IDAHO Department of Water Resources

HYDROLOGIC ANALYSIS
AND MONITORING
PHASE IV

Final Project Report for

Idaho Department of Water Resources

Prepared by

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PROJECT OVERVIEW

DOC, Award Number:	NA08NMF4380624
CFDA Number:	11.438
CFDA Project Title:	Salmon Restoration, State of Idaho
Geographic Area:	Salmon River, above the Middle Fork Salmon River, Idaho
OSC Project Number:	006 08 SA B4
Project Sub-Grantee:	Idaho Department of Water Resources
Project Contact Information:	Helen Harrington Planning Section Manager 322 E. Front Street, P.O. Box 83720 Boise, ID 83720-0098
Grant Period:	01/01/2010 – 12/31/2011
Total PCSRF Funds:	$359,217.66
Total Non-Federal Match:	$126,697.00
Primary PCSRF Objectives:	Salmon Research, Monitoring, and Evaluation (SRME)

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1. INTRODUCTION

The tributaries to the headwaters of the Lemhi River, and the headwaters themselves, historically provided key spawning and rearing habitat for large anadromous fish runs, specifically of Chinook salmon and steelhead trout (ISCC 1995). Due to several anthropogenic factors introduced in the last 150 years, the populations of these species returning to the Lemhi River Basin have been drastically reduced from historical numbers (Loucks 2000).

Stakeholders in the Lemhi River Basin seek to achieve greater stream flows and connectivity to provide quality habitat for ESA-listed anadromous and resident fish spawning, rearing, and migration. The Upper Salmon Basin Water Program (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 2011). In support of this effort, the USBWP Technical Team, composed of various federal, state, and non-profit agency personnel and local landowners, plans, implements, and monitors a variety of stream flow enhancement projects.

However, the success of these flow enhancement projects is ultimately dependent on the level of understanding of the complicated hydrologic processes in the Lemhi River Basin. The hydrology of this basin reflects an interconnected system of surface flows in stream channels, ground water flow in an unconfined alluvial aquifer, and anthropogenic wells, canals, and drains that interface with the surface and ground water reservoirs. A complete understanding of the relationships between the Lemhi River 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.

Although the efforts of the Idaho Department of Water Resources (IDWR) during the Phase IV Project (hereafter referred to as the Project) encompassed the greater Upper Salmon Basin (USB), due to the areal focus of our many collaborators on planning, implementing, and monitoring stream flow enhancement projects, the majority of work completed by IDWR during this Project was within the Lemhi River Basin.

2. LOCATION AND BACKGROUND

The Lemhi River Basin (hereafter referred to as the Lemhi) encompasses 1270 mi^2 in east-central Idaho, situated between the Lemhi Range and the Beaverhead Mountains, which form the Idaho-Montana border (Figure 2.1). As shown in Figure 2.1, the Lemhi is part of the larger Upper Salmon Basin (USB), encompassing the Upper Salmon, Pahsimeroi, Lemhi, and Middle Salmon – Panther River Basins, which historically supported critical habitat for vast numbers of anadromous fish. The USB, and particularly the Lemhi, has been a focal area for aquatic habitat restoration activities for the past 20 years because it contains 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.

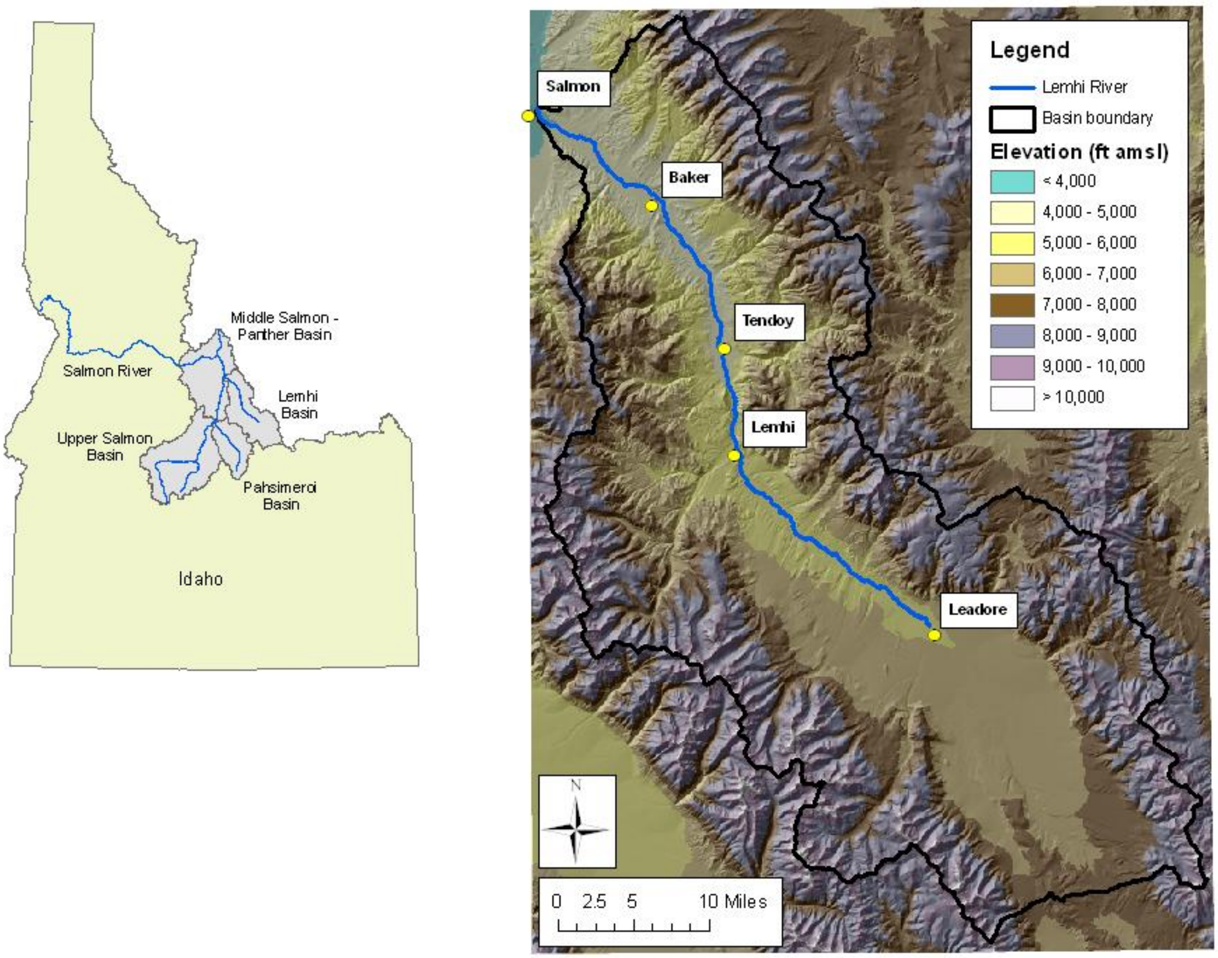


Figure 2.1 – Physical location of the greater Upper Salmon Basin and the Lemhi River Basin.

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 and pastures (Figure 2.2). The Lemhi River corridor, surrounding alluvial terraces, and tributary watersheds support productive agricultural operations that drive the local economy (Figure 2.3).

Figure 2.2 – Photograph of the Upper Lemhi River, illustrating the meandering channel and fertile agricultural land surrounding it.

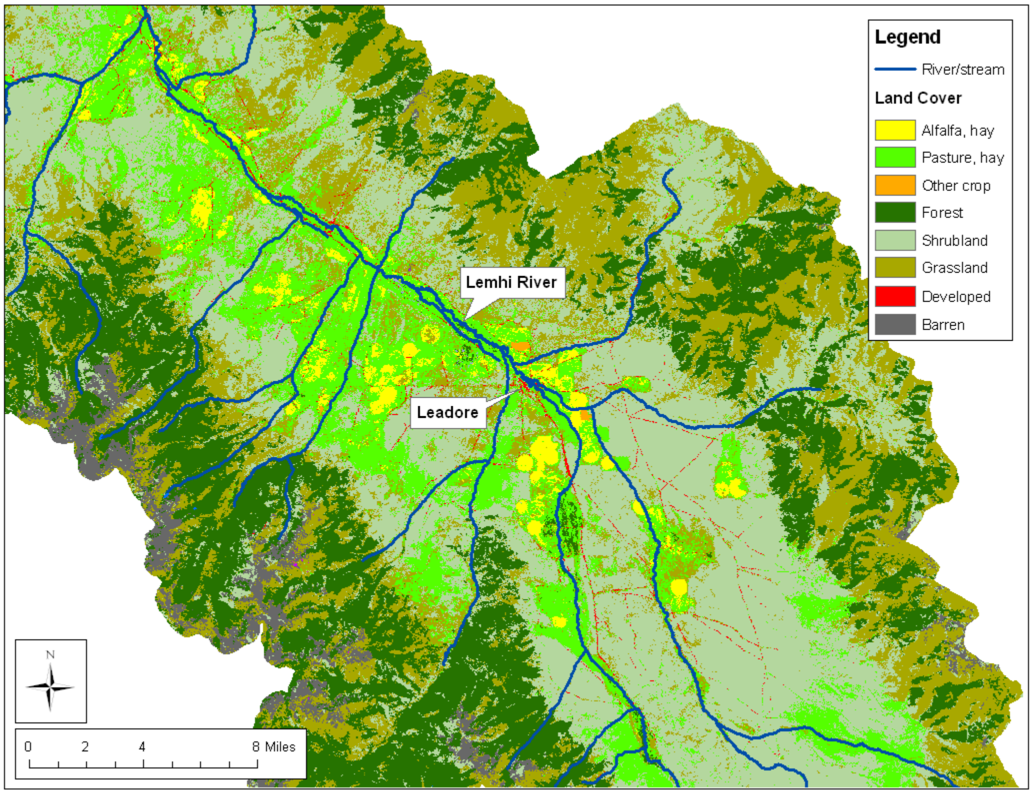


Figure 2.3 – Satellite imagery of the upper Lemhi River Basin, illustrating the abundance of agricultural land.

IDWR estimates that, from the 2001 U.S. Geological Survey (USGS) National Land Cover Dataset on file with IDWR, greater than 120,000 acres of land are irrigated in the Lemhi, chiefly for alfalfa hay and pasture. Because of the semi-arid climate, water availability for irrigation is heavily dependent on snow melt from the surrounding mountains. Consequently, landowners have created numerous earthen canals and ditches 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 reused 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 Lemhi into upper and lower halves based on the characteristics of the primary water bearing aquifer, composed of unconsolidated alluvial and glacial deposits (Spinazola 1998). A geologic constriction, forcing ground water to discharge to the Lemhi River between the towns of Lemhi and Tendoy forms this division – the Upper Lemhi located upgradient and to the south of the constriction, and the Lower Lemhi located downgradient and to the north (Anderson 1961, Spinazola 1998). Thus, effectively all of the surface and ground water originating in the Upper Lemhi flows to the Lower Lemhi through the divide, presumably via the Lemhi River channel (Donato 1998).

The Upper Lemhi constitutes the majority of the total basin area, and generally consists of thicker and more laterally-extensive alluvium deposits than the Lower Lemhi (Dorratcaque 1986). Estimates of saturated aquifer thickness in the Upper Lemhi, based on Spinazola (1998) and IDWR analyses of well drillers' logs, range from 5 – 50 ft along the Upper Lemhi River corridor to greater than 100 ft along the terraces flanking the corridor and upgradient of Leadore. Because the Lower Lemhi encompasses less area, and is generally not comprised of thick terrace deposits (Anderson 1956, 1957, 1961, Donato 1998), flows of the Lemhi River, as a whole, are seemingly largely fed by water originating in the Upper Lemhi, as well as from Hayden Creek (the largest tributary to the Lemhi River, located just downgradient of the divide).

The timing and delivery of water from the Upper Lemhi to the Lower Lemhi is affected potentially by both climatological factors (i.e. snow pack, spring rains, and temperatures), and by irrigation practices upgradient of the ground water divide (DHI 2006, Loucks 2010). 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). Because the Upper Lemhi comprises the majority of aquifer volume in the basin, irrigation and the resulting ground water recharge in the Upper Lemhi may be significant to stream flows in the Lower Lemhi. 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 Lemhi.

3. OBJECTIVES AND TASK SUMMARIES

During this Project, IDWR sought to help the USBWP Technical Team better understand the hydrologic systems of the Lemhi and the greater USB (priority in the order listed) through a combination of data collection and analysis activities, and modeling efforts. The Lemhi, and in particular the Upper Lemhi, was given priority based on the focus of the Technical Team in planning, implementing, and monitoring stream flow enhancement projects, and because the availability of stream flows for irrigators and for fish throughout the Lemhi is dependent on the volumes and usages of the surface and ground water reservoirs in the Upper Lemhi.

The main tasks undertaken by IDWR were: 1) managing stream gauge data, 2) performing flow measurements, including seepage runs, 3) collecting and analyzing hydrologic data, and 4) rebuilding the Upper Lemhi MIKE BASIN Model (MBM). Although the operation and management of stream gauges encompassed the greater USB, due to the priority of the Lemhi with respect to Technical Team stream flow enhancement project planning, implementation, and monitoring efforts, the other three tasks listed above were focused on the Lemhi, in particular the Upper Lemhi.

1) IDWR operated/managed 16 stream gauges located across the Lemhi, and an additional 6 gauges in the greater USB (i.e. along Carmen Creek, Challis Creek, Pahsimeroi Big Springs Creek, and the Pahsimeroi River). For 5 of the 16 gauges in the Lemhi, IDWR performed periodic manual flow measurements and constructed rating curves (i.e. relating stream depth to flow at the gauge locations). Additionally, stream flow data was collected from another 8 gauges in the Lemhi funded/operated by other agencies, and rating curves were developed for 2 of these gauges. This data has been used directly to help the Technical Team identify where flows are limited for future stream flow enhancement projects and how streams are responding to past projects. Stream gauge data is provided in Appendix A.

2) Flows of various non-gauged stream reaches were measured on multiple occasions by IDWR to support Technical Team data needs. Specifically, these measurements, collected several times throughout the irrigation seasons, helped assess the potential flow benefits of reconnecting the headwaters of spring-fed streams to the Lemhi River. Also, several flow measurements were collected along an additional Upper Lemhi tributary and its associated irrigation ditches (i.e. performed a seepage run) to estimate the potential flow effects of replacing one or more ditches with irrigation pipe.

3) On multiple occasions, IDWR assisted Technical Team members and outside agency personnel with hydrologic data collection and analysis activities. Examples include predicting the maximum flow through reaches of the Upper Lemhi River to aid in the design of a cross-channel structure, and bracketing the fraction of the water “saved” by reducing the amount diverted from a tributary stream that would benefit flows in the Upper Lemhi River (i.e. accounting for downstream irrigators that would likely divert this “saved” water due to water shortages). The latter example is a classic scenario for the Upper Lemhi MBM; however, as is discussed below, the Upper Lemhi MBM required several updates and refinements that IDWR felt were necessary before

employing it to model and predict hydrologic processes. However, the equivalent analysis that was performed, although more tedious, provided the Technical Team members with the information they sought.

Additionally, in partnership with the USBWP, ground water elevations were measured in 16 wells located across the Lemhi. This information was used to characterize the spatial and temporal variability of ground water supplies, with the specific aim of correlating changes in ground water with the irrigation season. Further, as is discussed in more detail below in Section 4.3, this data was illustratively analyzed to estimate ground water properties in the Upper Lemhi – information that is presently lacking, and is needed to identify where and when irrigation practices regulate stream flows through ground water recharge and subsequent return flows. A preliminary plan drafted by IDWR during this Project to help guide field efforts aimed at determining ground water processes in the Lemhi is provided in Appendix B.

4) The Upper Lemhi MBM at the beginning of this Project (hereafter referred to as the previous model) was equipped to tackle the direct impacts of relatively simple stream flow enhancement projects, with a structure and data set encompassing the major streams and associated irrigation diversions. However, the input data was slightly outdated and inconsistent, and the model lacked the detailed structure and capabilities required to answer more complicated questions, such as the connectivity of irrigation and stream flows through ground water recharge and subsequent return flows. In light of these issues and limitations, IDWR undertook a rigorous series of technical updates, modifications, and refinements to rebuild the Upper Lemhi MBM in a fashion that incorporates all the latest hydrologic data available and that is conducive to utilizing ground water processes. These efforts were aimed at increasing the accuracy and utility of the Upper Lemhi MBM in planning stream flow enhancement projects.

4. TASK DETAILS

4.1 <u>Stream Gauge Data Collection and Management</u>

IDWR has managed the collection of stream gauge data for the USBWP Technical Team, in support of planning, implementing, and monitoring stream flow enhancement projects, since 2004. During this Project, via PCSRF funding, IDWR contracted Idaho Power Co. (IPCo) to operate 17 stream gauges throughout the greater USB, and IDWR operated an additional 5 gauges in the Lemhi. Figure 4.1.1 displays the stream/river reaches in the greater USB that were monitored with stream gauges funded through this Project (i.e. IDWR and IPCo operated, funded through PCSRF), hereafter referred to as IDWR managed gauges. The Lemhi River tributary streams displayed in Figure 4.1.1 are not labeled for clarity, but they are discussed in detail below. Table 4.1.1 lists the IDWR managed stream gauges in the greater USB, excluding those within the Lemhi.

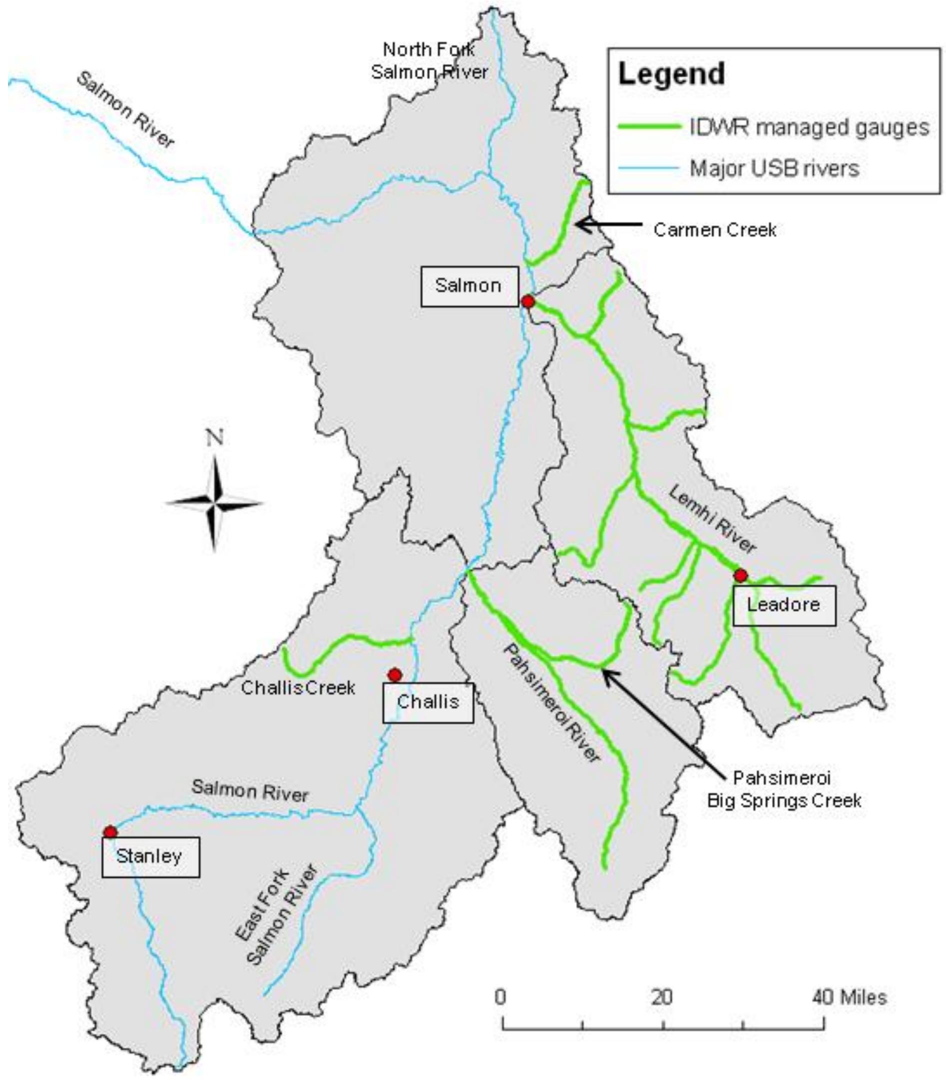


Figure 4.1.1 – Greater Upper Salmon Basin streams and rivers with PCSRF-funded gauges during this Project.

Stream gauge	Latitude (NAD 1983)	Longitude (NAD 1983)	Date range	Agency	Funding
Carmen Creek, Lower	45.244	-113.889	2005 - present	IDWR – IPCo contracted	PCSRF
Carmen Creek, Upper	45.345	-113.789	2005 - present	IDWR – IPCo contracted	PCSRF
Challis Creek, Lower	44.569	-114.194	2005 - present	IDWR – IPCo contracted	PCSRF
Challis Creek, Upper	44.572	-114.305	2005 - present	IDWR – IPCo contracted	PCSRF
Pahsimeroi River, at Furey Lane	44.525	-113.846	2004 - present	IDWR – IPCo contracted	PCSRF
Pahsimeroi Big Springs Creek, near May	44.606	-113.951	2009 - present	IDWR – IPCo contracted	PCSRF

Table 4.1.1 – Stream gauges in the greater Upper Salmon Basin, excluding those within the Lemhi, during this Project (funded through PCSRF).

Figure 4.1.2 shows the locations of the IDWR managed stream gauges in the Lemhi (i.e. funded through PCSRF), along with stream gauges managed by IDWR that were funded through other sources, and stream gauges operated by Water District (WD) 74 and the U.S. Geological Survey (USGS). The non-PCSRF funded gauges are included in Figure 4.1.2 because data from these gauges were utilized by IDWR during this Project to support the efforts of the USBWP Technical Team. Table 4.1.2 lists the gauges displayed in Figure 4.1.2.

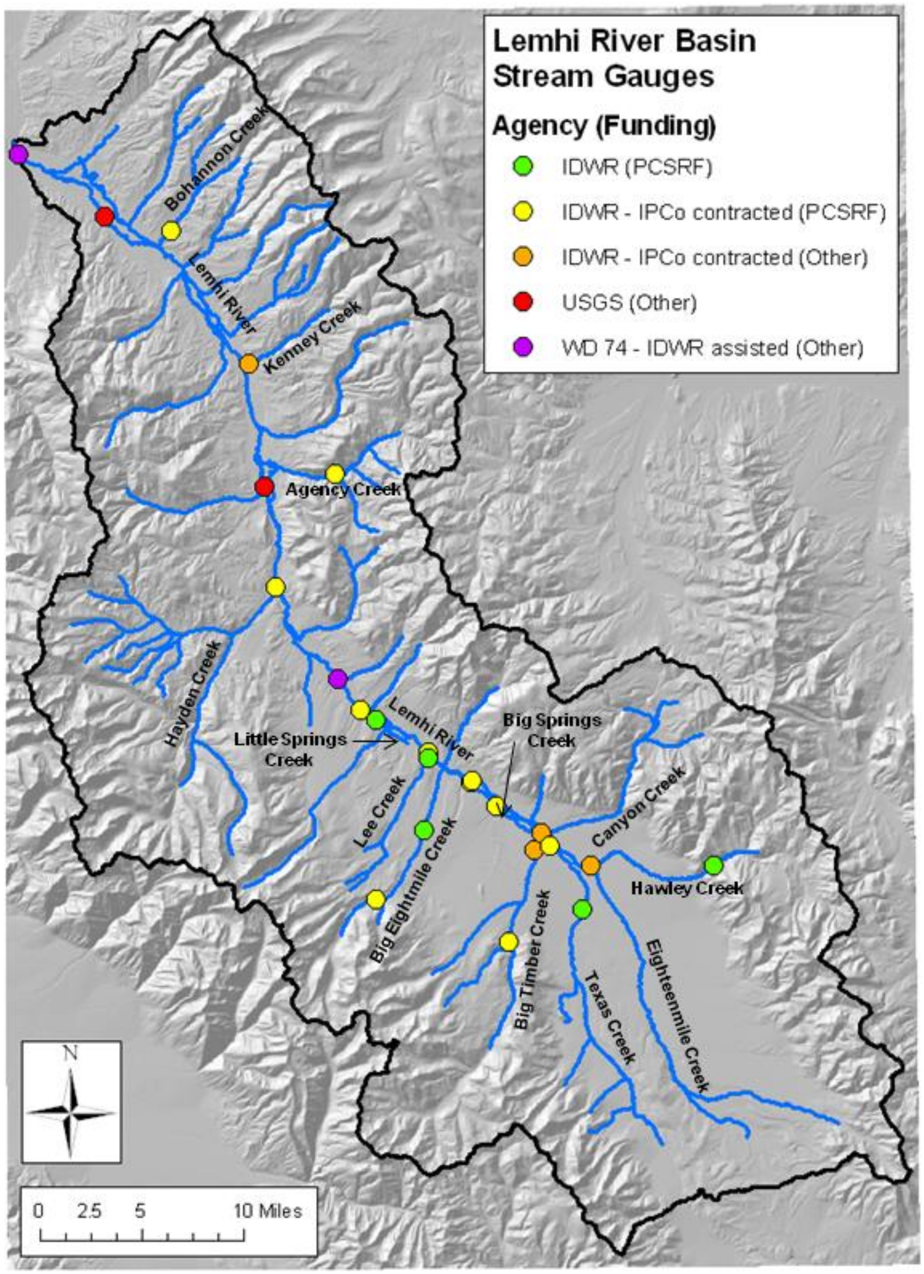


Figure 4.1.2 – All stream gauges in the Lemhi utilized for flow data during this Project.

Stream gauge	Latitude (NAD 1983)	Longitude (NAD 1983)	Date range	Agency	Funding
Agency Creek	44.949	-113.568	2005 - present	IDWR - IPCo contracted	PCSRF
Big Eightmile Creek, Lower	44.694	-113.482	2008 - present	IDWR	PCSRF
Big Eightmile Creek, Upper	44.644	-113.529	2005 - present	IDWR - IPCo contracted	PCSRF
Big Springs Creek, Upper	44.728	-113.433	2005 - present	IDWR - IPCo contracted	PCSRF
Big Springs Creek, Upper	44.711	-113.409	2008 - present	IDWR - IPCo contracted	PCSRF
Big Timber Creek, Lower	44.680	-113.371	2004 - present	IDWR - IPCo contracted	Other
Big Timber Creek, Upper	44.614	-113.397	2005 - present	IDWR - IPCo contracted	PCSRF
Bohannon Creek	45.122	-113.732	2008 - present	IDWR - IPCo contracted	PCSRF
Canyon Creek	44.691	-113.363	2008 - present	IDWR - IPCo contracted	Other
Eighteenmile Creek, Upper	44.668	-113.314	2006 - present	IDWR - IPCo contracted	Other
Hawley Creek	44.667	-113.192	2008 - present	IDWR	PCSRF
Hayden Creek	44.868	-113.628	2007 - present	IDWR - IPCo contracted	PCSRF
Kenney Creek	45.027	-113.654	2004 - present	IDWR - IPCo contracted	Other
Lee Creek	44.746	-113.476	2009 - present	IDWR	PCSRF
Lemhi River, above Big Springs	44.729	-113.433	2005 - present	IDWR - IPCo contracted	PCSRF
Lemhi River, above L-5 diversion	45.133	-113.799	2000 - present	USGS	Other
Lemhi River, above L-63 diversion	44.682	-113.356	2008 - present	IDWR - IPCo contracted	PCSRF
Lemhi River, at Cottom Lane	44.749	-113.476	2005 - present	IDWR - IPCo contracted	PCSRF
Lemhi River, at L-1 diversion	45.177	-113.886	1997 - present	WD 74 - IDWR assisted	Other
Lemhi River, at McFarland Campground	44.803	-113.566	1997 - present	WD 74 - IDWR assisted	Other
Lemhi River, near Lemhi	44.940	-113.639	1967 - present	USGS	Other
Little Springs Creek, Lower	44.780	-113.543	2008 - present	IDWR - IPCo contracted	PCSRF
Little Springs Creek, Upper	44.773	-113.528	2008 - present	IDWR	PCSRF
Texas Creek	44.636	-113.323	2008 - present	IDWR	PCSRF

Table 4.1.2 – All stream gauges in the Lemhi utilized for flow data during this Project.

During this Project, IPCo supplied IDWR with daily flow data obtained from the 17 stream gauges IDWR contracted IPCo to operate in the USB (including the Lemhi) for 2010 – 2011. Additionally, IDWR received 2010 – 2011 daily flow data for gauges IPCo is contracted to operate by IDWR through non-PCSRF funding that are also located in the Lemhi. Note that 2010 stream flow data supplied by IPCo is finalized, but 2011 IPCo data is considered provisional. Finalized 2011 IPCo data will be supplied to IDWR by March 1, 2012, following the data analysis, compilation, and review processes IPCo perform at the end of each calendar year.

For the 5 stream gauges operated and managed by IDWR during this Project (i.e. Lower Big Eightmile Creek, Hawley Creek, Lee Creek, Upper Little Springs Creek, and Texas Creek gauges), Aquarius software was employed to develop rating curves for each gauged reach, according to USGS protocols (Rants et al. 1982), to relate measured stream stage (ft) to flow (cfs). IDWR performed manual measurements of stream stage and flow at each of the 5 gauges during multiple field campaigns throughout 2010 and 2011 to serve as calibration points for the rating curves. IDWR had previously developed rating curves for these gauges; however, due likely to the lack of calibration points at the time (i.e. since these gauges were not installed until 2008), strict adherence to USGS protocols had not been met. Thus, IDWR determined that, in the interest of technical transparency and data accuracy, these rating curves would be re-evaluated. The re-evaluated rating curves were then used with the gauge-recorded stage values to generate daily time series of flow for each of these 5 gauges for years 2008 – 2011.

Similarly, IDWR assisted WD 74 in downloading recorded stage values at the Lemhi River L-1 and McFarland Campground gauges, and developed rating curves for these gauges using manual stage and flow measurements performed by WD 74. These rating curves were then used to generate daily time series of flow for these 2 gauges for years 2008 – 2011.

Additionally, IDWR downloaded daily flow data for the USGS Lemhi River near Lemhi and above L-5 gauges from the USGS WaterWatch website (USGS 2012) for years 2008 – 2011. As is the case for the non-PCSRF funded IPCo contracted gauges, and the WD 74 gauges, this data was acquired to supplement the USB stream flow data set housed by IDWR.

All 2008 – 2011 daily stream flow records mentioned above were then compiled into Microsoft Access databases, where they can be securely stored and rapidly queried for any request by the USBWP Technical Team or any other outside organization. Additionally, as is discussed in Section 4.4, these stream flow records served as critical data inputs to the Upper Lemhi MBM.

Graphical plots of the 2008 – 2011 daily stream flow data mentioned above are included in Appendix A.

4.2 <u>Manual Flow Measurements</u>

Although the stream gauge networks managed by IDWR and other agencies account for an expansive data set of daily stream flows across the Lemhi (refer to Section 4.1), often the USBWP Technical Team requires stream flow measurements in specific locations for planning, implementation, and/or monitoring purposes. During this Project, IDWR performed several flow measurements across the Upper Lemhi for USBWP Technical Team members, specifically along Lee Creek, Little Springs Creek, and Hawley Creek (refer to Figure 4.1.2).

4.2.1 Little Springs Creek

To augment spawning and rearing habitat for native anadromous and resident fish in the Upper Lemhi, Trout Unlimited (TU), a private non-profit agency active in the USBWP Technical Team, plans to restore stream channel connecting Walter Creek to the headwaters of Little Springs Creek (Myers 2011). Figure 4.2.1 displays Walter Creek, Little Springs Creek, the two Little Springs Creek gauges managed by IDWR, and the location of the flow measurements performed by IDWR for TU. Also shown is the approximate zone of channel restoration planned to reconnect Walter Creek to Little Springs Creek, which is expected to provide several miles of additional fish habitat along Walter Creek.

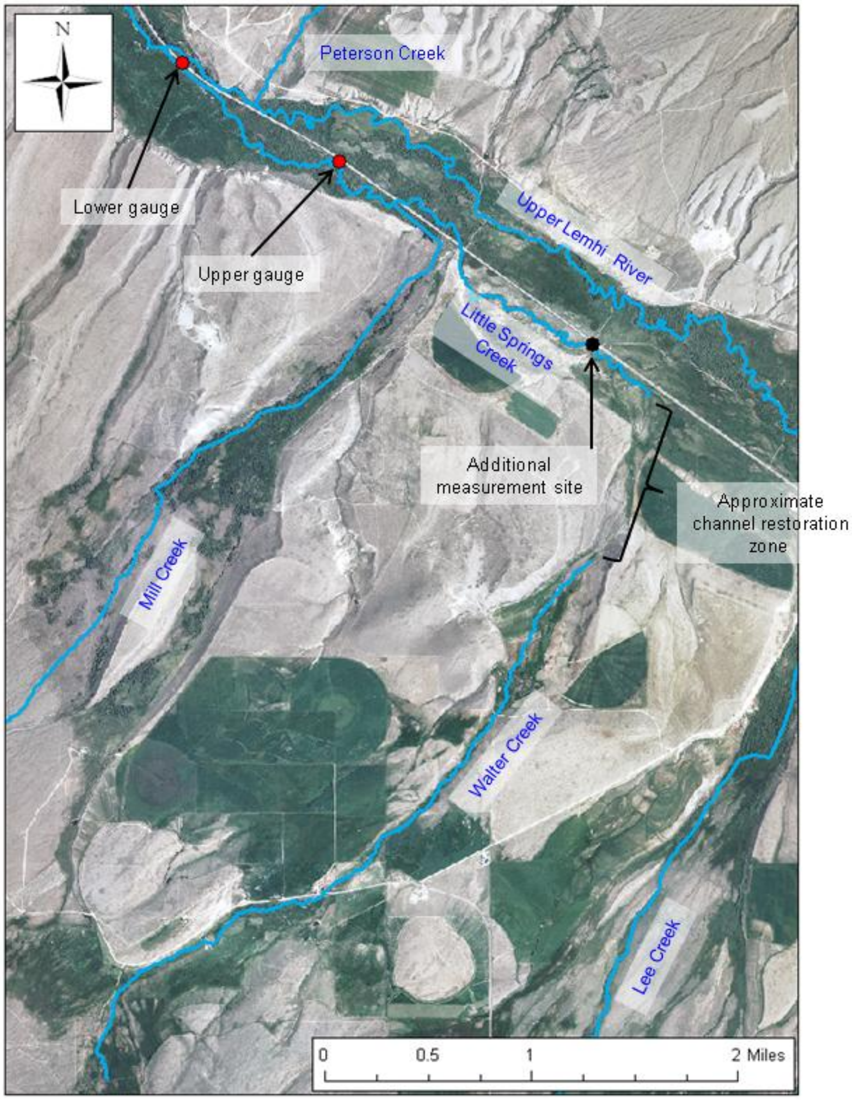


Figure 4.2.1 – Aerial photograph illustrating where stream flows were manually measured in support of the Trout Unlimited Walter Creek – Little Springs Creek reconnect scenario.

During this Project, IDWR measured the following flows through Little Springs Creek at the additional measurement site:

- May 4, 2011 4.7 cfs
- Jun 15, 2011 8.2 cfs
- Aug 4, 2011 11.7 cfs
- Sep 14, 2011 6.7 cfs
- Oct 27, 2011 5.7 cfs

Little Springs Creek is, as its name implies, largely fed by spring systems along the Upper Lemhi River corridor; thus, the primary source of the measured flow was likely natural spring discharge. Walter Creek likely contributed some flow to this reach of Little Springs Creek during this Project; however, the lack of a defined connecting channel likely resulted in a minimum amount of connected flow (i.e. due to braiding and fanning, and the resulting increased evapotranspiration and seepage loss).

Thus, the measurements performed by IDWR provided TU with an estimate of the minimum amount of flow expected to travel through the headwaters of Little Springs Creek (i.e. > 4 cfs). These efforts assisted TU in planning the reconnection project by providing information needed to assess whether enough flow would be available in the headwaters of Little Springs Creek to allow fish passage into the reconnected channel.

4.2.2 Lee Creek

Analogous to the TU project mentioned in Section 4.2.1, The Natural Conservancy (TNC), another private non-profit agency active in the USBWP Technical Team, plans to reconnect Lee Creek to the Upper Lemhi River to increase the number of stream miles available to native anadromous and resident fish in the Lemhi (Troy 2011). Currently, during the irrigation season, Lee Creek is intercepted by the L-58A and BSC-5 ditches, which divert water from the Upper Lemhi River and Big Springs Creek, respectively. These interceptions often partially- or fully-remove flow from Lee Creek, but also contribute flow at times. These interactions make it difficult to estimate the natural flow through this system. TNC plans to remove these ditch interceptions, and restore the lower reaches of Lee Creek, which currently flow through a barrow pit, to a more natural state. Figure 4.2.2 displays the current channel of Lee Creek, the approximate flow path of the planned restored channel, the Lee Creek gauge, and the L-58A and BSC-5 ditches.

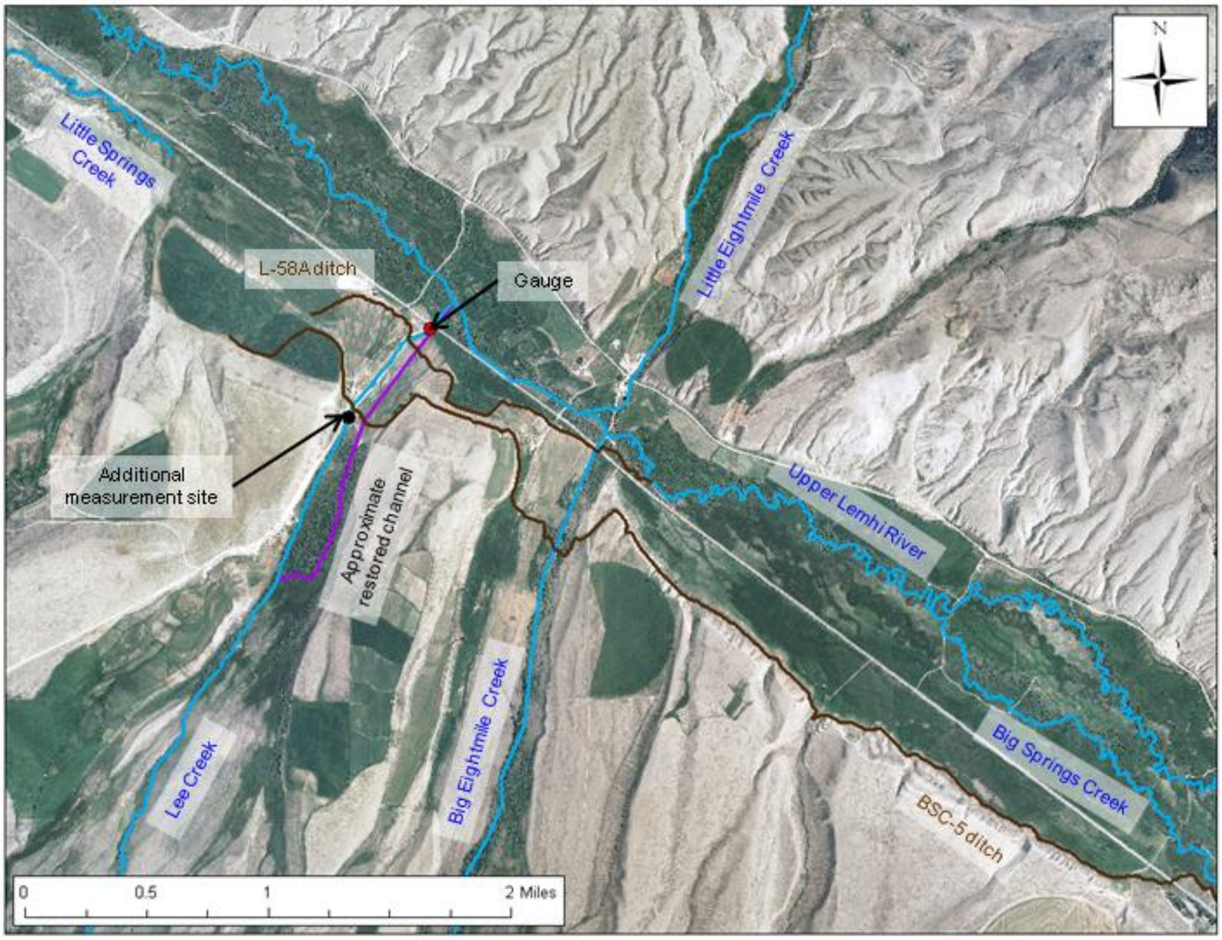


Figure 4.2.2 – Aerial photograph illustrating where flows were manually measured in support of The Nature Conservancy Lee Creek reconnect scenario.

