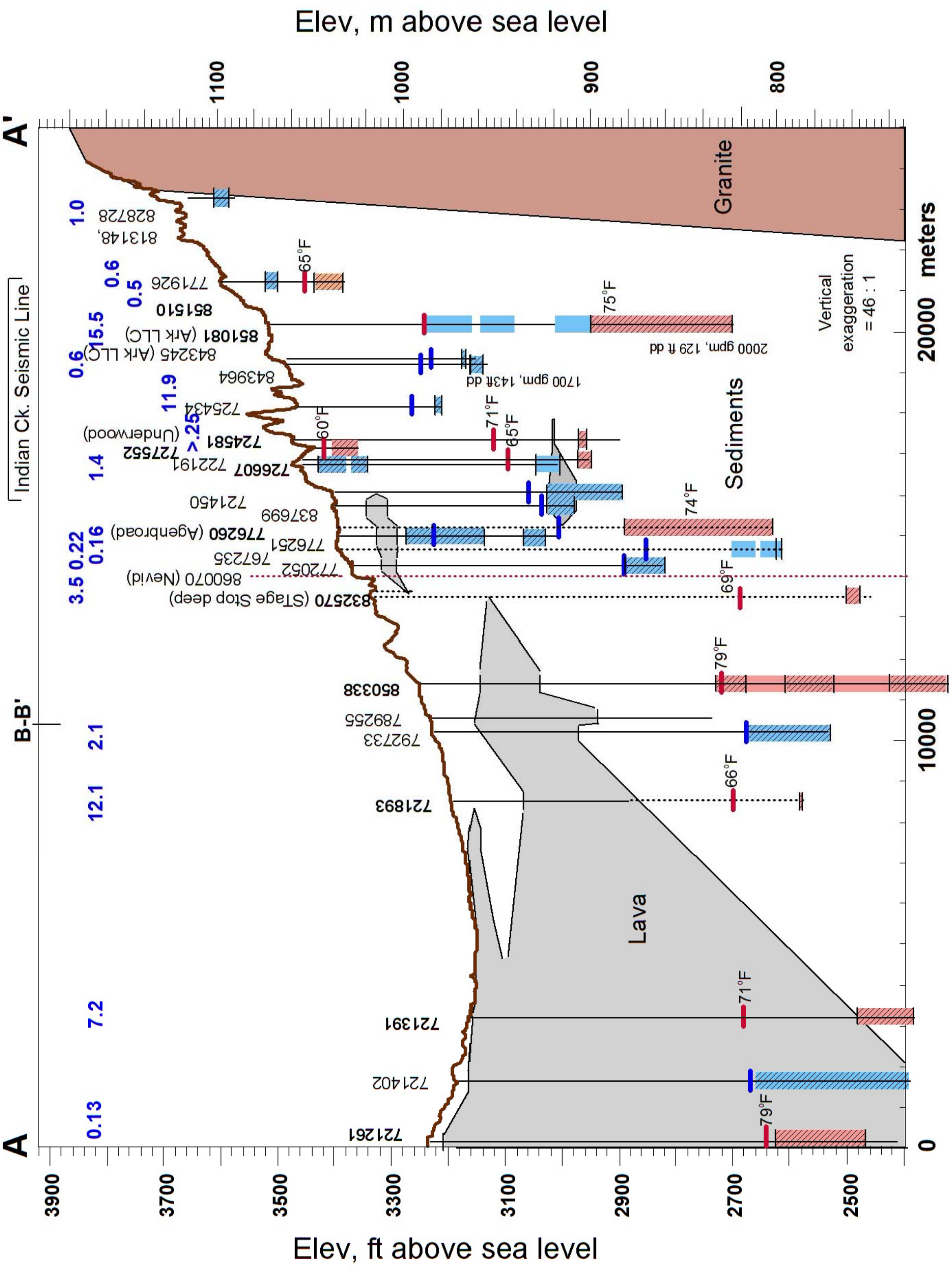


Figure 5 - Summary of relevant hydrologic information reported by drillers for wells along section A-A', including water-bearing zones (solid blue and red rectangles), well open intervals (hached rectangles), reported static water levels upon completion of drilling (heavy horizontal bars) and water temperatures (if reported). Well specific capacities (gpm/ft, from Table 1) are shown in bold blue font. Water-bearing zones, open intervals and static water levels for wells with water warmer than mean annual air temperature (55 °F;13 °C) are shown in red. Well number 776260 (Agenbroad) did not originally have a reported temperature but its temperature was measured in May, 1999 (SPF, 2007a).

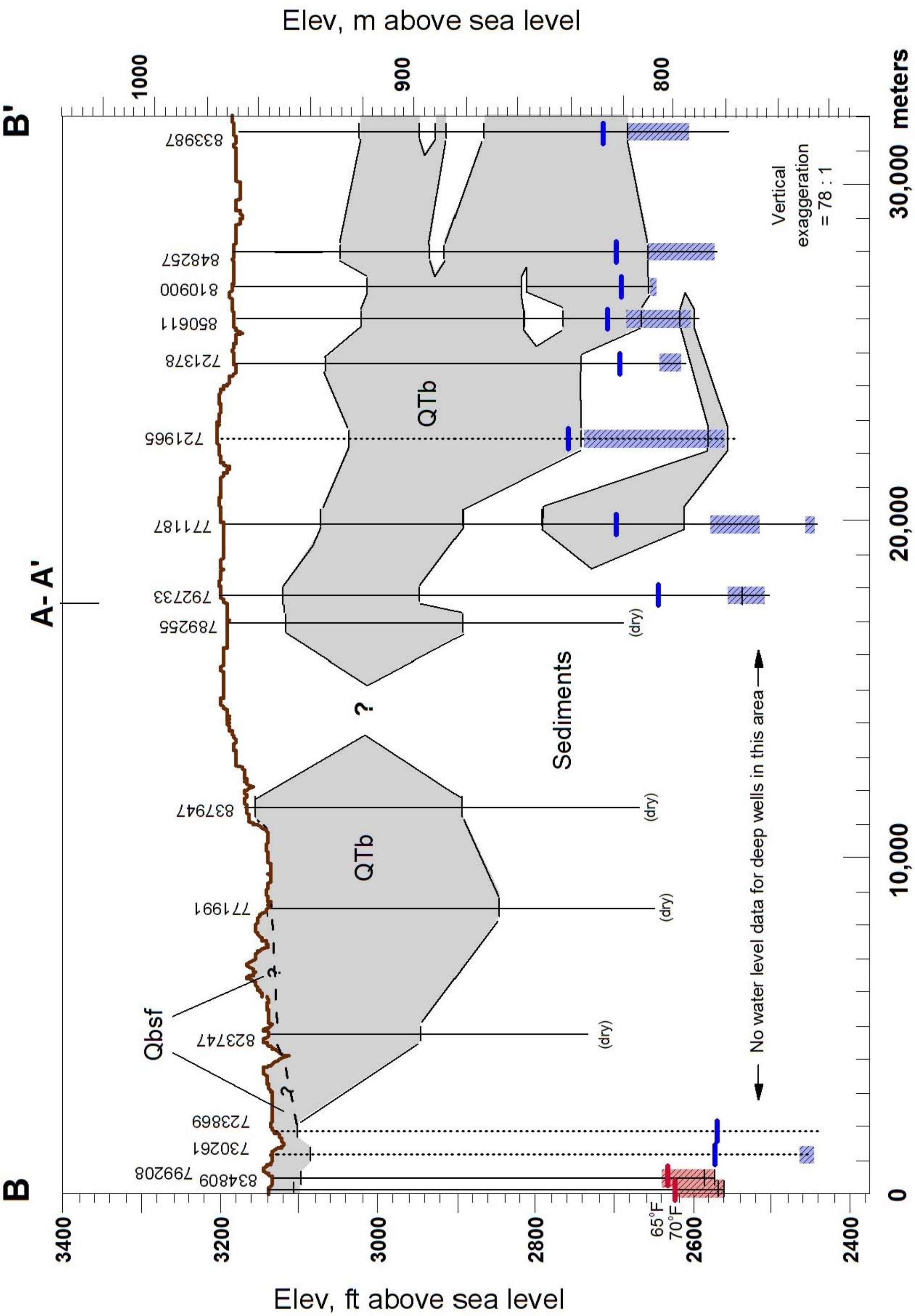


Figure 6 - Summary of all available hydrologically relevant information from drillers' reports for wells along section B-B'. Symbolism is described in Figure 5.

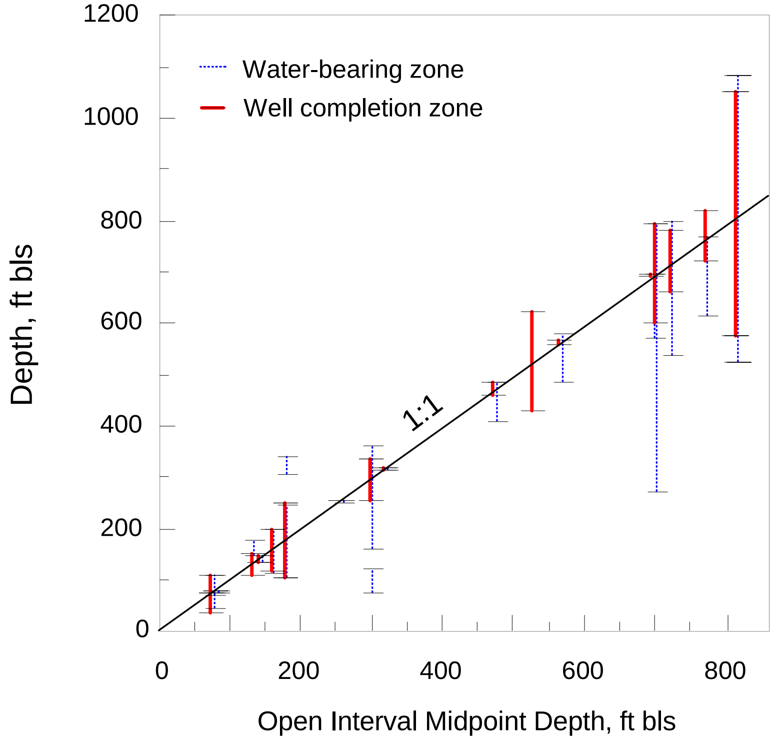


Figure 7 - Summary of depths at which drillers reported encountering water in wells along section A-A' and depth intervals over which the wells were eventually completed.

Table 1. Summary of specific capacity information from drillers' reports for wells along section A-A.'

Well Owner	Permit #	Depth feet	Production Zone Lithology	Yield gpm	Drawdown feet	Duration hours	Spec. Capacity gpm/ft	Development Method
Army National Guard	721261	825	Basalt	25	195	4	0.13	pumped
MATES / Ewing Co.	721402	800	Basalt	30	n.a.	1		air lift
MATES / ID National Guard	721391	753	Sand, clay	815	113	6	7.21	pumped
Frank Bonessa	721893	633	Sand, clay	9.7	0.8	12	12.13	pumped
Johnny Weimer	792733	695	Sand, gravel	25	121	5	2.08	bailed
Pacific west land LLC	850338	1082	Sand, clay	n.a.	n.a.	n.a.		no pump
Jim Phagan	772052	572	Sand, gravel	17	79	2	0.22	air lift
Tim Anderson	767235	665	Medium sand	20	122	1	0.16	air lift
Nevid LLC	860070	833	Sand	60	17	12	3.5	pumped
Blackie Stewart	817181	260	Sand (D.G.)	80	n.a.	2		other (air?)
Craig Wilson	837699	418	Cinders	15	n.a.	1		air lift
Neil Helmick	721450	510	Coarse sand	20	n.a.	5		air lift
James Underwood	727552	75	Sand	55	40	1.33	1.38	n.a.
James Underwood	722191	485	Sand	60	n.a.	2		air lift
James Underwood	724581	568	Fine sand	8.7	<35	65	>0.25	pumped
Ron Ambrose	725434	56	Sand, gravel	40	n.a.	3		air lift
Ark Properties LLC	843964	690	Fine-coarse sand	1700	142	8	11.97	pumped
Ark Properties LLC	851081	809	Fine-medium sand	2000	129	6	15.50	pumped
Larry Farnsworth	815531	147	Sand	60	n.a.	1		air lift
Bo Nielsen	843245	330	Sand, gravel	30	48	1	0.63	air lift
Mayfield Townsite LLC	851510	200	Fine-coarse sand	25	50	1	0.50	air lift
Leo Zummers722626	722626	200	Sand, gravel	20	33	2	0.61	air lift
Jeff Lord771926	771926	100	Sand	10	n.a.	2		air lift
Western Land and Cattle Co.	813148	82	Sand, gravel	25	25	4	1.00	pumped

