HYDROGEOLOGY OF SPRING VALLEY AND SURROUNDING AREAS

PART A: CONCEPTUAL FLOW MODEL

Presented to the Office of the Nevada State Engineer

On behalf of Great Basin Water Network and the Federated Tribes of the Goshute Indians

June, 2011

Prepared by:

____

Thomas Myers, Ph.D.
Hydrologic Consultant
Reno, NV

June 17, 2011

Date

Table of Contents

TABLE OF FIGURES

TABLE OF TABLES

Introduction

The Southern Nevada Water Authority (SNWA) proposes to develop 91,200 af/y of groundwater in Spring Valley of eastern Nevada. This report was prepared on behalf of the Great Basin Water Network, a coalition of protestants to those water right applications and the Confederated Tribes of the Goshute. This report revises an earlier report written by this author regarding the conceptual flow model for the flow systems in Spring and Snake Valley, Nevada and Utah (Myers, 2006).

The revised conceptual model utilizes new information regarding the hydrogeology of Spring and Snake Valley, including the BARCAS study (Basin and Range Carbonate Aquifer System) (Welch et al, 2008; Flint and Flint, 2007; Moreo et al, 2007; Lundmark et al, 2007; Sweetkind et al, 2008; and other supporting documents), Elliot et al (2006), Halford and Plume (2011), Mankinen et al (2006), and Watt and Ponce (2007). Various data sources were gleaned for this analysis. The following list presents some of the sources of data used herein. Data means water levels, well logs, or stream/spring flows. Others are cited in the text.

- BARCAS, Basin and Range Carbonate Aquifer System Study (Welch et al, 2008) and supporting documents as cited herein
- U.S. Geological Survey Online Sources including the National Water Information System for Nevada and Utah (http://waterdata.usgs.gov/nv/nwis/gw)
- Nevada Division of Water Resources Online Sources including well logs and water levels.
- Utah Geological Survey
- BioWest (2006 a and b)
- Pupacko et al, 1989
- Bunch and Harrill (1984)
- Elliot et al, 2006
- SNWA (spring valley reports)
- Google Earth for aerial photos

Several reports are mentioned as new information and data. The difference is that various reports present data such as flow rates or water levels that can be interpreted independently of the report's uses.

General Description of Study Area

The primary study area is Spring, Snake, Tippet, Hamlin, Pleasant, and Deep Creek Valleys in eastern Nevada and western Utah (Figure 1). All are part of the Great Basin, a land of internal drainage (Grayson, 1993). These six valleys are generally at the head of either the Great Salt Lake or Goshute flow system (Welch et al, 2008; Harrill et al, 1988). The valleys are part of the Basin and Range province, with thrust faulting forming the upthrust mountains and downthrust valleys. Most of the rock is of either sedimentary, volcanic, or intrusive origins (Welch et al, 2008).

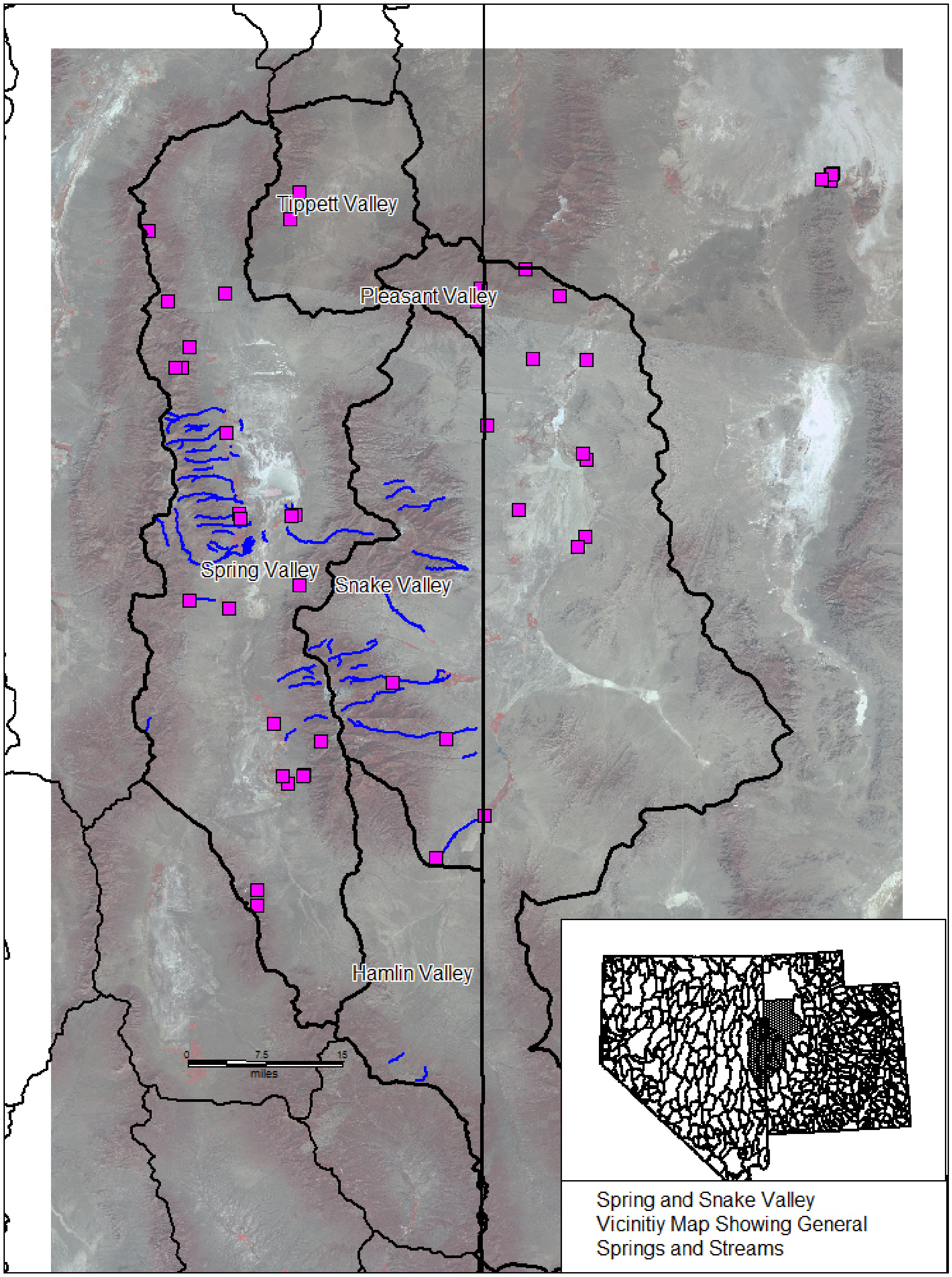


Figure 1: Vicinity map of Snake and Spring Valleys and Adjacent Areas.

Topographically, Spring and Tippett Valleys are closed. Tippett Valley is closed due to a low saddle on the north boundary, and on some maps labeled as part of Antelope Valley. Snake Valley drains into the Great Salt Lake (GSL) basin, which itself is closed. Groundwater occurs in either bedrock, predominately carbonate or fractured volcanic, or basin fill aquifers. It is part of the carbonate flow system (Harrill and Prudic, 1998; Harrill et al, 1988) in which flow between basins (interbasin flow) occurs primarily through carbonate rock (Welch et al, 2008). The area is part of the GSL Flow System (Harrill et al, 1988), although others have questioned whether Spring Valley is legitimately part of the GSL flow system because it previously had been considered to have very little interbasin flow to adjoining basins (Rush and Kazmi, 1965); it has been considered almost closed to groundwater flow.

The study area lies primarily in the Great Basin Desert, considered a cold desert which has short hot summers and long, cool winters. Precipitation is sparse, but, in the eastern half of the Great Basin, spread rather evenly through the year (Hood and Rush, 1965; Rush and Kazmi, 1965). Mountains control the distribution of precipitation, with from four to six times the annual precipitation in the mountains as in the valleys, with amounts on the ridges exceeding 30 inches and valleys as little as 5 inches (in northern Snake Valley) (Welch et al, 2008, Figure 20).

Groundwater Water Levels and Flow Directions

Wells have been constructed over a long time period in Snake Valley resulting in water level observations spanning variable time periods; the earliest Utah Snake Valley well level measurement is 1905. The overall database of water level information was created from well log files for Nevada in Spring, Hamlin and Snake Valley, USGS water level files for NV and UT, UGS well logs and springs using their surface elevations.

Steady State Water Levels

Steady state conditions are used to determine general flow patterns in the valley, determine the conceptual flow model, and to calibrate the numerical groundwater model. I assumed steady state conditions prevail before the commencement of substantial development in an area, conditions for which natural inflow and outflow, recharge and discharge, may be determined as an average (Myers, 2009). But, steady state is actually a dynamic equilibrium that shifts with time (Fetter, 2001), with inputs and outputs, primarily recharge and groundwater evapotranspiration (GW ET), varying seasonally due to snowmelt and summertime ET rate peaks and annually due to natural drought and wet period cycles. Steady state in nature is therefore illusory at best.

Assumptions are made therefore to define steady state in the field. Often, it can be assumed that water levels observed early in the development period represent pre-development conditions. These may be the static conditions observed upon well drilling or the average level in a fluctuating water level hydrograph. I based steady state water levels on the median groundwater level for wells which are steady or which fluctuate around an apparent annual average. For wells that have declined with time (see discussion below), I used the median well level observed prior to the early 1980s. Well levels for wells with just one observation were used only if they preceded the 1980s in areas in where levels have declined, otherwise they were assessed individually to determine whether their value should be used. The most recent single water level measurements were often done by the Utah Geological Survey in their well logging program for deep well water levels (http://geology.utah.gov/esp/snake_valley_project/index.htm).

Groundwater Contour Mapping

Well coordinates were converted to US State Plane Coordinate, 1983 Eastern Nevada. Depth was taken as the bottom of the screen or open interval. For springs, depth is 0. For wells without specified depth, it was assumed to be 100 to 300 feet. Dry wells have been eliminated from consideration – these were mostly the NV USGS wells.

I prepared three groundwater level contour maps to describe the flow patterns in the study area, including their variation with depth. Having combined the well data bases, the 30% and 70% cumulative probability corresponds with 80 and 200 feet, respectively (Figure 2), thereby providing convenient categories for shallow (less than 80 feet including springs), intermediate (ranging from 80 to 200 feet), and deep wells (exceeding 200 feet). With only a few exceptions, the well completions are in fill. There are insufficient bedrock wells to plot a separate contour map. The well data includes bedrock wells, therefore there is an implicit assumption that a hydraulic connection exists between the bedrock and fill.

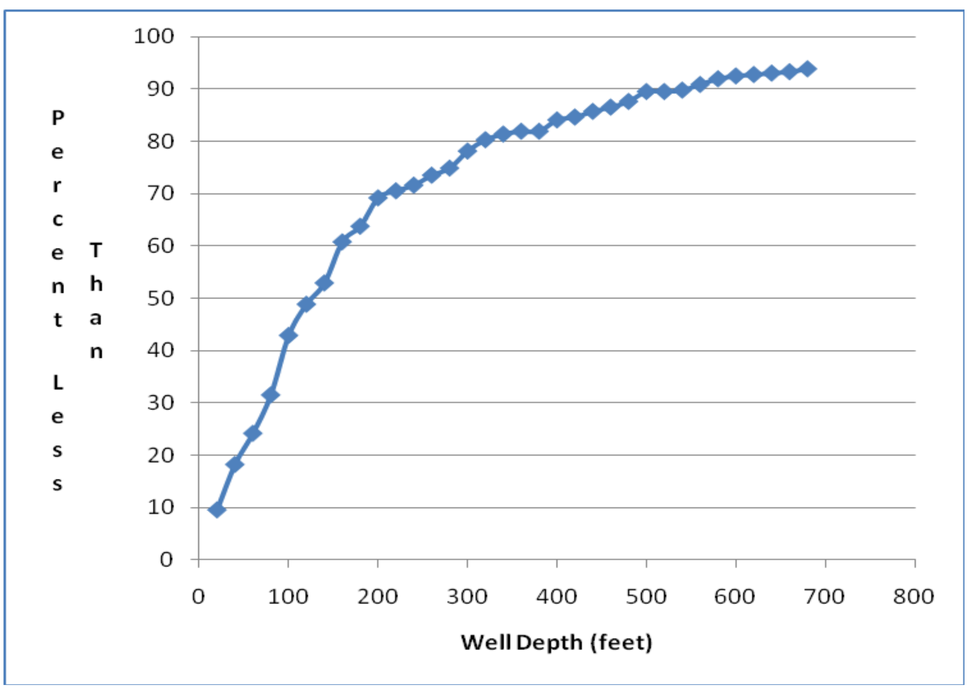


Figure 2: Cumulative distribution of well depths in Snake and Spring Valleys.

Groundwater contour mapping was completed automatically using inverse distance squared with 30,000 foot search radius. Contours were adjusted manually, especially for shallow wells, where necessary. Reasons for manual adjustments included conformance with topography because a statistical technique that smoothes the changes across the domain could miss changes caused by geology and relief.

In general the groundwater level in the bottom of Spring Valley varies from about 5600 to 5800 feet, and in Snake Valley slopes from about 5600 to 4800 ft amsl from south to north (Figures 3 through 5). The shallow groundwater contours (Figure 3) reflect steep gradients along the valley edges caused by springs at the head of the fan; just a few shallow well observations in the mountains cause a cluster of 100-foot contours. The shallow well contours are higher than the contours for other well levels because the mountain-front recharge causes a downward vertical gradient. The shallow well water level shows a nadir at about 5600 ft amsl in the northern third. The intermediate and deep well contours show a gently undulating water table around 5800 ft amsl, with a distinct slope to the southeast in the far south of the valley and to the northeast toward Tippet Valley (Figures 4 and 5). The apparent gradient suggests flow paths between the northern half of Spring and Snake Valley and from west to east through the Limestone Hills area. There is also a gradient from northern Spring to Tippett Valley, shown on the shallow wells contour map (Figure 3). Groundwater flow in Snake Valley, at all levels, is toward the north, dropping about 700 to 900 feet from near the boundary with Spring Valley and the northern most contours. Wells near Calao have water levels another 200 feet lower than shown on these maps.

These observed water levels demonstrate a gradient west to east at depth that is similar to the gradient in the carbonate aquifer found in BARCAS (Figure 6). Carbonate aquifer groundwater contours support the concept of a deep aquifer gradient from Spring towards Snake Valley (Figure 6), with an east to west gradient supporting flow from North Spring to Tippett Valley, Tippett to Deep Creek Valley, and Spring to Snake Valley.

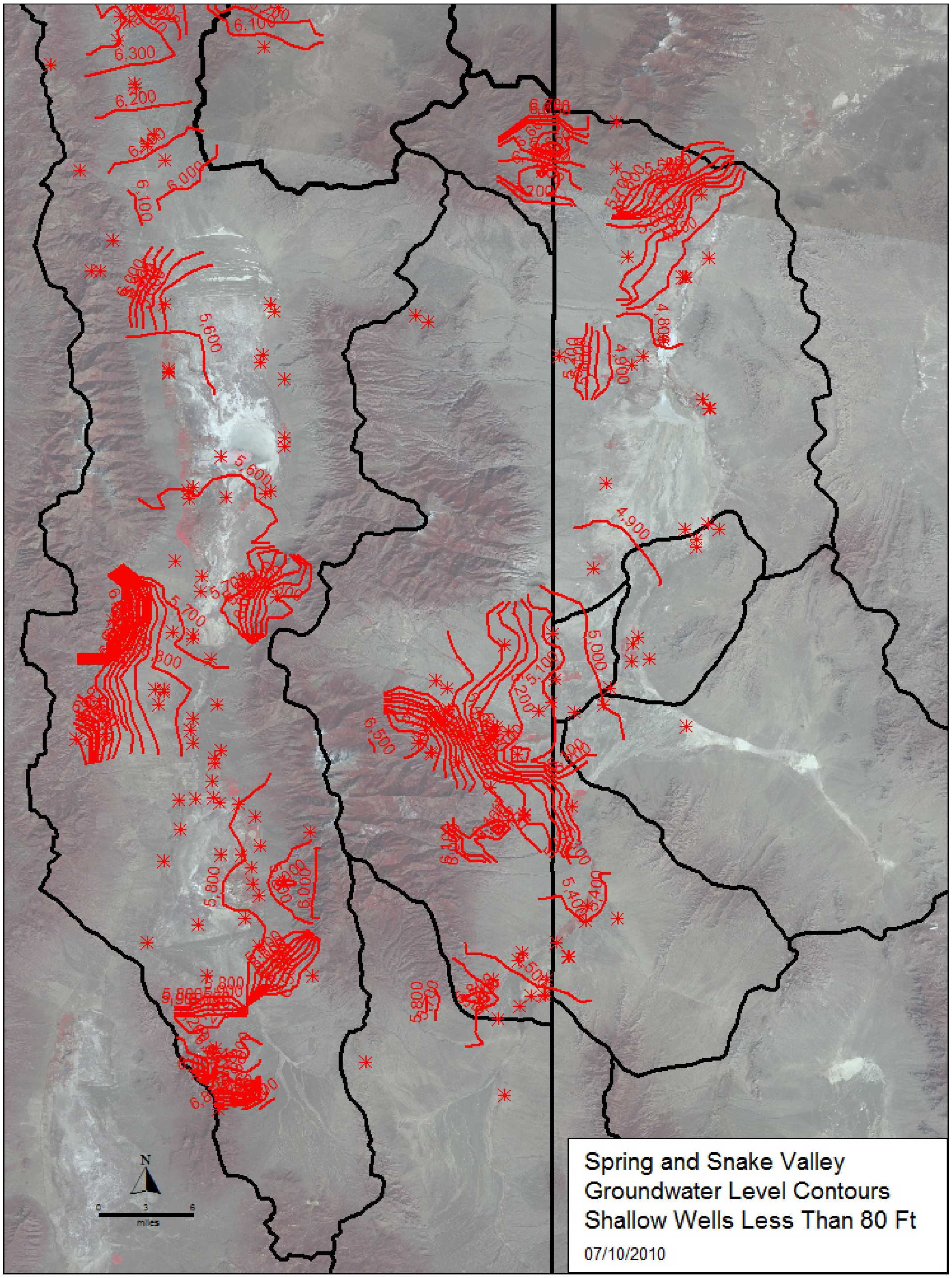


Figure 3: Steady state groundwater contours for shallow wells (<80').

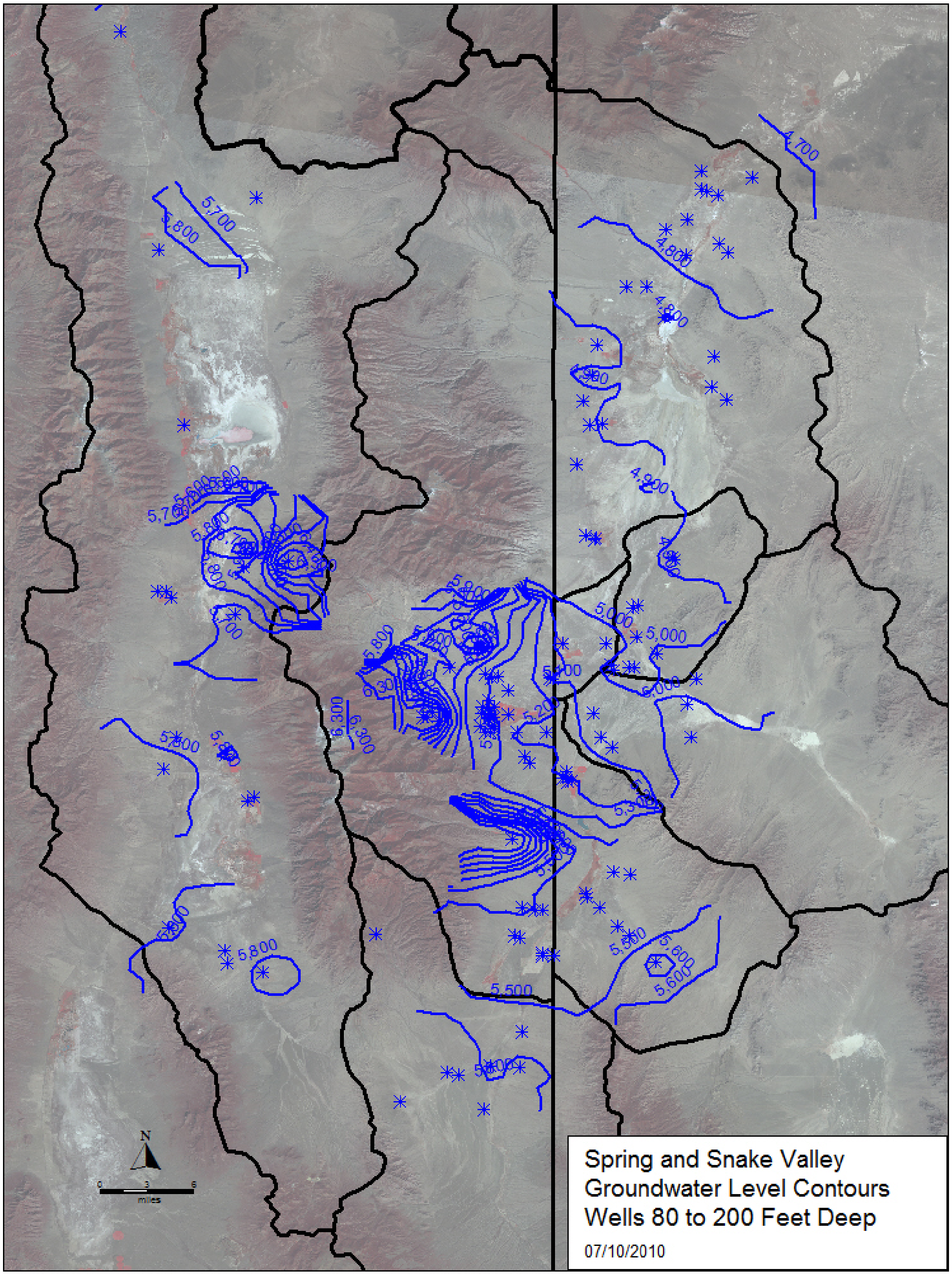


Figure 4: Steady state groundwater contours for intermediate wells (80-200'). White and red targets are SNWA applications.

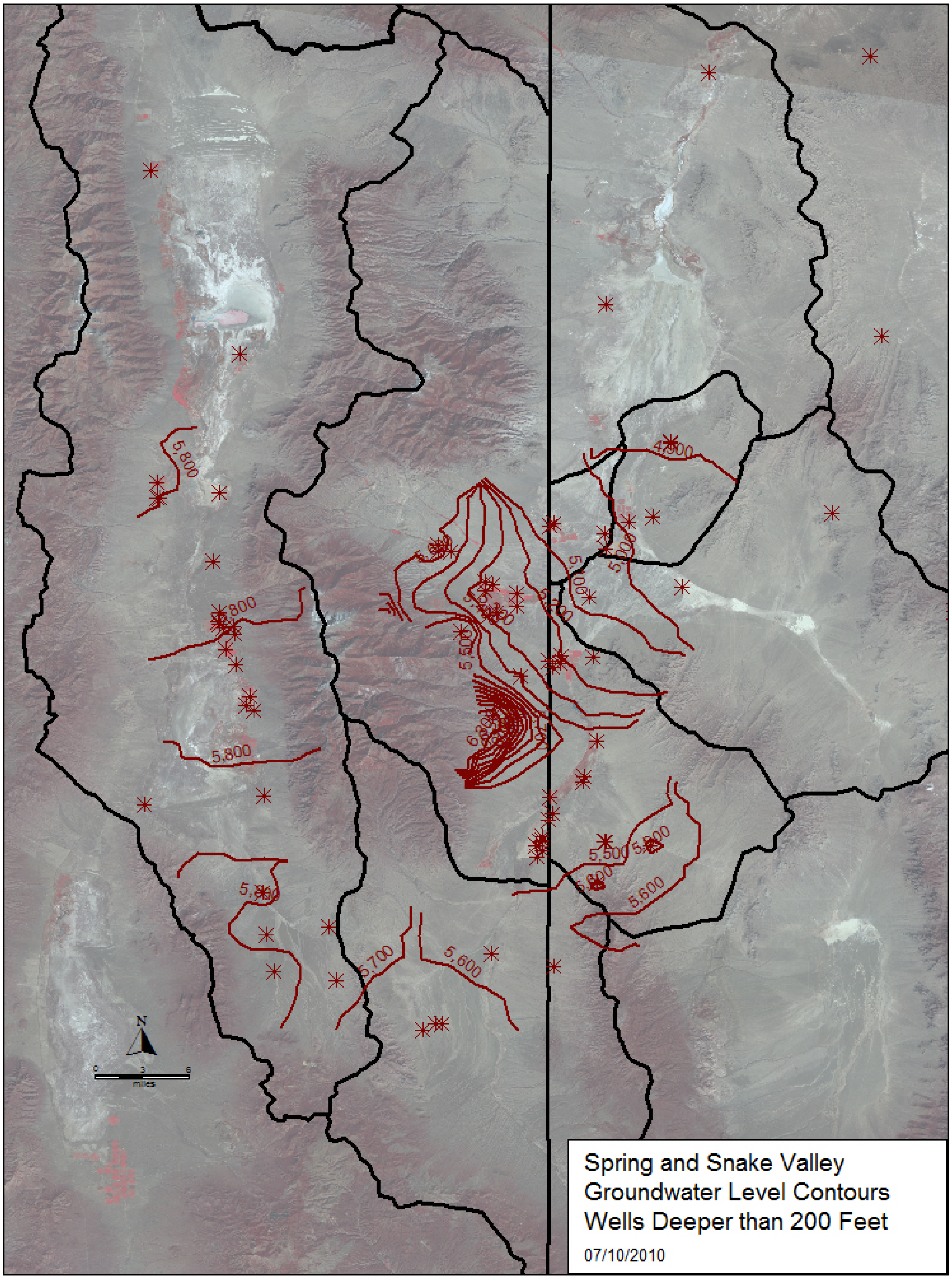


Figure 5: Steady state groundwater contours for deep wells (>200'). White and red targets are SNWA applications.

