GROUNDWATER SURFACE WATER INTERACTIONS STUDY

UPPER SALMON BASIN

Final Project Report for

Idaho Department of Water Resources

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Table of Contents

TABLE OF FIGURES

PROJECT OVERVIEW

In support of the Upper Salmon Basin Watershed Program (USBWP) and its collaborators, this project undertook a series of hydrologic field tests, research, and hydrologic modeling activities aimed at characterizing the relationships between ground water and stream flows at multiple scales. Assessing the contributions to stream flows from natural runoff, irrigation practices, and ground water was an important aspect of these activities, all while respecting and balancing the needs of irrigated agriculture and strengthening the local economy.

INTRODUCTION

Stakeholders in the Lemhi River basin seek to achieve greater stream flows and connectivity to provide quality habitat for native anadromous and resident fish spawning, rearing, and migration. The USBWP and several federal, state, and local organizations currently manage the basin's aquatic habitat. The USBWP (previously referred to as the Model Watershed Project) was established in 1992 to protect and restore habitat for ecologically- and socially-important fish species in the Lemhi, Pahsimeroi, and East Fork Salmon Rivers while, "respecting and balancing the needs of irrigated agriculture and strengthening the local economy" (USBWP, 2012).

In support of this effort, the USBWP Technical Team plans and implements a variety of stream flow enhancement projects. However, this team can only successfully implement these projects based on an accurate understanding of the basin hydrology, which is complex. The hydrology reflects an interconnected system of natural surface flows in stream channels, natural ground water flow in an unconfined alluvial aquifer, and anthropogenic wells, canals, and drains that interface with the surface and ground water system. A complete understanding of the relationships between the basin's water resources, water rights, and hydrologic processes is vital to the analysis of current water usages and proposed changes, and how these changes may affect fish habitat and water supplies for agricultural purposes.

There are several primary drivers for this study, including the impacts of flood and sprinkler irrigation practices on stream flows, the hydrologic benefits and costs of high flow irrigation, and the large-scale role irrigation plays in regulating stream flows throughout the basin. Historically, according to long-time residents and landowners, before the advent of commercial sprinkler systems, flood irrigation was widely used to water the basin's collection of pasture and hay fields. Irrigators developed schemes for applying this water to saturate the shallow aquifer, such as diverting water in excess of that required for irrigation (i.e. high flow irrigation), to help ensure stream flows were maintained throughout the irrigation season. As commercial sprinkler systems became available, some irrigators switched their practices to the more efficient and less work- and time-intensive irrigation method. Additionally, to mitigate low stream flows during critical fish migration periods, government, tribal, and private organizations began offering financial assistance to irrigators to install sprinkler systems, and the practice of high flow irrigation came into question. At present, many questions remain in the basin as to how irrigation practices affect stream flows and water supplies as a whole, and how enhancement projects should be implemented to ensure that desired stream flows are attained while minimizing the impacts to irrigators.

The USBWP, with the assistance of the Idaho Department of Water Resources (IDWR) and several collaborating agencies, seek to better understand the physical processes governing the seepage of irrigation water into the subsurface, the residence time of this shallow ground water, and the locations of its discharge to streams. Through a series of hydrologic tests and activities, this study aims to develop this information, and use it to help guide future stream flow enhancement projects and irrigation activities in the basin.

Since 2002, IDWR and DHI, Inc. has sought to gain an understanding of the basin's complex hydrologic system by developing and continually refining an empirical model using MIKE BASIN software (DHI, 2003). The model was designed to describe the distribution and usage of surface water across the basin, accounting for all irrigation diversions and places of use (i.e. irrigated fields), to aid the USBWP Technical Team in planning stream flow enhancement projects. Presently, the model is capable of helping estimate the impacts on stream flows from alterations to surface water rights, such as moving irrigation extraction locations from lower flow systems to higher flow systems. Although fairly robust in terms of surface water accounting, more defined information on ground water – surface water interactions can increase the model's functionality and physical accuracy. Knowledge of ground water flow paths, locations and timing of return flows from irrigation applications back to stream systems, and basin ground water underflow/outflow is critical to fully describing the basin hydrology. Incorporating this information into MIKE BASIN would result in a more powerful tool capable of better assessing how irrigation practices affect stream flows and overall basin water supplies.

LOCATION AND BACKGROUND

The Lemhi basin encompasses 1270 square miles in east-central Idaho, situated between the Lemhi Range and the Beaverhead Mountains, which form the Idaho-Montana border (Figure 1). The basin is part of the larger Upper Salmon River drainage, encompassing the Upper Salmon, Pahsimeroi, Lemhi, and Middle Salmon – Panther basins, which historically supported critical habitat for vast numbers of anadromous fish. The Upper Salmon River drainage, and the Lemhi basin in particular, has been a focal area for aquatic habitat restoration activities for the past 20 years because they are the headwaters of the some of the last remaining anadromous fish runs in Idaho.

The headwaters of the Lemhi River are formed by the confluence of several tributaries flowing from the surrounding mountains and the gradual southeastern valley terminating at Gilmore Summit (7000 ft above mean sea level, amsl). The mainstem valley floor ranges in elevation between 4000 – 6000 ft amsl and is semi-arid, receiving less than 10 in/yr of precipitation. Above the valley floor, precipitation is strongly correlated with elevation, and the higher surrounding mountains (exceeding 10,000 ft amsl) can receive greater than 40 in/yr of precipitation, primarily in the form of snowpack.

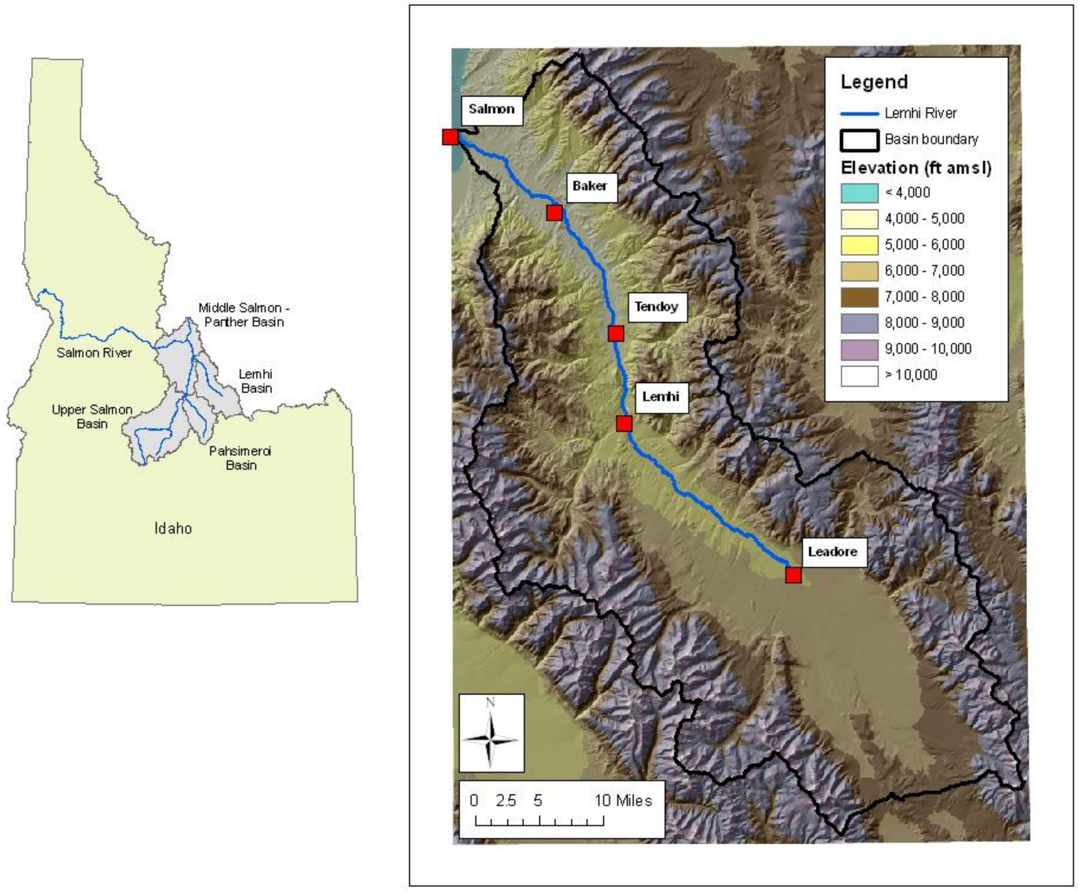

Figure 1. Location of the Lemhi basin

The Lemhi River flows in a northwest direction approximately 60 miles from the town of Leadore to its confluence with the Salmon River near the town of Salmon. The river corridor and associated tributaries are characterized by meandering channels through rural, fertile rangeland dotted with willow stands and irrigated fields. The Lemhi River valley, surrounding alluvial terraces, and tributary corridors support productive agricultural operations that drive the local economy.

From the 2001 U.S. Geological Survey (USGS) National Land Cover Dataset, IDWR estimates that greater than 120,000 acres of land are irrigated in the basin, chiefly for alfalfa hay and pasture. The water for this irrigation depends on snow melt given the semi-arid valley climate. Consequently, landowners have created numerous earthen canals and ditches in the basin to intercept runoff. Water flowing through these canals and applied to fields readily infiltrates the shallow alluvial sediments, and returns to streams by both surface and ground water flow paths (Donato, 1998). Thus, a given “packet” of water is likely re-used multiple times for irrigation as it travels downgradient from the headwaters, in and out of the aquifer, in and out of the river, and finally downstream to the Salmon River.

Previous researchers have generally divided the basin into upper and lower halves of the primary water bearing aquifer, composed of unconsolidated alluvial and glacial deposits (Spinazola, 1998), based on a geologic constriction between the towns of Lemhi and Tendoy (Anderson, 1961; Spinazola, 1998). The upper basin encompasses approximately two thirds of the total basin area, and generally consists of thicker and more laterally-extensive alluvium deposits than the lower basin (Dorratcaque, 1986). Estimates of saturated aquifer thickness in the upper basin, based on Spinazola (1998) and IDWR analyses of well drill logs, range from 5 – 50 ft along the Lemhi River corridor to greater than 100 ft along the terraces flanking the corridor and upgradient of Leadore. The lower basin encompasses less area and is generally not comprised of thick terrace deposits (Anderson, 1956, 1957, 1961; Donato, 1998); thus, the lower basin's ground water is likely fed by inflows from both the upper basin and lateral side channels.

The timing and delivery of water from the upper basin to the lower basin is affected potentially by both climatological factors (i.e. snow pack, spring rains, and temperatures), and by irrigation practices above the mid-basin ground water divide (DHI, 2006, Loucks personal communication). For example, the practice of high flow irrigation, in which spring runoff is diverted and used to fill canals at or near their capacities and fields are thoroughly soaked, may contribute significant recharge to the alluvial aquifer, and help supply late season surface flows through gradual aquifer discharge (DHI, 2006). However, quantitative, temporally- and spatially-distributed information on the effects on stream flows from irrigation practices is presently lacking, and is needed to characterize the hydrologic significance of irrigation across the basin; obtaining this information is one of the primary drivers of this study.

The basin has two key ground water flow locations: the mid-basin divide between the towns of Lemhi and Tendoy, and the downgradient basin boundary near the confluence of the Lemhi and Salmon Rivers. Based on geologic mapping (Anderson, 1956; Anderson, 1961) and analyses of well drill logs (Donato, 1998; Spinazola, 1998), the alluvial aquifer along the divide is both laterally and vertically constricted by shallow and outcropped bedrock formations. In this area, the aquifer is estimated to be less than 0.5 mi wide, less than 50 ft deep, and have depths to water of approximately 10 ft below land surface (bls). Similarly, the thickness of the aquifer at the downgradient basin boundary is estimated to be less than 50 ft, though the lateral extent is slightly greater than 1 mile. Seepage runs conducted along the Lemhi River in the late 1990's (Donato, 1998) indicated that the river flowing through the divide and boundary gained ground water input. Thus, the geologic conditions and seepage run results suggest that both the divide and boundary act as natural hydrologic constrictions to ground water flow (Donato, 1998; Spinazola, 1998).

Previous studies have either assumed or estimated the amount of ground water underflow at these locations to be insignificant to total water flow, as most flow is in the Lemhi River (Donato, 1998; Spinazola, 1998). However, relatively little quantitative information is known about the alluvial aquifer properties because most existing information was estimated from drill logs and general aquifer property literature. Quantitative information on aquifer properties is required to account for the amount and timing of water transmitted out of the basin at the downgradient boundary and through the mid-basin divide, and will foster the development of a basin-wide water balance (i.e. detailing the sources, uses, and losses of water across the basin). This is another primary driver of this study.

OBJECTIVES AND TASK DETAILS

The overarching goal of this project is to assess the contributions to stream flows from natural runoff, irrigation practices, and ground water in the Upper Salmon basin, specifically the Lemhi basin, to ensure salmonid recovery efforts are effectively planned and implemented. The specific objectives are 1) to provide the USBWP and landowners with hydrologic information in areas of priority for current or planned stream flow enhancement projects, and 2) to supply information descriptive of hydrologic processes across the basin. The overall focus of this project is to characterize the role of ground water in the basin at multiple scales.

Hydrologic Data and Interpretation

Dye tracer tests

Three dye tracer tests were conducted during this project, one in 2012 and two in 2013. The three tests were located throughout the basin to gather data on groundwater flow paths and flow rates from a variety of basin wide representative locations. Figure 2 shows the locations of the dye tracer test locations since 2011; the two preliminary tests in 2011 are shown for comparison.

Fluorescein dye was used in each of the three tests; this dye is purchased as an orange powder, and turns neon green when mixed with water. The fluorescein dye becomes invisible to the naked eye at concentrations lower than ~100ppb but can be detected by lab instrumentation at concentrations less than 1ppb. Fluorescein is a photo sensitive dye, meaning that the dye degrades when exposed to sunlight. Each test utilized charcoal packets and water samples to monitor dye as it moved through the hydrologic system. These samples were later analyzed in a laboratory by IDWR personnel. The samples are analyzed on a fluorometer, which measures the fluorescence of the solution, which is directly related to the amount of fluorescent dye present in each sample.

The charcoal packets consist of activated charcoal placed in a mesh enclosure which is secured inside a black PVC pipe (to minimize photo degradation). These pipes were placed in streams and locations where water seeps up from the ground. The charcoal absorbs the fluorescent dye that is in the water which is later extracted from the charcoal in a laboratory. Each time the charcoal packets are collected and new packets deployed, a water sample is also collected to determine if there is any dye moving through the hydrologic system at that point in time. Several locations for charcoal packet deployment are selected for each dye release based on where IDWR and collaborators think the dyed water will move through the system. This decision is based on topography of the land, landowner accounts of water movement at the site, and other hydrologic principles. Each site also has a control location for charcoal packets that is upstream of the dye release and should not see the dyed water move through the water at these locations.

The packets and water samples are collected regularly but the timing between sample collection changes as time progresses past the dye release. The concentration that is obtained from each charcoal packet analysis is a total concentration of dye captured by the charcoal over the period of time the charcoal packet was deployed in the system. As the amount of time between sample collections increases, the amount of dye captured by the packets should also increase. For this reason, an indexed concentration is used when the time between sample collections varies significantly. An indexed concentration is the total concentration divided by the number of days of deployment, to obtain an average concentration per day value.

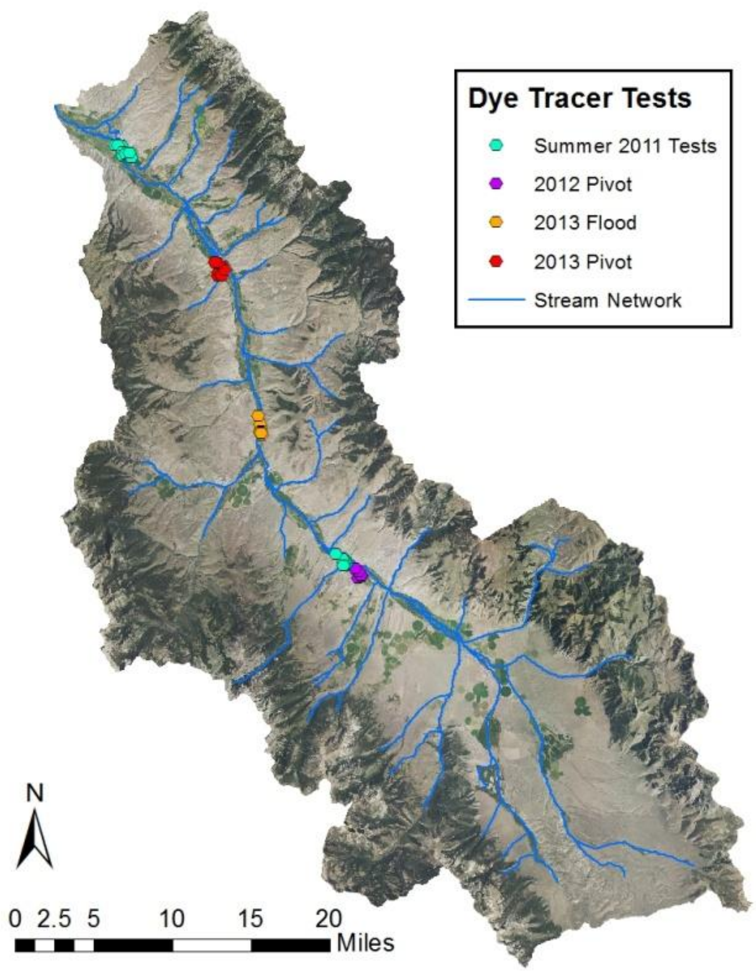

Figure 2. Dye tracer test locations (2011-2013)

Dye was released at the first site, a pivot irrigated field in the upper Lemhi basin between Lee and Mill Creeks, in August 2012 (see Figure 3). This pivot field sits on bar ground 800-1000 feet away, at an elevation 60-70 feet above the headwaters to Little Springs Creek. The landowner informed IDWR that 7-10 days after they begin irrigating this pivot field each year, water begins seeping from the ground in the gravelly boulder field directly below the field, slightly upgradient of the headwater pools of Little Springs Creek. This phenomena did not occur in either 2012 or 2013 but both of these years were worse water years than the region had experienced in the past several years. It is believed that the sprinkler irrigation on this pivot field simply pushed "old" water out of the ground below the field and not that the irrigation water itself was seeping out of the ground below. With two poor water years back to back, this "old" water was likely further below the surface and was not released to the surface water system until further downgradient in the Little Springs Creek complex.

The dye was released into four hand dug 18-24 inch deep holes, across the north end of pivot field, shown by the red dots below. Each hole was tested for draining characteristics prior to releasing dye in each hole to ensure that ~1 gallon of water drained from each hole in 20 minutes or less. Approximately four gallons of concentrated dye water (8 pounds of Fluorescein dye mixed with 15 gallons of water) were released in each hole, allowed to drain, then an additional 2-3 gallons of water were added to each hole and allowed to drain before backfilling each hole with soil. The center pivot was continuously running during this dye release and normal watering operations took place for the remainder of the irrigation season.

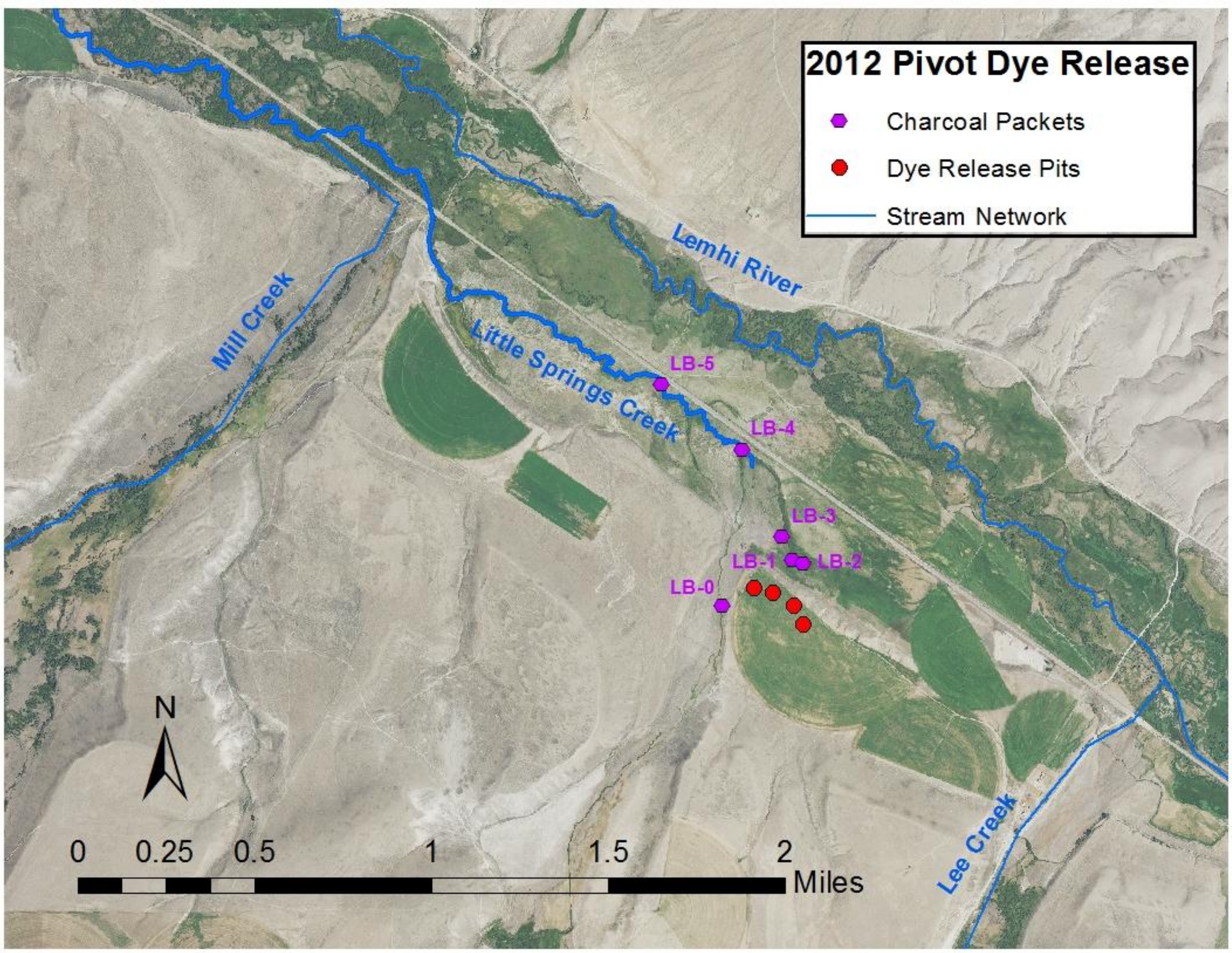

Figure 3. Charcoal packet and dye release pit locations for 2012 pivot dye release

The results from the charcoal packets are shown below (Figure 4), in an indexed fashion, based on the number of days the packets were deployed. The packet locations, depicted above, are on the x axis with the date of packet collection in the colored bars and relative (to the number of days of packet deployment) concentration on the y axis. Location LB-0 is the control, located upstream of the dye release. Locations LB-1 and LB-2 are in two of the headwater springs to Little Springs Creek, just below the pivot field, with the remaining locations being further downstream of the headwaters. There are slight increases in the indexed concentration at several sample locations between the dye release and 11/20/2012 sample date, but none are significant enough to confidently discern this increase from background noise in the fluorescence.

With no definite trends in the data, several hypotheses can be the cause. The first hypothesis is that the water from a pivot irrigated field does not infiltrate deep enough to reach the stream network 60-70 feet below in elevation, close to 1000 feet away, at least not in a time span of 1-2 years. Samples are still being collected and will, on a less frequent basis, to determine if the dye appears after an extended period of time. There could be interference with the dye and soil below the two foot depth that holes were dug. If there is significant clay content in the soil at any point between the dye release site and the stream network, the dye will absorb to the clay particles and will not move along with the water molecules. The final most logical hypothesis is that the water from this pivot field returns back to the stream network at other locations that were not monitored. IDWR feels that this is unlikely based on topography of the land and hydrologic principles.

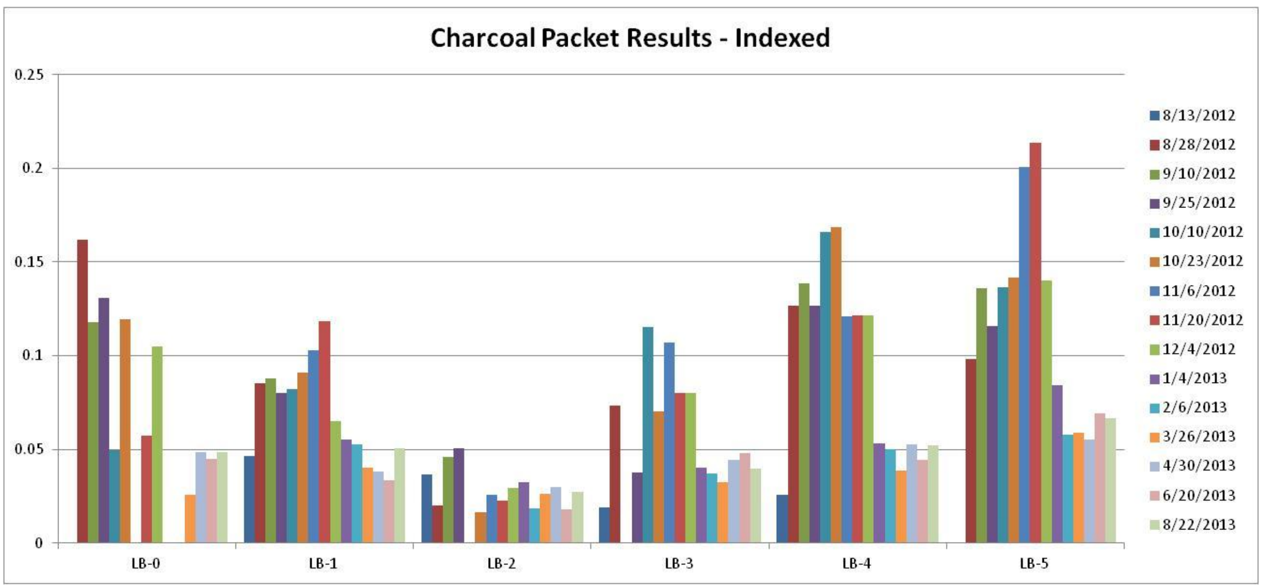

Figure 4. Dye release results from 2012 pivot irrigated field dye tracer release

The second test was performed on a flood irrigated field in the mid basin in July 2013. Ten pounds of Fluorescein dye were released between 11 taps across the southern end of the flood irrigated field (bottom of site map shown in Figure 5). These taps are regularly spaced sections in the ditch that release water onto the field for flood irrigation purposes. Each tap on this field is 60-70 feet from each other. The picture below was taken shortly after dye was released from a tap halfway across the southern end of the field. The dyed water was allowed to move across the field, some seeping into the ground, some moving across the surface, in the same fashion the irrigator typically utilizes. This site does not have a creek that is directly adjacent to the field so several irrigation ditches were utilized for sample locations, as well as some sites in the middle of the field where irrigation water returned to the surface in small pools on the field (low lying locations in the field).

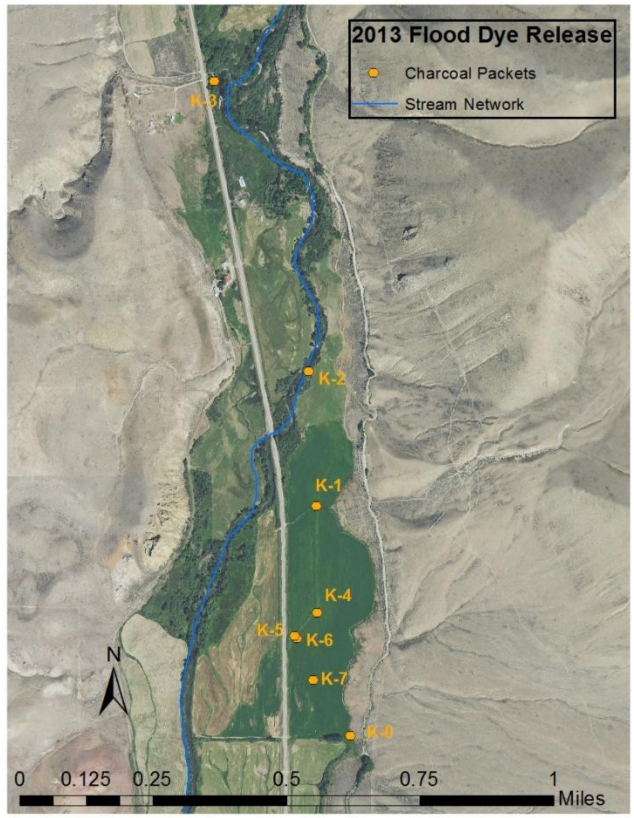

Figure 5. Flood field dye release in mid-basin

The nature of water movement across a flood irrigated field is such that some of the irrigation water will move directly across the field and some will infiltrate into the ground. This is evident in the preliminary results shown below (Figure 6), with the samples that were collected early have high concentrations of Fluorescein (red and green bars). The y axis in this plot has been truncated to be able to show the magnitude of the later samples collected, since we know the initial high concentrations are from the surface water portion of the irrigated water. This particular field was only irrigated two more times after the dye release because of the irrigators water being put into regulation and haying operations at this site. Several of the sample collection locations for this site were in areas in the middle of the field that had pooling water affects during irrigation. These sites are inherently dry during some of the collection days because there was not active irrigation at the site on those days. The packets in stream are still in place and will continue to be collected and analyzed throughout 2014. A subsequent dye release early in the irrigation season of 2014 is planned.