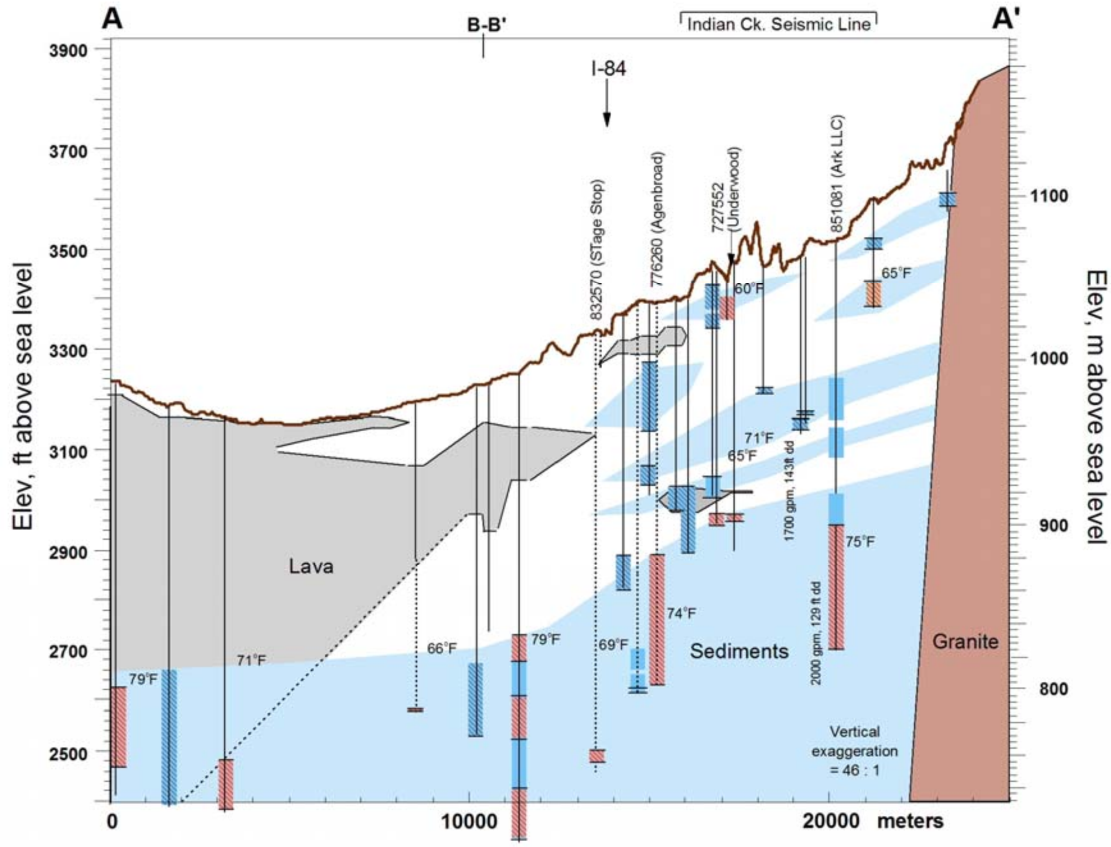


Figure 8 - One of many possible interpretation of aquifer geometry along section A-A' based solely on the locations of reported water-bearing zones.

In Figure 5, the spatial distribution of water-bearing zones suggests the possibility that multiple perched aquifers exist in the shallow, northeast part of the section. **Figures 8 and 9** represent two possible configurations drawn with and without piezometric information. Figure 8 depicts multiple perched zones based on the depths where water-bearing zones were reported. The interpretation shown in Figure 9 considers both water levels and their spatial relationship to reported water-bearing zones to infer the vertical extents of a perched aquifer and a deep aquifer. The point is that numerous interpretive scenarios of the spatial distribution of perched zone(s) are possible. What is important to recognize, however, is that one or more zones of perched water exist and that, like the regional aquifer below it, these zones are recharged from the highlands as well as from a possible range front fault zone.

The hydraulic gradient in the deep aquifer ranges from a low of 0.011 near the presumed fault to a maximum of 0.027 about 8 km southwest (in the vicinity of I-84). The larger gradient is similar to that depicted in SPF Engineering's contoured water table map (figure 7 in SPF, 2007a) and to the water table map generated by IDWR (C. Tesch, written comm., 2011). Neither interpretation differentiates between hydraulic heads measured in deep vs. shallow wells.

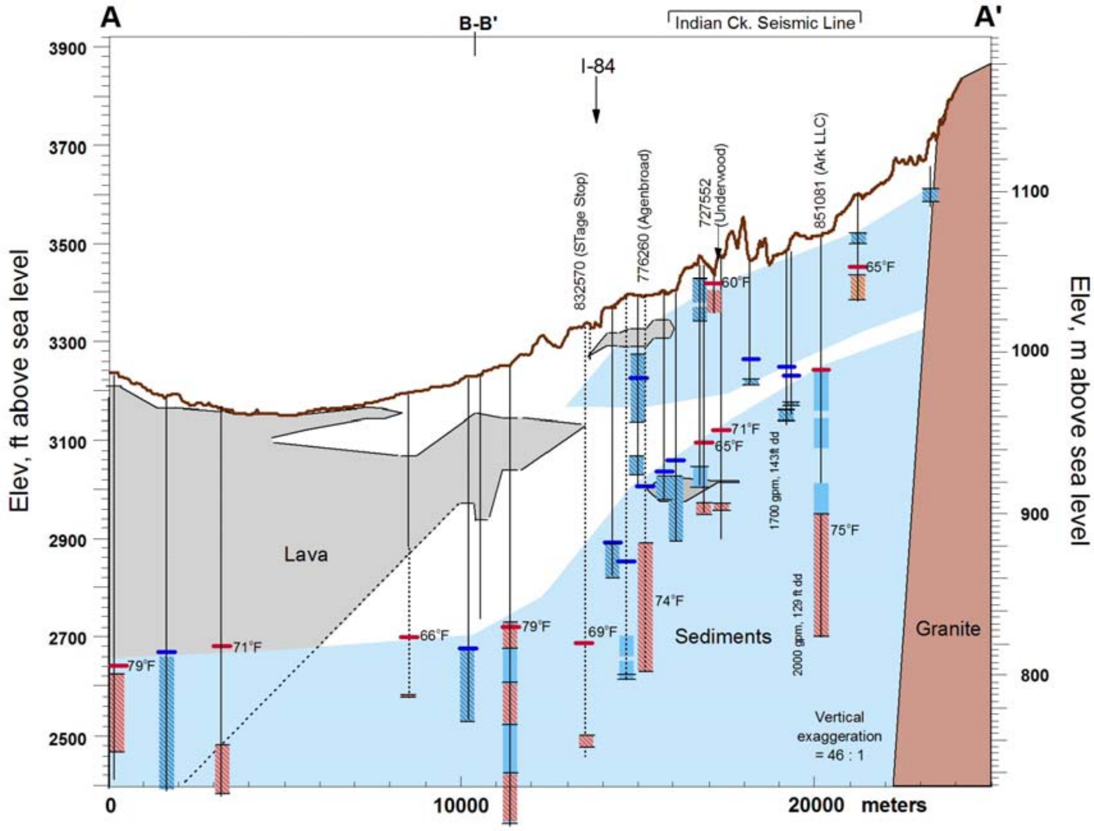


Figure 9 - A simplified interpretation of possible aquifer geometry along section A-A' based on reported static water levels as well as the locations of reported water-bearing zones.

Water-level information along section B-B' is quite sparse (Figure 6) compared to section A-A'. For example, very few deep wells encountered water northwest of section A-A', and perched water is almost never reported in the basalt-dominated part of the section. Possible factors responsible for the dearth of perched zones reported in the basalts include: (i) these lava flows are too permeable and have few aquitards to sustain significant perching; (ii) recharge rates are insufficient relative to vertical drainage rates; or (iii) the lavas are too impermeable to deliver water to an advancing wellbore so that most perched zones go unnoticed.

In this regard, **Figures 9** and **10** reveal a potentially relevant observation, namely that the regional hydraulic gradient appears to be steeper in the sediment-dominated portions of the aquifer system. More deep well water-level data, particularly in the basalt aquifer, are required to corroborate this suggestion but could shed light on the relative hydraulic characteristics of basalt vs. sediment in this part of the WSRP. The single specific capacity measurement in Table 1 for a well completed in basalt is significantly lower than the average of those reported for deep wells completed in sediment (0.1 vs. 0.9 gpm/ft). Whether this is because of drilling practices, inadequate well development, or low intrinsic permeability is unknown. Fundamental uncertainties regarding the basalt aquifer's transmissivity, thickness, storage capacity, and hydraulic impact on surrounding aquifers will only be addressed with additional data from deep wells drilled into these basalts in the future.

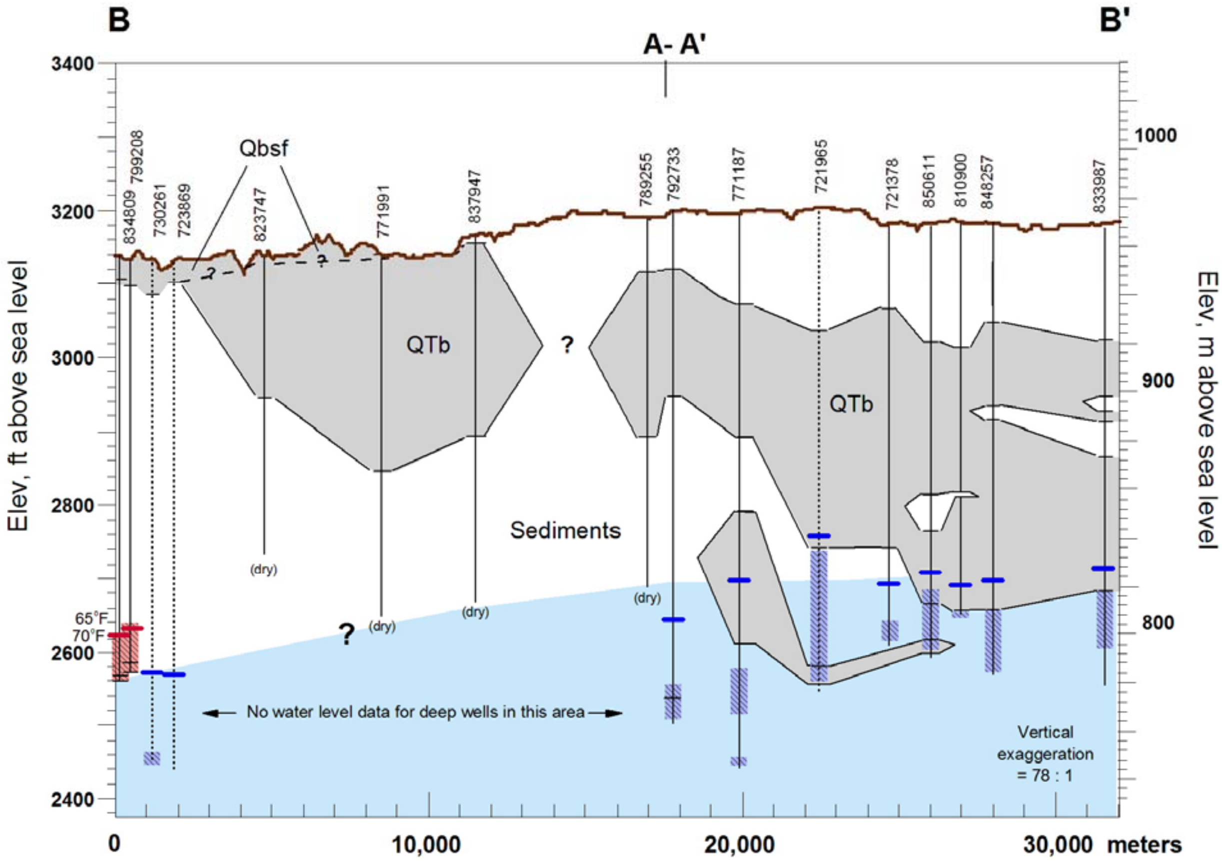


Figure 10 - Possible aquifer geometry based on depths of reported water-bearing zones and static water levels along section B-B'.

POSSIBLE RECHARGE SOURCES AND TEMPERATURES

Previous studies have considered two potential sources of recharge to this system: (i) infiltration of precipitation in excess of ET, mainly confined to higher elevations; and (ii) seepage losses from streams that flow out of the highlands onto the alluvial fans. SPF Engineering estimated annual average infiltration in the headwater areas of Indian Creek, Upper Sand Hollow and Bowns Creek watersheds (48,900 acre areal extent) to be 3130 acre-ft and stream seepage losses to be 6000 - 42,430 acre-ft (SPF, 2007a; 2007b). However, in a region known for its ubiquitous thermal water wells (Laney and Brizee, 2003), the contribution of a possible geothermal recharge component also needs to be considered.

The temperature information summarized in Figures 5 and 6 reflects measurements made by thermometer or thermocouple devices either during well development or when the static water level was measured. The data likely represent an incomplete and/or biased sample of the actual distribution of ground-water temperatures in the study area. The available data allow for two possible interpretations: (i) these aquifers actually have heterogeneous spatial (and possibly temporal) temperature distributions, or (ii) most of the ground-water temperatures in this area are elevated but are not reported consistently, measured accurately, or both.

Table 2a summarizes available temperature measurements reported in the map area (Figure 2); **Table 2b** lists wells that have been instrumented with continuous-recording data loggers since about May, 2010 (C. Tesch, written comm., 2011) and that have both hydrograph and thermograph data available. The spatial distribution of wells with reported water temperatures is shown in **Figure 11**.

Of three wells whose temperatures were not reported at the time of drilling, two that were since monitored by IDWR have above-normal temperatures (Agenbroad, 776260; Stage Stop Deep, 832570). The Underwood well's temperature was initially reported as 65 ^{o}F but measurements by IDWR since have not been higher than 55 ^{o}F, indicating that some erroneous measurements and reporting errors are contained in this data set. It is possible that drillers are less likely to notice and measure elevated ground-water temperatures in summer when air temperatures are high than during the cooler seasons. However, Table 2a indicates that almost as many elevated temperatures were reported in spring and winter (n = 24) as in the summer and fall (n = 26). Therefore, except for measurement and reporting error, it is assumed that these temperatures are representative of aquifer conditions and not reporting bias.

Figure 12a and **12b** summarize the frequency distribution of temperatures reported in wells across the map area and in the vicinity of section A-A', respectively. Reported temperatures range from 52 ^{o}F (11 ^{o}C) to 96 ^{o}F (35.5 ^{o}C). The low end of the range reflects Boise's average annual air temperature (50.9 ^{o}F) which is normal for meteoric recharge and is typical of this climatic zone (Gass, 1982). However, two-thirds of wells along section A-A' are in the 66-71 ^{o}F (19-22 ^{o}C) range, suggesting that other water sources contribute to this aquifer, namely: (i) seepage of seasonally warmer surface water from local streams, and/or (ii) a deep thermal source of water that rises along the Boise Front fault system and mixes with cold ground water derived from the highlands.