As shown in Figure 4.2.2, the stream gauge IDWR manages/operates on Lee Creek is located downstream of the ditch interceptions. Thus, to help TNC assess the flow benefit of reconnecting Lee Creek to the Upper Lemhi River by removing the ditch interceptions, IDWR performed several flow measurements at a location along the current channel just upstream of the interceptions.

During this Project, IDWR measured the following flows through Lee Creek at the additional measurement site:

- Nov 2, 2010 8.8 cfs
- Jun 2, 2011 6.6 cfs
- Jul 7, 2011 23.9 cfs
- Aug 30, 2011 2.8 cfs
- Sep 14, 2011 2.8 cfs
- Oct 27, 2011 5.1 cfs

An important piece of information is the expected minimum flow through lower Lee Creek, assuming the ditch interceptions were absent. Referencing the August and September 2011 measurements above, this appears to be approximately 2.8 cfs, which is 1 cfs greater than that recorded at the gauge during this time period. Thus, these efforts assisted TNC in planning the reconnection project by, again, providing information needed to assess whether enough flow would be available in this system to allow fish passage.

4.2.3 Hawley Creek

An additional stream flow enhancement project in the Upper Lemhi is being planned by the USBWP along Hawley Creek. Referencing Appendix A, flows recorded at the IDWR Hawley Creek gauge have exceeded 10 cfs for the past several years, suggesting ample flows for fish passage. However, three irrigation ditches currently divert water from Hawley Creek below the gauge. During 2008 – 2010, the average combined diverted rate through these ditches was approximately 8 cfs, but was observed to exceed 19 cfs for nearly 4 months of every irrigation season. Thus, the lower reaches of Hawley Creek often run dry. Figure 4.2.3 displays Hawley Creek and the three irrigation diversion ditches below the IDWR gauge.

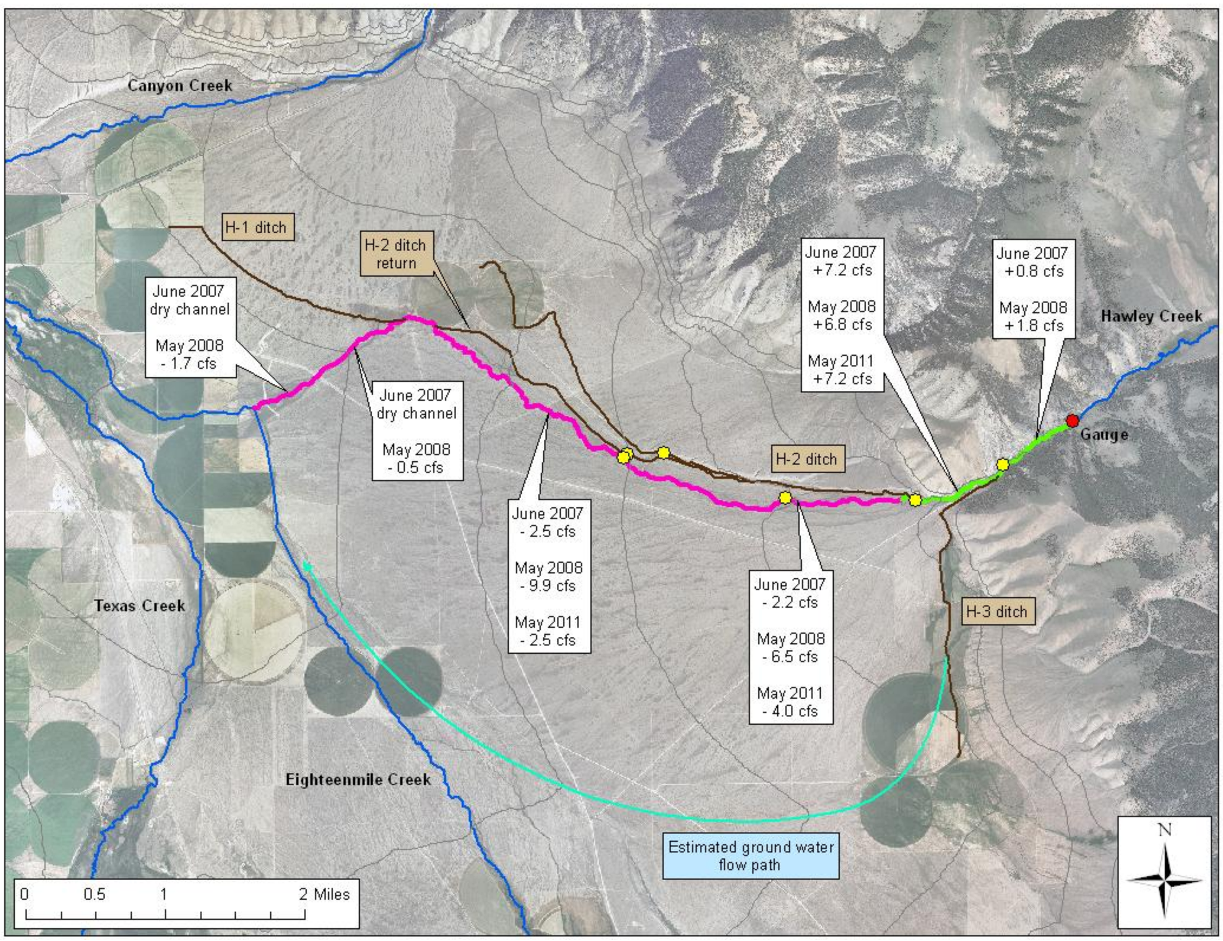


Figure 4.2.3 – Summary of seepage characteristics of Hawley Creek.

During this Project, in an effort to provide more flow through the lower reaches of Hawley Creek, the USBWP was developing tentative plans to replace the H-2 and H-3 ditches with pipe (Bradbury 2011). Since piping the irrigation water would eliminate conveyance loss (i.e. seepage), this project would result in more water in stream, but it would also decrease ground water recharge. Many landowners and irrigators in the Lemhi, including those serving on the USBWP Advisory Committee, see ground water recharge as a positive side effect of irrigation, as it likely results in ground water return flows that augment stream flows during the late irrigation season (refer to Section 2). To assist the USBWP in assessing the positive and negative effects of this proposed project, IDWR compiled all flow measurements along Hawley Creek in recent years (from IDWR and other agencies), and, with the assistance of the Idaho Department of Fish and Game (IDFG), performed several additional flow measurements along Hawley Creek and its diversion ditches in September 2011.

Figure 4.2.3 illustrates the results of previous flow measurements, along with the locations of measurements taken in September 2011. Based on previous flow measurements, the reaches above the H-2 diversion are consistently gaining reaches – that is, accounting for all surface inputs and outputs (i.e. ditch water coming in or leaving the stream), the reach gains flow from ground water discharge. However, the remaining lower Hawley Creek reaches consistently lose flow to the ground (i.e. stream seepage), suggesting that ground water recharge through conveyance of the H-2 and H-3 ditches does not amount to any return flows to Hawley Creek. This was supported by the flow measurements conducted in September 2011, which indicated that, although the H-2 and H-3 ditches were carrying more than 12 cfs combined, all measured Hawley Creek reaches below H-2 were losing reaches.

Additionally, in September 2011, the reach of Hawley Creek between the H-2 diversion and approximately 2 mi downstream was observed to lose greater than 5 cfs, whereas an equivalent reach of the H-2 ditch lost less than 4 cfs. This result suggests keeping more water in Hawley Creek by piping the H-2 and H-3 irrigation water may actually enhance ground water recharge in this area. Further, as illustrated in Figure 4.2.3, any return flows from seepage through either the ditches or the stream channel likely impact the same general area downstream (i.e. lower Eighteenmile Creek). Thus, in this specific example, reducing irrigation diversion rates should enhance stream flows for fish and maintain (if not increase) ground water recharge for downstream irrigators.

IDWR provided the results of the analysis discussed above to the USBWP, and assisted in presenting them to the USBWP Advisory Committee for project approval in December 2011.

4.3 <u>Collection and Analysis of Hydrologic Data</u>

A primary role of the IDWR Hydrologist is to assist USBWP Technical Team members with data requests and technical analysis needs. On multiple occasions during this Project, IDWR fielded the requests and needs of the Technical Team in support of stream flow enhancement project planning. Two examples of IDWR assistance, where hydrologic analyses were performed and results were provided to the Technical Team, are provided below.

Additionally, in support of the recent push by the USBWP Technical Team for ground water – surface water interactions data, IDWR partnered with the USBWP to measure ground water elevations in 16 wells across the Lemhi. This information was used to characterize the spatial and temporal variability of ground water supplies, with the specific aims of correlating changes in ground water with the irrigation season and supplying the Upper Lemhi MBM with ground water information.

4.3.1 Upper Lemhi River

In February 2011, an IDFG member of the USBWP Technical Team contacted IDWR for assistance in estimating a reasonable maximum flow expected through a reach of the Upper Lemhi River to ensure a planned cross-channel structure was built to realistic specifications (Diluccia 2011). The structure was planned on the Upper Lemhi River between the mouths of Mill Creek and Lee Creek. Figure 4.3.1 illustrates the approximate location of the project site, along with applicable Lemhi River gauges from which IDWR obtained historical and current flow data. The approach utilized by IDWR was to estimate the maximum flow by statistically extending the flow records of the two nearest gauges according to the long-term temporal behavior of the USGS Lemhi near Lemhi (i.e. Lemhi gauge).

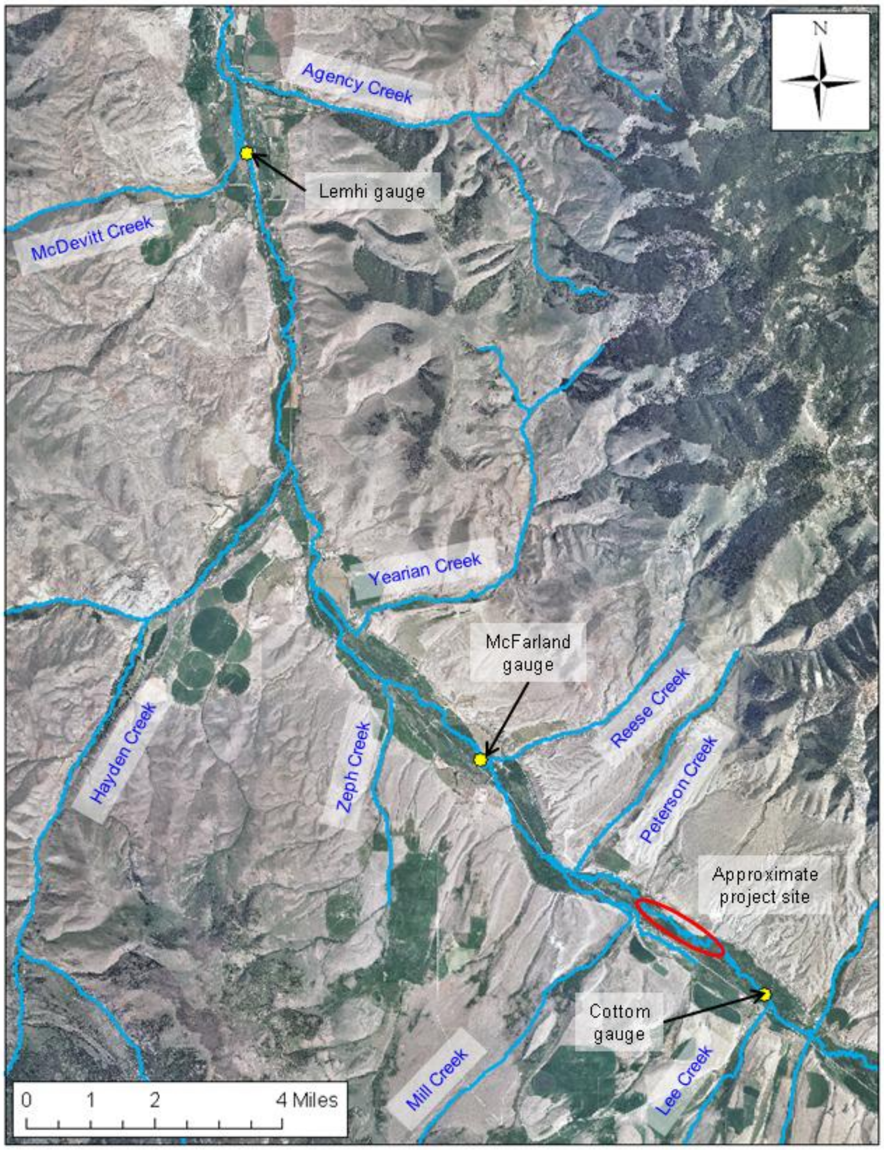


Figure 4.3.1 – Approximate location of IDFG/USBWP Technical Team project site with respect to available stream gauge data.

As shown, the Cottom Lane (i.e. Cottom) gauge is located on the Upper Lemhi River approximately 2 miles upstream of the project; the McFarland Campground (i.e. McFarland) gauge is located several miles downstream; and the Lemhi gauge is more than 15 miles downstream. Because of its location, the Cottom gauge is the best predictor of hydrologic conditions at the project site, but the period of record was less than 6 years at the time of this analysis. Continuous flow records for the McFarland and Lemhi gauges date back to 1997 and 1967, respectively, but significant surface water inputs from tributaries and groundwater influence these sites relative to the project location. Thus, a Maintenance of Variance Extension Type 1 (MOVE1) analysis (Hirsch 1982) was utilized to extend the Cottom gauge flow record back to 1967, using the USGS Lemhi gauge as the base station.

The results yielded a maximum flow at the Cottom gauge of approximately 800 cfs during 1984, (i.e. when the Lemhi gauge recorded 2100 cfs). The MOVE1 results were determined to be plausible given the general agreement between recorded peak flows at the Cottom gauge and those predicted during this same time period (i.e. 2005 – 2010). For example, the recorded and predicted 2009 maximum flows for the Cottom gauge are 609 and 548 cfs, respectively – a relative difference of just 10%. Assuming the MOVE1 analysis under-predicts peak flows by 10%, a reasonable estimate for the maximum flow at the Cottom gauge during the 1967 – 2010 period was estimated to be 900 cfs.

Additionally, annual maximum flows for both the MOVE1-extended record (i.e. 1967 – 2010) and actual recorded record (i.e. 2005 – 2010) were analyzed for exceedence probabilities (Dingman 2002). Given that a 50-year flow event is assumed to have an exceedence probability of 2%, the 50-year maximum flow at the Cottom gauge was estimated at 904 and 926 cfs using the MOVE1-extended record and actual record, respectively. These results, shown in Figure 4.3.2, again supported an approximate 50-year maximum flow for the Cottom gauge of approximately 900 cfs.

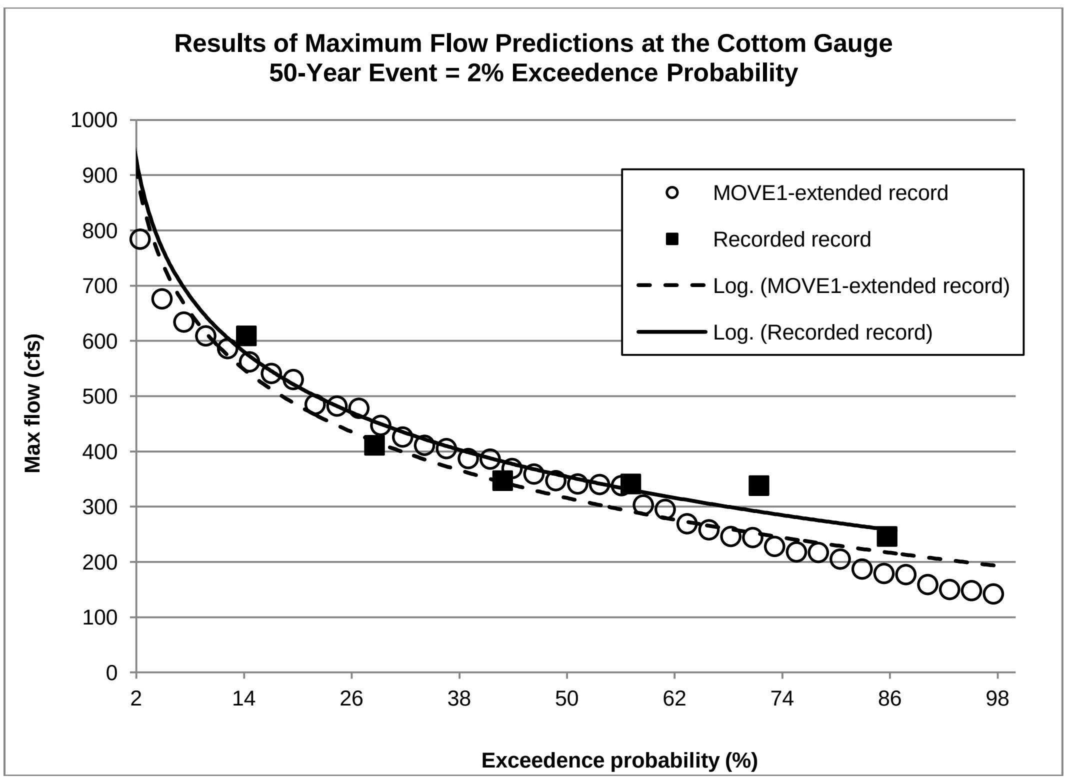


Figure 4.3.2 – Plots of maximum flows vs. exceedence probabilities.

4.3.2 Big Timber Creek

In May 2011, a TNC member of the USBWP Technical Team contacted IDWR to discuss the potential stream flow benefits of removing a large Big Timber Creek diversion, sourced by the Carey Act dam across Big Timber Creek (Davidson 2011). Figure 4.3.3 displays the irrigation ditches diverting water from Big Timber Creek via the Carey Act dam, as well as the irrigation POU served by these ditches. The Technical Team members were interested in estimating how much water kept in Big Timber Creek by removing the Carey Act diversion would make to the Upper Lemhi River (i.e. the mouth of Big Timber Creek). The complication in this scenario, and the reason IDWR was contacted for assistance, is any downstream Big Timber Creek water user that, prior to removing the Carey Act diversion, experienced water shortages would likely divert any extra water in stream up to their respective water rights. Thus, the amount of water "saved" by removing the Carey Act diversion likely would not equate to the amount of water spilled into the Upper Lemhi River.

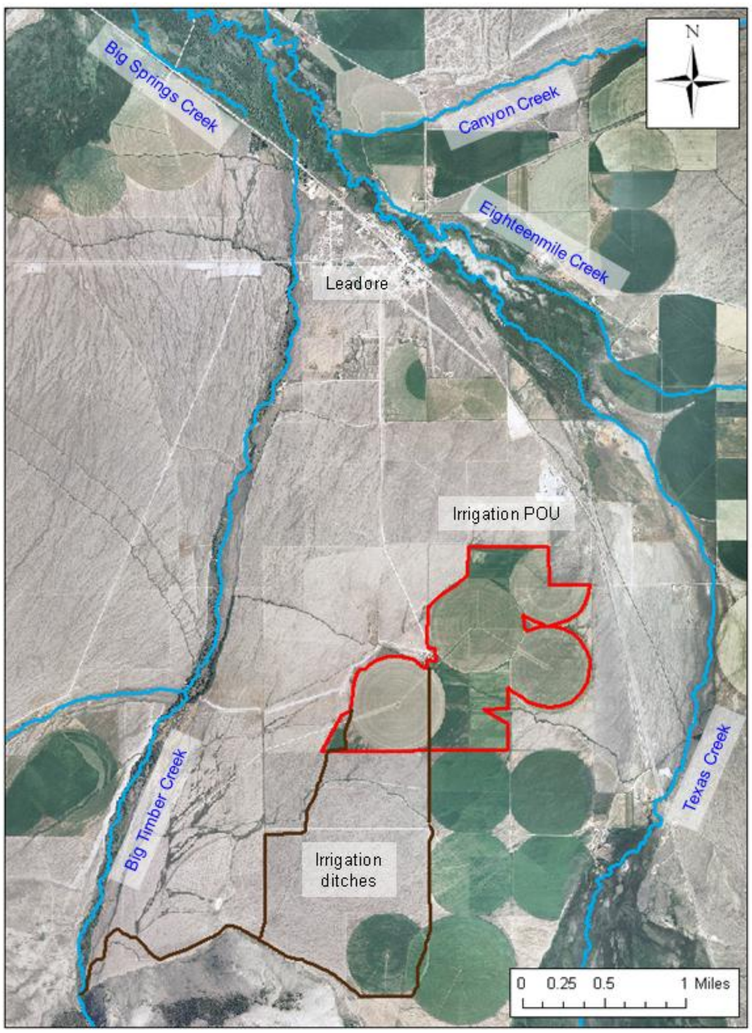


Figure 4.3.3 – Location of POU and Carey Act dam irrigation ditches delivering water to POU.

To address this complication, using Water District (WD) 74W watermaster reports, IDWR compiled and analyzed daily irrigation diversion rates for all irrigation water rights sourced by Big Timber Creek. Specifically, this entailed comparing the reported amounts diverted against the total maximum allowed per water right to estimate water shortages downstream of the Carey Act diversion. To estimate the water savings to the Upper Lemhi River, any available “saved” water was allocated to the water shortages of every downstream diversion.

IDWR provided the Technical Team members with a daily bracket of the expected flow reaching the mouth of Big Timber Creek for 2008 – 2010. The high daily estimate (Scenario A) was based on all downstream Big Timber Creek water users diverting only up to their decreed water rights or up to the amounts reported by the watermasters during 2008 – 2010 (whichever was greater), whereas the low daily estimate (Scenario B) was based on the users diverting up to their beneficial use recommendations. Figure 4.3.4 is a graph of the results of this analysis. Under Scenario A, the average daily flow savings reaching the Upper Lemhi River are approximately 18 cfs, and enhance the flow for nearly 70 days. However, under Scenario B, the average daily flow savings reaching the mouth of Big Timber Creek are approximately 5 cfs, and the flow is only enhanced for 50 days.

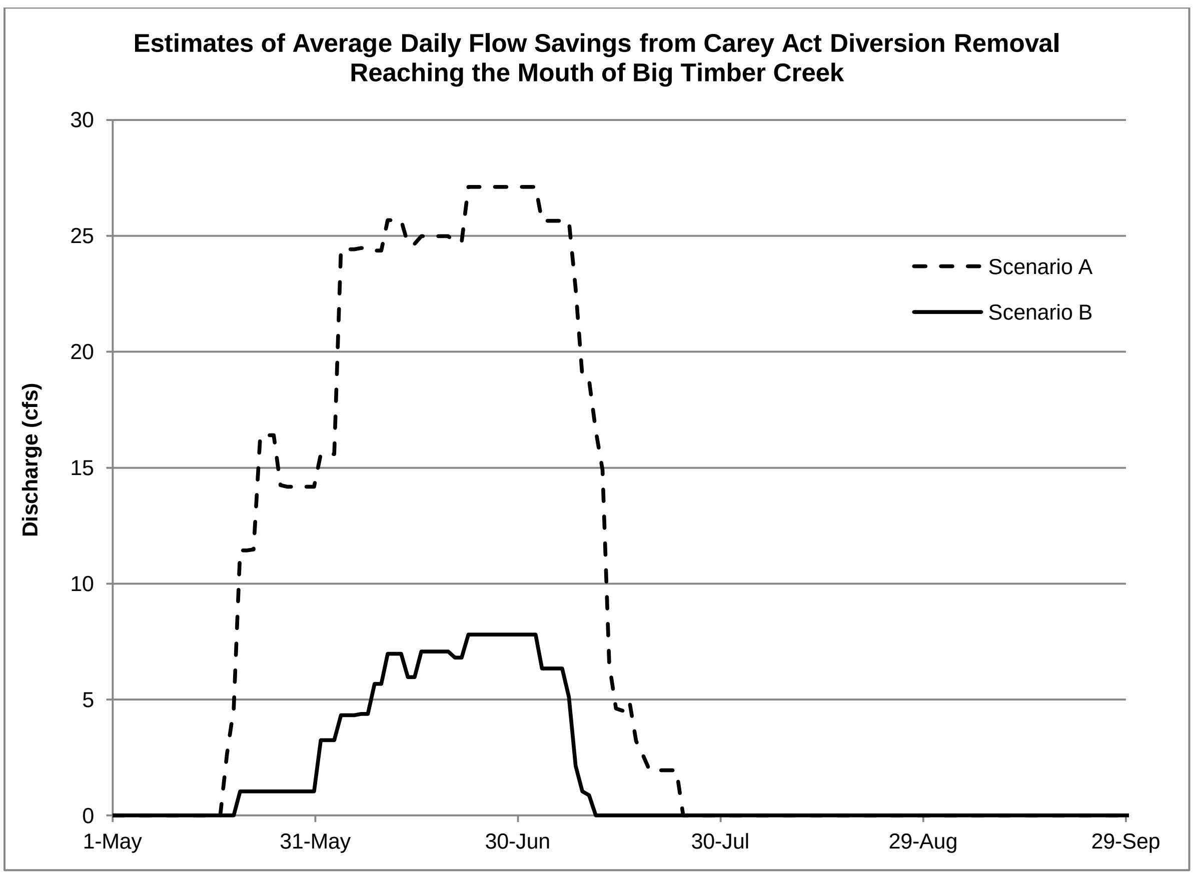


Figure 4.3.4 – Plots of Scenarios A and B considered by IDWR in estimating the amount of flow savings reaching the mouth of Big Timber Creek.

The results of this analysis suggest that the potential flow savings impacting lower Big Timber Creek and the Upper Lemhi River from removing the Carey Act diversion range between 5 – 18 cfs, and are expected to enhance stream flows during the approximately two months of the early irrigation season (i.e. mid-May to mid-July). These estimates are based on water usages reported during 2008 – 2010. Additionally, these estimates do not account for water right priority dates (i.e. any downstream water user can divert portions of the saved water); thus, the 5 – 18 cfs bracket can be viewed as a conservative estimate in the sense that, given priority date consideration, less saved water could be diverted before the mouth of Big Timber Creek.

4.3.3 Ground Water Elevation Measurements and Analyses

During this Project, IDWR sought to highlight several wells where measurements of depths to ground water might shed light on the physical properties of the shallow alluvial aquifer, as well as assist in determining the impacts of irrigation on water cycling in the Lemhi. In the latter half of 2010, IDWR began researching drill logs for all wells located in the Lemhi with the intent of identifying candidate wells for monitoring during 2011 and beyond. The search criteria included locations with respect to one or more areas of interest, productive zone(s) within the shallow alluvial aquifer, and, where possible, wells where previous ground water depth measurements had been collected. Figure 4.3.5 illustrates the locations of the 16 wells selected for monitoring during 2011, as well as the locations of 79 wells monitored by Spinazola (1998) during 1996 - 1997. Table 4.3.1 lists the locations and elevations of these wells.

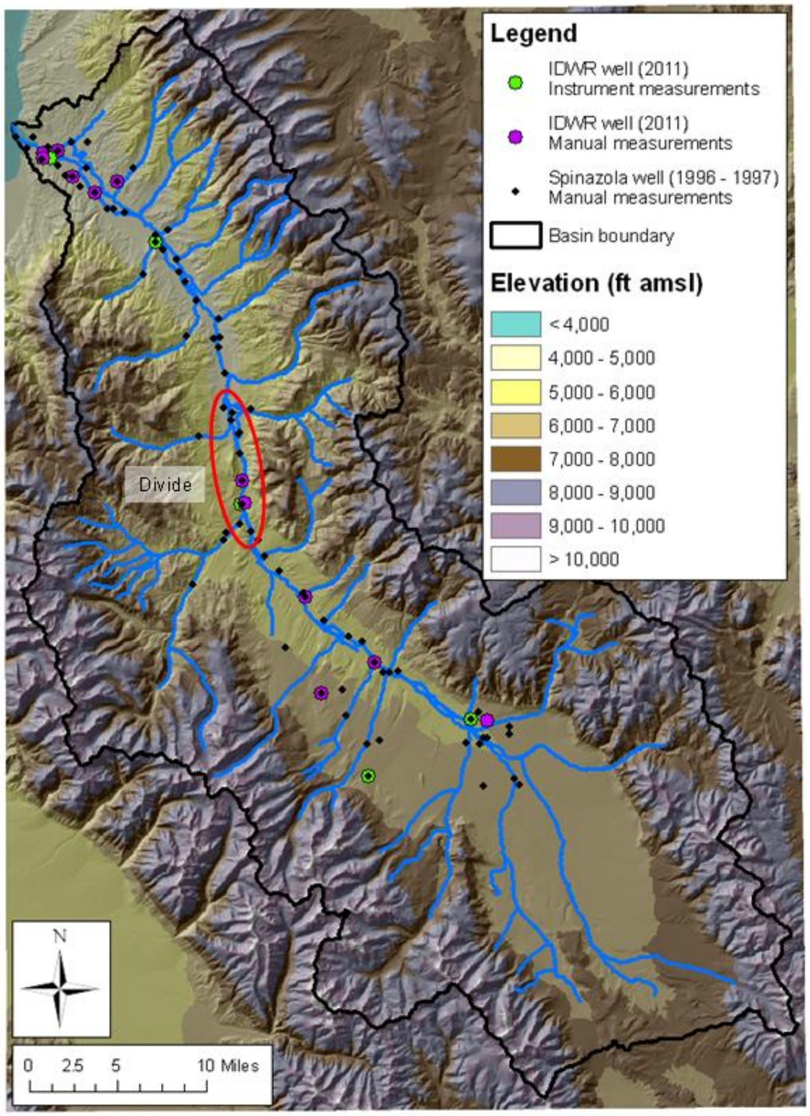


Figure 4.3.5 – Locations of well monitored by IDWR during this Project, and by Spinazola (1998) during 1996-1997.

Well	Agency	Period	Elevation (ft amsl)	Latitude (NAD 1983)	Longitude (NAD 1983)
BeyelerRental	IDWR	2011	5939	44.700	-113.367
Cheney	IDWR	2011	4048	45.160	-113.848
CockrellL	IDWR	2011	4070	45.165	-113.839
Fisher	IDWR	2011	4124	45.144	-113.822
Hayes	IDWR	2011	5669	44.746	-113.478
Jackson	IDWR	2011	4027	45.164	-113.856
Kibbee	IDWR	2011	5120	44.877	-113.625
McRea	IDWR	2011	6414	44.654	-113.485
McReaCemetery	IDWR	2011	6070	44.698	-113.349
OlsonV	IDWR	2011	4431	45.140	-113.771
Richardson	IDWR	2011	4185	45.131	-113.797
Snyder	IDWR	2011	5418	44.800	-113.556
Stout	IDWR	2011	5068	44.895	-113.628
Thomas	IDWR	2011	4043	45.159	-113.857
TylerS	IDWR	2011	6180	44.721	-113.538
Whitson	IDWR	2011	5112	44.876	-113.629
Adams	Spinazola	1996-1997	5343	44.847	-113.650
Allen	Spinazola	1996-1997	5317	44.853	-113.646
Andrews	Spinazola	1996-1997	4647	45.028	-113.655
Anglin	Spinazola	1996-1997	4889	44.944	-113.641
Bailey	Spinazola	1996-1997	3991	45.167	-113.875
BeyelerIrrigation	Spinazola	1996-1997	5975	44.684	-113.349
BeyelerRental	Spinazola	1996-1997	5938	44.700	-113.367
Bird	Spinazola	1996-1997	5207	44.932	-113.678
Bledsoe	Spinazola	1996-1997	4910	45.014	-113.691
CockrellL	Spinazola	1996-1997	4069	45.165	-113.839
CockrellR	Spinazola	1996-1997	4221	45.172	-113.823
Coleman	Spinazola	1996-1997	6084	44.645	-113.314
Colson	Spinazola	1996-1997	4748	45.064	-113.741
Daniels	Spinazola	1996-1997	4246	45.118	-113.782
Dart	Spinazola	1996-1997	6172	44.645	-113.355
Eastman	Spinazola	1996-1997	4877	44.951	-113.639
Elsworth	Spinazola	1996-1997	6063	44.651	-113.318
England	Spinazola	1996-1997	6174	44.703	-113.511
Ernest	Spinazola	1996-1997	4144	45.151	-113.806
Fisher	Spinazola	1996-1997	4124	45.144	-113.823
French	Spinazola	1996-1997	4077	45.153	-113.840
Goodell	Spinazola	1996-1997	4160	45.136	-113.813
Hayes	Spinazola	1996-1997	5669	44.746	-113.478
Hazlett	Spinazola	1996-1997	4238	45.118	-113.782
Herbst	Spinazola	1996-1997	4015	45.176	-113.868

Holscher	Spinazola	1996-1997	5552	44.768	-113.507
Howell	Spinazola	1996-1997	6038	44.724	-113.514
Isom1	Spinazola	1996-1997	6122	44.693	-113.323
Isom2	Spinazola	1996-1997	6100	44.688	-113.323
Jeffries	Spinazola	1996-1997	4047	45.169	-113.850
Jenson	Spinazola	1996-1997	4672	45.011	-113.661
Kauer	Spinazola	1996-1997	5415	44.803	-113.559
Kesl	Spinazola	1996-1997	4860	44.955	-113.649
Kossler	Spinazola	1996-1997	4982	44.917	-113.631
LeadoreAmbulance	Spinazola	1996-1997	5974	44.679	-113.357
Leathan	Spinazola	1996-1997	5965	44.684	-113.353
LoganD	Spinazola	1996-1997	4640	45.151	-113.751
LoganR	Spinazola	1996-1997	4408	45.091	-113.727
Mahaffey	Spinazola	1996-1997	5065	44.895	-113.628
Mathews	Spinazola	1996-1997	4119	45.145	-113.830
McKinney	Spinazola	1996-1997	5331	44.822	-113.586
McRea	Spinazola	1996-1997	6414	44.654	-113.485
Miller	Spinazola	1996-1997	4273	45.114	-113.762
Minor	Spinazola	1996-1997	4467	45.066	-113.700
Mulkey	Spinazola	1996-1997	4446	45.076	-113.702
Nirbaur	Spinazola	1996-1997	6040	44.706	-113.359
OlsonK	Spinazola	1996-1997	4386	45.172	-113.805
OlsonV	Spinazola	1996-1997	4430	45.140	-113.771
Phillips	Spinazola	1996-1997	3945	45.176	-113.887
Playfair	Spinazola	1996-1997	5192	44.854	-113.618
Probst	Spinazola	1996-1997	4665	45.013	-113.653
Rankin	Spinazola	1996-1997	4689	45.005	-113.655
Richardson	Spinazola	1996-1997	4183	45.131	-113.797
Sager	Spinazola	1996-1997	4400	45.084	-113.717
Sells	Spinazola	1996-1997	4751	44.984	-113.648
ShinerD	Spinazola	1996-1997	5278	44.834	-113.603
ShinerS	Spinazola	1996-1997	5326	44.847	-113.610
Shuff	Spinazola	1996-1997	5025	44.953	-113.617
Skinner	Spinazola	1996-1997	4439	45.101	-113.712
Slagg	Spinazola	1996-1997	5563	44.781	-113.535
Smith1	Spinazola	1996-1997	4971	44.935	-113.630
Smith2	Spinazola	1996-1997	4949	44.934	-113.633
SnookE	Spinazola	1996-1997	4497	45.058	-113.693
SnookQ	Spinazola	1996-1997	4550	45.043	-113.680
Snyder	Spinazola	1996-1997	5417	44.800	-113.556
Strupp	Spinazola	1996-1997	5982	44.759	-113.579
Summers	Spinazola	1996-1997	5645	44.764	-113.492

TaylorB	Spinazola	1996-1997	4361	45.097	-113.726
TaylorD	Spinazola	1996-1997	5221	44.860	-113.632
Thomas	Spinazola	1996-1997	4044	45.159	-113.857
Tonsmiere	Spinazola	1996-1997	5649	44.811	-113.686
TylerK1	Spinazola	1996-1997	5688	44.739	-113.461
TylerK3	Spinazola	1996-1997	5772	44.740	-113.451
TylerS	Spinazola	1996-1997	6180	44.721	-113.538
UdyIrrigation	Spinazola	1996-1997	6215	44.682	-113.472
Wagenkencht	Spinazola	1996-1997	5992	44.681	-113.374
Whitson	Spinazola	1996-1997	5111	44.876	-113.629
Whittaker	Spinazola	1996-1997	6258	44.682	-113.472
Young	Spinazola	1996-1997	5718	44.739	-113.468

Table 4.3.1 – Descriptive information for wells monitored by IDWR during the Project, and by Spinazola (1998) during 1996 – 1997.

The 2011 selected wells are classified as being in three general areas: along the divide, the Upper Lemhi upgradient of the divide, and the Lower Lemhi downgradient of the divide. The Spinazola wells are located across the Lemhi, primarily within the Lemhi River corridor, and 11 of these wells were chosen for monitoring in 2011 (i.e. 11 of the 16 wells monitored in 2011).

As discussed in Section 2, the divide is a key hydrologic area in the Lemhi because effectively all ground and surface water from the Upper Lemhi flows to the Lower Lemhi through this constriction, presumably via the Lemhi River channel (Donato 1998, Spinazola 1998). Thus, understanding the quantities and timing of ground and surface water passing through the divide may shed light on the contributions of irrigation and associated ground water recharge to the overall hydrology of the Lemhi.

Based on geologic mapping (Anderson 1956, Anderson 1961) and analyses of drill logs (Donato 1998, Spinazola 1998), the alluvial aquifer along the divide is both laterally and vertically constricted by shallow and outcropped bedrock formations. The width of the aquifer along the divide is estimated to be less than 0.5 mi, based on the distance between the east and west canyon walls flanking the Lemhi River corridor. Using data from Spinazola (1998) and IDWR analyses of additional drill logs, the aquifer in this area is approximately 30 ft thick with depths to water generally less than 10 ft below land surface (bls). In contrast, the aquifer upgradient and downgradient of the divide is much wider (i.e. greater than 1 mi), and is approximately twice as thick (if not greater) with greater depths to water. These physical characteristics, dictated by bedrock formations, suggest that a significant portion of the ground water flowing through this aquifer constriction may discharge to the surface (i.e. the Lemhi River) as it travels downgradient.