The high spikes seen at the K-1, K-2, and K-6 locations one and three days after the dye release are indicative of the dye moving through with the surface water. The irrigator was done watering his field by the 7/22/13 sample but had watered again just before the 8/2/13 sample collection time. The fact that K-6 saw an increased concentration on 8/2/13 after being dry on 7/22/13 indicates that the second watering of the field (between 7/22/13 and 8/2/13) moved some of the dyed water through the groundwater system, allowing it to resurface at the K-6 sample location. It was also apparent from the samples that the locations in the middle of the field (K-4, K-5, and K-7) were more likely puddles of irrigation water rather than resurfaced water from the ground. During the subsequent dye release in 2014, these locations will likely be used but with a pseudo well (small PVC pipe driven into the ground) that will capture the water moving through the ground at a specific depth, rather than water that resurfaced on the field itself.

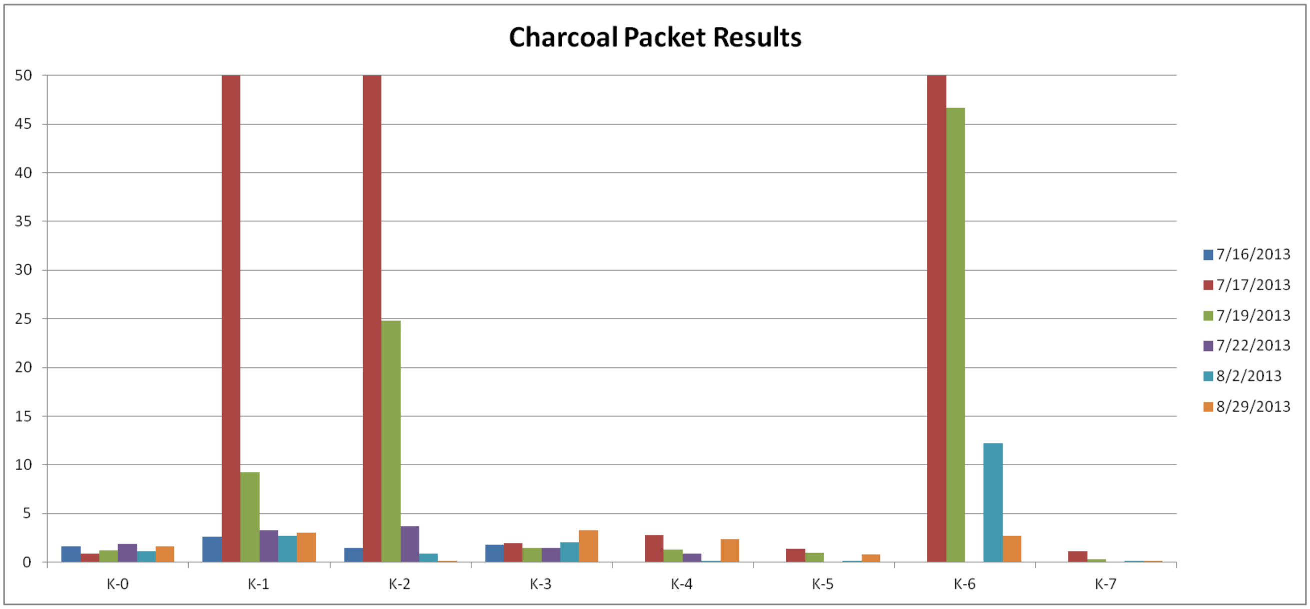

Figure 6. 2013 flood field charcoal packet results

The third dye release was on a pivot irrigated field in the lower basin. Eight pounds of Fluorescein dye was released in 4 hand dug holes, 18-24" deep. Each hole was allowed to drain, filled with 1-2 gallons of irrigation water, allowed to drain again, then backfilled with soil. The location of the holes and sample collection sites are depicted below in Figure 7. Each hole was tested for sufficient draining conditions (~1 gallon of water drained in 20 minutes or less) prior to releasing dye to ensure that the dye would drain from the hole in a timely manner. Sample locations were selected based on an assumed flowpath of the water from the field. This particular field has an irrigation ditch, L-30, that runs through the middle of the field (brown line through center of field in Figure 7). Several sample locations were chosen in this irrigation ditch, as well as in the L-22 ditch further downgradient, since there is constant flowing water in these ditches during irrigation season and the assumed flowpath crosses these ditches.

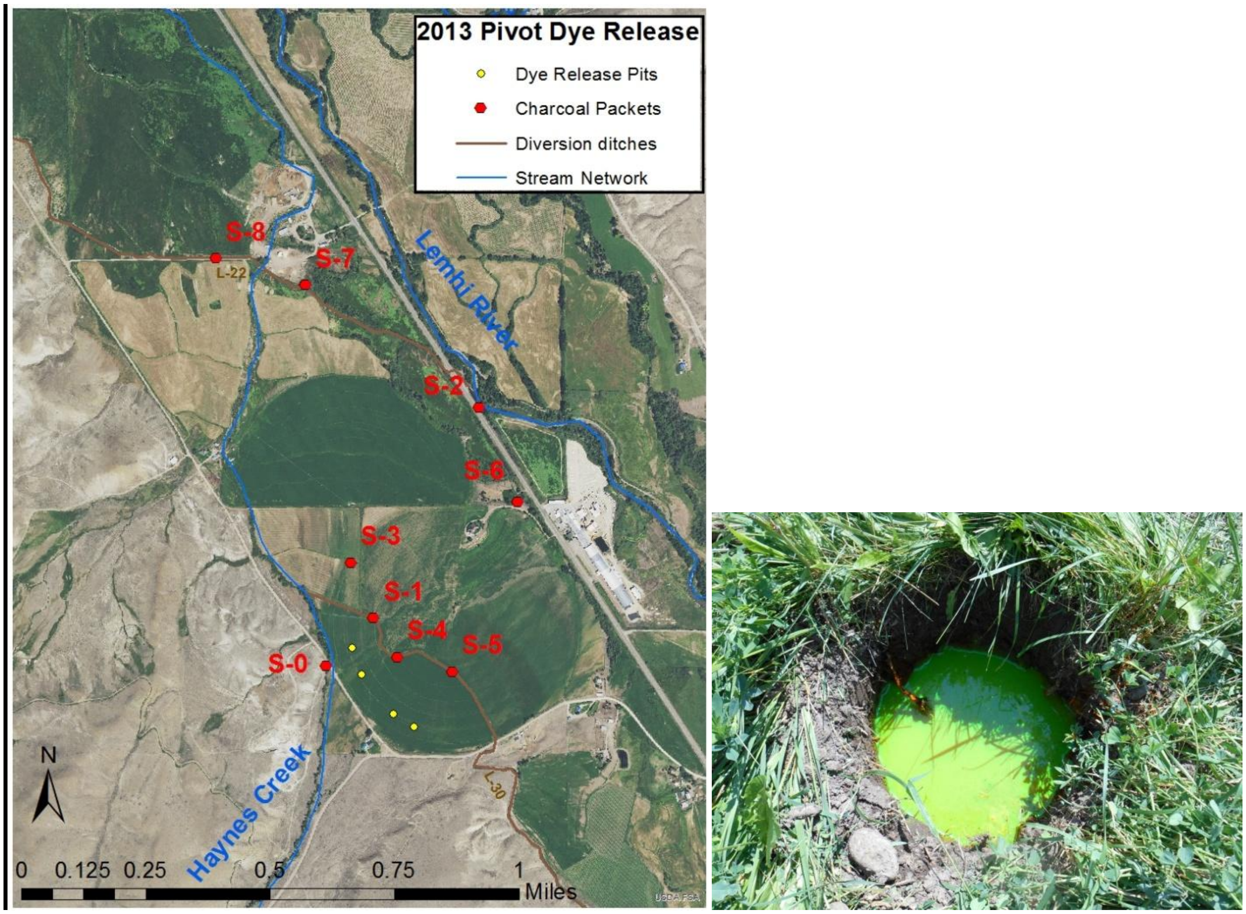

Figure 7. Dye release pit and charcoal packet locations for 2013 pivot field dye release

This dye release was initiated in August 2013 and shortly after the dye release, the water user's water right was placed into regulation and the pivot only ran one more full circle during the remainder of the irrigation season. There is not enough data to make conclusions about the movement of water in this system, due to the early shutoff of water shortly after the dye release. As the snow melts this spring and irrigation season begins again, the dye will be able to move through the system with the water. Charcoal packets are still in place and will be collected and analyzed throughout 2014. A subsequent dye release at this site is planned for early in the 2014 irrigation season. Preliminary results from this dye release are shown below in Figure 8.

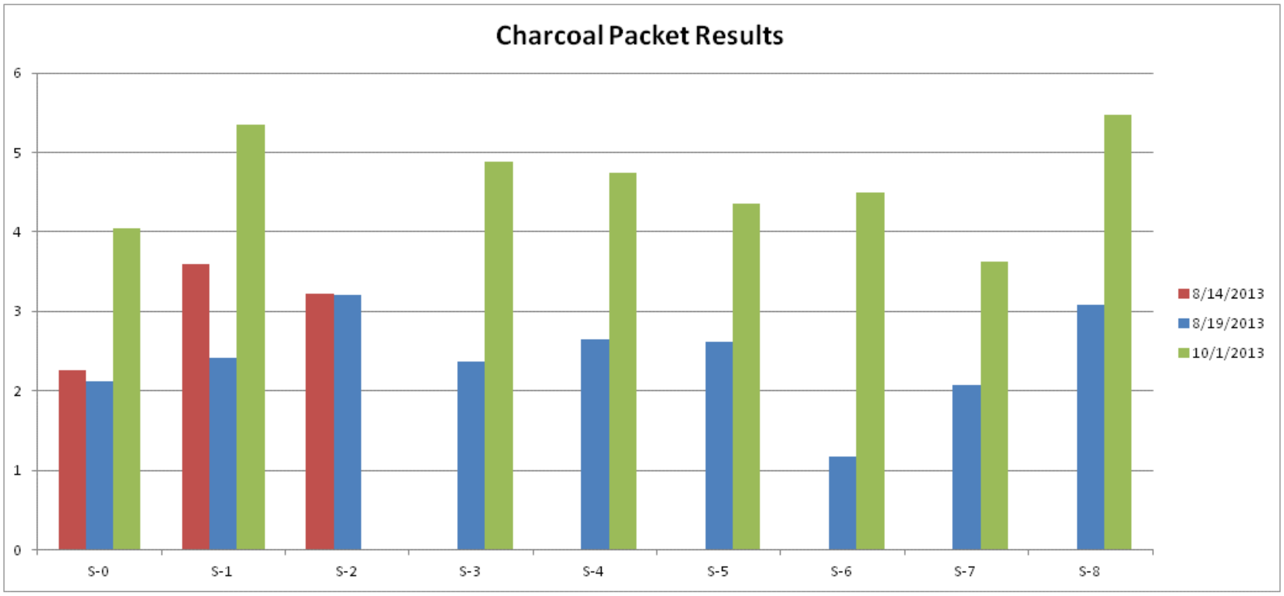

Figure 8. 2013 pivot dye release charcoal packet results

Ground water elevation measurements

Depth to groundwater is an important hydrologic variable to understanding the aquifer system and how the water table changes between irrigation and non-irrigation season. Sixteen wells continued to be monitored throughout 2012 and 2013 with five additional wells being added to the network in 2013. Most of these monitoring wells were measured in the late 1990's twice a month for two years (Spinazola, 1998) which allows for comparison of the data to historical conditions. A location map of the monitoring wells for depth to groundwater is shown below in Figure 9.

Twelve of the sixteen wells are measured biweekly by the Water District 74 Water Master, starting in early March through early November. The other nine monitored wells are equipped with In-Situ Level Troll data loggers. These data loggers are set to record the water temperature and depth to water once every six hours. The data loggers are left in the wells throughout the entire year to collect data on the water temperature and water table level year round. Trends from all of the monitored wells can be found in Appendix A.

Most of the monitored wells trended alongside the historical trends in depth and magnitude. There were a few exceptions which will be discussed below. Unfortunately, there were not many irrigation changes (from flood to sprinkler) that occurred next to wells that were monitored in the late 1990's to compare irrigation changes.

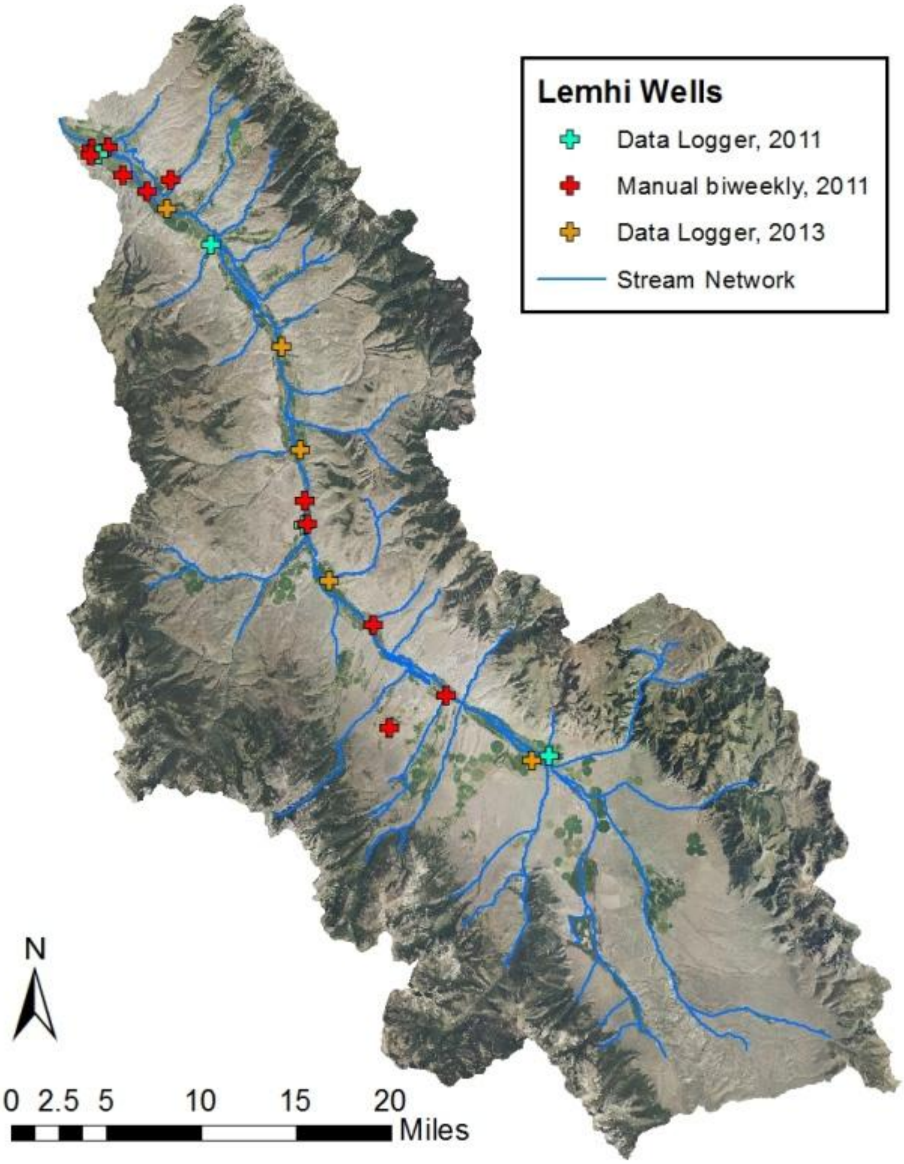

Figure 9. Well monitoring sites

The mid basin has several monitoring wells just downstream of where Hayden Creek enters the basin, as shown in Figure 10 below. Both the Whitson (equipped with a continuous reading data logger) and Kibbee wells (manual biweekly measurements) are directly influenced by seepage from the L-40 and L-42 ditches which run near the wells. This can be most easily seen in Figure 11 by the drop in water level in Whitson well midway through the summer of 2012 and 2013 when the diversion rates in the two ditches decrease. The Kibbee well also shows a decrease in water level halfway through the summer of 2013 when the L-42 ditch decreases in flow. The Whitson well also shows a trend in the water temperature due to this decrease in water level. As the water level dropped, with the decrease in diversion rates of the nearby ditches, the water temperature rose at a higher rate than in 2011 when there was not a water level decrease. The water temperature was higher in 2012 and 2013 than the highest temperature in 2011, by 3-4°F, and reached the high temperature 30-45 days earlier than in 2011. The water levels and amount of seasonal changes in these wells aligned well with historical conditions measured in the late 1990's (historical comparisons shown in Appendix A).

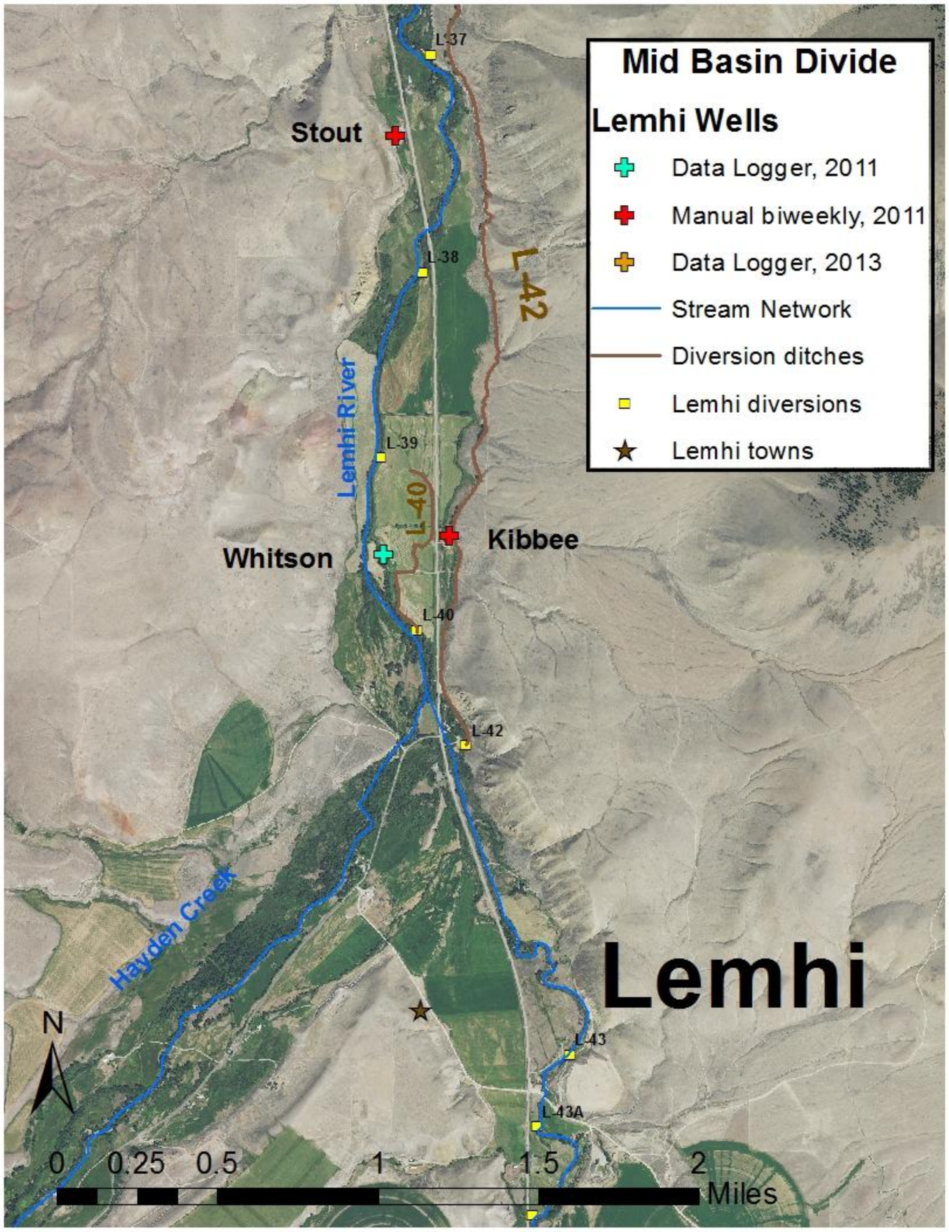

Figure 10. Mid basin divide location map

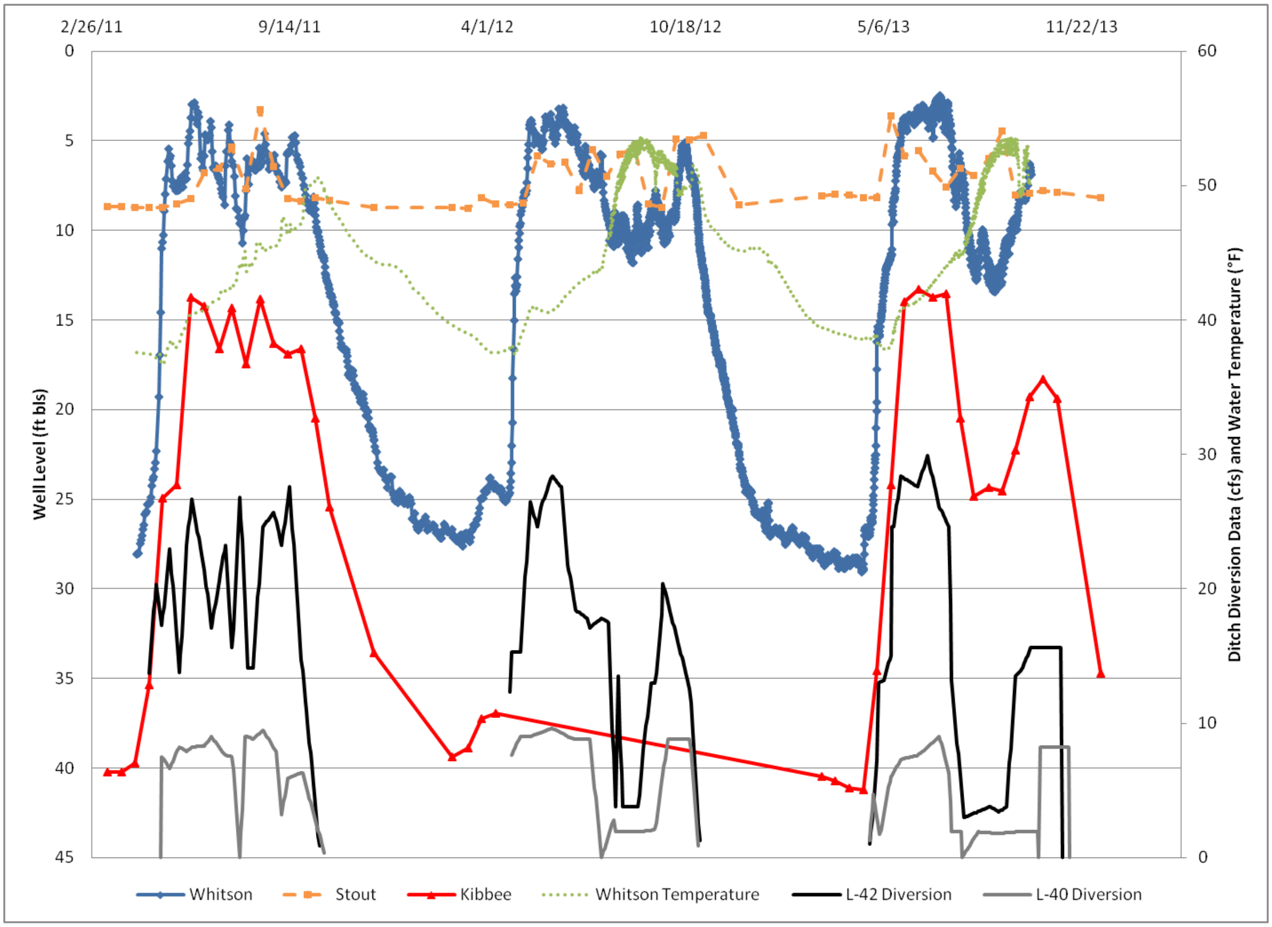

Figure 11. Mid basin well levels

The Little Springs Creek area has been an area of much focus by the USBWP Technical Team in the last several years. The majority of the diversions have been removed from Little Springs Creek and several diversion ditches have been consolidated and water rights transferred between tributaries and the Lemhi River to keep water in the tributary and create better fish habitat in Little Springs Creek. A location map depicting the three wells that have been monitored on a biweekly basis during irrigation, starting just before and ending after irrigation, in the Little Springs Creek area is shown below in Figure 12.

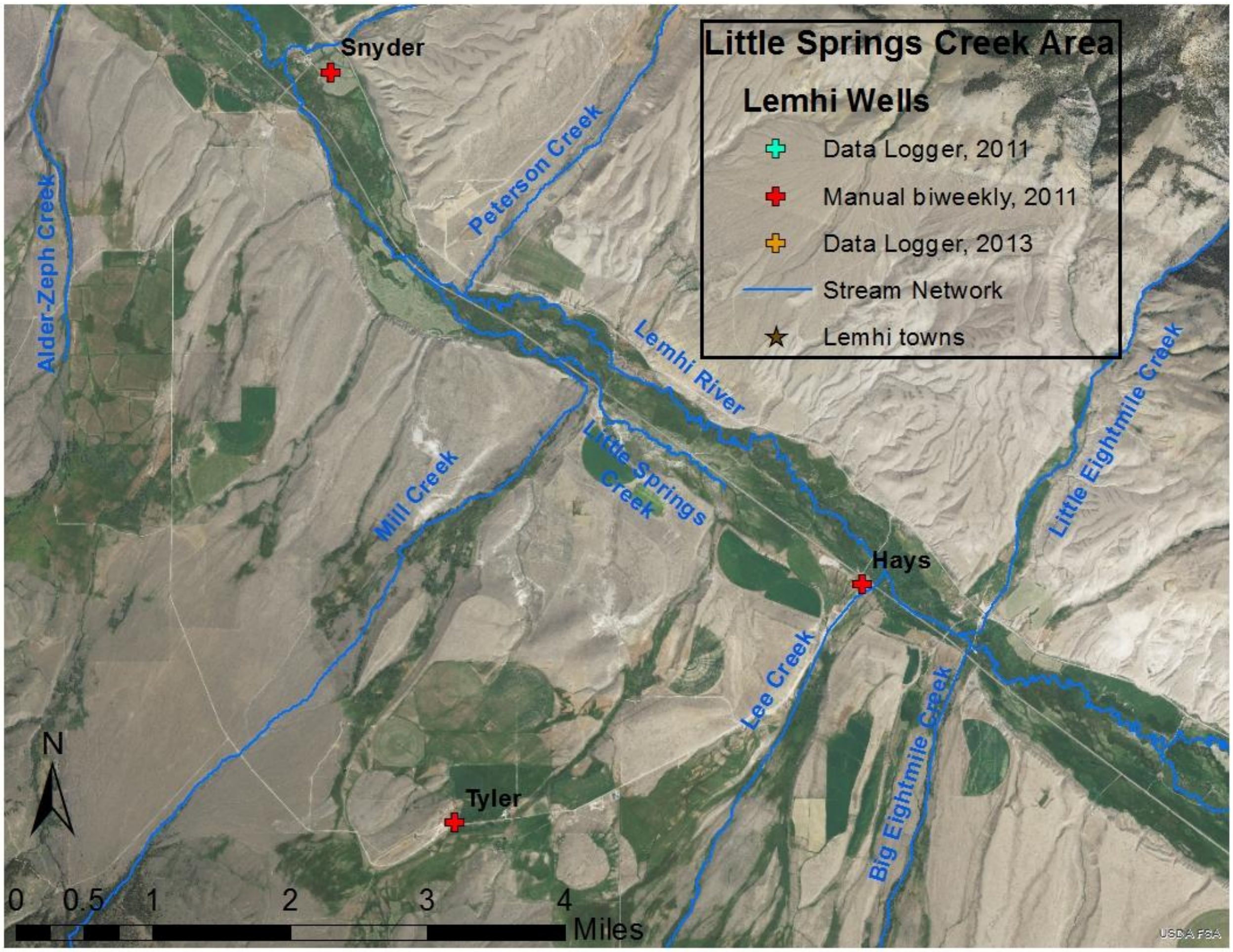

Figure 12. Little Springs Creek area wells

Depth to ground water level trends for the three wells surrounding Little Springs Creek is shown below in Figure 13, with the historical trends plotted on top in the dotted lines. All three wells show an increase in overall depth to groundwater (water table is deeper) since the monitoring began again in 2011. The Tyler and Hayes wells in particular show almost no movement in the depth to groundwater between irrigation and non-irrigation seasons from 2012 to 2013. Historically, the water in the Tyler well rose higher during irrigation season and was closer to the ground surface, by 5-15 feet. The lowering of the water table evident in all three of these wells is likely attributed to, at least in part, the poor water years experienced in 2012 and 2013.