The occurrence of thermal water reported in shallow wells that are influenced by stream infiltration could reflect seepage of warm surface water during the summer. Skinner (2005) demonstrated that shallow ground water temperatures near the lower Boise River respond to stream water infiltration. Ground water temperatures near the river typically rise from a baseline of 50-54 ^{o}F (10-12 ^{o}C) in early April to greater than 60 ^{o}F (15.5 ^{o}C) in July and August in response to infiltration of seasonally warmer stream water. The seasonal effect in the lower Boise River may be enhanced because of agricultural return flows, but Donato's (2002) analysis of stream temperature data from Idaho's highlands shows that seasonal temperature changes of 4-14 ^{o}F (2-8 ^{o}C) are normal. Based on these considerations it is assumed that ground-water temperatures higher than about 60 ^{o}F do not reflect surface water infiltration, particularly in deep (>200 ft) wells. More generally, adopting IDWR's definition of geothermal water, any ground water with a temperature above 68 ^{o}F is considered to have a geothermal component.

Local geothermal gradients in the western Snake River Plain are of the order of 30-40 ^{o}C/km (Waag and Wood, 1987) and are at least as high in the Idaho Batholith (Swanberg and Blackwell, 1973). To achieve a temperature of 96 ^{o}F (35.5 ^{o}C), the highest temperature reported in the map area, ground water would have to circulate to a depth of less than 1 km. However, there is no evidence that these temperatures reflect conduct heat flow gradients in the WSRP (Brott et al., 1976). For example, looking in more detail at section A-A', five of twelve wells deeper than 200 feet are above 75 ^{o}F. If supported by conductive heat flow, a temperature difference of this magnitude (21-25 ^{o}F; 38-45 ^{o}C) between the surface and 200-600 feet depth implies a conductive thermal gradient of more than 200 ^{o}C/km. Lacking a shallow heat source, therefore, these elevated temperatures must reflect mixing of thermal water that rises from depth.

Table 2a. Summary of reported temperatures in shallow and deep wells of the study area from drillers' logs. Wells in the vicinity of section A-A' are highlighted in bold font. 'Not reported' indicates that the well's temperature was not recorded in the driller's log.

Shallow Well	Permit No.	Depth, ft	T, oF	Drilled	Comments
Stage Stop Shallow	**721925**	66	55	05/17/1999	not reported
C.D. Mills	721685	140	Cold	06/23/1996	
Leo Zimmer	**722626**	200	59	09/04/1988	
Underwood	**727552**	75	54*	10/13/1993	IDWR data
Andy Bosworth	763164	120	52	01/20/2000	
Robert Bravo	**770361**	160	65	11/10/2000	
Lord House	**789248**	95	57	11/26/2002	
Oakwood Homes	850878	180	68	03/17/2008	
Mayfield Townsite	**851510**	200	65	06/10/2008	
Wayne Russell	852649	175	57	08/15/2008	

Deep Well	Permit No.	Depth, ft	T, oF	Drilled	Comments
Army Nat'l Guard	**721261**	825	79	11/10/1989	
Fred Smith	721307	431	58	03/26/1990	
MATES / Id. Nat'l Guard	**721391**	680	71	04/02/1992	
Ron Castle	721499	535	65	07/28/1993	
Ron Castle	721699	678	Cold	04/25/1996	
Jim Hopson	721829	580	60	02/06/1998	
Dan Hennis	721874	465	64	09/15/1998	
Frnk Bonessa	**721893**	580	66	05/01/1999	
Jim Hutchings	721896	540	56	12/12/1998	
State of Idaho	722342	1000	78	06/23/1988	
Underwood	**724581**	568	71	05/07/1991	
Danskin	**726607**	480	65	10/15/1993	
Idaho State Corr'n	765930	770	78	08/30/2001	
Bob Wickham	775948	460	68	01/11/2002	
Bud Pembroke	776129	416	71	04/15/2002	
Agenbroad	776260	763	73.5	09/04/1979	not reported
Mike Eisman	778010	640	63	06/20/2002	
Gloria Gangler	779607	600	56	07/02/2002	
Dale Payne	780944	720	70	05/21/1978	
Maurice Goff	781374	515	96	01/17/1998	
Arlin Woodbridge	783086	440	68	08/16/2002	
Dale Meeks	788349	435	60	11/01/2002	
Rich Cornell	789257	390	62	11/28/2002	
Steve Tupper	789402	490	72	12/19/2002	
Ron Robertson	799208	569	65	04/30/2003	
Hwy Dept,	811007	975	71	05/01/1969	
Jim Hutchings	816073	480	70	06/09/2004	
State of Idaho	819916	605	72	03/12/1966	
Allied Waste	828149	720	60	01/27/2005	
Fred Hickey	830176	600	72	02/15/1970	
StageStop Deep	**832570**	884	69-75	04/25/2005	not reported
Grimes	834809	582	70	07/30/2005	
Ricky Tullis	844723	458	Cold	10/27/2006	
Clarence Merrick	846446	725	92	11/28/1965	
Harold Pettibone	849367	480	72	10/18/2007	
Pacific West Land	**850338**	1087	78.6	03/21/2008	
Ark Properties LLC	**851081**	809	75	06/12/2008	
Joe Rowan	855693	405	68	04/11/1980	
Rick Taylor	855723	469	62	05/11/2009	
Frank Senn	856906	499	70	07/02/2009	

* IDWR has consistently measured a temperature of 54 ^{o}F in this well (C. Tesch, written comm., 2011), whereas the temperature reported in the driller's log is 65 ^{o}F.

Table 2b. Summary of monitoring wells for which both water-level and temperature data are available in the study area. Static water level (SWL) data are derived from IDWR's on-site data loggers except where noted; USGS data are from HydroOnline (http://www.idwr.idaho.gov/hydro.online/gwl/default.html). 'S' = seasonal water level or temperature fluctuation; 'D' = declining; 'I' = increasing; Δ = range in water level and temperature around the average. All changes are based on near-continuous time-series records so that changes of 0.1 °F or 0.1 ft are statistically significant.

Well Name	Permit No.	Elev, ft amsl	Open Interval, ft bls	Average SWL, ft	ΔSWL, ft	Average T, °F	ΔT, °F	
Danskin	726607	3425	420-460	300	S*	63.5	4	Seasonal max in Jul-Oct
Underwood shallow	727552	3425	28 - 75	40	D	53.7	0.8	Seasonal max in Jan
Stage Stop deep	832570	3347	880-884	642	S**	70.0	5.5	Pumping-induced+
Stage Stop shallow	721925	3343	54 - 66	52.5	D	55	D	Mostly monotonic trends
Agenbroad	776260	3353	500-752	390***	-	-	-	
Rest Stop	838418	3347	810-945	669***	-	-	-	
USGS-1	-	3150	550-750	483	D	69.5	I	40-year trend data available
USGS-2	-	3304	485-525	339	-	-	-	40-year trend data available

* Pumping-induced excursions of 12 to 14 ft
** Pumping-induced excursions of 7 ft
*** From driller's report at time of drilling
\+ Termperature responses coincide with pumping-induced drawdowns

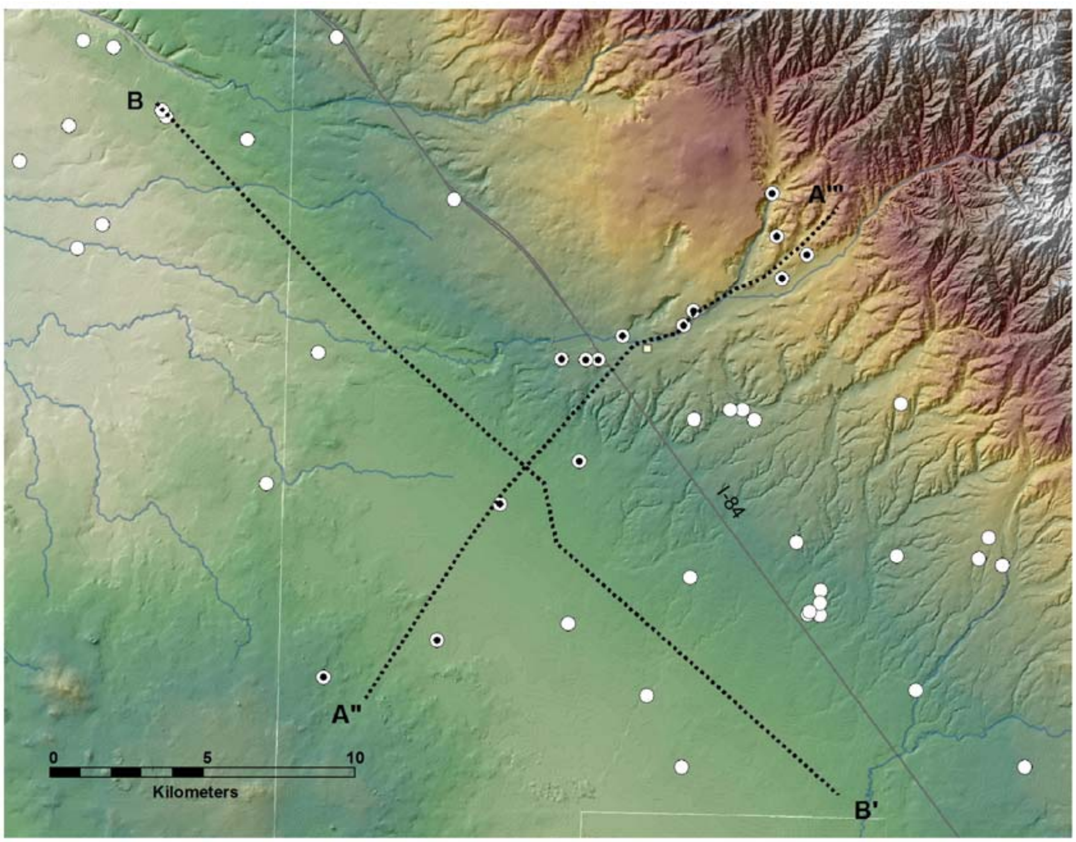


Figure 11 - Spatial distribution of water temperature information in shallow and deep wells within the map area (light circles) and in the vicinity of section A-A' (dark centers).

Given the range of observed temperatures, it is likely that East Ada aquifers are recharged by a mixture of cold, shallow ground water originating in nearby highlands and geothermally heated water that originates from greater depths and geographic distances. High concentrations of lithium and fluoride characterize all thermal waters in the Boise geothermal system and in theIdaho Batholith (Waag and Wood, 1987; Druschel and Rosenberg, 2000) and could be used as tracers to detect the presence of these thermal waters and to estimate their degree of mixing with cold ground water.

To the author's knowledge, there are no estimates available for the rate at which deeply circulating geothermal water recharges known thermal aquifers in the region. Of the geothermal production wells in Boise, six of the largest, ranging from 1100 to 3000 ft in depth, produce a total of about 1800 acre-ft of 155-165^{o}F (68-74^{o}C) water annually (Waag and Wood, 1987). Because the Boise geothermal system has experienced long-term head declines due to over withdrawal, the long-term average thermal recharge rate to the aquifers that supply these wells must be less than 1800 acre-ft/yr.

Regardless of the mechanism by which East Ada ground waters are heated, it is clear from the number of deep warm-water wells in the East Ada study area that a geothermal recharge source cannot be discounted in the water balance of this ground-water system.

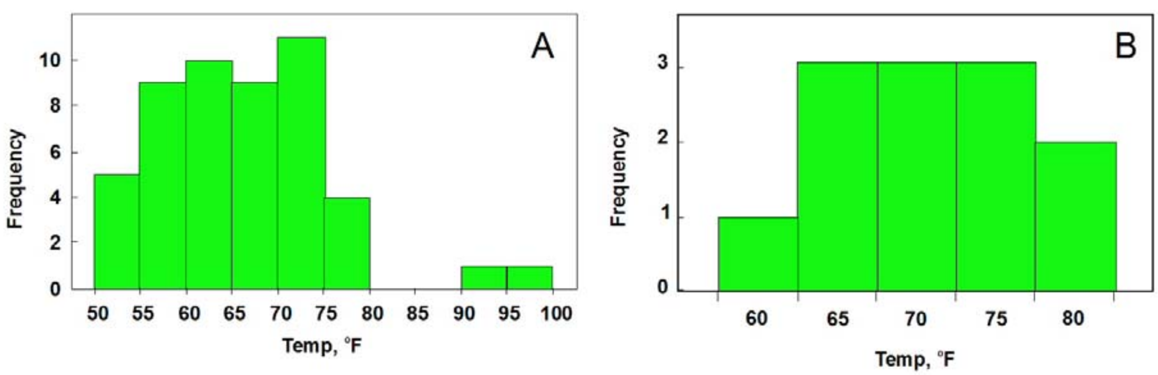


Figure 12 - Distribution of temperatures in (A) all wells for which temperatures were reported in the map area (Figure 11) and (B) only wells along section A-A'. Meteorically recharged ground water in this region is estimated to be in the 50-54 ^{o}F range based on Boise's average annual air temperature.

WELL HYDROGRAPHS AND THERMAL RESPONSES

Hydrogaphs generated by IDWR (C. Tesch, written comm., 2011) for four wells along section A-A' (two shallow and two deep wells) are shown in **Figure 13**. The deep wells display regular seasonal and pumping-induced head variations but no long-term trend information can be gleaned from two years of records. In contrast, both shallow wells exhibited year-long water level declines since the inception of logging (ca. May, 2009) through October-November, 2010.