Figure 4.3.6 illustrates the general vicinity of the divide, along with the locations of the Spinazola and 2011 IDWR monitored wells. The wells in Figure 4.3.6 highlighted as divide corridor wells are those in close proximity to the Lemhi River and/or not located on bench ground flanking the corridor. Depths to water from these divide corridor wells can be tentatively analyzed to help describe the hydrologic processes occurring along the divide. Figures 4.3.7A – J are plots of depths to water measurements in the divide corridor wells, collected in 1996 – 1997 by Spinazola (1998) and by IDWR during this Project (i.e. 2011). Referencing Figure 4.3.6 above, the water level measurements exhibit a trend of decreasing depths to water until downgradient of McDevitt Creek. Further, seasonal fluctuations in ground water elevations are clearly apparent in several of these wells.

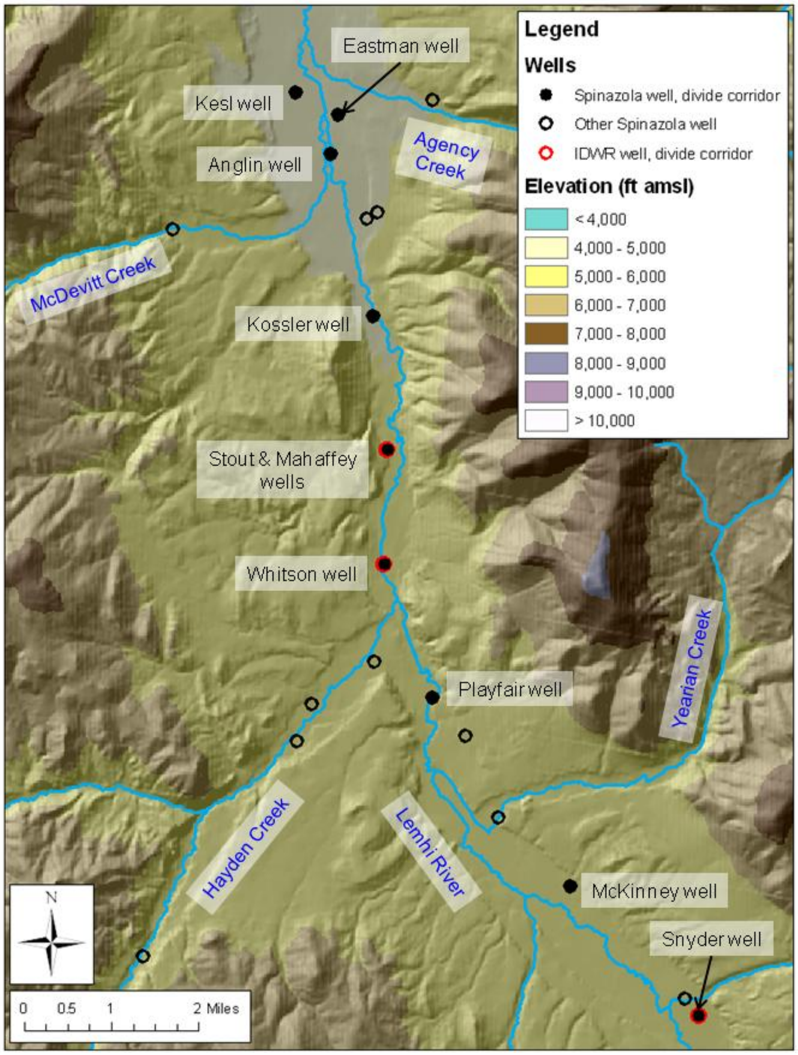
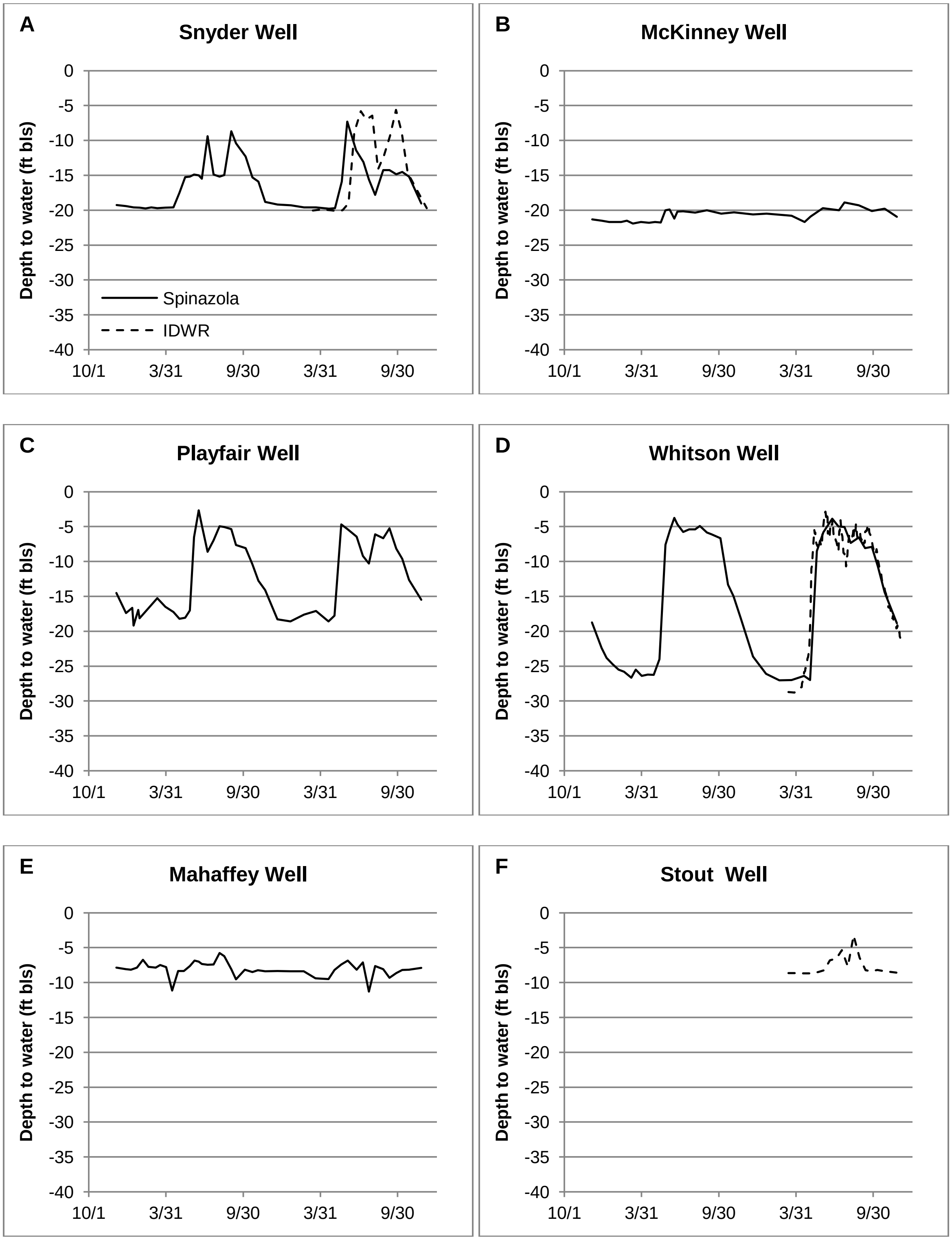
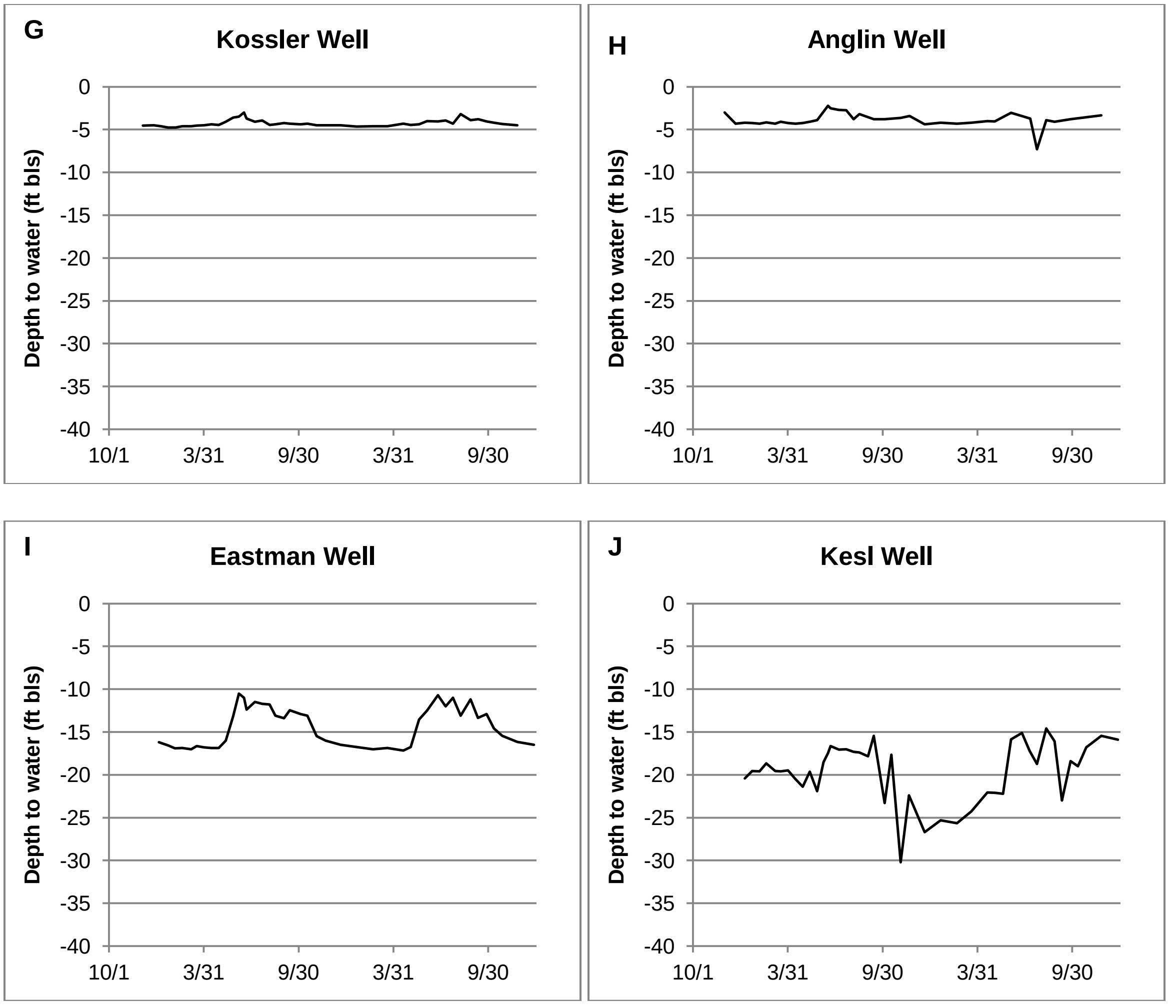


Figure 4.3.6 – Locations of wells monitored by IDWR during this Project, and Spinazola (1998) during 1996 – 1997, along the divide.


A
Snyder Well
Depth to water (ft bls)
0
-5
-10
-15
-20
-25
-30
-35
-40
10/1
3/31
9/30
3/31
9/30
Spinazola
IDWR
B
McKinney Well
C
Playfair Well
D
Whitson Well
E
Mahaffey Well
F
Stout Well



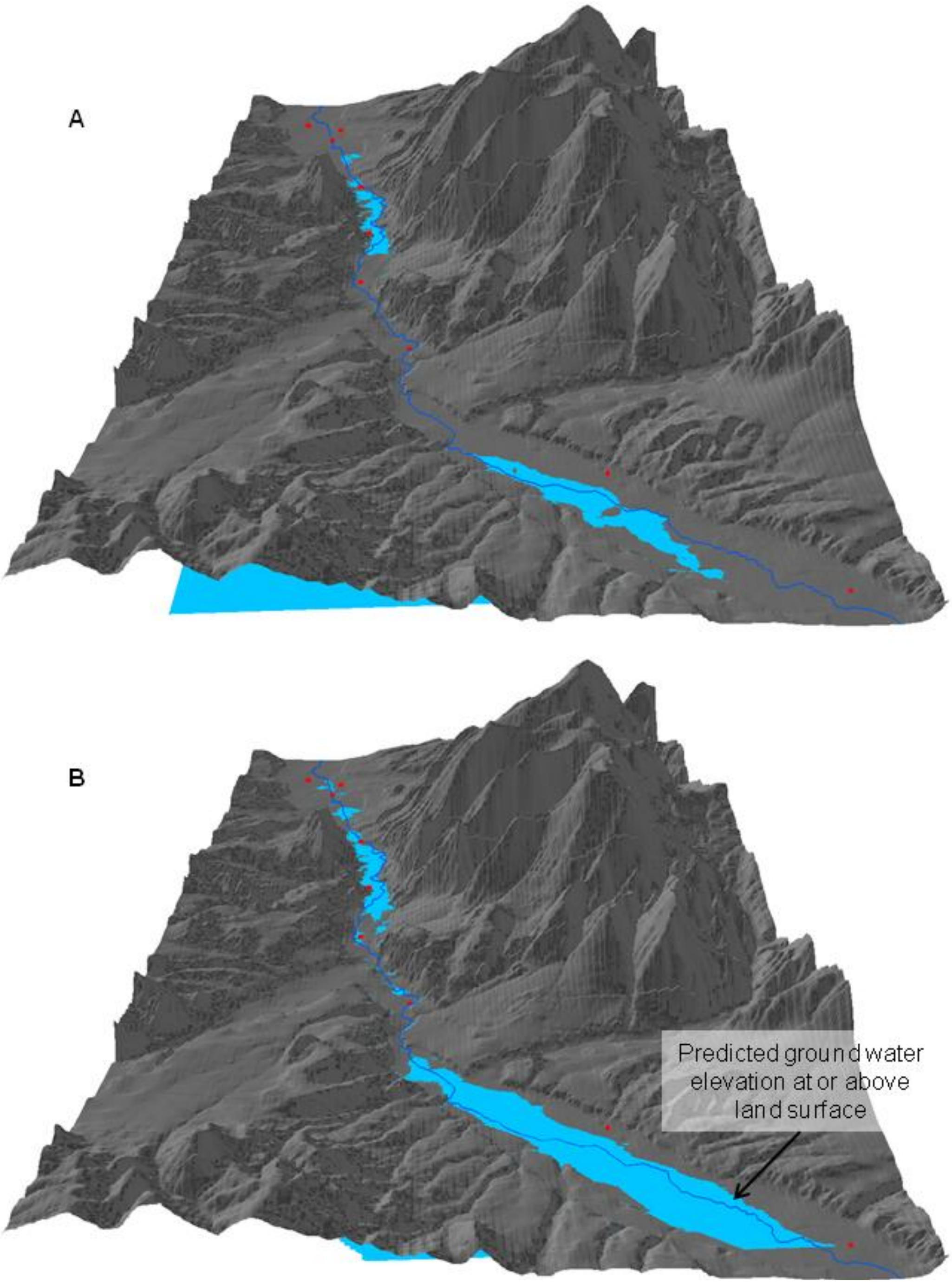
Figures 4.3.7A – J – Plots of depths to ground water in wells along the divide corridor measured by IDWR during this Project, and by Spinazola (1998) during 1996 – 1997.

The ground water measurements support the conclusions of previous researchers that a ground water traveling through the divide discharges to the Lemhi River (Donato 1998, Spinazola 1998). For example, referencing Appendices 1 and 2 and Figure 4, Donato (1998) estimated that greater than 160 cfs of ground water discharged to the Lemhi River between the approximate locations of the Snyder and Kesl wells (i.e. reaches 4 – 8 in the Donato report) in early August 1997. Geostatistics can also be utilized to visualize where ground water may rise to the land surface. Figures 4.3.8A and B illustrate the results of Ordinary Kriging applied to the minimum and maximum ground water elevations measured in the divide corridor wells (locations shown in the figures). Although incapable of incorporating ground water hydaulics to physically predict water table elevations, these spatial interpolation results do illustrate, based solely on land surface and assumed water table elevations, that ground water discharge is likely along much of the divide.

Another simplified approach can be employed to estimate the potential fraction of ground water flowing through the divide that discharges to the Lemhi River. Donato (1998) utilized basic geometric simplifications and Darcy’s Law to estimate the amount ground water underflow leaving the Lemhi (i.e. at the downgradient basin boundary near the town of Salmon). Using a similar approach to that employed by Donato with an approximate aquifer width of 0.75 mi (i.e. to account for the wider zones upgradient of the Playfair well and downgradient of the Kossler well), an estimated maximum aquifer thickness of 40 ft (i.e. based on IDWR analysis of drill logs), an average hydraulic gradient of 0.01, and an estimated average hydraulic conductivity of 40 ft/d (i.e. based on the Donato report and IDWR analysis of drill logs), the estimated specific discharge through the divide is 0.4 ft/d. In contrast, the average specific discharge of Donato's reaches 4 – 8 is approximately 40 ft/d (i.e. seepage rate normalized by average cross-sectional area), which is two orders of magnitude greater than the specific discharge (i.e. ground water flux through the divide) estimated with Darcy's Law. Thus, even if the average hydraulic conductivity is 4000 ft/d, the seepage rates measured by Donato account for effectively all of the ground water flowing through the divide.

A

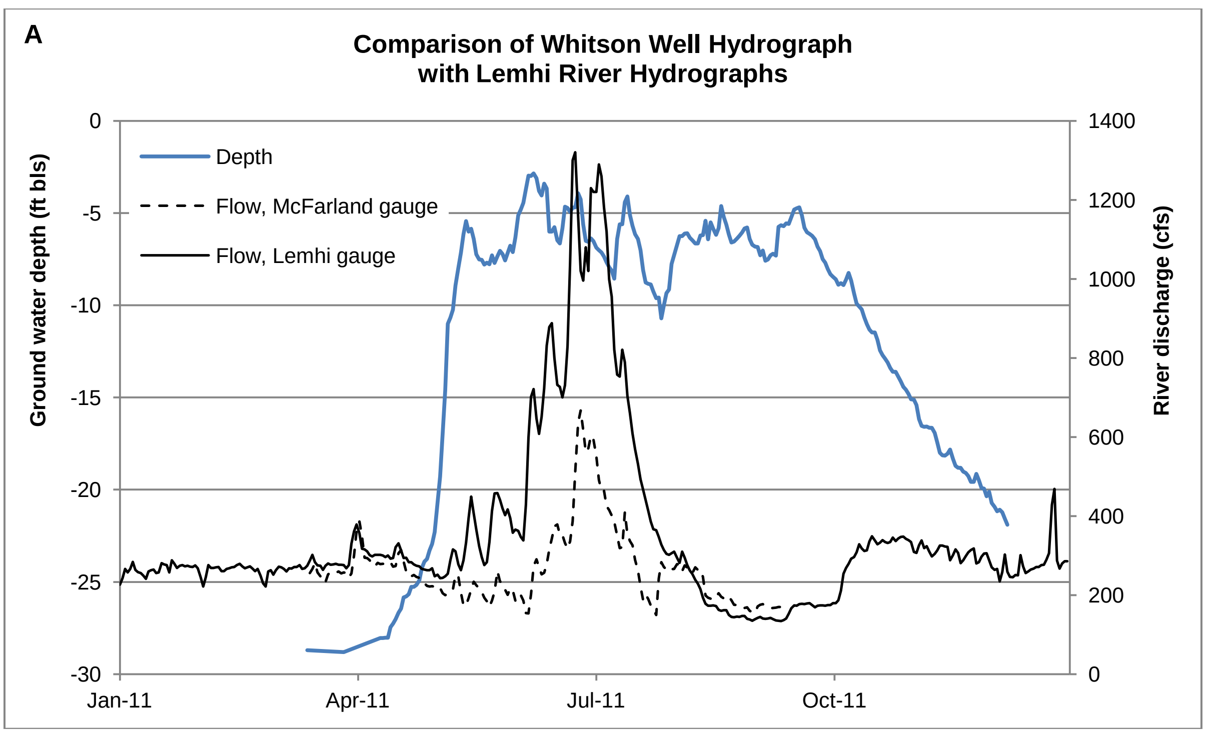
B

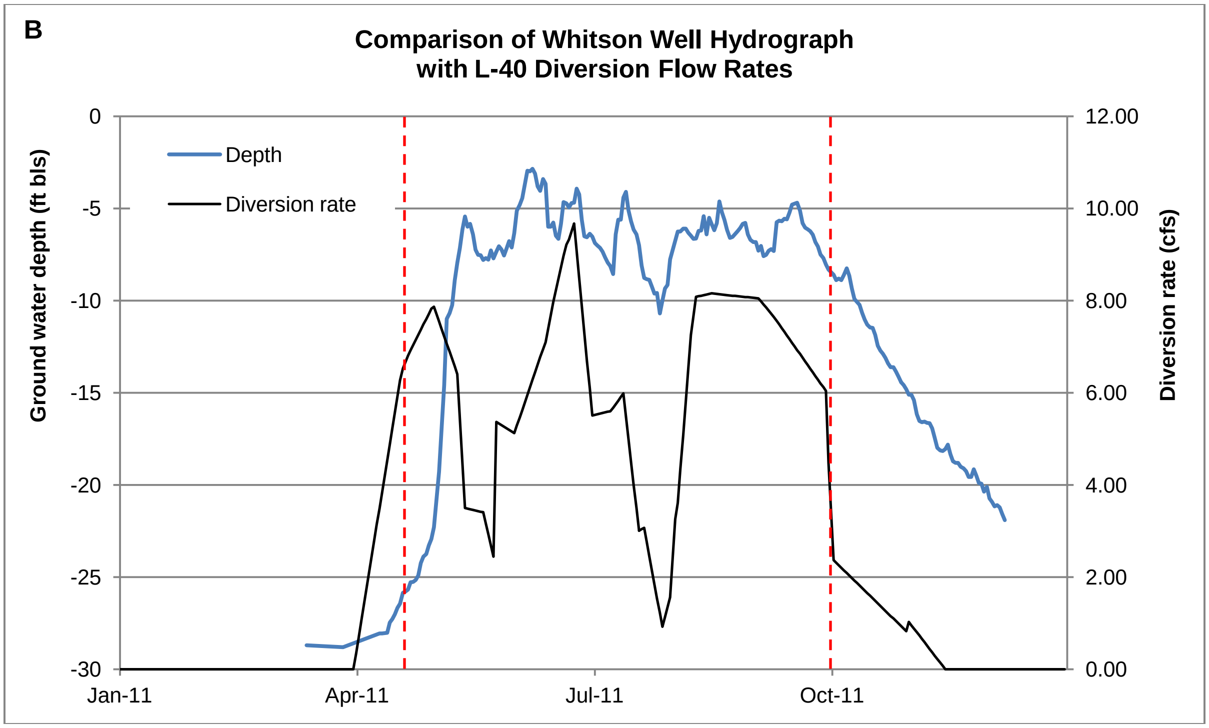


Figures 4.3.8A and B – Views of the divide (facing north) with water table elevations modeled from the divide corridor wells. Figure 4.3.8A displays the water table modeled from minimum ground water elevations, and Figure 4.3.8B displays analogous results using maximum ground water elevations.

Although the qualitative analyses above help support the overarching theory that Upper Lemhi ground water is primarily shuffled to the Lemhi River through the divide, what remains to be investigated are the factors contributing to ground water supplies (i.e. irrigation and spring runoff), specifically the cause(s) of seasonally enhanced water levels, as well as how much of the aquifer likely experiences seasonal fluctuations in water volume (i.e. the radial influence of higher well levels on the surrounding aquifer). Figure 4.3.9A is a plot of measured depths to ground water in the Whitson well (refer to Figure 4.3.6) and Lemhi River flows recorded at two gauges, one located 6.5 mi upstream (i.e. McFarland gauge) and one located 5 mi downstream (i.e. Lemhi gauge), during 2011. As shown, the temporal pattern of ground water elevation does not correspond well with the Lemhi River hydrographs, indicating some other factor dictates recharge to the alluvial aquifer in the vicinity of the Whitson well.

Figure 4.3.9B plots the measured depths to ground water in the Whitson well and average flow rates for the L-40 irrigation diversion, which serves the flood irrigation applied to the POU surrounding the well, for years 2008 – 2010 (i.e. 2011 diversion rates were not yet available at the time of this report). Although the diversion rates are not specific for 2011, the average hydrograph corresponds well with the temporal behavior of ground water elevation in the Whitson well. Further, per Rick Sager, the watermaster for WD 74, Mr. Whitson applied water to this POU every 10 days from April 20 – October 1, 2011, except for the latter part of July (i.e. during haying). The dashed lines in Figure 4.3.9B bracket the 2011 irrigation season for this POU. As shown, ground water rose sharply following the onset of flood irrigation, and slowly receded after irrigation was ceased. Further, the pronounced dip in elevation corresponds with the late July haying operations. Thus, the seasonal rise in ground water elevation observed in the Whitson well is primarily influenced by irrigation recharge, not spring runoff.





Figures 4.3.9A and B – Plots of depths to ground water measured in the Whitson well by IDWR during this Project vs. Lemhi River flows (A) and rates of diversion to the POU(s) flood irrigated around this well.

Although there is strong evidence supporting the influence of irrigation recharge on ground water as observed in the Whitson well, the radial extent of the recharge influence needs to be investigated. That is, the hydrologic impact of irrigation recharge cannot be assessed without knowing whether the enhanced ground water supplies are localized or wide spread. Further, analyses similar to the one presented above should be conducted across the Lemhi to determine which areas of the aquifer are impacted, if at all, by irrigation recharge vs. spring runoff.

One method of investigating the extent of irrigation recharge influence on the alluvial aquifer is mounding analysis. Hantush (1967) developed an analytical solution to the transient problem of unconfined ground water flow beneath an area experiencing uniform vertical percolation, such as that imposed by flood irrigation. The underlying theory is that the water table will rise up, or mound, beneath the recharge zone if the application, or percolation, rate exceeds the ability of the aquifer to transmit ground water, followed by a recession of water table elevation after the water application is ceased. Although flood irrigation application rates are rarely uniform or continuous, the Hantush method provides a relatively simple way to quantitatively estimate hydrogeologic processes occurring in response to irrigation, and aquifer properties – specifically hydraulic conductivity.

Figure 4.3.10 displays the location of the McRea well near upper Big Eightmile Creek, one of the 16 wells monitored by IDWR during this Project. Also shown is the approximate flood irrigation recharge zone (a simplification of the POU), the boundaries of the modeled local aquifer (which will be discussed below), and a generalized ground water flow path based on land surface elevation. Figure 4.3.11 provides a land surface view of the McRea well vicinity (viewing from south-southwest), illustrating the local topography.

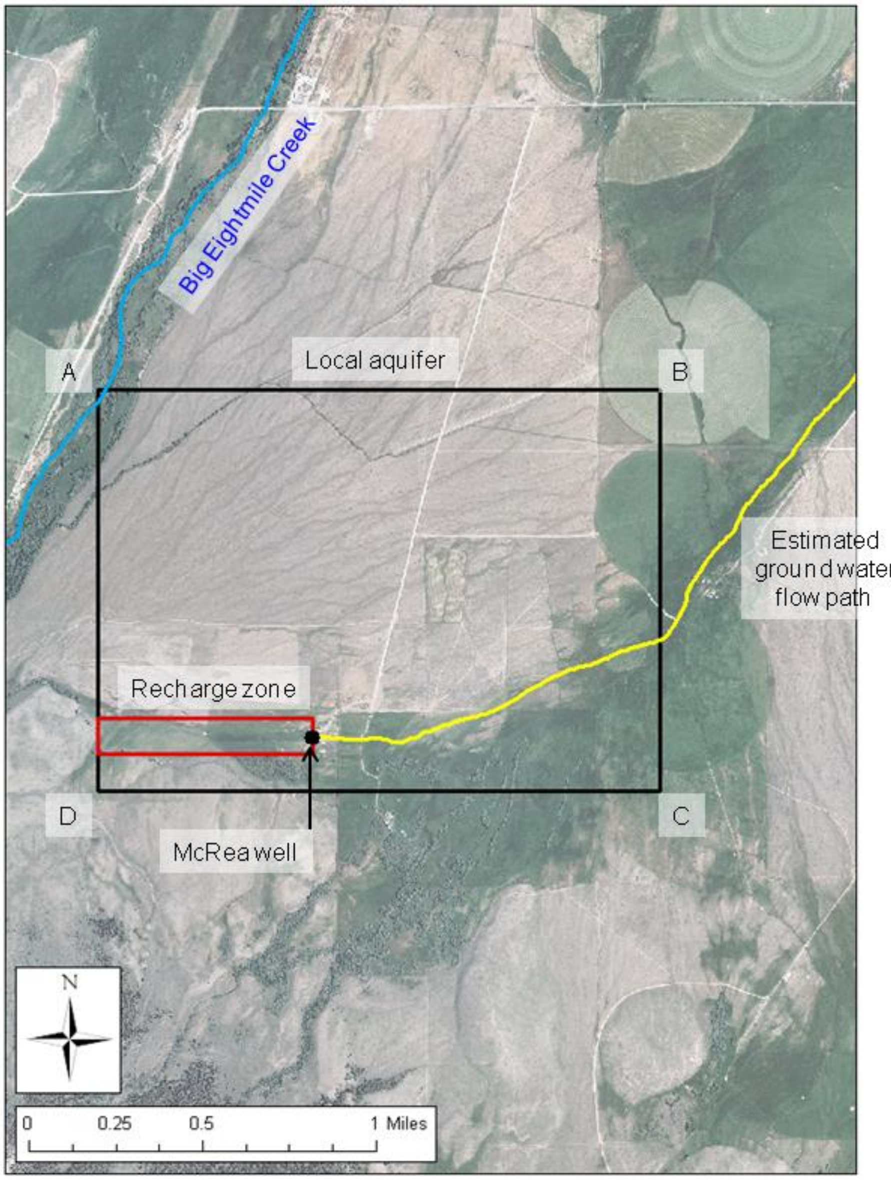


Figure 4.3.10 – Aerial view of the McRea well vicinity with modeled local aquifer and recharge zone boundaries shown, as well as an estimated ground water flow path based on land surface elevation.

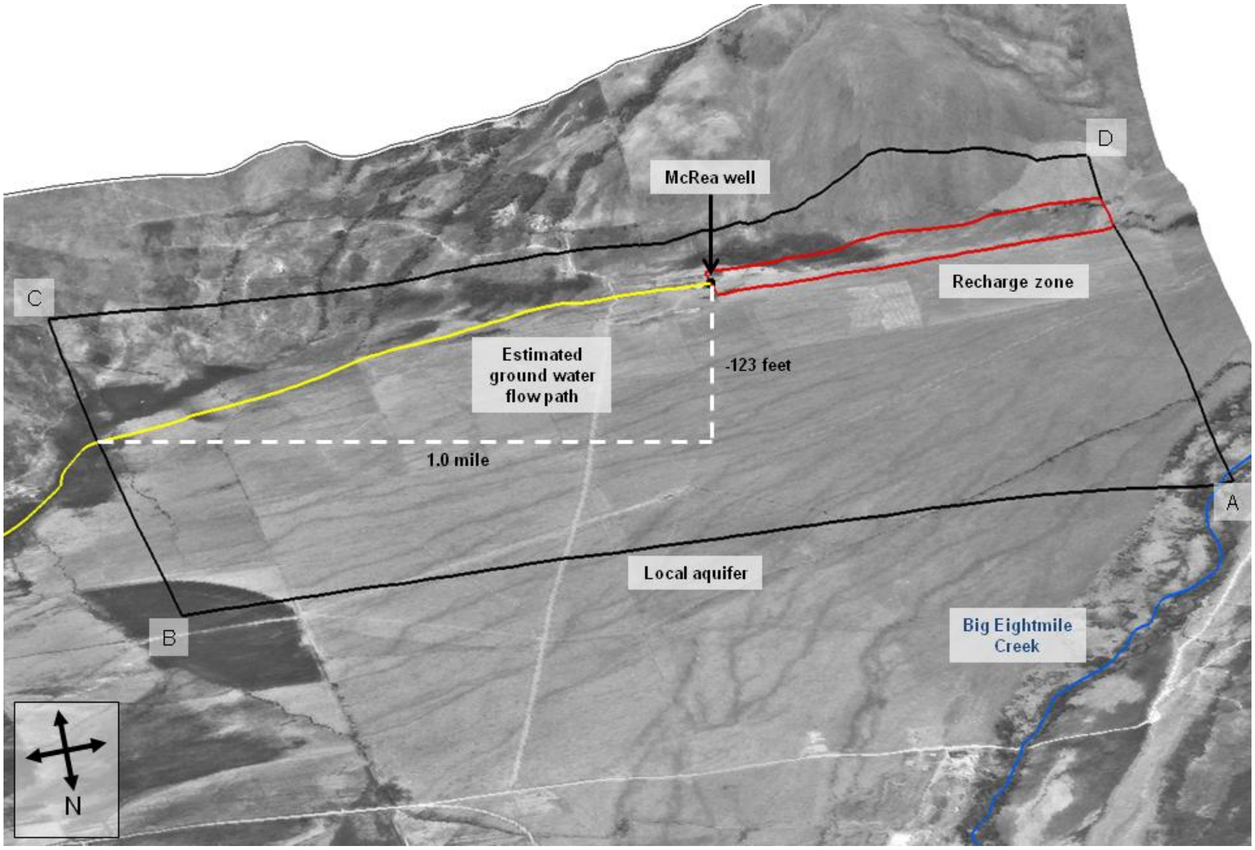


Figure 4.3.11 – Land surface view of the McRea well vicinity (facing south-southwest).

The recharge zone (i.e. POU) is flood irrigated with water diverted from Big Eightmile Creek at the BigEightmile-13 MBM diversion. The rates of diversion during 2011 were not yet available during the time of this report; however, during the irrigation seasons of 2008 – 2010, the average amount diverted at BigEightmile-13 was 9.25 cfs. Although it is unlikely that all of the water diverted at BigEightmile-13 is applied to the recharge zone (i.e. an adjacent POU is also served by this diversion), namely at a constant rate, IDWR assumed that a constant recharge zone application rate of 9.25 cfs during the 2011 irrigation season was reasonable for the purposes of this initial investigative analysis. Based on water rights associated with the POU represented by the recharge zone, a better approximation of the application rate might be 7 cfs; again, however, accounting for seepage from the ditch serving this and the adjacent POUs, as well as potential recharge from Big Eightmile Creek, 9.25 cfs was deemed appropriate for this initial analysis.

AQTESOLV software (v. 4.50 Professional), which incorporates the Hantush (1967) analytical solution for ground water mounding, was used to model the 2011 ground water measurements from the McRea well. Based on the local topography and spring systems to the east of the well, the local aquifer was modeled as having a constant head boundary along the BC boundary approximately 1 mi east of the well, to simulate ground water discharge to the surface along this section. The CD and AD boundaries were modeled as no flow boundaries to account for the rise in elevation to the south and west of the well (as well as the likelihood of aquifer confining bedrock outcroppings along the foothills). The AB boundary was set at 1 mi to the north of the well, to be consistent with the distance to the BC boundary, but was not specified as an aquifer boundary. Also, the initial saturated thickness of the local aquifer was assumed to be 50 ft, based on estimates from drill logs and iterative model runs, and the specific yield was estimated at 0.10 (Spinazola 1998).

Figure 4.3.12 displays the McRea well depths to water measurements collected during this Project and the results of the mounding analysis. The model assumed flood irrigation was started in late May and was ceased in early August, based on a conversation with the landowner (Sager 2011). As expected, the model does not simulate the shape of the well hydrograph exactly, namely early in the irrigation season, and this is likely due to variable application rates and/or the influence of spring runoff. Also shown in Figure 4.3.12 are stream flows recorded at the Upper Big Eightmile Creek gauge, located approximately 2.3 miles upgradient of the well. Based on the temporal behaviors of the well and stream hydrographs, it is difficult to dismiss that spring runoff had some effect on ground water recharge near the well. However, again, IDWR assumed a constant application rate of 9.25 cfs between late May and early August 2011 accounted for the overall recharge rate, from irrigation and spring runoff.

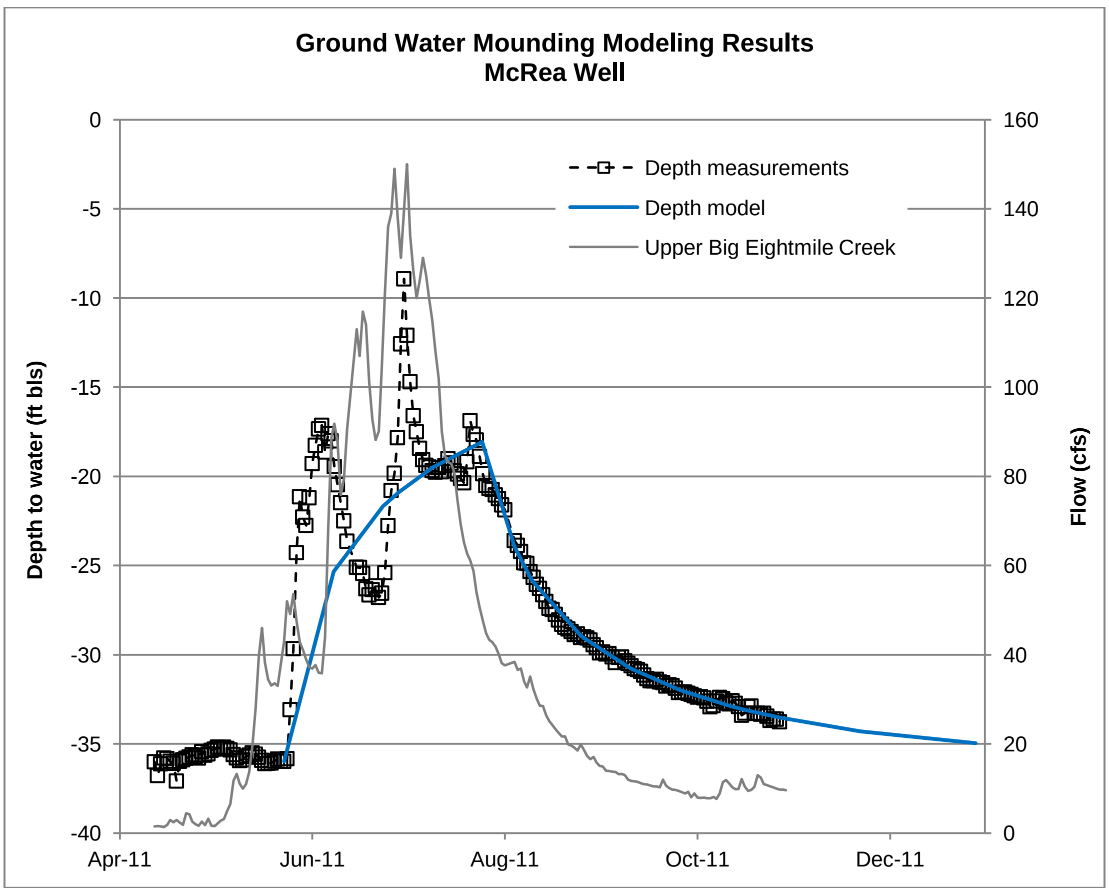


Figure 4.3.12 – Plot of depths to ground water measured in the McRea well by IDWR during this Project, results of the mounding analysis using the Hantush (1967) method, and flows recorded at the Upper Big Eightmile Creek gauge.

The utility of the mounding analysis model is evidenced by the fit of the recession limb of the model with the measured depths to water shown in Figure 4.3.12. The saturated hydraulic conductivity of the plotted model, determined by manual iterative convergence using AQTESOLV, was estimated to be 650 ft/d. Based on several iterations, this estimate appears reasonable within +/- 50%, given the assumptions of the modeled recharge zone and local aquifer, as well as the potential variability in recharge rate. Thus, IDWR assumes a probable range of conductivity for the aquifer near this well is 325 – 975 ft/d.