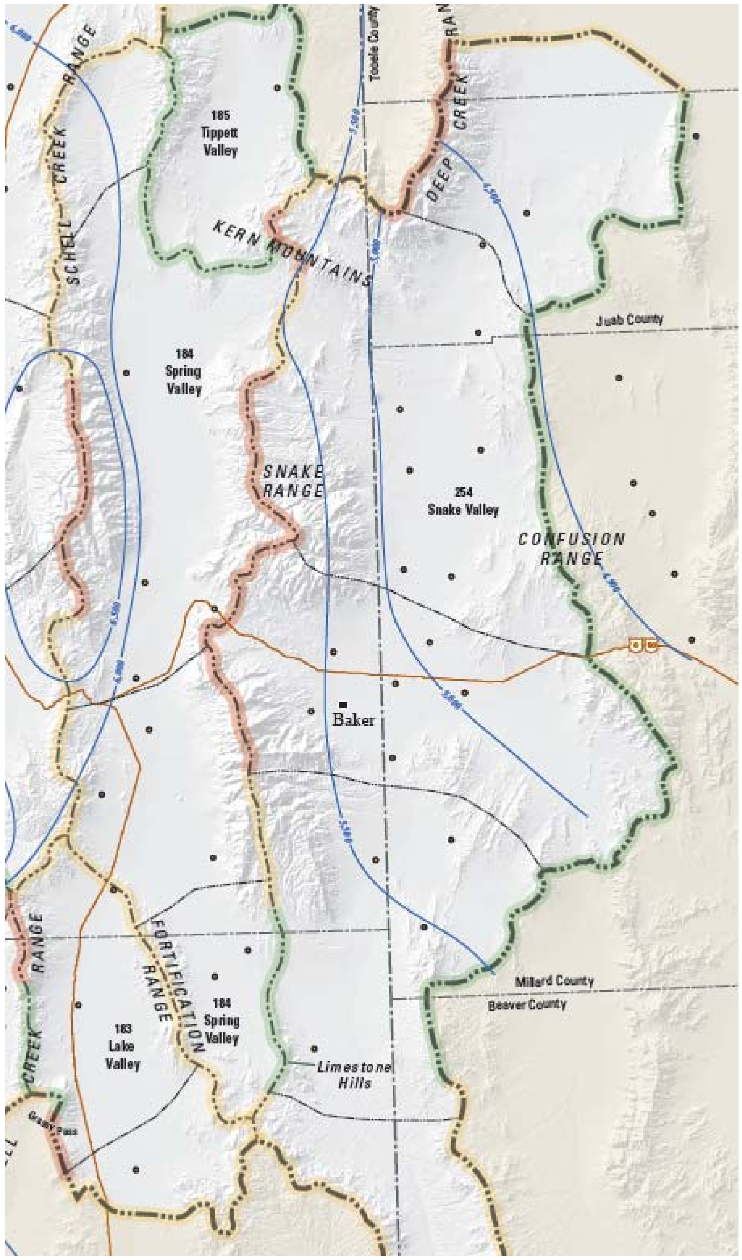


Figure 6: Snapshot from portion of Plate 3, Welch et al (2008), showing groundwater contours in the carbonate aquifer.

Transient Water Levels

Many wells have sufficient water level observations to plot a hydrograph and visualize trends with time (Figure 7). Appendix A contains plotted hydrographs for Spring Valley and Snake Valley in Utah and Nevada. A declining groundwater level was one for which most successive measurements since the mid-1980s have been lower than one collected at about the same time during the previous year. The mid-1980s were chosen as the starting time because most wells show increases or very significant spikes at that time due to very wet conditions. Other well hydrographs, not showing declines, are either steady, show mostly seasonal changes, or some show significant wet/dry period cycles with wet periods in the early 1980s, mid-1990s, and around 2005.

Figure 7 shows wells that have demonstrated a declining trend. Snake Valley is the only valley with groundwater level declines, due to the significant existing pumpage that occurs there. Downward trends cluster near Baker and south of Baker. Most are near or downgradient of areas with substantial underground water rights, which shows the effect that pumping water rights is having on the existing water levels. Monitoring wells not located near clusters of UG water rights tend to be steady or to fluctuate seasonally.

Groundwater levels in wells near Shoshone Ponds in Spring Valley have declined, but have mostly recovered during the late 2000s. The primary monitoring well has water levels about 24 feet above the ground surface, demonstrating its artesian character. Also, many hydrographs have an initial reading that is much lower than subsequent readings. This does not demonstrate a trend as much as it suggests the initial reading occurred just after construction when the water level had not yet stabilized.

General Description of Flow

Most of the precipitation occurs in the mountains. Precipitation recharges in the mountains where the geology is conducive, where the geology is fractured carbonate or volcanic rock, or runs off to potentially recharge at the mountain front, typically on the alluvial fans (Wilson and Guan, 2004). Groundwater discharges into streams, springs, or to phreatophytic vegetation in the valley bottoms. Perennial streams may exist in the mountain block if there is sufficient alluvium/colluvium to support perched aquifers that can support substantial longer-term flow. These streams may also recharge on the alluvial fans. Often in the Great Basin, groundwater discharge into streams and springs will recharge downstream, becoming secondary recharge.

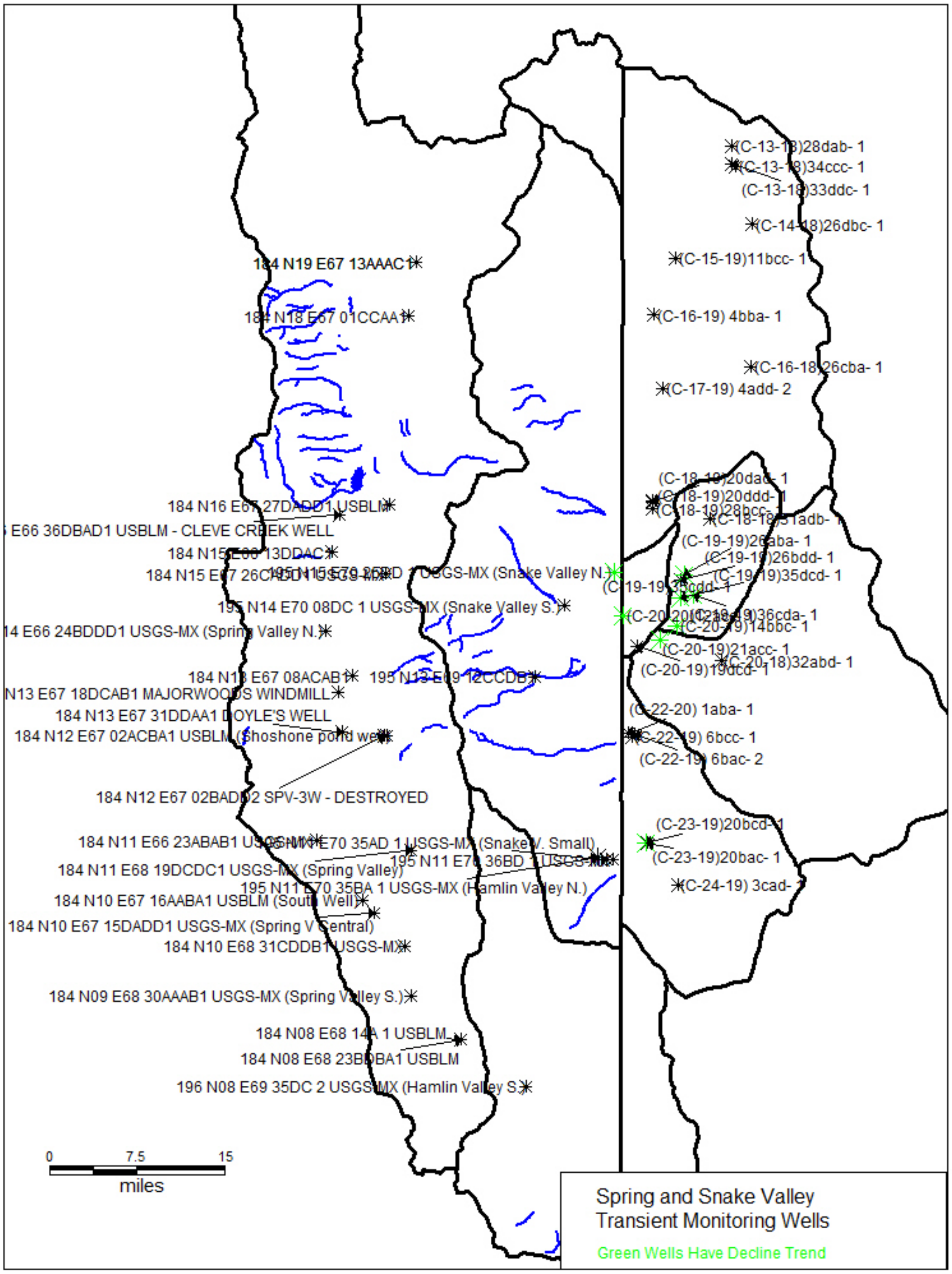


Figure 7: Snake Valley wells with hydrographs from USGS data. The map shows wells with declining water levels in green.

Figure 8, clipped from a USGS report (Eakin et al, 1976), shows the general types of flow system that occur in the Great Basin. The figures show the carbonate bedrock at depth underlying the basin fill in the valleys. Recharge enters the bedrock and basin fill. From right to left, the recharge either discharges to vegetation and to downstream, discharges mostly to downgradient basins, discharges only to in-basin vegetation and phreatophytes, or is isolated with no carbonate rock, no interbasin flow and only in-basin recharge discharging to in-basin playas and phreatophytes. All of the basins in this study are like the first one described (the rightmost basin in Figure 8), although Spring Valley had once been considered most like the undrained, closed basin of the far left only with some carbonate basin rock. Prior to the BARCASS study (Welch et al, 2008), Spring Valley had been considered to be almost totally without interbasin flow, excepting a small amount through the southeast portion to Hamlin or Snake Valley. Now, it is accepted, and utilized in this study, that interbasin flow leaves Steptoe Valley and enters Spring Valley either directly or by passing through Lake Valley (Welch et al, 2008).

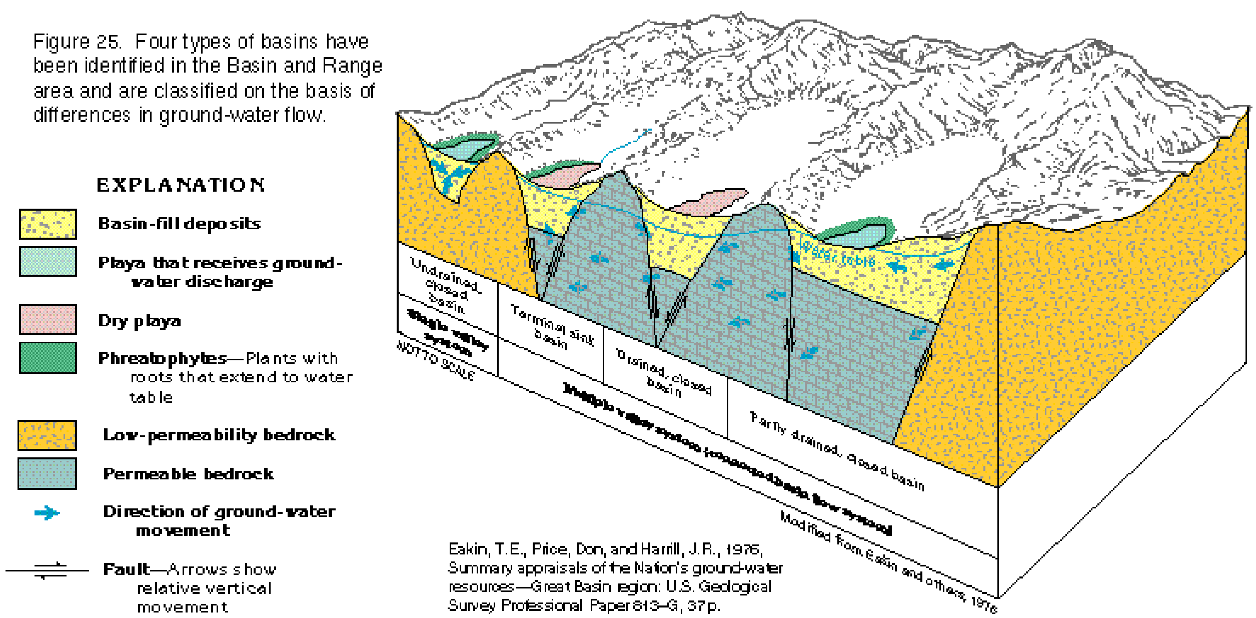


Figure 8: Generalized conceptual flow model from Eakin et al, 1976.

Hydrogeology

The Snake/Spring Valley study area includes several high elevation fault/block mountain ranges separated by deep basins filled with basin fill. Fractured carbonate rock and basin fill forms most of the aquifers in the area; locally, there are fractured volcanic rock aquifers. This study based the hydrogeology on classifications published in BARCAS (Welch et al, 2008, Sweetkind et al, 2008, Belcher et al, 2001) (Table 1 and Figure 9).

The hydraulic conductivity for the units ranges over multiple orders of magnitude (Table 1). Most of the studies used to develop the table are not from within these valleys; much of the data is from the Death Valley Flow System (Welch et al, 2008, p. 32; Belcher et al, 2001). Similar sourcing had been used for SNWA's former Spring Valley groundwater model (Durbin, 2006). Halford and Plume (2011) refined estimates in Snake Valley with small-scale and large-scale pump tests. Conductivity ranged from 0.1 to 3.0 ft/d for fine through coarse-grained basin fill and for intrusive and volcanic rocks would be less than 0.1 ft/d. They also assumed vertical anisotropy equaled 0.1, meaning that vertical conductivity is 10% of the horizontal value.

Conductivity can be quite variable, particularly for bedrock, with primary conductivity being close to zero but secondary conductivity, due to fractures, is much higher. Bedrock fractures may be large and highly connected but with an overall low thickness they have low transmissivity. Basin fill, consisting generally of soil particles with varying degrees of compaction and cementation, often is much thicker and has a higher transmissivity. Also, because the effective porosity of fill is higher than bedrock, the basin fill units store much more groundwater than does the bedrock, including carbonate rock. Bedrock fractures also are usually confined aquifers, therefore they release from two to four orders of magnitude less water for a unit drop in head than does fill. Welch et al (2008) estimated that Snake, Spring, and Tippett Valleys contain about 9, 3.5, and 0.8 maf of drainable water in the fill, assuming a uniform 100 foot drop in the water table, respectively.

Table 1: Hydrogeologic Units Used in this Study (Welch et al, 2008; Belcher et al, 2001)

		Hydraulic conductivity (ft/d)		
Description (Sweetkind et al, 2008)	Abbr.	Median	Min	Max
Fine-grained younger sedimentary rock unit	FYSU	19	0.01	111
Coarse-grained younger sedimentary rock	CYSU	10	0.0002	431
Older sedimentary rock unit (consolidated Cenozoic rocks, variant of rain sizes and depositional environments	OSU	0.4	0.0001	21
Volcanic flow unit (basalt, andesite, diorite, and rhyolite lava flows)	VFU	2.0	0.04	14.
Volcanic tuff unit (ash-flow tuffs)	VTU	37.	0.09	179.
Mesozoic sedimentary rock unit (limestones, sandstones, and siltstones)	MSU	0.004	0.0006	0.9
Upper carbonate rock unit	UCU	3.	0.0003	1045.
Upper siliciclastic rock unit	USCU	0.1	0.0001	3.
Lower carbonate rock unit	LCU	4	0.009	2704.
Lower siliciclastic rock unit	LCSU	0.0000003	.00000009	15.
Intrusive rock unit	IU	0.01	0.002	5.

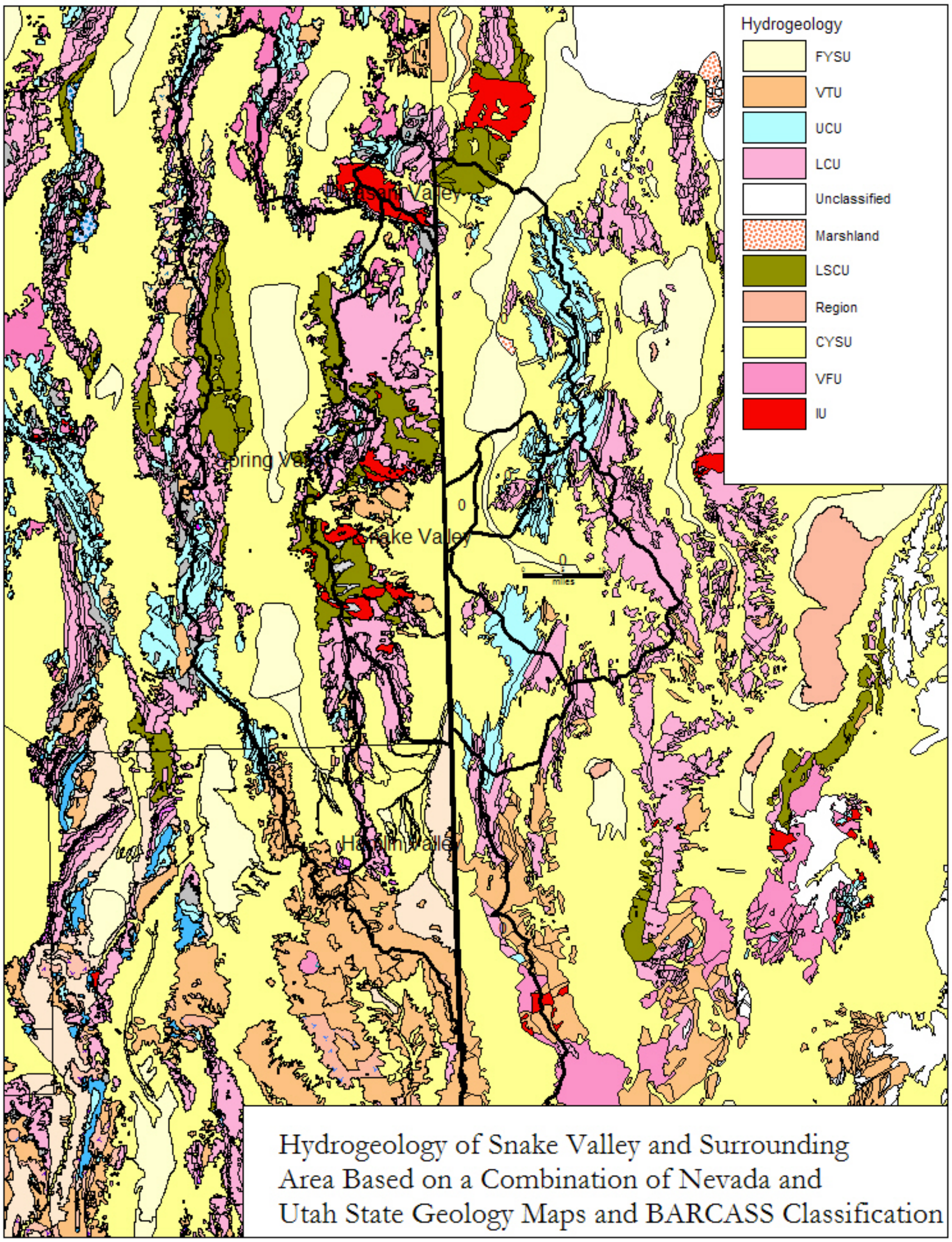


Figure 9: Hydrogeology of Spring and Snake Valley study area. See Table 1 for a description of the hydrogeology. Geology base prepared from Crafford (2007) and Hintze et al (2000).

The basin fill thickness varies from less than 1000 feet to greater than 15,000 feet in Spring, Snake, and Tippett Valleys (Mankinen et al, 2006; Watt and Ponce, 2007). The depth is not uniform with deep and shallow areas apparent on any north-south profile that could be constructed of the valleys. The deepest trough is in the middle of Tippett Valley (Figure 10) (Welch et al, 2008). Snake Valley has four deep troughs – east of the Deep Creek Mountains, east of the north Snake Range, east of Baker, east of the Limestone Hills, and in the far south portions of Hamlin Valley (Figure 10) (Mankinen et al, 2006). Intervening thickness especially between the Mt. Moriah and Confusion Range and just south of Baker is as little as 1000 feet. The basement rock in these shallower fill areas is carbonate (Sweetkind et al, 2008).

Spring Valley has three primary troughs, with the deepest, up to 15,000 feet, being in the north centered between Antelope and the north Schell Creek Ranges (Figure 10). A long trough exceeding 3000 feet extends south to about Rattlesnake Knoll, which is structural high effectively dividing the valley (Watt and Ponce, 2008). South of this high, the fill thickens to at most 3000 feet.

Hydraulic conductivity also decreases with depth due to the compression caused by the overlying material. Durbin (2006) found the following relationship of Kz to Ko, where Kz is conductivity at depth z and Ko is conductivity at the surface:

$$K_R = \frac{K_z}{K_o} = 10^{a_1 z + a_2 z^2}$$

Here, a_1 is -1×10^{-3} and a_2 is 2.5×10^{-7} with all units in feet. The relation obviously only applies to about 2000 feet bgs because the ratio decreases from 1 to about 0.1 at that point after which it begins to increase (Figure 11). This ratio provides a starting point for estimating initial conductivity for the valley fill units. Durbin (2006) did not fit the equation for carbonate rock, but indicated a three order of magnitude decrease over about 8000 feet with an average of about 5 ft/d. Due to fracturing, it is likely that the horizontal anisotropy is not 1, but the only data with which to set horizontal anisotropy different from 1.0 is the fact that major carbonate springs often discharge from a fracture zone with trends reflecting flow from the recharge to discharge point (Dettinger et al, 1995).

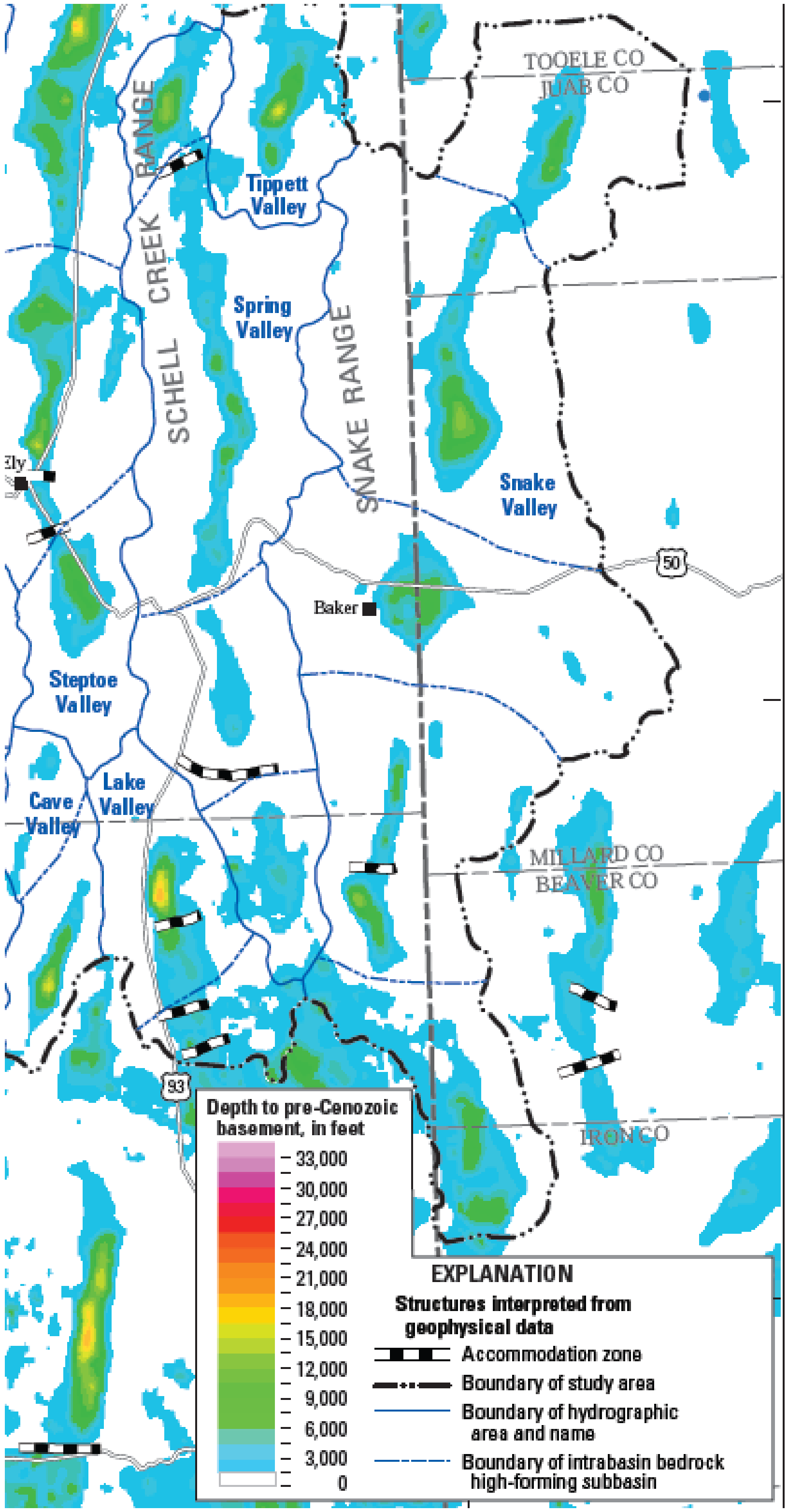


Figure 10: Snapshot from Figure 8, Welch et al (2008), showing the depth to basement rock.