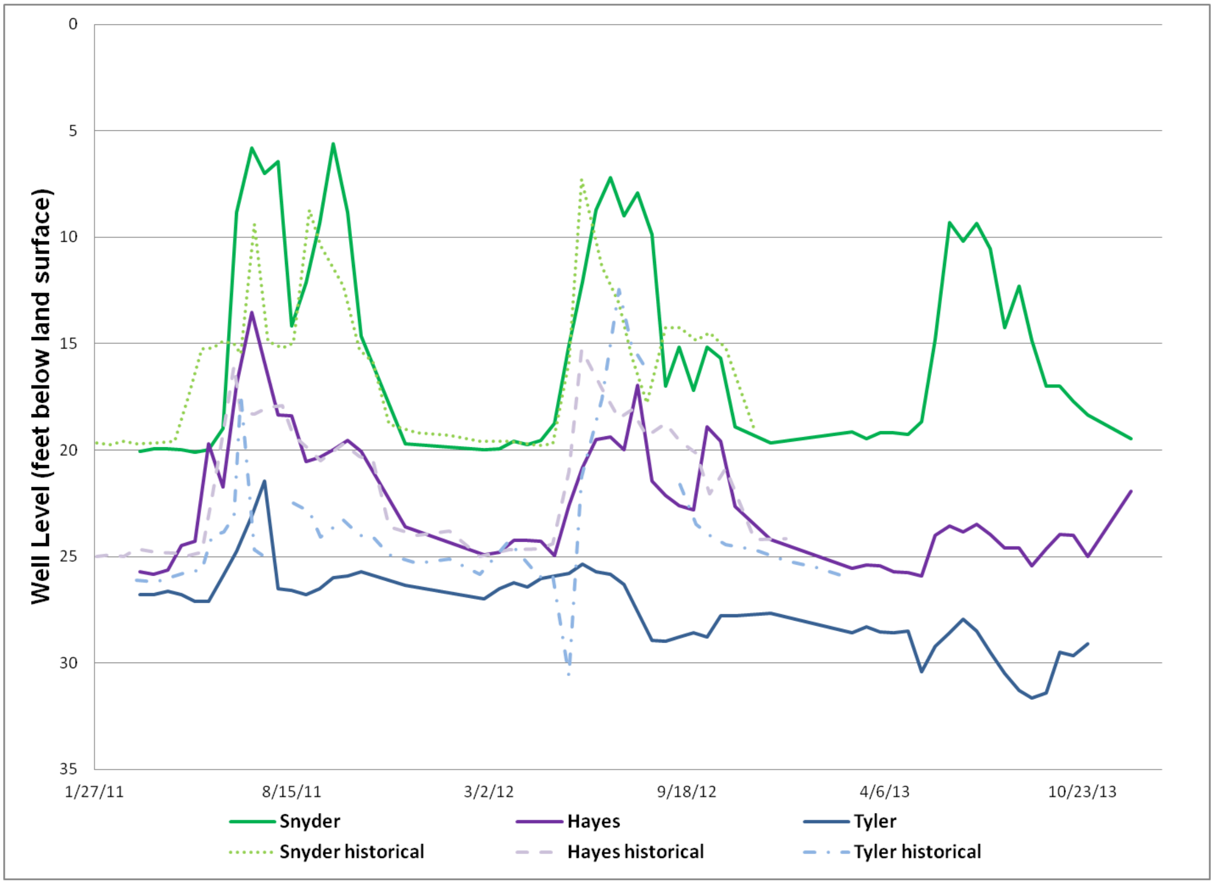

Figure 13. Little Springs Creek well trends compared with historical trends

The Beyler Rental well (trends shown in Figure 14) has a significant difference in the movement of the water table between current and historical conditions. Historically, the water table at this well had movement of 5-10 feet between irrigation and non-irrigation season. Current conditions show that the water table remains fairly stable throughout the year, moving only 2-3 feet seasonally. This is due to several factors; one of which is the irrigation change from flood to sprinkler irrigation (seen in image comparison in Figure 15). The other factor affecting this change in water table movement is the removal of the irrigation ditch next to the old flood irrigated field. This ditch was removed after the irrigation change and the seepage from the ditch was also affecting the water table levels.

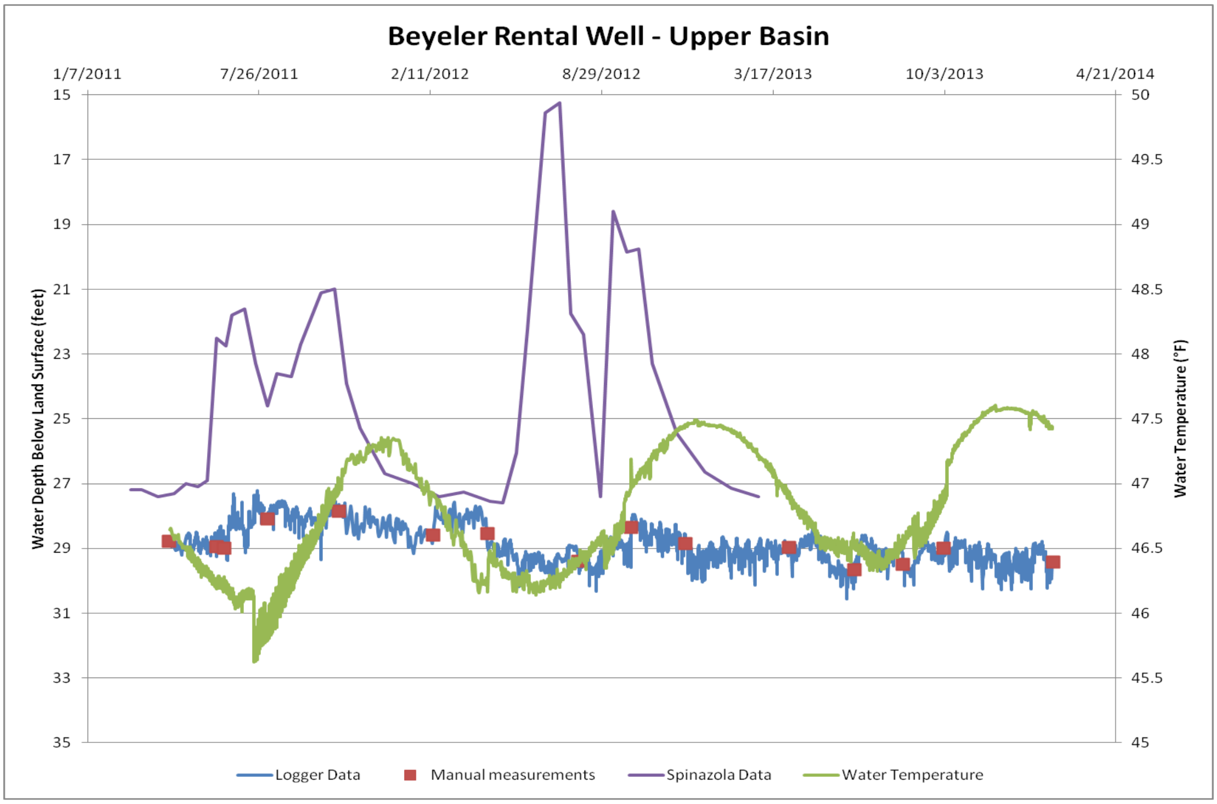

Figure 14. Beyeler Rental well trends

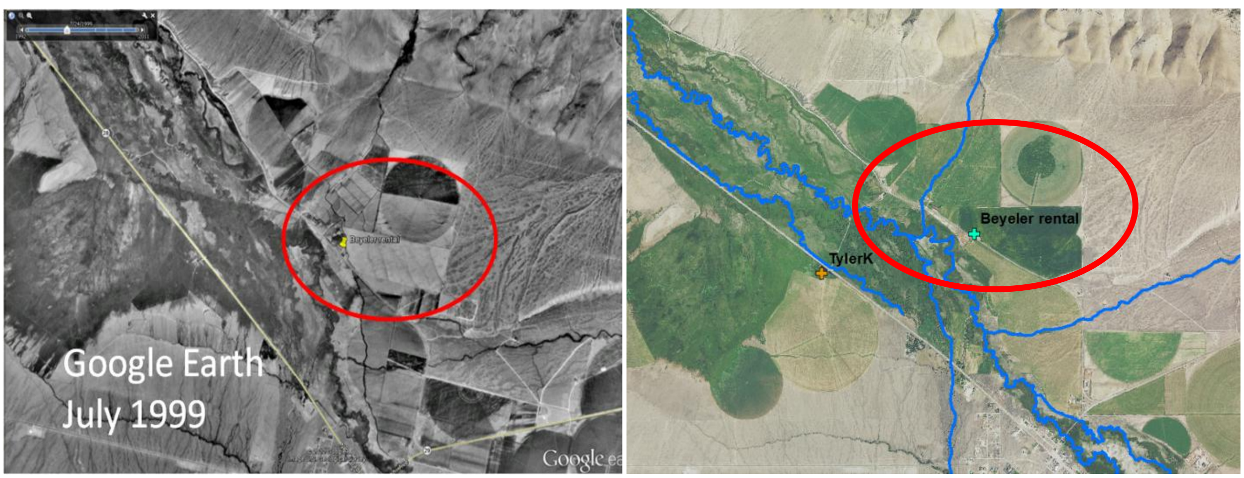

Figure 15. Imagery of Beyeler Rental well location, July 1999 on left from Google Earth, 2013 on right from NAIP

Soil moisture measurements

A network of soil moisture sensors at various depths were installed in two fields during the summer of 2012, one in a pivot irrigated field and one in a flood irrigated field. The goal of the soil moisture sensors was to differentiate between irrigation types and how the water moves through the soil column under each type of irrigation. Each site had a network of sensors installed at depths ranging from 0.5 feet to 5 feet below the land surface. Each sensor is comprised of a gypsum block on the end of a PVC pipe that measures resistance of the block. The resistance is measured once every 8 hours and is not an actual measure of moisture content but can be used to see the trend between wet and dry conditions. Each network of sensors was also enclosed in metal cow paneling in order to keep cows and other animals from disturbing the network of sensors.

Figure 16. Soil moisture sensor network installed in pivot irrigated field

The chart below in Figure 17 shows the trends in soil moisture from the pivot irrigated field. The right axis shows the soil's resistance, an indication of moisture, with high values being dry soil and low values close to zero being saturated soil. The pivot passes over the network of sensors every 2-4 days and this is shown in the data by the cyclic nature of the three shallowest sensors (0.5 ft, 1 ft, and 2 ft depths, darker red, green, and blue lines). The lighter colored lines (purple, gray, and orange lines) are for the deeper sensors (3ft, 4 ft, and 5 ft depths) and show low resistance values with very little movement in the resistance of the soil. This indicates that the soil moisture stays constant and mostly saturated at these depths. Once irrigation was turned off, the sensors all slowly began to dry out, shown by the rise in the resistance values starting around October.

Precipitation is represented by the pink diamonds where values at the top of the chart are minimal precipitation events and diamonds closer to the bottom of the chart are heavier precipitation events. The sensors also show significant responses to rainfall in the most shallow sensors, for example, several larger rainfall events in August show a wetting response (darker solid lines dropping) in the resistance of the sensor. There are a few gaps in the data set shown below. These gaps are during times when the field was being hayed and the sensors were removed as well as times when rodents had chewed through the wiring connecting the sensors to the data loggers.

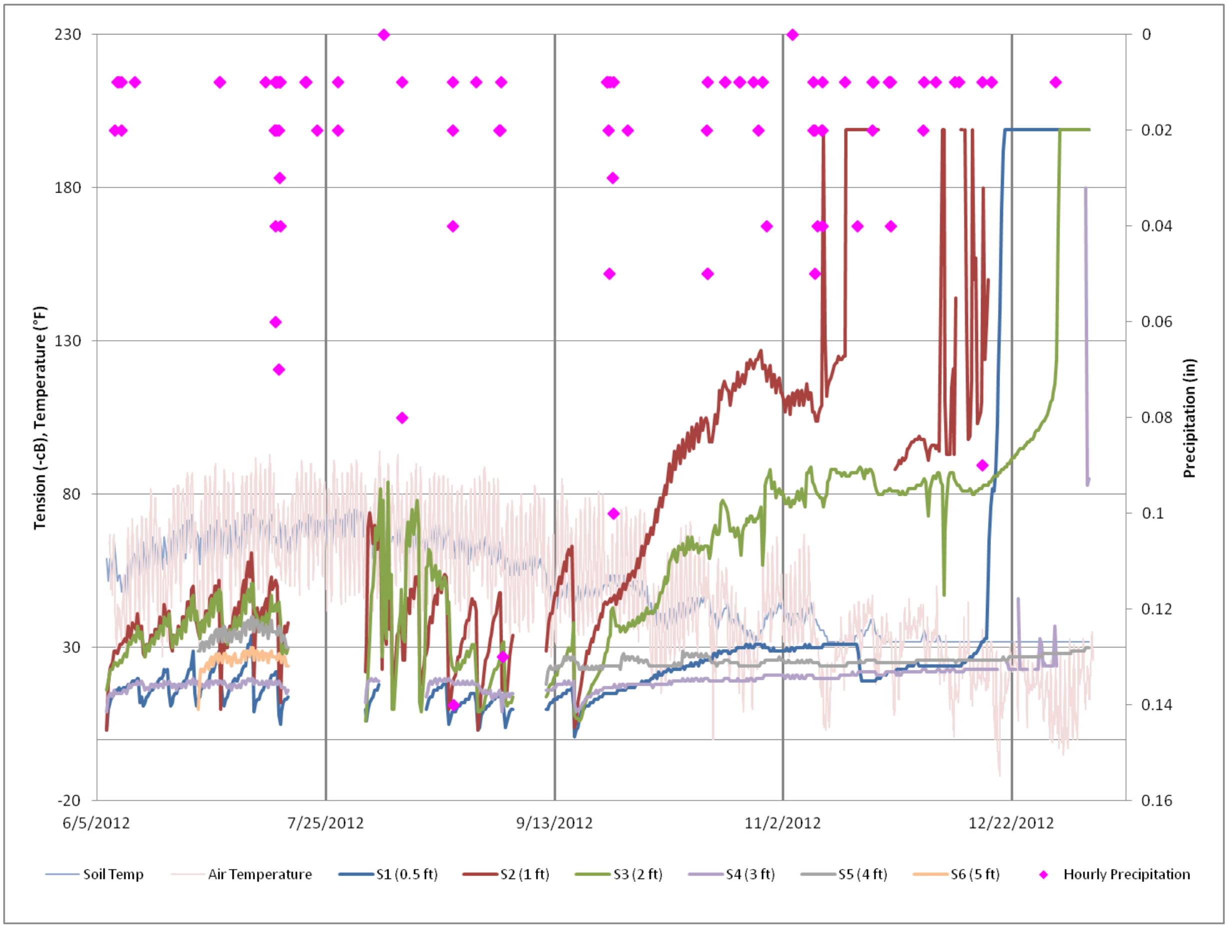

Figure 17. Soil moisture trends from pivot field site

Stream gaging, flow measurements, and seepage runs

Five tributaries were continuously monitored for streamflow throughout the project period by IDWR personnel with an additional 17 gages being monitored for streamflow throughout the Upper Salmon basin by Idaho Power. Eleven of these 17 gages are in the Lemhi basin. Two additional gages were added to the network during 2013, one in the Lemhi basin on Bohannon Creek and the other in the Upper Salmon basin on Bayhorse Creek. Ratings curves and a time series of streamflow were created for the five longer-term sites as well as two additional sites, L-1 and McFarland, in the Lemhi basin. There has not been enough data collected on the two newest gages to accurately create a rating curve at this time. The Lemhi basin Water Master made most of the streamflow measurements at the L-1 and McFarland sites. A few point measurements were also made on Wimpey Creek, Pratt Creek, and the upper Pratt Creek diversion throughout 2013.

Streamflow overall during this project period was lower than in previous years because the snowpack was much less. Several tributaries did not see a true spring runoff peak in the hydrograph that is normally seen because of the amount of snow in the mountains feeding the stream network. This change in timing and magnitude of streamflow throughout the basin played a direct role in the water management practices in the basin.

Two seepage runs were performed during the project period, one on Little Springs Creek in 2012, following the dye release at the pivot field above the headwaters of Little Springs Creek (see Table 1 and Figure 18), and one on Bohannon Creek in 2013, after the new gage was installed above all diversions (see Table 2 and Figure 19).

Measurement Location	X	Y	Date	Substrate	Discharge (cfs)	Inflows	Seepage
channel leaving headwaters pond	2539936	1505848	8/22/2012 14:12	sandy, small gravels	1.407	1.407	
channel leaving willows	2539908	1505841	8/22/2012 14:25	sandy	1.778	1.778	
downstream from staff	2539902	1505868	8/22/2012 15:01	very soft, mucky	1.365		-1.820
channel on east side of Little Springs	2539880	1506076	8/22/2012 15:29	large cobbles, mud	0.3195	0.3195	
downstream from east side channel	2539870	1506095	8/22/2012 15:47	gravelly, some small boulders	2.264		1.219
downstream of Walter Creek	2539620	1506329	8/22/2012 16:42	mud, plants	2.094		-0.17
Above culvert	2539531	1506433	8/22/2012 16:49	mucky, grassy	2.095		0.001
culvert	2539588	1506522	8/22/2012 18:10		0.4456		
Below culvert	2539421	1506517	8/22/2012 17:39	gravel, cobbles, grassy vegetation	5.082		2.541
Culvert to pond #2	2538864	1506824	8/22/2012 18:53	cobbles	6.367		1.285
Pond channel	2538333	1506955	8/24/2012 9:33	cobbles	1.54	1.54	
Downstream of Amonson pond	2538278	1507260	8/22/2012 18:52	small cobbles, sand	11.2		3.293
before road crossing	2537795	1507758	8/24/2012 10:41	boulders and grass	13.367		2.167
LS Gage	2537341	1508044	8/24/2012 11:52	grassy, cobbles	12.35		-1.017
lower LS Gage	2536120	1508812	8/24/2012 12:00		9.3		-3.05

Table 1. Little Springs Creek Seepage Run 2012

The Little Springs Creek seepage run was performed by two IDWR staff, over a two day period. Most measurements were made with a SonTek FlowTracker and two small inflows to Little Springs Creek were measured by other methods. The first of these was a time velocity measurement on the spring channel that was one foot wide and shallow. The culvert inflow was measured with a stopwatch and 5 gallon bucket. Most sections of Little Springs Creek were gaining with the exception of the section between the upper and lower gages. There is a loss to the groundwater system shown in Table 1 in the third measurement, downstream of an in stream staff plate. The measurement just below the staff was a very difficult measurement as the stream channel consists of very soft silty mud. This silty mud makes velocity measurements by the FlowTracker incur many errors and more errors are induced by the hydrologist trying to find channel bottom in the soft silty mud. A rechannelization project was nearing completion at the mouth of Little Springs, for a fish habitat and streamflow enhancement project by USBWP collaborators.

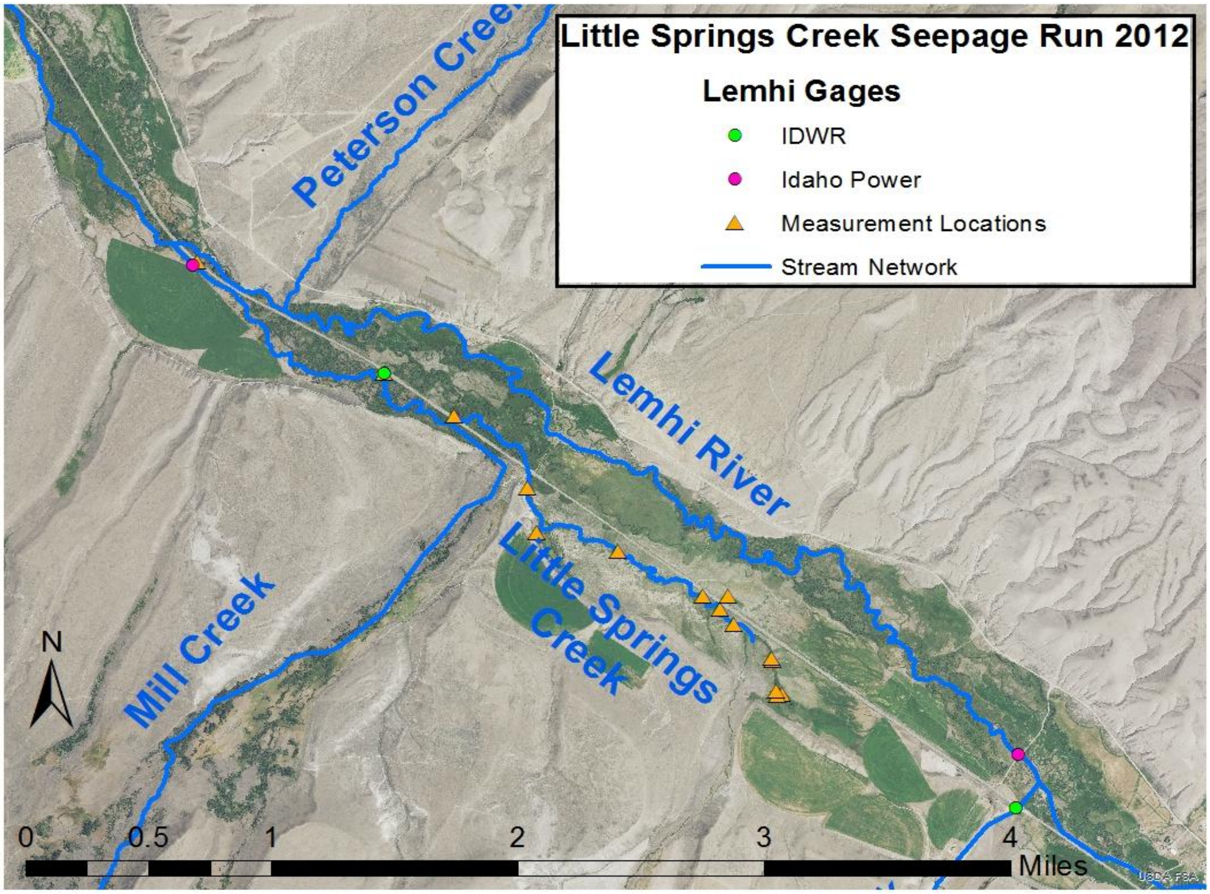

Figure 18. Little Springs Creek Seepage Run, August 2012

Measurement Site Name	Latitude	Longitude	Date/Time	scharge (c	Outflow	Inflow	Bohannon Flow	Seepage	Temp (F)
Bohannon - upstream of Lemhi Back Road	2520171	1545965	8/7/2013 17:47	0.23385				0.095	
Lower Bohannon Gage	2521059	1546798					2.273		
BC-3	2521034	1546788			2.25		0.1389		
Below BC-4	2521737	1547932	8/7/2013 15:53	2.3889				-2.288	
BC-4	2521772	1547996			3.53		4.67715		
Above BC-4	2521824	1548038	8/7/2013 14:32	8.20715				0.074	
BC-5	2522189	1548324			2.3		8.133		
Above BC-5	2522197	1548359	8/7/2013 19:05	10.433				1.393	
BC-6	2522504	1549033			0				
Above BC-6	2522550	1548914	8/7/2013 18:33	9.04				-0.533	56
Bohannon below East Fork	2523109	1549975	8/7/2013 17:36	9.573457			11.97585	-2.402	
East Fork Bohannon	2523265	1550207	8/7/2013 16:08			10.24585			
BOH ABOVE EAST FORK	2523186	1549967	8/7/2013 17:48	1.73				-0.190	66
BOH7	2522789	1551618	8/7/2013 16:54	1.92				0.060	61
BC-7	2522786	1551879			0				
Below BC-9	2523045	1552775	8/7/2013 14:45	1.86			1.9	-0.040	60
BOH 9 FISH SCREEN	2523261	1553067	8/7/2013 13:33		3.8				58
BOH 9	2523247	1553169	8/7/2013 13:09	1.4					56
BC-9	2523240	1553227			3.3		2.3520335		
Below BC-10	2523529	1553614	8/7/2013 14:32	5.652034				-0.278	
BC-10	2523584	1553679			2.4		5.93		
Below BC-12	2523880	1554015	8/7/2013 11:22	8.33				0.024	47
BC-12	2523937	1554134			0				
Below BC-13	2524028	1554212	8/7/2013 10:42	8.305643				3.181	
BC-13	2524075	1554249			2.34		5.1247606		
Upper Bohannon Gage	2524283	1554433	8/7/2013 9:46	7.464761					50

Table 2. Bohannon Creek Seepage Run 2013

The Bohannon Creek seepage run was performed by three teams of two people each, from IDWR and the USBWP office. Two teams used SonTek FlowTrackers and one team used a Marsh-McBirney FlowMate device. A comparison section was measured by all three teams at the Bohannon Creek 9 diversion. During this comparison, it was determined that one of the FlowTrackers was in need of repair. The instrument was still used for the duration of the day and these values were corrected later. There were several gaining and losing reaches of Bohannon Creek with the largest gaining reach being between Bohannon Creek 12 and 13 diversions, at 3.18 cfs returned to the creek. The largest losing reach is just below the confluence of East Fork Bohannon with the main stem Bohannon Creek, at 2.40 cfs lost to the groundwater system. The next biggest loss to groundwater was between Bohannon Creek 4 and 5 diversions, losing 2.29 cfs to the groundwater system.

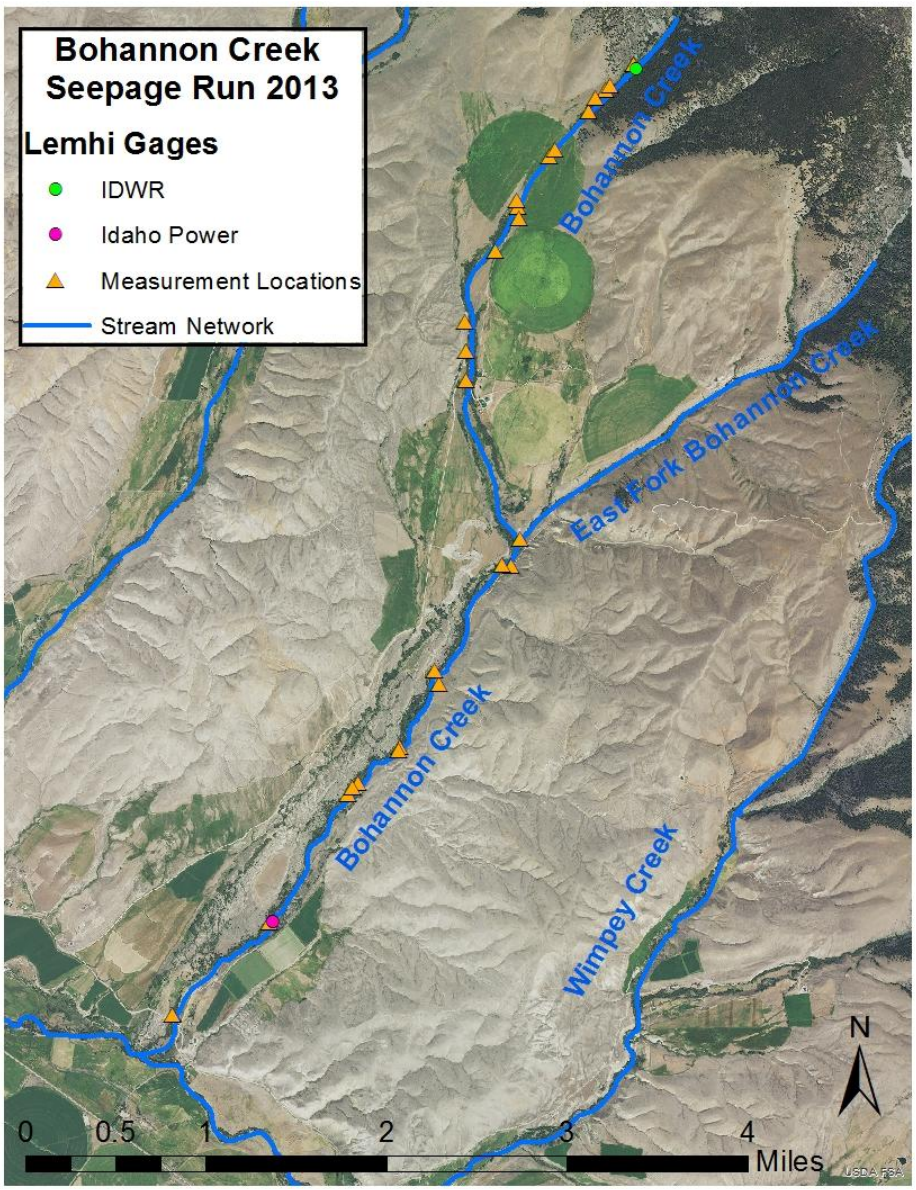

Figure 19. Bohannon Creek Seepage Run, August 2013

Hydrologic Modeling and Interpretation

The MIKE BASIN Model (MBM) was used throughout the duration of this project to represent the hydrologic system and model project scenarios for our collaborators on the Technical Team for the Upper Salmon basin. As mentioned in the Hydrologic Analysis and Monitoring Phase IV Final Project Report (Dixon, 2012), the previous version of the MBM did not include aquifer catchments (purple features in Figure 20 below) to represent the alluvial aquifer present below the higher elevation mountainous regions of the basin. These features were added to the Upper Basin during Phase IV but the lower basin, below the mid-basin divide near the town of Lemhi, was not changed during that phase of the project.

During this phase of the project, the Lower MBM was revamped to include accurate plumbing and water usage for all water users in the lower basin, including a representation of the aquifer in the lower reaches of each tributary watershed. There were also some minor changes to the stream and water user network in the upper basin. The lower and upper basins were then combined to create a Full Lemhi Basin MIKE BASIN Model (MBM) that was used for all scenario and model development work throughout the remainder of the project period. A current model representation is shown below in Figure 20, depicting the upland catchments in tan, lower aquifer catchments in purple, water users in orange, river channels in blue, and diversion link channels in black.

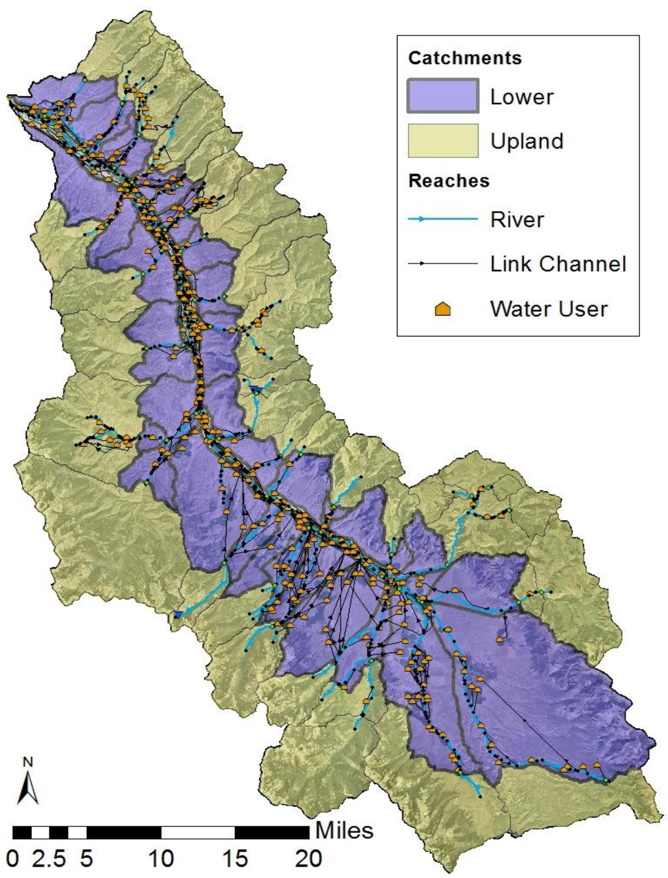

Figure 20. Lemhi MIKE BASIN Model, with water users, catchments and stream network.