The example mounding analysis discussed above illustrates how well depth measurements can be utilized to estimate aquifer properties, specifically saturated aquifer thickness and hydraulic conductivity. Inherently, mounding analysis also provides insight into aquifer response to recharge. Figure 4.3.13 depicts a topographic output of AQTESOLV, illustrating the ground water mound modeled at 2 months following the cessation of water application (i.e. early October in Figure 4.3.12) to the recharge zone near the McRea well. As shown, with the AD and CD boundaries set as no flow boundaries, and the BC boundary (i.e. near spring systems) set as a constant head boundary, the ground water mound extends to and slightly beyond the AB boundary, which is at minimum 1 mi from the well. Thus, this example analysis suggests recharge occurring on POUs in the Upper Lemhi may impact the alluvial aquifer at distances greater than the "local" scale, namely where there are adjacent POUs.

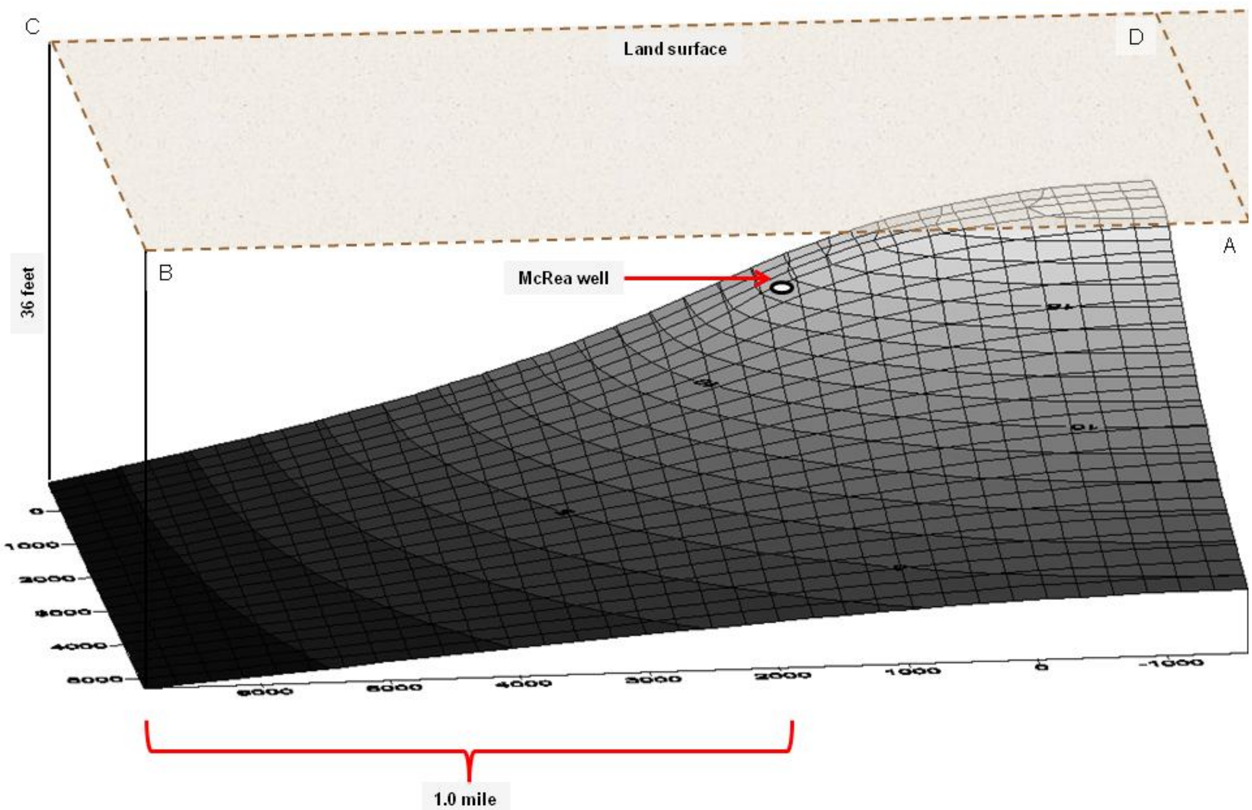


Figure 4.3.13 – Output of AQTESOLV using the Hantush (1967) method, illustrating the modeled ground water mound in the vicinity of the McRea well (facing south-southwest).

Thus far, the discussion on well data has highlighted the significance of irrigation, specifically flood irrigation, on seasonally enhancing ground water levels, and that aquifer response may extend well beyond the boundaries of the POUs irrigated. The other aspects of this discussion, however, are how and where irrigation-induced ground water recharge translates into stream flows, which are primary concerns for the USBWP Technical Team in planning stream flow enhancement projects.

Referencing the estimated range of saturated hydraulic conductivity for the local aquifer surrounding the McRea well (i.e. 325 – 975 ft/d), and assuming appropriate ranges for aquifer porosity and hydraulic gradient, a bracket for expected ground water velocity in this vicinity can be determined. Based on the USGS Digital Elevation Model (DEM, 30 m resolution) of the Lemhi, the hydraulic gradient between the McRea well and the Upper Lemhi River corridor, assuming the water table generally mimics the land surface topography, ranges between 0.01 and 0.025. Assuming an effective aquifer porosity between 0.15 and 0.35 (McWhorter and Sunanda 1977), encompassing the range of silty and gravely sands composing the alluvial aquifer (Donato 1998, Spinazola 1998), the expected average linear velocity for ground water traveling from the McRea well downgradient is 14 – 160 ft/d. These velocities equate to an estimated return time for irrigation water applied to the POU near the well of 1 – 12 months per mile between the POU and ground water discharge locations.

The information presented throughout Section 4.3.3 supports the efforts of IDWR and the collaborating USBWP at collecting depths to ground water measurements in wells throughout the Lemhi. The mounding analysis presented above for the McRea well could be extended to many other measurement data sets from wells in areas where the alluvial aquifer is identified as being impacted by irrigation recharge, such as discussed above using the Whitson well as an example. Initial estimates of saturated hydraulic conductivity, ground water velocity, and irrigation return times across much of the Lemhi could be determined in this manner, which could be utilized in hydrologic models to further assist the USBWP Technical Team plan and monitor stream flow enhancement projects.

4.4 <u>Reconstruction of the Upper Lemhi MBM</u>

4.4.1 Motivations

Since 2002, IDWR has utilized empirical hydrologic models based on MIKE BASIN software to describe the Lemhi River Basin (DHI 2003). These previous models were designed by DHI, Inc. and IDWR to describe the distribution and usage of surface water across the basin, accounting for the main stream systems, irrigation points of diversion (PODs), and irrigation places of use (POUs), to aid the USBWP Technical Team in planning stream flow enhancement projects. The previous models were not originally intended to account for all of the hydrologic processes affecting stream flows (Borden 2010), and data limitations prevented the degree to which the previous models could be physically based.

In the previous Upper Lemhi MBM, return flows accounted for the fraction of water diverted (i.e. extracted) for irrigation that reentered the stream system, where this water re-entered, and specified the lag time between diversion and re-entry. The return fraction was calculated as the relative amount diverted that was in excess of the consumptive use of the crop(s) served (DHI 2006), and was thus pseudo-physically based. However, due to data limitations at the time, the return locations and lag times were largely estimated through conversations with watermasters, water users (i.e. irrigators and landowners), and project collaborators, as well as through model calibrations (Borden 2010). Further, the return fractions were not modeled as first contributing to ground water prior to reentering the stream system. Thus, because the unconfined alluvial aquifer was not incorporated in the previous model, the return flow network lacked a solid physical basis – that is, the return fractions were not routed through a ground water system and could not be characterized as augmenting the subsurface reservoir.

Further, because the previous model's irrigation diversion and return flow networks were largely based on numerous conversations with watermasters, water users, and project collaborators, the physical accuracy and applicability of these networks could not be verified without revisiting every feature in person and/or through similar conversations. Because changes to PODs, POUs, and amounts diverted occur every year through many stream flow enhancement projects, the ability to continually verify and modify the modeled diversion and return flow network based on available and/or collected data is crucial to maintaining and improving the utility of the MBM.

Also, when the previous model was originally designed, certain data and analysis tools were unavailable, such as more accurate meteorological (i.e. precipitation, temperature, and evapotranspiration) data and computer scripts to spatially interpolate this data across watersheds. Because inflows of the MBM (i.e. stream flows fed by runoff from snow melt and rainfall) are derived through calibrations of a separate precipitation-runoff model (i.e. MIKE 11 NAM), changes to input data and/or analysis techniques that feed into MIKE 11 NAM require that many aspects of the MBM be reevaluated. Specifically, updating the input stream flows requires that irrigation return flows are reconsidered (i.e. better calibrated stream flows illustrate where return flows occur and where they likely to do not). Further, several stream gauges were not installed in the Upper Lemhi until 2008 (see Table 4.1.2); thus, the previous model could only be calibrated in a limited fashion.

Additionally, as implied above, the previous model was not designed with the physical basis necessary to answer the complex questions regarding interactions between irrigation, ground water, and stream flows. In addition to the return flow network lacking a solid physical basis, the previous model, due again to a lack of available data at the time, did not account for every stream or catchment contributing flow to the Upper Lemhi River, or the irrigation diversions/return flows in these areas. To identify, quantitatively, the timing and sources of stream flows in the Upper Lemhi, the model should account for all discernible hydrologic processes. Specifically, this includes the physical extent of the ground water aquifer, the sources of ground water, and the timing and amount of ground water flow to tributaries and the Upper Lemhi River.

There were four goals of rebuilding the Upper Lemhi MBM: 1) ensure IDWR is providing an accurate and useful tool for our project partners planning stream flow enhancement projects; 2) develop a transparent and reproducible technical workflow for the entire MBM process, from gathering input data to calibrating and running the MBM; 3) structure the MBM to be more physically based; and 4) enable the incorporation of ground water data during the 2012 – 2013 grant period.

The first goal is simply a continuation of the original aim of IDWR's involvement in the greater USB. The complicated nature of irrigation-altered river basin hydrology necessitates the use of a model to assess the hydrologic benefits and costs of irrigation practices at multiple scales. The second goal stems from the limited duration appointment of the IDWR hydrologist position. It is imperative that all functions of the MBM process are well documented and repeatable based on the data available to IDWR so as to prevent the utility of the MBM being hindered by turnover in the position. Lastly, the third and fourth goals are designed to help answer the more complicated questions posed by and to the USBWP Technical Team regarding the interactions between irrigation, ground water, and stream flows, which are the primary foci of IDWR's involvement in the Lemhi, and the greater USB, during 2012 and 2013.

4.4.2. Modifications

4.4.2.1 Catchments and Aquifer Features

As mentioned above, the design of the previous model was meant to capture the main surface flows in the Upper Lemhi, but not to quantitatively account for all sources – such as snow melt runoff from all high elevation catchments and discharge from the unconfined alluvial ground water aquifer. Figure 4.4.2 displays the reach and catchment structure of the previous Upper Lemhi MBM. The Little Springs and Big Springs catchments (i.e. in purple in Figure 4.4.2) were each constructed with an underlying pseudo-aquifer feature. The recharge to, discharge from, and properties of these pseudo-aquifer features were calibrated parameters; that is, no physical basis was used to characterize these features (i.e. aquifer thickness, porosity, etc.). Table 4.4.1 lists the stream reaches and catchments utilized in the previous model. The Reach Gain/Loss features listed in Table 4.4.1 were additional calibrated features to compensate for where modeled flows over- or under-predicted observed flows. Figure 4.4.3 illustrates the Eighteenmile Reach Gain/Loss feature, which is essentially a mock catchment populated with the calibrated gains/losses.

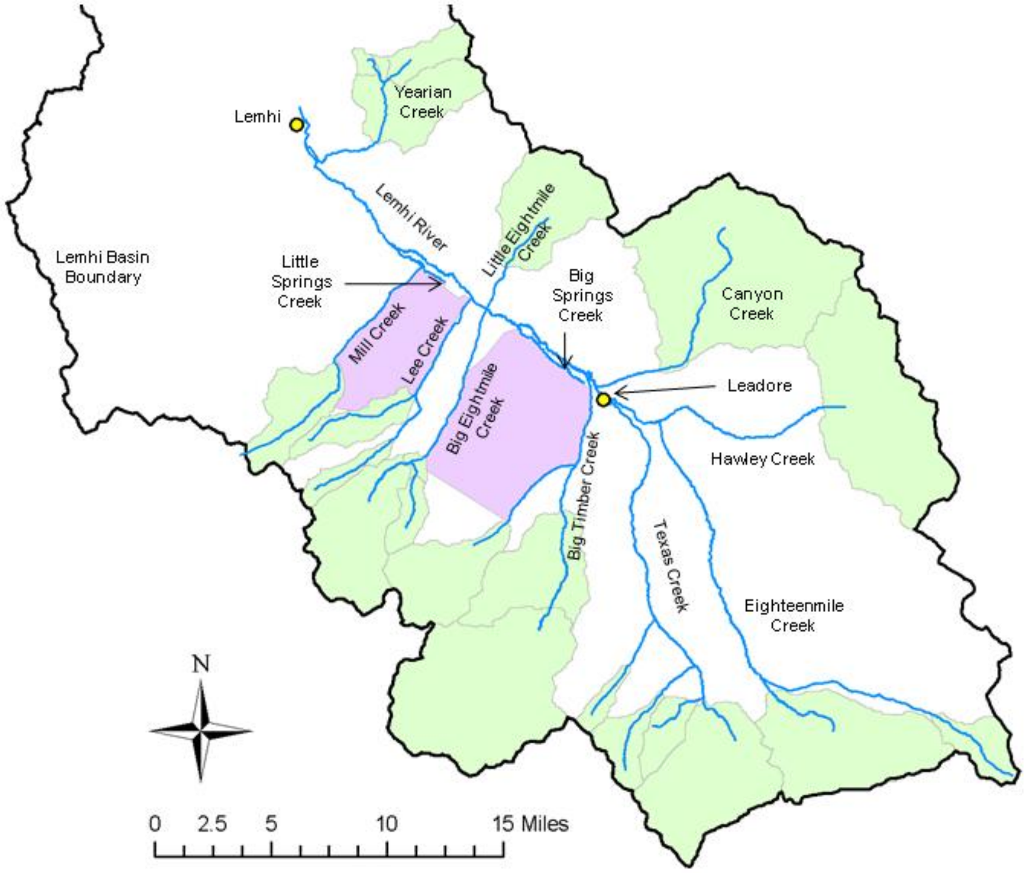


Figure 4.4.2 – Reach and catchment feature structure of the previous Upper Lemhi MBM.

Feature	Name	Feature	Name
Stream	Big Eightmile, Lower	Catchment	Big Eightmile, Lower
Stream	Big Eightmile, Upper	Catchment	Big Eightmile, Upper
Stream	Big Springs	Catchment	Big Springs
Stream	Big Timber, Lower	Catchment	Big Timber, Lower
Stream	Big Timber, Upper	Catchment	Big Timber, Upper
Stream	Canyon	Catchment	Canyon
Stream	Deer	Catchment	Deer
Stream	Devils Canyon	Catchment	Devils Canyon
Stream	Divide	Catchment	Divide
Stream	Eighteenmile	Catchment	Eighteenmile
Stream	Everson-Stroud	Catchment	Everson-Stroud
Stream	Hawley	Catchment	Hawley
Stream	Lee	Catchment	Lee
Stream	Lemhi, Upper	Catchment	Little Eightmile
Stream	Little Eightmile	Catchment	Little Springs
Stream	Little Springs	Catchment	Little Timber
Stream	Little Timber	Catchment	Mill
Stream	Mill	Catchment	Negro Green
Stream	Negro Green	Catchment	Sourdough Gulch
Stream	Sourdough Gulch	Catchment	Texas
Stream	Texas	Catchment	Yearian, Lower
Stream	Yearian, Lower	Catchment	Yearian, Upper
Stream	Yearian, Upper	Catchment	Yearian, West Fork
Stream	Yearian, West Fork	Aquifer	Big Springs
Reach Gain/Loss	Big Timber	Aquifer	Little Springs
Reach Gain/Loss	Eighteenmile		

Table 4.4.1 – List of physical features in the previous Upper Lemhi MBM.

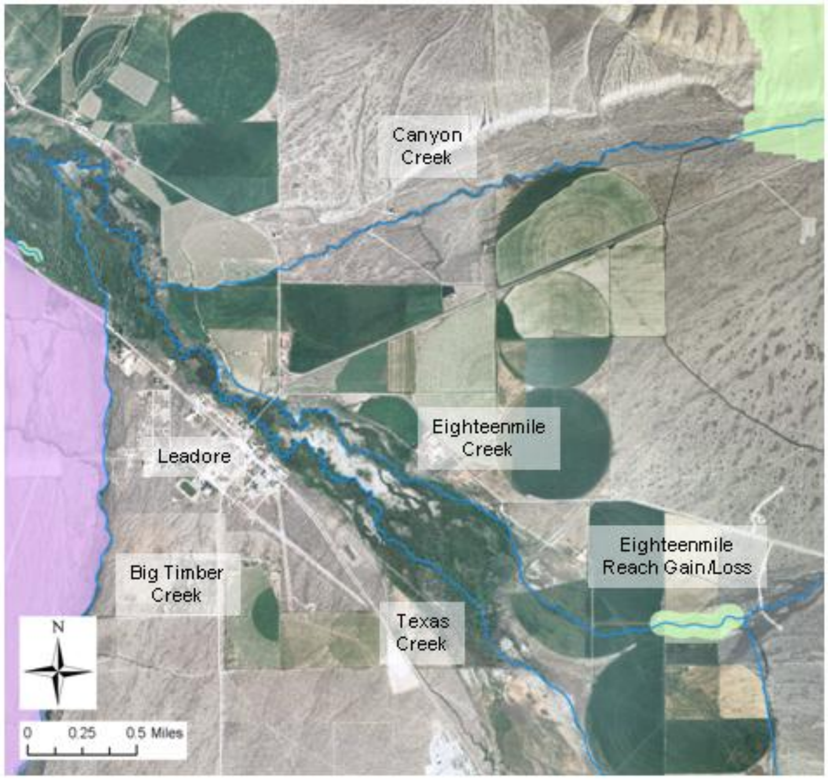


Figure 4.4.3 – View of previous Upper Lemhi MBM displaying the Eighteenmile reach/gain loss feature used to aid in model calibrations.

Based on data collected by IDWR and the USBWP during this Project, as well as the reports of Spinazola (1998) and Donato (1998), the unconfined alluvial ground water aquifer in the Upper Lemhi is a significant reservoir of water. Therefore, determining the recharge to the aquifer and the physical properties governing the locations, timings, and amounts of discharge from this system is vital to quantitatively describing the Upper Lemhi hydrology. Thus, during the rebuilding of the Upper Lemhi MBM, several aquifer features, that together encompass nearly all lower elevation zones where the physical ground water aquifer is a significant hydrologic component, were added to the model. Additionally, all high elevation zones in the Upper Lemhi were assigned one or more catchments and associated stream reaches, as well as associated aquifer features, to account for both the direct runoff contributions and indirect ground water recharge from these zones.

Figure 4.4.4 displays the reach, catchment, and aquifer structure of the rebuilt Upper Lemhi MBM. All of the previously delineated catchments were re-delineated based on the U.S. Geological Survey (USGS) Digital Elevation Model (DEM, 30 m resolution) and National Hydrography Dataset (NHD) hydrologic unit code (HUC, level 12 hydrologic unit) shapefiles on file with IDWR. Because customized levels of resolution were required to delineate the model catchments, an array of Esri ArcGIS and MIKE BASIN tools were utilized to segregate or merge HUC shapefiles based on DEM data. Although ground water boundaries can be quite different from surface water boundaries, this information for the Upper Lemhi was not available during this Project; thus, a process equivalent to that utilized for catchment delineation was employed to classify the aquifer feature boundaries. The unclassified zone paralleling and encompassing the Upper Lemhi River corridor was designed as a placeholder for one or more additional aquifer features that may be added in the future to account for observed reach gains and/or losses along the river. The flow paths of the additional tributaries where new catchments were constructed were determined using NHD flowlines. Table 4.4.2 lists all of the physical features incorporated in the rebuilt Upper Lemhi MBM.

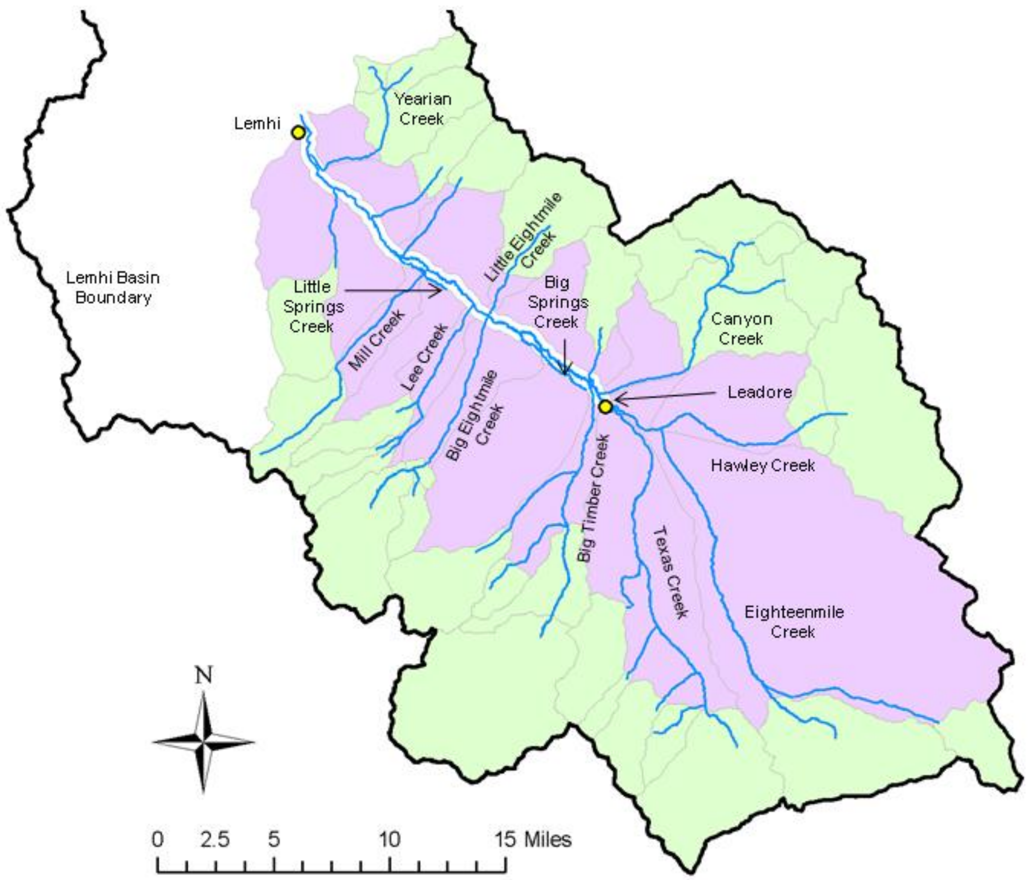


Figure 4.4.4 – Reach, catchment, and aquifer feature structure of the rebuilt Upper Lemhi MBM.

Feature	Name	Feature	Name	Feature	Name
Stream	Alder-Zeph	Catchment	Alder-Zeph	Aquifer	Alder-Zeph
Stream	Basin	Catchment	Basin	Aquifer	Big Eightmile
Stream	Big Eightmile	Catchment	Big Eightmile, Lower	Aquifer	Big Springs
Stream	Big Timber	Catchment	Big Eightmile, Upper	Aquifer	Big Timber
Stream	Canyon	Catchment	Big Timber, Lower	Aquifer	Canyon
Stream	Chippie	Catchment	Big Timber, Upper	Aquifer	Canyon-Hawley
Stream	Cruikshank	Catchment	Canyon	Aquifer	Eighteenmile
Stream	Deer	Catchment	Chippie	Aquifer	Hawley
Stream	Devils Canyon	Catchment	Cruikshank	Aquifer	Jakes Canyon
Stream	Divide	Catchment	Deer	Aquifer	Lee
Stream	Eighteenmile	Catchment	Devils Canyon	Aquifer	Little Eightmile
Stream	Everson	Catchment	Divide	Aquifer	Little Springs
Stream	Hawley	Catchment	Eighteenmile	Aquifer	Mill
Stream	Hood Gulch	Catchment	Everson	Aquifer	Peterson
Stream	Jakes Canyon	Catchment	Hawley, Lower	Aquifer	Reese
Stream	Lee	Catchment	Hawley, Upper	Aquifer	Texas
Stream	Lemhi, Upper	Catchment	Hood Gulch	Aquifer	Yearian
Stream	Little Eightmile	Catchment	Jakes Canyon		
Stream	Little Timber	Catchment	Lee		
Stream	Mill	Catchment	Little Eightmile		
Stream	Negro Green	Catchment	Little Timber		
Stream	Peterson	Catchment	Mill		
Stream	Purcell	Catchment	Negro Green		
Stream	Reese	Catchment	Peterson		
Stream	Sourdough Gulch	Catchment	Purcell		
Stream	Stroud	Catchment	Reese		
Stream	Texas	Catchment	Sourdough Gulch		
Stream	Yearian	Catchment	Stroud		
Stream	Yearian, West Fork	Catchment	Texas		
		Catchment	Yearian, Lower		
		Catchment	Yearian, Upper		
		Catchment	Yearian, West Fork		

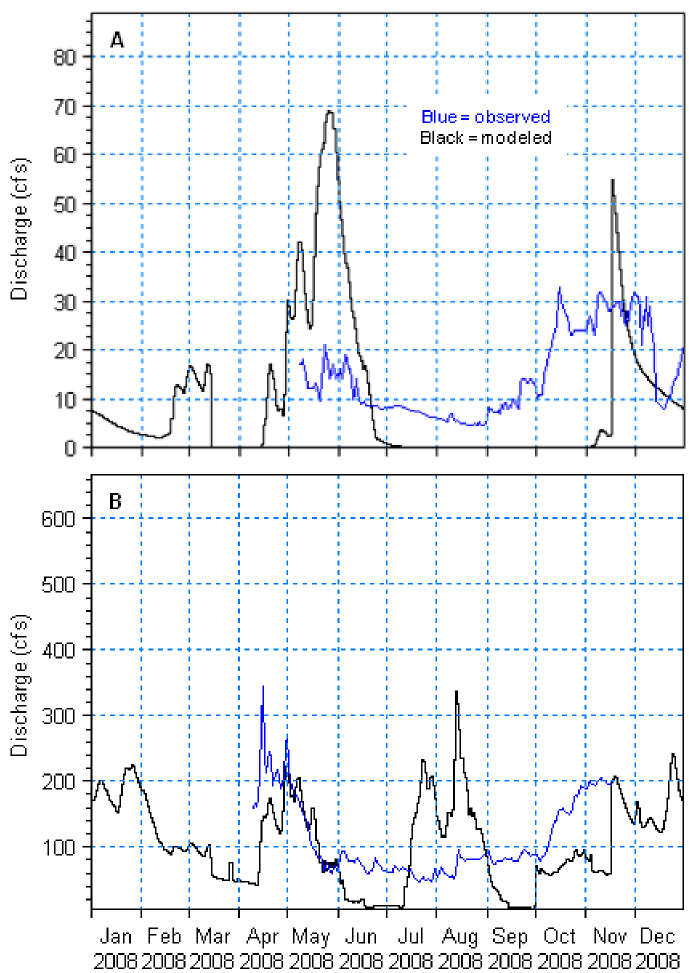
Table 4.4.2 – List of physical features in the rebuilt Upper Lemhi MBM.

4.4.2.2 Calibrating Input Stream Flows

The primary motivation for rebuilding the Upper Lemhi MBM was enhancing its accuracy at modeling and predicting stream flows. Figures 4.4.5A and B display the flows observed along the Upper Lemhi River at gauges just upstream of the town of Leadore (i.e. L-63 gauge) and downstream between the confluences of Little Springs Creek and Hayden Creek with the Upper

Lemhi River (i.e. McFarland gauge), respectively, along with the flows modeled with the previous Upper Lemhi MBM. Refer to Figure 4.1.2 and Table 4.1.2 for stream gauge details. As shown, the modeled flows do not coincide well with those observed during 2008 – the last year the previous model was updated with data.

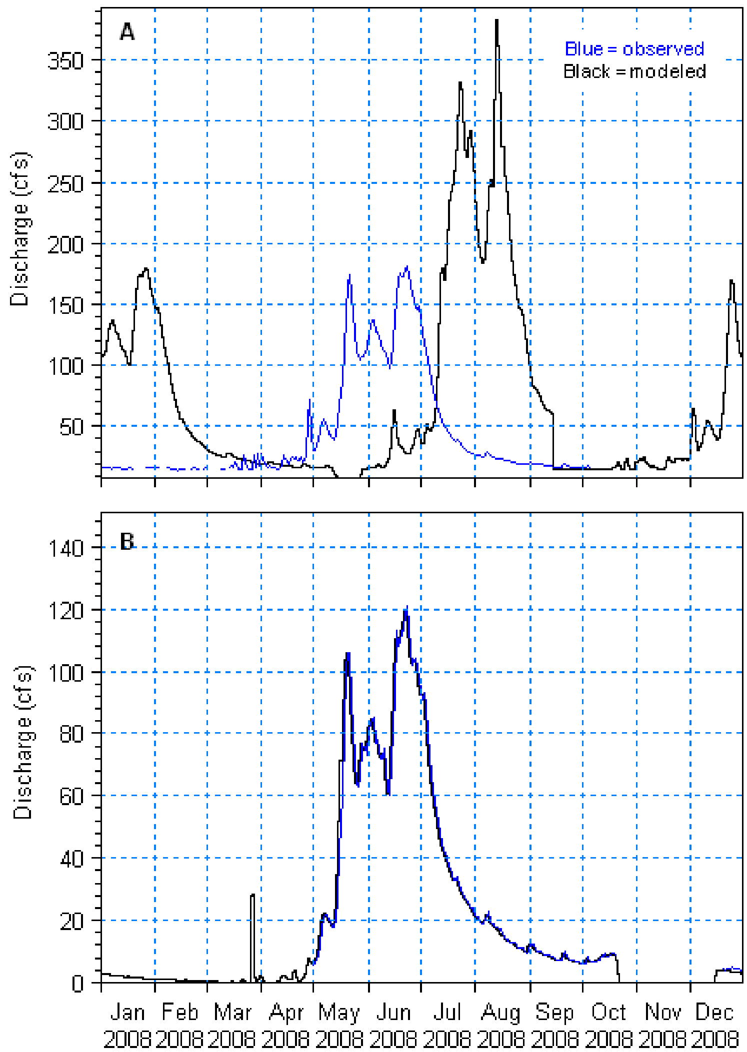
There are several reasons for the discrepancies seen in Figures 4.4.5A and B, the most notable of which is a lack of well calibrated tributary stream flows. As previously mentioned, several stream gauges were not installed until 2008; thus stream flows were not accurately known across the Upper Lemhi when the previous model was last updated. The separate precipitation-runoff model (i.e. MIKE 11 NAM) used to calibrate MBM input stream flows (i.e. stream flows fed by snow melt and rainfall from the high elevation catchments) requires a meticulous, iterative approach to determine catchment properties that yield close approximations to observed stream flows. To ensure calibrated catchment properties reflect realistic conditions, knowledge of stream flow response to snow melt and rainfall across the model domain is necessary. Thus, the limited number of stream gauges available to IDWR and DHI, Inc. prior to this Project likely hindered the accuracy of MBM input stream flows.



Figures 4.4.5A and B – Upper Lemhi River flows modeled with the previous Upper Lemhi MBM at the L-63 and McFarland gauges, respectively, along with flows observed at these gauges, during 2008.

Figure 4.4.6A displays the flows observed at the outlet of the Big Timber catchments (i.e. Upper Big Timber gauge, refer to Figure 4.1.2 and Table 4.1.2), along with the flows modeled by the previous Upper Lemhi MBM. As shown, the modeled flows significantly overestimate the quantity and incorrectly model the timing of runoff from the catchments during 2008 – the last year the previous model was updated with data. Because well calibrated runoff simulations were not possible for many catchments in the previous model, available observed flows (i.e. stream gauge data) were used as the MBM input stream flows (i.e. vs. model calibrated flows) in many cases. Figure 4.4.6B illustrates an example of where this approach was utilized, for the outlet of the Upper Big Eightmile and Devils Canyon catchments (i.e. Upper Big Eightmile gauge, refer to Table 4.1.2). As shown, the observed and "modeled" flows coincide exactly for the majority of 2008. However, this approach is not very useful, given, for instance, that several catchment outlets do not have stream gauges.

The primary need for the Upper Lemhi MBM is to assist the USBWP Technical Team in planning stream flow enhancement projects, where predicting stream flows during a variety of hydrologic conditions (i.e. dry years vs. wet years) is required. Inadequate runoff calibrations, or utilizing observed flows in place of calibrated flows, imply the previous model will not respond appropriately to varying climatological conditions. Figures 4.4.6A and B demonstrate that the previous Upper Lemhi MBM lacked the physical basis required to accurately model and predict runoff into Big Timber Creek and Big Eightmile Creek. Because these issues were not isolated to just two tributaries, but extended to many others, the modeled flows in the Upper Lemhi River, also lack a physical basis and are inaccurate (refer to Figures 4.4.5A and B).



Figures 4.4.6A and B – Big Timber Creek and Big Eightmile Creek flows modeled with the previous Upper Lemhi MBM at the upper Big Timber Creek and upper Big Eightmile Creek gauges, respectively, along with flows observed at these gauges, during 2008.

As previously mentioned, rebuilding the Upper Lemhi MBM involved re-delineating and adding catchments and aquifer features. This task was performed to structure the model in a more physical sense – that is, to span the model domain with hydrologic reservoirs. The next step was calibrating runoff from the catchments to observed flows (i.e. stream gauge data) using MIKE 11 NAM, the external precipitation-runoff model. This involved a series data gathering and preprocessing steps, including topographically and meteorologically characterizing the catchments, which are described below.

Precipitation and Temperature

Any precipitation-runoff model requires accurate precipitation data. In an area like the Upper Lemhi, where snow melt is the primary driver of runoff, accurate temperature data is also needed (i.e. to distribute precipitation as rain and snow). Thus, daily precipitation and temperature data distributed spatially across each catchment is required to provide quality runoff calibrations. In

2008, DHI, Inc. designed a Python computer program for IDWR to spatially interpolate daily weather station precipitation and temperature data across catchments using monthly grid data as a statistical basis for the interpolation (Borden 2010). During this Project, gridded monthly average (1971 – 2000) precipitation and temperature data were obtained from the Oregon State University PRISM Climate Group (OSU 2010), and daily precipitation and temperature data were obtained from several weather stations operated by the Natural Resource Conservation Service (NRCS) SNOTEL network (NRCS 2011) and the Desert Research Institute RAWS network (DRI 2011). Figure 4.4.7 displays PRISM data for the Lemhi for the month of March, and the locations of the SNOTEL and RAWS weather stations applicable to the Upper Lemhi MBM. Table 4.4.3 lists descriptive information for the weather stations shown in Figure 4.4.7.

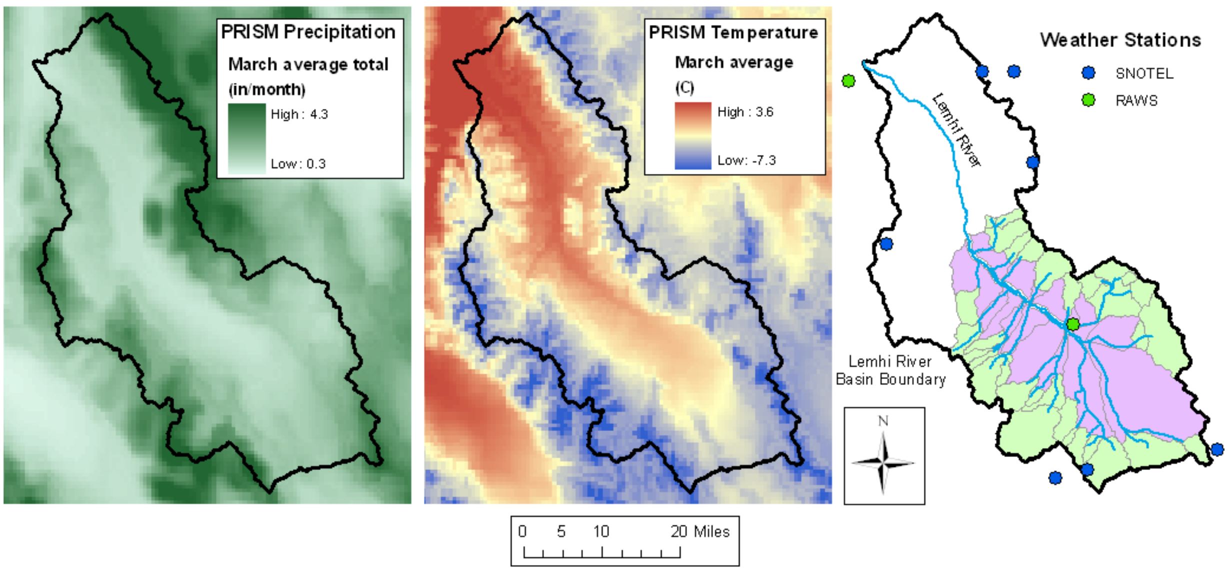


Figure 4.4.7 – PRISM monthly precipitation and temperature data for the Lemhi, and locations of weather stations utilized for daily precipitation and temperature data in rebuilding the Upper Lemhi MBM.

Station	Network	Latitude (NAD 1983)	Longitude (NAD 1983)	Elevation (ft amsl)
Beagle Springs	SNOTEL	44.467	-112.983	8850
Bloody Dick	SNOTEL	45.167	-113.500	7600
Darkhorse Lake	SNOTEL	45.167	-113.583	8600
Leadore	RAWS	44.700	-113.350	6000
Lemhi Ridge	SNOTEL	45.000	-113.450	8100
Meadow Lake	SNOTEL	44.433	-113.317	9150
Moonshine	SNOTEL	44.417	-113.400	7440
Salmon	RAWS	45.150	-113.930	4960
Schwartz Lake	SNOTEL	44.850	-113.833	8540

Table 4.4.3 – List of weather stations utilized in rebuilding the Upper Lemhi MBM.

During this Project, IDWR modified the Python program to better distribute temperature data based on Diluzio et al. (2008). The program was then utilized to create daily area-weighted average precipitation (Pavg) and temperature (Tavg) values for each catchment listed in Table 4.4.2, and this information was entered into MIKE 11 NAM. Figure 4.4.8 displays the monthly sum of Pavg for three Upper Lemhi catchments for January 2008, along with the total January 2008 precipitation recorded at neighboring weather stations and the PRISM area-weighted average total precipitation for the month of January.

As shown in Figure 4.4.8, the Python program produces Pavg values that fall between those recorded at weather stations and statistically estimated via the PRISM Climate Group. This is physically appropriate because 1) the weather station data are from point locations at specific elevations, and cannot be assumed to represent area-weighted average precipitation for nearby catchments exactly, and 2) the PRISM data are statistically based 1971 – 2000 monthly averages that help guide how precipitation is spatially dependent, but cannot be assumed to represent specific time period precipitation exactly.

Additionally, the Python program output Tavg values were found to agree reasonably well with both daily temperatures recorded by weather stations and monthly average temperatures calculated by the PRISM Climate Group. For example, for the three catchments listed in Figure 4.4.8, the monthly averages of Tavg from the Python program were within 5 – 15% of both the monthly average temperatures recorded at nearby weather stations and the area-weighted average monthly temperatures calculated by the PRISM Climate Group for January and July 2008.