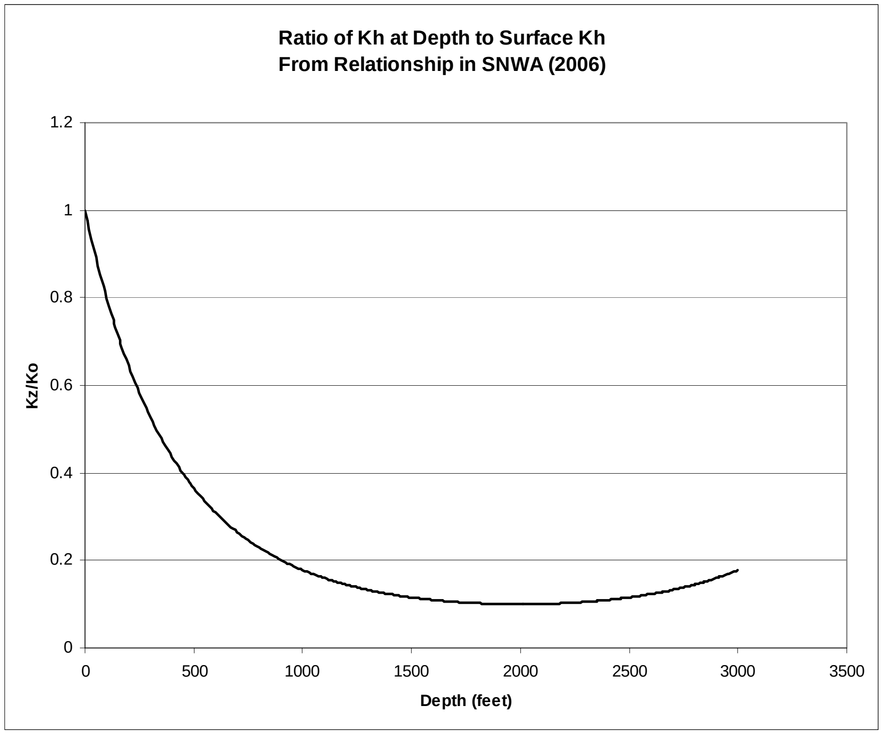


Figure 11: Variation of conductivity with depth for upper valley fill (Durbin, 2006).

Water Balance for Study Area

The water balance for a basin consists of inflow and outflow, which are equal if the system is at steady stated. Inflow to a basin is recharge and interbasin flow. Outflow from a basin is groundwater evapotranspiration (GWET) which includes spring discharge and transpiration from the phreatophytes. If not at steady state or at a dynamic state as discussed above, some groundwater moves in and out of storage so that a change in storage term is added to the water balance, or change in storage equals the difference between inflow and outflow.

Recharge

Basinwide recharge is the total recharge within a basin to the regional aquifer. Recharge to perched aquifers is not included unless a stream discharging from these aquifers recharges secondarily further downslope. Secondary recharge of streamflow percolating back into groundwater after having discharged into a stream also is not counted.

Numerous recharge estimates have been made for these basins. Reconnaissance reports (Hood and Rush, 1965; Rush and Kazmi, 1965; Eakin et al, 1967; NV Div of Water Resources, 1971) used the Maxey-Eakin method to estimate basinwide recharge (Maxey and Eakin, 1949). These reports had been considered the standard for recharge estimates within these basins, with their accuracy holding up to scrutiny (Avon and Durbin, 1994). Often forgotten in recent applications of the method, the Maxey-Eakin method uses coefficients to estimate recharge based on annual precipitation depth and therefore depends on the use of the same precipitation database used to determine the coefficients. For this reason, the estimates of SNWA (2006) were incorrect. Also, the Maxey-Eakin method includes all recharge, not just mountain block recharge, because Maxey and Eakin derived it based on estimates of discharge from the entire basin as ET and spring flow. It is not appropriate to consider additional runoff recharge, as was also mistakenly done by SNWA (2006). An additional caveat is that Maxey-Eakin coefficients are not the amount of water that recharges at a point, but again are tantamount to regression coefficients used to estimate basinwide recharge (Stone et al, 2001).

Other methods have also been used to estimate recharge in this study area. These inclue isotope mixing (Dettinger, 1989), soil water balances (Flint and Flint, 2007; Flint et al, 2004), adjusting the Maxey-Eakin coefficients to make them compatible with up-to-date precipitation estimates (Nichols, 2000), or calibrating a groundwater model to equal observed discharges (Brothers et al, 1993 and 1994). Table 2 shows estimates basinwide recharge made for the project area valleys in various reports. Steptoe Valley was included for comparison. Pleasant Valley and Hamlin Valley are part of Snake Valley.

One source of error in recharge estimates is the precipitation estimate. Many recharge estimates use PRISM (Daly et al, 1994) to estimate total precipitation or distribute it across a basin (Myers, 2011; Halford and Plume, 2011; Flint and Flint, 2007; Flint et al, 2004; Nichols, 2000). Some have noted that PRISM may overestimate, even grossly, the average precipitation in areas near Lake Valley and Hamlin Valley (Myers, 2011; Halford et al, 2011; Jeton et al, 2005). The inaccuracies inherent in PRISM should be considered with all estimates of recharge (and groundwater ET) utilizing PRISM precipitation estimates.

Table 2: Basinwide recharge estimates (kaf/y) for project area basins, from previous studies.

	Snake Valley	Spring Valley	Steptoe Valley	Tippett Valley	Deep Creek
Reconnaissance Reports (Hood and Rush, 1965; Rush and Kazmi, 1965; Eakin et al, 1967; NV Div of Water Resources, 1971)	103	75	85	7	17
Watson et al (1976)		63	75	5	
		33	45	6	
Nichols (2000)		104	132	13	
Epstein (2004), as referenced in Welch et al (2008)		93	101	9	
Dettinger (1989)		62			
Flint and others (2004)	93	67	111	10	12.3
	82	56	94	8	11.4
Brothers et al (1993 and 1994), as referenced in Welch et al (2008)	110	72			
Flint and Flint (2007); Welch et al (2008)	111	93	154	12	
Average (af/y)	**99.8**	**71.8**	**99.6**	**8.8**	**13.6**

The estimates in Table 2 are all basinwide estimates. Flint et al (2004) and Flint and Flint (2007) estimated recharge by doing a soil water balance (the basin characterization model, or BCM) for model cells distributed across the basins. The method uses simulated climate data with broad-scale soil and geologic parameter estimates. An advantage to the method is that it is physically based – not based on a statistical analysis or otherwise on the estimates of coefficients. A drawback is that the recharge estimates are not calibrated to observed values. It is also problematic that the mountain-front recharge was assumed to equal 15% of the runoff, without justification. A major advantage is that the method estimates recharge across the basin based on geology, soils, and precipitation. Point recharge in the study area varied from essentially 0 to as much as a foot per year (Figure 12). It is unclear why the three BCM methods resulted in such variable estimates, especially for Spring Valley.

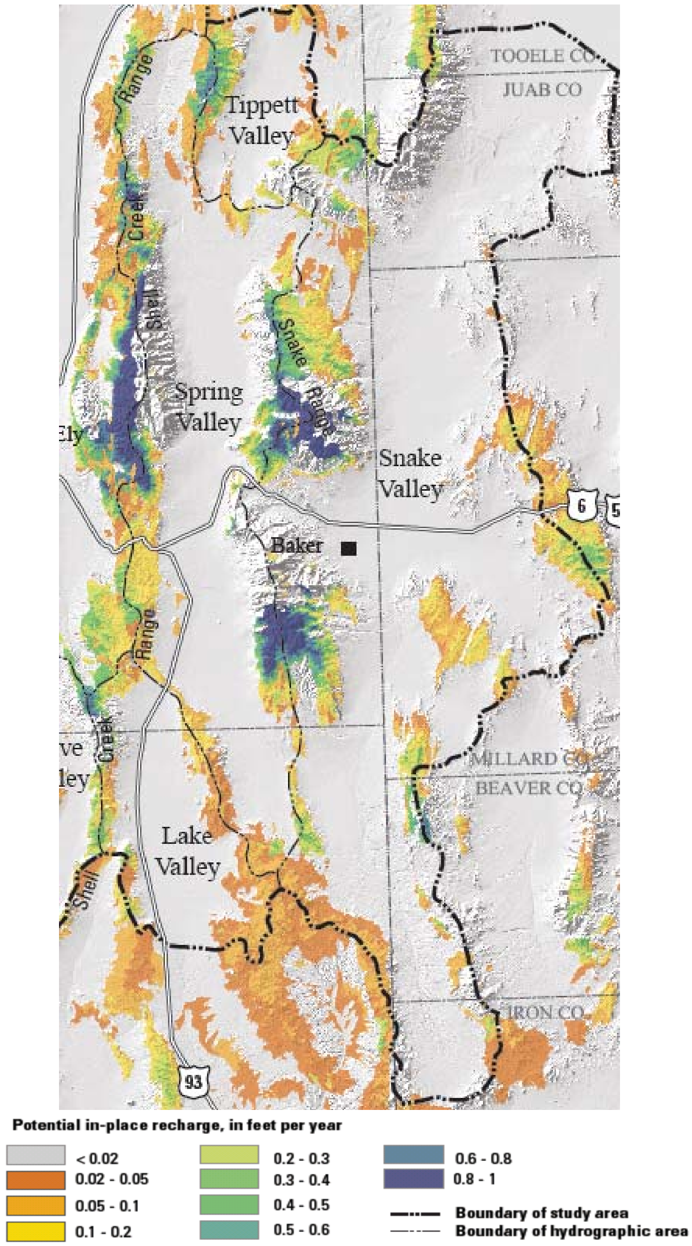


Figure 12: Snapshot of Figure 6 (Flint and Flint, 2007) showing simulated in-place recharge.

Mountain blocks with the least recharge included the Snake Range west of Baker around Wheeler Peak, the south portion of the Kern Mountains, the south two-thirds of the Deep Creek Range, and the east ridge on the north portion of the Schell Creek Range (Figure 12). The low recharge was due to intrusive or sililiciclastic rocks which reject percolating water. These areas all host perennial streams that have high flows during snowmelt and low flows during the late summer, early autumn baseflow. The streams and the runoff from these mountains will recharge at the mountain front, usually at the top of the fans.

Conductive rock, such as carbonate, allows high recharge in three primary mountain areas – two in the Snake Range and one in the Schell Creek Range; these areas all have from 0.8 to 1.0 ft/y of recharge. Other carbonate mountain block areas have recharge at lesser amounts due to less precipitation (Figure 12).

Secondary Recharge

Perennial streams and springs discharge water onto the valley floor that has previously discharged from the groundwater. This is secondary recharge. It differs from runoff recharge I that it was baseflow. Several perennial streams discharge onto the valley floor where they percolate into the basin fill groundwater. This recharge is secondary because it had previously discharged into the stream. Cleve Creek, Snake Creek, and Baker Creek are examples, which will be discussed below.

Discharge: Evapotranspiration, Springs, and Streams

Groundwater discharge occurs in two ways: as evapotranspiration (ET) and/or as spring/stream discharge. The interactions between surface and groundwater complicates the consideration of discharge - spring discharge frequently percolates back into the ground from which it supports groundwater ET or may form a second spring. This percolation of spring flow is secondary recharge. It is important to not doublecount spring discharge and ET of the same water. This is problematic in both Spring and Snake Valleys. Spring Valley has many springs at the base or the top of fans which discharge into short channels that support phreatophytes downstream.

Welch et al (2008) estimated groundwater discharge by basin based on the ET distribution shown on Figure 13. Their estimate for Spring, Snake, Steptoe, and Tippett Valleys was 75,600, 132,000, 101,500, and 1700 af/y, respectively. These values are total discharge including spring discharge because the spring flow goes to the various types of discharge and some of the ET discharge is from channels below the springs.

Most all of the Spring Valley ET occurs in the middle two-thirds of the valley (Figure 13), the section west of the entire length of the Snake Range. Most of the groundwater ET in Snake Valley occurs in the middle three subbasins, although the northernmost of those three subbasins discharges almost 55,000 af/y partly because of Gandy Warm Springs. Because much of the recharge occurs in the south half of the basin, there must be significant intrabasin flow from south to north, in addition to interbasin flow from Spring Valley (Welch et al, 2008).

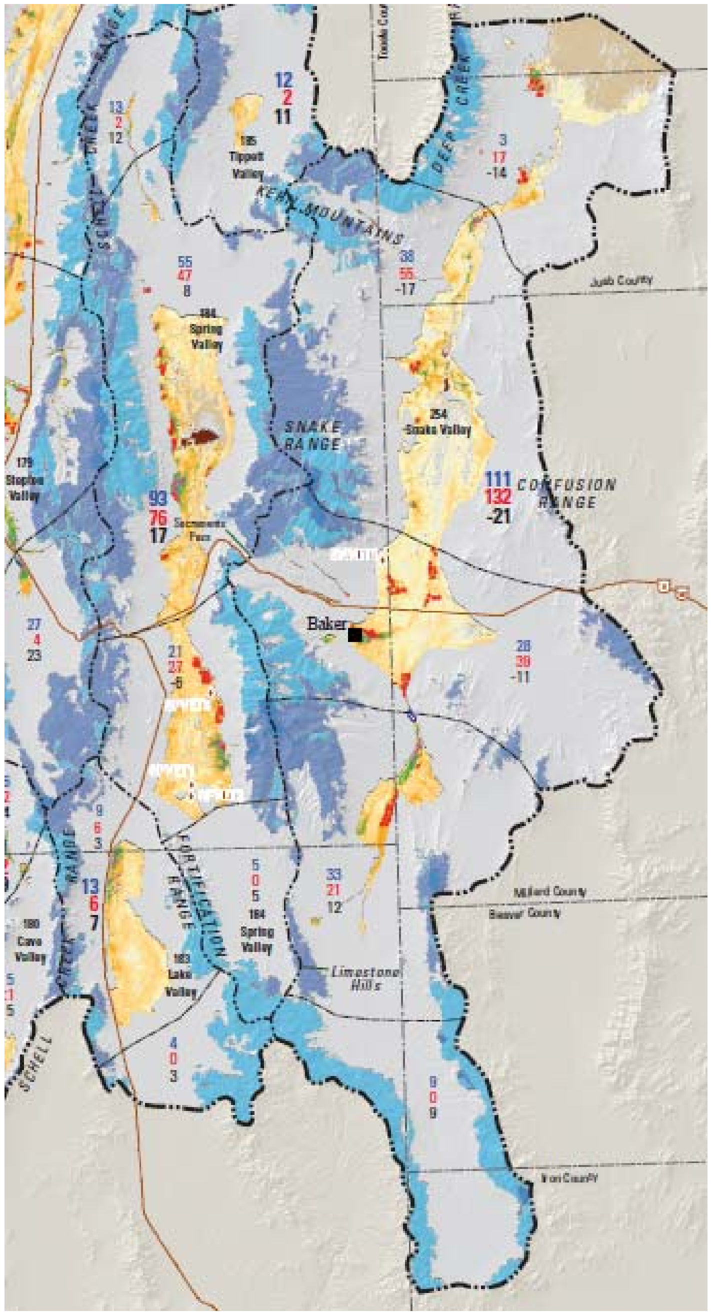


Figure 13: Snapshot of Welch et al (2008), Plate 4, showing distribution of evapotranspiration and locations of in-place recharge or runoff. The ET shading is from about 0.6 ft/y, tan for playa, through yellow (shrubs) to green (marshland) at over 4 ft/y.

Interbasin Flow to and from the Valleys

The model domain is Spring, Snake, Tippett, and Deep Creek Valley, with an expansive Snake Valley definition including Hamlin and Pleasant Valley (Figure 1). Potential inflow to the model domain is from the west, Steptoe or Lake Valley basins, and discharge from the domain is to the north from Tippett or Deep Creek Valley to Antelope Valley or from Snake Valley to the Great Salt Lake Desert basin.

Geology controls flow across the boundaries of the study area. As outlined by Welch et al (2008, p 33), there is either continuous permeable rock, substantial impermeable rock blocking the flow, the system is uncertain, or both factors are present. Figure 15 in Welch et al (2008) provides a map describing the boundaries of the flow system considered in that report; the following paragraphs expand the description as pertains to the Spring/Snake Valley flow system.

The potential inflow to Spring Valley is interbasin flow from Steptoe Valley. Welch et al (2008) estimated that recharge substantially exceed GW discharge within Steptoe Valley, so they estimated interbasin flow from Steptoe Valley to many adjacent valleys to balance the flows. The estimate for flow to Spring Valley was 4000 af/y. Flow from Lake to Spring Valley was estimated at 29,000 af/y, but this mostly originated in Steptoe Valley. Steptoe Valley would therefore be the head of both the Great Salt Lake and White River Flow systems (Eakin, 1966).

Sedimentary rock, primarily of carbonate composition, forms most of the mountain ranges along the east boundary of Snake Valley (Watt and Ponce, 2007). The Confusion Range, bounding the northeast portion of Snake Valley (Figure 1), consists of significant amounts of limestone (Figure 9) which permits interbasin flow from the Snake Range to the valleys to the east, including Fish Springs Flat (Welch et al, 2008; Kirby and Harlow, 2005).

Volcanic rock bounds the south end of Snake and Spring Valley; although not impermeable, groundwater flow would likely be limited to localized systems. This may impede interbasin flow between Snake and Wah-Wah Valley. The southernmost portion of Snake Valley may be a subbasin relatively isolated from the remainder of the valley due to volcanic rock (Welch et al, 2008, p. 36). Volcanic portions of the Fortification Range bound southwest Spring Valley and may impede flow between Spring and parts of Lake Valley. Northwest of the Fortification Range along Lake Valley summit, there is carbonate rock (UCU) through which the postulated interbasin flow would occur, but with a "thin Chainman shale" layer which may slow or prevent flow through that region (Welch et al, 2008).

About a third of the Schell Creek Range, from Hwy 50 to Lake Valley summit, consists of carbonate rock but with a detachment fault which may impede flow. As described in BARCASS:

> *Ground-water flow is possible, but uncertain, across HA boundaries identified as having permeable carbonate rocks (LCU or UCU) overlying a shallow detachment fault. All these segments are associated with detachment faults in the Cherry Creek, Egan, Grant, Snake, and* ***Schell Creek Ranges*** *where the lower plate beneath the detachment faults may not be exposed but whose presence in the shallow subsurface reasonably is inferred. In these areas, the upper plate consists of highly faulted carbonate rocks that may have enhanced permeability caused by the structural disruption*. (Flint et al, 2008, p. 36)

This boundary is highly important to this flow system because of the potential for inflow from Steptoe Valley.

Impermeable bedrock forms the core and prevents interbasin flow between Steptoe and Spring Valleys through the central third of the Schell Creek Range. The north end of the Schell Creek Range has carbonate rock but also substantial faulting. There is a gradient of about 200 feet in 15 miles (0.0025) through carbonate rock between Steptoe and northern Spring Valley (Welch et al, 2008, Plate 3). A recharge-induced divide in the northern Schell Creek range would prevent flow between the valleys. Interbasin flow in this area is uncertain.

Volcanic flow dominates the outcrops in the north end of Tippetts and Spring Valley, although there is basin fill on the northwest boundary of Tippetts Valley. The project boundary at the north end of Deep Creek Valley is alluvium underlain by volcanic or siliceous rock, which suggests that interbasin flow would occur through upper layers but not at depth.

The north end of Snake Valley opens to the broad open basin and playa of the Great Salt Lake. Carbonate rock bounds the east side of Snake Valley, and the gradient indicates that flow occurs in that direction and contribute to discharge from Fish Springs. The BARCAS estimate for flow from Snake Valley to these two areas is 29,000 af/y.

Interbasin Flow between Project Subbasins

The north end of the study area contains both the highest and lowest elevation basin areas. The north end of Spring Valley is as high as 6500 feet; east of that is Tippett Valley at about 5500 ft amsl, Deep Creek Valley at 5000 ft amsl, and northern Snake Valley as low as 4200 ft amsl. Groundwater does not flow directly along that profile, however, due to geology. Interbasin flow is primarily from Spring Valley to Tippett and Snake Valley, with flow from Tippett to Deep Creek and possible further east to Snake Valley.

The ridge between the north end of Spring Valley and Tippets Valley is primarily carbonate rock, which would allow flow between the basins; the degree and role of fracturing or impeding faults is uncertain; there are also zones with volcanic flow units. Interbasin flow between Tippett and Deep Creek Valley is complicated by mixtures of carbonate and volcanic rock. North of the Kern Mountains, the boundary between Tippett and Deep Creek Valley is carbonate, but further north it is volcanic and siliceous.

Potential flow between Spring and Snake Valleys is an important factor because development in one basin could affect resources in the adjoining basin, but geology makes estimating the impacts complicated. Prior to BARCAS, most studies had identified only small amounts of interbasin flow between these valleys; one estimate was 4000 af/y through the Limestone Hills region (Hood and Rush, 1965). Groundwater gradients show a general trend for flow from Spring to Snake Valley.

In the north, the Kern Mountains have impermeable intrusive rock which likely prevents flow, but just south there is potentially flow through Pleasant Valley from Spring to Snake Valley. The northern portion of the Snake Range, north of Hwy 50, has substantial carbonate rock but detachment faults which may prevent interbasin flow; this faulting may also direct recharge in that carbonate rock to flow north – towards Gandy Warm Springs (Flint et al, 2008, Plate 1). The northern half of the South Snake Range, just south of Hwy 50, is impermeable due to intrusive and siliciclastic bedrock. The southern half is carbonate with a detachment fault on the east (Elliot et al, 2006) which may enhance the permeability. The west half of Hamlin Valley, a portion of Snake Valley, has substantial amounts of carbonate rock, and the fault just east of the Snake Range may direct flow from this carbonate towards Big Springs. In other words, flow to Big Springs may result from interbasin flow through the Limestone Hills and carbonate flow from the south Snake Range. In summary, the best potential for interbasin flow from Spring to Snake Valleys is through the southwest third of Snake Valley and through Pleasant Valley.

The estimated flux rate between valleys is very uncertain. The flux depends on the water balance of Spring Valley – whether there is more recharge and interbasin flow to Spring Valley than GWET. BARCAS estimates that 33,000 af/y discharges to Snake Valley through the southern end and 16,000 af/y through Pleasant Valley or through carbonates in the Kern Mountains. There is also 2000 af/y discharging to Tippett Valley, based on BARCAS. Thus, interbasin flow discharging from Spring Valley totals about 51,000 af/y (Welch et al, 2008), which depends almost totally on inflow from Steptoe Valley (most of the inflow from Lake Valley originates in Steptoe Valley).

The total recharge estimate for the study area was 194,000 af/y, based on average values from other studies. Interbasin inflow originating in Steptoe Valley could be as much as 33,000 af/y. The outflow to the north from Tippett and Deep Creek Valley is about 12,000 af/y, and to the Great Salt Lake and Fish Spring Flat is about 29,000 af/y. The BARCAS GWET estimate is 209,000 af/y. The flux values just presented have a residual of about 23,000 af/y, which is a good estimate of the uncertainties in the overall water balance for the study area.

Conceptual Models of springs and Streams

The previous section has generally described the flow through the four study area valleys.; it has provided a good conceptual model of that valleywide flow. However, each stream and spring is a detailed manifestation of that flow. They are important recharge and/or discharge points within the overall model. Local-scale geology may control each of these points. This section describes briefly some of the flow details, including geology and measured flows for individual points. Some of the streams and springs are perennial and flow measurements provide estimates of secondary recharge. Figure 14 locates many springs and perennial streams in the study area.