The only long-term hydrographs available for the study area are from two USGS monitoring wells located several kilometers from sections A-A’ and B-B’ (Figure 2). **Figures 14 (a, b) and 15 (a, b)** show the depths of USGS-1 and USGS-2’s intake zones projected onto sections A-A’ and B-B’, respectively, as well as their lithologic context relative to other wells in their immediate vicinity. In keeping with the deep wells’ muted well responses in Figure 13, long-term water levels in USGS-1 and USGS-2 also vary little from year to year and change very gradually over decade-long time scales.

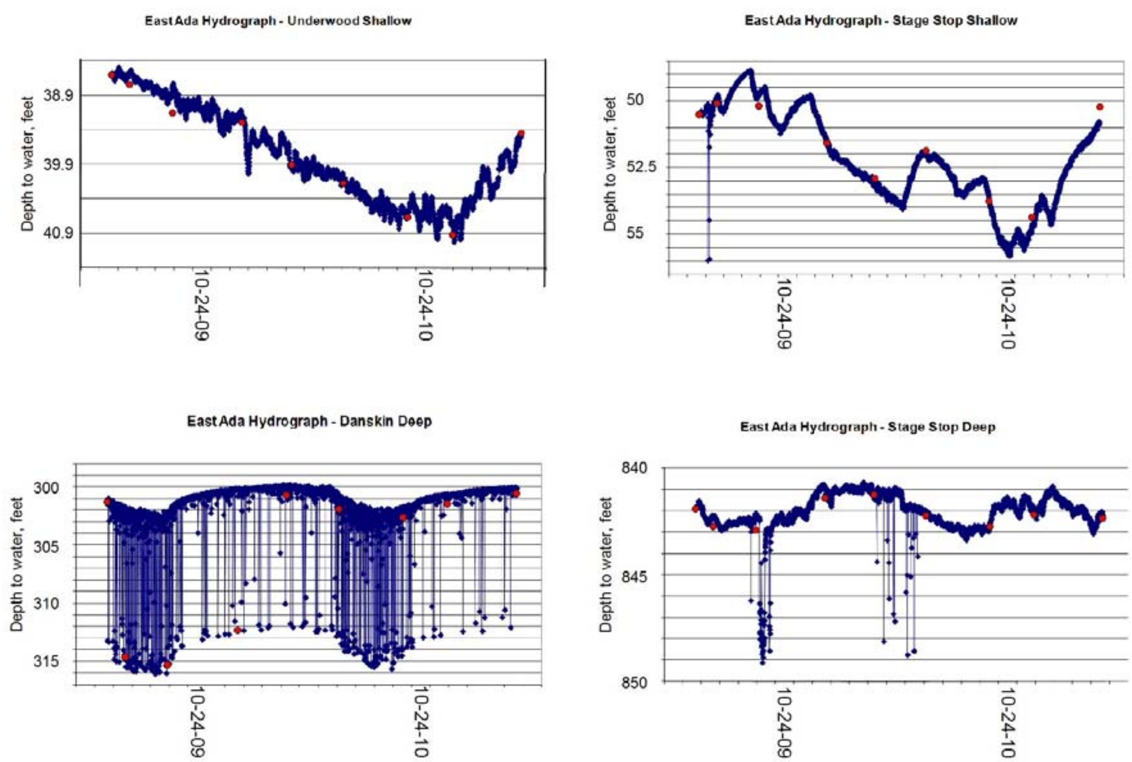


Figure 13 - Hydrograph data collected by IDWR for two shallow and two deep wells along section A-A'. Red symbols indicate hand-measured water levels.

Thermographs for the four wells shown in Figure 13 are summarized in **Figure 16**. Several conclusions can be drawn from these data:

- minimum temperatures in the Underwood and Stage Stop shallow wells are near normal for meteoric recharge in this area (53-55 ^{o}F; ca. 12 ^{o}C);
- significantly higher ground-water temperatures indicate the influence of either seasonally warmed surface water or deep geothermal water;
- seasonal cyclic temperature variations in shallow wells (e.g., Underwood) indicate infiltration of warm surface water into the shallow aquifer;
- temperature variations in the two deep wells demonstrate that varying proportions of a geothermal component is mixing with cold ground water.

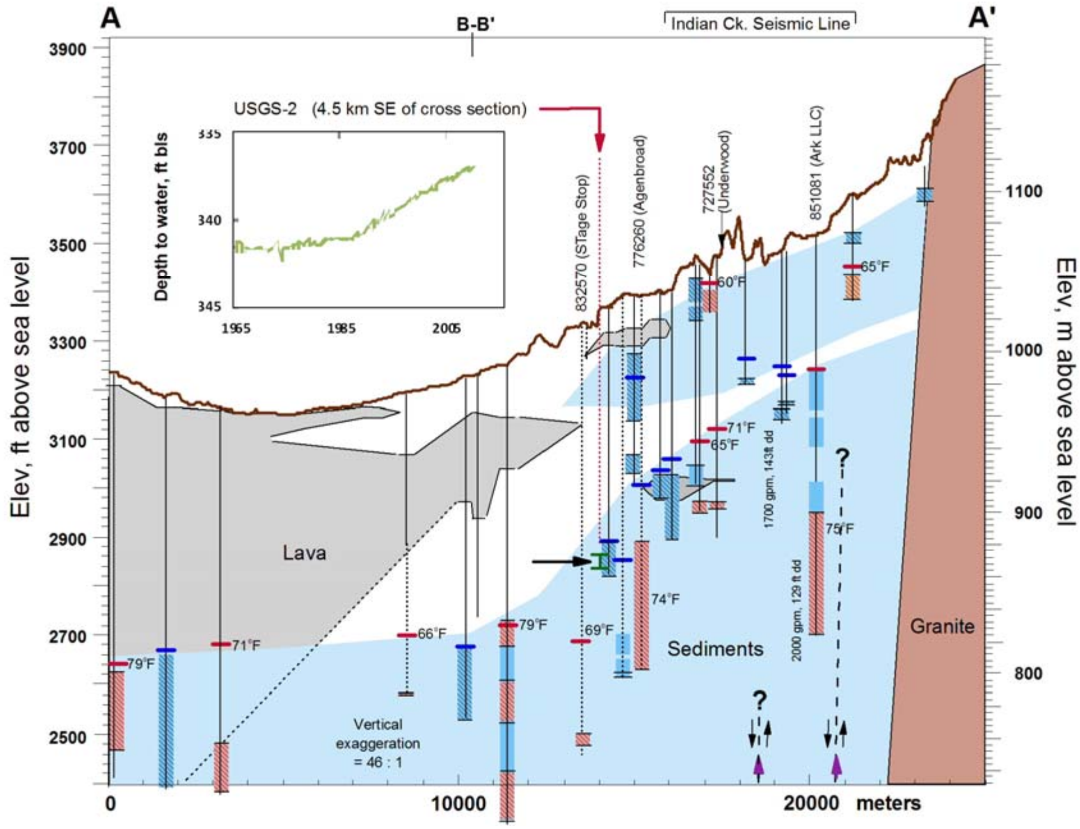


Figure 14a - Location of USGS-2 monitoring well, projected 5 km onto section A-A', and the depth over which it communicates with the subsurface (arrow, green bar). The 40-year hydrograph shows a long-term, very gradual rise in water level with no strong seasonal effects, indicating that the deep aquifer is actively recharged but on a protracted time scale. Arrows at lower right show approximate location of buried faults from Phillips et al. (2012), projected up to the elevation of this cross section.

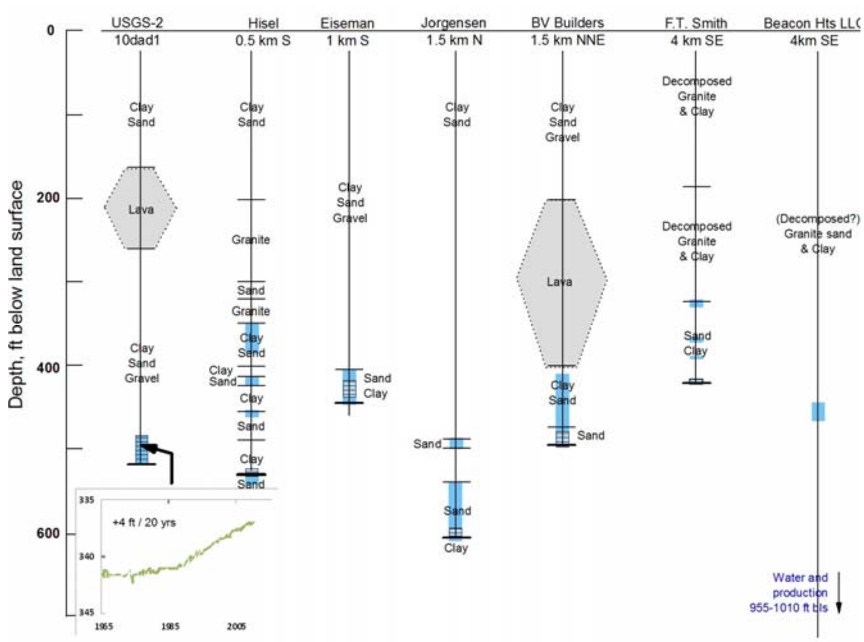


Figure 14b - Comparison of reported lithologies, water-bearing zones and open intervals for water wells drilled in the immediate vicinity of USGS-2. Heavy horizontal bars indicate completion depth.

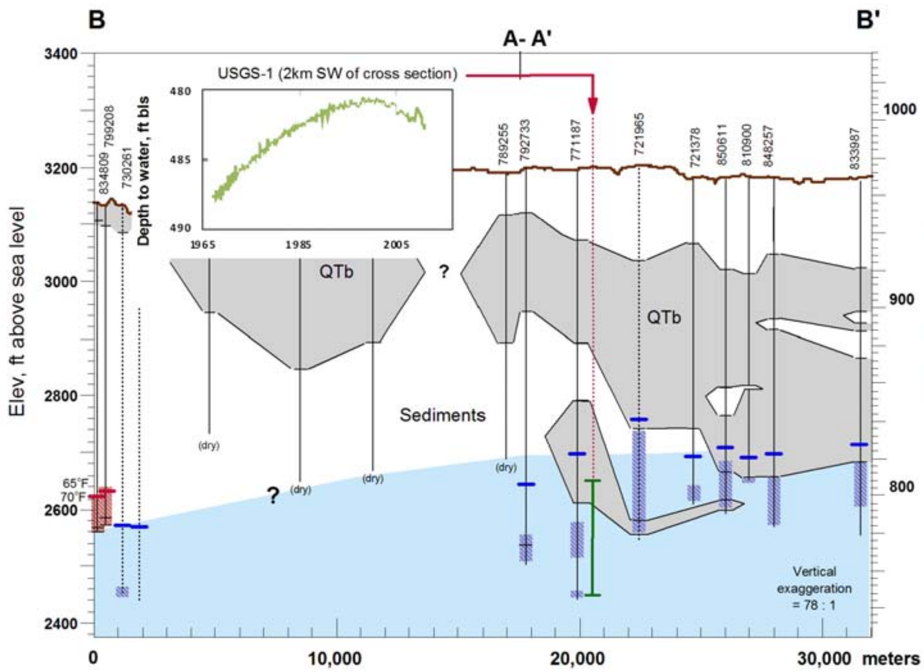


Figure 15a - Location of USGS-1 monitoring well, projected 2 km onto section B-B', and the depth over which it communicates with the subsurface (green bar). The 40-year hydrograph also shows a long-term, very gradual change in water level with no strong seasonal effects, indicating that the deep aquifer is actively recharged on a decadal time scale. Symbolism is as described in Figure 5.

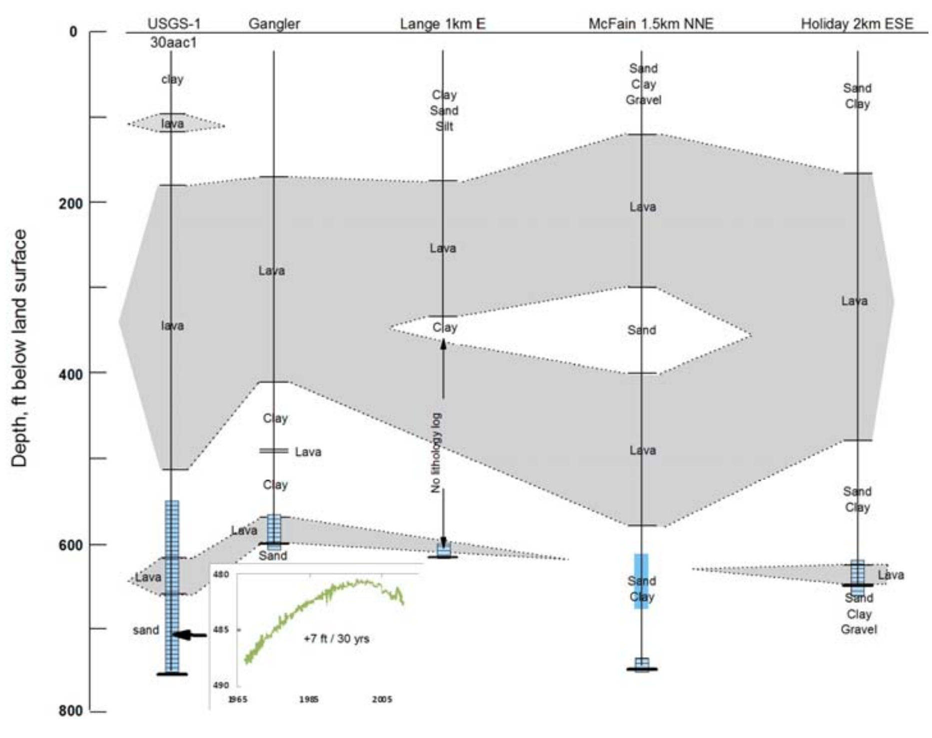


Figure 15b - Comparison of reported lithologies, water-bearing zones and open intervals for water wells drilled in the immediate vicinity of USGS-1. Heavy horizontal bars indicate completion depth.