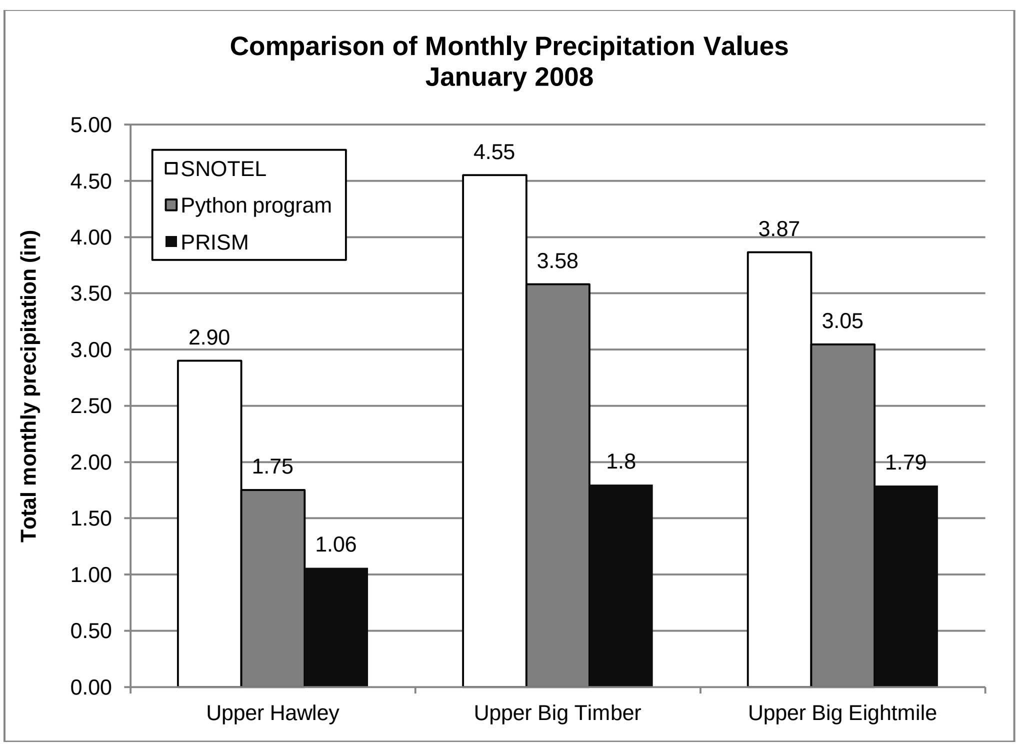


Figure 4.4.8 – Monthly precipitation values for three rebuilt Upper Lemhi MBM catchments.

Catchment Elevation Zones
Because the catchment features encompass mountainous areas with dramatic variations in elevation, and precipitation and temperatures are strongly correlated to elevation in the Upper Lemhi (as evidenced by the PRISM precipitation and temperature data displayed in Figure 4.4.7), each catchment feature was subdivided into five elevation zones. The elevation classification was completed using the ArcGIS Spatial Analyst Reclassify tool on the individual catchment DEM rasters, with the Natural Breaks (Jenks) classification method. Figure 4.4.9 displays the Upper Hawley catchment subdivided into its elevation zones. The average elevation of each elevation zone, the area within each elevation zone, and the total area for the catchment, were then calculated and entered into MIKE 11 NAM, where the precipitation-runoff model corrects the Pavg and Tavg data for the average elevations of the five elevation zones.

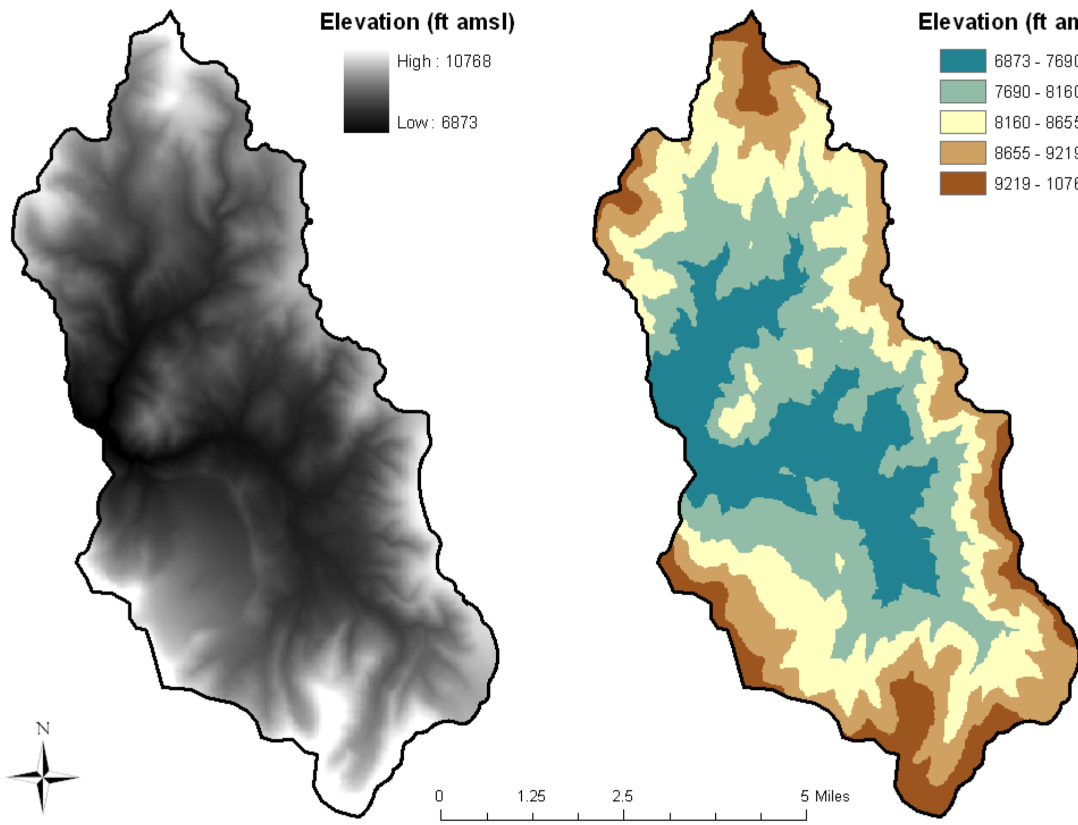


Figure 4.4.9 – DEM elevations and elevation zones of the Upper Hawley catchment in the rebuilt Upper Lemhi MBM.

Precipitation Correction Factors
In MIKE 11 NAM, a precipitation correction factor (Pc) can be applied to each catchment to account for higher elevations receiving greater precipitation than lower elevations. This required first determining a reference elevation (Epr) for each catchment (i.e. to provide MIKE 11 NAM with a base elevation to adjust by). The Epr for each catchment was determined by comparing the annual area-weighted average precipitation for each elevation zone within a catchment (i.e.

determined using the PRISM grid precipitation data) to the annual average Pavg for the whole catchment (i.e. determined using the Python program mentioned earlier). For example, the annual average PRISM precipitation for the second elevation zone of the Upper Hawley catchment (i.e. 7690 – 8160 ft amsl in Figure 4.4.9) was calculated to be 15.5 in/yr, and the annual average Pavg for the whole Upper Hawley catchment was calculated to be 15.2 in/yr. Thus, the Epr for the Upper Hawley Pc was determined to be the average elevation of the second elevation zone (i.e. 7925 ft amsl).

Following, the Pc, which corrects for the change in precipitation per unit of elevation difference from the Epr, for each catchment was calculated by comparing the average elevation and annual average PRISM precipitation for each elevation zone within a catchment to the Epr and annual average PRISM precipitation at the Epr. Table 4.4.4 lists this information and results of this analysis for the Upper Hawley catchment.

Elevation zone	Average elevation (ft amsl)	Annual area-weighted average precipitation (in/yr)	Precipitation difference	Epr (ft amsl)	Pc
1	7081	14.0	5%	7756	10%
2	7756	15.5	N/A		
3	8281	18.8	14%		
4	8847	21.7	12%		
5	9958	24.3	8%		

Table 4.4.4 – List of the elevation zones and calculated precipitation reference elevation and precipitation correction factor for the Upper Hawley catchment in the rebuilt Upper Lemhi MBM.

Temperature Correction Factors

MIKE 11 NAM can also incorporate a temperature correction factor (Tc), or lapse rate, to account for the change in temperature with elevation. The Tc for each catchment was determined in an analogous fashion to that mentioned above for Pc, but using the average elevations and annual average PRISM temperatures of the elevation zones within a catchment and the annual average Tavg for the whole catchment. Table 4.4.5 lists this information and results of this analysis for the Upper Hawley catchment. Note that the reference elevation for temperature correction (Etr) for this catchment was calculated to be the average of the average elevations of the first and second elevation zones. Also, the Tc is in units of °C/100 m to be consistent with the calculation utilized by MIKE 11 NAM.

Elevation zone	Average elevation (ft amsl)	Annual area-weighted average temperature (in/yr)	Temperature difference (°C/100 m)	Etr (ft amsl)	Tc (°C/100 m)
1	7081	2.44	N/A	7419	-0.31
2	7756	1.57	-0.42		
3	8281	1.38	-0.29		
4	8847	1.08	-0.25		
5	9958	0.19	-0.26		

Table 4.4.5 – List of the elevation zones and calculated temperature reference elevation and temperature correction factor for the Upper Hawley catchment in the rebuilt Upper Lemhi MBM.

Evapotranspiration

In addition to precipitation and temperature data, the other primary meteorological factor affecting catchment runoff that is included in MIKE 11 NAM is evapotranspiration (ET), which effectively reduces the amount of precipitation received by a catchment that contributes to runoff. In contrast to the traditional approach utilized in the previous Upper Lemhi MBM where reference (i.e. non-water limited) ET (ETr) data are calculated for irrigated alfalfa at one or more weather stations (DHI 2006) and applied across a basin, IDWR incorporated METRIC (Mapping EvapoTranspiration at high Resolution with Internalized Calibration) data in the rebuilt Upper Lemhi MBM. METRIC data is acquired by IDWR in collaboration with the University of Idaho, and is based on satellite data and energy balance calculations (IDWR 2010). In addition to providing data across a spatial domain (i.e. vs. point data from weather stations), similar to PRISM data, METRIC data accounts for water limitations and various land covers (i.e. vs. only irrigated alfalfa). Thus, METRIC data is considered actual ET (ETa). Incorporating METRIC data into the rebuilt model is a significant enhancement in the physical basis of the Upper Lemhi MBM (Borden 2011).

Figure 4.4.10 displays METRIC data for the Lemhi for the month of July, and the locations of the RAWS weather stations applicable to the Upper Lemhi MBM. Refer to Table 4.4.3 for descriptive information for the weather stations shown in Figure 4.4.10. The higher ETa rates shown in Figure 4.4.10 are indicative of irrigated fields, riparian areas, and other densely vegetated areas, and the lower ETa rates correspond to water limited and/or sparsely vegetated areas, such as dry brush lands and rock outcroppings.

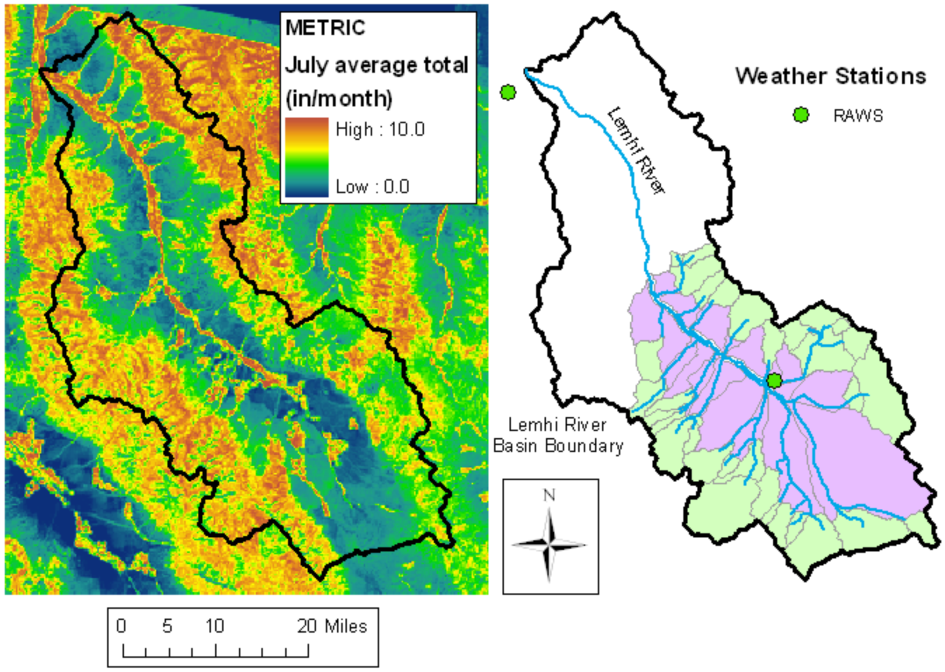


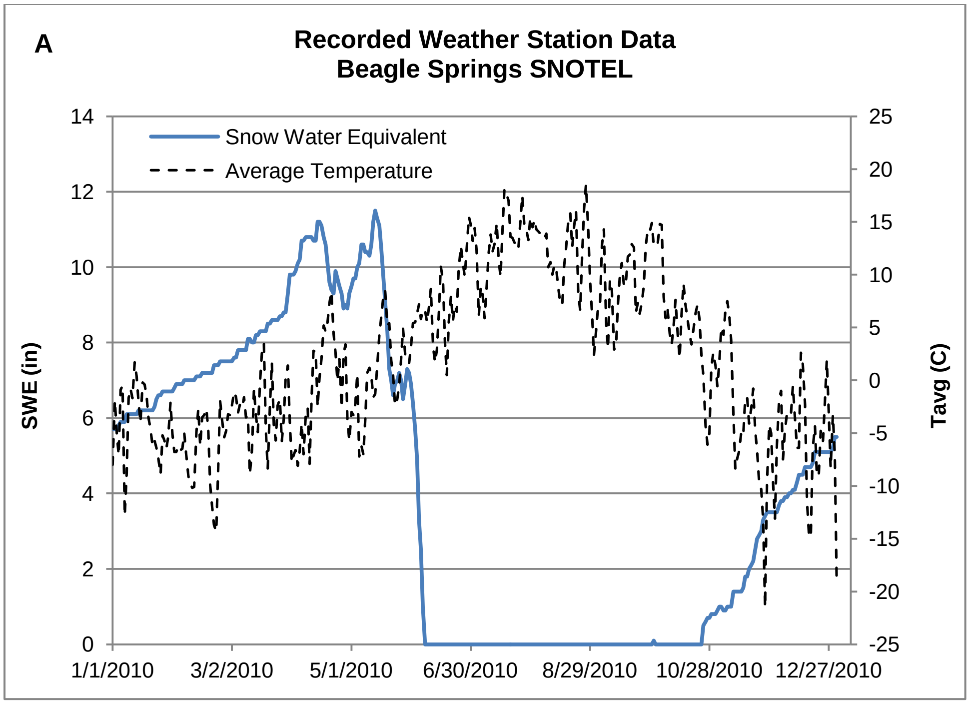
Figure 4.4.10 – METRIC monthly evapotranspiration data for the Lemhi, and locations of the weather stations utilized for daily evapotranspiration data in rebuilding the Upper Lemhi MBM.

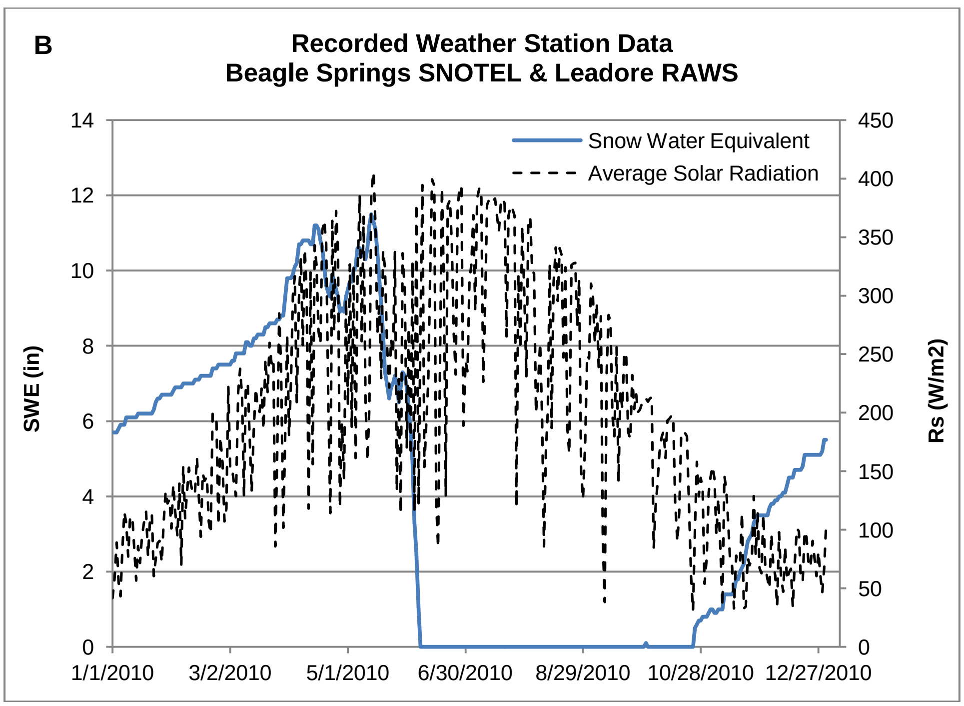
During this Project, IDWR adapted the Python computer program, mentioned in the above Precipitation and Temperature subsection of Section 4.4.2.2, to spatially interpolate daily ETa across catchments using daily weather station ETr and METRIC monthly grid data. This modification was based on Diluzio et al. (2008). Gridded monthly average METRIC data, averaged from the available years of 1996, 2000, and 2006, was provided by IDWR, and daily ETr data was calculated from RAWS weather station data and the University of Idaho Ref-ET program (UI 2011). The Python program output daily area-weighted average ETa (ETa,avg) values were imported into MIKE 11 NAM for runoff calibrations.

The ETa,avg correlated strongly to the METRIC data, which is physically appropriate because ETr values are strictly for a given crop with no water limitations. For example, the monthly total ETr (i.e. used directly in the previous model) for the Upper Hawley catchment for July 2008 was 8.7 in. In contrast, the monthly total ETa,avg for this catchment for the same time period was 3.8 in, which is the same value calculated as the monthly area-weighted average METRIC ETa. Referring to Figure 4.4.10 above, this is reasonable given the relative lack of high ET zones in the Upper Hawley catchment. Although, according to METRIC documentation (IDWR 2010), METRIC data is not specifically designed for use in non-irrigated areas (i.e. forested areas common in the Upper Lemhi MBM catchments), IDWR assumed that using the METRIC data to scale ETr values across catchments was reasonable in a conservative sense – that is, applying ETr values across catchments would be an overestimation of ETa, given the relative lack of irrigated areas in the catchments. Although MIKE 11 NAM runs calculations to estimate ETa from input ETr based on modeled water limitations, according to DHI Inc. (Borden 2011), it is best to use input ET values that are more physically based (i.e. METRIC-scaled ETa,avg) to ensure MIKE 11 NAM calculated ETa values do not overestimate the amount of water "lost" from the system that would otherwise be available to stream flows and ground water.

Snow Melt Coefficients
Additionally, MIKE 11 NAM can incorporate snow melt coefficients (Csnow) to account for melting rates that vary according to seasonal factors, such as albedo, relative humidity, and solar radiation (DHI 2009a). During this Project, IDWR investigated how to effectively describe Csnow values for each catchment by comparing weather station recorded values of daily average snow water equivalent (SWE), temperature, and solar radiation (Rs). The SWE and temperature data were obtained from SNOTEL stations, and the Rs data were gathered from RAWS stations (refer to Table 4.4.3). Although temperature dependence is already inherent in Csnow (units mm/day•°C), a relationship between SWE and temperature was investigated because temperature was thought to be a useful surrogate for other seasonal factors (i.e. albedo and relative humidity) that are not readily available from many SNOTEL stations.

Figures 4.4.11A and B plot SWE vs. temperature and Rs, respectively, using the Beagle Springs SNOTEL and Leadore RAWS data for 2010. As shown, it is difficult to visually attribute the decrease in SWE primarily to increasing temperature or Rs. This is physically reasonable considering that several seasonal factors (i.e. albedo, relative humidity, solar radiation, canopy cover, etc.), affect Csnow (DHI 2009a). However, plotting the normalized values of the data shown in Figures 4.4.11A and B yields correlation coefficients of -0.02 for SWE vs. temperature and +0.53 for SWE vs. Rs. This indicates that higher SWE values are more strongly correlated with higher Rs values, which is not the relationship sought (i.e. lower SWE correlated with higher temperature or Rs). Thus, IDWR decided to scale Csnow by the daily area-weighted average temperatures (Tavg) for each catchment determined via the process listed in the above Precipitation and Temperature subsection of Section 4.4.2.2. The appropriateness of this decision was verified through iterative calibrations of MIKE 11 NAM, which will be discussed in more detail in the MIKE 11 NAM subsection of Section 4.4.2.2.





Figures 4.4.11A and B – Plot of snow water equivalent and daily average temperature recorded at the Beagle Springs SNOTEL station (A), and snow water equivalent and daily average solar radition recorded at the Leadore RAWS station (B) for 2010.

According to the MIKE 11 User Guide (DHI 2009a), Csnow values typically do not exceed 4 mm/day•°C. Based on this general limit, IDWR normalized and scaled Tavg values to fall between 1 – 3 units, and attributed these values to Csnow. The IDWR imposed limits were based on iterative calibrations of MIKE 11 NAM, which will be discussed below in the MIKE 11 NAM subsection of Section 4.4.2.2. In this manner, Csnow varies directly with Tavg, a surrogate for the combination of seasonal factors affecting snow melt, but falls within an acceptable range (i.e to ensure other catchment calibration parameters lie within a physical realm). Figure 4.4.12 illustrates calculated values of Csnow and Tavg for the Upper Hawley Creek catchment.

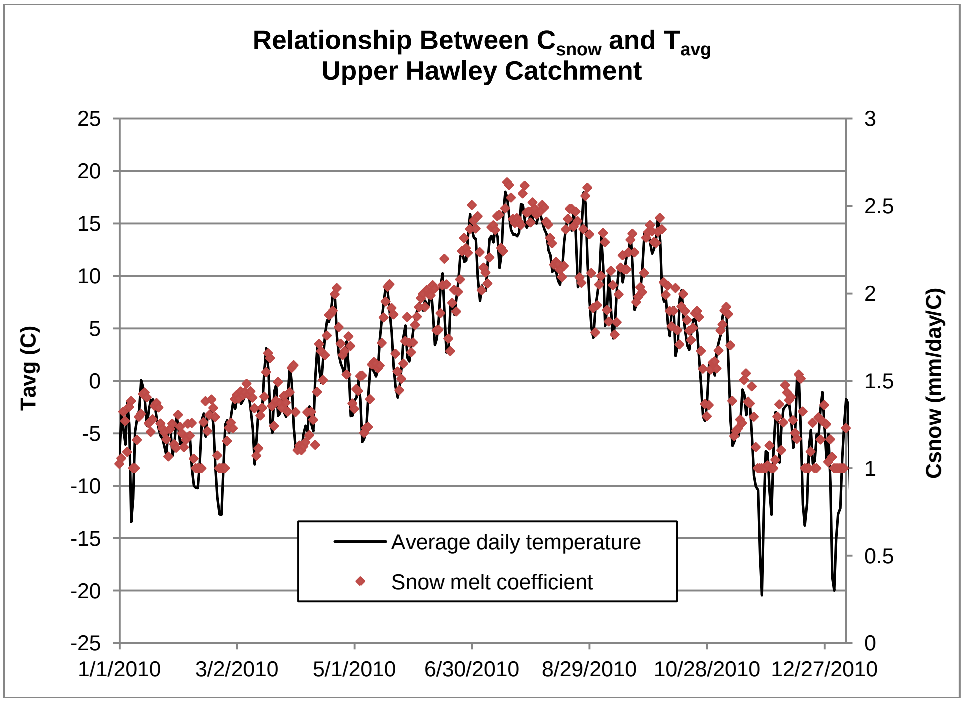


Figure 4.4.12 – Plot of daily average temperature recorded at the Beagle Springs SNOTEL station and calculated daily Csnow values for the Upper Hawley catchment in the rebuilt Upper Lemhi MBM.

MIKE 11 NAM

The MIKE 11 NAM model is considered a lumped conceptual model – that is, the model utilizes empirical hydrologic equations to mimic combinations of physical hydrologic processes (DHI 2009b). This treatment is common in the arena of watershed-scale precipitation-runoff modeling because of the data requirement and model structure complexities associated with modeling large-scale processes with physical hydrologic equations. Using Tavg to scale Csnow, discussed in the above Snow Melt Coefficients subsection of Section 4.4.2.2, is an example of conceptually lumping physical hydrologic processes.

Essentially, MIKE 11 NAM differentiates total runoff into the conceptually different hydrologic flow paths available: overland flow, interflow, upper baseflow, and lower baseflow. Additionally, four hydrologic reservoirs are modeled: snow, surface zone, root zone, and ground water zone. A series of model parameters, and input meteorological time series, govern the distribution of precipitation into these hydrologic reservoirs, the distribution of runoff from these reservoirs into the hydrologic flow paths, and the temporal behavior of runoff along each path (i.e. hydrographs).

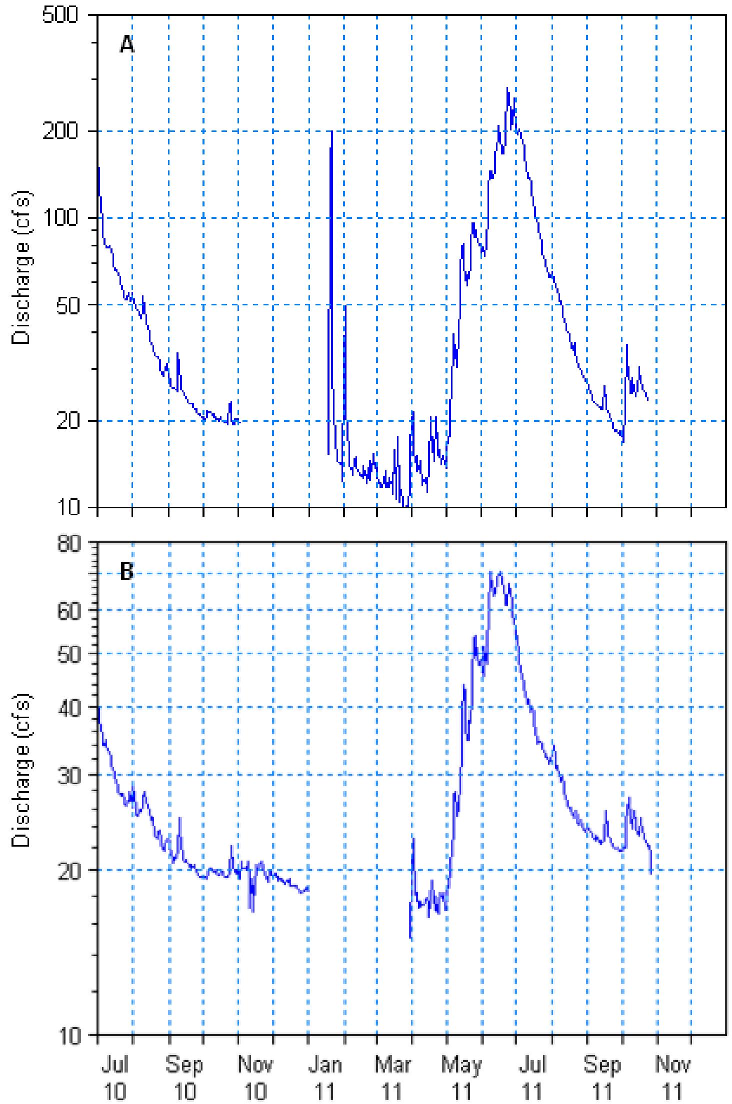
- Overland flow: runoff that travels over the land surface through and out of the catchment; quantity primarily affected by the capacities of the surface zone (Umax) and root zone (Lmax), and the distribution of excess precipitation between overland flow and infiltration (CQOF); the hydrograph is modeled in a kinematic fashion with time constants CK1,2.

- Interflow: runoff that travels through the intermediate subsurface, below the surface but above the water table (i.e. ground water zone); quantity primarily affected by Lmax and CQOF; the hydrograph is modeled in a linear reservoir fashion with time constant CKIF.

- Upper and lower baseflow: runoff that travels through the ground water zone, where the upper zone responds faster to recharge than the lower zone; quantities primarily affected by Lmax, CQOF, the root zone threshold for ground water recharge (TG), and the distribution of ground water between upper and lower zones (CQlow); the hydrographs are modeled in a linear reservoir fashion with time constants CKBF and CKlow

Although the foundation of MIKE 11 NAM is conceptual, because physical catchment properties are represented in lumped fashion, general physical properties can still be deduced from running the precipitation-runoff model, given that the input data is physically-based. For example, the relative amount of total runoff routed through a catchment's ground water reservoir and the length of time the subsequent baseflow is significant to stream flow are important pieces of information that MIKE 11 NAM can estimate.

Figures 4.4.13A and B display the observed runoff (plotted on a log scale) from the Big Timber and Hawley catchments, respectively, for July 2010 through October 2011. Figure 4.4.14 illustrates the locations of the Upper Big Timber Creek and Hawley Creek stream gauges, as well as the catchments contributing flow to these stream reaches. The combined area of the Big Timber catchments is approximately 30% greater than the combined area of the Hawley catchments (54.8 mi2 and 42.2 mi2, respectively), and the total volume of water exiting the former catchments is 66% greater than that exiting the latter catchments (45,100 acre-ft and 27,100 acre-ft, respectively). However, as implied by the gradually declining stream flows from October 2010 to April 2011 in Figures 4.4.13A and B, the relative contribution of baseflow is greater for the Hawley catchments. This information suggests that relatively more runoff is routed through the ground water reservoir, and that baseflow is more significant to Hawley Creek.



Figures 4.4.13A and B – Semi-log plots of observed flows at the Upper Big Timber Creek and Hawley Creek stream gauges, respectively, for July 2010 through October 2011.

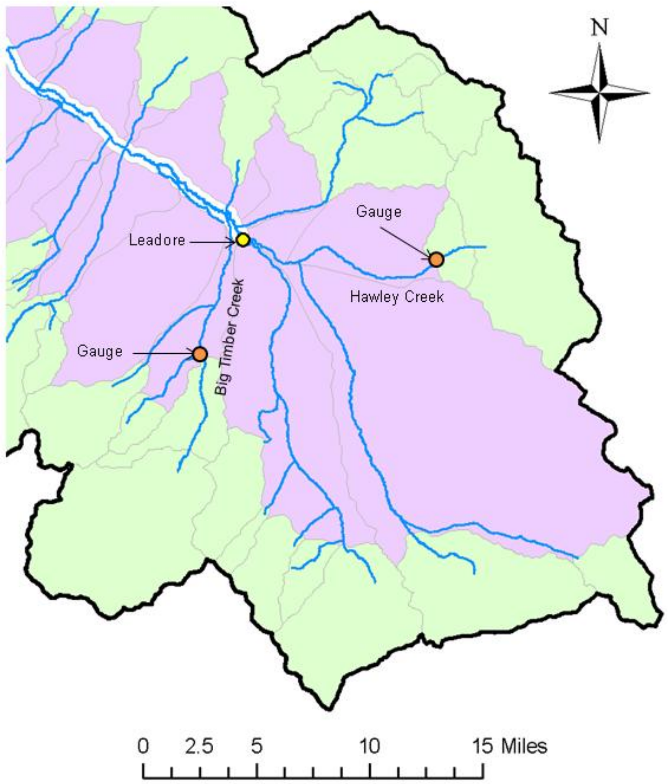


Figure 4.4.14 – Locations of the Upper Big Timber Creek and Hawley Creek stream gauges.

Calibrations of MIKE 11 NAM for the Big Timber and Hawley catchments, which will be discussed in more detail below, yielded catchment parameters that support the greater significance of baseflow to Hawley Creek. For example, the Big Timber catchments were calibrated as having a higher root zone threshold before ground water recharge occurs (TG = 0.7), whereas TG = 0.0 for the Hawley catchments – implying that ground water recharge occurs more readily and is a more significant component to the hydrology in the Hawley catchments. Additionally, the Big Timber catchments were calibrated without lower baseflow (CQlow = 0), and with CKBF = 10,000 hr (or 1.1 yr). In contrast, the Hawley catchments were calibrated with CQlow = 75, and with CKBF = 10,000 hr and CKlow = 18,000 hr (or 1.1 yr and 2.1 yr, respectively). These parameters suggest that baseflow contributes to Hawley Creek for a longer time period.

The MIKE 11 NAM calibration examples mentioned above illustrate that, with physically-based and accurate input data, and appropriate topographic and meteorologic characterizations of the catchments, the precipitation-runoff model can guide the physical characterization of the MBM. This is specifically important in characterizing runoff from catchments where stream flows cannot be observed upgradient of confounding factors, such as irrigation diversions and/or return flows.

For the rebuilt Upper Lemhi MBM, three aggregate catchments, driven by where stream gauges are located upgradient of most diversions and probable return flow locations, were used as the calibration features for MIKE 11 NAM: 1) Big Eightmile aggregate – Upper Big Eightmile and

Devils Canyon catchments, 2) Big Timber aggregate – Lower Big Timber, Upper Big Timber, and Basin catchments, and 3) Hawley aggregate – Lower Hawley and Upper Hawley catchments. Catchments were aggregated using the ArcGIS Aggregate Polygons tool. Figure 4.4.15 displays these aggregate features, along with the separate catchments that comprise them, and the locations of stream gauges in the Upper Lemhi. As shown, the Upper Big Eightmile, Upper Big Timber, and Hawley gauges are located just downgradient of the associated catchments, whereas all other Upper Lemhi stream gauges are located in more downgradient zones where irrigation diversions and associated ground water recharge and return flows likely play significant hydrologic roles. Thus, because of the lack of confounding anthropogenic processes, the Upper Big Eightmile, Big Timber, and Hawley catchments were chosen as calibration features.

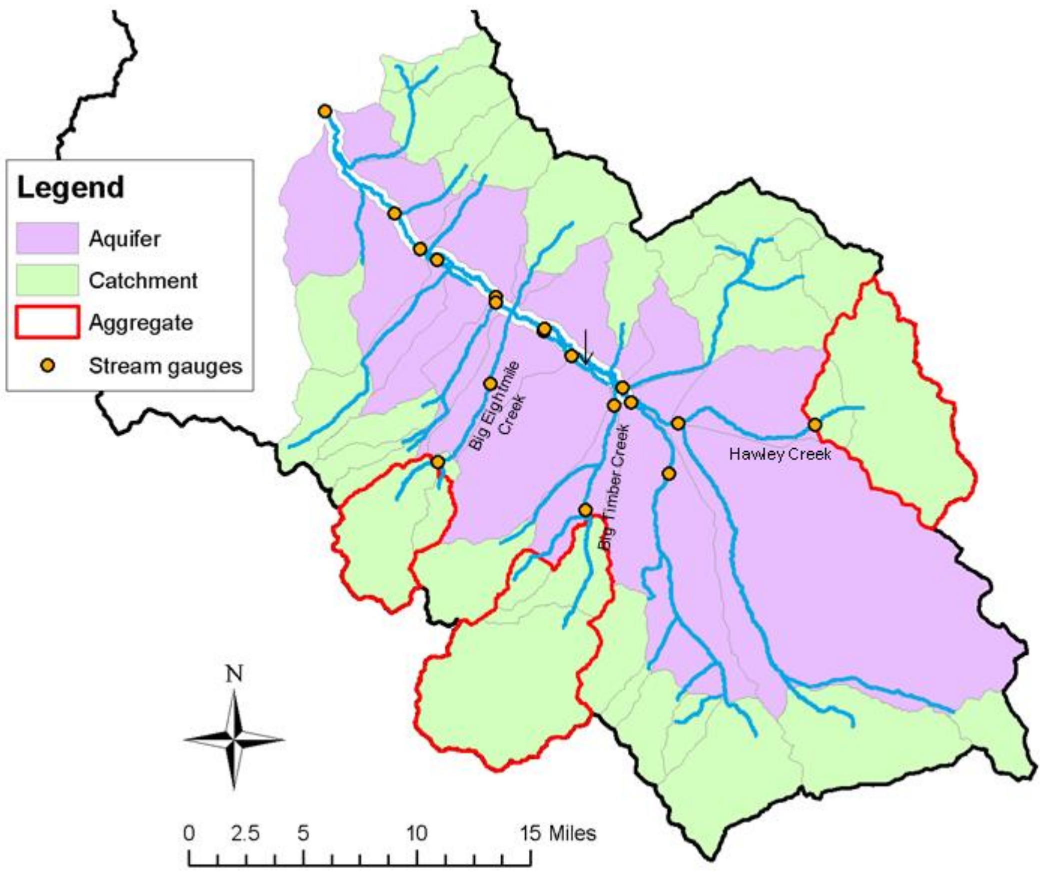


Figure 4.4.15 – Aggregate features used to calibration MIKE 11 NAM for the rebuilt Upper Lemhi MBM, as well as the locations of stream gauges in the Upper Lemhi.

The input data requirements for calibrating runoff from the aggregate catchments in MIKE 11 NAM are detailed in the above subsections of Section 4.4.2.2, and are summarized as:

Daily time series:

- Precipitation (Pavg) – area-weighted average, determined using Python program with PRISM, SNOTEL, and RAWS data; described in Precipitation and Temperature subsection of Section 4.4.2.2
- Temperature (Tavg) – area-weighted average, determined using Python program with PRISM, SNOTEL, and RAWS data; described in Precipitation and Temperature subsection of Section 4.4.2.2
- Evapotranspiration (Ea,avg) – area-weighted average, determined using Python program with METRIC and RAWS data; described in Evapotranspiration subsection of Section 4.4.2.2
- Snow melt coefficients (Csnow) – scaled from Tavg; described in Snow Melt Coefficients subsection of Section 4.4.2.2
- Observed runoff – stream gauge data; described in Section 4.1.