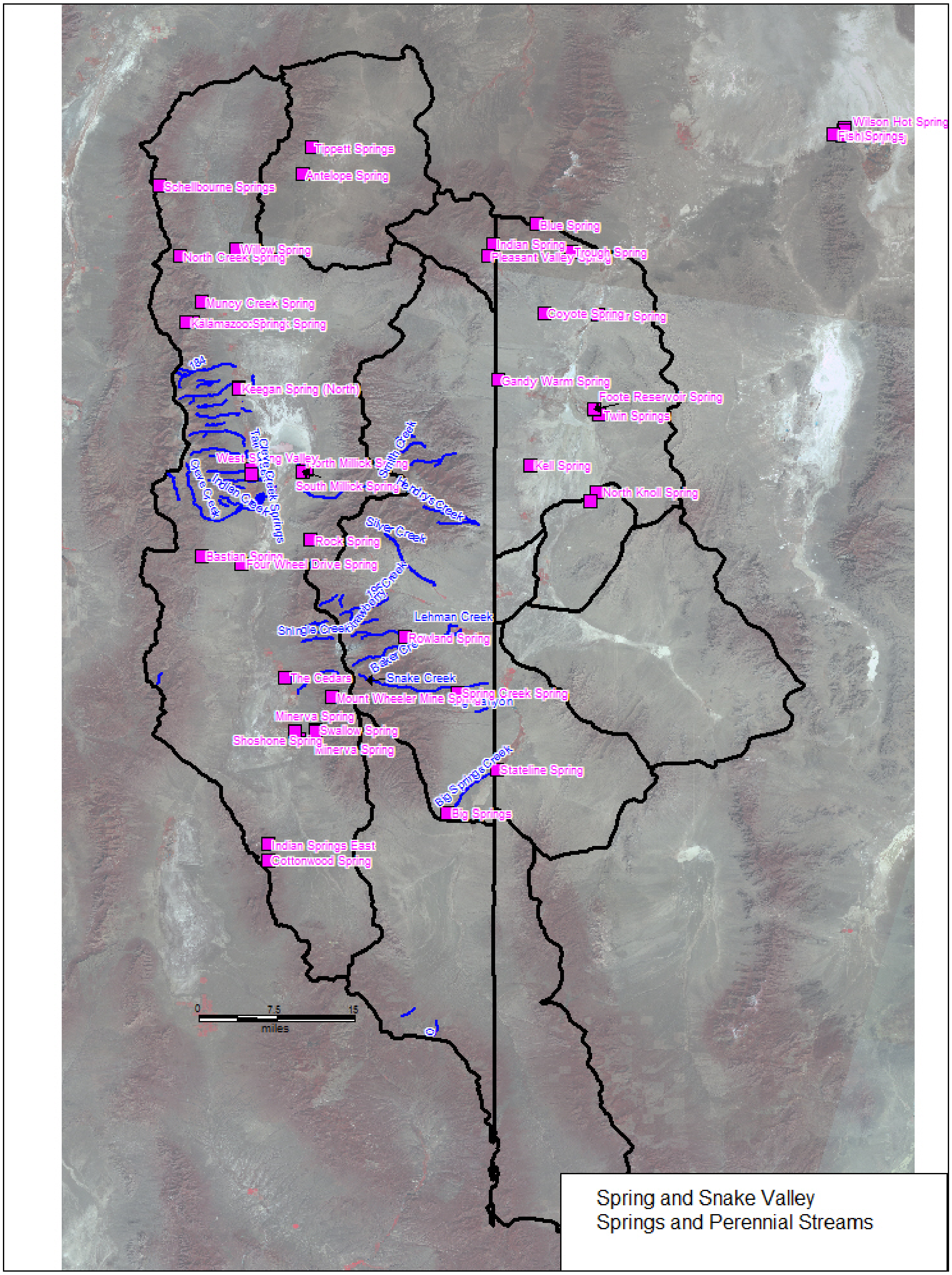


Figure 14: Perennial streams and major springs in Spring and Snake Valley.

Strawberry and Shingle Creeks

Most of the perennial flow in Strawberry Creek is runoff and discharge from glacial and alluvial deposits in the stream's upper watershed. Just above the park boundary, some flow percolates, but then discharges back to the creek. Because of the underlying intrusive rock, the discharge and recharge above the park boundary is likely not connected to the regional water table (Figure 15). The stream loses its flow to percolation and ET downstream of site St4 (Figure 15). In June 2003, the flow at the park boundary was 3 cfs (Elliot et al, 2006) which would have recharged the alluvial fan if not diverted; in October, the flow was about 0.2 cfs. Average secondary recharge should be about 0.5 cfs.

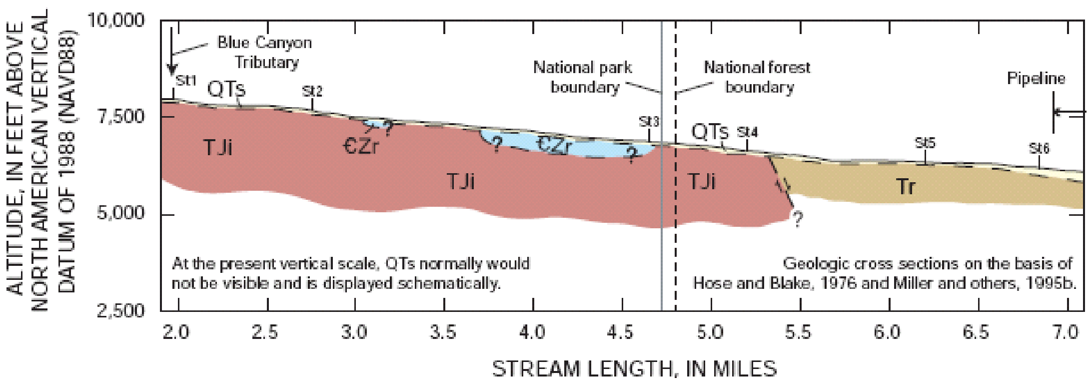


Figure 15: Geologic profile of Strawberry Creek in the Snake Range. From Elliot et al (2006).

Shingle Creek flows off the northwest of the southern Snake Range into Spring Valley (Figure 16). It flows mostly over older differentiated rock with an intrusive rock outcrop in the upper reaches (Figure 16). Based on flow rates and specific conductivity at four sites along the stream, little discharge or recharge occurs above about 6300 feet msl. Most of the flow, about 1.9 or 0.5 cfs in June or October, 2003, would have recharged into the alluvial fan below the mountain front, if not diverted into a pipeline. Elliot et al (2006) noted that the range-bounding fault likely crosses Shingle Creek west of the upstream end of the pipeline. Otherwise, the alluvium would thicken and flow losses increase somewhere between Sh4 and Sh3.

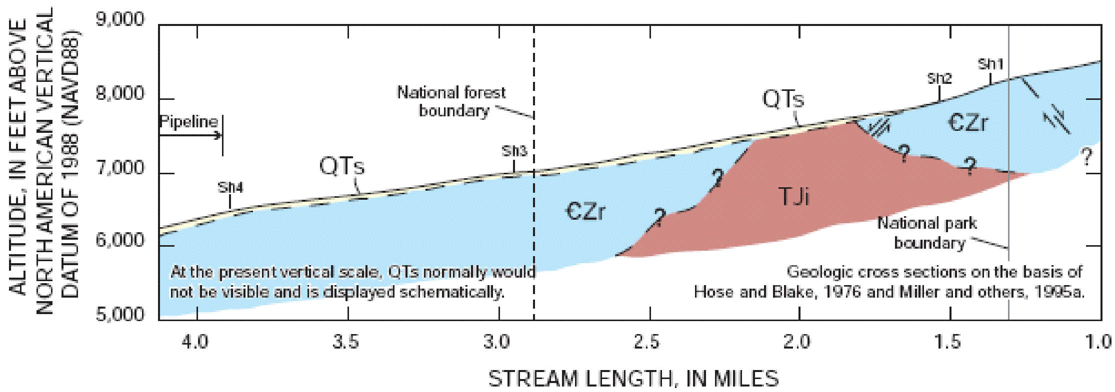


Figure 16: Geologic profile of Shingle Creek in the northwest portion of the South Snake Range. From Elliot et al (2006).

Baker/Lehman Creek System

Lehman and Baker Creeks head in the cirques north- and southeast of Wheeler Peak. Year-round flow results from groundwater storage in glacial/colluvial deposits, which are underlain by older undifferentiated or lower siliciclastic rock, in the high elevation valleys. Baker Creek discharges into Lehman Creek, under natural conditions, about two miles downstream of the park boundary. Both streams cross an intrusive outcrop which may cause groundwater discharge to the stream and coincides with the highest flow rates along the stream profile (Elliot et al, 2006) (Figures 17 and 18). Below the outcrops, the streams cross carbonate rock prior to reaching a thin veneer of basin fill which may be underlain by volcanic rock. Further downstream, the range front bounding fault may coincide with a significant increase in cross-sectional area for groundwater which would also be the location for significant recharge to the fill.

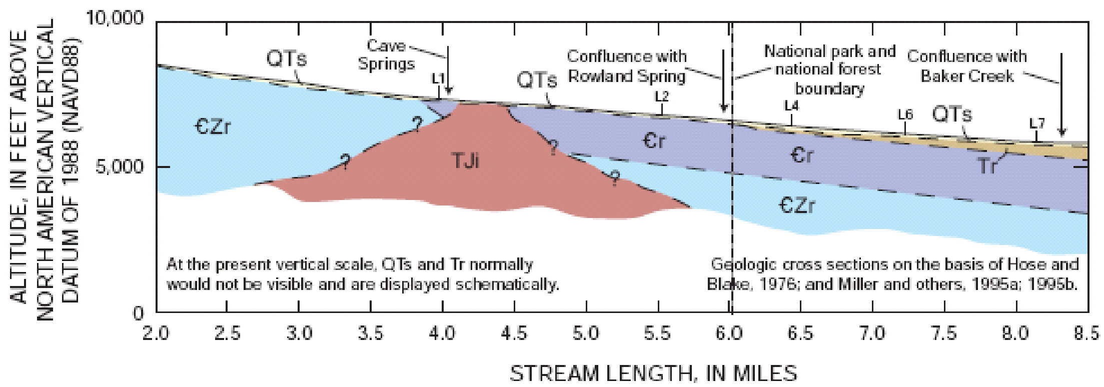


Figure 17: Geologic profile of Lehman Creek from Wheeler Peak to Baker. The profile shows clearly a carbonate rock layer above the older undifferentiated rock. From Elliot et al (2006).

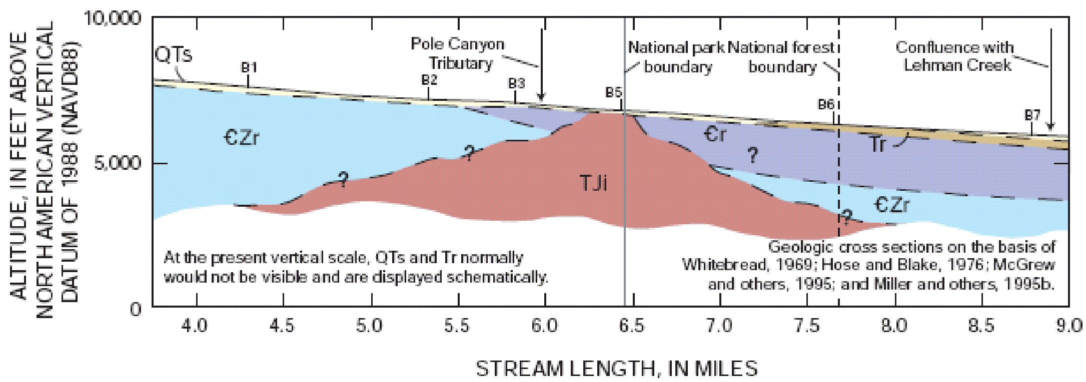


Figure 18: Geologic profile of Baker Creek. The profile shows clearly a carbonate rock layer above the older undifferentiated rock along with intrusive rock which corresponds to the Rowland Spring. From Elliot et al (2006). This corresponds with rows 80 through 83.

Average flow in Lehman and Baker Creeks is 5.1 and 9.1 cfs, respectively (Elliot et al, 2006), but October/November baseflow is more similar - in Lehman and Baker Creeks it averages 2.6 and 2.1 cfs and 2.8 and 2.5 cfs, respectively (Figure 20). The higher average flow in Baker Creek reflects the higher spring runoff (Figure 19) from a larger drainage area (16 v. 11 sq. miles). Baker Creek therefore apparently provides substantial recharge to the carbonate aquifer, possibly supporting Rowland Springs. Because Rowland Spring does not exhibit peak flows nearly as proportionally high as the two streams, the recharge to the carbonate is likely limited, so the alluvium likely receives occasional large volumes of recharge.

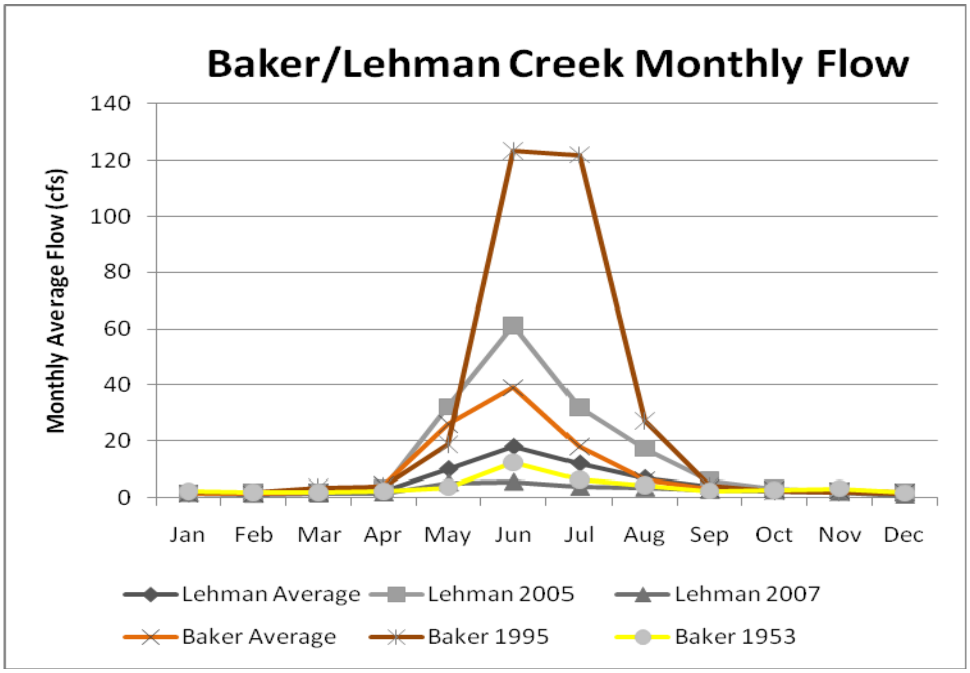


Figure 19: Monthly hydrographs for Lehman Creek near Baker, NV (#10243260) and Baker Creek at Narrows (#10243240) for average, high (2005) and low flows (2007).

Lehman Creek either gains flow or is steady along its length upstream from the confluence with Baker Creek (Elliot et al, 2006). Stream flow at the downstream Lehman Creek monitoring point, L7, was 11.7 cfs in July 2003 and 5.7 cfs in October (Elliot et al, 2006). During July 2003, the flow above the monitoring point gained while during October 2003 flow rates were steady. Elliot et al (2006) postulate that this indicates groundwater discharge to the stream during the snowmelt period and little or no recharge during the baseflow period. Based on the synoptic flows, which show that between L2 and the downstream point, the flow rates had increased about 3, 3, and 5.5 cfs in September 1992, October, and July 2003, respectively. Including flow from Rowland Spring, there is about 8 cfs recharge to the fan downstream under natural conditions, without diversion. This is about 5800 af/y of primary and secondary natural recharge just west and in Baker along Lehman Creek (1840 ac or 0.00863 ft/d in zone 176) which probably supports Rowland Springs. Lehman Creek also does not have a losing reach (Elliot et al, 2006; Figure 17), so there would be no recharge simulated above Rowland Springs.

Flow rates in Baker Creek near site B2 were about 8 and 4 cfs in July and October, 2003, respectively, and about 5 cfs upstream from B2 in September, 1992. About 50% of this flow was lost between B2 and B5 in 2003 and about 80% in 1992. The loss appeared to be recharge to carbonate under the creek, which may recharge Rowland Springs (see below). Below this point to the confluence with Lehman Creek, during September, 1992 and July, 2003, the flow remained mostly steady suggesting groundwater levels are close to the creek levels with minor gaining and losing conditions.

Near the park boundary, the stream appears to be in close contact with the water table, losing small amounts of flow during high flow and gaining during low flow periods (Elliot et al, 2006). Elliot et al (2006) use this as hydrologic evidence for claiming the range front fault lies east of the Baker/Lehman confluence; because the basin structure drops at the range-bounding fault, the alluvium would thicken sharply at the fault. This would increase substantially the cross-sectional area.

Cave Springs discharges from near a small outcrop of Cr intrusive rock, which Prudic and Glancy (2009) identified as its source. Based on isotope data, the water does not originate in Lehman Creek. The high EC (Elliot et al, 2006) is likely caused by limestone piled near the spring during reconstruction of the spring collection system (Prudic and Glancy, 2009). Cave Springs is probably not connected to the regional water table.

Rowland Springs discharges from alluvial deposits underlain by carbonate rock 15 feet above nearby Lehman Creek (Elliot et al, 2006). The USGS measured flow rates from October 2002 to September 2004 (Figure 20); the average, standard deviation, maximum, and minimum were 2.3, 0.79, 3.7, and 0.75 cfs, respectively. The NPS has collected flow and temperature data for much longer (Figure 21). During the overlapping period, the NPS data corresponds with the USGS data (Figures 20 and 21). The NPS data spiked to 4.8 cfs on July 15, 2005, and then commenced a downward trend which lasted until 2008. This corresponds to a dry period following a wet 2004/5 winter. Stream temperatures continue to fluctuate between about 8 and 10 C, reflecting a carbonate source (Elliot et al, 2006). The data suggest a short-term response to seasonal changes (recharge) and a consistent baseflow. A reasonable baseflow target is 2 cfs.

Elliot et al present specific conductance data for Rowland Spring and Lehman Creek which shows that the spring contains far more dissolved solids than does Lehman Creek. This suggests the spring does not originate from Lehman Creek from which groundwater would flow through alluvium to the spring. The most likely sources, though with significant uncertainty (Elliot et al, 2006), is that Baker Creek is a primary source with a flow path through Pole Canyon limestone which dips northeast from Baker Creek from elevations higher than Rowland Springs.

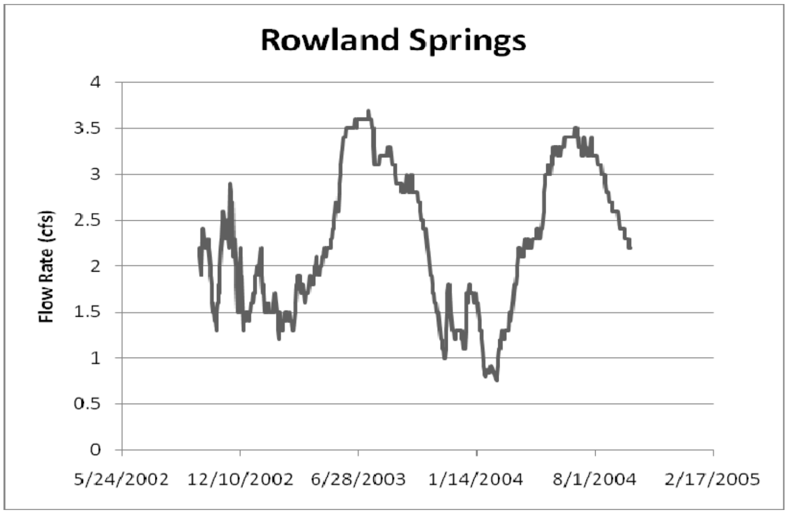


Figure 20: Rowland Spring flow data. USGS Site10243265

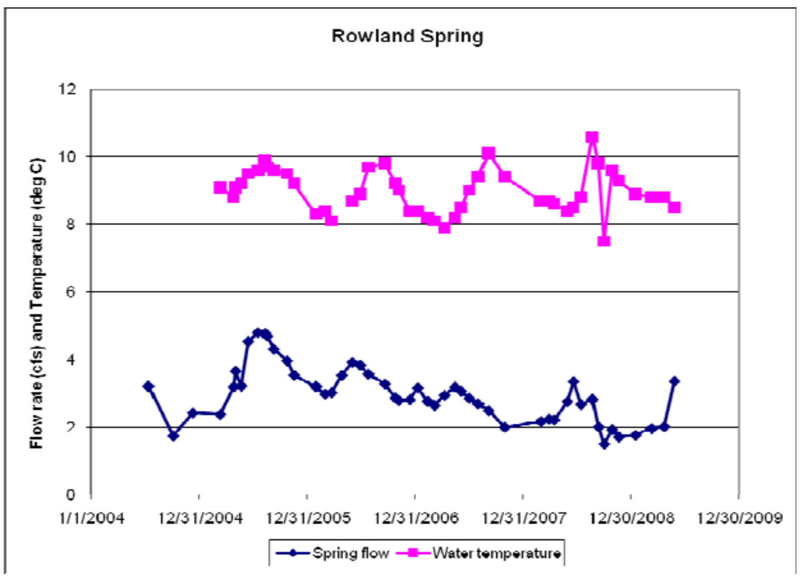


Figure 21: Rowland Spring monthly flow and temperature data, collected by the NPS.

Snake Creek System

Snake Creek originates in glacial colluvium and alluvial deposits that over lay quartzite and intrusive rocks. It crosses lower carbonate rock in its upper reaches, above 7000 ft amsl, which currently has a 3-cfs pipeline designed to prevent seepage as it crosses the Pole Canyon limestone (Cr) and Prospect Mountain quartzite (CZr) (Figure 22).

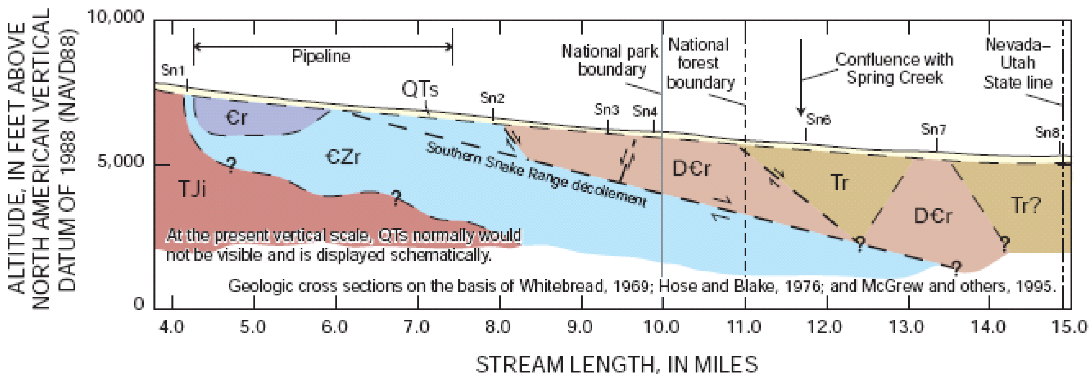


Figure 22: Geologic profile of Snake Creek in the Snake Range. From Elliot et al (2006).

During June 2003, the flow was 15.5 cfs above and 12.9 cfs below the pipeline, respectively, for a 2.6 cfs loss. During October 2003, all 1.05 cfs was diverted (Elliot et al, 2006). Also during October 2003, about 0.09 cfs seeped into the channel above the downstream end of the pipeline which suggests that a small amount of the flow lost to CZr returns to the creek. Flow lost to the Pole Canyon limestone, however, may not return to the creek due to the southeast dip of the Snake Range decollement which may cause seepage to flow away from Snake Creek and discharge at Big Springs or into the wetland areas below Big Springs (Elliot et al, 2006, page 37). Downstream of the pipeline, the flow and geology become more complicated. Between sites SN2 and SN3, crossing younger undifferentiated rocks, mostly limestone, the flow increased about 1 cfs during June 2003 and decreased slightly during October 2003. Flows during June in this reach ranged from 12.9 to 13.9 cfs and during October were around 1 cfs, reflecting the high influence of snowmelt on this streamflow.

The 2002-2004 hydrograph for three gages, above the pipeline, at the park boundary, and below the confluence with Spring Creek, demonstrates that the stream loses significant amounts of water to recharge during snowmelt runoff (Figure 23). Flow loss during peak runoff is as much as 28 cfs over the carbonate outcrop (Table 3, between stations Sn1 and Sn4) during the late May/early June 2003 snowmelt period. Flow losses occur all year, however, as the flow above the pipeline exceeds the flow at the park boundary during the ten non-snowmelt months of the year. Although an imperfect estimate due to the short period of record, the average flow at the upper two gaging stations is 2.6 and 1.2 cfs, respectively, or an average 1908 and 857 af/y (Figure 23). Based on hydrographs for Baker and Lehman Creeks, 2003 and 2004 were slightly below and far below average runoff years, respectively. This suggests the average recharge over these carbonate outcropping on Snake Creek would exceed 1050 af/y.