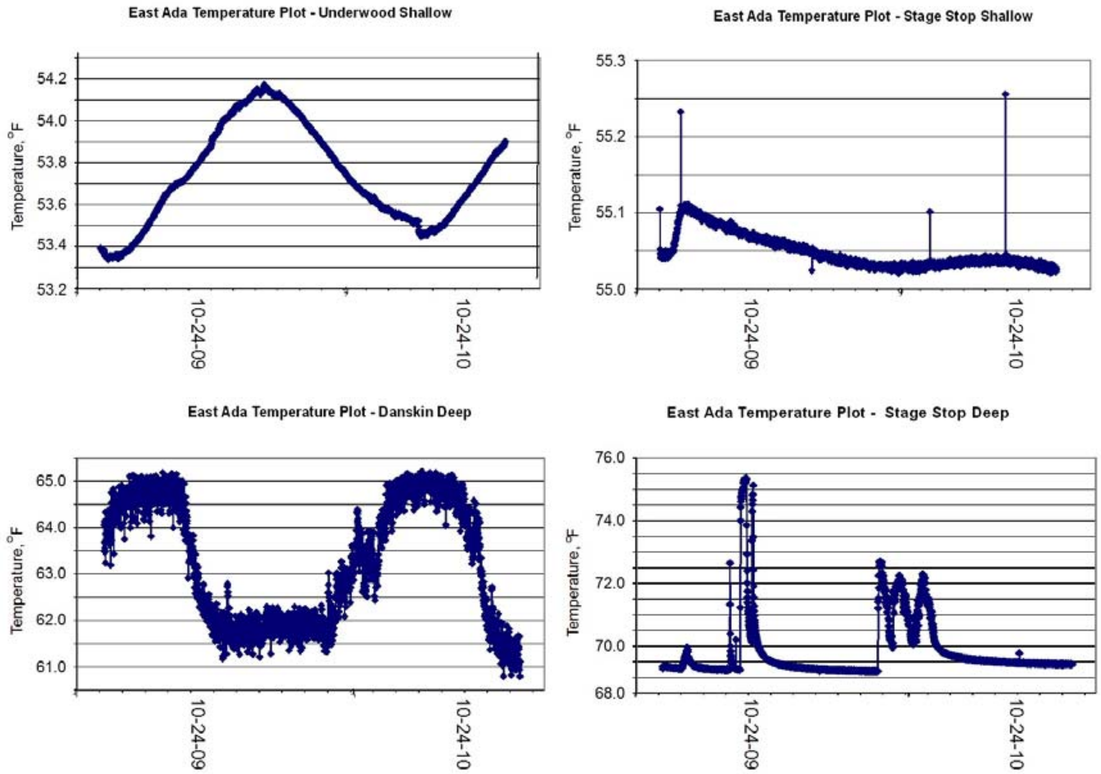


Figure 16 - Thermograph data collected by IDWR for the same two shallow and two deep wells shown in Figure 12.

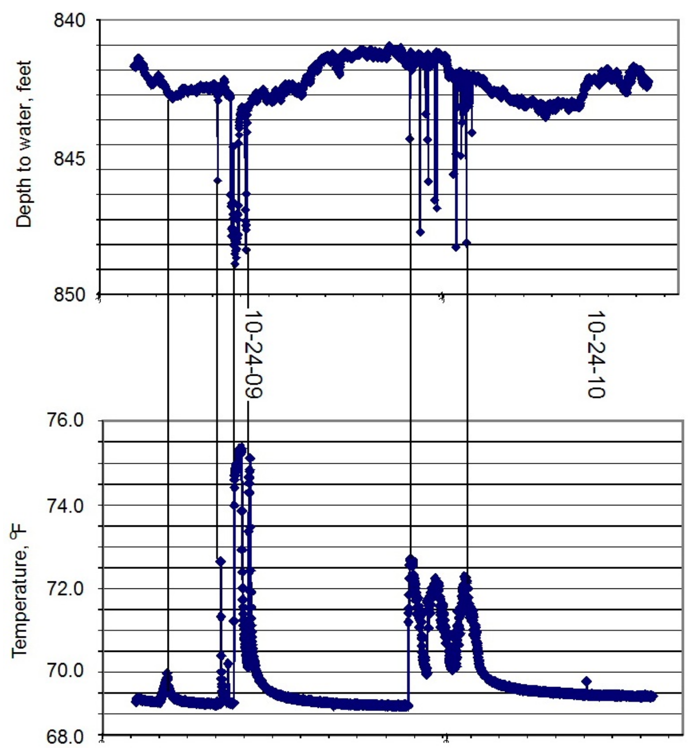


Figure 17 - Comparison of hydrograph and temperature responses to pumping in the Stage Stop deep well.

The Danskin deep well pumps on and off year-round (C. Tesch, written comm., 2011) so the regularity of its seasonal temperature variation suggests that mixing of warm and cold water is primarily controlled by seasonal changes in the hydraulic heads that characterize the recharge sources. In contrast, the timing of temperature fluctuations in the Stage Stop deep well (**Figure 17**) indicates that local mixing proportions also respond to pumping-induced incursions of thermal water into the well's intake zone.

Taken together, these observations demonstrate that cold and warm water recharge components coexist in the East Ada deep aquifer and that their proportions change due to seasonal influences and to local pumping. What is not known are (i) the spatial scale(s) over which the cold and warm components intermingle, (ii) where and how the thermal component enters the deep aquifer, and (iii) the relative magnitude of geothermal recharge in the deep aquifer's water balance.

HYDROGEOLOGIC CONCEPTUAL MODEL

Based on the evidence presented, a conceptual flow system model is proposed to test some basic premises. **Figure 18**, adapted from Wood and Waag (1987), summarizes the large-scale elements of the model:

- Zones of perched water in the East Ada area are sustained by recharge from local catchments and by seepage losses from local streams.
- Water temperatures in the shallow perched aquifer can fluctuate due to infiltration of seasonally warmer stream water and dilution with cold meteoric recharge.
- Geothermal fluids that recharge the East Ada deep aquifer derive from deep circulation along fracture zones in the Idaho Batholith. They represent regional-scale recharge characterized by temperatures that reflect the high regional geothermal gradient in the Batholith (30-40 ^{o}C/km), very long residence times (>7000 years; Waag and Wood, 1987; Mayo et al., 1984), and circulation to depths of a kilometer or more.
- Faults near the range front channel geothermal fluids into the deep aquifer where they are diluted to varying degrees by cold meteoric water.
- Water temperature in the deep aquifer can also fluctuate both spatially and temporally due to seasonally varying mixing proportions, but in a much subdued manner compared to shallow wells.

Figure 19 summarizes the features of the conceptual model on a local scale. A perched aquifer (or collection of perched aquifers) is recharged across the range front fault from nearby watersheds and by leakage from local streams. No perched water is reported in wells drilled farther to the southwest, so the perched water zone(s) near the range front fault must either drain to the underlying deep aquifer, creating a recharge mound (shown as a dashed line in Figure 19), or they must drain out of the cross section. The deep aquifer is recharged by a combination of meteoric water derived from local catchments and deep geothermal water rising along buried faults associated with the Boise Front. Two of these faults, identified from seismic data (Liberty, 2010), are shown in Figure 19 with their approximate locations projected vertically upwards into cross section A-A'. The hydraulic gradient of the deep sedimentary aquifer is much steeper than the regional basalt-dominated aquifer into which it drains. Moving from the basalt aquifer toward the range front, the hydraulic gradient steepens because of a combination of lower`

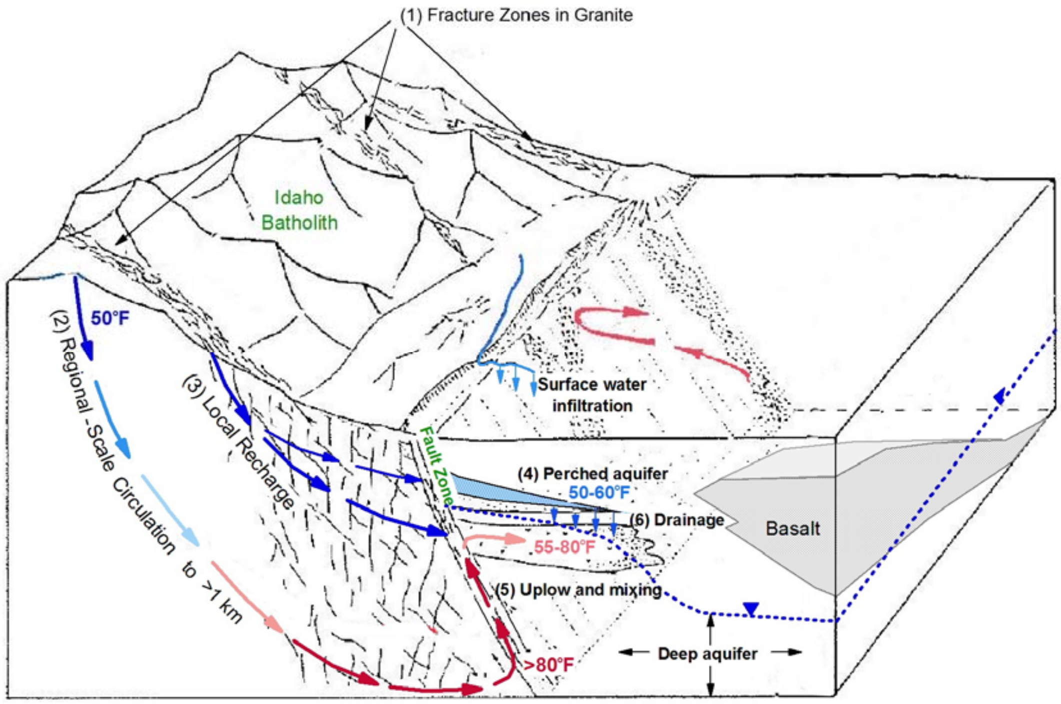


Figure 18 - Regional-scale conceptual model of the East Ada study area showing the principal elements of the flow system: (1) permeable fracture zones in the Idaho Batholith and in the Boise Front fault system; (2) regional-scale recharge via deep circulation through the Idaho Batholith that leads to a characteristic geochemical signature of these thermal waters; (3) meteoric recharge in the headwaters of the Upper Indian Creek, Sand Hollow Creek and Bowns Creek catchments (non-thermal source); (4) a shallow, perched aquifer (blue hachured) that is recharged by a combination of meteoric recharge and infiltration from local streams flowing out onto the alluvial fans; (5) upflow of thermal recharge along the range front fault and mixing between thermal and non-thermal recharge components in the East Ada deep aquifer (dotted blue line); and (6) vertical drainage of the perched aquifer to the deep aquifer. Adapted from a figure by Waag and Wood (1987) depicting the hydrogeologic elements of the Boise geothermal system.

transmissivity in the sediments relative to the basalt and because of recharge that originates from the range front. Nearest the range front, the hydraulic gradient (I_1 = 0.011) reflects the recharge flux derived from local catchments (R_1). Farther from the range front, the gradient steepens markedly (I_2 = 0.027), reflecting either (i) a systematic decrease in transmissivity away from the range front or (ii) localized additional recharge. Possible sources of localized recharge are geothermal fluids (R_2) that enter the aquifer along buried faults or water that drains from the overlying perched aquifer (R_3), either or both of which would lead to a mounding of the deep aquifer's water table. In either scenario (i) or (ii), the observed range in hydraulic gradients allows the magnitude of recharge flux the deep aquifer to be constrained. The conceptual model suggests two immediately testable hypotheses:

(1) Using concentrations of fluoride and other indicator elements in the thermal component to estimate mixing proportions in the deep aquifer; and

(2) Using the spatial variation of the deep aquifer's hydraulic gradient to constrain the magnitude of recharge fluxes to the deep aquifer.