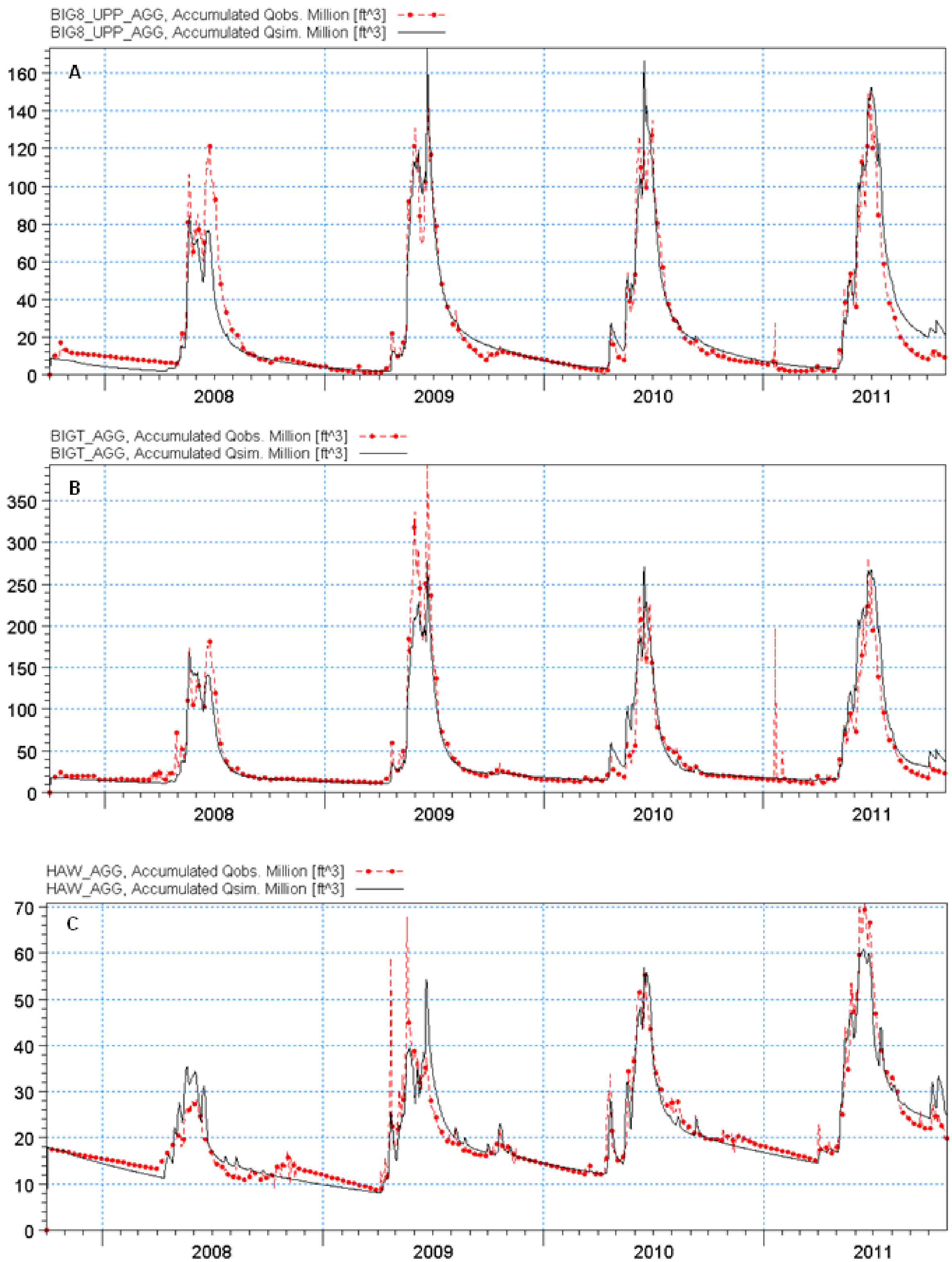
Catchment characteristics:

- Total catchment area – calculated with ArcGIS Calculate Areas tool
- Elevation zones:
  - Number of zones (5)
  - Average elevation of each zone – determined from elevation zone raster table; described in Catchment Elevation Zones subsection of Section 4.4.2.2
  - Area of each zone – calculated with ArcGIS Calculate Areas tool
  - Reference elevation for precipitation (Epr) – described in Precipitation Correction Factors subsection of Section 4.4.2.2
  - Precipitation correction factor (Pc) – described in Precipitation Correction Factors subsection of Section 4.4.2.2
  - Reference elevation for temperature (Etr) – described in Temperature Correction Factors subsection of Section 4.4.2.2
  - Temperature correction factor (lapse rate, Tc) – described in Temperature Correction Factors subsection of Section 4.4.2.2
- Initial conditions:
  - Relative water content in surface zone (U/Umax)
  - Relative water content in root zone (L/Lmax)
  - Overland flow (QOF)
  - Interflow (QIF)
  - Upper baseflow (BF)
  - Lower baseflow (BFlow)
  - Snow storage

Because MIKE 11 NAM simulations were chosen to start at the beginning of a water year (i.e. October 1), initial U/Umax and L/Lmax were set to 0.0 and 0.3, respectively (DHI 2009b). Additionally, BF was assumed to dominate the observed stream flow at the beginning of a water year, and so initial QOF and QIF were set to 0 and initial BF was set to equal the observed flow at the simulation start date (DHI 2009b). Initial BFlow was only relevant to the Hawley aggregate calibration, but it was set to 0 based on iterative calibrations. Lastly, snow storage was neglected, again, because of the simulation start date (i.e. beginning of water year).

Because of the lumped conceptual foundation of MIKE 11 NAM, all other catchment parameters were effectively determined through iterative model calibrations, using various combinations of manual and auto-calibration techniques. Upper and lower limits of each parameter were converged upon through successive calibrations, and based upon typical ranges reported by DHI, Inc. (DHI 2009a, DHI 2009b). Best-fit parameters were converged upon by selecting the Overall Root Mean Square Error option with 30,000 evaluations.

Figures 4.4.16A, B, and C display the MIKE 11 NAM runoff calibrations results for the Big Eightmile, Big Timber, and Hawley aggregate features, respectively, for water years 2008 – 2011. This time period was chosen based on the availability of data, specifically stream flow records. For the Big Eightmile aggregate, the correlation coefficient between the observed and simulated runoff is 0.91, and the simulated runoff is +1.2% of that observed. The correlation coefficient for the Big Timber aggregate is 0.89, and the simulated runoff is +0.3% of that observed. Lastly, the correlation coefficient for the Hawley aggregate is 0.89, and the simulated runoff is -1.3% of that observed. Errors in observed flows (i.e. stream gauge data), interpolation and/or measurement errors in precipitation, temperature, and ET data, and inherent errors in conceptualizing the catchment features prevent simulations that exactly mirror the physical runoff. Given the uncertainties involved in modeling watershed runoff, however, the results obtained indicate the MIKE 11 NAM calibrations capture the physical runoff reasonably well. Table 4.4.6 lists the calibrated parameter values for the three aggregate features.



Figures 4.4.16A, B, and C – Plots of calibrated MIKE 11 NAM model runoff for the Big Eightmile, Big Timber, and Hawley aggregate features, respectively, along with stream flows measured at the Upper Big Eightmile Creek, Upper Big Timber Creek, and Hawley Creek stream gauges during 2008 – 2011.

Parameter	Calibrated values for aggregate features			Description	Units
	Big Eightmile	Big Timber	Hawley		
A	22.7	54.8	42.2	Total catchment area	mi2
Umax	0.082	0.082	0.0198	Maximum water content in surface zone	ft
Lmax	.251	.414	0.082	Maximum water content in root zone	ft
CQOF	.433	.436	.102	Overland flow runoff coefficient	()
CKIF	1243	2000	572.2	Time constant for interflow	hr
CK1	9.59	4.36	24.4	Time constant for overland flow	hr
CK2	328	348	411	Secondary time constant for overland flow	hr
TOF	0	0	0	Root zone threshold for overland flow	()
TIF	0	0	0	Root zone threshold for interflow	()
TG	0.7	0.7	0	Root zone threshold for ground water recharge	()
CKBF	3000	10000	10000	Time constant for upper baseflow	hr
CQlow	0	0	75	Lower baseflow recharge	%
CKlow	N/A	N/A	18797.9	Time constant for lower baseflow	hr
Csnow	*	*	*	Snow melt coefficient	mm/day·°C
T0	3	3	4	Snow-rain temperature	°C
NEZ	5	5	5	Number of elevation zones	N/A
Epr	7300	7875	7756	Reference elevation for precipitation	ft amsl
Pc	4	7	10	Precipitation correction factor	%
Etr	8064	7446	7419	Reference elevation for temperature (lapse rate)	ft amsl
Tc	-0.37	-0.35	-0.31	Temperature correction factor (lapse rate)	°C/100 m
EZ1_E	7300	7017	7081	Zone 1 average elevation	ft amsl
EZ2_E	8064	7875	7756	Zone 2 average elevation	ft amsl
EZ3_E	8685	8544	8281	Zone 3 average elevation	ft amsl
EZ4_E	9304	9234	8847	Zone 4 average elevation	ft amsl
EZ5_E	10177	10471	9958	Zone 5 average elevation	ft amsl
EZ1_A	2.96	10.25	5.8	Zone 1 area	mi2
EZ2_A	4.57	12.14	12.21	Zone 2 area	mi2
EZ3_A	5.54	13.26	11.45	Zone 3 area	mi2
EZ4_A	6.08	12.63	8.65	Zone 4 area	mi2
EZ5_A	3.55	6.57	4.12	Zone 5 area	mi2
U/Umax	0	0	0	Initial relative water content in surface zone	()
L/Lmax	0.3	0.3	0.3	Initial relative water content in root zone	()
QOF	0	0	0	Initial overland flow	cfs
QIF	0	0	0	Initial interflow	cfs
BF	9	18	18	Initial upper baseflow	cfs
BFlow	N/A	N/A	0	Initial lower baseflow	cfs
SS	0	0	0	Initial water content in snow storage	()

Table 4.4.6 – Calibrated parameter values for the aggregate calibration features. *Csnow was supplied as a daily time series, not as a fixed parameter. Note that not all parameters available in MIKE 11 NAM were utilized in these calibrations. This decision was based primarily on the availability of data to support the use of additional parameters. Thus, any parameters not listed in above were not utilized.

Because the physical runoff from other catchments could not be observed directly (i.e. due to ungauged streams and stream gauges located below confounding factors, such as irrigation diversions and/or return flows), the calibration parameters for the aggregate features were applied to all other catchments according to the proximity of each catchment to an aggregate. Thus, referencing Figure 4.4.15 and Table 4.4.6, the Big Eightmile aggregate parameters were applied to the Alder-Zeph, Mill, Lee, Stroud, Everson, Lower Big Eightmile, Upper Big

Eightmile, and Devils Canyon catchments. The Big Timber aggregate parameters were applied to the Little Timber, Basin, Lower Big Timber, Upper Big Timber, Purcell, Negro Green, Deer, Sourdough Gulch, Texas, Divide, and Eighteenmile catchments. Lastly, the Hawley aggregate parameters were applied to the West Fork Yearian, Upper Yearian, Lower Yearian, Reese, Peterson, Little Eightmile, Jakes Canyon, Hood Gulch, Canyon, Chippie, Cruikshank, Lower Hawley, and Upper Hawley catchments, as well as to the Eighteenmile aquifer. However, daily time series of Pavg, Tavg, ETa,avg, and Csnow were determined for each catchment independently using the methods described above in Section 4.4.2. Additionally, the elevation zones of each catchment were characterized independently. However, the Epr and Etr of each uncalibrated catchment were based on the relative elevation zones that the associated calibrated catchment's Epr and Etr were located (though the Pc and Tc values were applied from the associated calibrated catchment).

Once daily time series and MIKE 11 NAM catchment properties were attributed to every Upper Lemhi MBM catchment shown in Figure 4.4.4 and listed in Table 4.4.2, the precipitation-runoff model was implemented to simulate the runoff from each catchment for water years 2007 – 2011. The simulated daily runoff time series were then imported in the rebuilt Upper Lemhi MBM, where they serve as the input stream flows.

4.4.2.3 Irrigation Diversion and Return Flow Networks

The structure of the previous Upper Lemhi MBM essentially had three basic components: inflows supplied by precipitation runoff, surface water diverted for agricultural purposes, and return flows to stream reaches estimated as the fractions of diverted water not consumed by crops or evapotranspired. Although the rebuilt Upper Lemhi MBM incorporates additional catchment and aquifer features, the rebuilt model maintains the basic structure of the previous model. Thus, the irrigation diversion and return flow networks are significant components of the rebuilt Upper Lemhi MBM, and meticulous efforts were aimed at investigating these networks during this Project to ensure the "shuffling" of water across the Upper Lemhi was accurately modeled. Additionally, IDWR compiled all MBM diversion flows for the Upper Lemhi for years 2008 – 2010 into an Access database for central housing and organizational purposes. Data for 2011 was not available at the time of this report.

Diversion Network

Because multiple water rights often serve a single place of use (POU), and a single point of diversion (POD) often serves multiple POUs in the Upper Lemhi, the modeled diversion network aggregates water rights into MBM diversions based on the physical locations of the PODs and POUs for each water right. Thus, when changes are made to a water right, such as reducing the maximum diversion rate or changing the right's POD and/or POU, updates to the MBM diversion network are needed. Since 2008, several stream flow enhancement projects have been implemented by the USBWP Technical Team, and have resulted in alterations to irrigation water rights, PODs, and POUs in the Upper Lemhi. Additionally, IDWR has improved its accounting of water rights in the Upper Lemhi in recent years, including more accurate locations of PODs. Thus, since the previous model was last updated, several factors have contributed to inaccuracies in the previous Upper Lemhi MBM diversion network.

During this Project, discrepancies in the previous model's diversion network were first noticed when IDWR attempted to update the previous model with daily diversion rates supplied by Water Districts (WDs) 74Q, 74W, and 74Z, which are sub-districts to WD 74 (i.e. charged with managing surface water usage in the Lemhi). For instance, several water rights with daily diversion rates reported by the watermasters for these sub-districts were not accounted for in any MBM diversion. Also, in many cases, water rights were incorrectly aggregated among MBM diversions (i.e. not placed accurately according to proximity of POD with respect to MBM diversion). Thus, updating the previous model with daily diversion rate data was not possible using the previous model's diversion network.

To correct these discrepancies, IDWR investigated its spatial database of active water rights, claims, and recommendations, and the associated PODs and POUs. All PODs and POUs located in the Upper Lemhi that have irrigation, irrigation storage, irrigation from storage, and stockwater water uses were queried from the IDWR database. Several pre-processing steps were performed to remove records duplicated in the active rights, claims, and recommendations results, ensuring that active recommendation records took precedence (Ciscell 2011). Hereafter, water rights, claims, and recommendations are referred to as water rights for clarity. An ArcGIS script was then employed to connect each POD to the associated POU(s) (i.e. based on water rights) with visible lines. These displays of PODs connected to POUs were meticulously analyzed in ArcGIS to lump water rights into MBM diversions using MIKE BASIN ArcGIS tools. Records detailing the distribution of water rights into MBM diversions from the previous model, as well as watermaster records of daily diversion rates per water right, were also used to guide this process. Many of the previous Upper Lemhi MBM diversions were renamed and/or restructured according to water rights to reflect the most recent records in the IDWR database during the rebuilding of the Upper Lemhi MBM. MBM diversions were named according to the stream (or river) extracted from followed by a number, increasing from the mouth of the associated stream (or river) upgradient.

Examples of how IDWR modified the diversion network are shown in Figures 4.4.17A and B. Figure 4.4.17A illustrates the IDWR database POUs and PODs associated with water rights 74-338B, 74-349, 74-369, 74-1105, 74-1136, 74-15787, and 74-15788, as well as the previous and rebuilt Upper Lemhi MBM extractions (i.e. diversions). At the end of each MBM extraction is an MBM water user node (not shown for clarity). Because POUs are often stacked – that is, several water rights can serve the same acreage, it can be difficult to differentiate exactly where a given diversion serves. For example, water rights 74-369, 74-1136, and 74-15788 have Everson Creek as a source, but serve the same general acreage (i.e. POU) as water rights 74-338B, 74-349, 74-1105, and 74-15787, which have Big Eightmile Creek as a source. Thus, in the rebuilt model, the Big Eightmile Creek water rights listed above are modeled as serving the same section of the POU (i.e. the two Big Eightmile Creek MBM extractions serving a single water user node), and the Everson Creek water rights listed above are modeled as serving the other section of the POU. This is a simplification of the previous model, where, as shown in Figure 4.4.17A, there were two Big Eightmile Creek water user nodes, and two Everson Creek water user nodes. This modification was performed to simplify both the diversion network and the return flow network (which will be discussed below), since excess water applied to the same general POU will likely have the same return flow location(s). Additionally, the west-most Everson Creek MBM extraction in the previous model was structured to deliver water right 74-

157, which is actually sourced from springs, not Everson Creek. Thus, in the rebuilt Upper Lemhi MBM, this water right was not included in the diversion network.

Figure 4.4.17B displays a similar scenario just downstream on Lee Creek (which Everson Creek is a tributary of). In the previous model, the two Lee Creek MBM extractions delivered water rights 74-949 and 74-1831 to the POUs displayed, and the one Everson Creek MBM extraction (with its origination on Everson Creek not shown for scale) was structured without associated water rights. Based on IDWR POD records, however, water rights 74-949 and 74-1831 are extracted downstream of where the previous model located the Lee Creek extractions. Thus, in the rebuilt model, these water rights are associated to MBM extractions slightly downstream (i.e. north-most rebuilt MBM extractions on Lee Creek shown in Figure 4.4.17B). Additionally, again based on IDWR POD records, water rights 74-361, 74-362, 74-363, 74-364, 74-365, 74-367, and 74-368, are associated with the south-most rebuilt MBM extractions on Lee Creek shown in Figure 4.4.17B. It is assumed that these water rights were meant to be attributed to the previous model's Everson Creek MBM extraction mentioned above, but IDWR POD records in years prior may have not identified the correct extraction location.

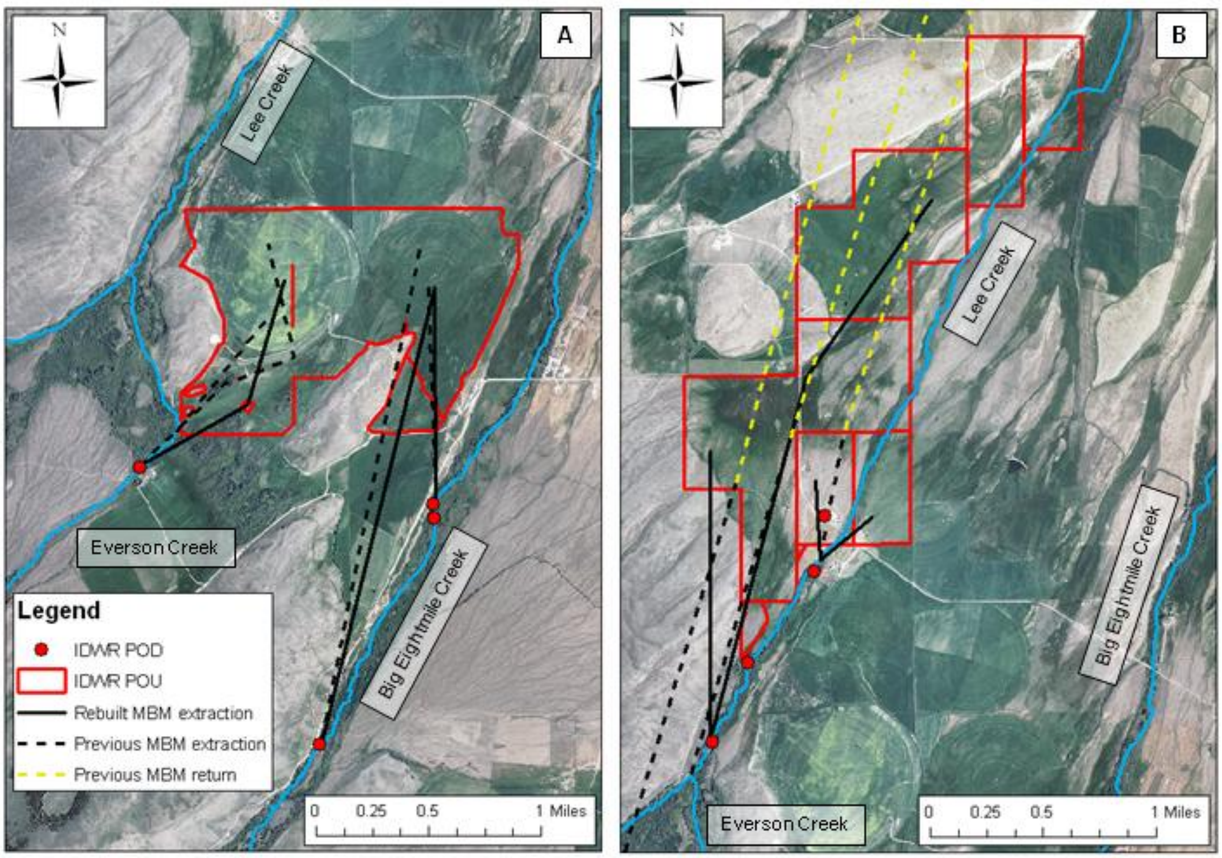


Figure 4.4.17A and B – Displays of IDWR POD and POU spatial files and associated previous and rebuilt Upper Lemhi MBM extractions and return flows.

With the Upper Lemhi water rights appropriately lumped into the rebuilt MBM diversions, the next step was compiling daily diversion rates for each MBM diversion. The watermasters for WD 74, 74Q, 74W, and 74Z report daily irrigation diversion rates per water right to IDWR after the end of each irrigation season. These WDs report on daily diversion rates for the following streams:

- WD 74: Upper Lemhi River and Big Springs Creek
- WD 74Q: Mill Creek
- WD 74W: Big Timber Creek, Canyon Creek, Hawley Creek, Little Timber Creek, and Texas Creek
- WD 74Z: Big Eightmile Creek, Devils Canyon Creek, Everson Creek, Lee Creek, and Stroud Creek

Figure 4.4.18 illustrates the streams where irrigation diversions are reported on by the WDs listed above, as well as the streams where there is not regular reporting. Refer to Table 4.4.2 for a list of all streams in the rebuilt Upper Lemhi MBM.

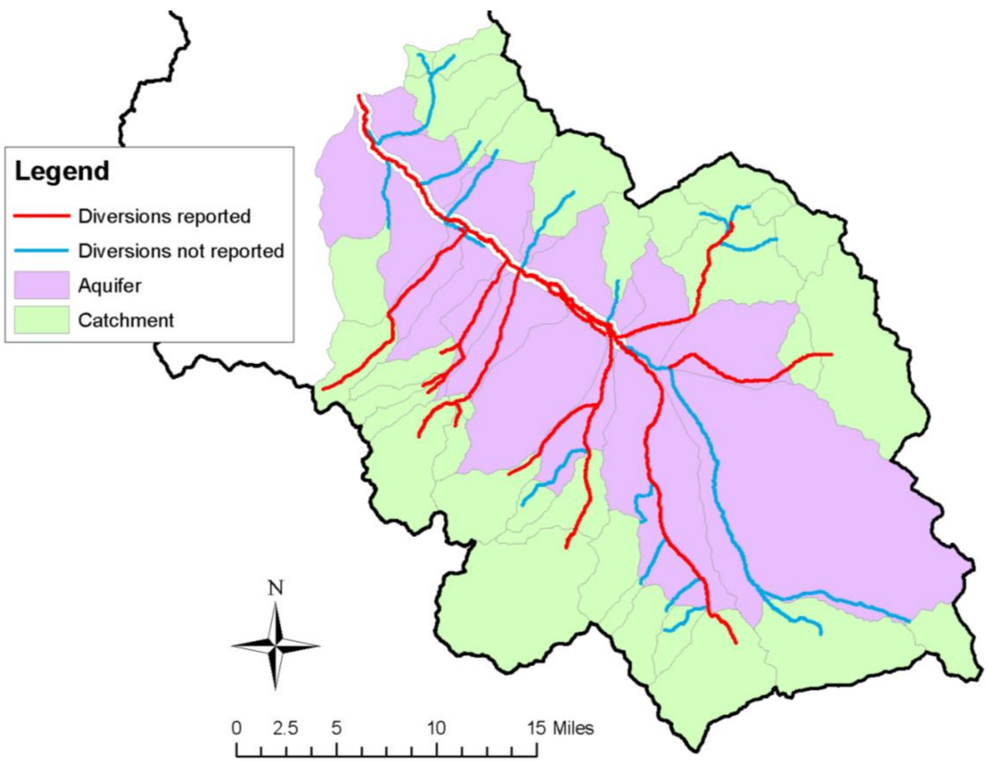


Figure 4.4.18 – Display of rebuilt Upper Lemhi MBM streams where diversions are reported on by water districts.

During this Project, the daily MBM diversion rates for these streams were calculated by summing the daily diversion rates for the water rights by associated MBM diversion using Microsoft Access. A Microsoft Excel program developed by DHI, Inc. for IDWR was then employed to linearly interpolate diversion rates where temporal gaps existed in the data; the interpolator program sets the diversion rate to 0 between November 15 and April 1 to ensure diversion rates are not interpolated outside of irrigation seasons. A process equivalent to that described above was followed to estimate daily MBM diversion rates for streams where the diversions are not regularly reported on. For these MBM diversions, the daily diversion rates were estimated by summing the maximum diversion rates of the water rights by associated MBM diversion, again ensuring not diversion rates are estimated outside of an irrigation season (i.e. November 15 – April 1). All of the interpolated or estimated daily MBM diversion rates were then imported into the rebuilt Upper Lemhi MBM, where they serve as the water user node time series, as well as into an Access database for central housing and organizational purposes.

Return Flow Network
Also displayed in Figures 4.4.17A and B are the previous Upper Lemhi MBM return flows for the extractions shown. No return flows were included in the previous model for the Everson Creek and Big Eightmile Creek extractions shown in Figure 4.4.17A. The previous model's return flows for the Everson Creek and Lee Creek extractions shown in Figure 4.4.17B were modeled as flowing into the Upper Lemhi River (not shown for scale). Although not shown in Figures 4.4.17A and B, the rebuilt model generally maintains the return flows included in the previous model; however, they are not shown because IDWR seeks to restructure these features based on rebuilt model simulations and future field data.

As mentioned above in Section 4.4.1, the return flow paths and lag times in the previous Upper Lemhi MBM were largely estimated through conversations with watermasters, water users (i.e. irrigators and landowners), and project collaborators, as well as through model calibrations. Further, the return fractions were not modeled as first contributing to ground water prior to reentering the stream system. Thus, because the unconfined alluvial aquifer was not incorporated in the previous model, the return flow network lacked a solid physical basis – that is, the return fractions were not routed through a ground water system and could not be characterized as augmenting the subsurface reservoir.

During this Project, IDWR rebuilt the Upper Lemhi MBM to enhance its physical basis, including refining its structure with more aquifer features to account for all input hydrologic reservoirs, incorporating all latest input data/pre-processing procedures and iteratively calibrating and simulating precipitation-runoff to enhance the accuracy of input stream flows, and meticulously modifying the diversion network to ensure water extractions from streams are appropriately accounted for. The next step is to redefine all return flows to ensure that water cycling, and specifically the contributions of irrigation to stream flows, in the Upper Lemhi is accurately modeled. This is one focus of IDWR's involvement in the Upper Lemhi during 2012 and 2013. As will be discussed below in Section 4.4.2.4, locations where return flows likely impact stream flows, and locations where they likely do not, can be investigated with the rebuilt Upper Lemhi MBM in its current state.

4.4.2.4 Applications of and Future Direction for Rebuilt Upper Lemhi MBM

As detailed throughout the above subsections of Section 4.4.2, the capability of the previous Upper Lemhi MBM at simulating and predicting stream flows is limited by the availability of data and data processing tools, as well as the primary motivations for the model, at the time of construction and utilization. Following a natural progression for hydrologic models, the rebuilt Upper Lemhi MBM was reconfigured with more physically based data, which were pre-processed with newly available technical tools, and restructured to reflect the contemporary needs of the USBWP Technical Team. Although the reconfiguration is not entirely complete, as the objectives of IDWR during 2012 – 2013 are aimed at this goal, the rebuilt model can be utilized to investigate hydrologic processes in its current state.

In Figures 4.4.5A and B, plots of the previous Upper Lemhi MBM simulated flows at the L-63 and McFarland gauges, respectively, are compared against the flows observed at these gauges. The lack of correspondence between the simulations and the observed flows, during both base flow and high flow periods, suggest that the previous model is not equipped to investigate physical processes in the Upper Lemhi – i.e. the previous model is limited in its physical representation of the Upper Lemhi. This was supported by the lack of well calibrated input stream flows, as well as discrepancies in the diversion network, in the previous model.

Figure 4.4.19 illustrates the rebuilt Upper Lemhi MBM simulated flows at the McFarland gauge, along with the flows observed at this gauge. Note that the model simulation was run with all modeled diversion flows accounted for, but no return flows (as was discussed in Section 4.4.2.3) or ground water processes (i.e. no aquifer features or seepage contributing to ground water). As shown, although the timing and quantity of high flows appear to be fairly well approximated, the model simulated base flows consistently under predict the observed base flows. This comparison supports that the input stream flows in the rebuilt Upper Lemhi are well accounted for, since high flows in the Upper Lemhi are primarily the result of snow melt runoff from the high elevation catchments; however, it also reveals that the hydrologic processes controlling base flows are not well represented.

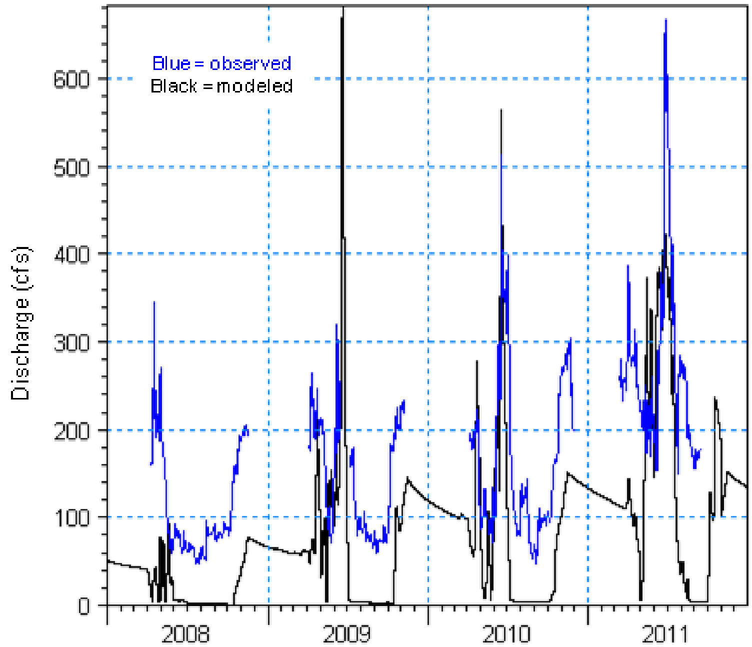


Figure 4.4.19 – Plots of flows recorded at the McFarland gauge and flows simulated at this location using the rebuilt Upper Lemhi MBM.

Irrigation return flows in the Upper Lemhi can take both subsurface and surface flow paths. According to the WD 74 watermaster, diverted water may quickly re-enter streams via direct ditch connection or overland flow from flood irrigated fields (Sager 2012). Thus, at least a portion of the discrepancies between simulated and observed flows illustrated in Figure 4.4.19 is likely due to surface return flows, which are currently not accounted for in the rebuilt Upper Lemhi MBM. However, because the Upper Lemhi is known to have a relatively extensive alluvial aquifer with connectivity to the surface water system (Donato 1998, Spinazola 1998), and field applied irrigation water, as well as stream and ditch seepage, likely contributes to this aquifer, the current exclusion of ground water processes from the rebuilt Upper Lemhi MBM is thought to be the more notable cause of the under predicted base flows illustrated in Figure 4.4.19.

Based on available literature, and many discussions with landowners and natural resource managers, the significance of the alluvial aquifer to stream flows in the Upper Lemhi is not ground breaking; however, the ability of the rebuilt model to highlight this characteristic of the Upper Lemhi is a step forward. Providing the USBWP Technical Team with a technical tool capable of investigating the significance of ground water processes to stream flows is exactly what has been asked of IDWR. Although, at the current stage, the rebuilt Upper Lemhi MBM does not account for ground water processes, it is structured with aquifer features that can be populated with ground water information. Further, seepage from stream, diversion, and return flow channels, which would feed into the aquifer features and ground water supplies, can be included. Thus, throughout 2012 – 2013, IDWR can iteratively update the Upper Lemhi MBM with ground water and seepage information, and the simulated base flows will more closely align with those observed.

Additionally, with updated and more accurate information on input stream flows and diversion rates across the Upper Lemhi, large-scale quantitative information can be used to investigate hydrologic processes. For example, Figure 4.4.20 is a plot of the difference between total runoff flows (i.e. sum of input stream flows from all catchments) and total diversion flows from the rebuilt Upper Lemhi MBM. As shown, between approximately July and November of each year the total amount diverted for irrigation exceeds the total available stream flow, based only runoff from the high elevation catchments. However, referring to Figure 4.4.19, the Upper Lemhi River did not run dry during any part of the 2008 – 2010 period. This suggests hydrologic processes other than rainfall (and/or snowmelt) runoff, namely irrigation return flows and ground water discharge, are contributing significant flows to streams in the Upper Lemhi during the latter part of the irrigation season. In fact, using the rebuilt Upper Lemhi MBM, the total amount of water diverted in the Upper Lemhi during 2008 – 2010 is estimated to be 452,000 acre-ft, whereas the total runoff during this period is approximately 493,000 acre-ft. Thus, over 90% of the total water available from rainfall (and/or snowmelt) runoff is diverted for agricultural purposes. However, because the Upper Lemhi River exhibits good flow year-round (i.e. greater than 50 cfs at the McFarland gauge during 2008 – 2010), irrigation return flows, via both surface and subsurface flow paths, and/or natural ground water discharge must be responsible for helping maintain flow in the stream and river channels, namely when natural runoff is limited (i.e. during the late irrigation season).

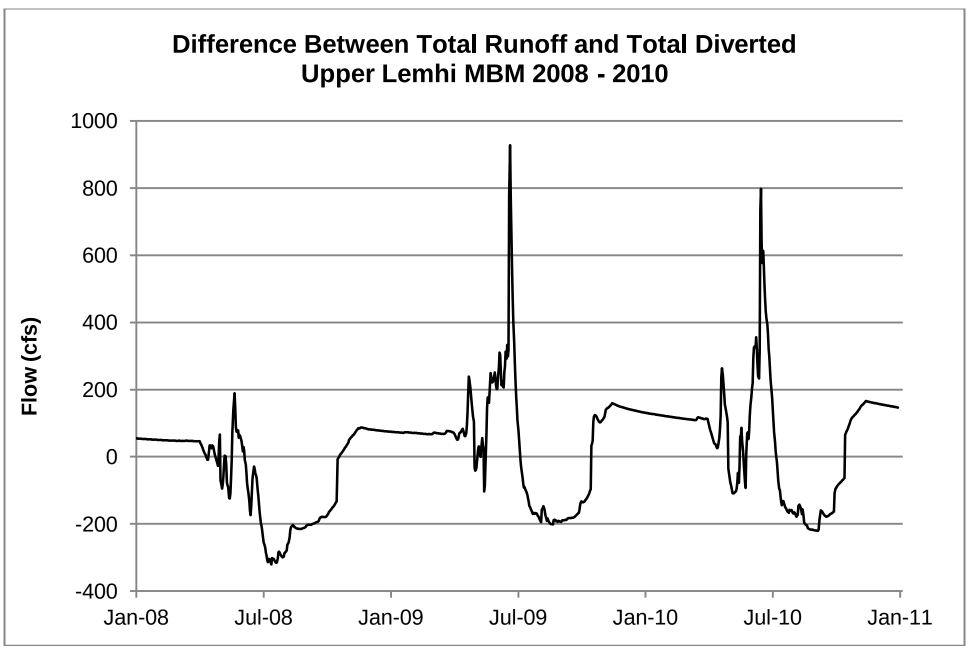


Figure 4.4.20 – Comparison of total runoff and total diverted in the Upper Lemhi, as modeled by the Upper Lemhi MBM.

Future efforts of IDWR, specifically during the 2012 – 2013 period, will be to continue enhancing the Upper Lemhi MBM by identifying where return flows and natural ground water discharge likely impact stream flows. As mentioned above, this can be investigated with the

Upper Lemhi MBM in its current state (i.e. absent of return flows or ground water discharge). Conversely, the current model can also be used to estimate where stream flow likely seeps into the ground, thereby contributing to the alluvial aquifer (i.e. where the model over predicts stream flows). Additionally, field data collected by IDWR and the USBWP, such as through ground water elevation measurements, seepage runs, and possibly hydrologic tracer tests, will be used to populate the aquifer features and help identify where the interactions between the ground and surface waters in the Upper Lemhi are significant.

Lastly, the efforts focused on the Upper Lemhi MBM during 2010 – 2011 will be extended to the Lower Lemhi MBM to produce a full basin-scale hydrologic model capable of assessing the impacts of irrigation to stream flows.