Calibration

The next step to creating a running model is providing the stream network with accurate volumes of water entering each tributary from their highest elevations. Since the Lemhi basin is a snowmelt dominated watershed, this water input primarily comes from snowmelt runoff during the spring months and throughout the year. The MIKE 11 NAM rainfall-runoff program (more details on NAM in Dixon, 2012) was utilized to create a time series of water input to each tributary catchment (tan features in Figure 20 above). These high elevation catchments were delineated using digital elevation models and are upland of most diversions on each tributary, where the majority of the snow accumulates and runs off during the spring.

Inputs to NAM include daily time series of temperature, precipitation, and evapotranspiration (ET) for each catchment. The time series for precipitation and temperature were created by aggregating monthly PRISM (Parameter-elevation Regressions on Independent Slopes Model) grids (PRISM, 2012) with daily time series of temperature and precipitation from several SNOTEL (Snow Telemetry) sites inside and surrounding the Lemhi basin. The monthly PRISM grids used in this phase were calculated using the new normals from 1981-2010, which became available after the last calibration in 2010. Evapotranspiration time series were created by aggregating monthly METRIC (Mapping EvapTranspiration at high Resolution with Internalized Calibration) grids (IDWR, 2010) with daily time series of ET calculated using Ref-ET software and weather station data from the Leadore and Salmon RAWS (Remote Automated Weather Stations) stations. This process is described in more detail in the Phase IV Final Report (Dixon, 2012).

Four upland catchments were used for calibration of this rainfall-runoff data, Hawley Creek, Big Timber Creek, Big Eightmile Creek, and Agency Creek. Each of these tributaries has a stream gage located upstream of most or all diversions, near the delineated catchment boundary. The NAM modeled runoff, predicted using the precipitation, temperature, and ET time series described above along with a set of calibration parameters, was compared to the observed flow time series in these four catchments. The calibration parameters were adjusted iteratively until a satisfactory match of the modeled and observed runoff/streamflow was produced. An example of a final calibration plot is shown below in Figure 21. The red dotted line is the observed streamflow while the black solid line is the simulated runoff from NAM.

The most critical time periods to ensure simulated streamflow matches observed streamflow are during times of high irrigation demand and lower or base flow conditions, when the river is put into regulation by the local water master. As such, the peak streamflows do not need to always be modeled as accurately, as long as the rising and falling limbs of the hydrographs are modeled with more accuracy.

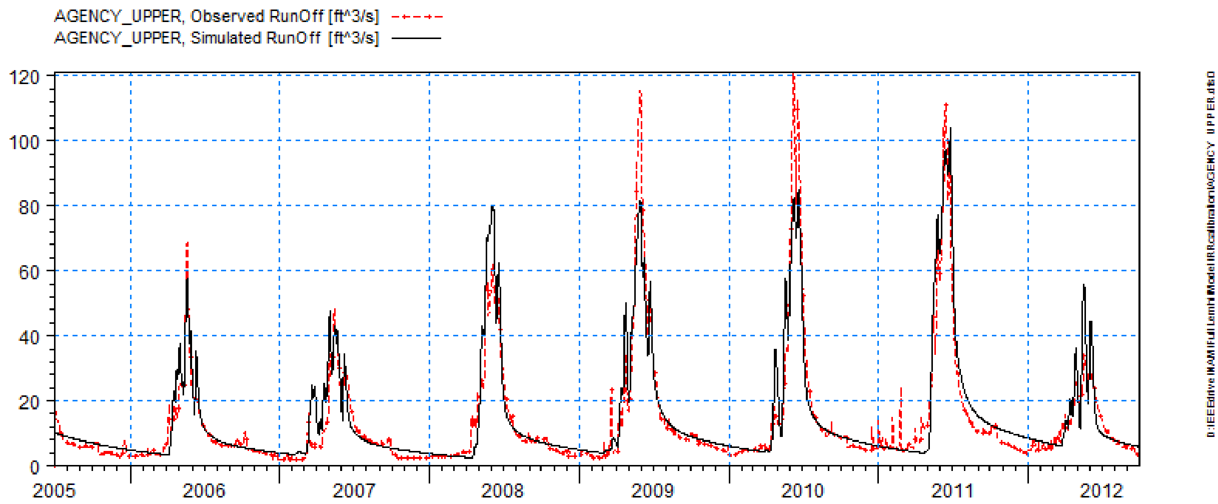

Figure 21. Final calibration plot for Agency Creek upland catchment.

After satisfactory calibration plots were created for each of the four upland calibration catchments, the set of calibration parameters were then applied to the other upland catchments across the basin. Each non-calibrated upland catchment was assigned one of the four calibrated catchments set of calibration parameters, based on geologic, topographic, and hydrologic similarities between the calibrated and non-calibrated catchments. Once the upland catchments all had parameters assigned to them, the NAM was ran again, producing runoff time series for each upland catchment delineated in the model framework.

A similar calibration strategy was then performed on three lowland catchments/aquifers (purple features in Figure 20), Big Timber Creek, Canyon Creek, and Kenney Creek, utilizing observed streamflow data that was collected as part of this and previous Pacific Coast Salmon Recovery Fund funded projects. The lowland catchments are more complicated to calibrate because of active diversions and high water practices that occur in the lower portion of each catchment. These high water practices, where irrigators take as much water as their ditches can handle during the high spring flow, are not well documented in regards to the timing of when water is being used and how much is being used.

The objective of calibrating these lowland catchments is to determine the contribution of water input to the stream network from each lowland catchment. This volume is inherently not as significant as the upland catchments because there is minimal snow storage in the lower portions of each catchment. Once satisfactory calibration results were achieved for these lowland catchments, the parameter sets were then assigned to the other lowland catchments based on geologic, topographic, and hydrologic similarities between the calibrated and non-calibrated lowland catchments. The NAM is then run again to create a time series of water input from each of these lowland catchments.

The final step in the calibration process is to account for losses and gains to the stream network from the groundwater system. Since the LRMBM does not include the groundwater layered reservoir at this time, the gains and losses are accounted for in a more elementary fashion.

Starting at the most upstream gage location, the observed streamflow at the gage is compared to the modeled streamflow and then adjusted to match the observed streamflow. This adjusted time series accounts for gains and losses to the catchment/stream network on a daily basis. The model is then ran again and the next downstream gage location observed streamflow is compared to the simulated streamflow and again adjusted to match. This is performed iteratively, moving downstream in the system until the furthest downstream observed streamflow location is compared to the simulated flow, and adjusted accordingly. The model is now considered calibrated and can be utilized to run scenarios representing past, current, and future projects that affect the timing and movement of water through the basin.

Scenarios

With a calibrated model, projects that are in the planning stages and/or being implemented in the basin can be represented by the LRMBM, allowing users to see the effects a project will have on the hydrology of the basin at any point in the stream network. A number of project scenarios were suggested by the USBWP Technical Team to be modeled and these results were presented to the group for feedback in early 2014. Running model scenarios and comparing the results to our knowledge of the basin, areas of potential improvement in the model representation can be identified for future model modifications.

Conclusions

Surface and ground water processes in the Lemhi basin are complex, being affected by changes in irrigation practices and timing of these changes as well as weather conditions that change the volume of water available for junior and senior water users alike. Several hydrologic tests that were planned for this project period were disrupted from weather conditions which changed the timing of some projects and caused others not to occur during this project phase. Changes to these methods and tests have been made and will be utilized in the upcoming irrigation season under Phase 2 of the Ground Water Surface Water Interactions Study. Another aspect of Phase 2 of the study is to gain a more thorough understanding of the aquifer system by performing an aquifer characterization and water budget of the Lemhi basin, as well as a ground water modeling assessment to determine the future directions of the hydrologic model representation of the Lemhi Basin.

A significant amount of time was spent working with the modeling during this phase of the project, some due to software and hardware complications. The model is in a working, calibrated state now, that can be used to represent project scenarios from our collaborators with the USBWP. The model will continue to be refined and used in this fashion throughout the next phase of this project.

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Appendix A: Monitoring Wells Data