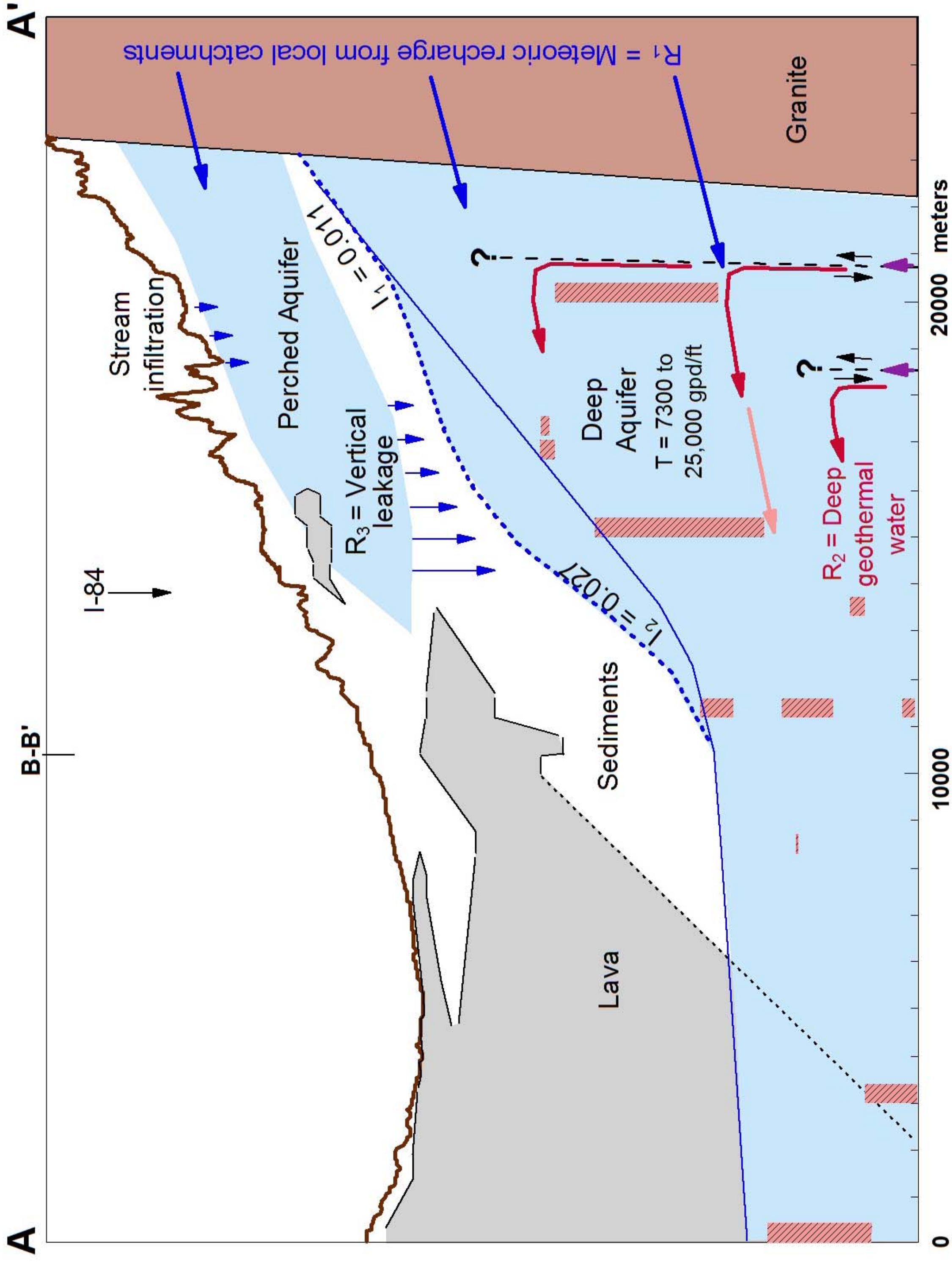


Figure 19 - A local-scale conceptualization of the East Ada aquifer system, showing the principal recharge components and hydraulic gradients to which they give rise. Local, shallow meteoric recharge (R_1) contributes to both the perched and deep aquifers and mixes with deep geothermal water (R_2) rising along buried faults to recharge the deep aquifer. The perched aquifer, which is partially recharged by seasonally warmed losses from local streams, may drain to the deep aquifer and provide a third recharge component (R_3). The total flux, R_1+R_2 (+R_3?), supports the steeper hydraulic gradient (I_2). Alternatively, a zone of lower transmissivity could be responsible for the steepening.

HYPOTHESIS 1 - WATER CHEMISTRY

Table 3a compares major ion chemistry of thermal springs and wells of the Idaho Batholith and the Boise geothermal system. **Table 3b** compares the major ion chemical composition of a water sample collected from the Agenbroad well (763 ft deep; permit #776260) in May, 1999 (SPF, 2007a) with the average composition of waters from the Boise geothermal system and Idaho Batholith hot springs. The striking chemical similarity among the Boise

Table 3a. Chemical similarity of hot springs of the southern Idaho Batholith and wells of the Boise geothermal system. Data are from: Druschel and Rosenberg, 2000 (S. Fork Payette River springs); Young, 1985 (other Idaho Batholith springs); and Mayo et al., 1984 (Boise geothermal system wells).

Site	T	pH	Conductivity	Ca	Mg	Na	K	F	Cl	SO4	CO3	HCO3	SiO2	
	(oC)		micro-mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	
Deer Creek HS	78.2	8.0	1300	3.0	n.a.	149.0	5.4	11.5	31.4	77.1	1.4	162.2	102.6	
Goller HS	42.5	9.2	475	1.2	n.a.	84.8	1.3	14.7	7.0	28.8	7.8	110.9	64.8	
Danskin HS	37.1	9.4	400	1.3	n.a.	79.7	0.9	13.1	5.2	37.1	7.8	90.2	52.4	
Pine Flats HS	59.4	9.2	556	1.1	n.a.	88.0	1.1	16.1	6.0	32.5	5.0	91.8	61.9	
Kirkham HS	60.3	9.2	500	1.3	n.a.	76.4	1.1	13.5	3.7	33.2	3.1	70.7	59.4	
Bonneville HS	83.9	9.1	975	1.2	n.a.	92.8	2.7	16.4	6.0	45.0	0.9	90.2	98.2	
Sacajawea HS	65.1	9.2	600	1.2	n.a.	89.8	2.6	14.5	8.6	41.9	5.9	108.5	85.1	
Middle Fork Boise River	76.0	9.4	297	1.6	n.a.	64.0	1.7	9.2	2.4	28.0	n.a.	16.0	100.0	
Idaho City	42.0	9.5	317	2.0	0.1	65.0	0.8	13.0	2.7	22.0	n.a.	41.0	57.0	
North Fork Payette	86.0	8.9	331	1.4	0.1	74.0	1.9	12.0	11.0	12.0	n.a.	95.0	86.0	
Boiling Springs	88.0	9.2	n.a.	2.2	0.0	74.0	1.9		14.0	12.0	n.a.	106.0	81.0	
Warm Spr. District	79.5	8.2	n.a.	3.2	0.1	82.8	1.4	19.2	6.0	21.6	n.a.	109.8	63.5	
Boise Geothermal No.2	74.0	8.4	n.a.	1.6	0.1	86.7	1.3	16.9	7.8	25.9	n.a.	111.1	31.7	
Capitol Mall No.1	65.0	8.5	n.a.	1.6	0.1	89.0	0.7	18.2	0.9	16.3	n.a.	126.3	56.5	
Capitol Mall No.2	70.5	7.6	n.a.	1.3	0.1	79.3	0.6	16.0	19.6	19.2	n.a.	114.1	55.6	
														'Chg.Balance
Avg. of Idaho Batholith spr	65.3	9.1	575.1	1.6	0.1	85.2	1.9	13.4	8.9	33.6	4.6	89.3	77.1	8.0%
Avg. of Boise geothermal	72.3	8.1	n.a.	1.9	0.1	84.5	1.0	17.6	8.6	20.8	0.0	115.3	51.8	4.3%

Table 3b. Comparison of major ion chemistry of thermal water in the East Ada area (Agenbroad well) with average compositions of hot springs in the Idaho Batholith and wells in the Boise geothermal system. Data from the Agenbroad well are from SPF (2007a) and data on the Boise geothermal and Idaho batholith waters is from Table 3a.

Site	T	pH	Conductivity	Ca	Mg	Na	K	F	Cl	SO4	CO3	HCO3	SiO2
	(oC)		micro-mho	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l
Agenbroad well	23.1	8.2	225	22.6	0.91	24.3	1.2	0.51	2.63	n.a.	n.a.	142	17.7
Avg. of Batholith springs	65.3	9.1	575.1	1.6	0.1	85.2	1.9	13.4	8.9	33.6	4.6	89.3	77.1
Avg. of Boise geothermal	72.3	8.1	n.a.	1.9	0.1	84.5	1.0	17.6	8.6	20.8	0.0	115.3	51.8

system and hot springs in the Idaho Batholith, especially the low charge balance error based on their <u>average</u> compositions, indicates that these thermal waters have a similar origin. Mixing models also indicate that the Agenbroad well's water composition is consistent with the mixing of a Ca-dominated local ground water with a Na-dominated silica-rich thermal end member like that of Idaho Batholith hot springs and the Boise geothermal system.

Additional geochemical data summarized by SPF (2007a) can be used to test hypothesis (1): 25 analyses of fluoride concentrations from eight East Ada wells spanning 13 years ranged from a low of 0.3 mg/l to a high of 0.5 mg/l with a mean of 0.36 mg/l. Similar fluoride concentrations, averaging 0.6 mg/l and spanning a range from 0.16 to 2.1 mg/l, occur in ground water of the lower Boise River (Parliman et al., 2000). If the lowest concentration (0.16 mg/l) is representative of cold ground water in the western Snake River Plain and geothermal recharge to the deep aquifer has a temperature and fluoride content similar to hot springs of the southerm Idaho Batholith and wells in the Boise geothermal system (65 ^{o}C, 13-18 mg/l; Table 3a), then the highest fluoride levels in East Ada wells (including Agenbroad) indicate that the deep aquifer contains less than 3% of a 70 ^{o}C geothermal component. However, the observed temperature in the Agenbroad well (73.5 ^{o}F, 23.1 ^{o}C) indicates that the proportion of geothermal water is about ten times higher (20%). The conclusion is that fluoride does not behave conservatively, likely because of fluorite (CaF_2) solubility constraints (Nordstrom and Jenne, 1977). However, a more comprehensive investigation of the kinetics of fluorite precipitation under East Ada deep aquifer geochemical conditions would ensure that drinking water supplies developed in the deep aquifer would not be adversely impacted by short-term pumping-induced mixing (such as observed in the Stage Stop deep well, Figure 17).

HYPOTHESIS 2 - CONSTRAINTS ON RECHARGE

As shown in Figure 19, the hydraulic gradient of the deep aquifer varies from I_1 = 0.011 to I_2 = 0.027 over a distance of 4-5 miles (6-8 km). SPF (2007a, b) estimated the combined rate of meteoric recharge from the Indian Creek, Upper Sand Hollow and Bowns Creek catchments at 2.9 Mgpd (3130 acre-ft/yr) from a headwater catchment area of approximately 35 square miles and recharging the East Ada aquifer system across about a 10 km (33,000 ft) length of the Boise Front (see Figure 2). They also provided transmissivity estimates from two pump tests (Ark Properties LLC; Agenbroad wells) that ranged from 7300 to 25,000 gpd/ft, respectively. Darcy's Law relates transmissivity and gradient in the form:

$$R_1 = T * I_1 * L \qquad \text{Eqn. 1}$$

where T is transmissivity, L is the width over which flow takes place (33,000 ft), and I_1 is the hydraulic gradient (0.011) that reflects recharge to the deep aquifer from local catchments (R_1) plus possible geothermal fluids rising along unknown faults in the immediate vicinity of the range front. Using SPF's range of transmissivity estimates and assuming that the hydraulic gradient near the fault is unaffected by leakage from the perched aquifer, the calculated annual average recharge (cold meteoric + geothermal water) ranges from a minimum of 2.6 Mgpd to a maximum of 15.6 Mgpd (2900 to 17,500 acre-ft/yr). The low end of the calculated range is close to SPF's estimated catchment-derived recharge rate (R_1) of 3130 acre-ft/yr. However, theirs is an unconstrained estimate based on the arbitrary assumption that annual precipitation exceeds evapotranspiration by 5% in local catchments.

The hydraulic gradient more than doubles to 0.027 in the vicinity of I-84 either because of a decrease in transmissivity or an additional source of recharge (geothermal fluids and / or leakage from the overlying perched zone). No evidence exists for a systematic decrease in transmissivity away from the range front. The most reliable estimate of specific capacity in the vicinity of the steep gradient is the Nevid LLC well, 1 km east of USGS-2. That value (3.5 gpm/ft; Table 1) implies a transmissivity that is only slightly lower than the estimate of 7300 gpd/ft observed in the Agenbroad well whose specific capacity (4-5 gpm/ft) is equivalent to the 5.7 gpm/ft average for all deep wells along section A-A'(Table 1). Therefore, the mounding of the deep aquifer's water table in this area must reflect additional recharge input(s).

If additional sources of recharge are the cause of the steepened gradient (I_2), then their magnitude can be quantified based on R_1. The ground-water flux supporting the steepest gradient is:

$$R_1+R_2+R_3 = T * I_2 * L \qquad \text{Eqn. 2}$$

where T is of the order of 7000 gpd/ft and L is 33,000 ft. The sum of R_2+R_3 represents the combined inputs of geothermal fluid (R_2) rising along the buried faults identified by Liberty (2010; written comm., 2011) plus possible leakage of shallow ground water (R_3) from the overlying perched zone. The resulting total flux is 6.2 Mgpd/yr. By mass balance, the previous calculation (R_1 = 2.6 Mgpd) limits the combined amount of geothermal recharge and leakage from the overlying perched zone to R_2+R_3 = 3.6 Mgpd (4030 acre-ft/yr). If SPF's high-end transmissivity estimate (25,000 gpd/ft) were assumed in Eqn. 1, then the resulting total flux would be 22 Mgpd/yr and the magnitude of additional recharge increases to 6.5 Mgpd (7280 acre-ft/yr), which is within a factor of two of that derived from the low-end transmissivity estimate.

If the hydraulic gradient's steepening is solely due to a zone of low transmissivity, then R_2+R_3 would be negligible and the range of effective transmissivities is constrained by:

$$T_1 * I_1 = T_2 * I_2 \qquad \text{Eqn. 3}$$

where T_1 and T_2 are the average bulk transmissivities proximal to and distal from the range front, respectively. Assuming that T_2 is in the 7,000 gpd/ft range, T_1 would have to be about 18,000 gpd/ft and from Eqn. 1, R_1 = 11.2 Mgpd (12,600 acre-ft/yr).

Ultimately, however, all of the above estimates are based on knowledge of the average aquifer transmissivity. In light of the cost and time required to improve our knowledge of the deep aquifer's effective transmissivity, it may be more cost effective to obtain fundamental estimates of precipitation, runoff and evapotranspiration in the headwater region so as to independently constrain I_1, T_1 and related parameters so that greater confidence can be placed in recharge estimates derived from the above arguments.