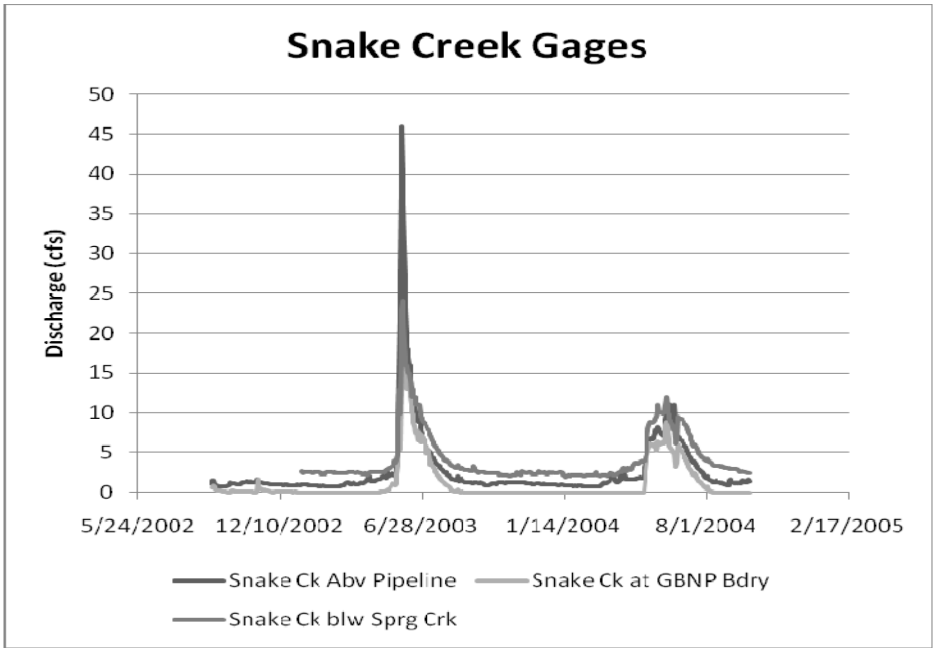


Figure 23: Hydrograph for three USGS gaging stations on Snake Creek. USGS 10243230 SNAKE CK ABV PIPELINE NR BAKER, NV; USGS 10243232 SNAKE CK AT GREAT BSN NAT PK BDY NR BAKER, NV; USGS 10243233 SNAKE CK BLW SPRING CK NR GARRISON, UT

Table 3: Snake Creek: Daily Flow (cfs) during snowmelt peak, 2003.

	Ab Pipeline	At Bdry	Below Spring Creek
5/28/2003	22	5.4	9.9
5/29/2003	28	6.4	11
5/30/2003	38	14	18
5/31/2003	46	18	28
6/1/2003	40	16	24
6/2/2003	36	16	22
6/3/2003	31	17	19
6/4/2003	27	15	17
6/5/2003	23	14	16
6/6/2003	20	14	16
6/24/2003	9.4	7.4	11
8/27/2003	2.5	1	4.1

Spring Creek is a tributary to Snake that discharges from a spring about one mile south of Snake Creek near the Forest Service boundary. It primarily discharges from the DCr outcrop which also underlies the creek below Sn4 (Figure 22). The spring flow increases the EC in Snake Creek substantially which indicates the spring has a carbonate pathway from recharge in Snake Creek. A fault controls the spring and forces the discharge at this point (Elliot et al, 2006). Spring Creek flows vary from 1 to 3 cfs, a variability which reflects seasonality of recharge from Snake Creek (Figure 24). The spring flow correlates with flow in Snake Creek reflecting higher spring discharge following snowmelt periods; peak spring flow occurs during July or August with peak streamflow occurring in May or June, reflecting an average two-month lag, or flow time. Also, the rearing station supervisor reported that the spring discharge has temporary peaks higher than reported on Figure 24 and that the water is sometimes turbid after a large storm; this reflects local recharge to the spring. A reasonable baseflow target flow is about 1 cfs.

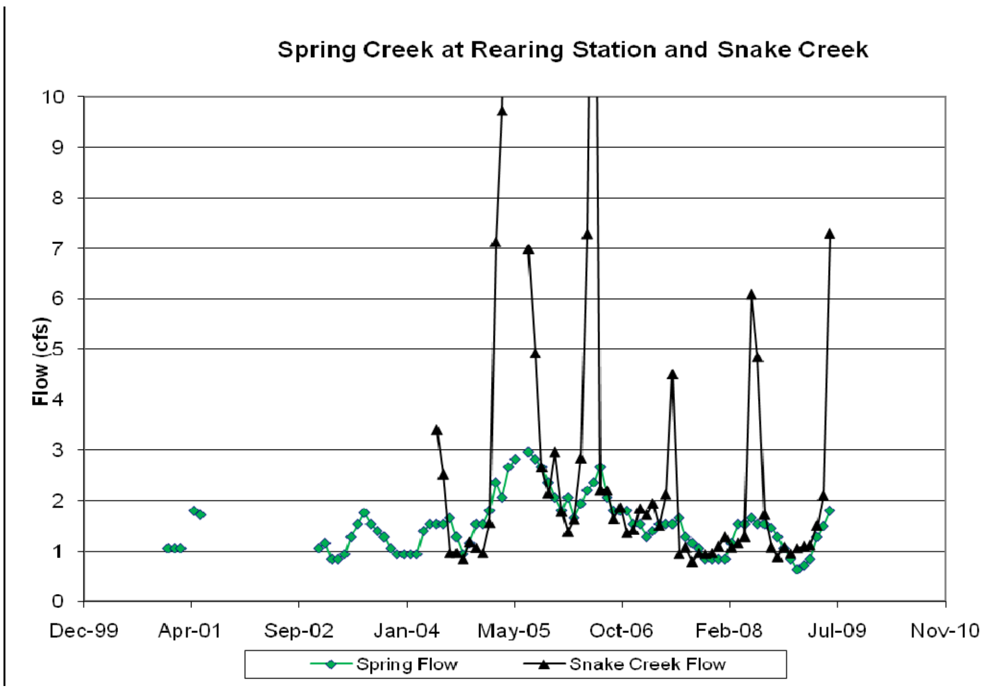


Figure 24: Spring flows and Snake Creek flow rates as measured by the Nevada Division of Wildlife at the Snake Creek rearing station.

Below Spring Creek, Elliot et al (2006) found little change with distance in flow rate on Snake Creek; EC even decreased slightly during some periods suggesting that groundwater returned to the creek from bank storage after snowmelt peaks. A synoptic survey conducted by this author on August 6, 2009, essentially verified those findings, although flow rate decreased a little more than one cfs in 1.7 miles between the confluence with Spring Creek and a road crossing near a Dg outcrop (Figure 25). This may have been evapotranspirative loss during the late summer; air temperatures were not taken, but it was hot. This indicates the water table is near the stream water surface downstream from Spring Creek.

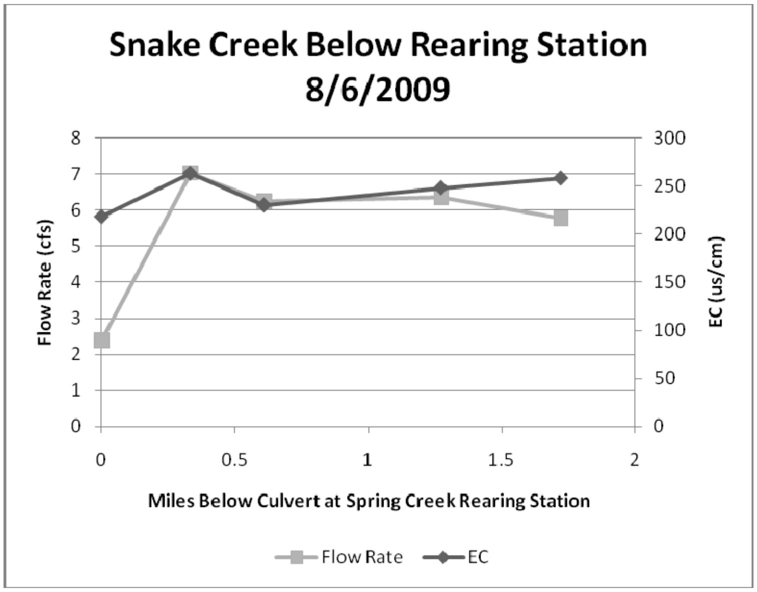


Figure 25: Synoptic survey on Snake Creek below the Spring Creek rearing station, 8/6/2009.

The data and geology suggest different models for three separate stream reaches. Upstream, where it crosses the carbonate rock, the stream loses much runoff to recharge. This rock is the lower plate of the Snake Creek decollement. Elliot et al (2006) suggest it is a primary source of flow from Big Springs or ET near Lake Creek. Synoptic surveys and gaging stations indicate that at least 1050 af/y recharge in this reach; because the gages operated during dry years, it is likely the recharge is substantially more. At the Baker and Lehman Creek gages considered above, the period of record flow average is 1.6 and 1.5 times the 2003- 2004 water year flow average, therefore it is reasonable to consider that Snake Creek recharge through this reach, the carbonate outcrop, is about 1600 af/y.

Downstream from the carbonate, the DCr (Figure 26) connects with the spring forming Spring Creek. In this area the DCr is combination of Eureka quartzite and limestone. A fault forces flow to the surface at this spring. Elliot et al (2006) suggest the pumping in Snake Valley could affect this spring, but that would manifest only if the fault was not a flow barrier. The stream does not lose flow over the DCr, so groundwater within it must be distributed recharge or recharge from Snake Creek in the CZr east of Sn2 but west of the fault. The flow lost from Snake Creek above Sn2 would not support Spring Creek and must flow to Big Springs. Because the geology supports the upper reach supporting Big Springs, most of the flow from Spring Creek must come from distributed recharge, not upstream on Snake Creek. This is reasonable with DCr being limestone. Between the confluence with Spring Creek and the terminus of the stream, Snake Creek appears to be in contact with the water table. The flow is relatively constant to the Nevada/Utah stateline (Elliot et al, 2006 and Figure 25).

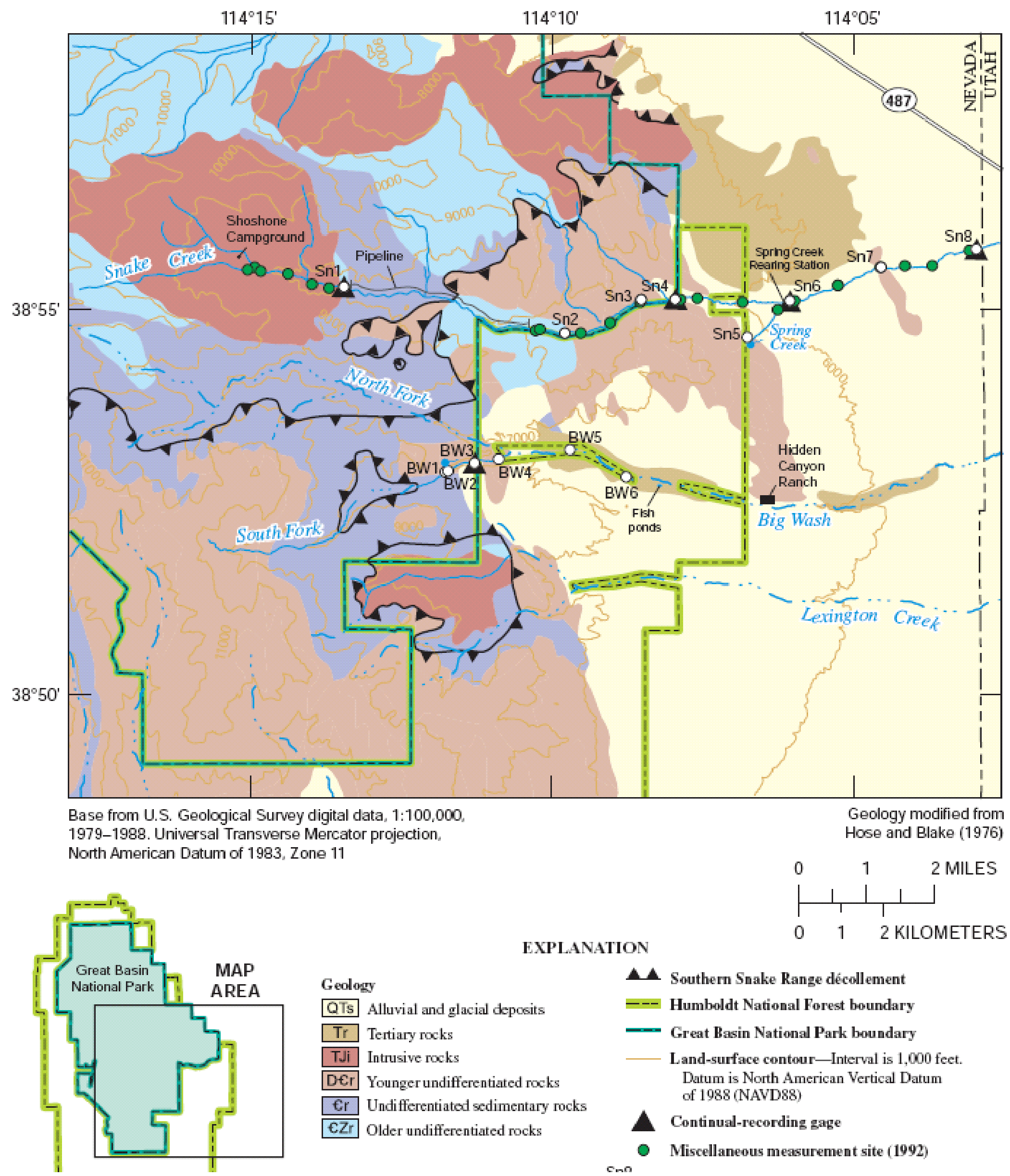


Figure 26: Geology of Snake Creek and Big Wash area, from Elliot et al (2006).

Big Wash

Big Wash drains the south portion of the Snake Range about three miles south of Snake Creek. It is much drier than Snake Creek because the prevalence of carbonate rock in the upper reaches of the watershed (Figures 26 and 27). During snowmelt, June 2003, the flow through the entire reach was relatively constant. However the EC was higher than other runoff dominated streams which suggests the runoff may be interflow through the carbonate rock. The stream had mostly dried by October, with flows being less than 0.5 cfs, dry in intermediate reaches, and increasing to more than 0.5 cfs downstream, probably due to canyon restrictions.

There are no obvious gaining or losing sections, and the survey does not go far enough downstream to determine where or whether recharge occurs. Elliot et al (2006) describe the channel as intermittent with near-channel springs supporting short perennial reaches.

The gaging station at the park boundary exhibited significant snowmelt runoff, reaching 21 cfs on May 29, 2003, just before the synoptic survey found just 4 cfs at that point (Figure 28). Flow had decreased to less than 0.1 cfs by the end of July – likely a residual discharge from the spring just upstream. Big Wash likely does not receive significant discharge from regional groundwater, and likely contributes recharge at a downstream point. The average discharge was about 380 af/y for 2003 and 2004. Based on the same comparison with Baker and Lehman Creek as completed for Snake Creek, there is likely secondary recharge at the mountain front of about 600 af/y.

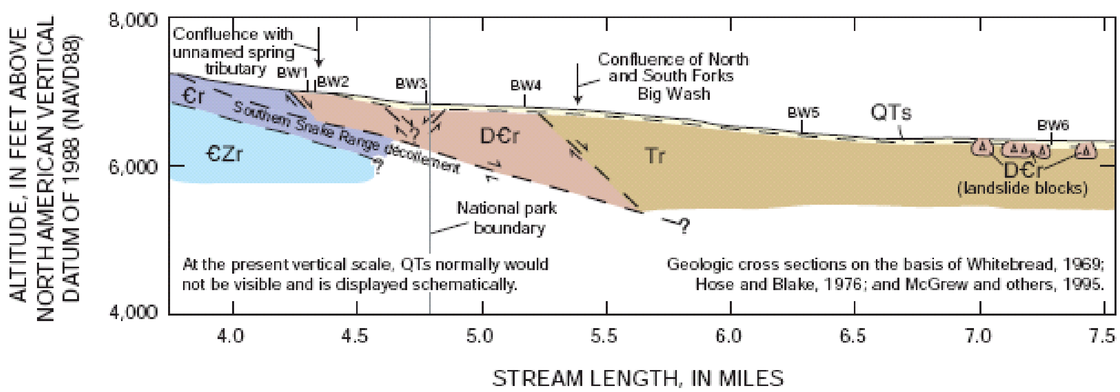


Figure 27: Geologic profile of Big Wash in the Snake Range. From Elliot et al (2006).

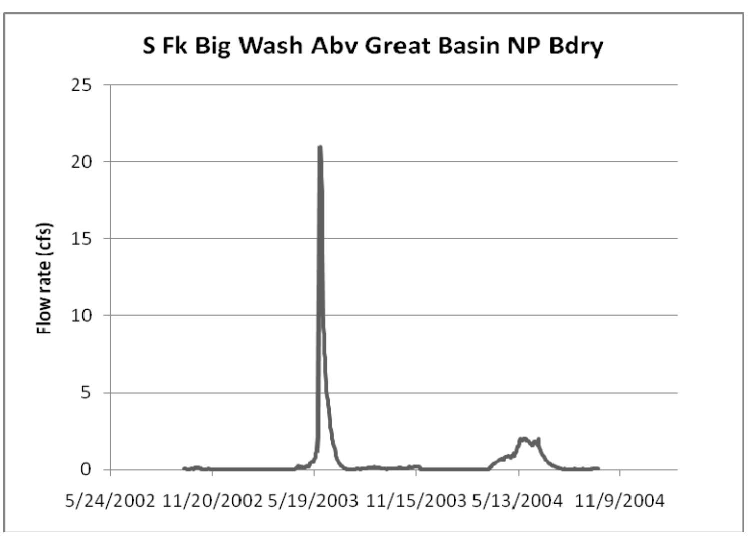


Figure 28: Hydrograph of USGS gaging station, Big Wash at GBNP boundary.

Cleve Creek

Cleve Creek discharges onto Spring Valley from the Schell Creek Range (Figure 14). It has intermittent flow records dating from 1914. The highest daily flow was 280 cfs in May 1984. Seasonal peaks occur every year, however, with daily peaks exceeding 50 cfs during most years. The average flow in both May and June is 23.1 cfs for the period of record and the long-term mean and median is 10.7 and 7.7 cfs. During dry to average conditions, the flow percolates into the alluvial fan before reaching the playa east of the gage, but during wet periods much water reaches the playa (personal observations in 1995, 2004, 2005, 2006, 2009, and 2010). The springs at the base of the fan discharge large flows which is likely percolation from Cleve Creek. The median flow, 5500 af/y, represents the percolation into the fan. This is secondary recharge of stream baseflow. Based on the stratified lithology in the area, flow in the fan may be partly perched, therefore it cannot be assumed that the water table approaches the ground surface.

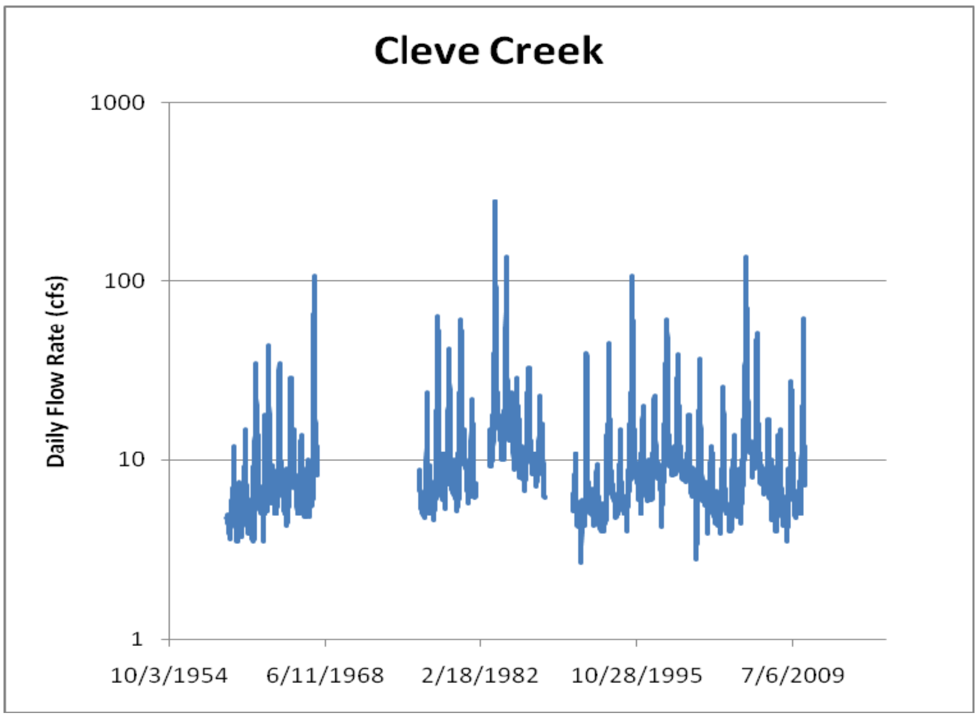


Figure 29: Daily flows at the Cleve Creek gage, USGS #10243700, since 1956.

Spring Discharge

Spring Valley lives up to its name, having many springs discharging at the base of alluvial fans into the adjacent playas. As noted above, these springs and/or seeps may provide much of the water that evapotranspires from the playas and other wetlands in the base of the valley. The published inventories of springs (Welch et al, 2008; BioWest, 2006; Pupacko et al, 1989) vary greatly, with variable estimates of flows. The largest springs are in Snake Valley, including Gandy Warm, Big, and Stateline Springs (Figure 30), although the mass of springs discharging at the base of the fan east of Cleve Creek (referred to as Cleve Creek Springs) may have a larger discharge than any in Snake Valley.

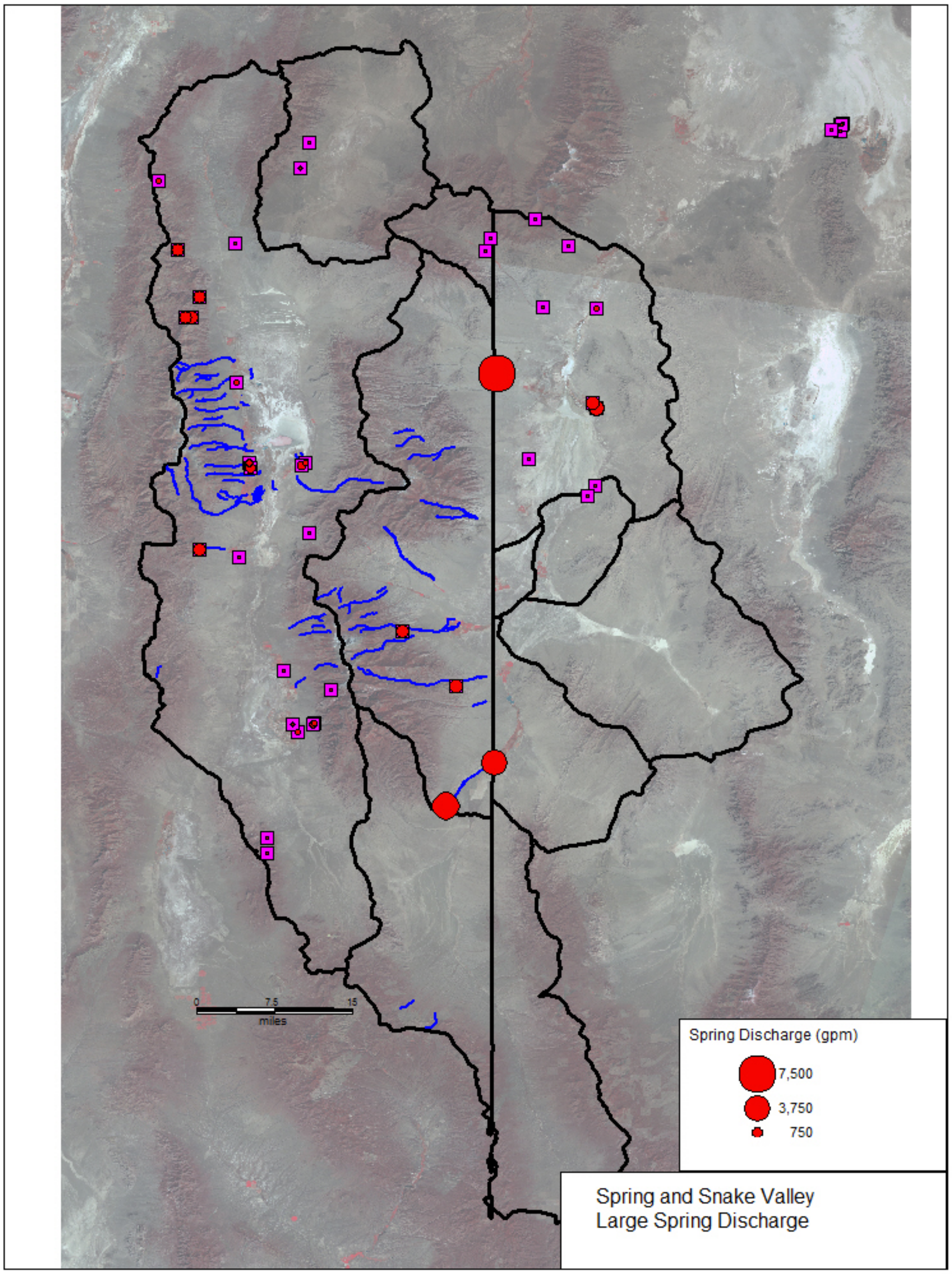


Figure 30: Spring discharge in Spring, Snake, and Tippett Valley. See Figure 14 for spring names. In Spring Valley, the USGS tabulated spring discharge measurements totaling about 28,000 af/y (Pupacko et al 1989), although the estimate is of only a few springs of the total in the valley. Flow sources: Welch et al, 2008; BioWest, 2006; Pupacko et al, 1989.

Water rights associated with springs provide an alternative estimate of spring discharge. Based on water rights downloaded from the Nevada State Engineer's water rights database (http://water.nv.gov/, read in 2006), there are 3118, 660, 467, and 118,450 for a total 122,695 af/y of certificated, permitted, reserved and vested water rights in Spring Valley, respectively. Most spring water rights are for small amounts of water, although the list contains 12 vested rights, V02817 through V02828, for 9600 af/y each. The point of diversion (POD) indicates this spring complex is the Cleve Creek Springs. Most of the flow discharges to wetlands and the playa northeast of the spring POD. There are also two irrigation pivots shown on Figure 31. A site visit by this author on June 5, 2006, showed that extensive irrigation of fields and meadows occurs in this area. Therefore, while the total vested rights almost certainly exceed the actual spring flow, they indicate that substantial flow discharges from the springs in that area.