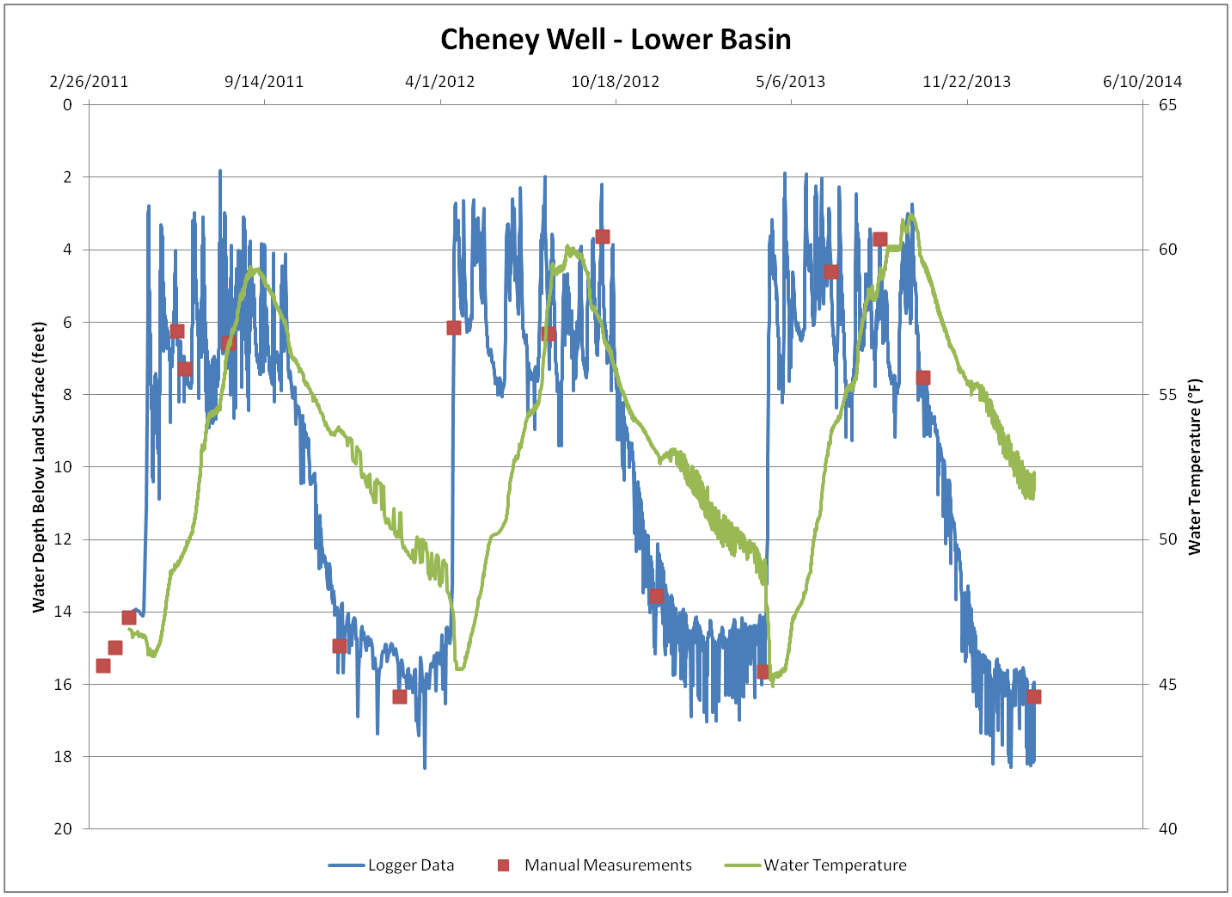


Figure A1. Cheney Well Trends

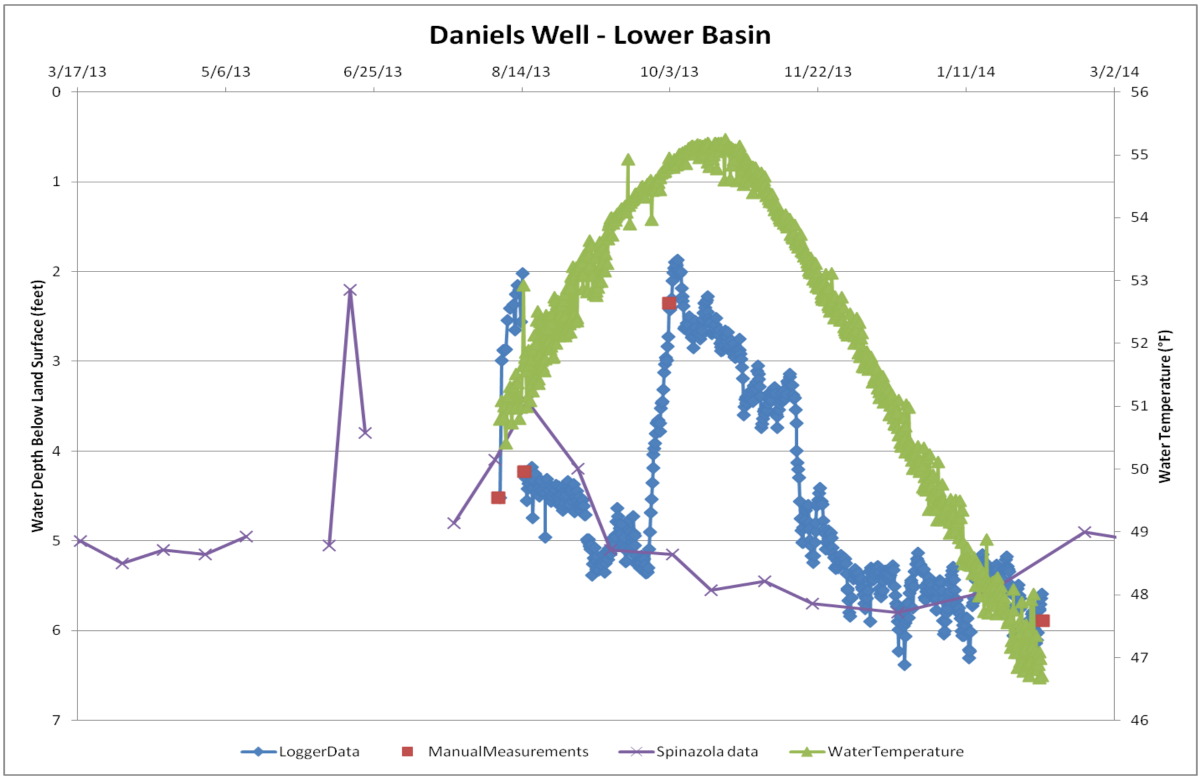


Figure A2. Daniels Well Trends

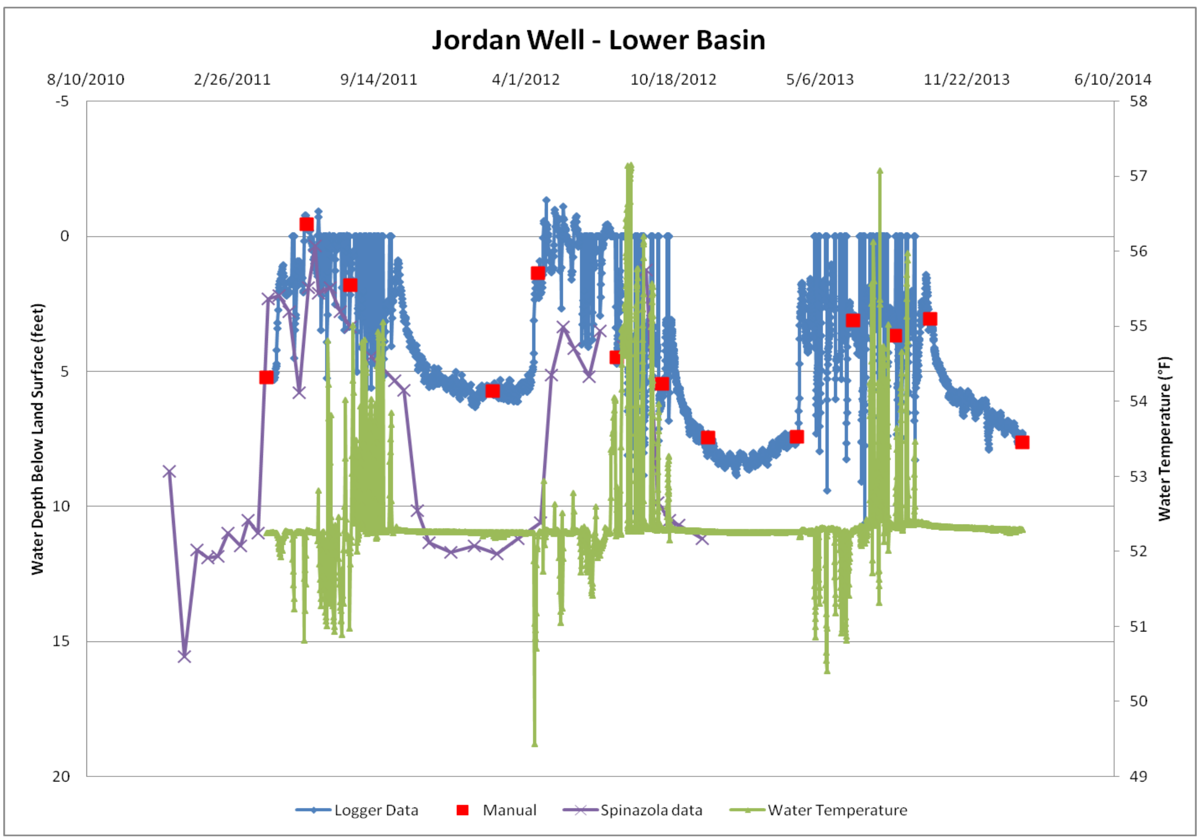


Figure A3. Jordan Well Trends

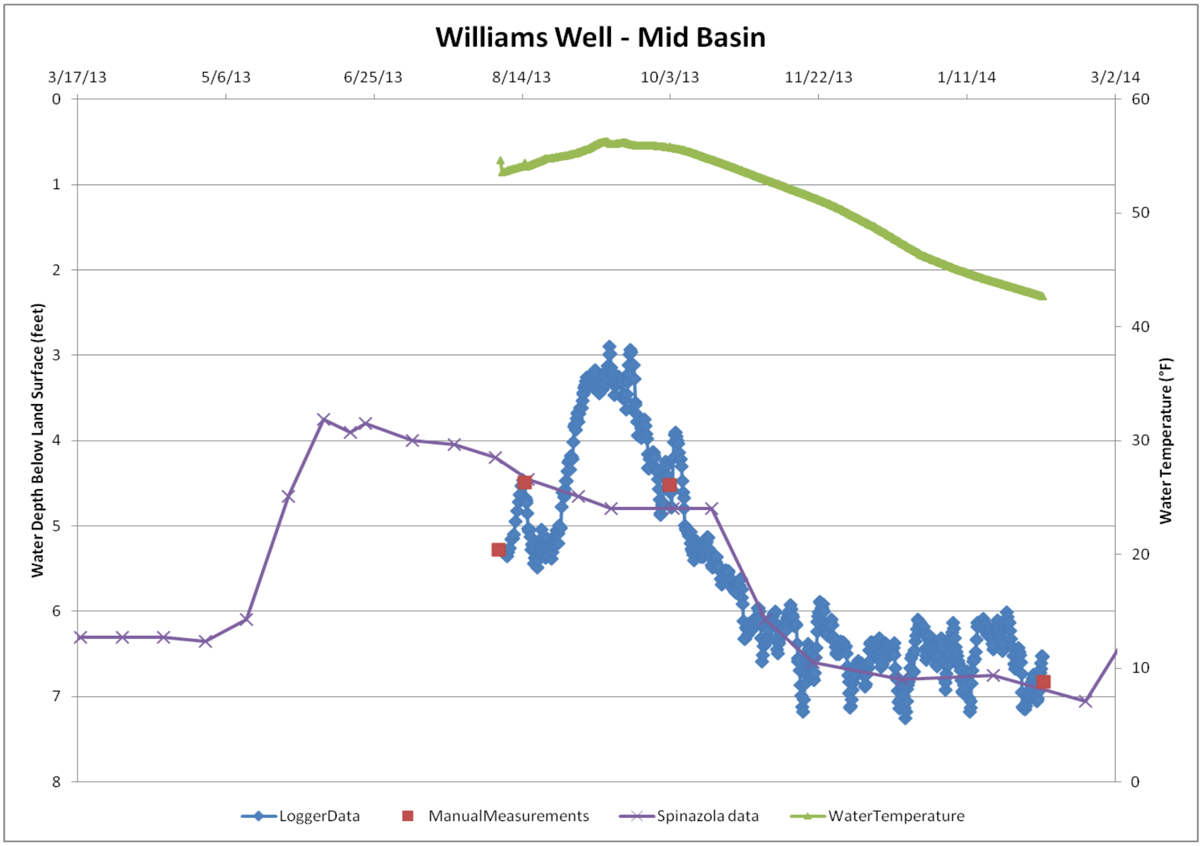


Figure A4. Williams Well Trends

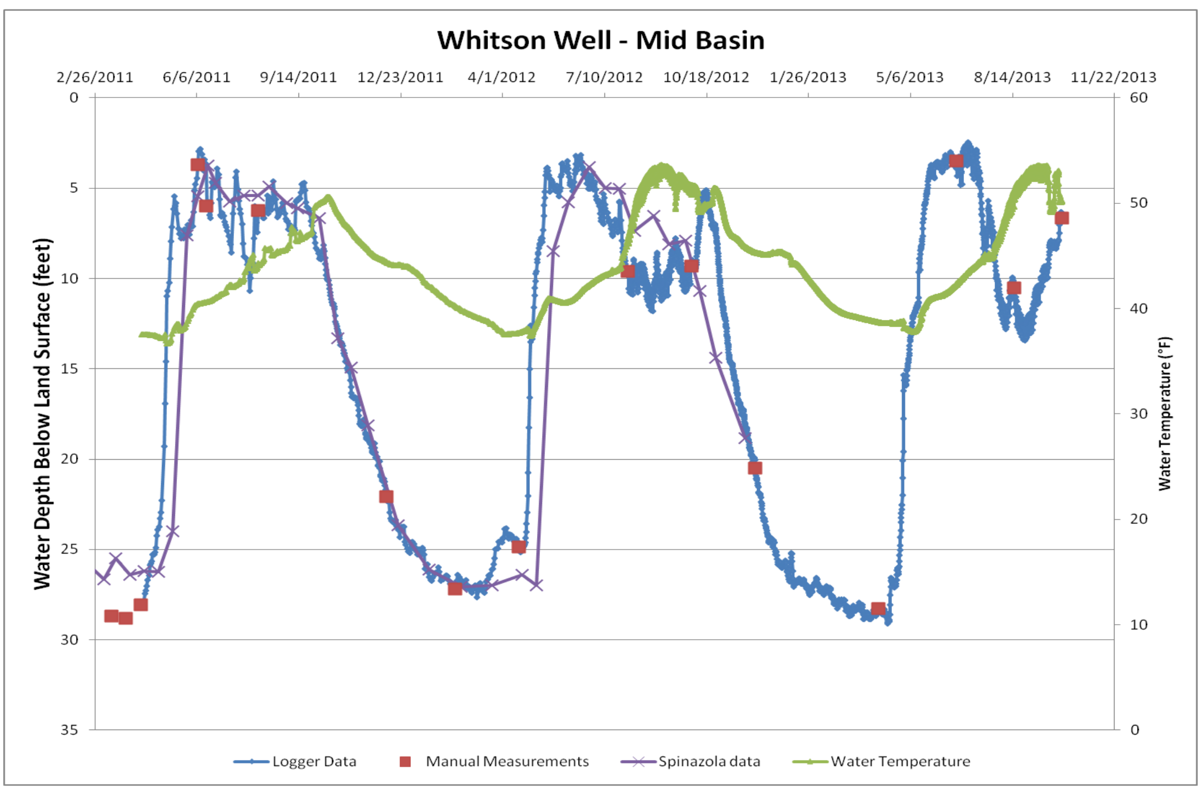


Figure A5. Whitson Well Trends

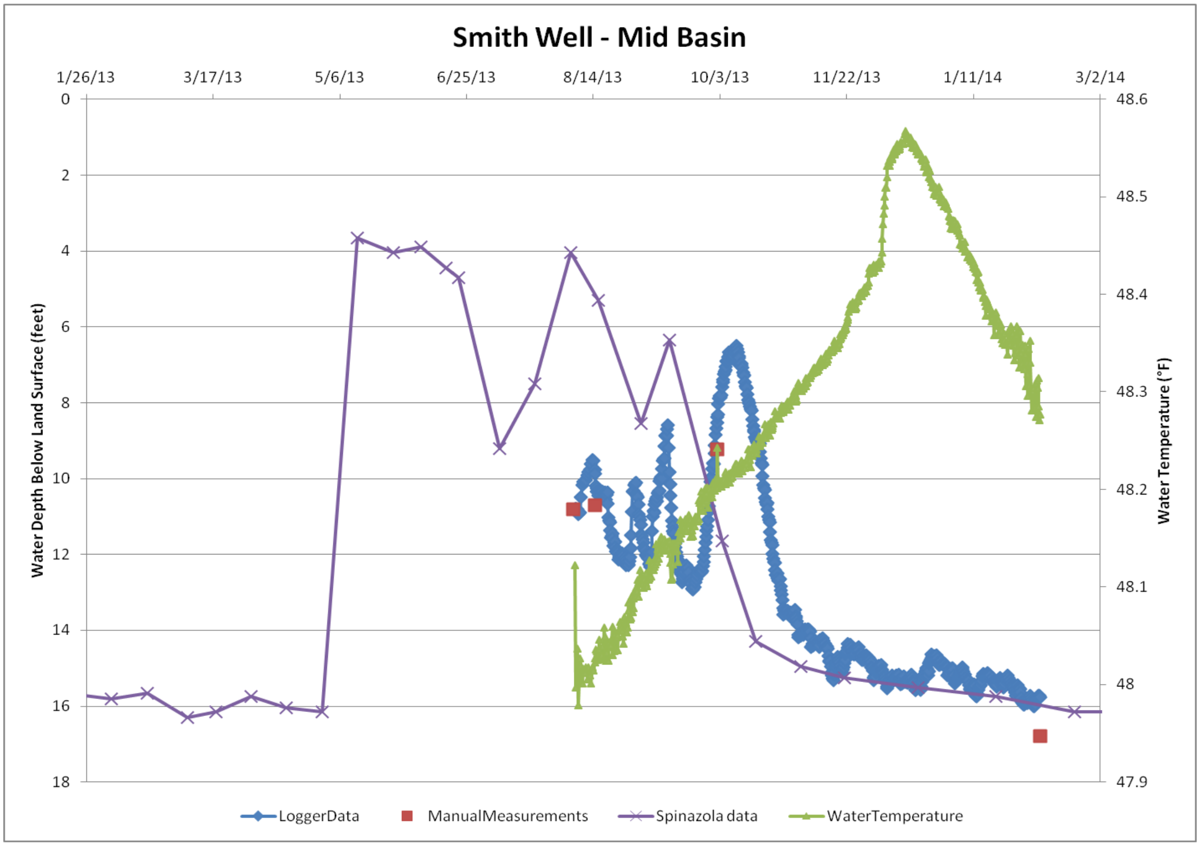


Figure A6. Smith Well Trends

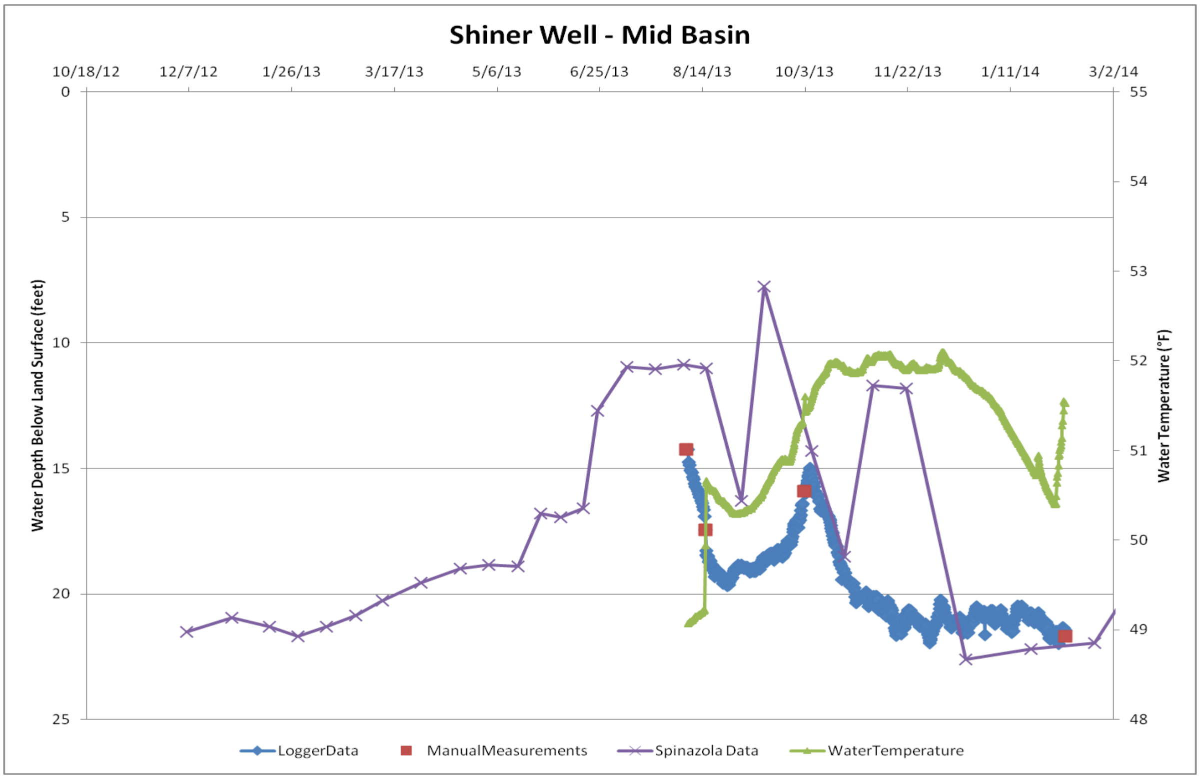


Figure A7. Shiner Well Trends

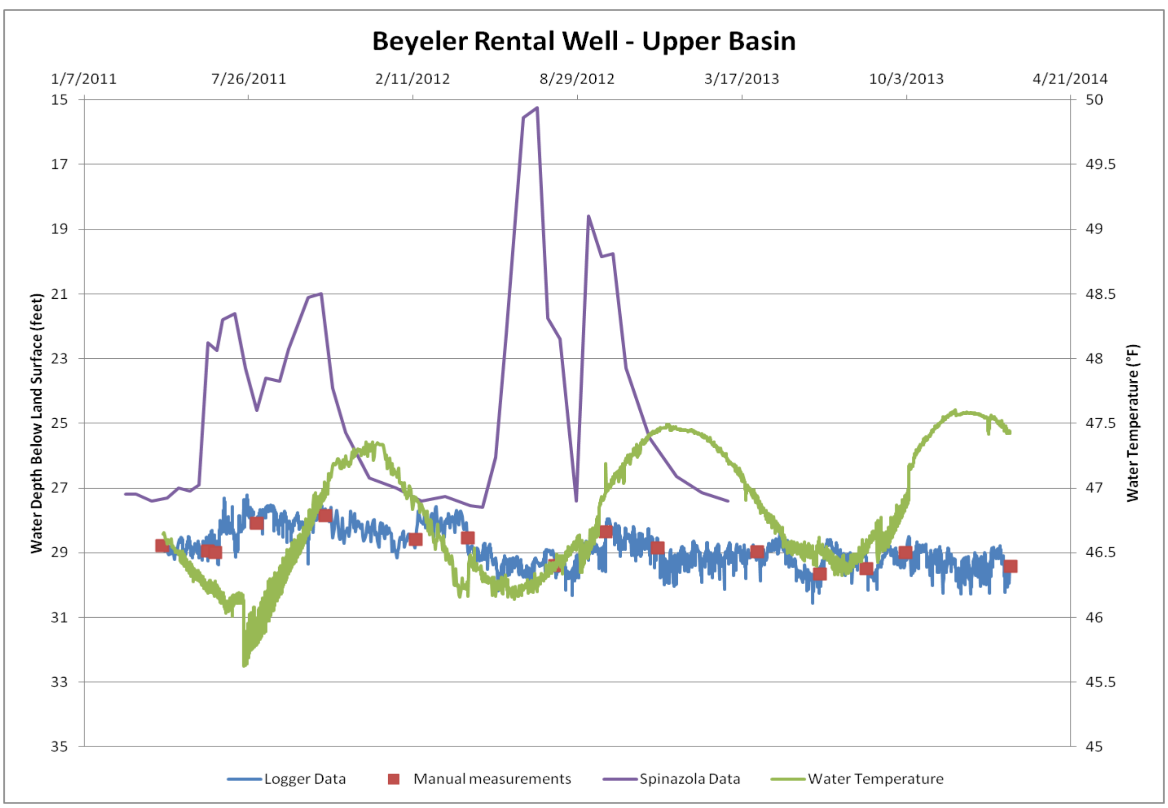


Figure A8. Beyeler Rental Well Trends

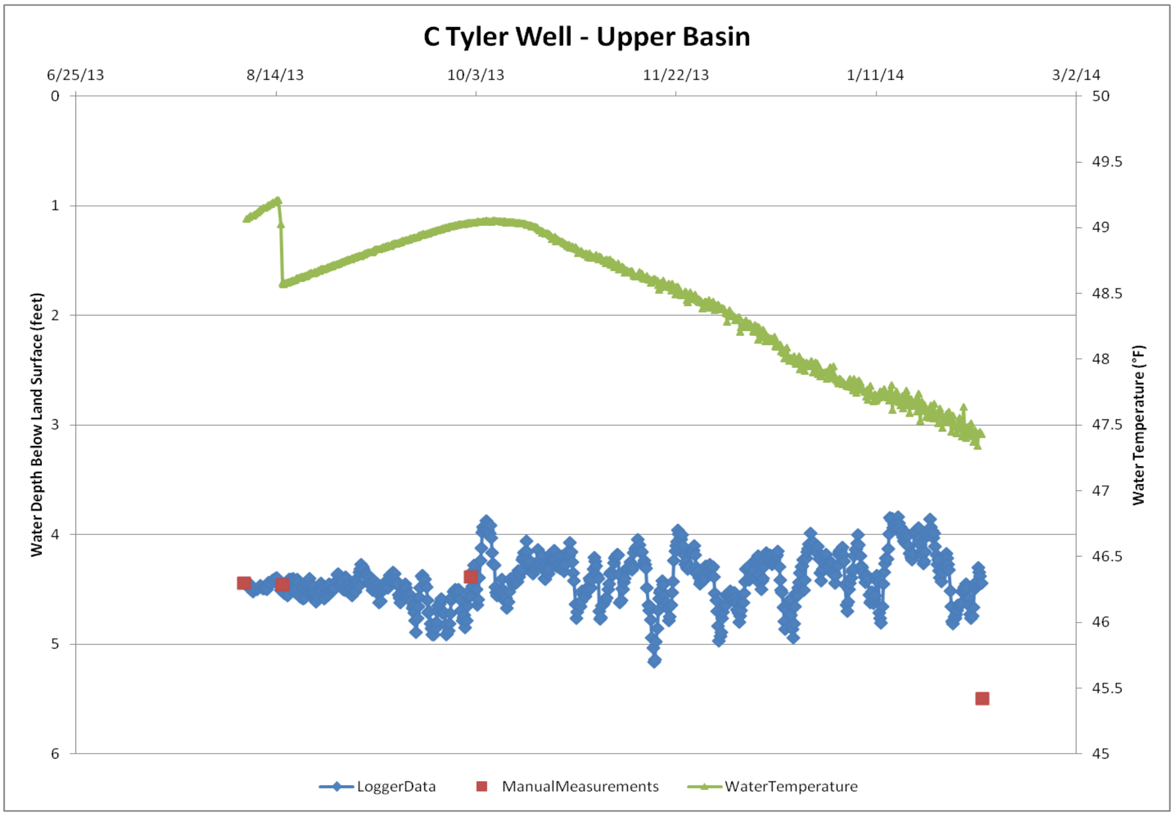


Figure A9. C Tyler Well Trends

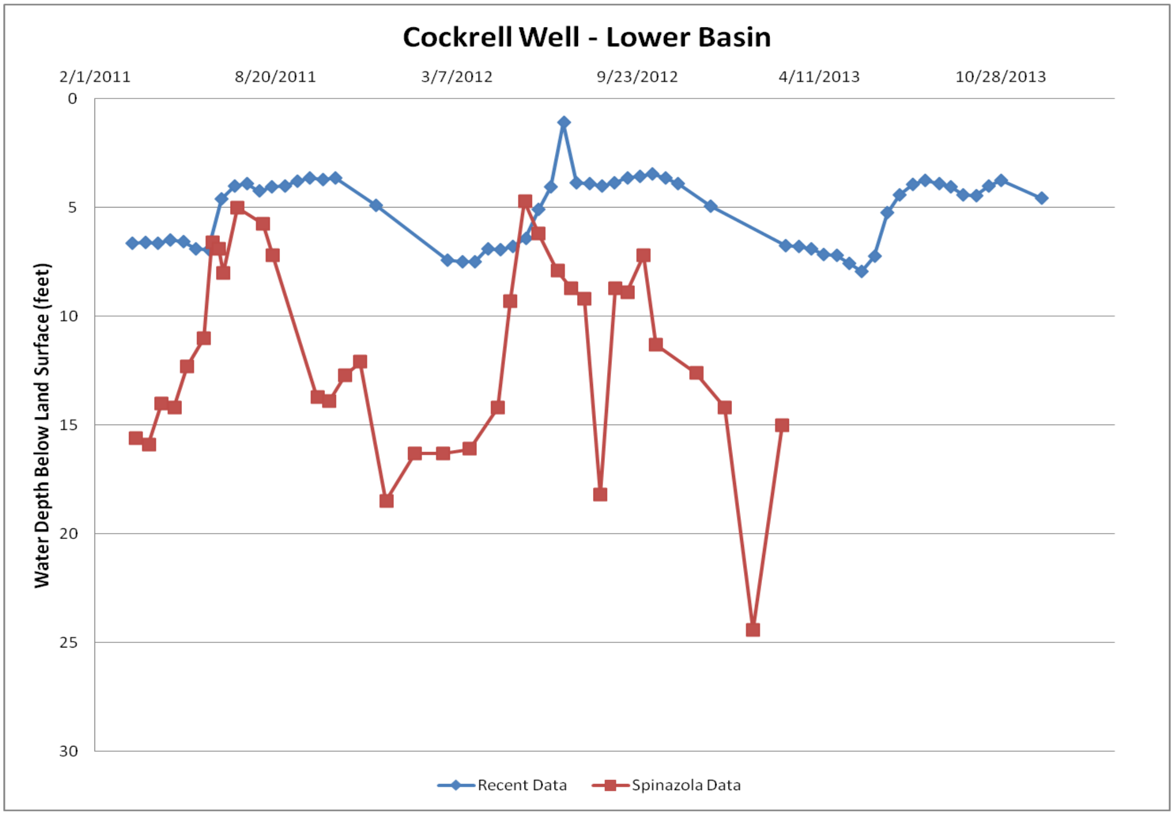


Figure A10. Cockrell Well Trends

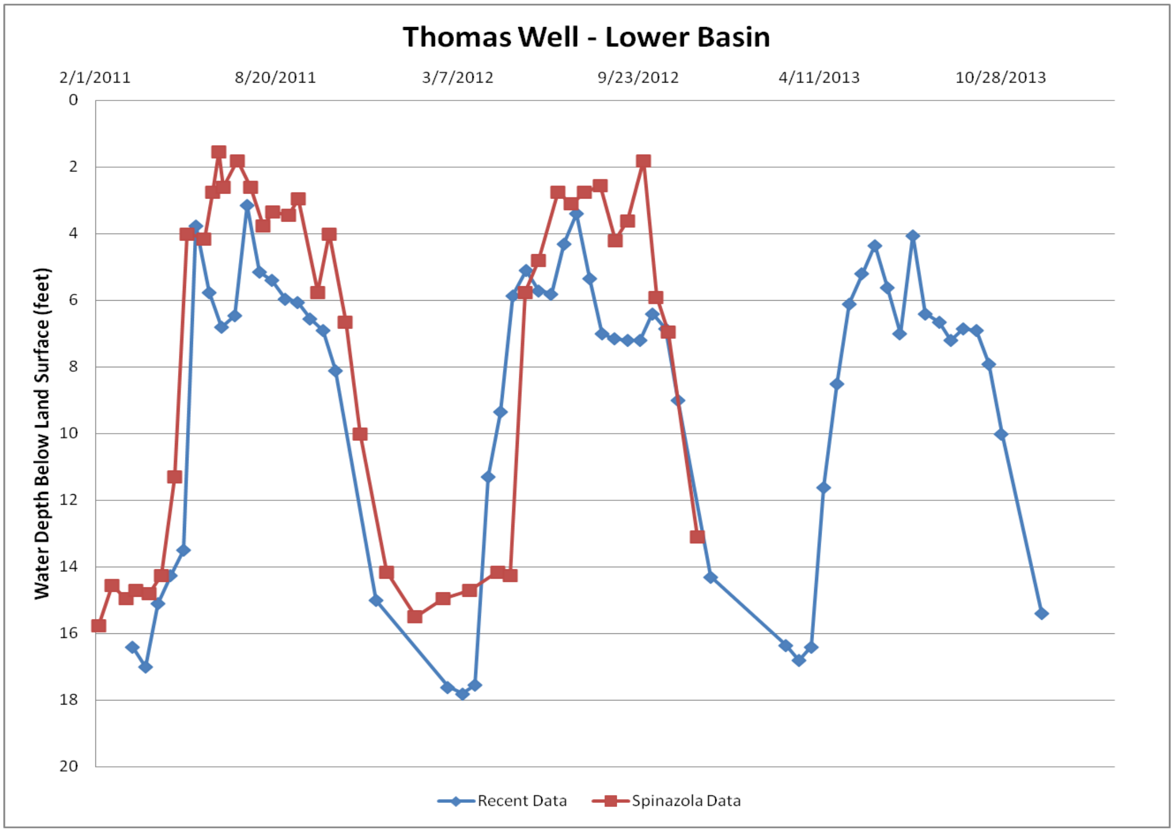