SUMMARY AND RECOMMENDATIONS

LITHOLOGY AND STRUCTURE

In the study area, subsurface lithology is dominated by fine sands and gravels out to ca. 10-12 km from the Boise Front and by thick accumulations of basalt lavas closer to the basin's depo-center. One or more faults associated with the Boise front are assumed to exist within the study area. A recent seismic survey by BSU (Liberty, 2010; written comm., 2011) and work by Phillips et al. (2012) provides corroborating evidence for the presence of at least two buried bedrock faults near the range front. The hydrogeologic interpretation developed in this report does not explicitly invoke structural controls to explain the hydrogeologic features observed within the study area, although the location of the two buried faults helps to explain many of the details of thermal water occurrences and hydraulic gradients in the deep aquifer. Instead, the analysis relied solely on hydraulic information to impose constraints on the magnitudes of the recharge fluxes that influence the deep aquifer.

HYDROGEOLOGY

Drillers have reported encountering very little or no perched water in the axial basalts of the WSRP, particularly along section B-B'. Possible reasons for this include: (i) the basalts contain too few aquitards to sustain any significant perching; (ii) recharge to the basalts is insufficient to sustain perched water zones; or (iii) the lavas are too impermeable to deliver water to an advancing wellbore. The very low regional hydraulic gradient in the basalt-dominated portion of sections A-A' and B-B' suggests that the basalt's transmissivity is significantly greater than the sediment aquifer, though, which leaves (i) and (ii) as the most plausible.

In contrast to the basalt-dominated portion of the system, perched water is routinely encountered above the deep, regional aquifer in the sediment-dominated part of the East Ada aquifer system, but only within 4-5 miles (6-8 km) of the range front. The hydraulic gradient in the deep aquifer was estimated by explicitly differentiating between deep and perched water-producing zones and ranges from 0.011 to 0.027 along section A-A'.

Almost all of the wells along this cross section have low specific capacities, averaging 5.7 gpm/ft. This may be due to drilling and well completion practices, inadequate well development, or to overall low transmissivities in the sediment-dominated part of the aquifer.

THERMAL INFLUENCES

The temperature information in drillers' reports represents an incomplete and/or biased sample of the actual distribution of aquifer water temperatures in the study area. Two possibilities exist: (i) East Ada's aquifer system is characterized by spatially (and temporally?) heterogeneous ground-water temperatures, or (ii) the deep aquifer's temperature is above normal throughout this part of the WSRP but the accuracy of drillers' measurements does not reflect this. From the data evaluated in this report, possibility (ii) cannot be ruled out.

Given the available evidence, it is clear that both cold and warm water components contribute recharge to East Ada's deep aquifer. The normal range of ground water temperatures in this region is 50-54 ^{o}F (10-12 ^{o}C), but temperatures reported by drillers in the WSRP between Mountain Home and Boise range up to 96 ^{o}F (35.5 ^{o}C). Almost all elevated readings are in wells deeper than 400 feet, and their widespread occurrence indicates that thermal recharge is ubiquitous across this part of the WSRP. With a local geothermal gradient of 30-40 ^{o}C/km, regional-scale ground water circulation need only penetrate to depths of about a kilometer to be heated to the observed temperatures.

Two-thirds of East Ada wells are in the 66 to 71 ^{o}F (19-22 ^{o}C) range, with the lowest temperatures consistently reported in shallow wells (<200 ft deep). Minimum temperatures in the shallow Underwood and Stage Stop monitoring wells (53-55 ^{o}F; ca. 12 ^{o}C) are typical of normal ground water. However, the influence of stream water infiltration into shallow aquifers may explain seasonal temperatures fluctuations seen in some shallow wells (e.g., Underwood).

Meteoric recharge to shallow aquifers results in ground water temperatures very near average annual air temperature (50-54 ^{o}F, in this region). Five of twelve wells deeper than 200 feet along section A-A' are above 75 ^{o}F (Figure 5). If such temperatures are supported by conductive heat flow that results in warming of shallow ground water, a temperature difference of 21-25 ^{o}F (38-45 ^{o}C) over 200-600 feet implies a conductive thermal gradient of more than 200 ^{o}C/km, more than four times the regional gradient (30-40 ^{o}C/km). In the absence of a shallow heat source, these temperatures must therefore reflect mixtures of thermal water and ground water. Seasonal and pumping-induced temperature fluctuations ($\Delta T > 4$ ^{o}F) in the Danskin and Stage Stop deep wells indicate that both seasonal hydraulic factors and local pumping can affect the mixing proportion of geothermal water in the aquifer and thereby explain the nearly 45 ^{o}F range of temperatures observed in WSRP wells.

Assuming that the thermal end member is similar to hot springs in the Idaho Batholith and wells in the Boise geothermal system (about 160 ^{o}F, 70 ^{o}C), then well waters in the 70 ^{o}F (21 ^{o}C) range comprise at least 20% of a geothermal recharge component. However, such mixing proportions are unlikely to result in waters high in dissolved fluoride because this element appears not to behave conservatively, possibly due to fluorite (CaF_2) solubility constraints; fluoride does not exceed about 0.5 mg/l in any of the wells for which data are available.

CONCEPTUAL MODEL

The spatial distribution of three possible sources of recharge exert the primary controls on the deep aquifer's hydraulic gradient: (i) meteoric recharge from local watersheds that supplies both the perched and deep aquifers, (ii) geothermally heated water that enters the deep aquifer via faults along the Boise Front, and (iii) infiltration of seasonally warmer surface water from local streams into perched aquifers that subsequently drains to the deep aqufer. The proposed conceptual model does not invoke structural discontinuities to explain the observed hydraulic gradients. Instead, two purely hydraulic scenarios were considered: (a) spatially uniform transmissivity across the deep aquifer, vs. (b) a zone of lower transmissivity between three and five miles from the range front.

At the range front, the hydraulic gradient of the deep aquifer ($I_1 = 0.011$) reflects a combination of shallow recharge from local catchments (R_1) and possibly upflow of deep geothermal fluids (R_2) along unknown faults. Under transmissivity scenario (i), a mound on the deep water table (I_2 = 0.027) farther from the range front may be supported by R_1 plus R_2 and possibly drainage (R_3) from the overlying perched aquifer. Under scenario (ii), the ground-water mound relects a zone of lower transmissivity through which R_1+R_2 flow from the range front.

RECHARGE ESTIMATES

Based on the generally low specific capacities of East Ada wells and the systematic change in hydraulic gradient away from the range front, the average transmissivity in the deep aquifer is estimated to be 7000 gpd/ft which is at the low end of SPF's (2007a) estimates. Based on this transmissivity, recharge to the deep aquifer from local watersheds (R_1) is estimated to be ca. 3000 acre-ft/year, also at the low end of previous estimates (SPF, 2007a, b). The steepening of the deep aquifer's hydraulic gradient in the vicinity of I-84 is consistent with an additional 4000 acre-ft/year contributed by some combination of geothermal water rising along buried faults and / or drainage from the overlying perched aquifer.

Of the two transmissivity scenarios considered, the uniform transmissivity model predicts the least amount of recharge to the deep aquifer (of the order of 7,000 acre-ft/year) compared to a model that invokes a zone of decreased transmissivity (12,600 acre-ft/year). In scenario (i), the perched aquifer's leakage rate cannot be larger than about 8000 acre-ft/year, whereas it could be negligible in scenario (ii). All of these estimates, however, depend on knowledge of the average bulk transmissivity of the deep aquifer. Greater confidence in the derived estimates ultimately depend on obtaining fundamental estimates of precipitation, runoff and evapotranspiration in the headwater region.

If the average temperature of the East Ada deep aquifer is 70 ^{o}F (22 ^{o}C) and the geothermal fluids responsible for contributing fluoride to the deep aquifer are as hot as those in the Idaho Batholith and the Boise geothermal system (160 ^{o}F, 70 ^{o}C), then the proportion of geothermal recharge to the deep aquifer may be as high as 20%.

In their analysis of the East Ada ground water budget, SPF (2007a) concluded that if actual recharge is greater than 14,400 acre-ft/yr (the upper two-thirds of their estimated range), then "the chances of developing the entire water supply for this project from ground-water sources are good." The results of the present analysis indicate that this conclusion is overly optimistic.

More work is needed to better define the mixing fraction of geothermal recharge, which has not been considered in previous analyses, as well as the fundamental water balance of the high-elevation catchments responsible for supplying the aquifer's meteoric recharge. Determining whether the geothermal contribution represents a significant fraction of the deep aquifer's recharge will be vital in designing a sustainable ground-water development plan.

RECOMMENDATIONS

(a) Subsurface Architecture

The configuration of water-bearing zones and water levels in the perched domain and in the deep aquifer are poorly constrained by available subsurface data. Additional work is needed to define the principal water-bearing zones in the East Ada aquifer system and to segregate water level information into shallow and deep subsets so that piezometric surfaces can be constructed separately for the perched zone(s) and for the deep aquifer. In addition, the possibility of a buried fault that drains the perched zone(s) in the vicinity of I-84 needs to be evaluated. All these objectives could be addressed by drilling one or more test wells (vertical or inclined) through the southwestern extremity of the perched zone, through the underlying unsaturated zone, and into the deep aquifer. A complete suite of borehole geophysics should be conducted, especially neutron and gamma-density logging to detect variations in porosity and moisture content that could indicate vertical drainage and the presence of faulting.

As development pressures in this area increase, interest in the deep regional basalt aquifer is sure to grow. However, this aquifer is so poorly characterized at present that even very basic questions about the aquifer's stratigraphy, distribution of porous zones and degree of weathering or alteration cannot be addressed with confidence. In the future, when IDWR issues drilling permits for deep wells, the IGS recommends that arrangements be made to have at least a student geologist monitor progress during drilling and collect chip samples so that future studies will have a modest library of samples for major and minor chemical correlations, textural logging, and alteration/weathering analysis to help understand the hydrogeology of this important aquifer.

(b) *Aquifer Transmissivity*

More controlled pumping tests are needed in the deep aquifer, specifically in the areas of maximum and minimum hydraulic gradients, to evaluate whether transmissivity differences are responsible for the range of hydraulic gradients. Such data would also better define the deep aquifer's average bulk transmissivity and better constrain estimates of the cold and thermal recharge fluxes as well as the importance of vertical recharge from the perched zone.

(c) Geochemical Data

Additional water chemistry and temperature data are needed to characterize the geothermal signature in the deep aquifer, to estimate the temperature of the geothermal end-member, and to constrain its relative importance in the aquifer's water balance.

(d) Data Collection

This analysis has identified several important monitoring activities that represent a continuation of existing IDWR programs and an expansion of others:

(i) Pumping-induced incursion of geothermal fluid has been observed in at least one well in the deep aquifer. Transient changes in well water chemistry associated with mixing on the short time scales observed in the Stage Stop deep well need to be monitored so that the potential for excessive fluoride concentrations can be evaluated.

(ii) A temperature survey of existing deep wells would help constrain the aquifer's average temperature and the fraction of geothermal recharge in its overall water budget.

(iii) Residents, applicants for drilling permits, and the commercial drilling community should be better educated regarding the prevalance of thermal water in this region and, as a condition of the permitting process, well drillers should be required to provide accurate water temperature information as part of their reporting obligations.

(iv) Transcribing water temperature information from drillers' reports into IDWR's on-line database would make the temperature data searchable and more accessible. Over time, this would help to build awareness among water users and drillers as well as provide a technical basis for water rights allocations. In addition, better knowledge of ground-water temperatures would lead to better estimates of natural inter-basin water transfers that are geothermally driven and lead to improved conjunctive management of shallow vs. deep ground water resources.

REFERENCES

Bendixsen, S., 1994, Summary of hydrologic conditions in the Mountain Home and Cinder Cone Butte areas; Idaho Department of Water Resources, 17 pp.

Brott, C.A., Blackwell, D.D. and Mitchel, J.C., 1976, Heat flow study of the Snake River Plain region, Idaho; Idaho Department of Water Resources, Water Information Bull. 30, Part 8, 54 pp. plus appendices.

Druschel, G.K. and Rosenberg, P.E., 2001, Non-magmatic fracture-controlled hydrothermal systems in the Idaho Batholith: South Fork Payette geothermal system; Chemical Geology, 173, p.271-291.

Gass, T.E., 1982, Geothermal heat pump; Geothermal Resources Council Bull. 11(11), pp. 3-8.

Laney, P. and Brizee, J., 2003, Idaho geothermal resources; Idaho Geothermal Resources Map, Publication No. - INEEL/MIS-2002-1618 Rev. 2; http://geothermal.inel.gov/maps/id.pdf

Liberty, L.M., 2010, Geophysical characterization at the North Ada and East Ada sites; unpubl. IDWR report, September 13, 27 pp.

Mayo, A.L., Muller, A.B., and Mitchell, J.C., 1984, Geochemical and isotopic investigations of thermal water occurrences of the Boise front area, Ada County, Idaho: Idaho Department of Water Resources Water Information Bulletin 30, pt.14, 55p.

Newton, G.D., 1991, Geohydrology of the regional aquifer system, western Snake River Plain, southwestern Idaho; U.S. Geological Survey Prof. Paper 1408-G.

Nordstrom, D.K. And Jenne, E.A., 1977, Fluorite solubility equilibria in selected geothermal waters; Geochim. Cosmochim. Acta 41, p.175-188.

Othberg, K.L., Bonnichsen, B., Swisher, C.C. III, and Godchaux, M.M., 1995, Geochronology and geochemistry of Pleistocene basalts in the western Snake River Plain and Smith Prairie, Idaho; Isochron West, no. 62, p.16-29.

Parliman, D., Nicholls, S. And Boyle, L., 2000, Canyon County ground water study of the Boise River corridor, Canyon County, Idaho; IDEQ Water Quality Status Report No. 119, 29 pp.