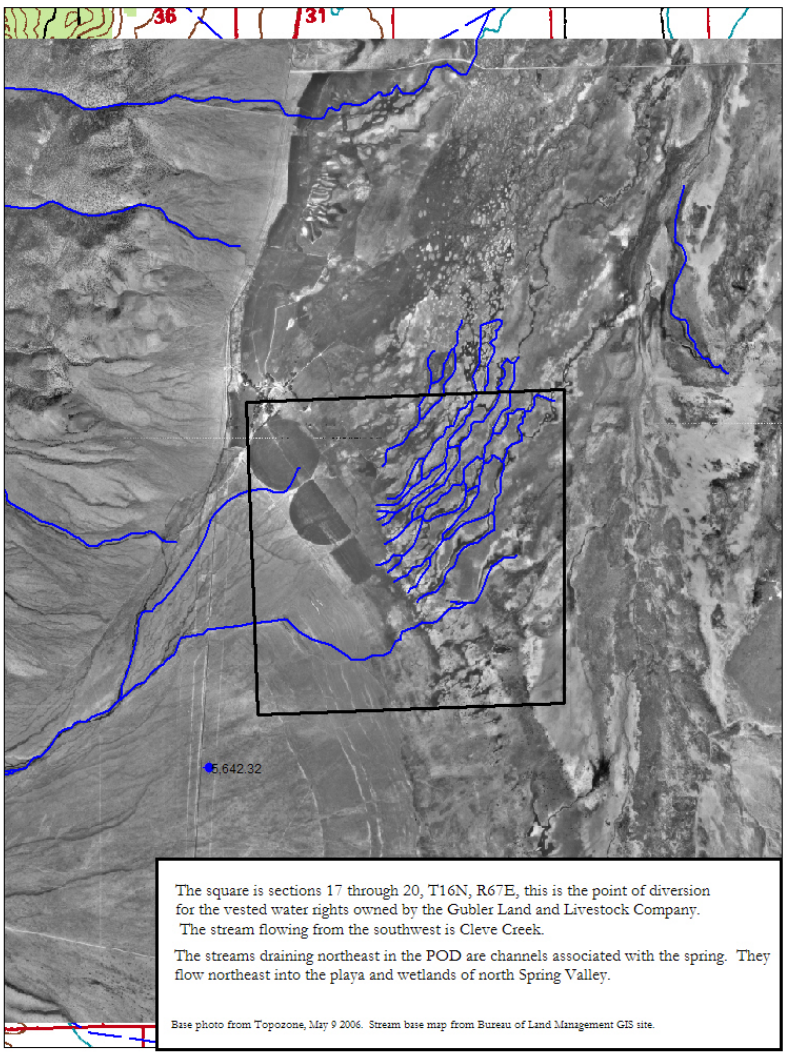


Figure 31: Aerial photograph of springs and point of diversion for vested water rights listed as owned by Gubler Land and Livestock Company near Cleve Creek.

Most Spring Valley springs are local, based on their not discharging from carbonate rock (Prudic et al, 1995; Plume, 1996), meaning that they discharge recharge from within Spring Valley, not flow from adjacent basins. Relatively high water temperatures in some northern Spring Valley springs, including Willow and North Spring, suggest deep circulation and an upward vertical gradient. The variability shown in the discharges of the few springs with multiple measurements indicates springs respond quickly to climatic changes; regional springs have much more stable flow regimes because they are not quickly affected by climate fluctuations and seasonal changes.

The spring in Swallow Canyon is a good example of a local spring (Figure 32). The spring is at the mouth of a small canyon on the west side of the Snake Range, a quarter mile west of limestone outcrops (Figure 14). The discharge varies substantially and low flows are a small fraction of the high flows (Figure 32), which suggests the residence time in the contributing watershed is short. Flows in Swallow Canyon percolate into limestone so that the stream rarely has flow; the percolation in this canyon may flow through the limestone and discharge into the alluvium east of the actual spring. This suggests the effective discharge from the spring is actually to the east in the limestone. The spring discharge naturally supports a small vegetated area just below the spring and a much larger spring fed wetland area in the playa a short distance to the west showing springs and wetlands at Swallow Canyon). Discharge from the spring both satisfies ET demand and infiltrates becoming secondary recharge. This secondary recharge may satisfy ET demand on the playa or discharge from springs near the playa.

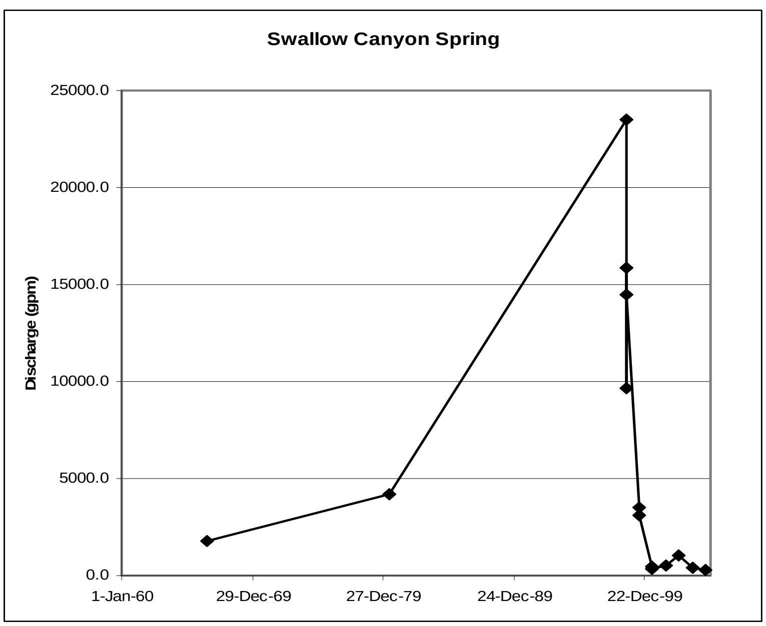


Figure 32: Discharge hydrograph for Swallow Canyon spring. The observation on 6/15/1980 was adjusted to 4200 gpm reflecting Pupacko et al (1989). Average discharge is 5766 gpm and the lowest (baseflow) is 295 gpm.

Big Springs' flows have been monitored since 2005 in two gages near the upstream end of the channel (Figure 33). The sum of the two gages has averaged 10 cfs with a standard deviation of 0.6 cfs since 10/1/2005. However, the flow rate has apparently decreased about 1 cfs since 2008. Also apparent is a decrease in the flow variability since then. Primarily it is the North gage which has had a decrease in variability. The flow rate in the North Channel also decreased about 0.7 cfs while the flow rate in the South Channel decreased about 0.3 cfs.

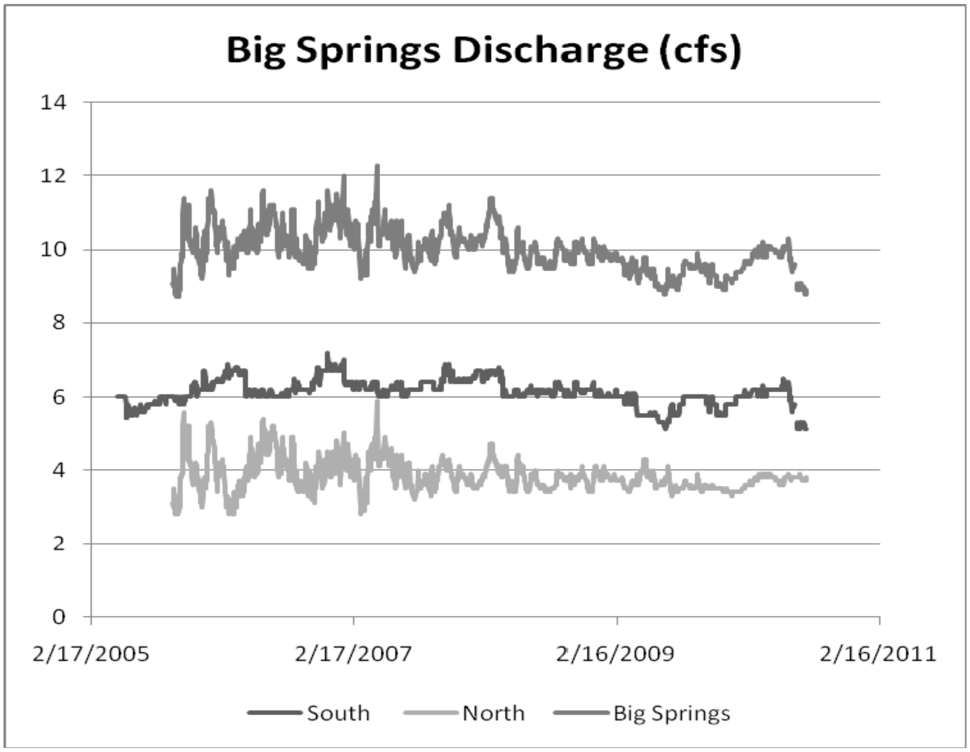


Figure 33: Flow rate hydrograph for Big Springs. USGS gages 10243224 and 102432241, South and North Channel.

There is significant uncertainty about the source of water discharging from Big Springs. There appear to be two carbonate sources of flow to the springs, from interbasin flow from Spring Valley through the Limestone Mountains or the carbonate rock that mantles the south half of the Snake Range. The general dip of this rock would combine the carbonate pathways at the springs, which also coincide with a range-front fault east of the Snake Range.

The decreased flow from the springs since 2008 may reflect ongoing development in the area, just as pumping near Baker has decreased groundwater levels as documented above. Several new irrigation pivots have developed west of the springs since about 2005 (personal communication, Dean Baker, 2006, and field observations by this author).

Stateline Springs are also a significant source of groundwater discharge downstream from Big Springs, measured at about 3700 gpm (8.2 cfs), which is close to the discharge from Big

Springs. The spring is not warm, and may be partly discharge of secondary recharge from Big Springs.

Conclusion

The conceptual groundwater model developed and documented in this report is an accurate description of the hydrogeology, water balance fluxes, springs and streams for Spring, Snake and surrounding valleys. It provides an accurate conceptualization for a numerical model which can be coded and calibrated to simulate the proposed SNWA water rights applications.

References

Avon, L. and T.J. Durbin, 1994, Evaluation of the Maxey-Eakin method for estimating recharge to ground-water basins in Nevada. Water Resources Bulletin 30(1).

Belcher, W.R., Elliott, P.E., and Geldon, A.L., 2001, Hydraulic-property estimates for use with a transient ground-water flow model for the Death Valley regional ground-water flow system, Nevada and California: U.S. Geological Survey Water-Resources Investigations Report 01–4210, 25 p.

Biowest, 2007a. Ecological Evaluation of Selected Aquatic Ecosystems in the Biological Resources Study Area for the Southern Nevada Water Authority's Proposed Clark, Lincoln, and White Pine Counties Groundwater Development Project, Final Report: Volume 1. Submitted to Southern Nevada Water Authority. March 2007.

Biowest, 2007b. Ecological Evaluation of Selected Aquatic Ecosystems in the Biological Resources Study Area for the Southern Nevada Water Authority's Proposed Clark, Lincoln, and White Pine Counties Groundwater Development Project, Final Report: Volume 2, Biological Resources Study Area Vegetation Maps. Submitted to Southern Nevada Authority. March 2007.

Brothers, K., Buqo, T.S., Bernholtz, A.J., and Tracy, J.V., 1994, Hydrology and steady state ground-water model of Spring Valley, Lincoln and White Pine Counties, Nevada: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 13, 69 p.

Brothers, K., Buqo, T.S., and Tracy, J., 1993, Hydrology and steady state ground-water model of Snake Valley, east-central Nevada, and west-central Utah: Las Vegas Valley Water District, Cooperative Water Project, Series Report No. 9, 66 p.

Bunch, R.L., and J.R. Harrill, 1984. Compilation of Selected Hydrologic Data from the MX Missile-Siting Investigation, East-Central Nevada and Western Utah. U.S. Geological Survey Open-File Report 84-702.

Crafford, A.E.J., 2007. Geologic Map of Nevada: U.S. Geological Survey Data Series 249, 1 CD-ROM, 46 p., 1 plate.

Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology, 33, 140-158

Dettinger, M.D., 1989. Reconnaissance estimates of natural recharge to desert basins in Nevada, U.S.A., by using chloride-balance calculations. J of Hydrology 106(1/2):55-78.

Dettinger, M.D., J.R. Harrill, and D.L. Schmidt, 1995. Distribution of Carbonate-Rock Aquifers and the Potential for their Development, Southern Nevada and Adjacent Parts of California, Arizona, and Utah. U.S. Geological Survey Water-Resources Investigations Report 91-4146.

Durbin, T., 2006. Development and Use of a Groundwater Model for the Spring Valley Area. Prepared for the Southern Nevada Water Authority. Presented to the Nevada State Engineer, Spring Valley Hearing, 2006.

Eakin, T.E., 1966. A regional interbasin ground-water system in the White River area, southeastern Nevada: Water Resources Research, v. 2, no. 2, p. 251-271.

Eakin, T.E., Hughes, J.L., and Moore, D.O., 1967, Water resources appraisal of Steptoe Valley, White Pine and Elko Counties, Nevada: Nevada Department of Conservation and Natural Resources, Water Resources-Reconnaissance Report 42, 48 p.

Eakin, T.E., D. Price, and J.R. Harrill, 1976. Summary appraisals of the Nation's ground-water resources – Great Basin region. U.S. Geological Survey Professional Paper 813-G, 37 p.

Elliott, P.E., D.A. Beck, and D.E. Prudic, 2006. Characterization of surface-water resources in the Great Basin National Park Area and their susceptibility to ground-water withdrawals in adjacent valleys, White Pine County Nevada. U.S. Geological Survey Scientific Investigations Report 2006-5099, 156 p.

Epstein, B.J., 2004, Development and uncertainty analysis of empirical recharge prediction models for Nevada's desert basins: University of Nevada, unpublished master's thesis, 131 p.

Fetter, C.W., 2001. Applied Hydrogeology, Fourth Edition. Prentice-Hall.

Flint, A.L. and L.E., Flint 2007. Application of the Basin Characterization Model to Estimate In-Place Recharge and Runoff Potential in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah; Sci Inv Rep 2007-5099.

Flint, A.L., L.E. Flint, J.A. Hevesi, and J.B. Blainey, 2004. Fundamental Concepts of Recharge in the Desert Southwest: A Regional Modeling Perspective. Pages 159-184 in Hogan, J.F., F.M. Phillips and B.R. Scanlon (eds.), Groundwater Recharge in a Desert Environment: The Southwestern United States, Water Science and Application 9. American Geophysical Union, Washington.

Grayson, D.K., 1993. The Desert's Past, A Natural Prehistory of the Great Basin. Smithsonian, Washington, D.C.

Halford, K.J., and Plume, R.W., 2011, Potential effects of groundwater pumping on water levels, phreatophytes, and spring discharges in Spring and Snake Valleys, White Pine County, Nevada, and adjacent areas in Nevada and Utah: U.S. Geological Survey Scientific Investigations Report 2011-5032, 52 p.

Harrill, J.R., Gates, J.S., and Thomas, J.M., 1988, Major ground-water flow systems in the Great Basin region of Nevada, Utah, and adjacent States: U.S. Geological Survey Hydrologic Investigations Atlas HA-694-C, scale 1:1,000,000, 2 sheets.

Harrill, J.R. and D.E. Prudic, 1998. Aquifer systems in the Great Basin Region and Nevada, Utah, and Adjacent States – Summary Report. Regional Aquifer-System Analysis – Great Basin, Nevada-Utah. U.S. Geological Survey Professional Paper 1409-A.

Hintze, L.F., G.C. Willis, D. Y.M. Laes, D.A. Sprinkel, and K.D. Brown, 2000. Digital Geologic Map of Utah. Utah Geological Survey, Utah Dept. of Natural Resources, Salt Lake City, UT.

Hood, J.W., and Rush, F.E., 1965, Water-resources appraisal of the Snake Valley area, Utah and Nevada: Nevada Department of Conservation and Natural Resources, Water Resources-Reconnaissance Report 34, 43 p.

Hose, R.K., Blake, M.C., Jr., and Smith, R.M., 1976, Geology and mineral resources of White Pine County, Nevada: Nevada Bureau of Mines and Geology Bulletin 85, 105 p.

Jeton, A.E., S.A. Watkins, T.J. Lopes, and J. Huntington, 2006. Evaluation of Precipitation Estimates from PRISM for the 1961–90 and 1971–2000 Data Sets, Nevada. Scientific Investigations Report 2005-5291. U.S. Geological Survey, Carson City, NV.

Kirby, S., and H. Hurlow, 2005. Hydrogeologic Setting of the Snake Valley Hydrologic Basin, Millard County, Utah, and White Pine and Lincoln counties, Nevada – Implications for Possible Effects of Proposed Water Wells, Report of Investigation 254. Utah Geological Survey, Utah Dept. of Natural Resources, Salt Lake City, UT.

Lundmark, K.W., G.M. Pohll, R.W.H. Carroll, 2007. A Steady-State Water Budget Accounting Model for the Carbonate Aquifer System in White Pine County, Nevada, and Adjacent Areas in Nevada and Utah: DHS Publication No. 41235. Desert Research Institute, Reno NV

Mankinen, E.A., C.W. Roberts, E.H. McKee, B.A. Chuchel, and B.C. Moring, 2006. Geophysical data from the Spring and Snake Valleys area, Nevada and Utah. U.S. Geological Survey Open File Report 2006-1160.

Maxey, G.B., and Eakin, T.E., 1949, Ground water in White River Valley, White Pine, Nye, and Lincoln Counties, Nevada: Nevada State Engineer, Water Resources Bulletin 8, 59 p.

Moreo, M.T., R.J. Laczniak, and D.I. Stannard, 2007. Evapotranspiration Rate Measurements of Vegetation Typical of Ground-Water Discharge Areas in the Basin and Range Carbonate-Rock Aquifer System, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah, September 2005-August 2006.

Myers, T., 2009. Groundwater management and coal-bed methane development in the Powder River Basin of Montana. J Hydrology 368:178-193

Myers, T., 2011. Hydrogeology of Spring Valley and Surrounding Areas, Part B: Groundwater Model of Snake and Spring Valleys, and Surrounding Areas. Presented to the Office of the Nevada State Engineer on behalf of the Great Basin Water Network and the Confederated Tribes of the Goshute Indians.

Myers,T., 2006. Hydrogeology of Spring Valley and Effects of Groundwater Development Proposed by the Southern Nevada Water Authority, White Pine and Lincoln County, Nevada. Presented to the Nevada State Engineer.

Nevada Division of Water Resources, 1971. Water for Nevada. Nevada Division of Conservation and Natural Resources, Division of Water Resources, Carson City, NV.

Nichols, W.D., 2000, Regional ground-water evapotranspiration and ground-water budgets, Great Basin, Nevada: U.S. Geological Survey Professional Paper 1628, 82 p.

Plume, R.W., 1996. Hydrogeologic Framework of the Great Basin Region of Nevada, Utah, and Adjacent States, U.S. Geological Survey Professional Paper 1409-B. Washington D.C.

Prudic, D.E., and Glancy, P.A., 2009, Geochemical investigation of source water to Cave Springs, Great Basin National Park, White Pine County, Nevada: U.S. Geological Survey Scientific Investigations Report 2009–5073, 28 p.

Prudic, D.E., Harrill, J.R., and Burbey, T.J., 1995, Conceptual evaluation of regional ground-water flow in the carbonate-rock province of the Great Basin, Nevada, Utah, and adjacent States: U.S. Geological Survey Professional Paper 1409-D, 102 p.

Pupacko, A., D.B. Wood, and R.P. Williams, 1989. Geohydrologic Data for Selected Springs in Eastern Nevada through 1982, with Emphasis on White Pine County. U.S. Geological Survey Open-File Report 88-712.

Rush, F.E., and Kazmi, S.A.T., 1965, Water resources appraisal of Spring Valley, White Pine and Lincoln Counties, Nevada: Nevada Department of Conservation and Natural Resources, Water Resources-Reconnaissance Report 33, 39 p.

Southern Nevada Water Authority (SNWA), 2006. Water Resources Assessment for Spring Valley, Presentation to the Office of he Nevada State Engineer. June 2006.

Stone, D.B., C.L. Moomaw, and A.Davis, 2001. Estimate recharge distribution by incorporating runoff from mountainous areas in an alluvial basin in the Great Basin region of the southwestern United States. Ground Water 39(6):807-818.

Sweetkind, D.S., L.A. Knochenmus, D.A. Ponce, A.R. Wallace, D.S. Scheirer, J.T. Watt, and R.W. Plume, 2008. Hydrogeologic Map and Cross Sections, White Pine County, Nevada, and Adjacent Areas in Nevada and Utah. In Welch et al (2008).

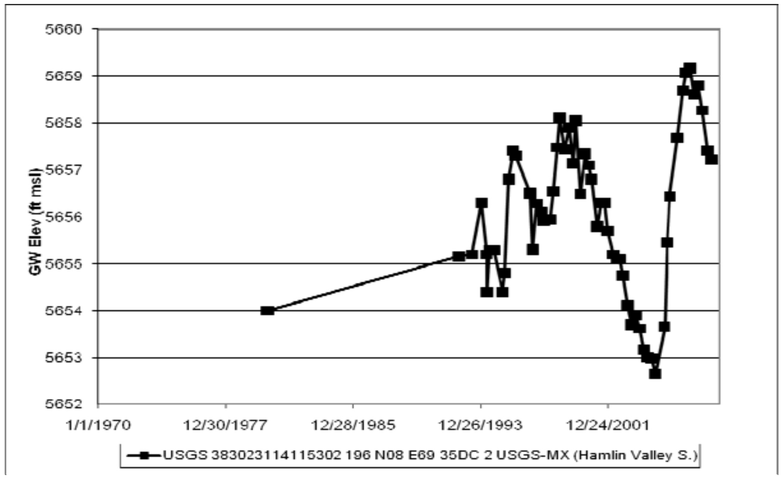
Watson, P., Sinclair, P., and Waggoner, R., 1976, Quantitative evaluation of a method for estimating recharge to the desert basins of Nevada: Journal of Hydrology, v. 31, p. 335-357.

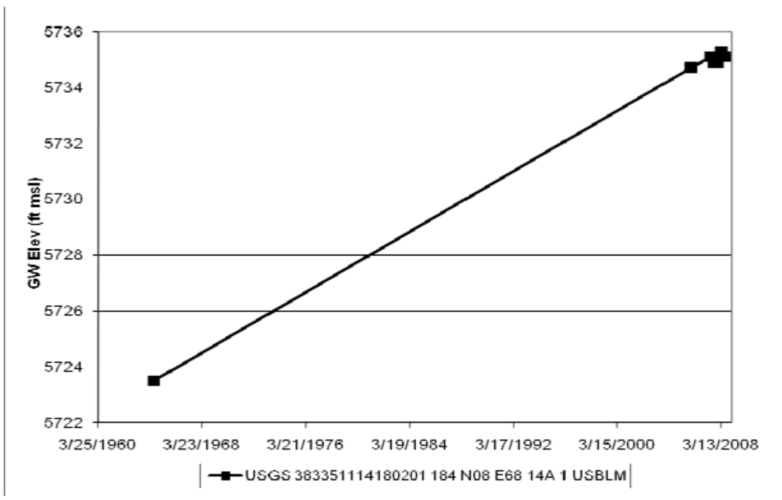
Watt, J.T., and D.A. Ponce, 2007. Geophysical framework investigations influencing ground-water resources in east-central Nevada and west-central Utah, with a section on Geologic and geophysical basin-by-basin descriptions by Wallace, Alan R., Watt, Janet T., and Ponce David A.: U.S. Geological Survey Open-File Report 2007-1163.

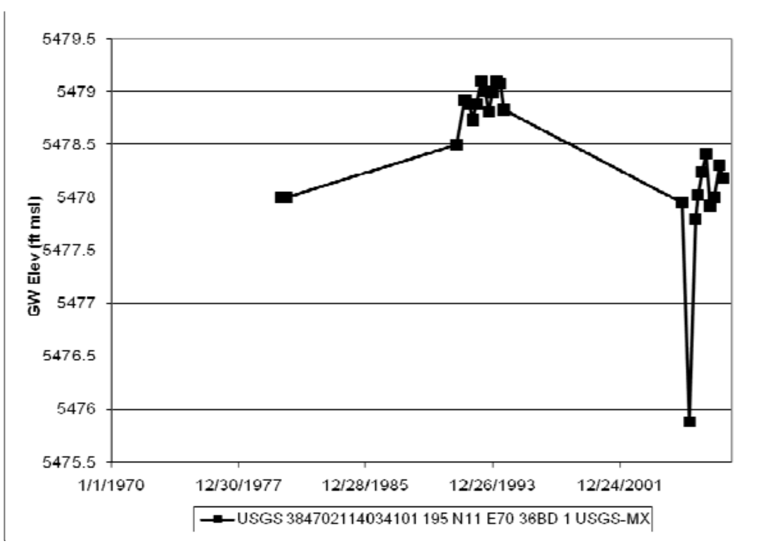
Welch, A.H., Bright, D.J., and Knochenmius, L.A., eds., 2008. Water resources of the Basin and Range carbonate-rock aquifer system, White Pine County, Nevada, and adjacent areas in Nevada and Utah. U.S. Geological Survey Scientific Investigations Report 2007-5261, 96 p.