Figure A11. Thomas Well Trends

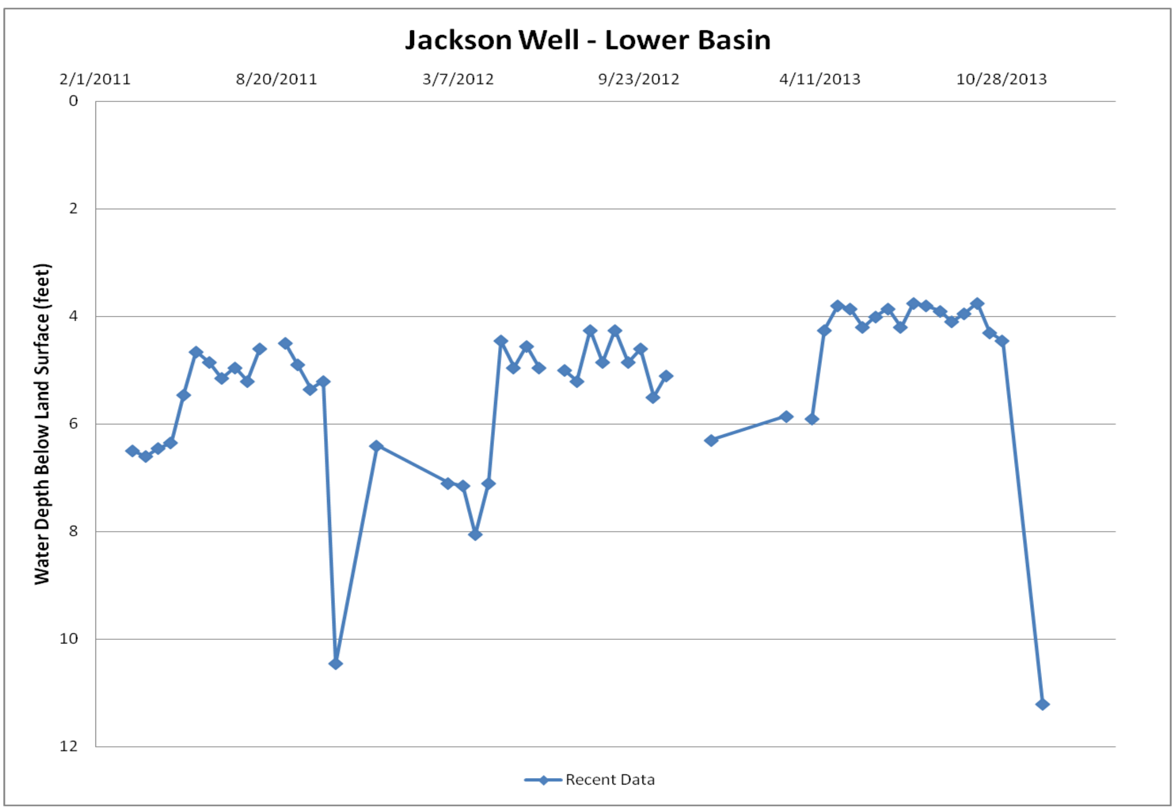


Figure A12. Jackson Well Trends

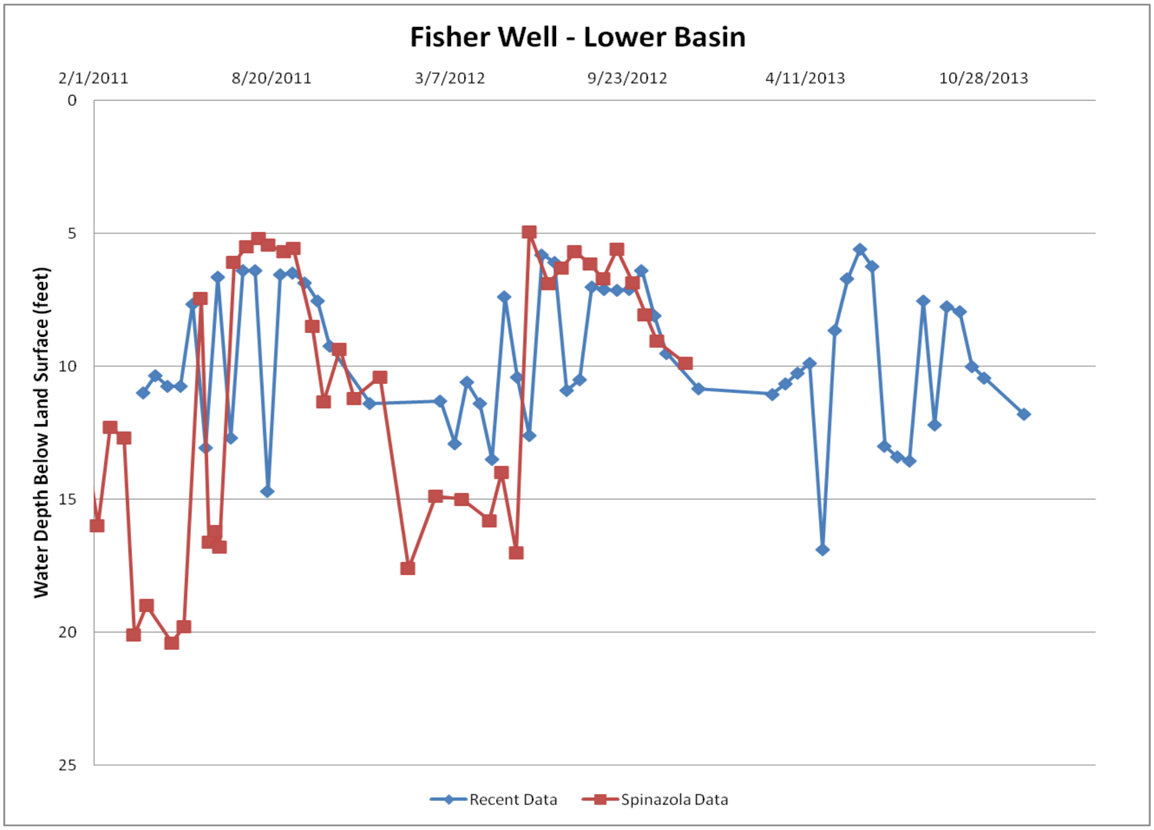


Figure A13. Fisher Well Trends

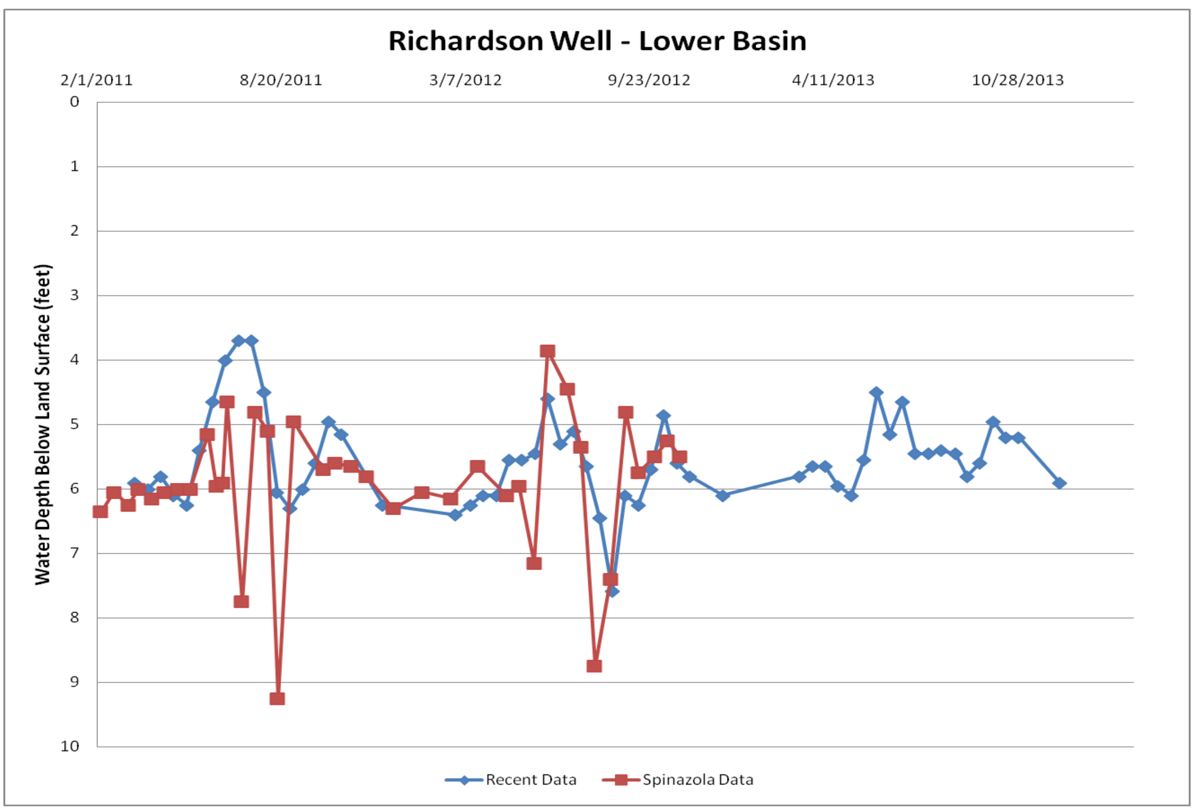


Figure A14. Richardson Well Trends

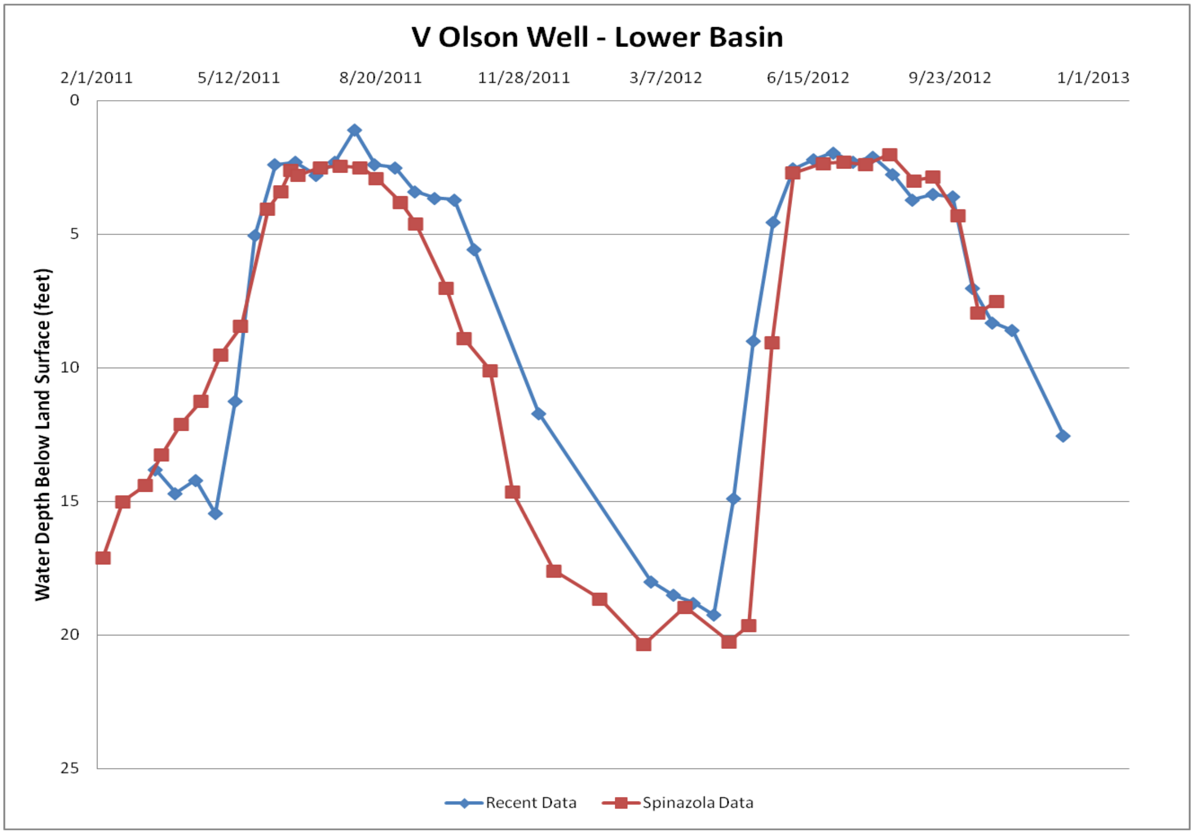


Figure A15. V Olson Well Trends

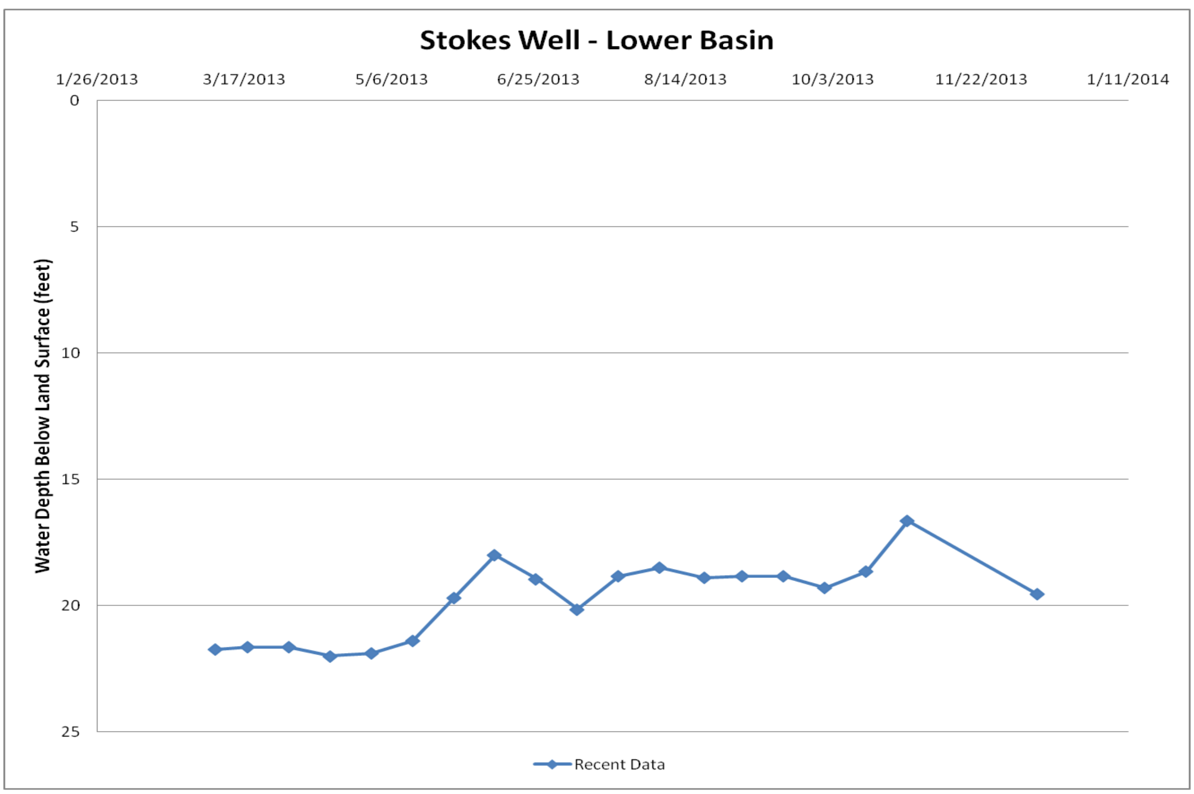


Figure A16. Stokes Well Trends

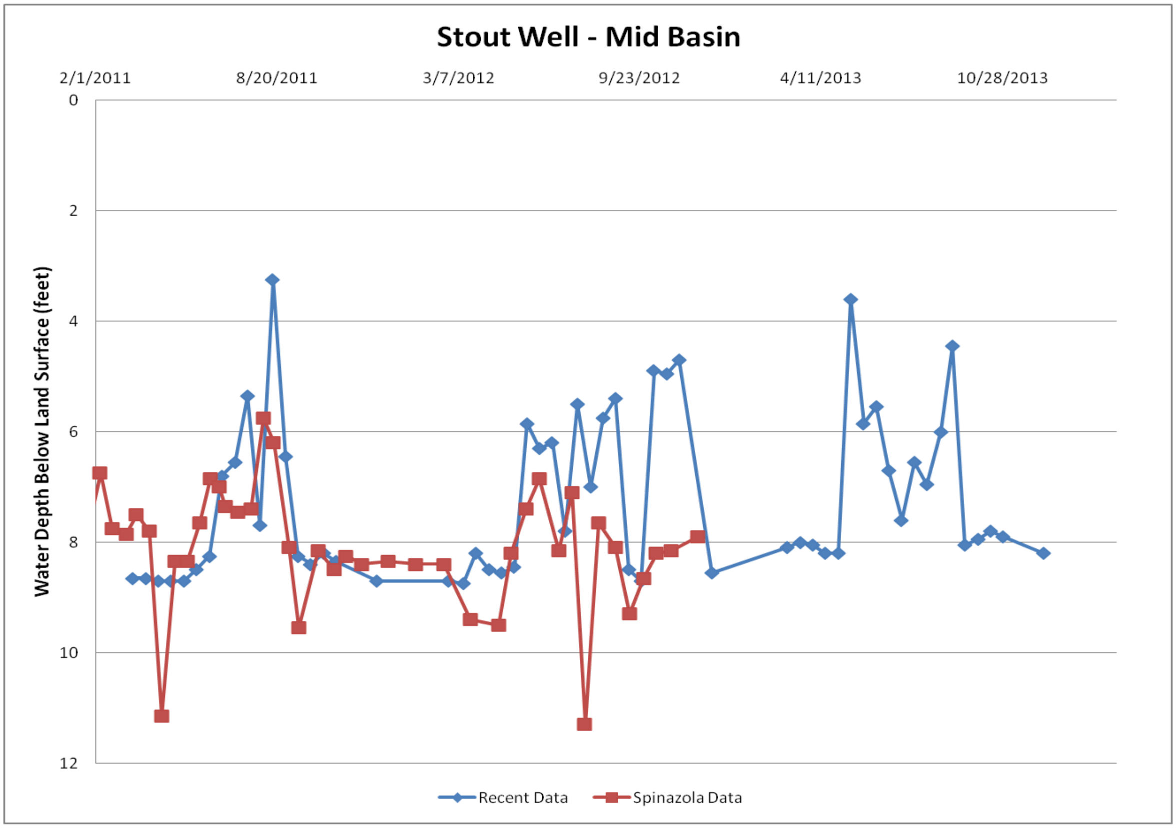


Figure A17. Stout Well Trends

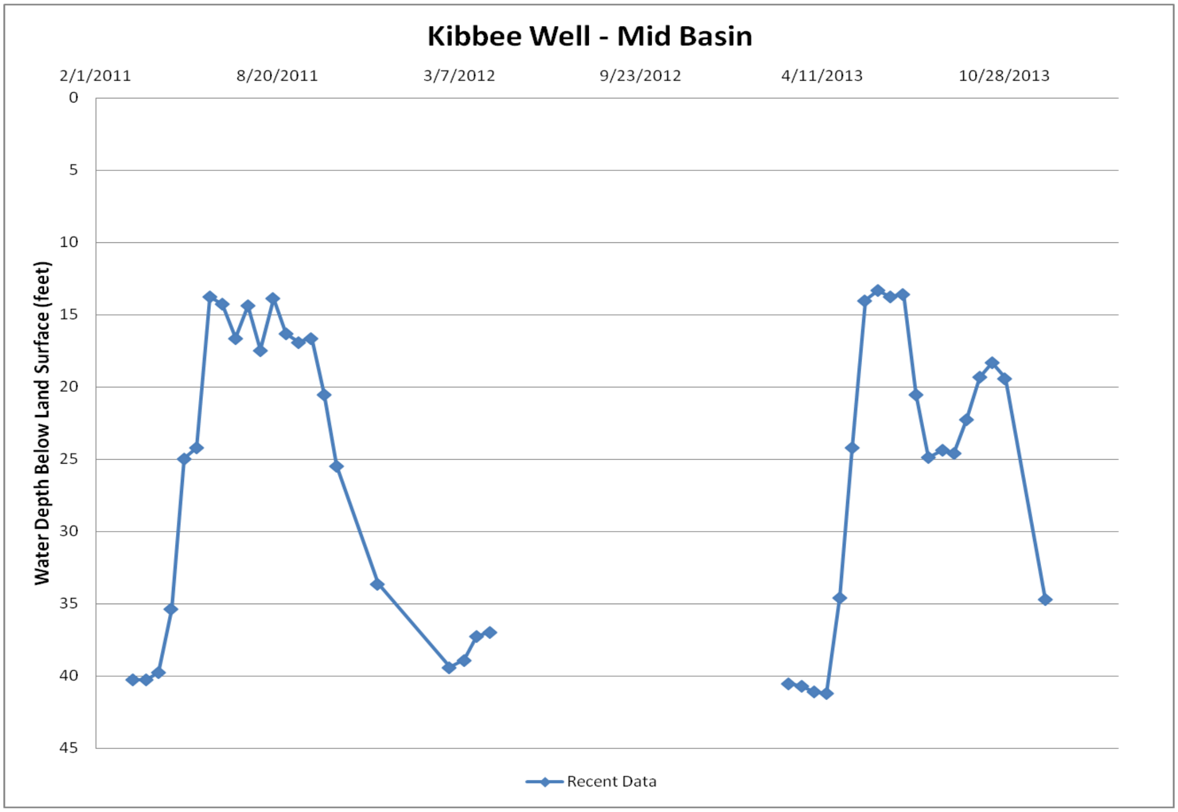
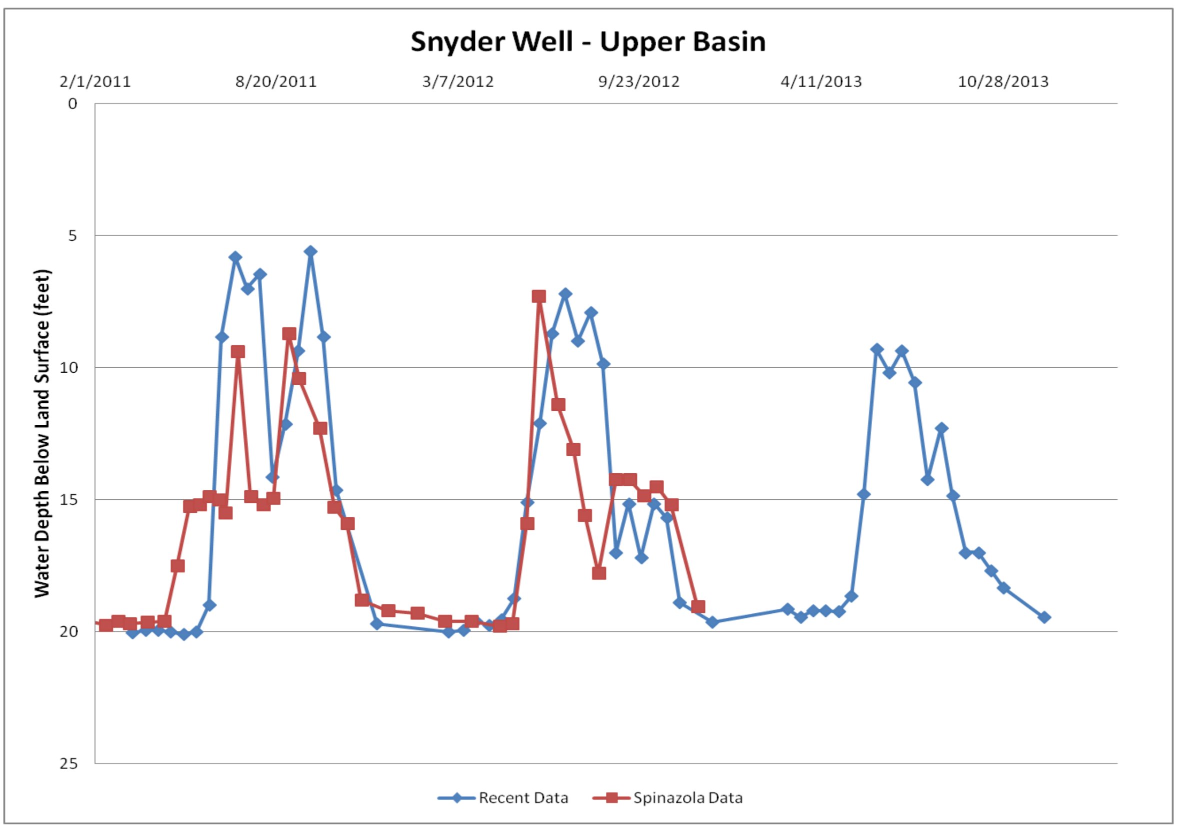


Figure A18. Kibbee Well Trends



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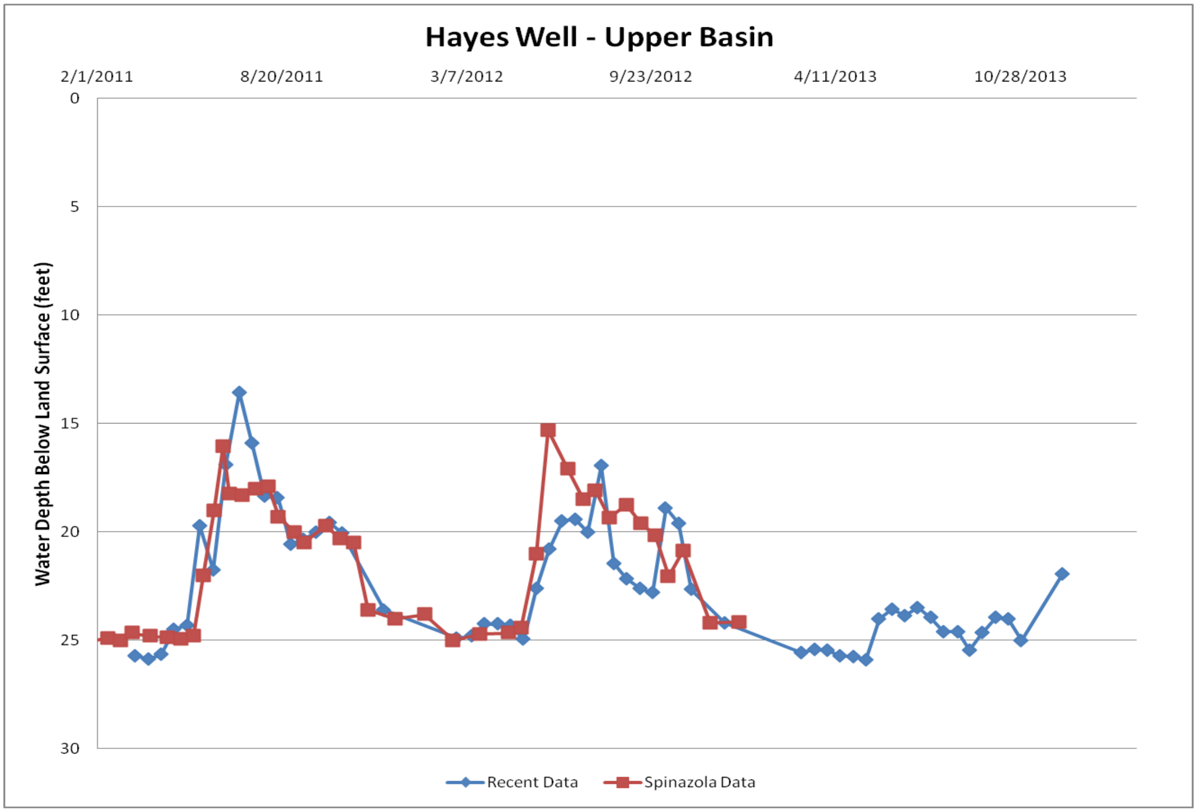

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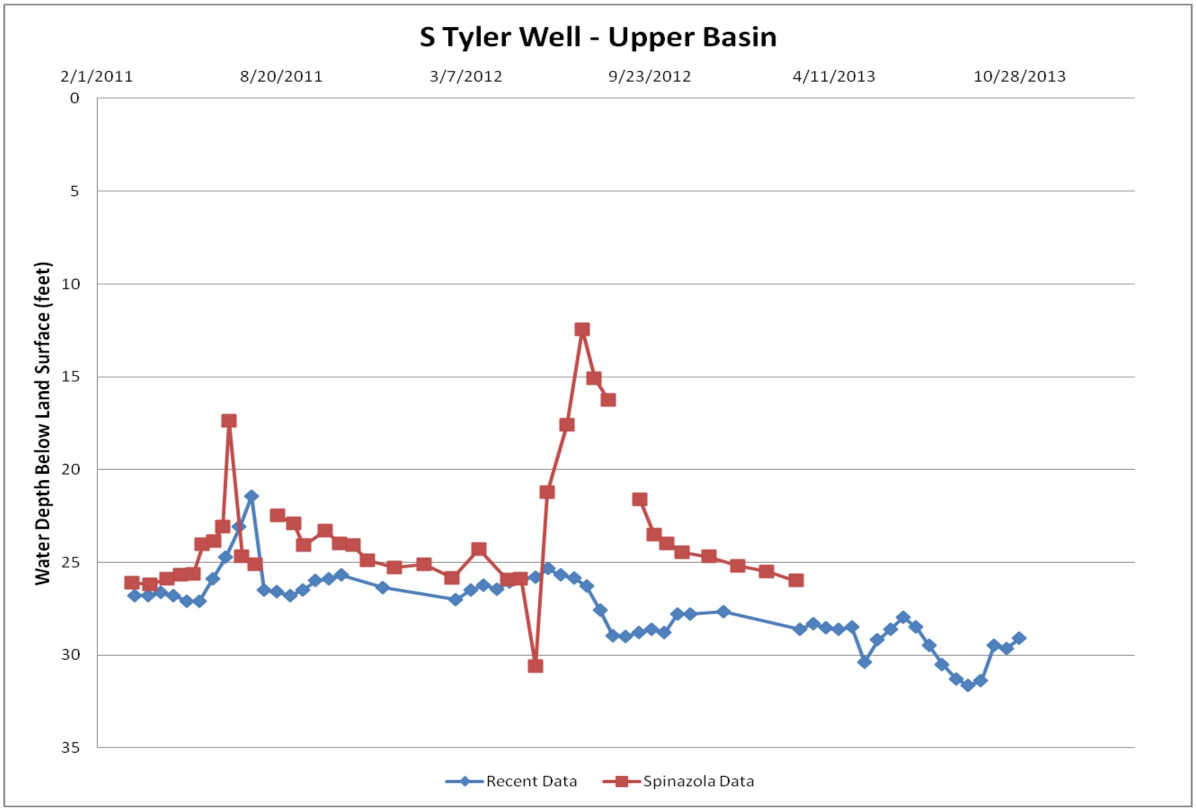