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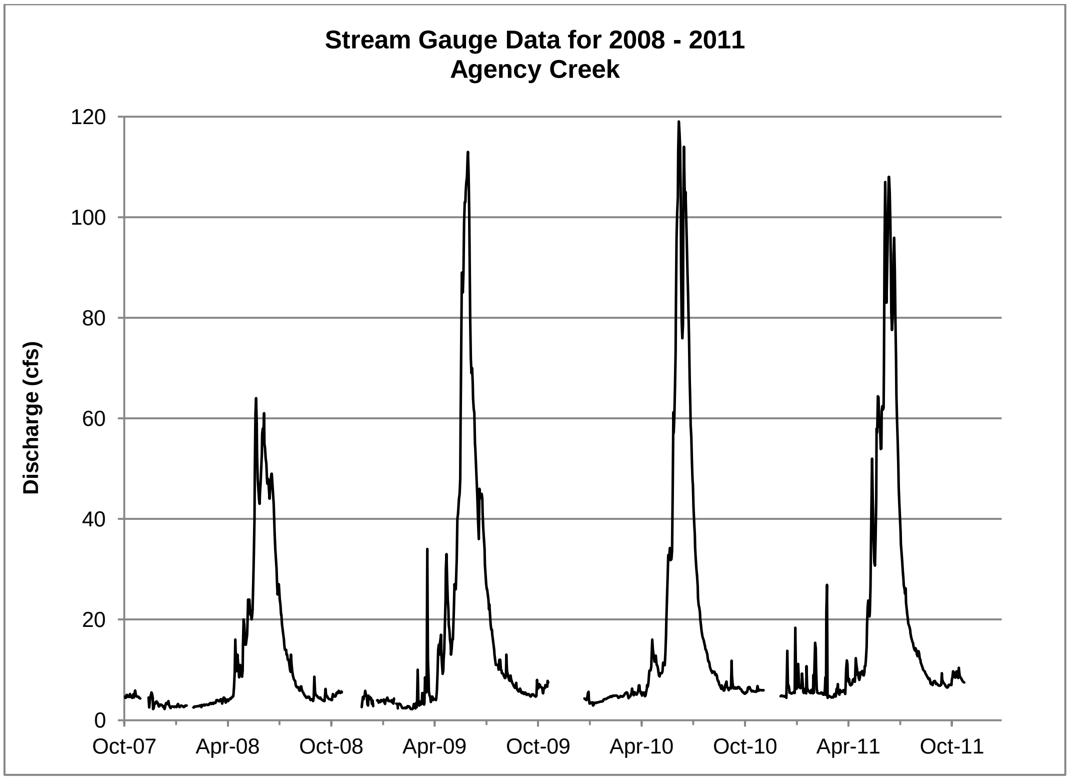
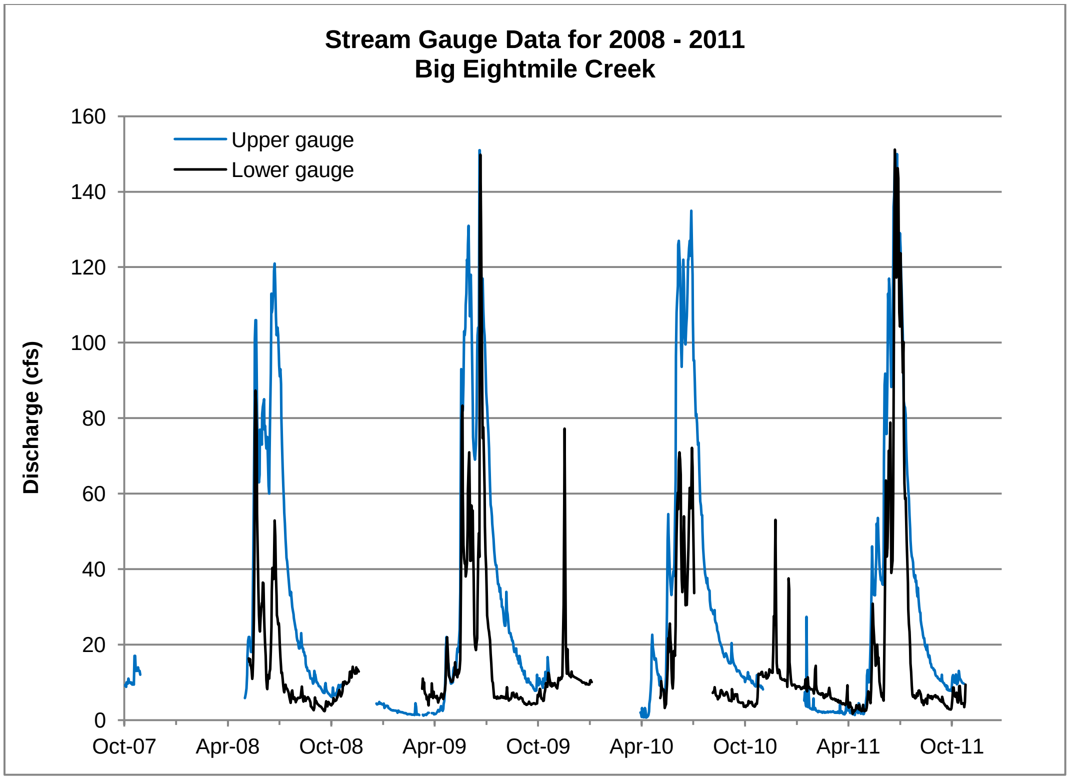
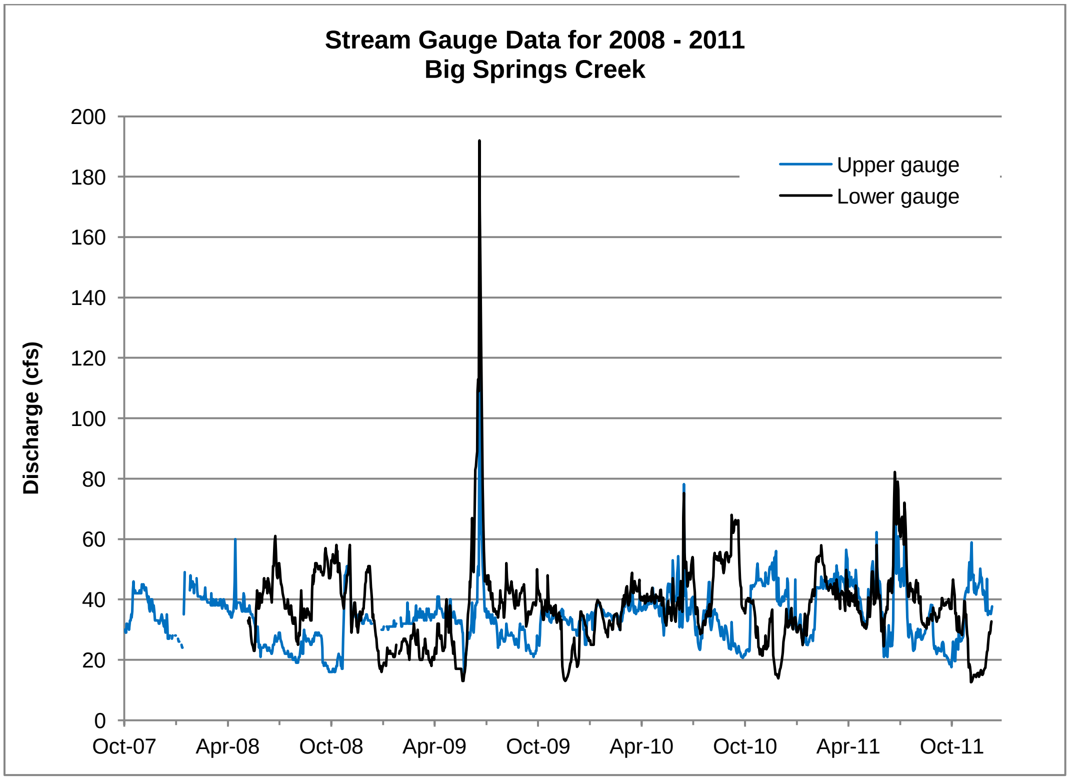
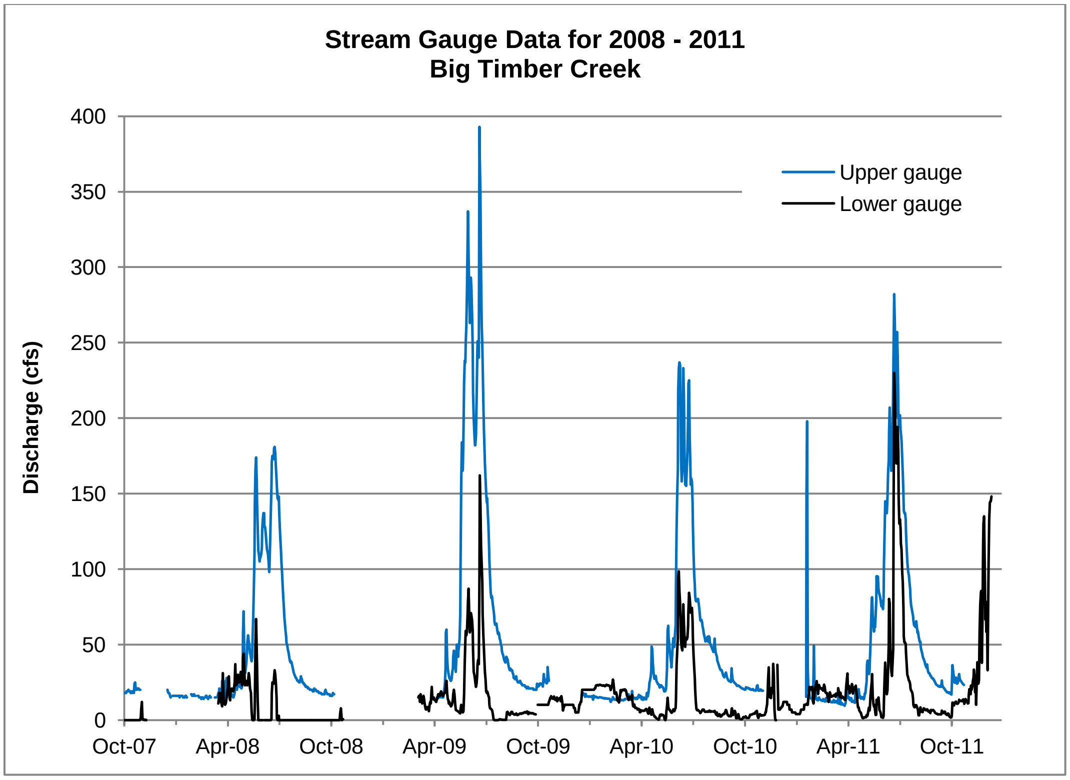
APPENDIX A

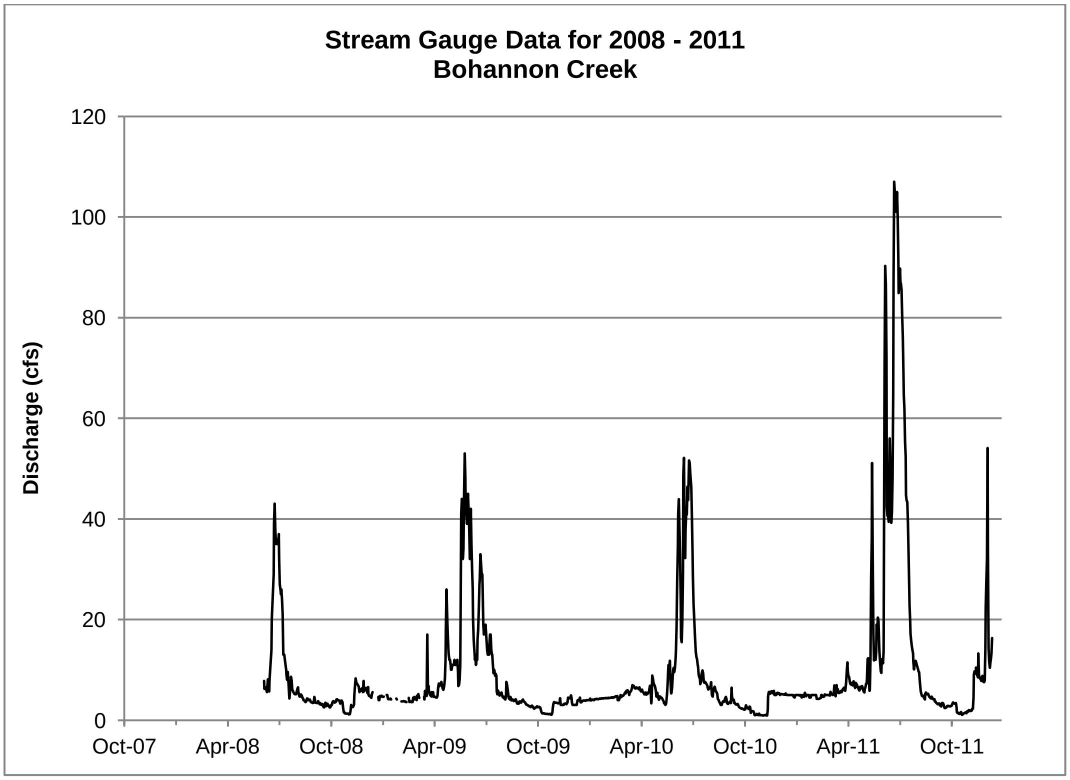
Graphical plots of all stream gauge data collected during this Project for years 2008 – 2011 are provided below. Refer to Section 4.1 for descriptions and locations of these stream gauges.

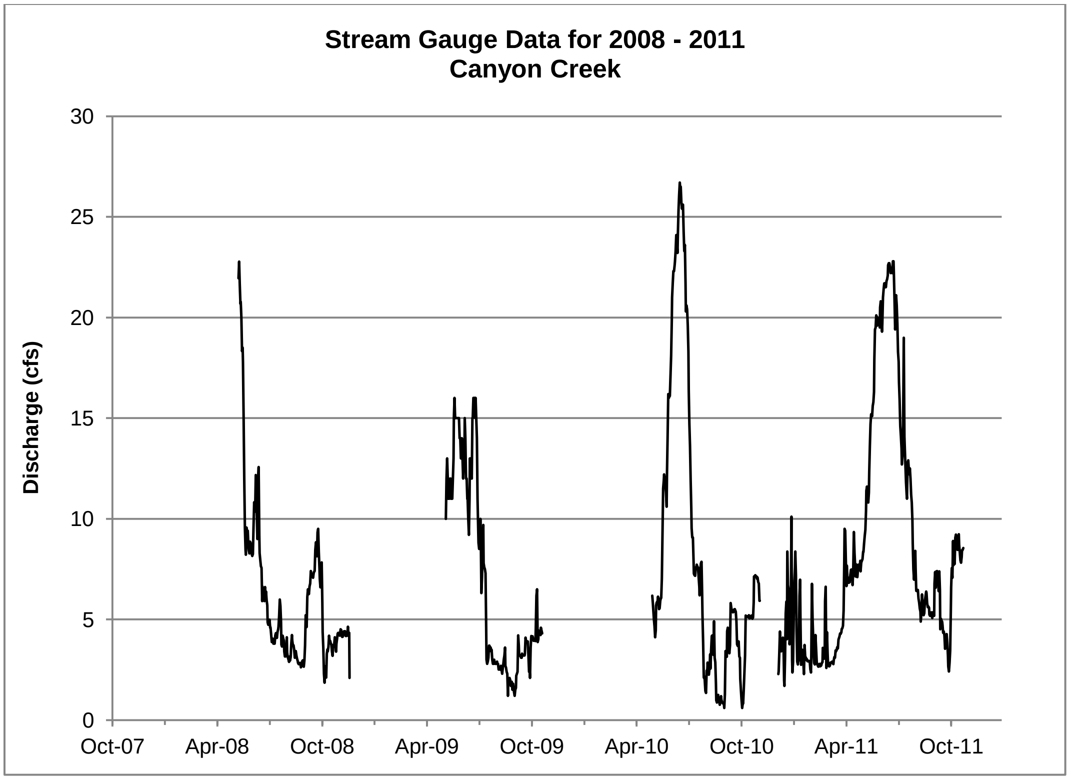


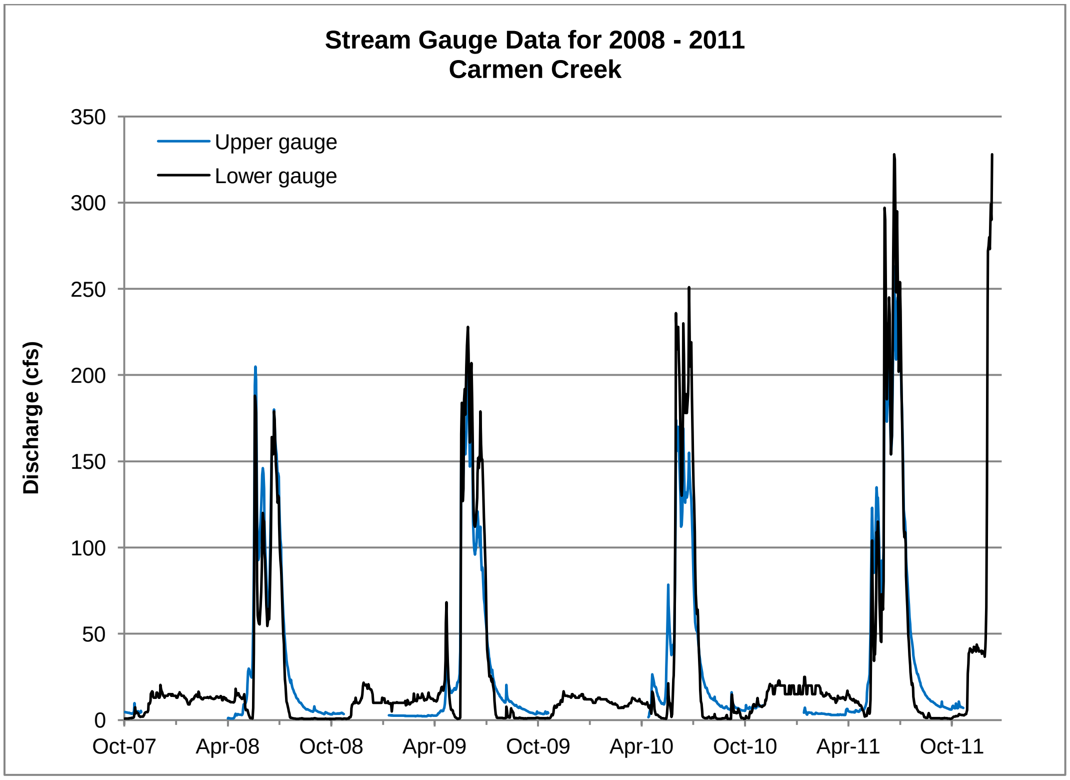

Stream Gauge Data for 2008 - 2011
Big Eightmile Creek
Discharge (cfs)
Upper gauge
Lower gauge
0
20
40
60
80
100
120
140
160
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11

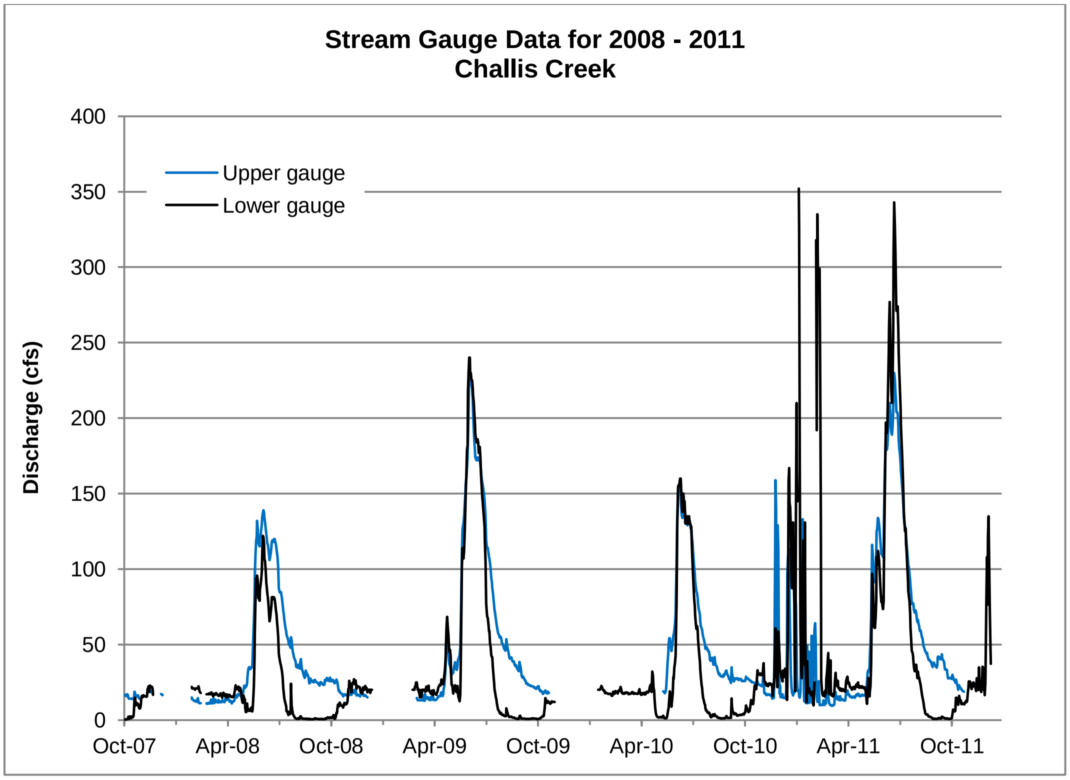

Stream Gauge Data for 2008 - 2011
Big Springs Creek
Discharge (cfs)
Upper gauge
Lower gauge
0
20
40
60
80
100
120
140
160
180
200
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11

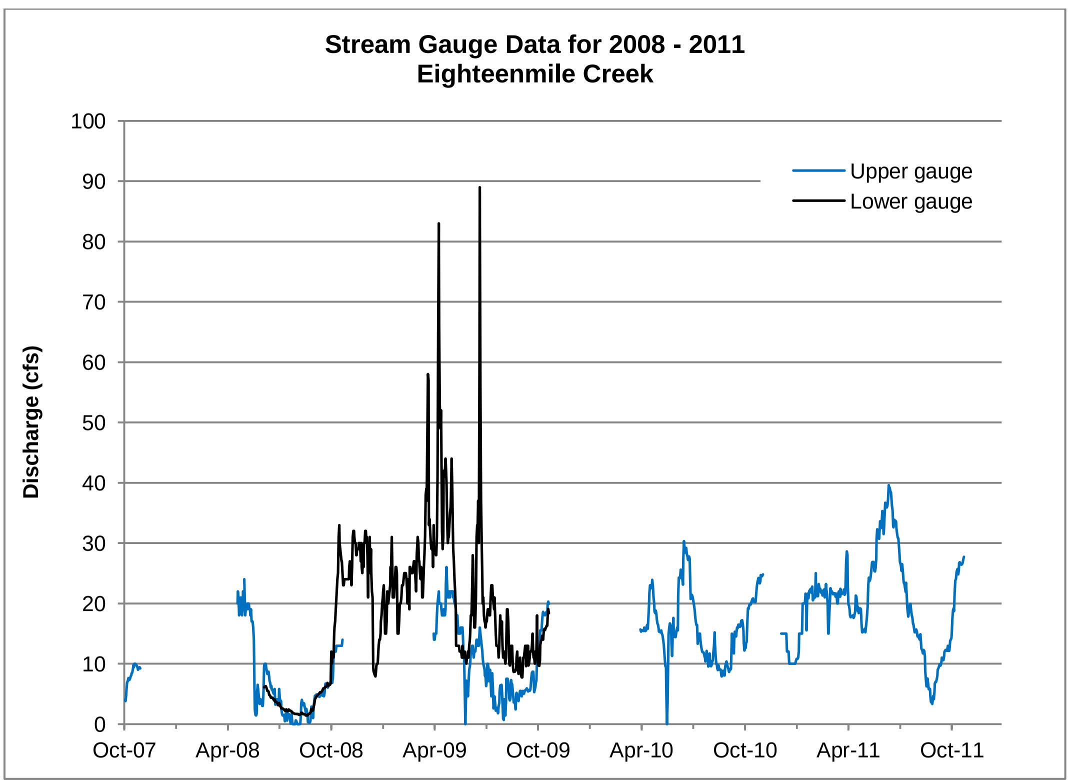

Stream Gauge Data for 2008 - 2011
Big Timber Creek
Upper gauge
Lower gauge
Discharge (cfs)
400
350
300
250
200
150
100
50
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Bohannon Creek
Discharge (cfs)
120
100
80
60
40
20
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Canyon Creek
Discharge (cfs)
0
5
10
15
20
25
30
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Carmen Creek
Discharge (cfs)
Upper gauge
Lower gauge
0
50
100
150
200
250
300
350
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Challis Creek
Discharge (cfs)
400
350
300
250
200
150
100
50
0
Upper gauge
Lower gauge
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Eighteenmile Creek
Discharge (cfs)
100
90
80
70
60
50
40
30
20
10
0
Upper gauge
Lower gauge
Oct-07
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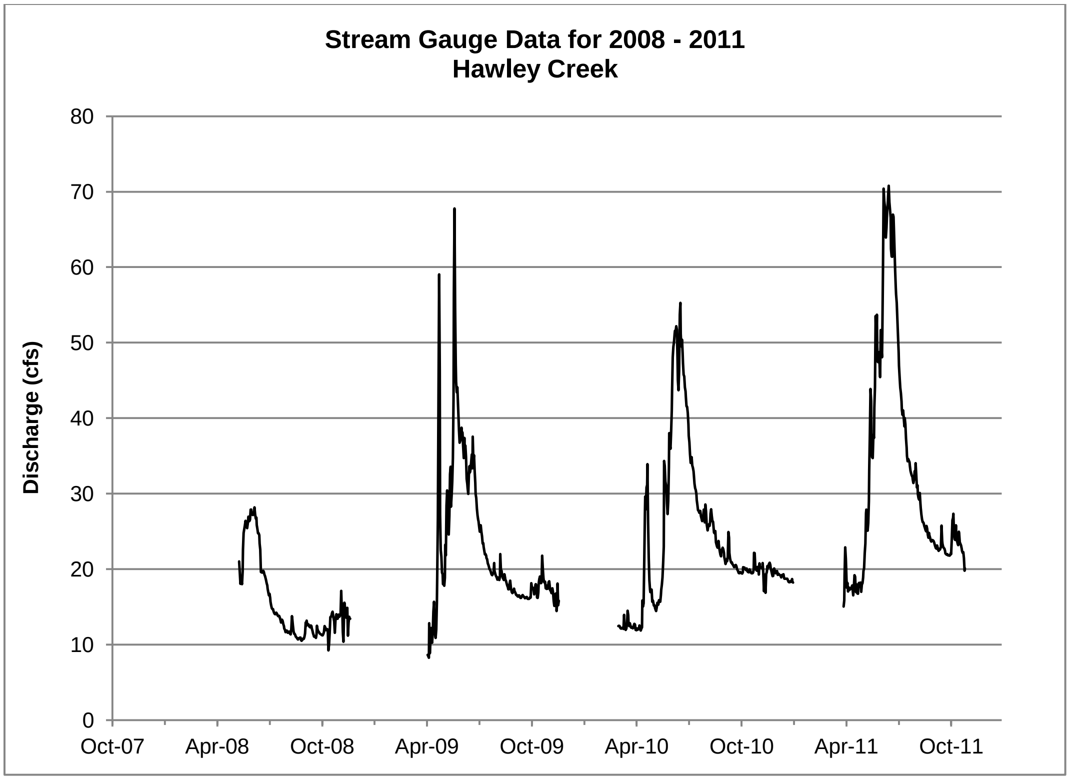
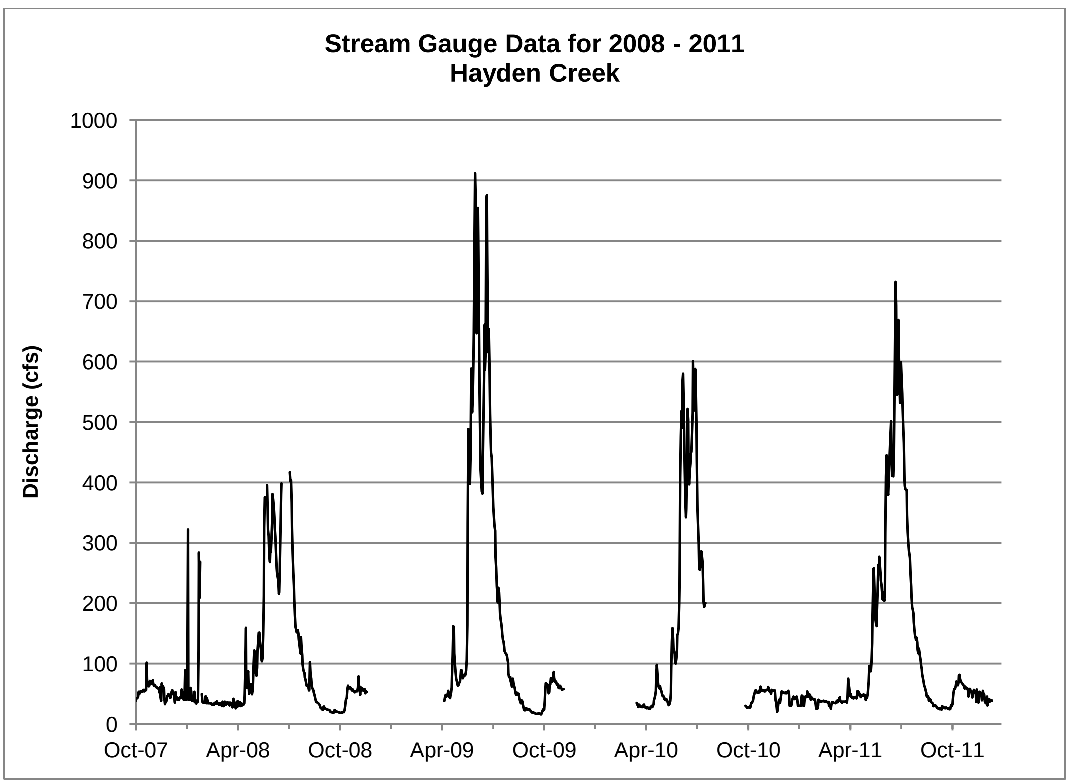
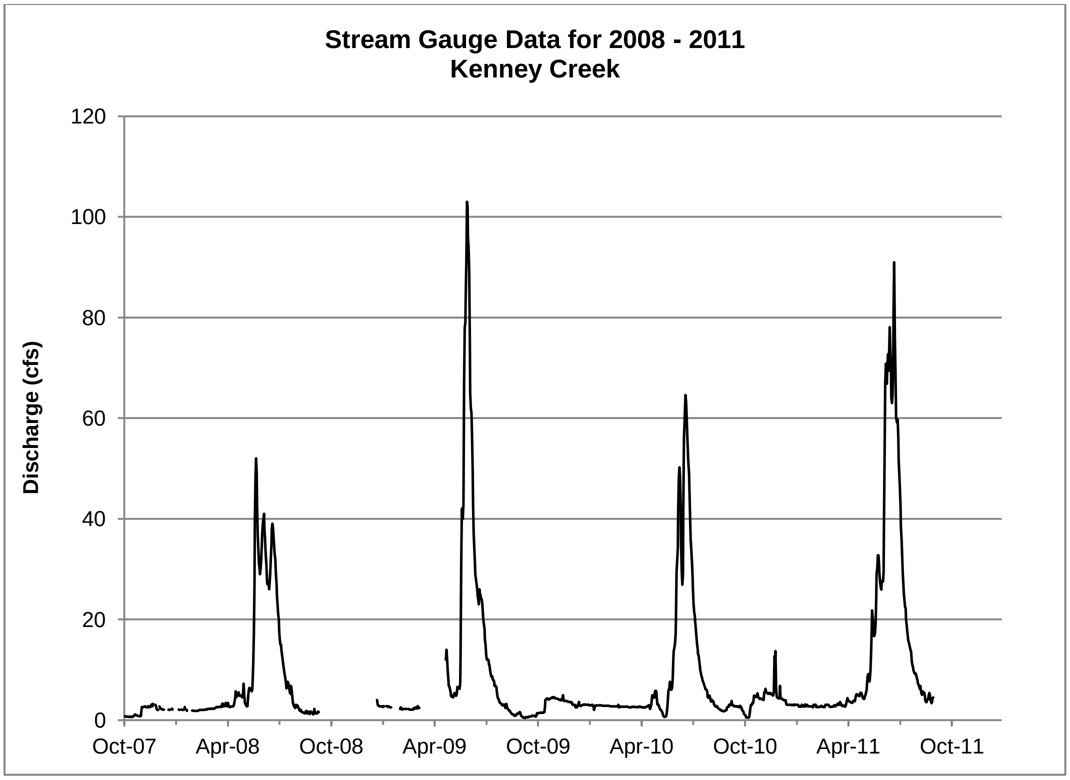
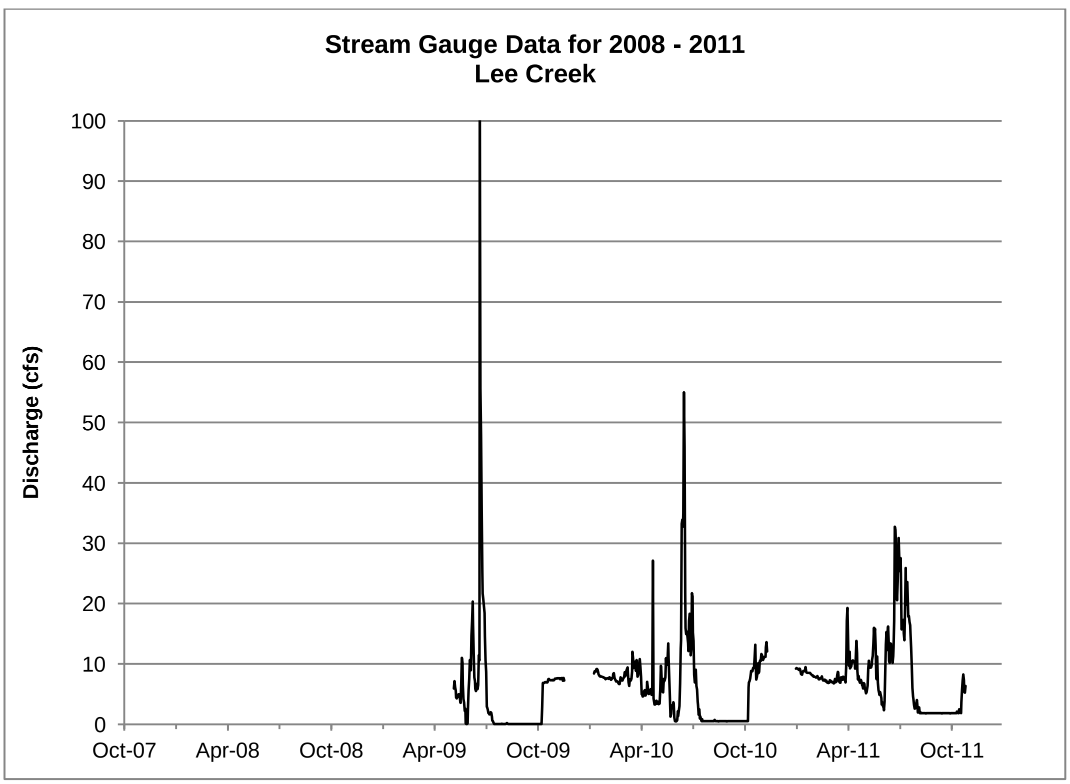
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Hawley Creek
Discharge (cfs)
80
70
60
50
40
30
20
10
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11

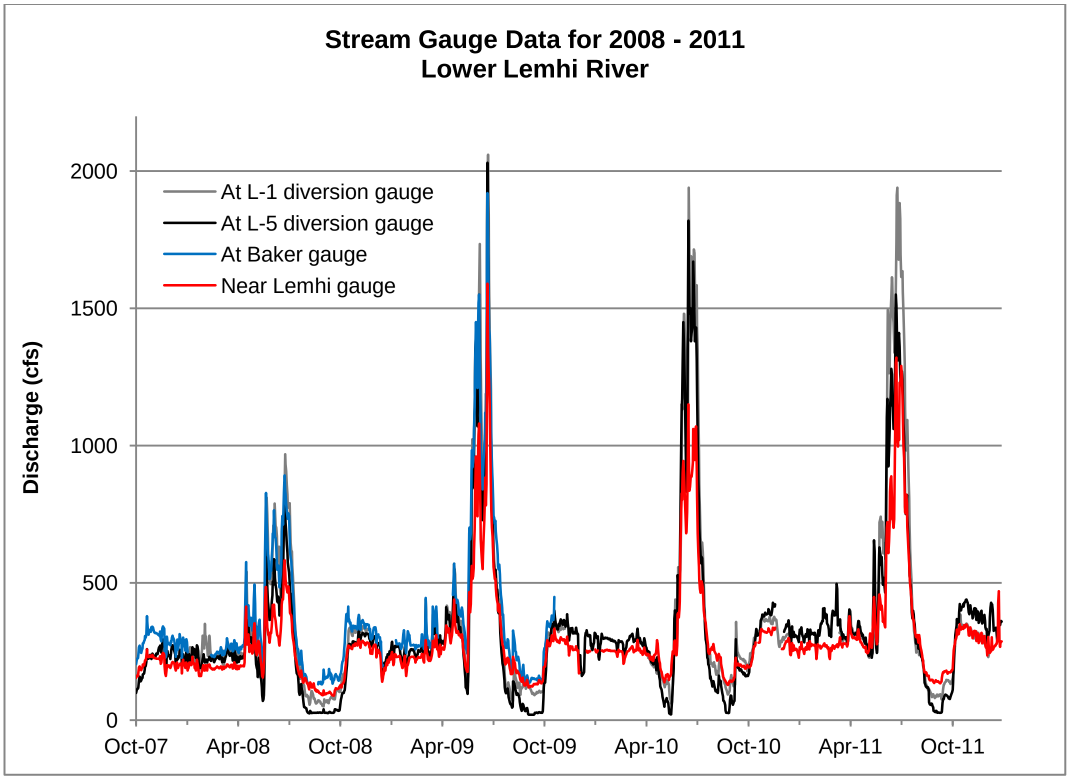

Stream Gauge Data for 2008 - 2011
Hayden Creek
Discharge (cfs)
1000
900
800
700
600
500
400
300
200
100
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11



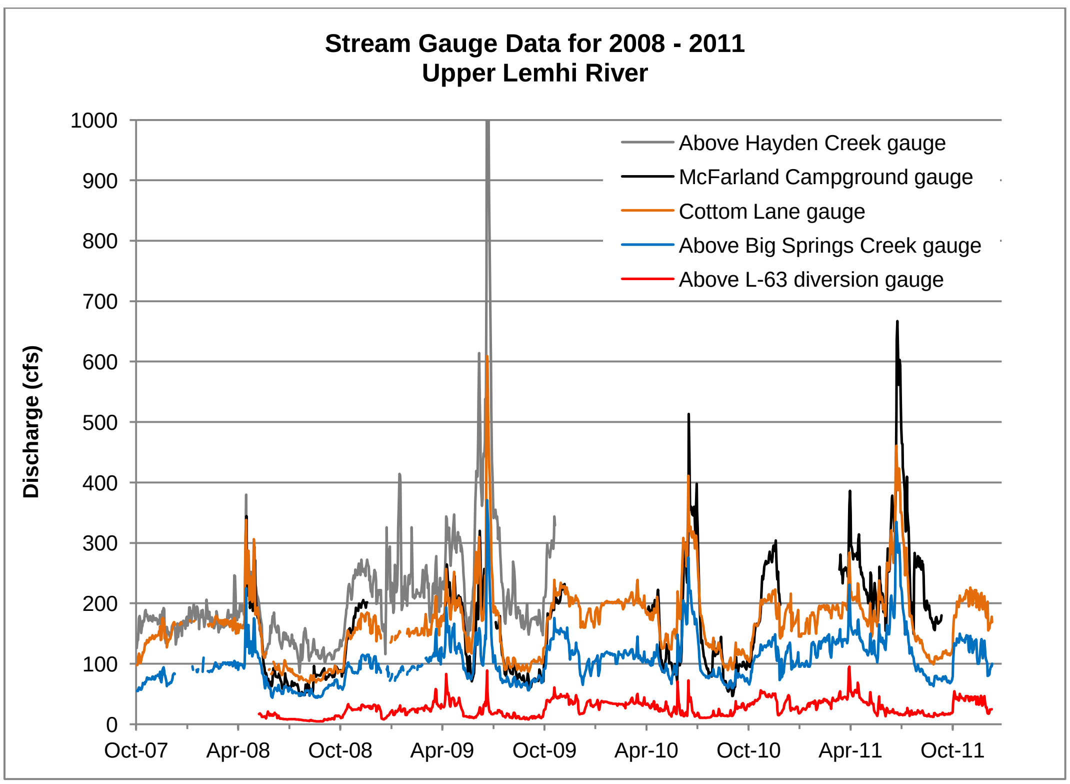
Stream Gauge Data for 2008 - 2011
Kenney Creek
Discharge (cfs)
120
100
80
60
40
20
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11



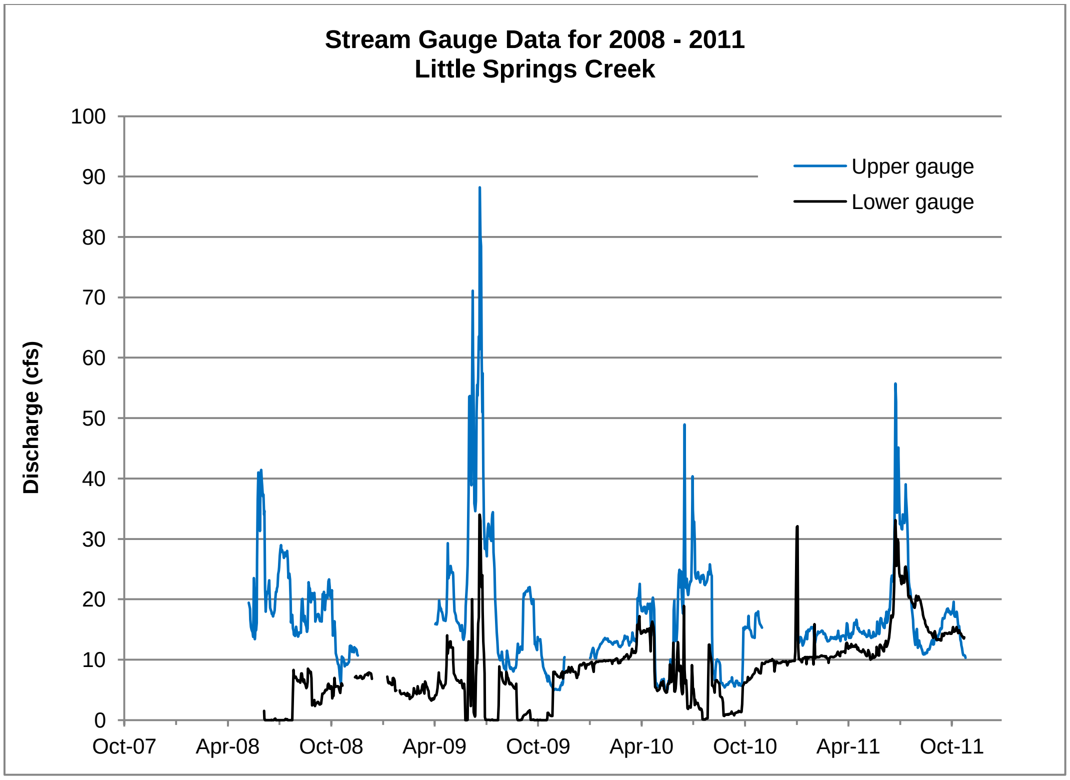
Stream Gauge Data for 2008 - 2011
Lee Creek
Discharge (cfs)
100
90
80
70
60
50
40
30
20
10
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11