Phillips, W.M. and Welhan, J.A., 2011a, Geologic Map of the Firth Quadrangle, Bingham County, Idaho; Idaho Geological Survey Digital Web Map DWM-123; http://www.idahogeology.org/Products/reverselook.asp?switch=title&value=Geologic_Map_of_the_Firth_Quadrangle,_Bingham_County,_Idaho

Phillips and Welhan, 2011b, Geologic Map of the Woodville Quadrangle, Bingham and Bonneville Counties, Idaho; Idaho Geological Survey Digital Web Map DWM-124; http://www.idahogeology.org/Products/reverselook.asp?switch=title&value=Geologic_Map_of_the_Woodville_Quadrangle,_Bingham_and_Bonneville_Counties,_Idaho

Phillips, W.M., Welhan, J.A. and Breckenridge, R.M., 2010, Geodatabase of NEHRP Site Class and Liquefaction Susceptibility Maps for the Idaho Falls - Rexburg Area, Southeast Idaho; Idaho Geological Survey Digital Database DD-1; http://www.idahogeology.org/Products/reverselook.asp?switch=title&value=Geodatabase_of_NEHRP_Site_Class_and_Liquefaction_Susceptibility_Maps_for_the_Idaho_Falls_-_Rexburg_Area,_Southeast_Idaho

Phillips, W.M., Lewis, R.S., Gillerman, V.S., Garwood, D.L. and Stewart, D.E., 2012, Geologic Map of the Mayfield Area, Ada and Elmore Counties, Idaho; Idaho Geological Survey Digital Web Map DWM-144, scale 1:36,000.

Skinner, K.D., 2005, Estimating streambed seepage using heat as a tracer on the lower Boise River, Canyon County, Idaho; U.S. Geological Survey Scientific Investigations Report 2005-5215, 16 pp.

SPF Water Engineering, 2007a, Ground-water supply evaluation for the Mayfield townsite property; November 1, 30 pp. plus appendices.

SPF Water Engineering, 2007b, Groundwater supply evaluation for Elk Creek Village, Application for Permit No. 61-12090; December 17, 17 pp. plus appendices.

Swanberg, C.A. And Blackwell, D.D., 1973, Areal distribution and geophysical significance of heat generation in the Idaho batholith and adjacent intrusions in eastern Oregon and western Montana; Geol. Soc. Am. Bull., 84, p.1261-1281.

Tesch, C. And S. Vincent, 2009, Evaluation of aquifer recharge in areas of planned community applications along the I-84 corridor from Boise to Mountain Home; IDWR internal memo, 17 pp.

Waag, C.J. And Wood, S.H., 1987, Evaluation of the Boise geothermal system; Final report to Idaho Department of Water Resources, December, 70 pp.

Walton, W.C., 1988, Groundwater pumping tests; Lewis Publishers, Chelsea, MI; 201 pp.

Welhan, J.A., 2009, Preliminary Hydrogeologic Analysis of Fraser Plateau, Clearwater County, Idaho; Idaho Geological Survey Staff Report S-09-1, 14 pp. ; http://www.idahogeology.org/Products/reverselook.asp?switch=title&value=Preliminary_Hydrogeologic_Analysis_of_Fraser_Plateau,_Clearwater_County,_Idaho

Welhan, J.A., An analysis of lithologic and water-level information contained in Idaho's on-line well construction database; Staff Report, in prep.

Whitehead, R.L., 1992, Geohydrologic framework of the Snake River Plain regional aquifer system, Idaho and Oregon; U.S. Geological Survey Prof. Paper 1408-B, 32 pp.

Wood, S.H., 1996, Cross sections of the southeast boundary of the Treasure Valley groundwater study area: Notes on geology of the Mayfield-Orchard area, Ada and Elmore Counties; unpubl. report, Boise State University, October 7, 2 pp. plus figures.

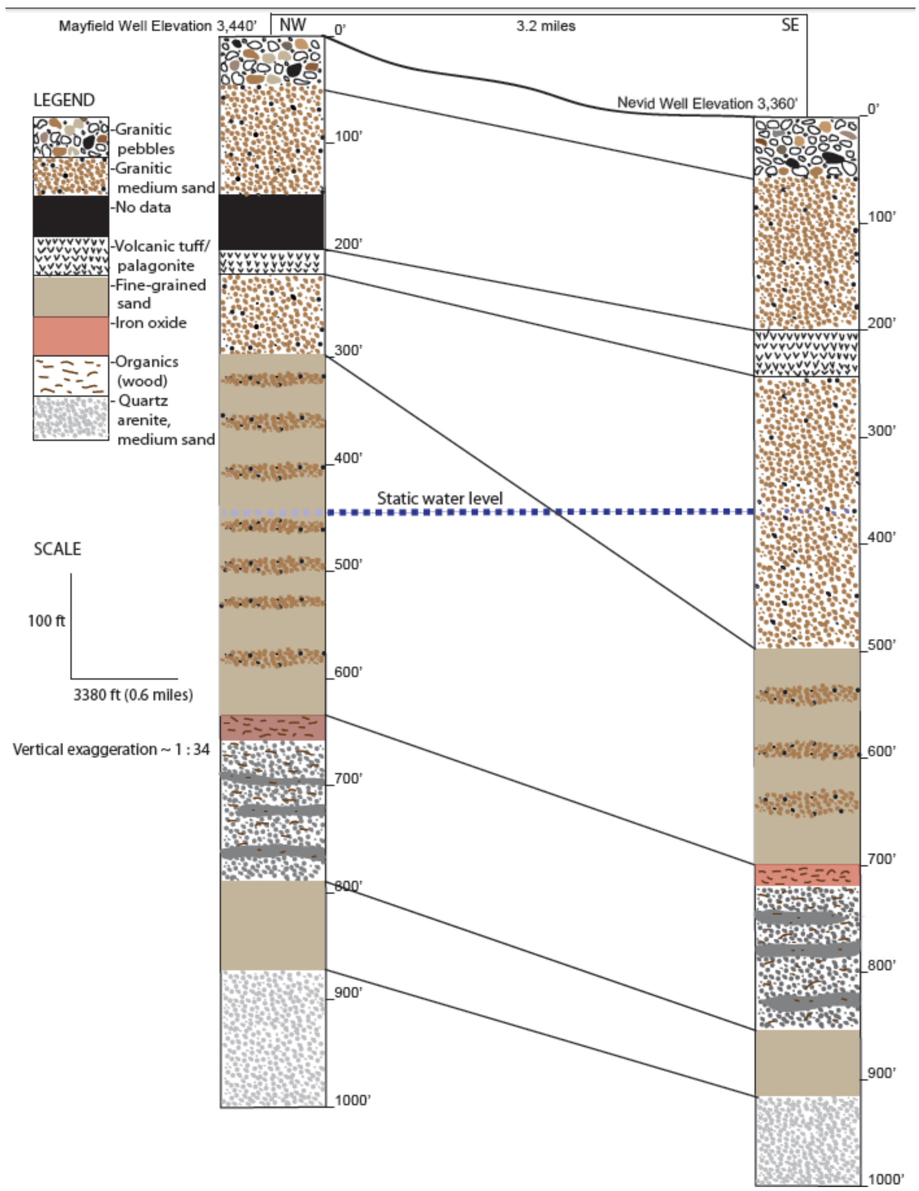
APPENDIX I

Summary of Lithologic Data and Stratigraphic Analysis of

The Mayfield and Nevid Test Wells

Virginia Gillerman

Idaho Geological Survey



APPENDIX II

Geologic Notes on Mapping and Analysis of Drillers' Reports

Bill Phillips

Idaho Geological Survey

Analysis procedure:
The shapefile of all IDWR wells was downloaded 7/14/10 and clipped to the Mayfield 1:24,000 quadrangle. Wells were plotted on a scanned geologic map base and examined to determine if locations indicated in the drillers' reports were valid. Wells that were obviously mislocated were disregarded. It was found that none of the wells in the IDWR database penetrate the basalt of Slater Flat, because they are mislocated. A total of 40 valid well locations were identified and their well logs reviewed and summarized for relevant hydrogeologic information. WellID numbers reported below correspond to data record identifiers in IDWR's on-line database (http://www.idwr.idaho.gov/ apps/appswell/searchwc.asp).

Shallow wells near/in granite bedrock
Well depths range from 200-375 ft. Yields are low (4-10 gpm). Logs shows thin cover (~10 ft) of alluvium/colluvium on weathered granite separated by clay-filled fractures. Weathered granite is usually called "decomposed granite" by drillers.
WELLID: 343658, 305505, 374910, 385793, 379209, 380316

Shallow wells developed on alluvial fans
Well depths range from 60-200 ft TD. Yields are 10-30 gpm with water encountered at 70-157 ft. Stratigraphy consists of interbedded sand and clay with lesser gravels (interpreted to be lake sediments, unit Ts), with some local cementation of sand and gravel. Locally, Ts is capped with gravel/weathered granite, probably of alluvial fan origin. Petrocalcic soils (duripans) noted as caliche in field exposures below ~3600 ft elevation.
WELLID: 387867, 304257, 343838, 306384, 421306

Wells with basalt near Stage Coach Gas Station
Well depths range from 66-103 TD. All of the wells that encountered basalt are in area of relatively shallow groundwater. Yields are about 20 gpm. Basalt is present within 50-70 ft of the surface in the area near the Stage Coach, extending eastward to the Regina area. Basalt is 10-35 ft thick, is typically described as "gray basalt" in drillers' logs, and is associated with cinder

and red clay at its base (likely representing baked / oxidized zones). Based on proximity to outcrops, this basalt is likely a lobe of the basalt of Slater Flat, isolated from the main outcrop area by erosion and deposition of Indian Creek sediments. It likely corresponds to occurrences of subsurface basalt inferred from magnetic and seismic surveys (Liberty, 2010). No other drillers' reports that were reviewed penetrated basalt in the Mayfield quadrangle.
WELLID: 348095, 408141, 306455, 388918, 348779

<u>Shallow wells developed on Indian Creek and Slater Creek</u>
Relatively shallow wells on major drainages have relatively good yields of 30-60 gpm. Depths range from 147-330 feet. All are developed in interbedded sand, clay, and lesser gravels interpreted to be lake sediments (Ts), capped with thin Quaternary alluvium (QTS; weathered granite, clay). Water encountered at 138-315 ft. Static water levels at 250-270 ft. The deepest well in the quadrangle (Arc Properties, 420886) is also on Indian Creek (see below).
WELLID: 302994, 386209, 413431

<u>Deep Wells</u>
Well depths range from 809-510 ft. Yields range from 2000 gpm (Arc 420886) to as little as 9 gpm. Most are 20-45 gpm. Water is found between 270-500 ft depth in sandy zones of lake sediments (Ts), mostly brown and gray fine to coarse sand and clay and minor pea-sized gravels interbedded on scale of 15-20 ft. Some cemented sand and gravel is reported. Clay becomes blue near bottom of some wells. Apparent fining of sediments over a mile or two seen in comparing Arc Properties 420886 with Ken Agenbroad 348104. There doesn't seem to be any distinctive units in the deep wells that permit correlation between wells. None of the deep wells encounter basalt or granite.
WELLID: 420886, 348104, 417665, 339232, 303686, 307519

<u>Relationship to surface geologic unit descriptions</u>
Based on well logs, the "alluvial fan" (QTs) sediments consist of lake sediments with thin reworked surface deposits of granule- to pebble-sized grus and cobbles and boulders of resistant granitic units. It is probably difficult for drillers to distinguish between coarser lake deposits and QTs because it is difficult to impossible to see a QTs / Ts break in the logs. Where exposed, Ts sediments are characterized by color (yellow and white) and grain size (medium to fine sand) from the reddish brown "reworked grus" typical of QTs. It may be that the fan-like forms are mostly eroded Ts (compare with North Ada project area where units of Pierce Gulch sands are eroded into rounded hills with complex drainage net).

<u>Correspondence between well logs and seismic lines</u>
The well logs generally support the interpretation of seismic lines made by Liberty (2010). The shallow basalt in vicinity of Stage Coach gas station is the shallow basalt encountered in water wells. This is most likely lobe of basalt of Slater Flat, isolated by deposition and erosion along Indian Creek from main outcrop. However, the basalt interpretation by Liberty on upper portion of Indian Creek seismic line is not supported by any of the drillers' reports reviewed in this analysis. The seismic lines image sediments (Ts) with limited lateral continuity or large acoustic contrasts – this is compatible with near-shore facies lake sediments.

Structural information

The drillers' reports are not helpful with structural interpretations because of the lack of any unit that can be correlated between wells. No wells penetrate to bedrock between the end of Indian Creek seismic line at Mayfield, and the granite/alluvial fan contact.

SUMMARY

Groundwater resources are very limited in areas underlain by granitic rocks. Wells are shallow and have yields of 10 gpm or less. The bedrock/sediment contact is a gently southwest dipping surface (pediment?) possibly cut by at least two small displacement normal faults. Springs (most developed by ranchers) are present along granite/sediment contact zone. Where alluvium and lake deposits are relatively thin over granitic bedrock, groundwater resources are limited by depth to water. In southern portion of quadrangle, lake sediments are at least 800 ft thick and contain multiple sand beds interbedded with clay or silts. Largest yields (as much as 2000 gpm) are from deep wells along Indian and Slater Creek that apparently pump multiple sands in the lake sediments. Other major drainages in the study area may have same resource potential. Basalts play no role in groundwater resources in Mayfield quadrangle except perhaps to create high water table in the area around Stage Stop. The only basalt is thin basalt of Slater Flat that is stratigraphically above major water-bearing units and may be a barrier to water and good barrier for pollution of underlying water resources.