Figure A21. S Tyler Well Trends

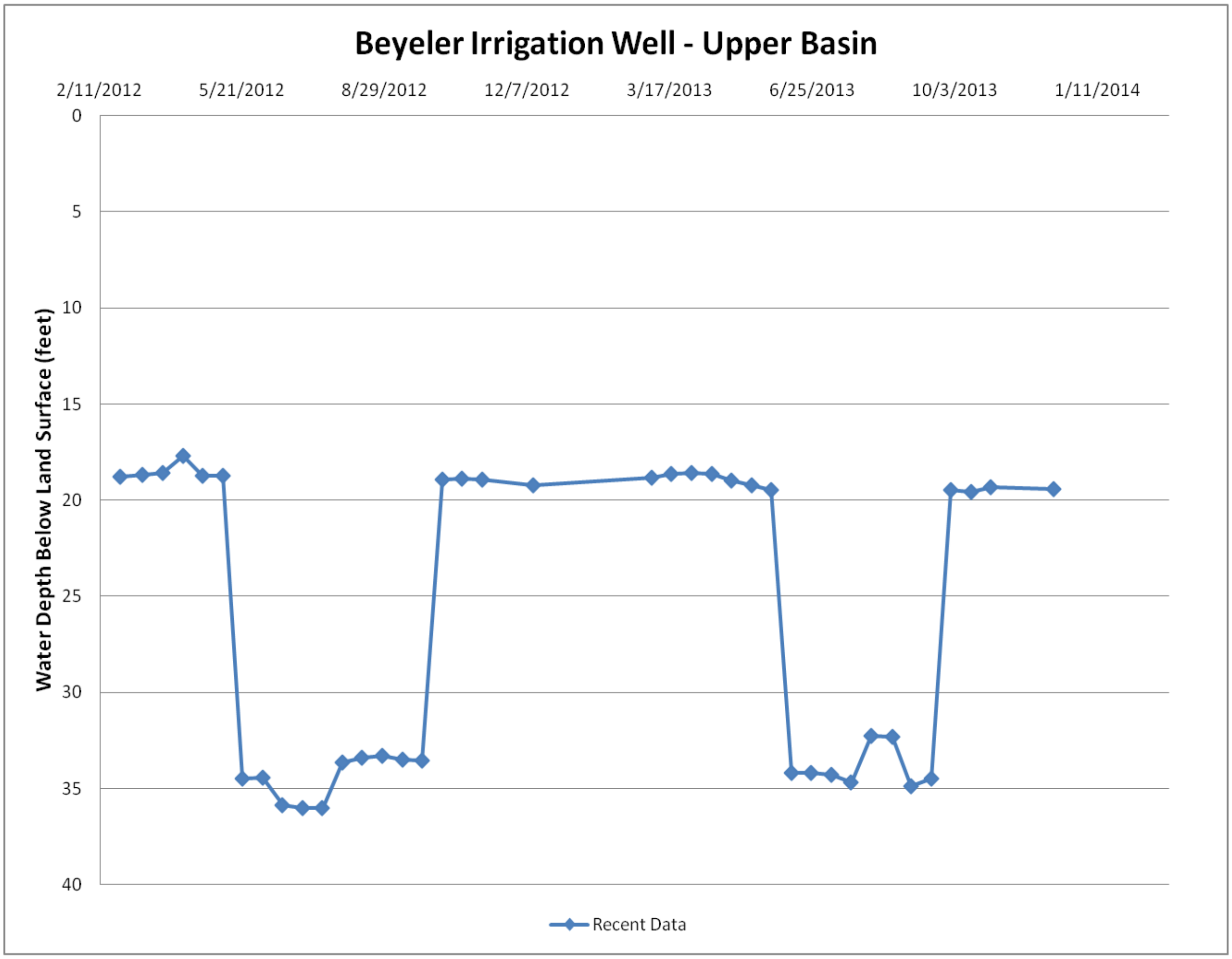

Figure A22. Beyeler Irrigation Well Trends

Appendix B: Stream Gage Data

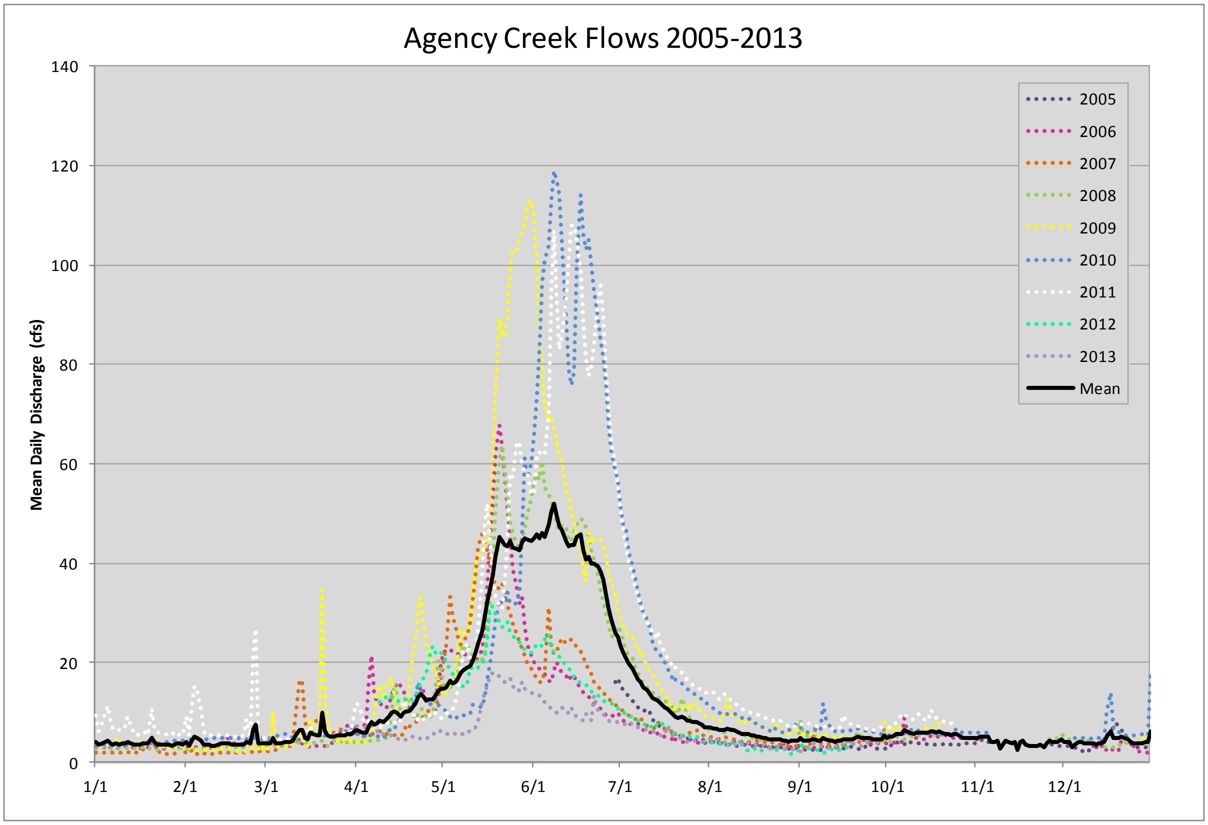

Figure B1. Agency Creek Flows 2005 - 2013

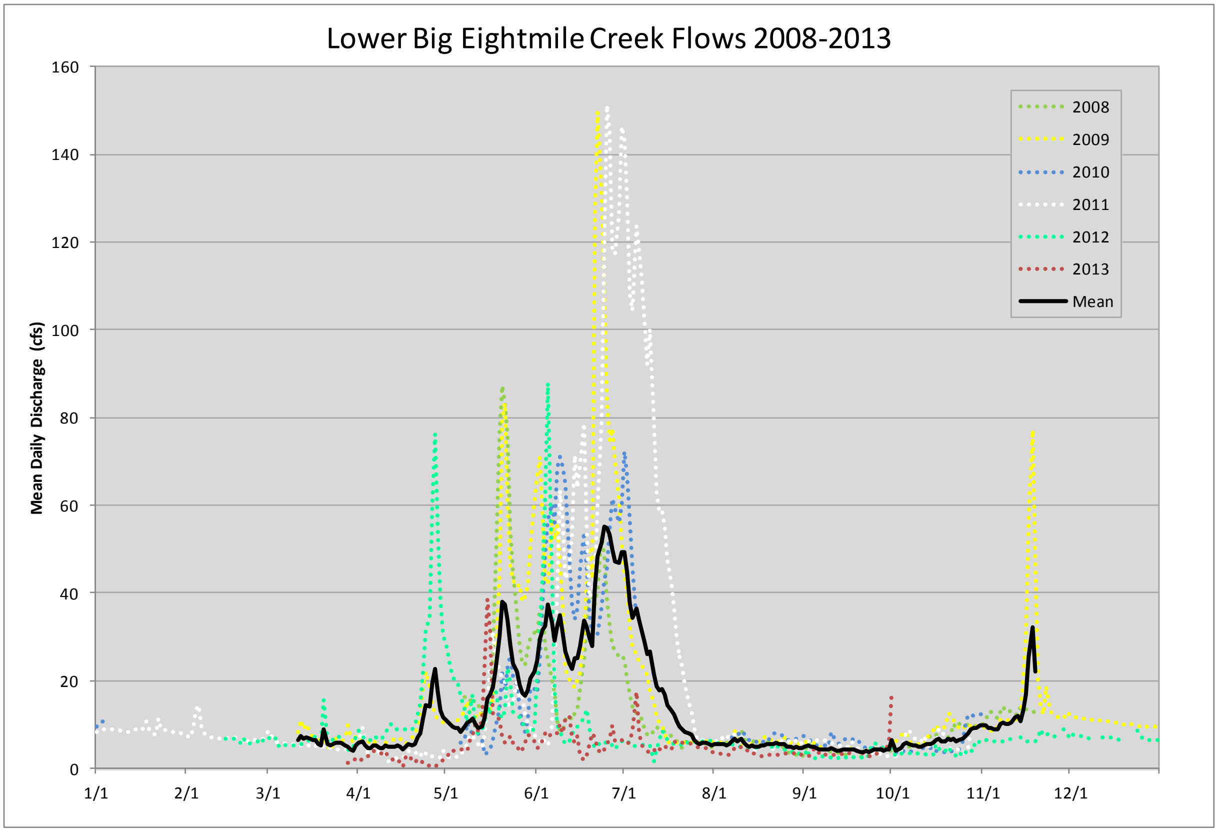

Figure B2. Lower Big Eightmile Creek Flows 2008 - 2013

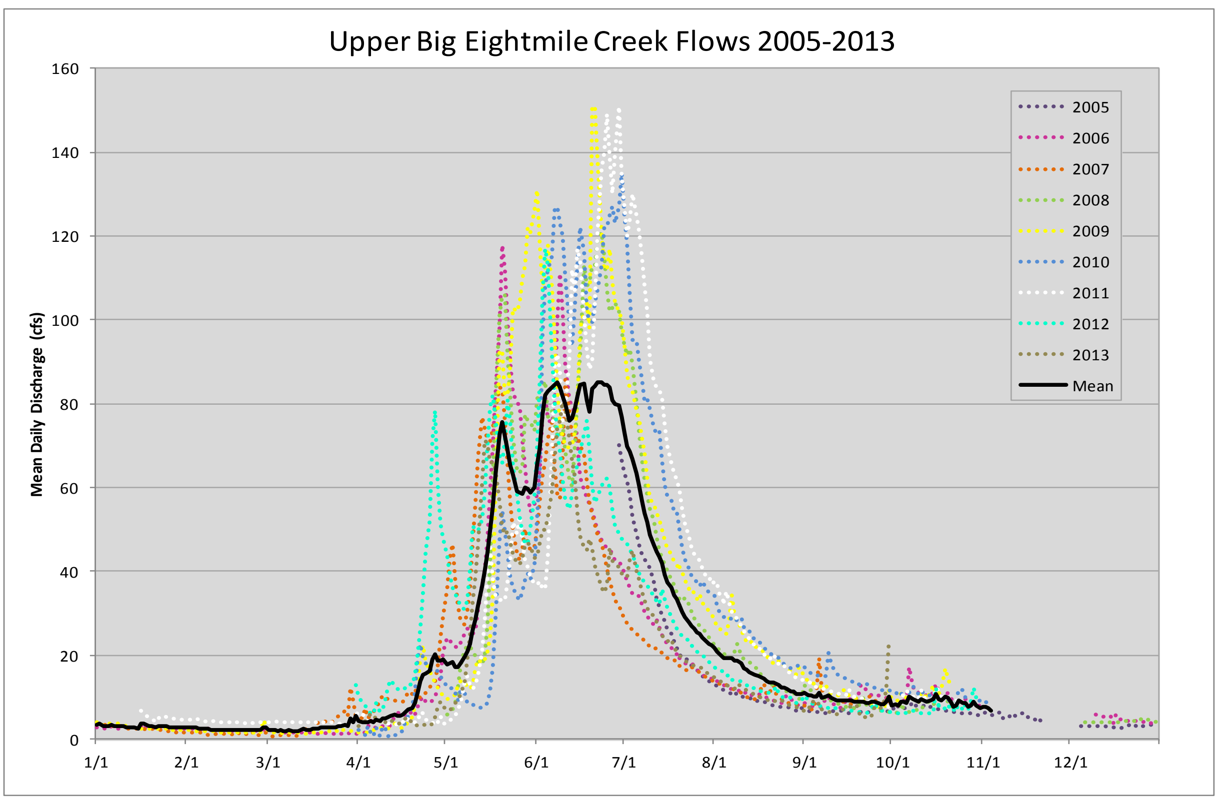

Figure B3. Upper Big Eightmile Creek Flows 2005 - 2013

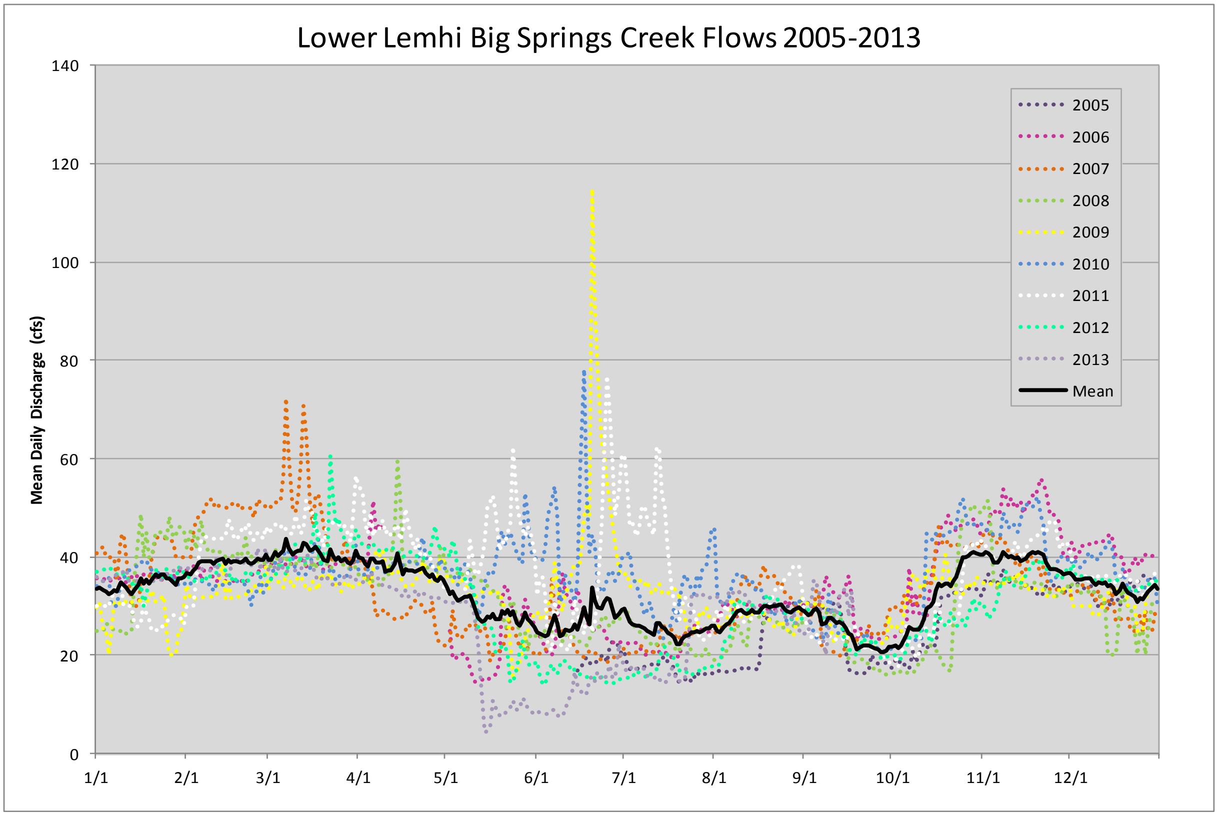

Figure B4. Lower Lemhi Big Springs Creek Flows 2005 - 2013

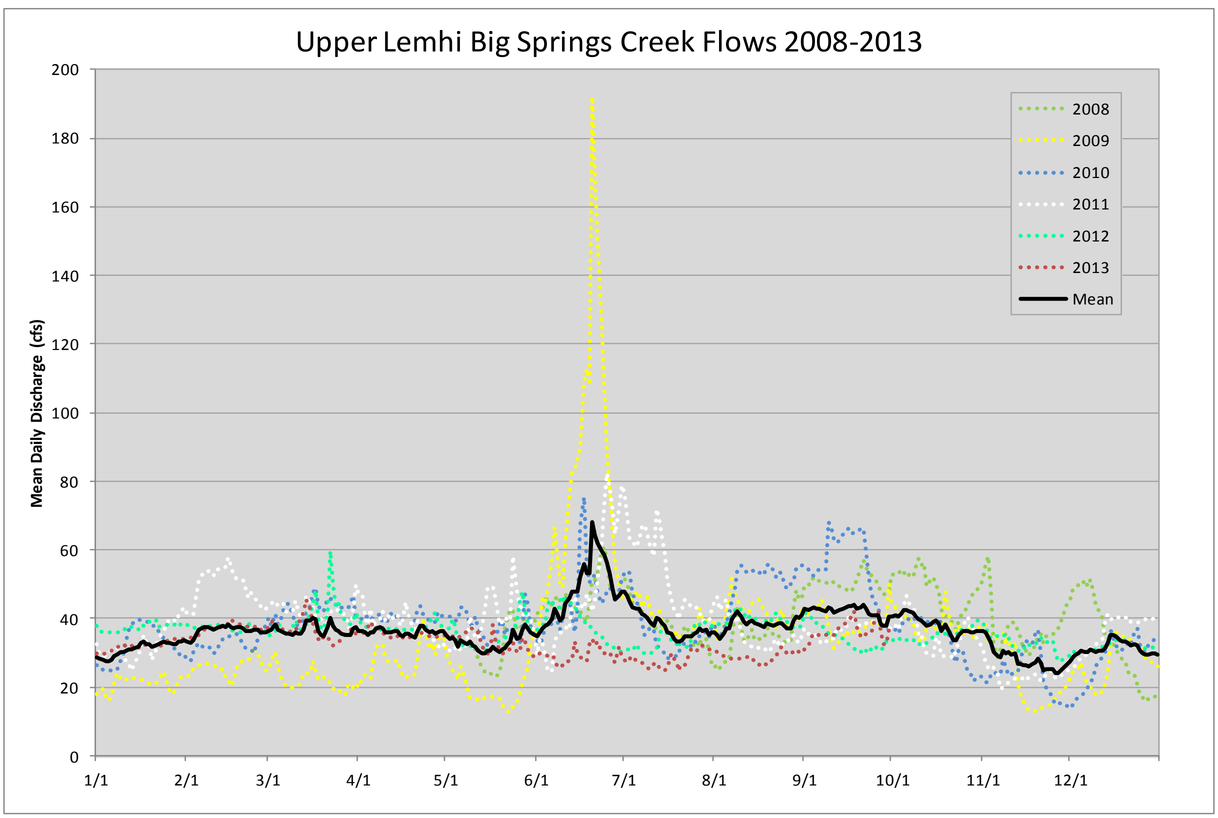

Figure B5. Upper Lemhi Big Springs Creek Flows 2008 - 2013

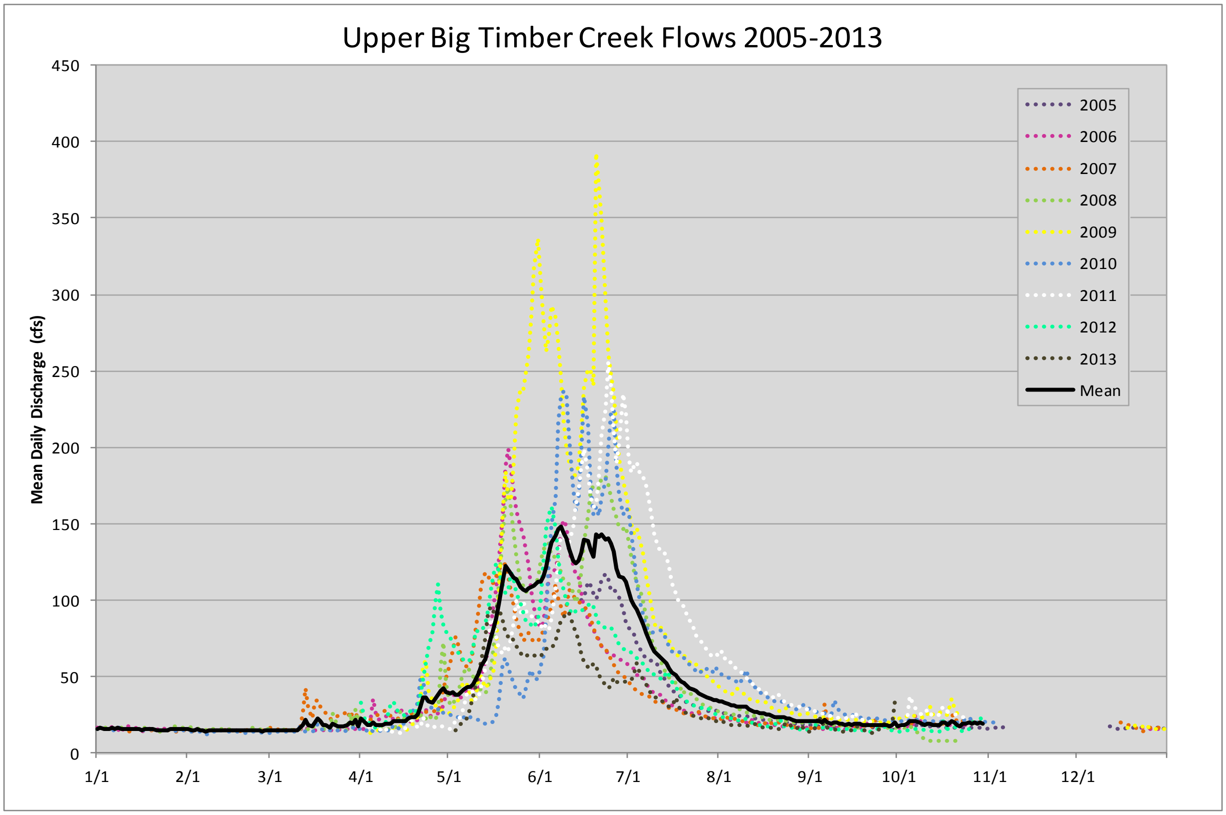

Figure B6. Upper Big Timber Creek Flows 2006 - 2013

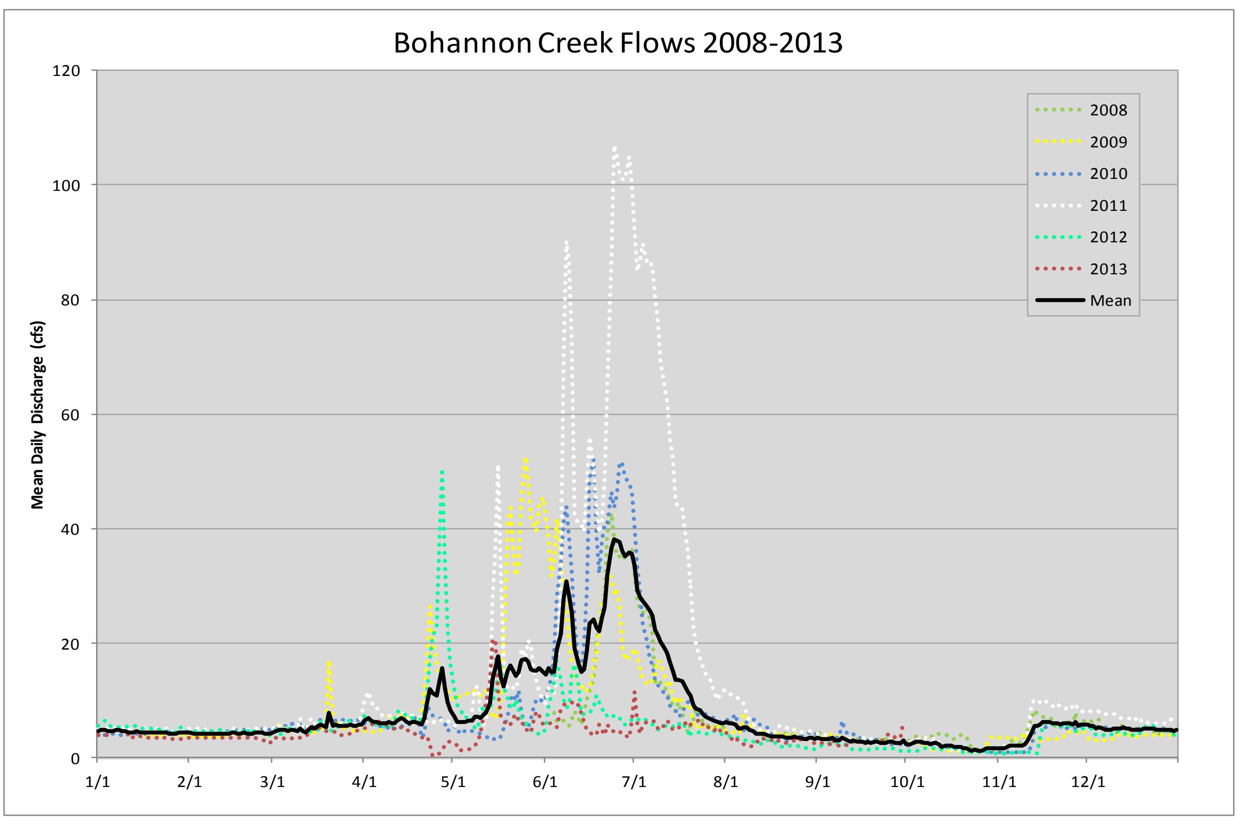

Figure B7. Bohannon Creek Flows 2008 - 2013

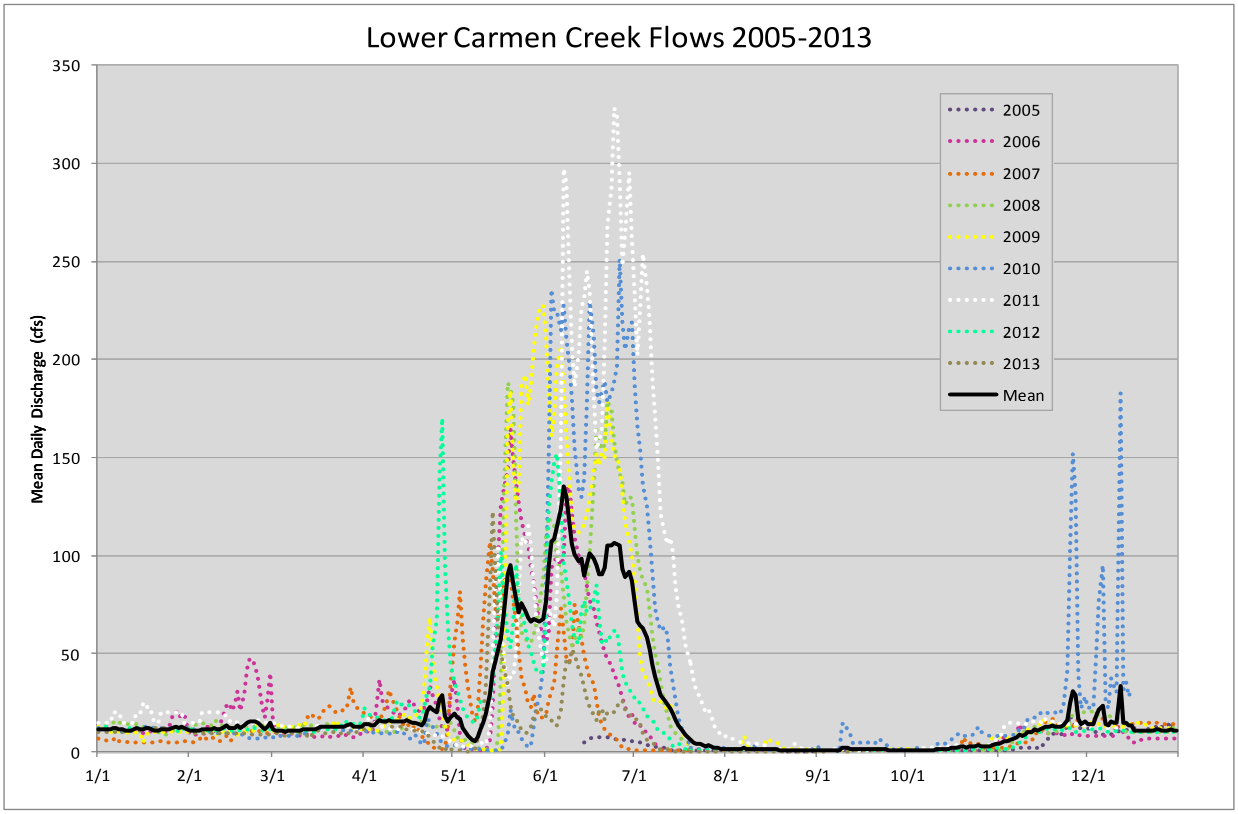

Figure B8. Lower Carmen Creek Flows 2005 - 2013

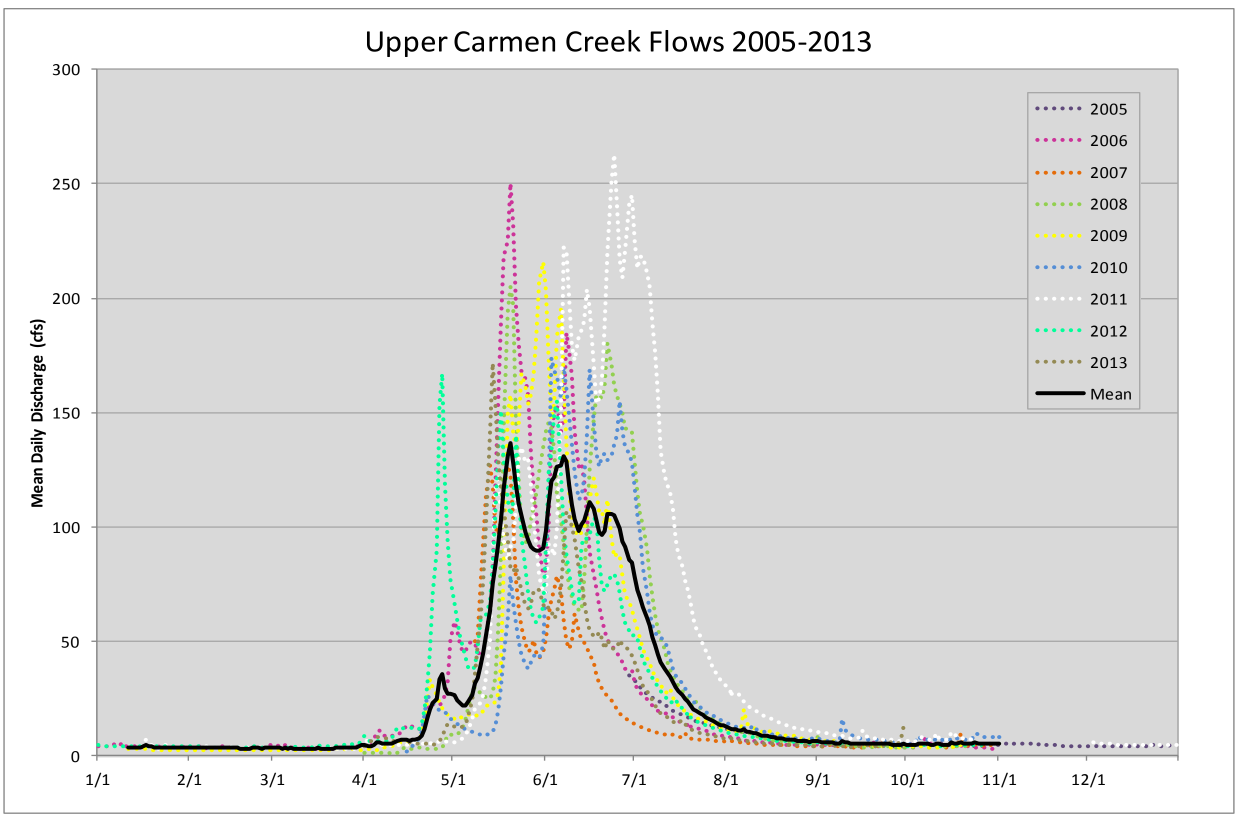

Figure B9. Upper Carmen Creek Flows 2005 - 2013

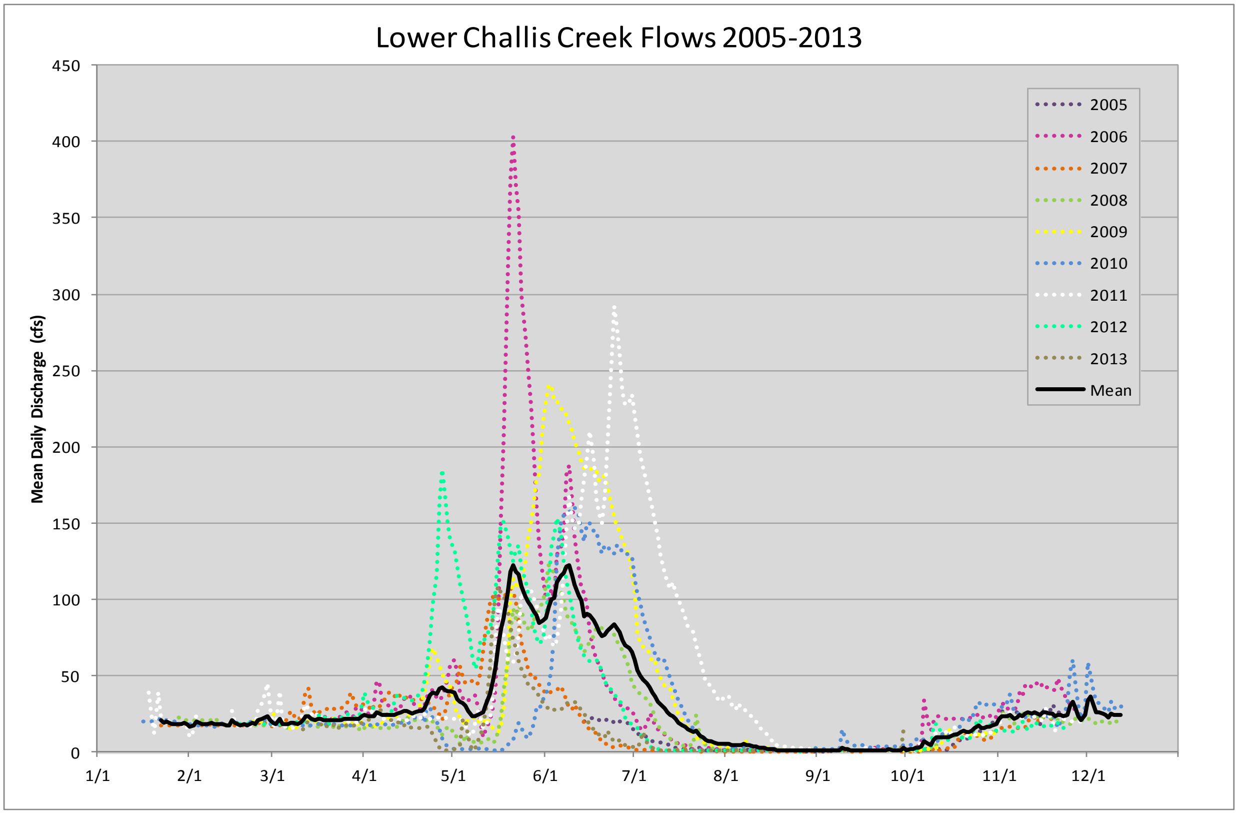

Figure B10. Lower Challis Creek Flows 2005 - 2013

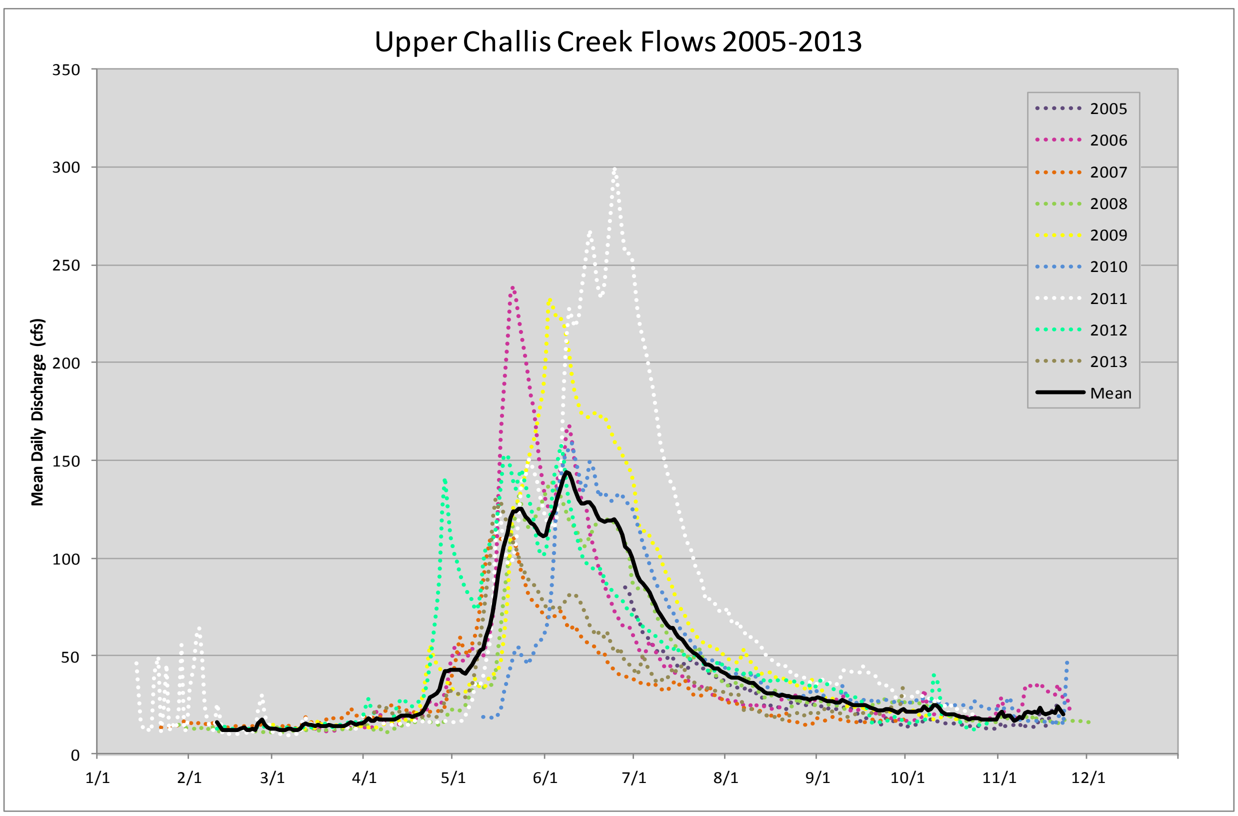