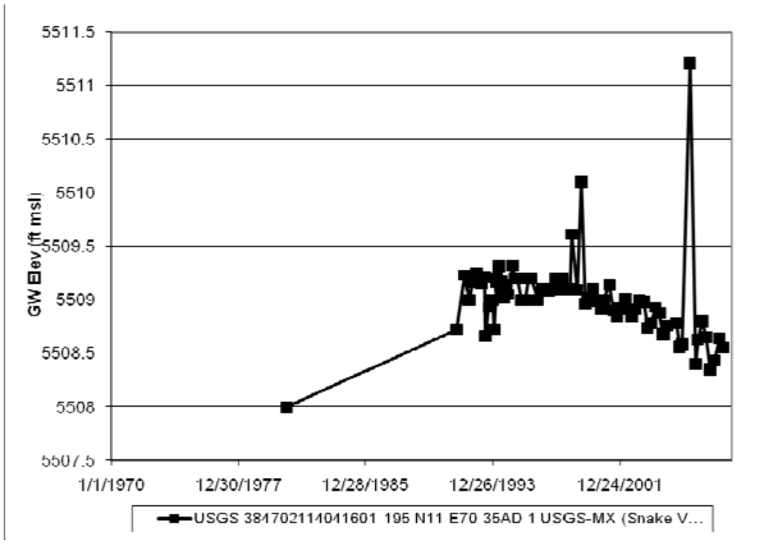
Wilson, J.L. and H. Guan, 2004. Mountain Block Hydrology and Mountain Front Recharge. In Hogan, J.F., F.M. Phillips, and B.R. Scanlon (eds.), Groundwater Recharge in a Desert Environment: The Southwestern United States, Water Science and Application 9. American Geophysical Union, Washington.

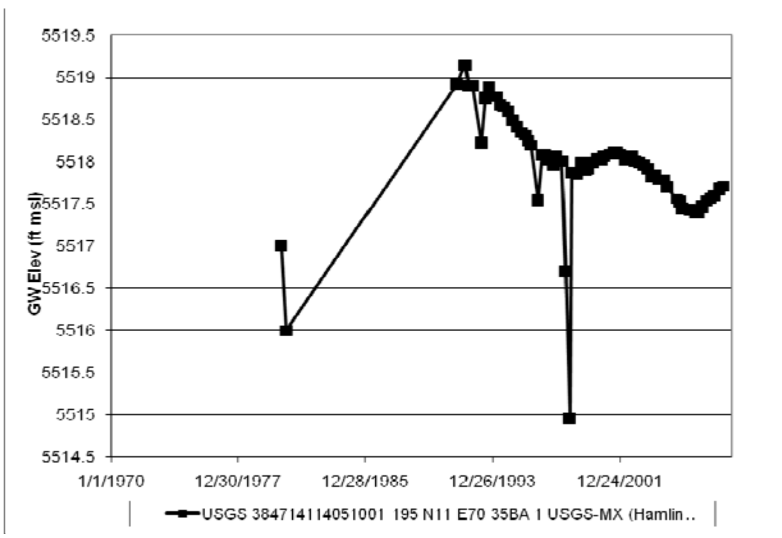
Appendix A: Miscellaneous Groundwater Level Hydrographs

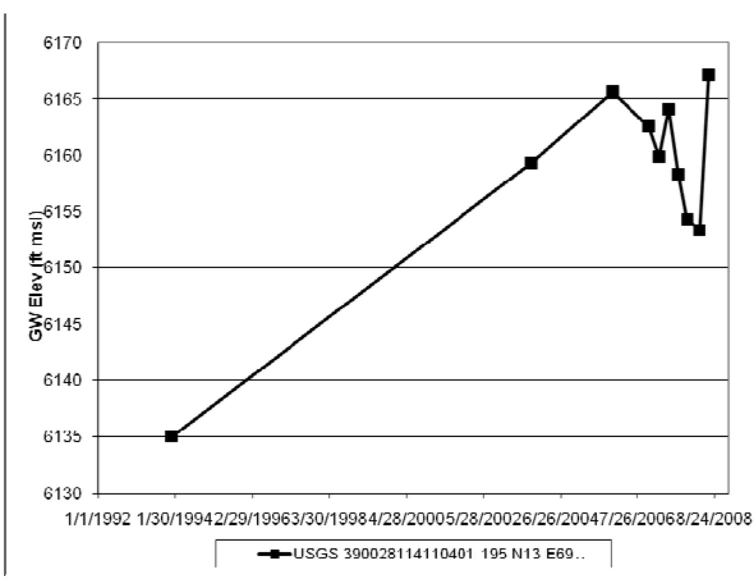


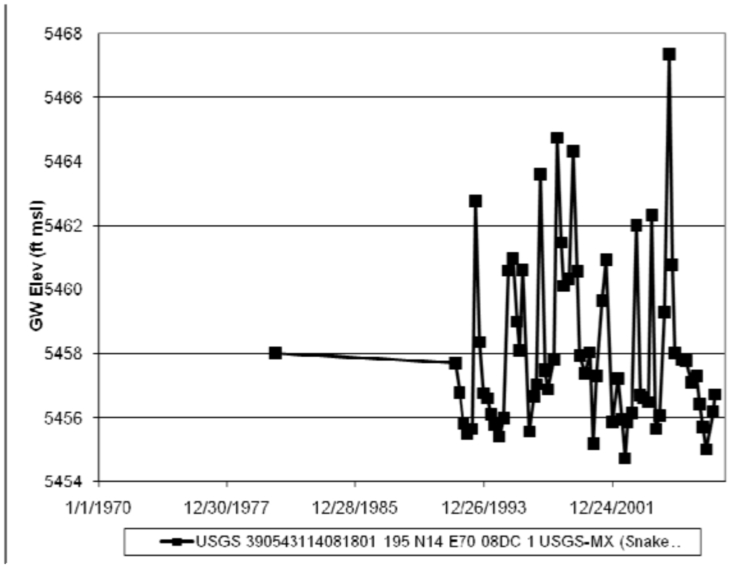




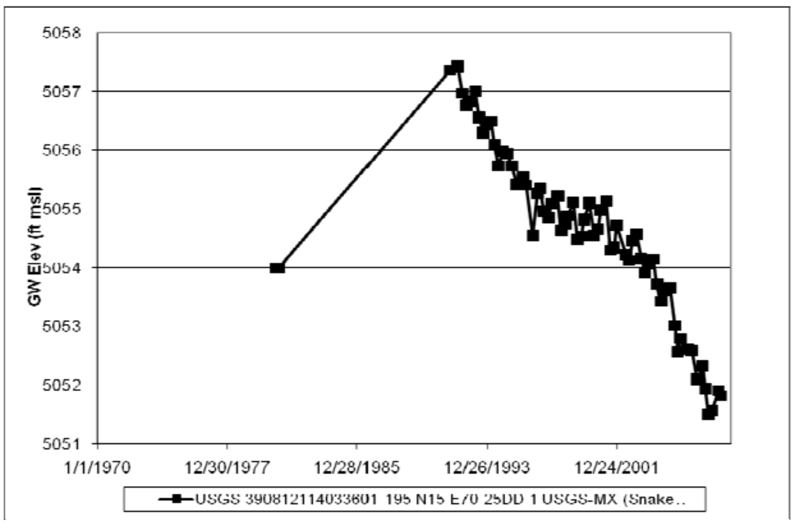

5511.5
5511
5510.5
5510
5509.5
5509
5508.5
5508
5507.5
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 384702114041601 195 N11 E70 35AD 1 USGS-MX (Snake V…


5519.5
5519
5518.5
5518
5517.5
5517
5516.5
5516
5515.5
5515
5514.5
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 384714114051001 195 N11 E70 35BA 1 USGS-MX (Hamlin…

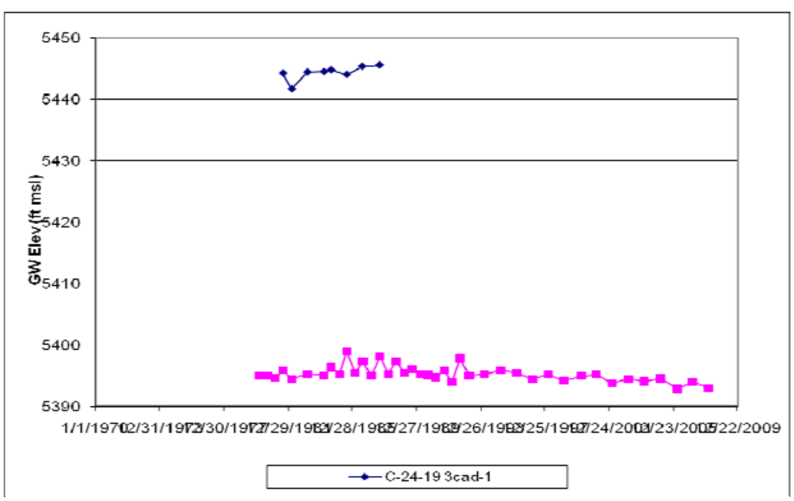

6170
6165
6160
6155
6150
6145
6140
6135
6130
GW Elev (ft msl)
1/1/1992 1/30/19942/29/19963/30/19984/28/20005/28/20026/26/20047/26/20068/24/2008
USGS 390028114110401 195 N13 E69…



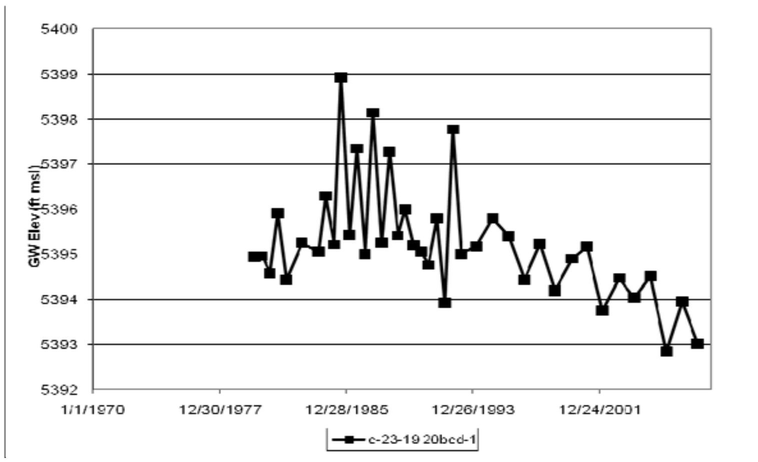
5468
5466
5464
5462
5460
5458
5456
5454
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 390543114081801 195 N14 E70 08DC 1 USGS-MX (Snake..



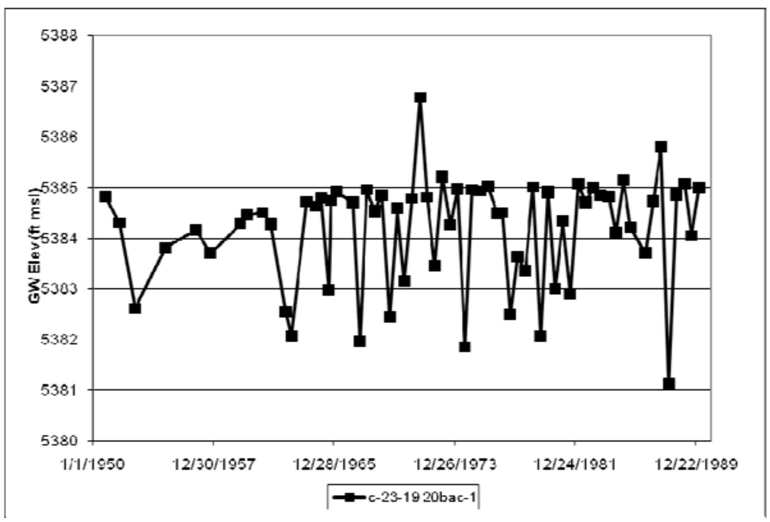
5058
5057
5056
5055
5054
5053
5052
5051
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 390812114033601 195 N15 E70 25DD 1 USGS-MX (Snake..



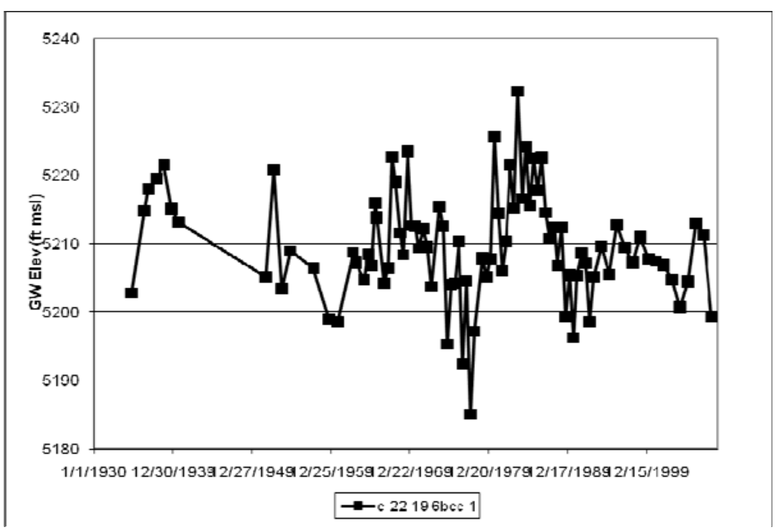
5450
5440
5430
5420
5410
5400
5390
GW Elev (ft msl)
C-24-19 3cad-1



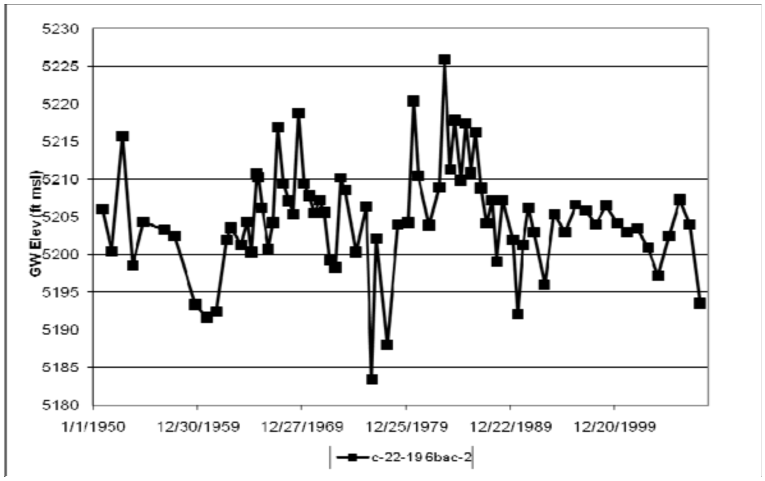
5400
5399
5398
5397
5396
5395
5394
5393
5392
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-23-19 20bcd-1

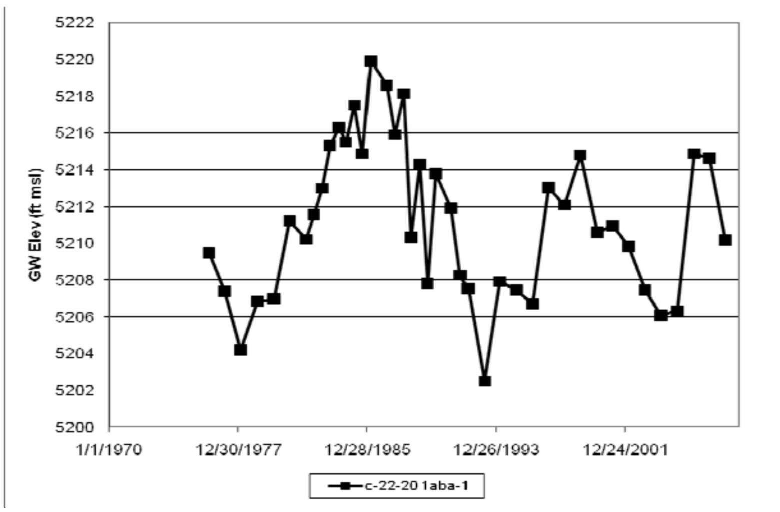


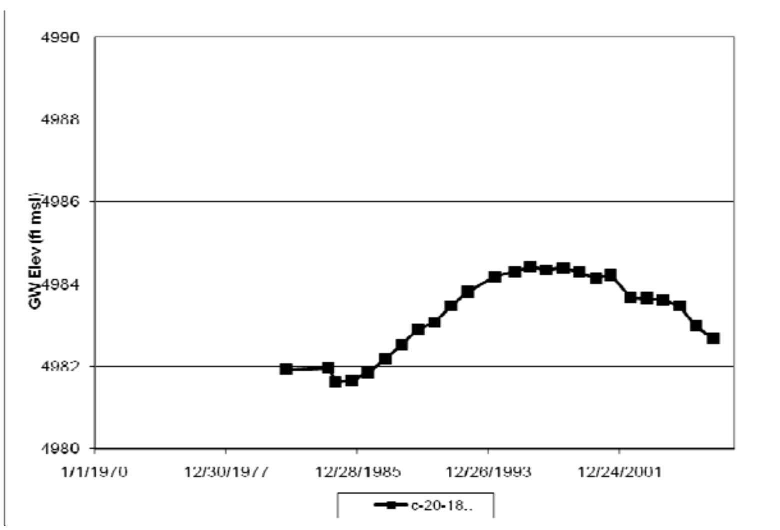
5388
5387
5386
5385
5384
5303
5382
5381
5380
GW Elev (ft msl)
1/1/1950
12/30/1957
12/28/1965
12/26/1973
12/24/1981
12/22/1989
c-23-19 20bac-1

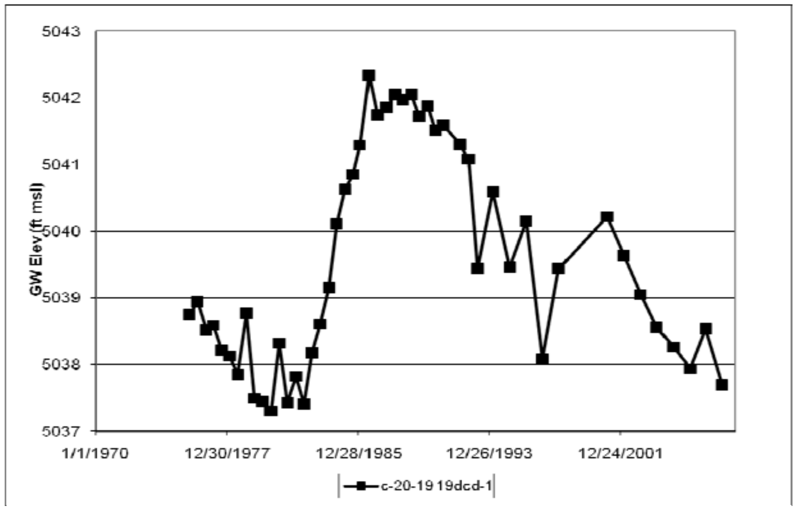


5240
5230
5220
5210
5200
5190
5180
GW Elev (ft msl)
1/1/1930
12/30/1939
12/27/1949
12/25/1959
12/22/1969
12/20/1979
12/17/1989
12/15/1999
c 22 19 6bcc 1

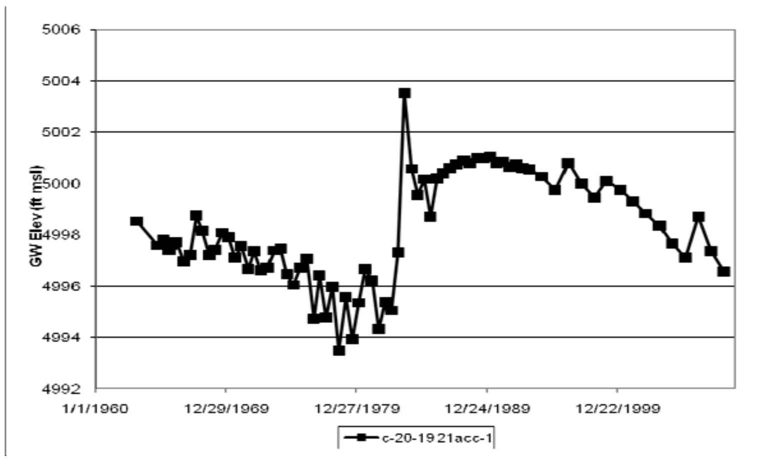

5230
5225
5220
5215
5210
5205
5200
5195
5190
5185
5180
GW Elev (ft msl)
1/1/1950
12/30/1959
12/27/1969
12/25/1979
12/22/1989
12/20/1999
c-22-19 6bac-2


5222
5220
5218
5216
5214
5212
5210
5208
5206
5204
5202
5200
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-22-20 1aba-1

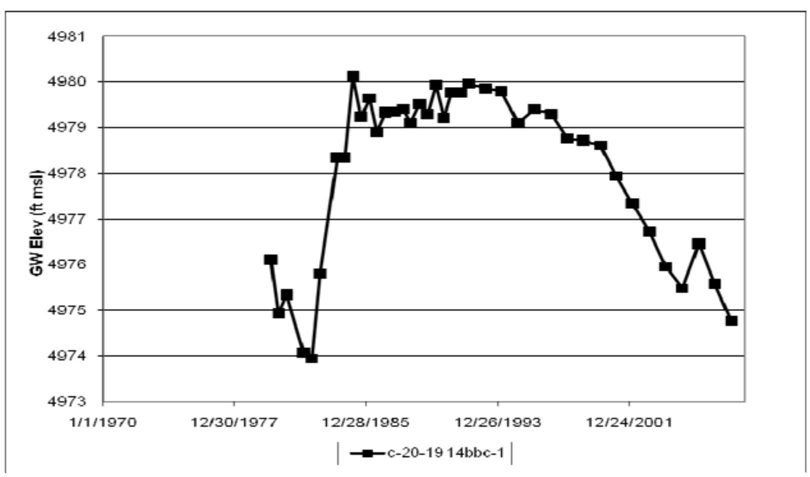

4990
4988
4986
4984
4982
4980
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-20-18..