Figure B11. Upper Challis Creek Flows 2005 - 2013

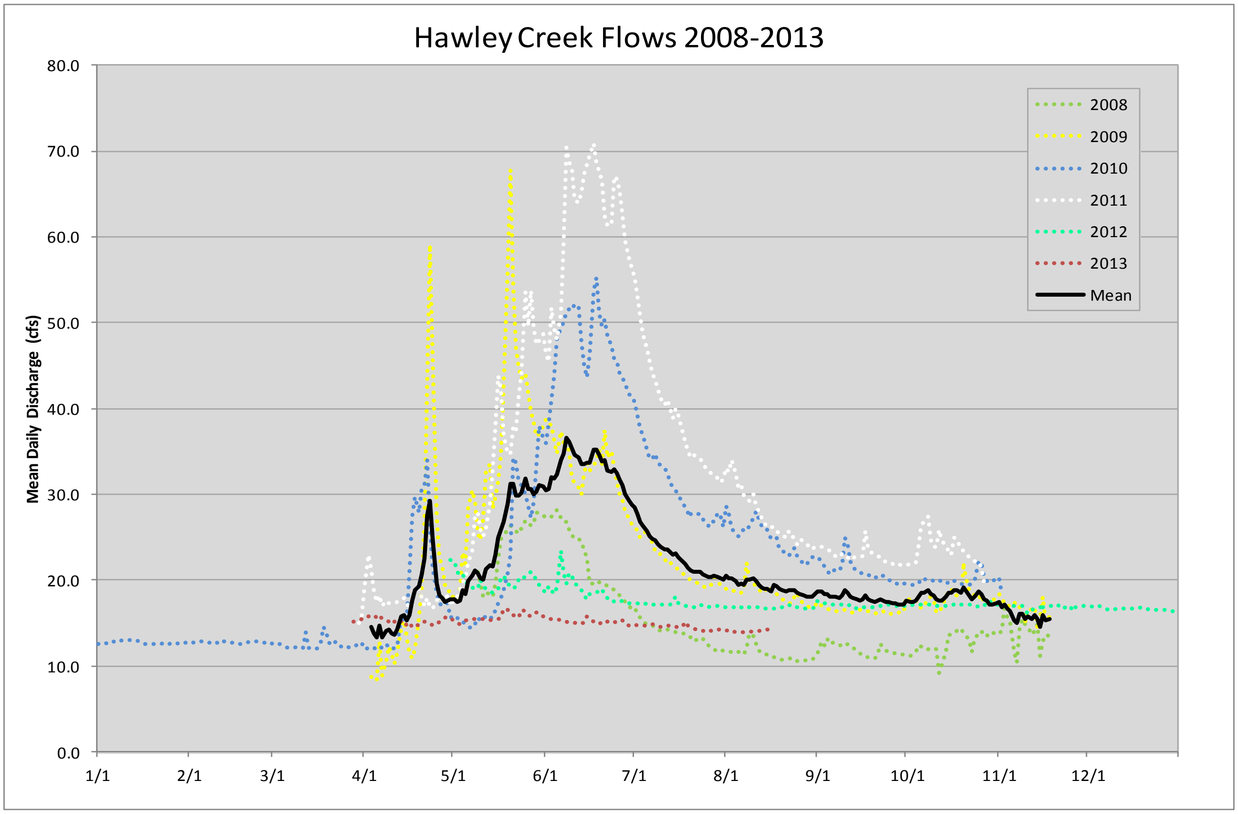

Figure B12. Hawley Creek Flows 2008 – 2013

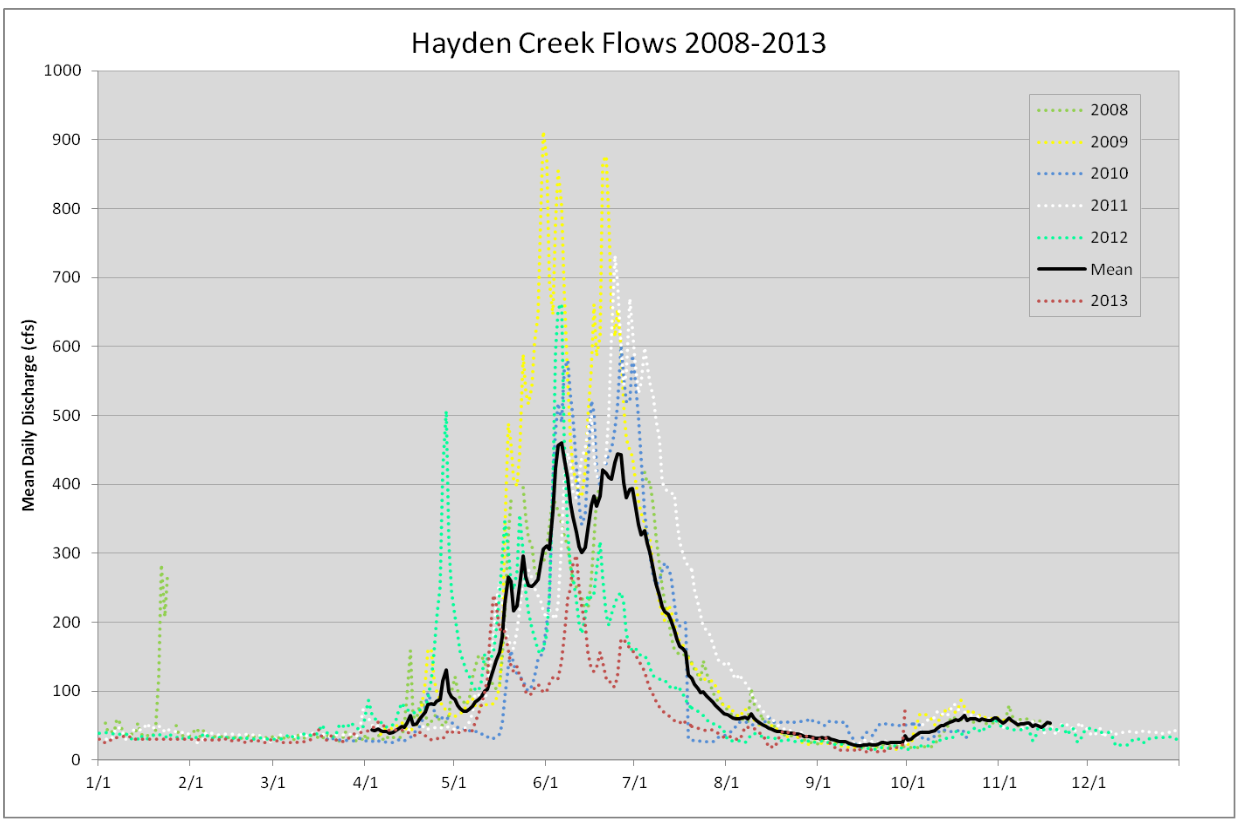

Figure B13. Hayden Creek Flows 2008 - 2013

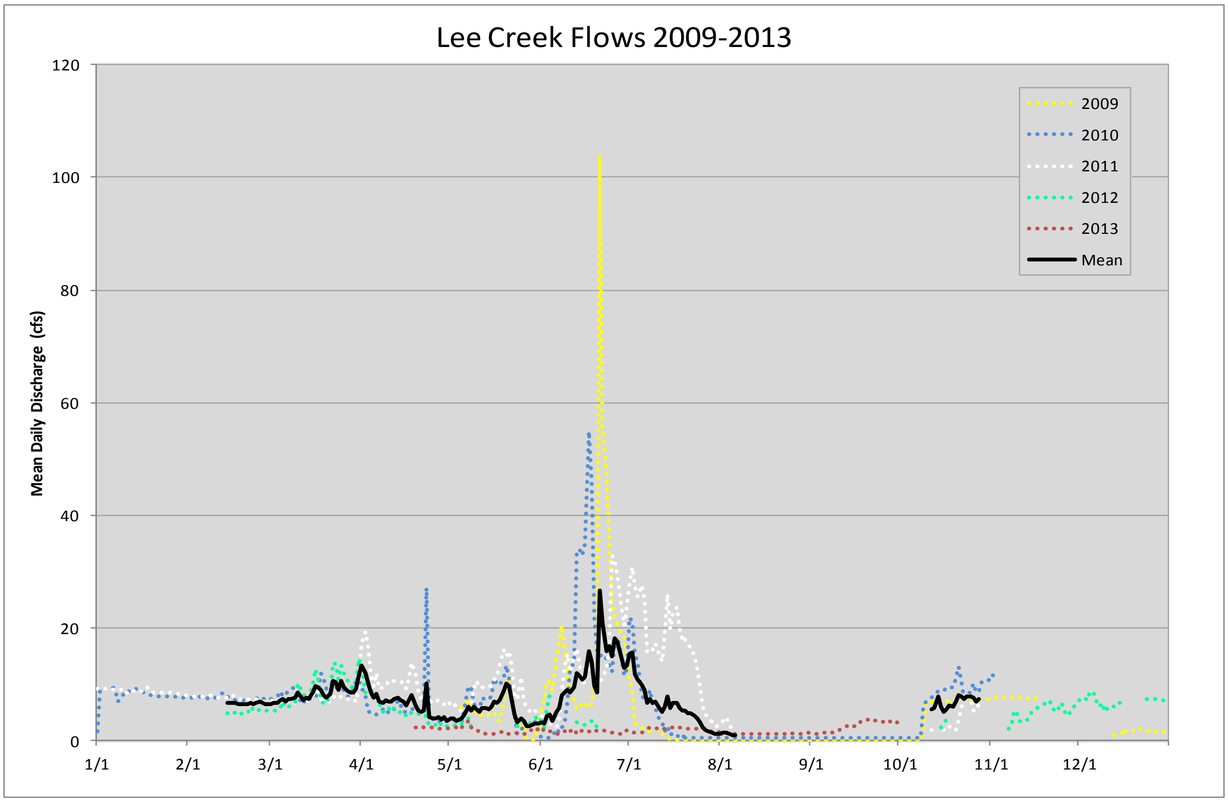

Figure B14. Lee Creek Flows 2009 - 2013

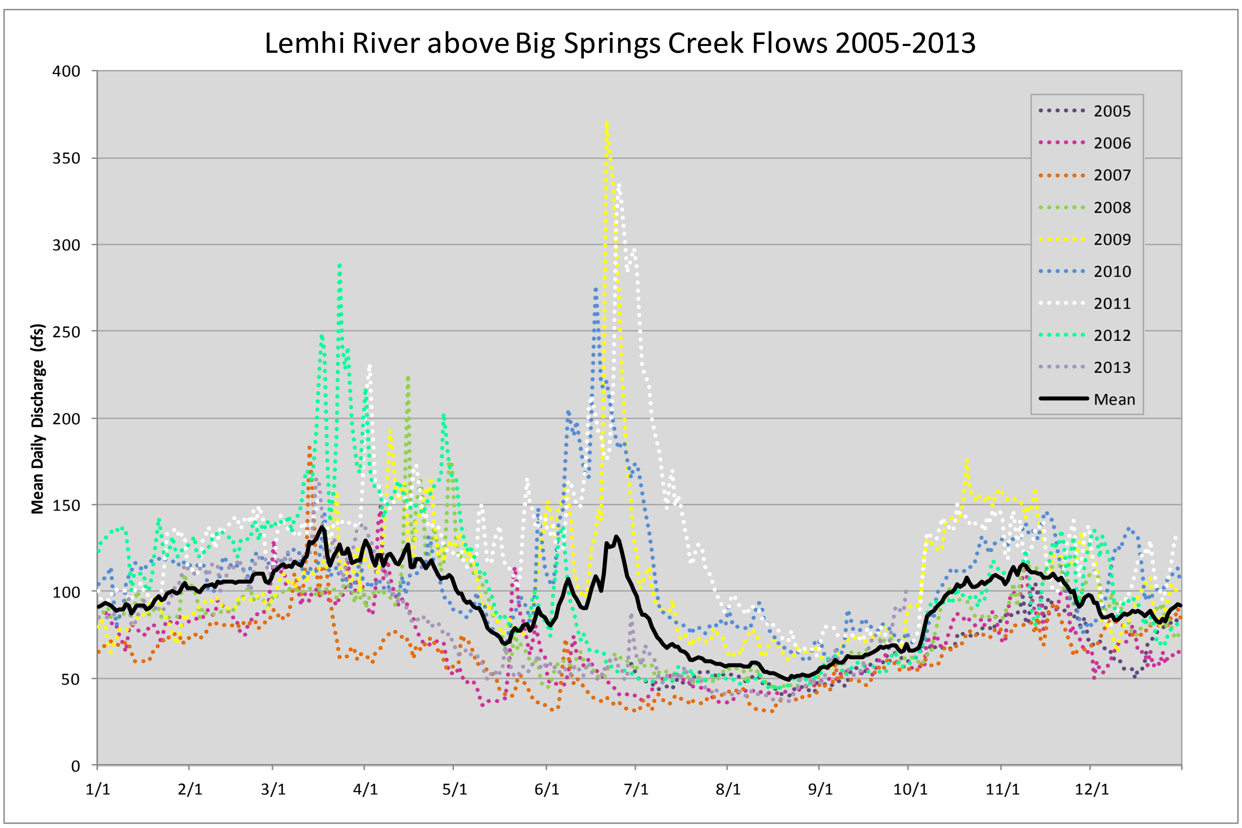

Figure B15. Lemhi River above Big Springs Creek Flows 2005 - 2013

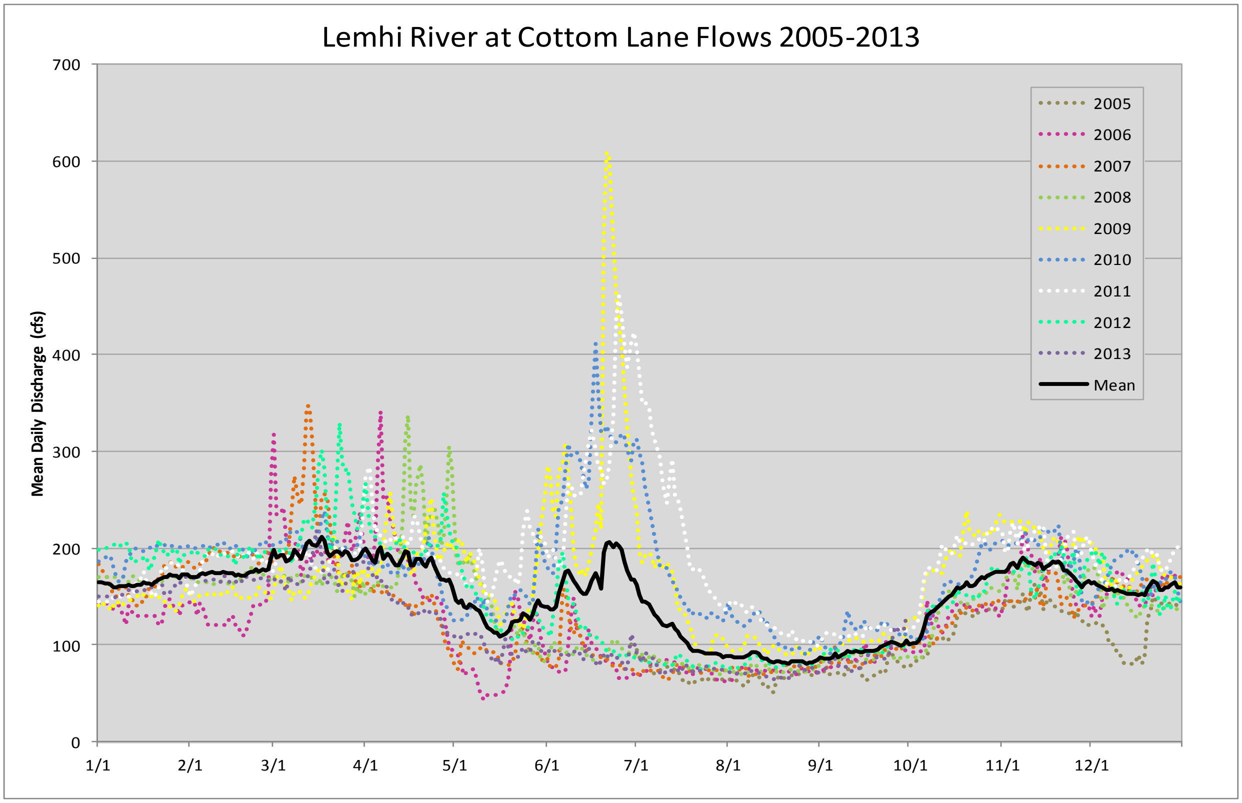

Figure B16. Lemhi River at Cottom Lane Flows 2005 - 2013

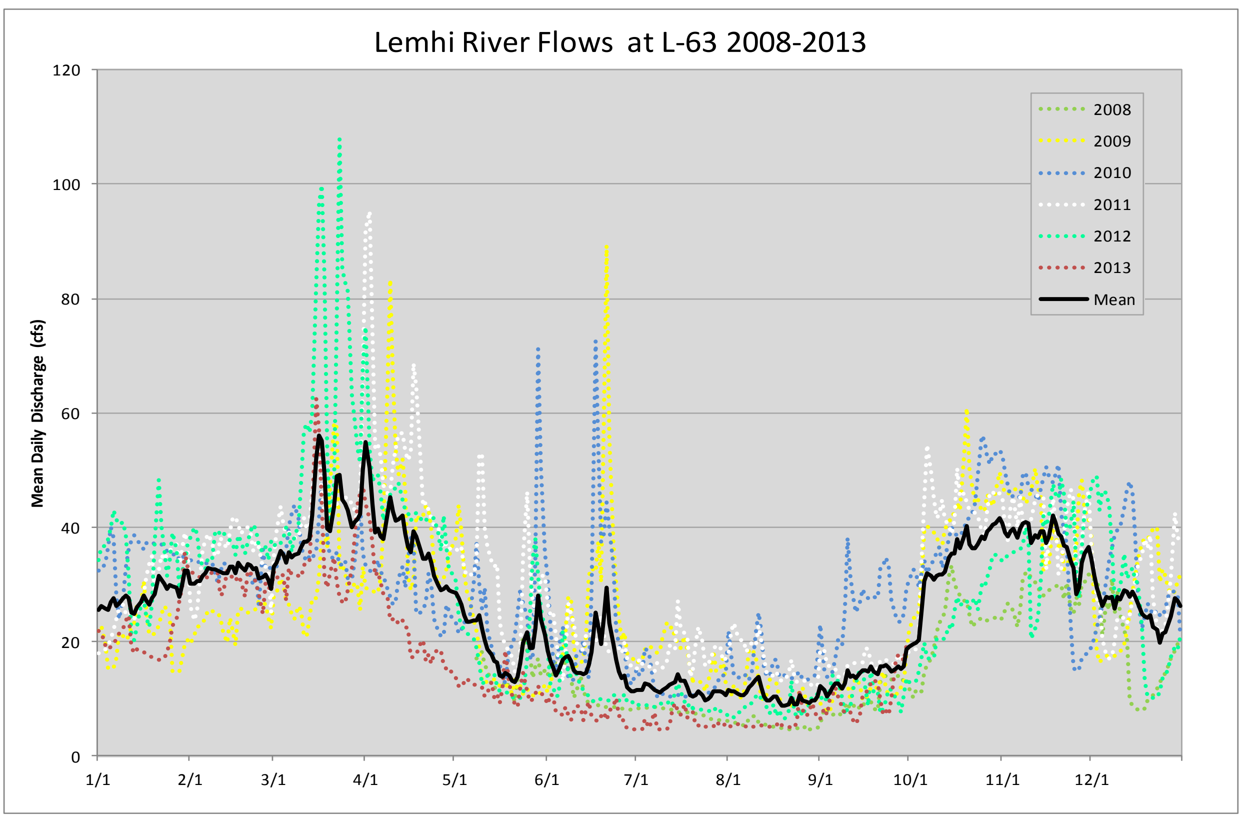

Figure B17. Lemhi River at L-63 Flows 2008 – 2013

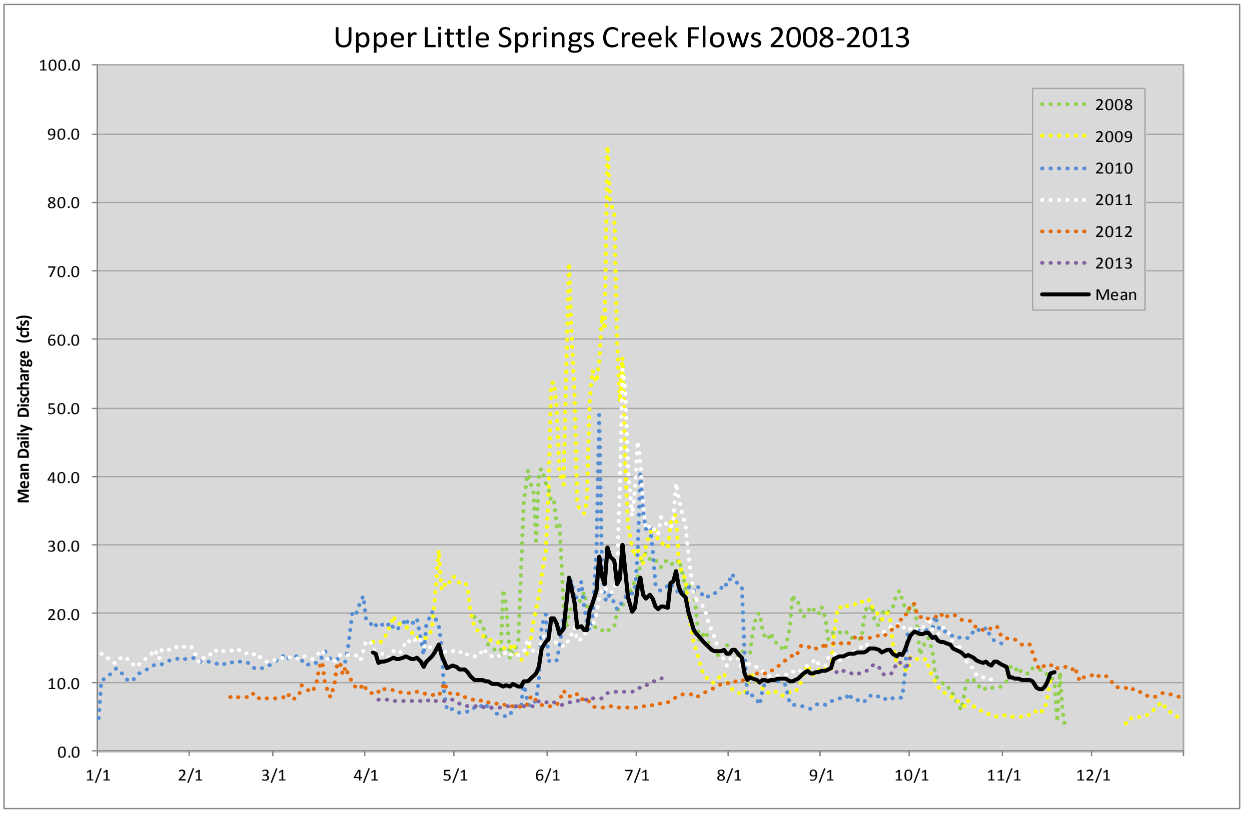

Figure B18. Upper Little Springs Creek Flows 2008 - 2013

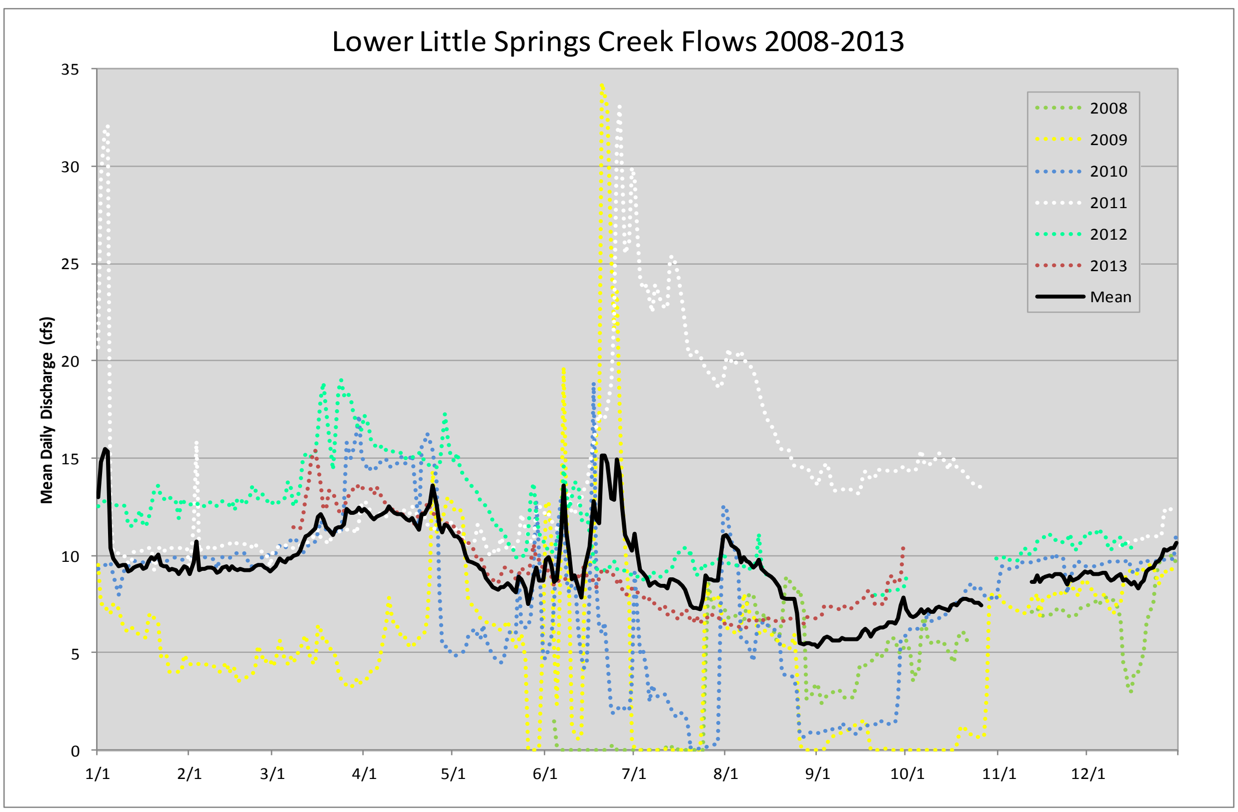

Figure B19. Lower Little Springs Creek Flows 2008 - 2013

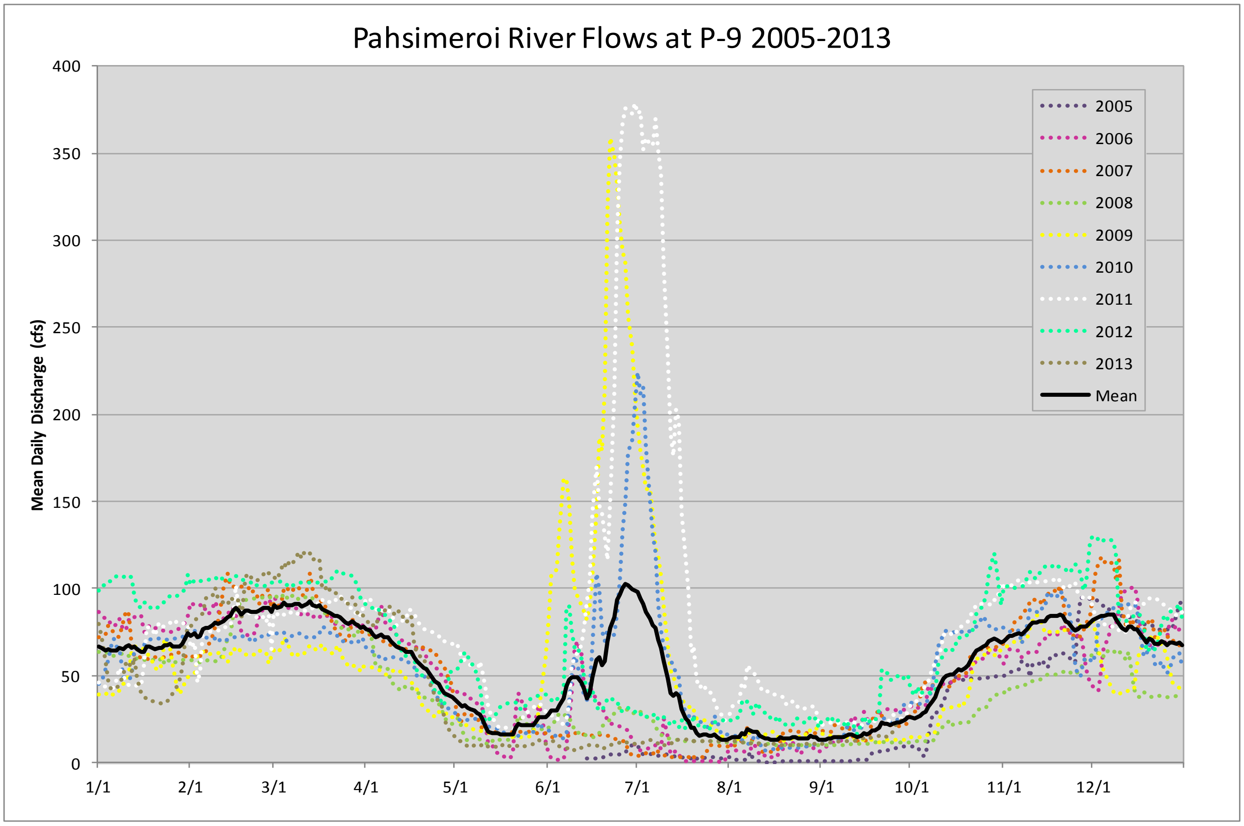

Figure B20. Pahsimeroi River at P-9 Flows 2005 - 2013

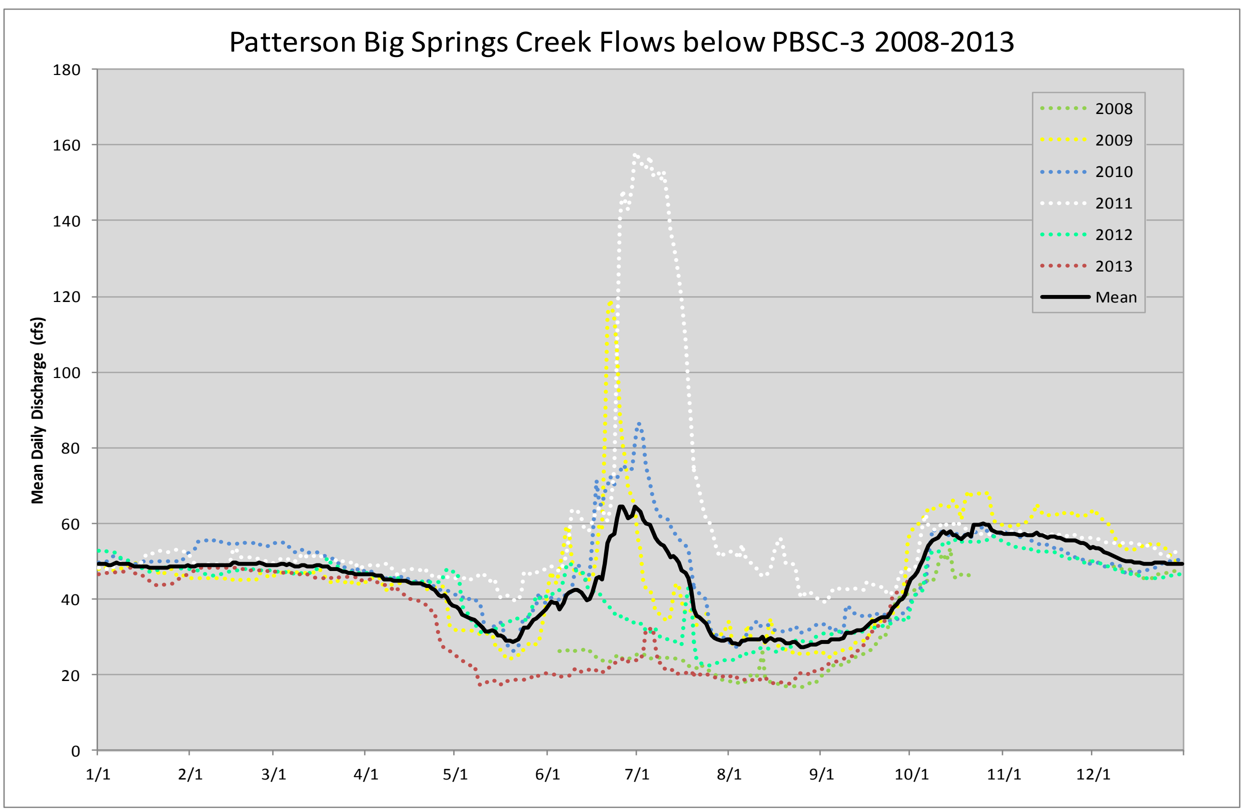

Figure B21. Patterson Big Springs Creek below PBSC-3 Flows 2008 - 2013

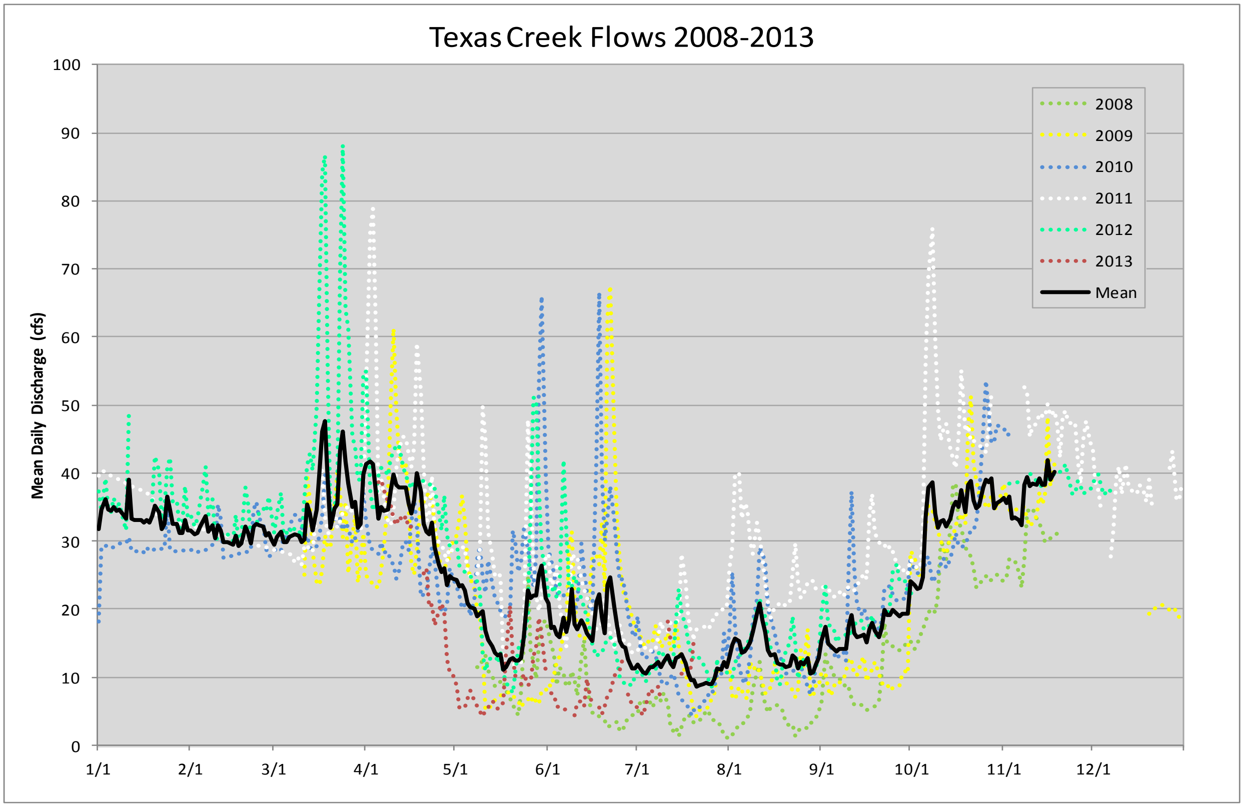

Figure B22. Texas Creek Flows 2008 - 2013