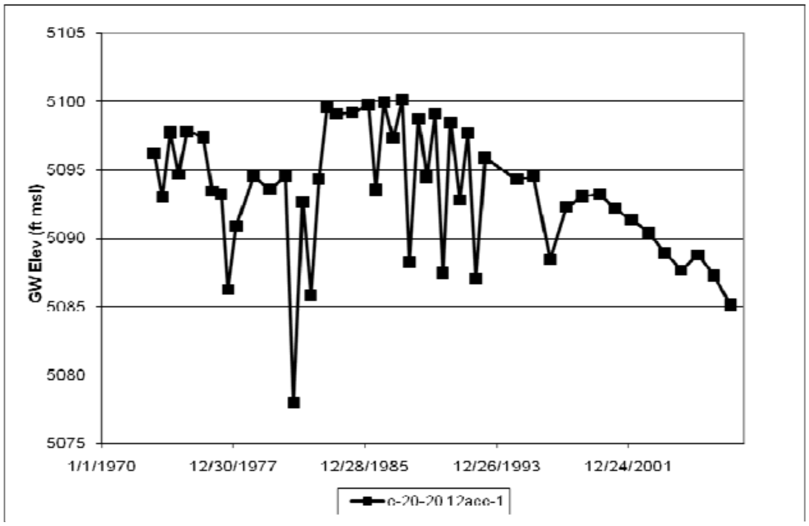
5043
5042
5041
5040
5039
5038
5037
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-20-19 19dcd-1

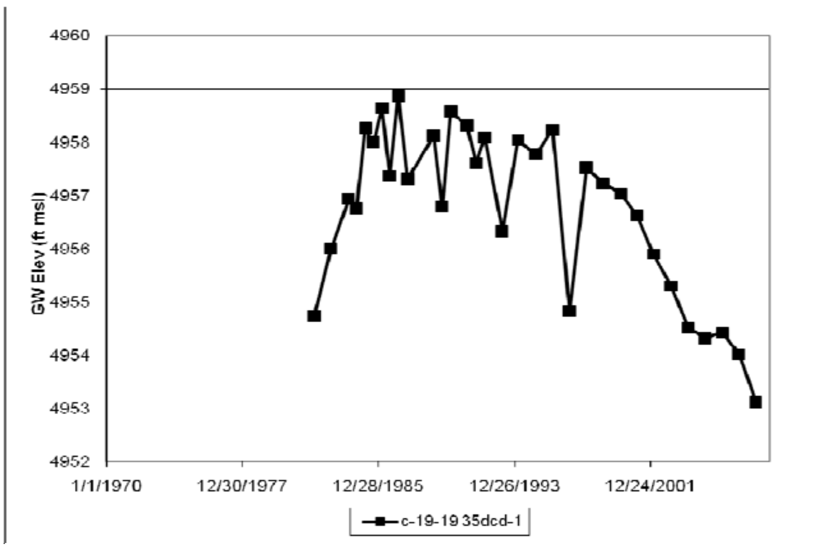


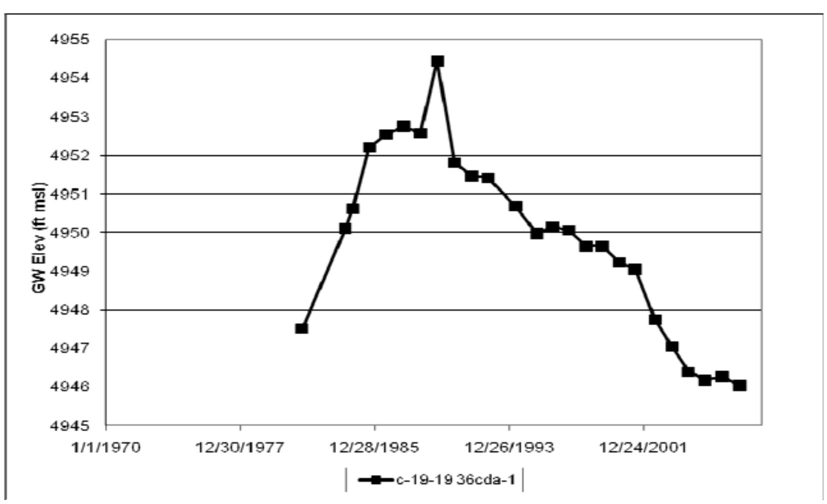
5006
5004
5002
5000
4998
4996
4994
4992
GW Elev (ft msl)
1/1/1960
12/29/1969
12/27/1979
12/24/1989
12/22/1999
c-20-19 21acc-1

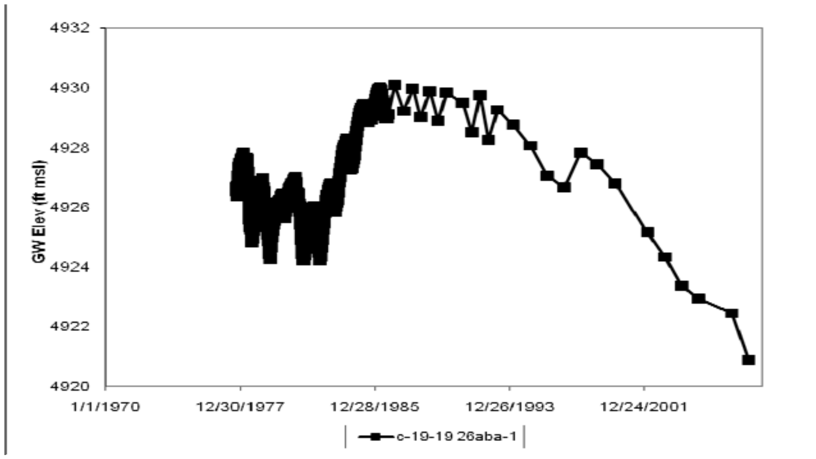


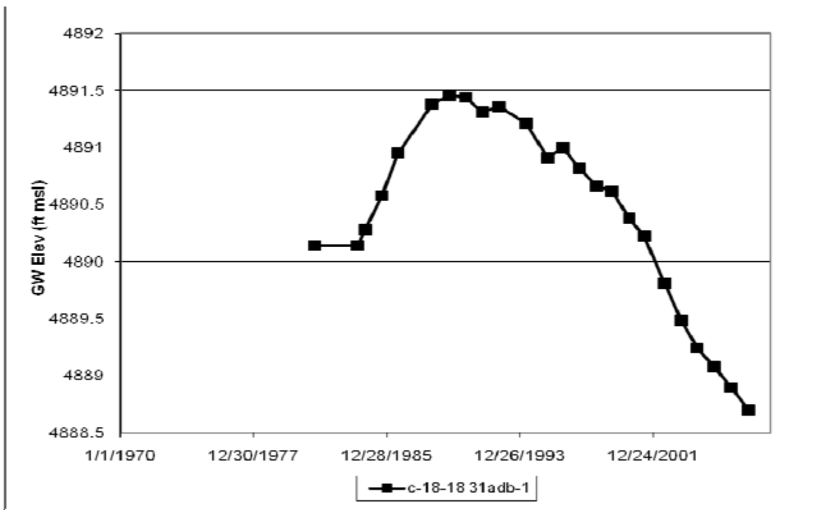
4981
4980
4979
4978
4977
4976
4975
4974
4973
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-20-19 14bbc-1

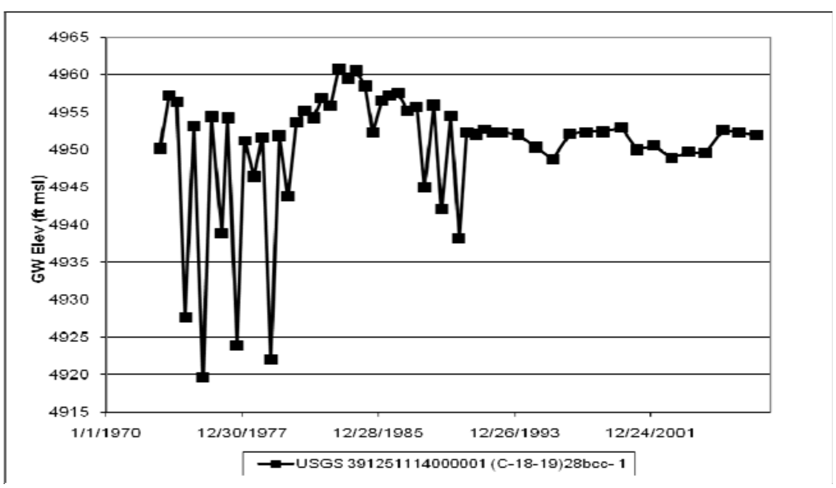

5105
5100
5095
5090
5085
5080
5075
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-20-20 12acc-1

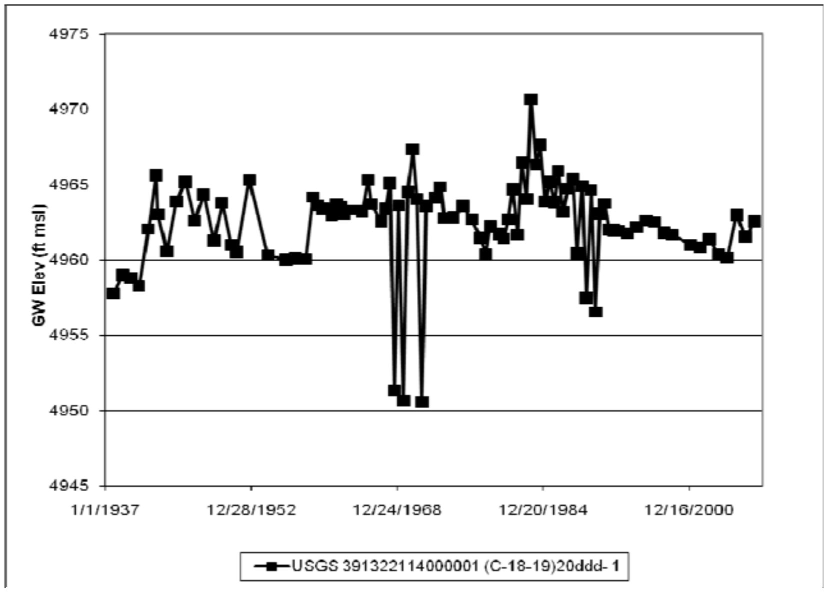

4960
4959
4958
4957
4956
4955
4954
4953
4952
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-19-19 35dcd-1

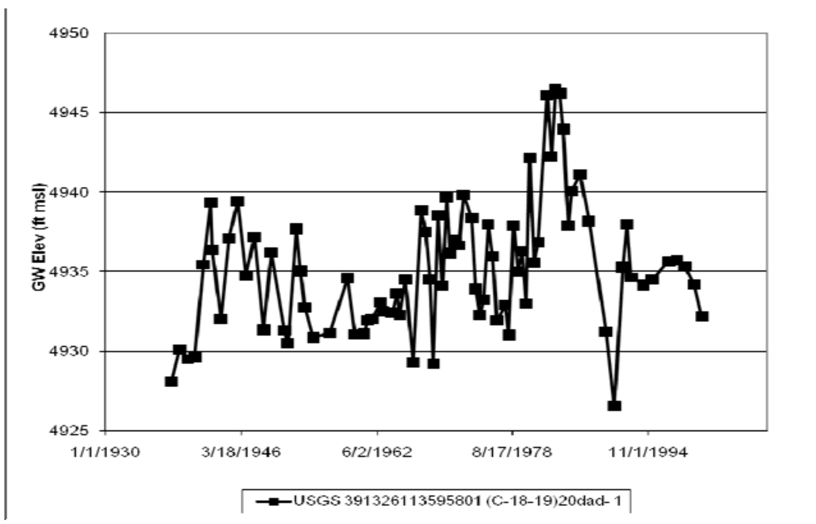

4955
4954
4953
4952
4951
4950
4949
4948
4947
4946
4945
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-19-19 36cda-1

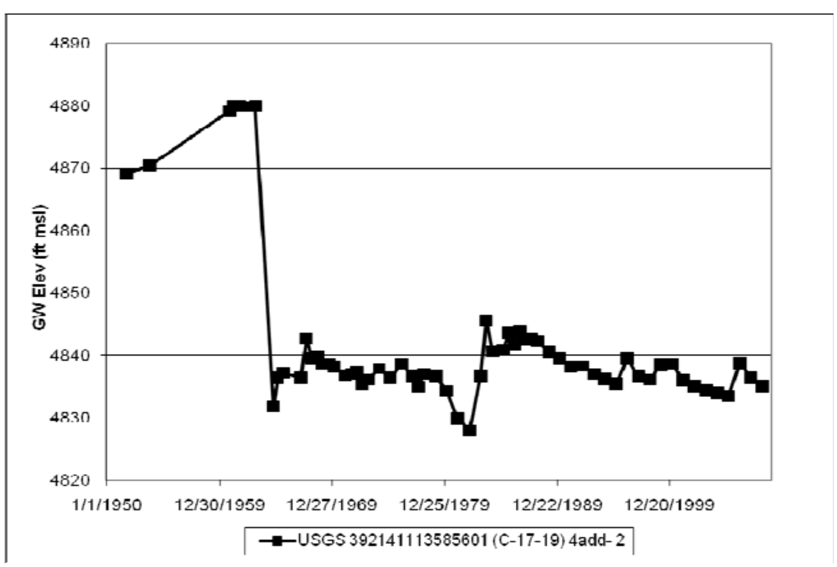

4932
4930
4928
4926
4924
4922
4920
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-19-19 26aba-1

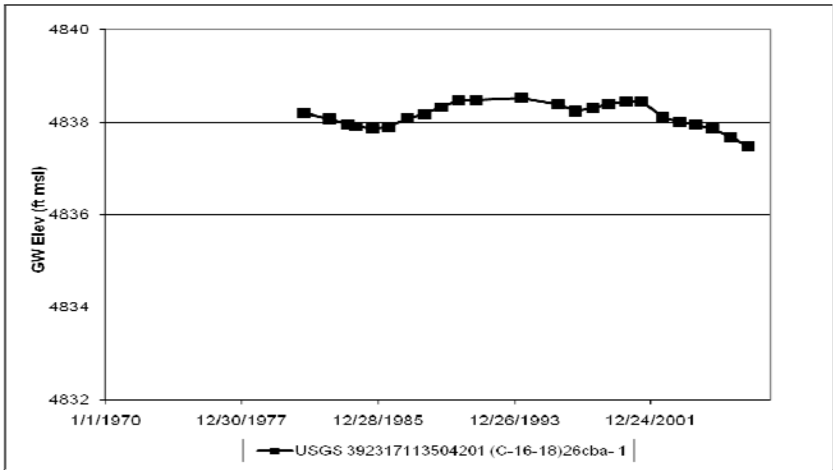

4892
4891.5
4891
4890.5
4890
4889.5
4889
4888.5
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
c-18-18 31adb-1

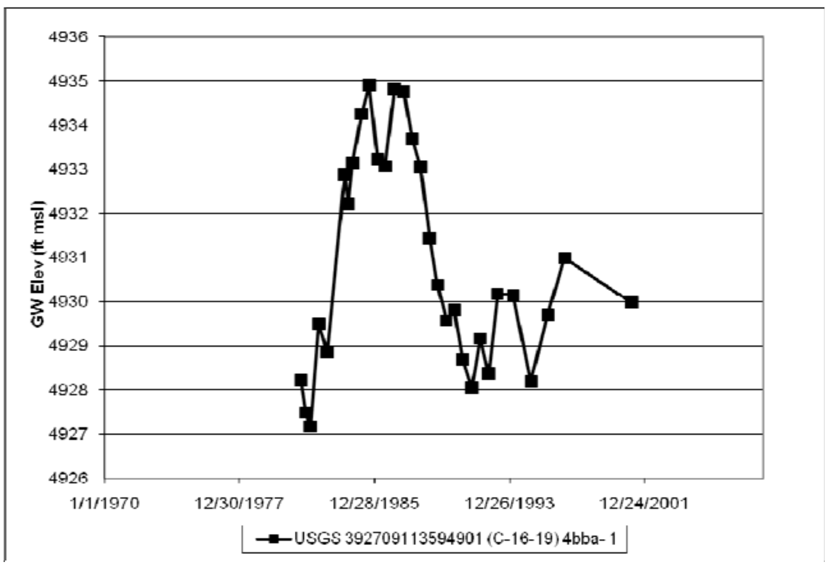

4965
4960
4955
4950
4945
4940
4935
4930
4925
4920
4915
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 391251114000001 (C-18-19)28bcc- 1

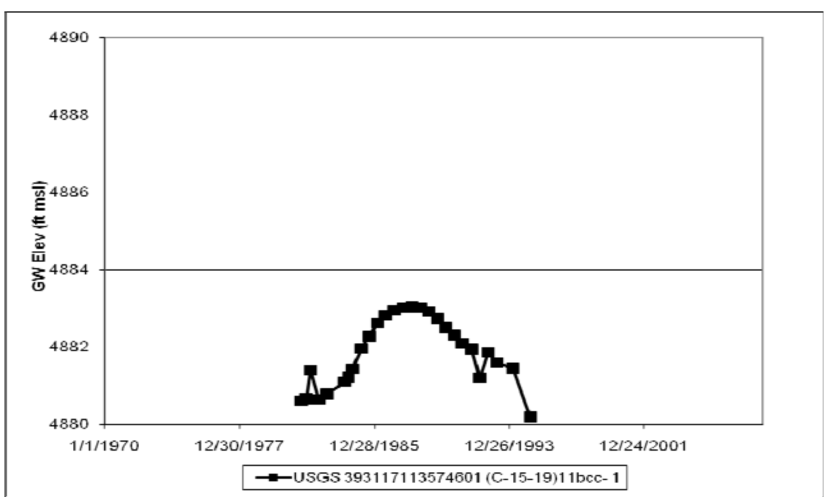

4975
4970
4965
4960
4955
4950
4945
GW Elev (ft msl)
1/1/1937
12/28/1952
12/24/1968
12/20/1984
12/16/2000
USGS 391322114000001 (C-18-19)20ddd- 1

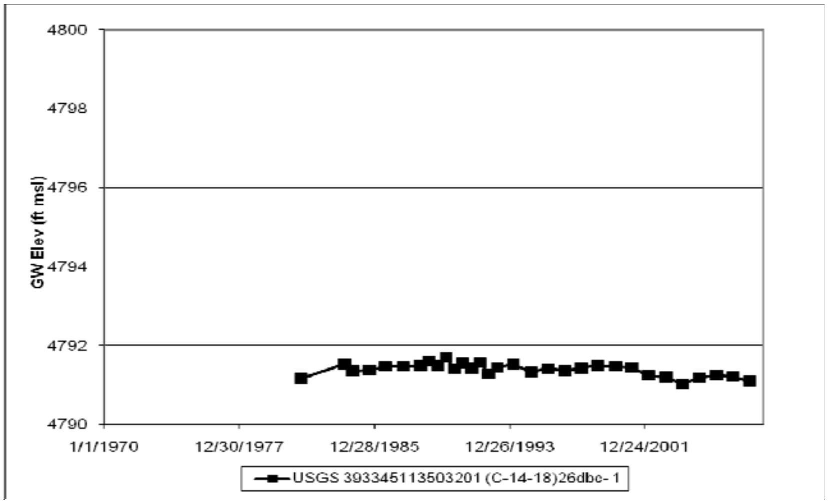

4950
4945
4940
4935
4930
4925
GW Elev (ft msl)
1/1/1930
3/18/1946
6/2/1962
8/17/1978
11/1/1994
USGS 391326113595801 (C-18-19)20dad- 1

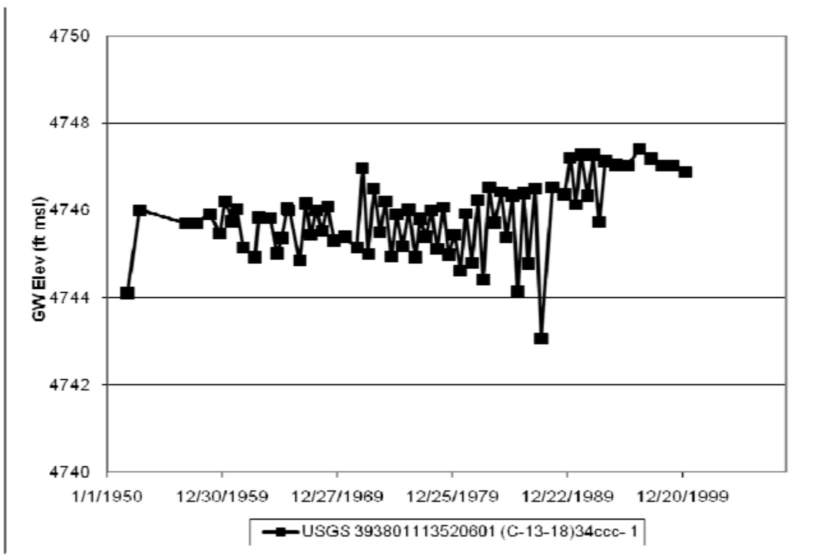

4890
4880
4870
4860
4850
4840
4830
4820
GW Elev (ft msl)
1/1/1950
12/30/1959
12/27/1969
12/25/1979
12/22/1989
12/20/1999
USGS 392141113585601 (C-17-19) 4add- 2

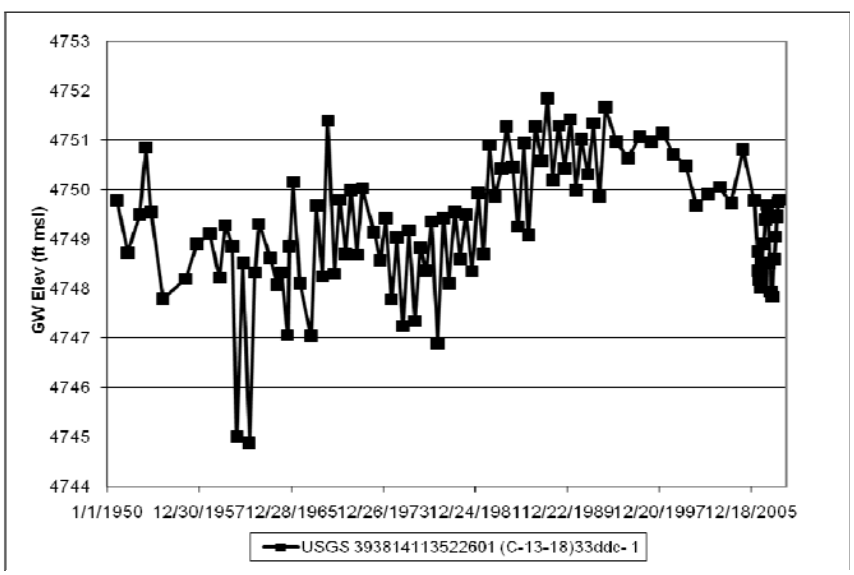

4840
4838
4836
4834
4832
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 392317113504201 (C-16-18)26cba- 1

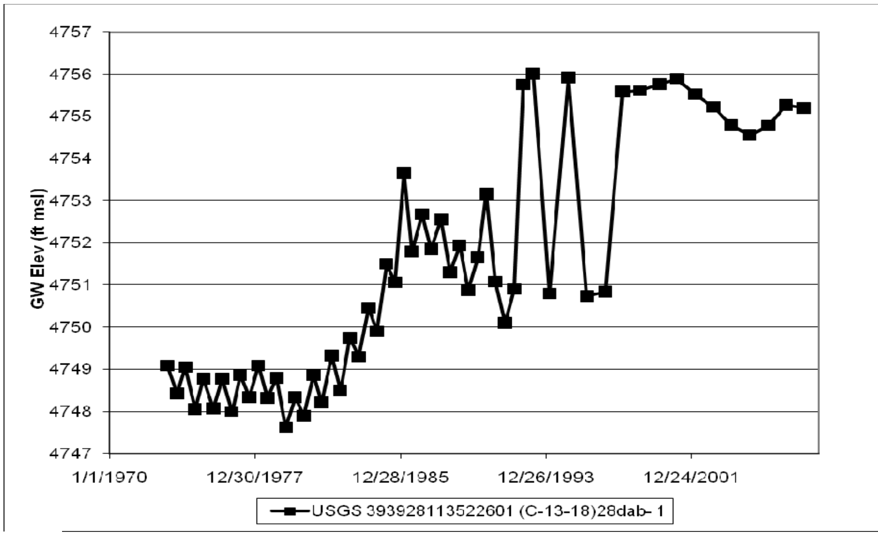

4936
4935
4934
4933
4932
4931
4930
4929
4928
4927
4926
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 392709113594901 (C-16-19) 4bba- 1

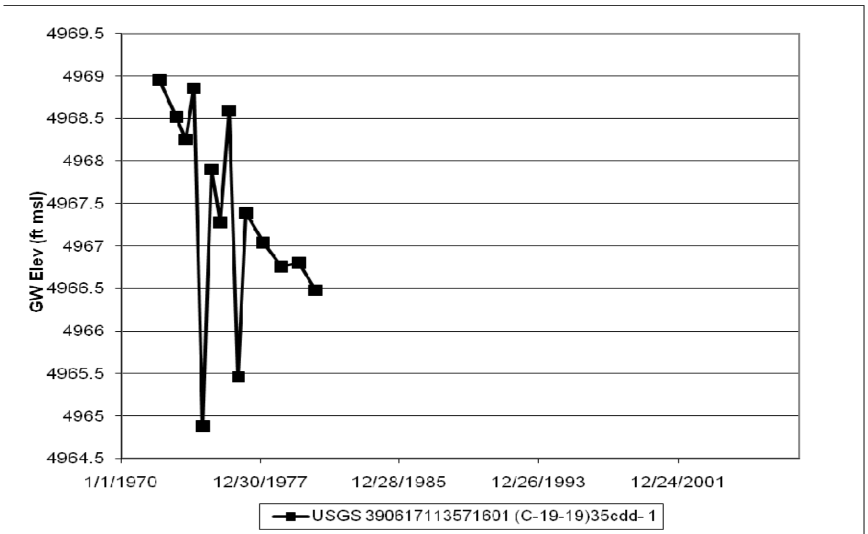

4890
4888
4886
4884
4882
4880
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 393117113574601 (C-15-19)11bcc- 1

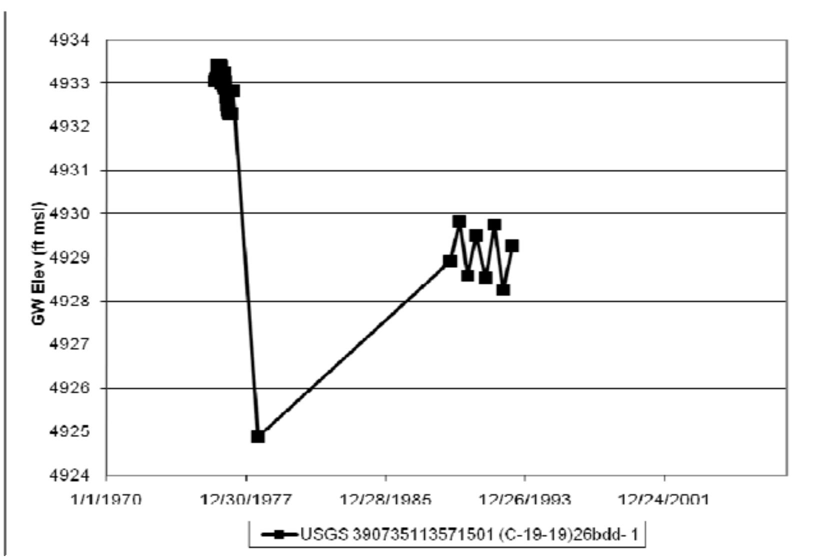

4800
4798
4796
4794
4792
4790
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 393345113503201 (C-14-18)26dbc- 1


4750
4748
4746
4744
4742
4740
GW Elev (ft msl)
1/1/1950
12/30/1959
12/27/1969
12/25/1979
12/22/1989
12/20/1999
USGS 393801113520601 (C-13-18)34ccc- 1


4753
4752
4751
4750
4749
4748
4747
4746
4745
4744
GW Elev (ft msl)
1/1/1950
12/30/1957
12/28/1965
12/26/1973
12/24/1981
12/22/1989
12/20/1997
12/18/2005
USGS 393814113522601 (C-13-18)33ddc- 1


4757
4756
4755
4754
4753
4752
4751
4750
4749
4748
4747
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 393928113522601 (C-13-18)28dab- 1


4969.5
4969
4968.5
4968
4967.5
4967
4966.5
4966
4965.5
4965
4964.5
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 390617113571601 (C-19-19)35cdd- 1


4934
4933
4932
4931
4930
4929
4928
4927
4926
4925
4924
GW Elev (ft msl)
1/1/1970
12/30/1977
12/28/1985
12/26/1993
12/24/2001
USGS 390735113571501 (C-19-19)26bdd- 1