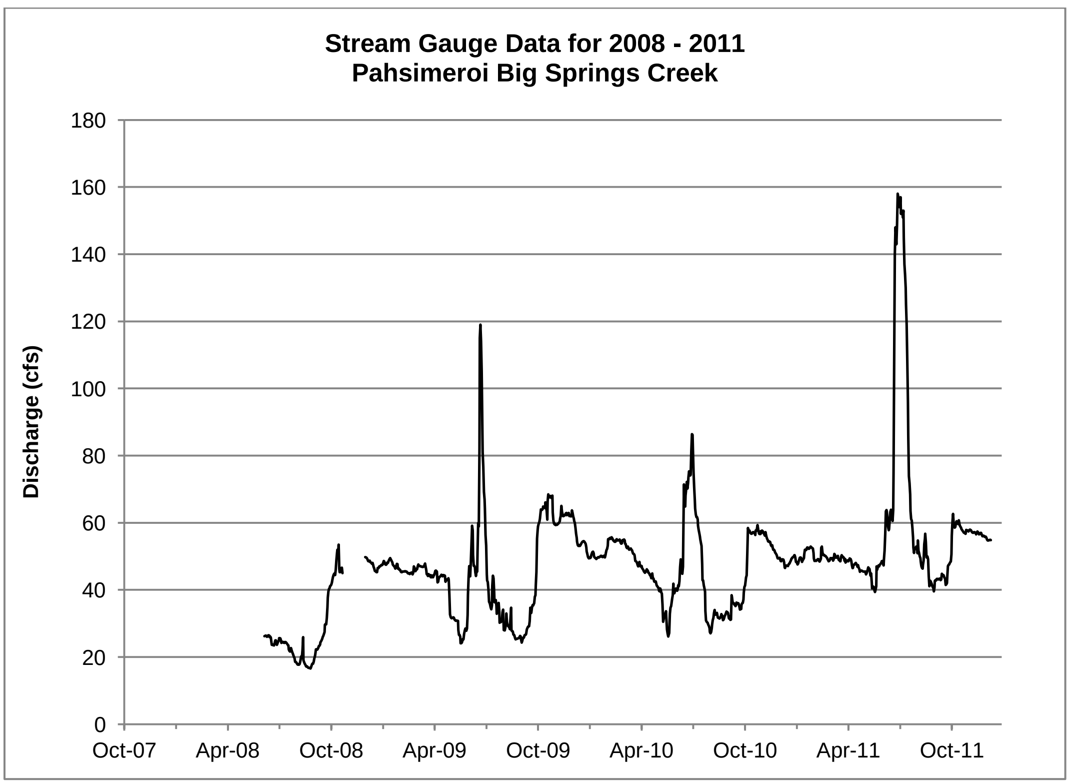
Stream Gauge Data for 2008 - 2011
Lower Lemhi River
Discharge (cfs)
2000
1500
1000
500
0
At L-1 diversion gauge
At L-5 diversion gauge
At Baker gauge
Near Lemhi gauge
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11



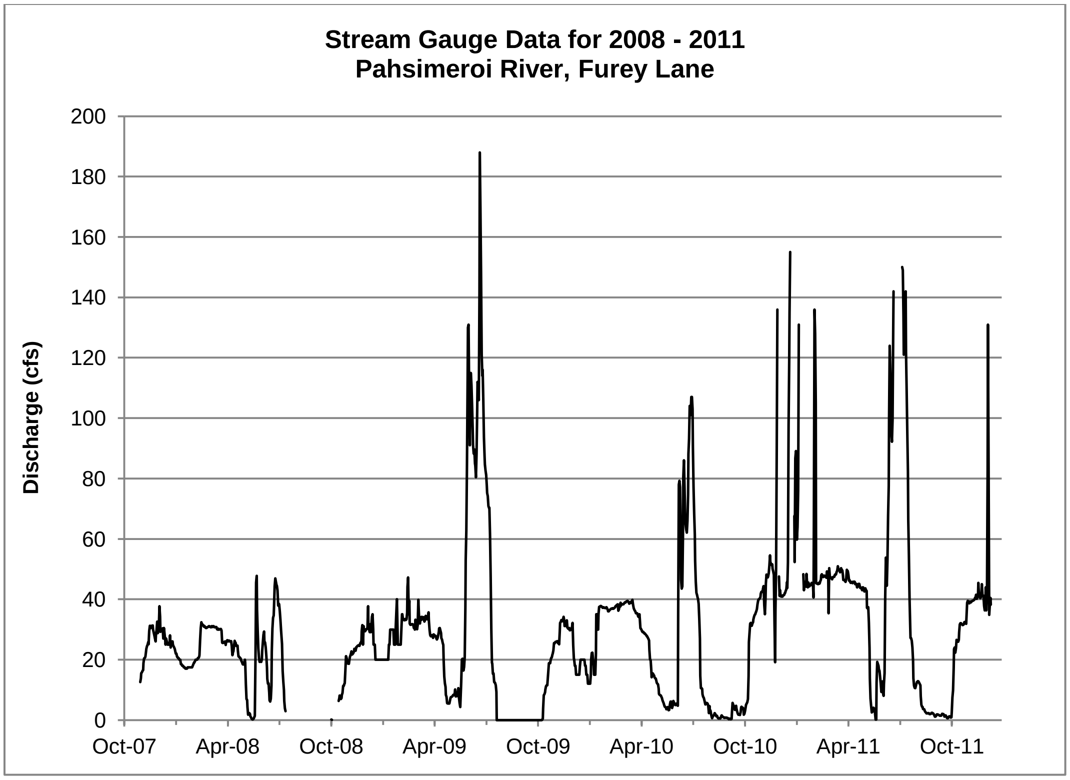
Stream Gauge Data for 2008 - 2011
Upper Lemhi River
Discharge (cfs)
1000
900
800
700
600
500
400
300
200
100
0
Above Hayden Creek gauge
McFarland Campground gauge
Cottom Lane gauge
Above Big Springs Creek gauge
Above L-63 diversion gauge
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11

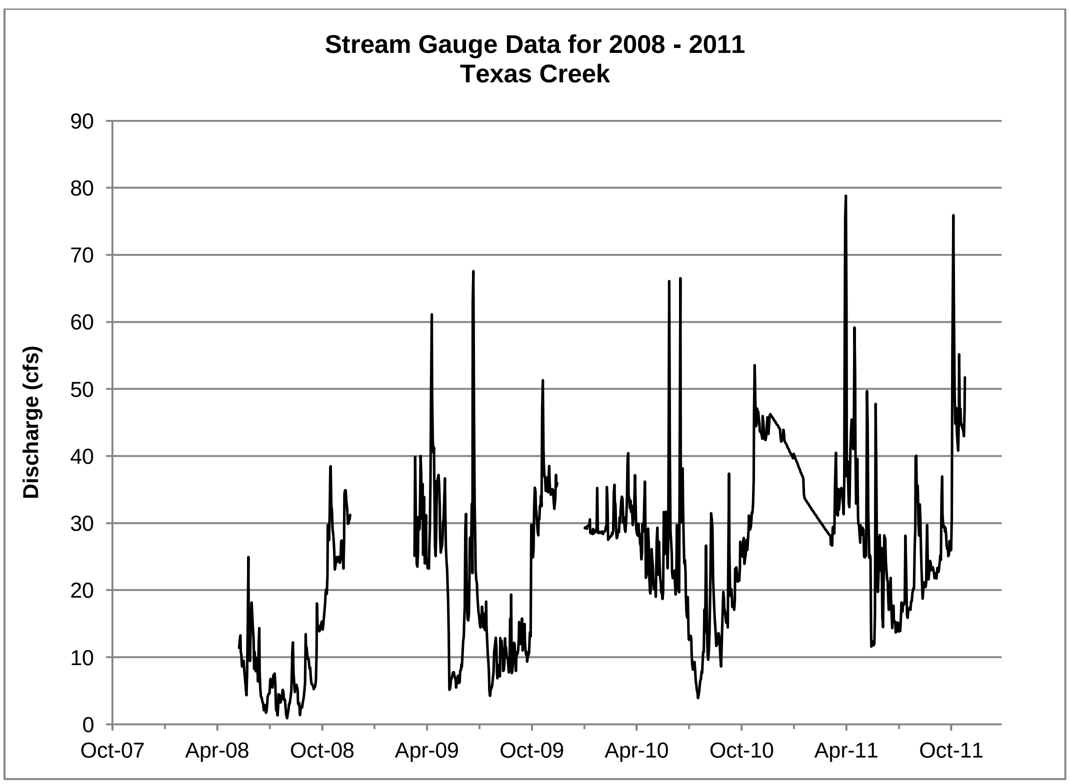


Stream Gauge Data for 2008 - 2011
Little Springs Creek
Discharge (cfs)
100
90
80
70
60
50
40
30
20
10
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11
Upper gauge
Lower gauge



Stream Gauge Data for 2008 - 2011
Pahsimeroi Big Springs Creek
Discharge (cfs)
180
160
140
120
100
80
60
40
20
0
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Pahsimeroi River, Furey Lane
Discharge (cfs)
0
20
40
60
80
100
120
140
160
180
200
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11


Stream Gauge Data for 2008 - 2011
Texas Creek
Discharge (cfs)
0
10
20
30
40
50
60
70
80
90
Oct-07
Apr-08
Oct-08
Apr-09
Oct-09
Apr-10
Oct-10
Apr-11
Oct-11

IDAHO Department of Water Resources

APPENDIX B

INVESTIGATING GROUND WATER – SURFACE WATER INTERACTIONS IN THE LEMHI RIVER BASIN, IDAHO

PROJECT PLAN

Prepared by

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In cooperation with
Idaho Governor's
Office of Species Conservation
Upper Salmon Basin Watershed Program

With funding from
U.S. Army Corps of Engineers
Authority:
Section 22, Planning Assistance to States

July 2011

Executive Summary

Successful implementation of stream flow enhancement projects by the Upper Salmon Basin Watershed Program (USBWP) Technical Team depends on an accurate understanding of the Lemhi River Basin hydrology, which 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 sensitive anadromous fish habitat and water supplies for agricultural purposes. For example, the impacts of flood and sprinkler irrigation practices on the timing and quantity of stream flows is currently not well understood in the Basin, and knowledge of these processes is in high demand from local water users and natural resource management personnel.

The proposed study aims to undertake a series of hydrologic tests and activities to better characterize the role of ground water in the Basin at multiple scales. The goal of this study is an improved understanding of water resources in the Lemhi River Basin, from a Basin-scale water budget standpoint but also, more importantly, from a site-to-site water management perspective. Information gained through this study will be directly applicable to increasing the functionality and accuracy of the Lemhi River Basin MIKE BASIN model, which will supplement the tool set used by the USBWP Technical Team in ranking proposed stream flow enhancement projects.

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1.0 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 Upper Salmon Basin Water Program (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 2011).

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.

1.1 Location and Setting

The Lemhi Basin encompasses 1270 mi^2 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.

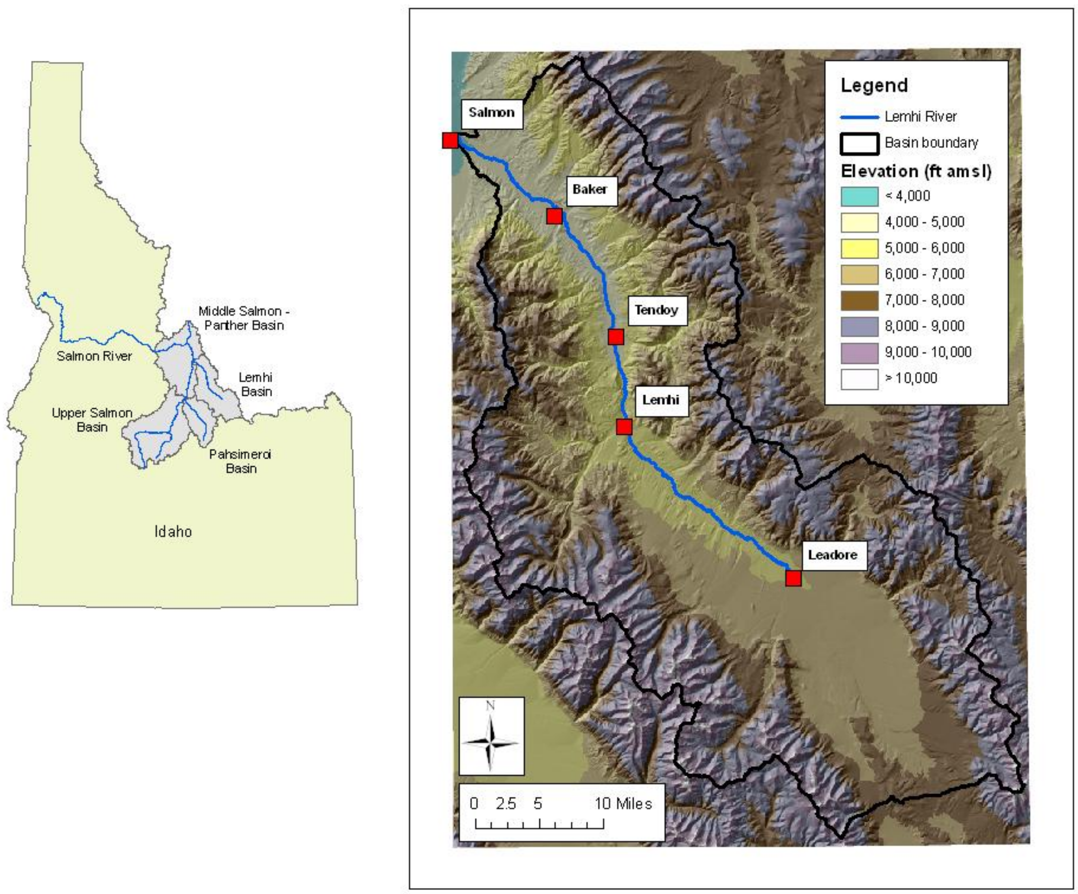

Figure 1. Location of the Lemhi Basin.

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 (Figure 2). The Lemhi River valley, surrounding alluvial terraces, and tributary corridors support productive agricultural operations that drive the local economy (Figure 3).

Figure 2. Photo of the Lemhi River, showing a reach meandering between irrigated fields and flanked by an abundance of riparian willow stands (courtesy of Loucks 2000).

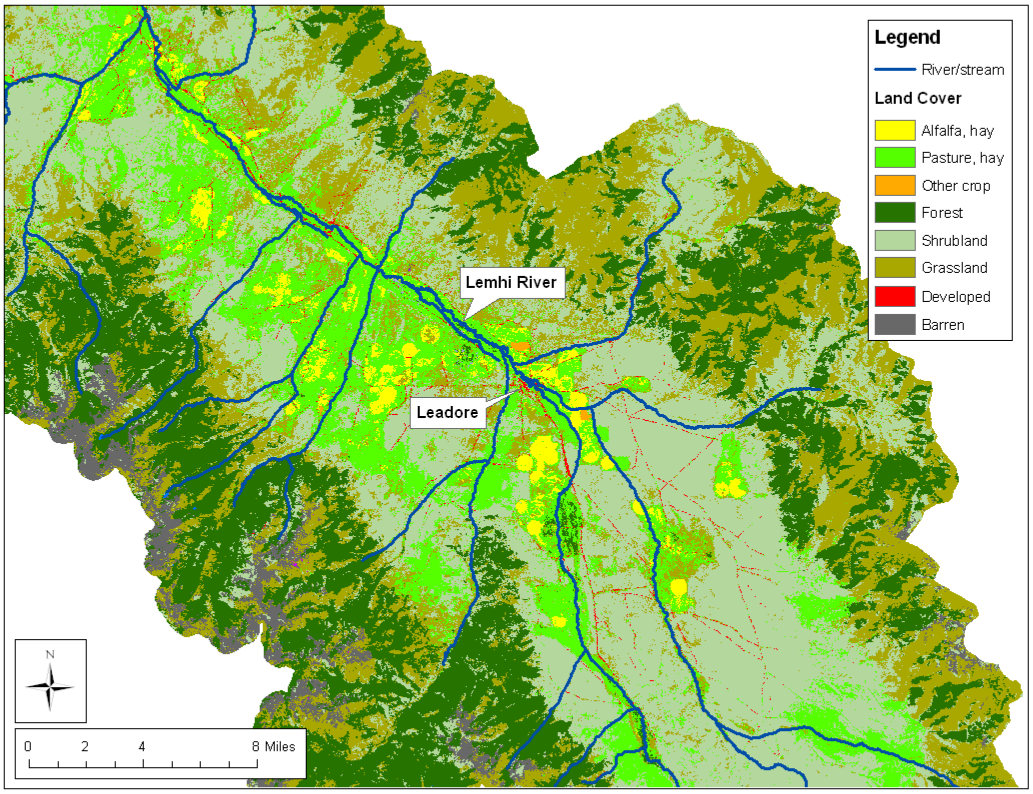

Figure 3. Land cover map of the Lemhi Basin near Leadore, ID. The bright green, yellow, and orange areas indicate irrigated land.

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 $^{2}/_{3}$ 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 2010). 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 mi. 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.

1.2 Summary and Analysis of Previous Studies

Recognizing the importance of the Lemhi Basin to support both fisheries and irrigation opportunities, a number of previous investigators have attempted to characterize the Basin's complex surface water and ground water interactions. For example, there is evidence that seepage from high flow irrigation augments ground water levels, and that ground water flow, in turn, augments surface flows during the late irrigation season. The results of previous studies are incorporated to allow the work proposed in this plan to leverage that information, provide a technical foundation for proposed activities, and to help tie together these separate pieces of information into a more integrated and better understanding of Basin-wide surface water and ground water interactions.

Spinazola (1998)

Aiming to relate ground water pumping to stream depletion, a U.S. Bureau of Reclamation (USBR) study conducted by Spinazola (1998) investigated dozens of wells across the Basin to characterize the seasonal ground water level fluctuations and physical properties of the shallow alluvial aquifer. The results indicated that, from 1995 – 1998, water levels in approximately 30 wells increased significantly (i.e. greater than 5 ft up to 25 ft) and remained elevated during the irrigation season. However, Spinazola also observed that the seasonal dependence of water levels in nearly as many wells was questionable (i.e. less dramatic fluctuations, and increased levels not maintained).

Figure 4 plots the data collected by Spinazola for two shallow wells (i.e. total depth less than 50 ft bls) separated by just 1 mi, both along the Lemhi River corridor near the downgradient Basin boundary. As shown, the Thomas well was observed to experience a significant and sustained rise in water level during the irrigation season, whereas the temporal deviation in water level in the Cockrell well is much less notable. Interestingly, according to the drill logs, both wells have 6 – 8 ft open intervals in clay/gravel water-bearing zones, and both experienced approximately 20 ft of drawdown during equivalent driller's production tests. Thus, although the results of Spinazola suggest a high degree of connectivity between irrigation and ground waters in many areas of the Basin, what remains unclear is why ground water levels increased significantly in some areas but not in others. For example, because nearly all wells monitored in the Spinazola study are located within or downgradient of irrigated areas, the effects on ground water levels from irrigation practices vs. natural runoff cannot be separated.

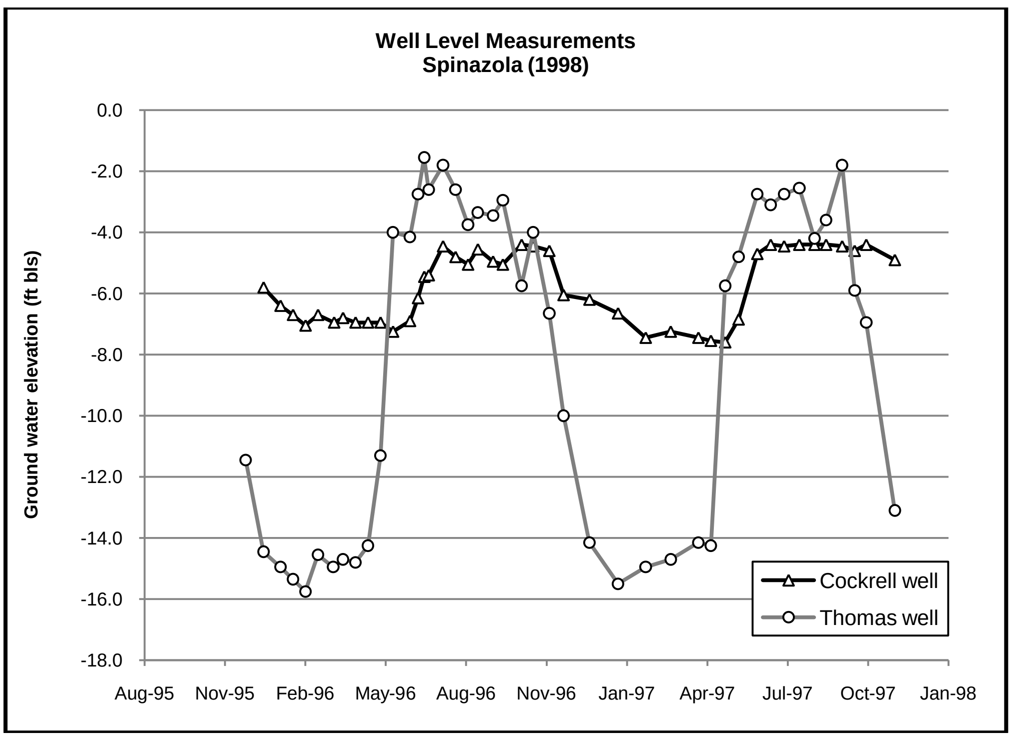

Figure 4. Graph of well level measurements for two neighboring wells monitored by Spinazola (1998).

Additionally, Spinazola examined alluvial aquifer properties in the Basin. Referencing Table 1 of the Spinazola report, which contains estimates of aquifer properties from dozens of well drillers' logs, an approximate geometric mean saturated hydraulic conductivity (K_{sat}) in the upper Basin can be calculated at approximately 22 ft/d, a value typical of silty sands and gravels (Fetter 2001). However, Spinazola referenced an earlier study conducted by Young and Herenberg (1973), which reported a much higher average transmissivity (T) for the neighboring Pahsimeroi Basin (30,800 ft^2/d, as compared to 532 ft^2/d in the upper Lemhi Basin), and suggested that ground water in the upper Lemhi Basin may travel faster than is implied by the Lemhi drill log estimates. Referencing Table 9 and the well logs summarized in Young and Herenberg, K_{sat} in the Pahsimeroi Basin can be estimated at 400 ft/d (based on the pumping tests of three irrigation wells). This value may be interpreted as an upper estimate of K_{sat} in the upper Lemhi Basin because: according to Spinazola and others (Dorratcaque 1986), the hydrogeology of the Pahsimeroi Basin is similar to that in the upper Lemhi Basin; but, the use of irrigation well pumping tests likely positively biases estimates of T and K_{sat} due to the productive nature of irrigation wells. Please refer to Appendix A for example hydrologic calculations that can be used to calculate the above parameters.

The estimates of K_{sat} obtained from the reports of Spinazola (1998) and Young and Herenberg (1973) can be used to bracket the expected average ground water velocity in the upper Basin. Please refer to Appendix A for example hydrologic calculations that can be used to calculate the parameters that follow. Assuming aquifer properties representative of the upper Basin, a K_{sat} of 22 ft/d yields an approximate average linear ground water velocity (v_{gw}) of 1.5 ft/d; with a K_{sat} of 400 ft/d, v_{gw} increases to 27 ft/d. These ground water velocities imply that the return time of irrigation water seeping into the subsurface and traveling 1 mi underground before discharging to a stream could range from several months to several years.

Although, to irrigators in the Basin that have observed late season stream flows supplemented by early season irrigation practices, a return time on the order of several months is reasonable (Dorratcaque 1986, Olson personal communication 2011, Dunn personal communication 2011), the potential range in K_{sat} suggests that return times may be quite variable across the Basin. Additionally, aquifer properties based on well logs cannot be considered quantitative, given uncertainties in drillers' methodologies. Further, what remain unknown are ground water flow paths – where ground water originates and where it returns to the surface. Thus, return times across the Basin cannot be accurately estimated without additional hydrologic tests (i.e. water could flow less than a mile or many miles underground before reaching the surface).

Donato (1998)

In a related USGS study conducted by Donato (1998), the amount and timing of water flowing through the Lemhi River during the irrigation season was examined. During 1997, many reaches of the Lemhi River were gaining systems (i.e. where ground water discharges into the river) during the latter part of the irrigation season (i.e. August), and fewer were losing reaches (i.e. where surface water seeps through the riverbed and recharges the aquifer). Following the irrigation season (i.e. October), several previously gaining reaches transformed into losing reaches. Donato attributed these results to a positive relationship between irrigation practices, ground water levels, and late season stream flows. Again, however, what remains unknown is the spatial dependence of these relationships, which is critical in assessing how irrigation practices will impact stream flows across the Basin.

Extrapolating the upper Basin results of Spinazola to the lower Basin, Donato also estimated that the amount of ground water leaving the Basin (i.e. outflow through the downgradient Basin boundary at the town of Salmon) is negligible in comparison to surface water outflow (i.e. Lemhi River flow into the Salmon River). Please refer to Appendix A for details of the hydrologic calculations employed in Donato's analysis. Donato supported this result with a similar analysis by Young and Harenberg (1973), where ground water outflow from the neighboring Pahsimeroi Basin was estimated to be small in comparison to total water outflow. It must be noted, however, that the outflow estimates from both of these studies were based on many simplifying assumptions of the physical characteristics of the alluvial aquifers. Thus, additional hydrologic tests, including true measurements of aquifer properties and ground water velocity, are needed to provide more accurate estimates of the Basin's ground water outflow.

Haws et al. (1977)

In an earlier study conducted by Haws et al. (1977), a dye tracer was deployed in three upper Basin ditches to investigate whether flood irrigation applied in the upper Basin would emerge as surface water flow in the lower Basin. The results indicated a large proportion of the tracer made its way to downstream reaches of the Lemhi River via ground water flow paths, suggesting a high degree of connectivity between irrigation in the upper Basin and stream flows in the lower Basin. However, some of the tracer appeared in the river within just a couple of days, and some remained in the ground water system for several months. Further, no correlations between tracer deployment location and emergence in the Lemhi River were made. Thus, again, it is unclear where ground water flows rapidly, where it flows slowly, and which pathways it follows.

Taken together, the reports of Spinazola (1998), Donato (1998), and Haws et al. (1977), among others, suggest that ground water in the Basin is relatively mobile and acts to supplement stream flows. Specifically, there is evidence that irrigation augments ground water levels by seeping into the subsurface, and that ground water, in turn, acts to supplement stream flows and downstream water users during the late irrigation season. However, additional tests are warranted to provide more detailed information regarding where ground water is recharged by irrigation and natural runoff processes, what directions it flows, where it discharges to the surface, and how long it takes to travel from source to discharge location. Knowledge of this information is critical to assessing the impacts on the seasonal variations of stream flows from various irrigation practices, and would help improve the design and implementation of stream flow enhancement projects throughout the Basin.

1.3 Purpose and Objectives

This project plan describes the specific tasks and methods that will be employed to better characterize the subsurface component of the Basin's hydrologic system, specifically the degree of interaction between ground and surface waters. These efforts are expected to shed more light on the unknowns that are critical to balancing agricultural needs with water resources in the Basin, such as where flood irrigation benefits stream flows and downstream water users, and where it is more appropriate to conserve stream flows by utilizing sprinkler irrigation. Data collected will be incorporated into MIKE BASIN, and will be used to help the USBWP Technical Team and local landowners make water management decisions that are more physically-based and result in the successful enhancement of stream flows in the Lemhi Basin.

Through discussions among the USBWP, IDWR, and collaborating agencies, specific objectives of this project have been identified as: 1) those providing the USBWP Technical Team and landowners with hydrologic information in areas of priority for current or planned stream flow enhancement projects, and 2) those applicable to supplying information descriptive of hydrologic processes across the Basin. These objectives are listed below, and the locations of focal areas identified by Objective I are shown in Figure 5.

I. Determine the flow rates, locations, and magnitudes of return flows from irrigation waters extracted from the following focal areas (ordered according to the downstream direction):
   - Big Timber Creek
   - Hawley Creek
   - Little Springs Creek
   - Mill Creek
   - Kenney Creek
   - Withington Creek
   - Bohannon Creek

II. Describe the relative contributions of high flow water rights and base flow rights to ground water in the Basin

III. Determine the relative contributions of surface and ground waters from the upper Basin to the lower Basin (i.e. through the mid-Basin divide)

IV. Estimate the magnitude of ground water outflow (i.e. through the downgradient Basin boundary)

V. Estimate the impacts on ground water supplies and stream flows when irrigation practices are converted from flood to sprinkler application

As implied by the objectives listed above, and in contrast to previous studies, the focus of this project is to characterize the role of ground water in the Basin at multiple scales. The expected outcome of this project is improved understanding of water resources in the Lemhi Basin, from a large-scale water budget standpoint but also, more importantly, from a site-to-site water management perspective.

It must be noted that this study plan is designed to be a living document; it is not designed to be comprehensive in terms of directing all hydrologic tests and activities. During and following 2011 field activities and data collection, it is expected that information will be gained that will aid and/or direct subsequent efforts. Thus, this plan will likely be revised over the course of this project.

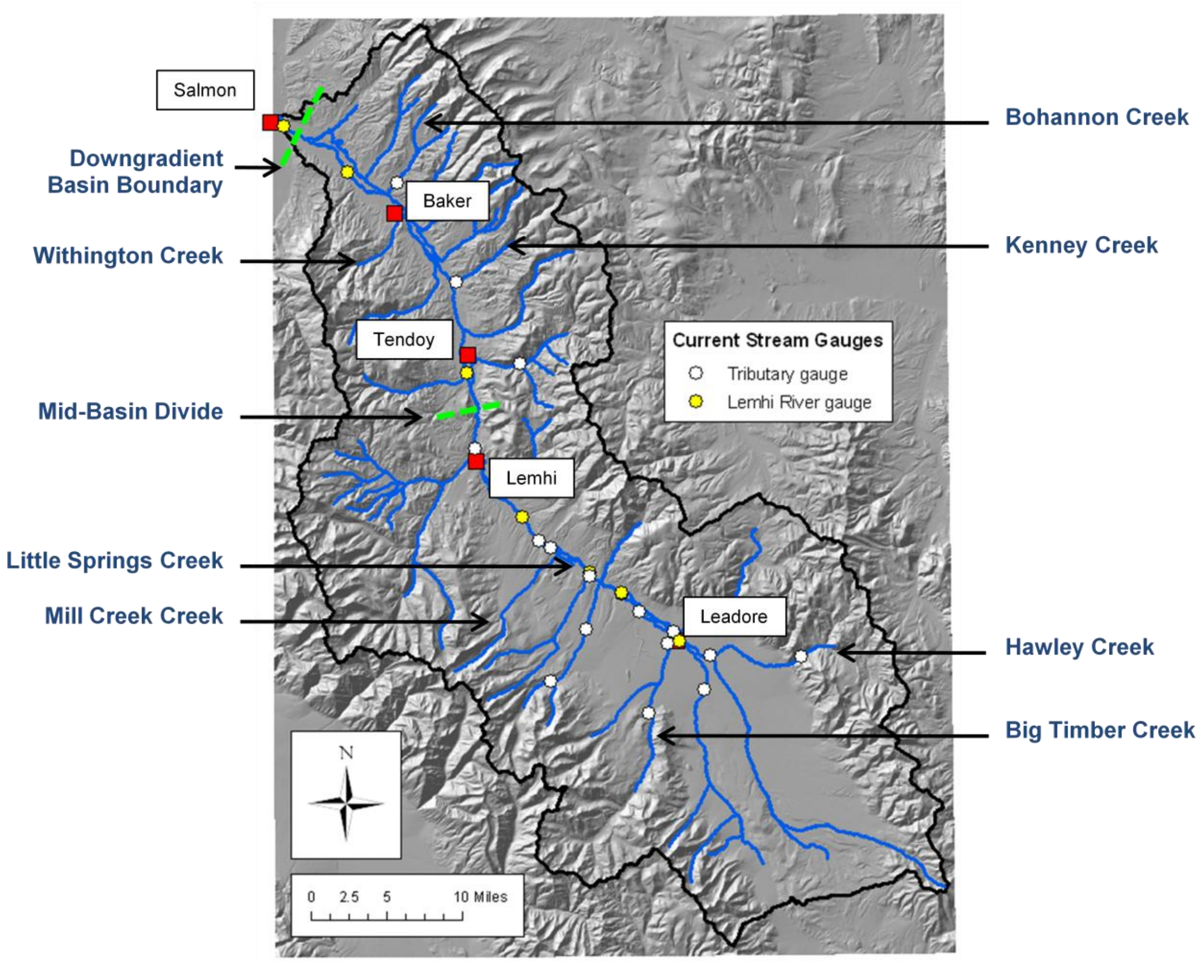

Figure 5. Focal areas identified by Objective I, and stream gauges currently in operation in the Lemhi Basin.

2.0 Methods

The five objectives listed in Section 1.3, individually and combined, are broad in scope, and thus necessitate a variety of techniques to fulfill. Reviews and analyses of existing soils data, previously conducted seepage runs, and previously conducted well level measurements will be performed to supplement the data generated through various hydrologic tests and field activities, many of which will be conducted concurrently. It is presumed that no one objective can be met with a single test, type of test, or field activity. Table 1 links the various activities with the study objectives.

Hydrologic Test/Activity	Objective I	Objective II	Objective III	Objective IV	Objective V
Dye tracer tests	X	X			X
Seepage runs	X	X	X	X	X
Analysis of previously conducted seepage runs	X	X	X	X	X
Well level measurements	X	X	X	X	X
Analysis of previously conducted well level measurements	X	X	X	X	X
Aquifer tests			X	X	
Collection of stream gauge data	X		X	X	X
Soil moisture measurements		X			X
Analysis of existing soils data		X			X
Incorporation of measured/collected data into MIKE BASIN model	X	X	X	X	X

Table 1. Hydrologic tests and activities associated with each of the study's objectives.

2.1 Hydrologic Tests and Activities

Each of the 10 hydrologic test/activities listed in Table 1 are discussed in the following sections.

2.1.1 Dye Tracer Tests

This study will use hydrologic dye tracing, ideally during both high flow (i.e. early season) and base flow (i.e. late season) periods, to delineate ground water flow paths (i.e. recharge and discharge locations) and return times of diverted water (i.e. amount of time between when water is extracted for irrigation and when it returns to stream flow). This information will not only be applicable to the specific focal areas identified in Section 1.3, but will also aid in clarifying the roles of flood vs. sprinkler and high flow irrigation practices in regulating ground water supplies.

The primary hydrologic tracer utilized in this study will be sodium fluorescein (also known as acid yellow 73), a green fluorescent dye. Rhodamine WT (also known as acid red 388), a red fluorescent dye, may also be used. Both dyes are commonly used in ground water tracing (Davis et al. 1985, Field et al. 1995, Aley 2002), as well as in various manufactured goods (Aley 2002). Both fluorescein and rhodamine WT are widely accepted as being non-ecotoxic, and pose no threat to human health when used in concentrations applicable to tracer studies (Smart 1984, Field et al. 1995, Leibundgut and Hadi 1997). The suggested safe limit (i.e. posing no threat to human or ecological health) for these tracers is 1 parts per million (ppm) (Field et al. 1995), and the tracers are essentially colorless at 0.1 ppm (Farmer and Blew 2011). Although the tracers adsorb onto organic materials to an appreciable extent, their anionic character resists adsorption onto inorganic materials such as clays, sands, and rocks (Aley 2002), which likely comprise the bulk of the alluvial aquifer in the Lemhi Basin. Additionally, both tracers can be detected in samples at sub-parts per billion (ppb) concentrations, and are relatively inexpensive (Davis et al. 1985, Aley 2002). These properties highlight fluorescein and rhodamine WT as very useful and safe tracers for deployment in the Lemhi Basin.

The tracer injection schemes discussed below aim to introduce the tracer as a slug or pulse, and should result in tracer breakthrough peaks that estimate average ground water travel times or return times. Up to 4 lbs of solid fluorescein (75% by weight, powder form) or 12 lbs of rhodamine WT (20% by weight, liquid form) will be mixed with several gallons of water in plastic carboy containers. The mixture will be shaken periodically for 1 hr, and then will sit overnight, in the dark, to promote complete dissolution and mixing.

Please refer to Appendix A for detailed calculations associated with the following tracer concentrations. For trench deployment, the mixture will be poured into a constructed trench and flushed into the subsurface with up to 2,000 gal of irrigation water. The maximum resulting trench-deployment tracer concentration will be about 400 ppm. Based on the local hydrogeology of the field sites (from drill logs) where trench-deployment will be utilized, the resulting tracer plume will be diluted to the suggested safe limit within less than 1 acre of downgradient land.

If tracer is injected via well, potable water will be used to pre-dilute the tracer and to help induce tracer migration into the aquifer. The maximum resulting well-deployment tracer concentration will be about 1500 ppm. Based on the local hydrogeology of the field site (from drill logs) where well-deployment will be utilized, the tracer plume will be diluted to the suggested safe limit within less than 0.25 acre of downgradient land.

The tracer in the ground water at each downgradient monitoring location will be collected with a charcoal packet. Each charcoal packet will consist of approximately 4 g of activated coconut shell charcoal placed in a rectangular-shaped fiberglass mesh enclosure. Each packet will be placed inside a 2 in diameter black PVC tubing and cut to lengths that fully enclose the packets to protect them from animal interference. The packets will be secured inside the PVC tubing with plastic cable (i.e. zip) ties wrapped through small drilled holes in the PVC tubing. The packets will be deployed in the field by fully submersing each in water, preferably in shaded locations, and anchoring each to a sturdy tree, rock, or other immovable object with plastic-insulated electrical wire wrapped through the PVC tubing. The packets will be deployed prior to tracer injection, and will sit in the field for no longer than 2 weeks before being collected and replaced by fresh packets.

Permitting information for conducting tracer tests in Idaho is summarized in Appendix B.

Analytical techniques required to quantify detected tracer quantities are detailed in Section 2.2.

2.1.2 Seepage Runs

Seepage runs on stream and/or ditch reaches will be conducted within each focus area concurrently with the tracer tests. During a seepage run, flow in the river, all diversions, and all returns will be measured to estimate distributed river gains from and losses to ground water. This produces a snapshot of the hydrologic condition of the river because measurements are made within a short time period. Seepage runs provide a measure of the spatial distribution of ground water recharge and discharge, and thus will aid in extrapolating the results of the tracer tests across each focus area. Additionally, quantifying the gains and losses of the Lemhi River along the mid-Basin divide and downgradient Basin boundary will aid in determining the volumes of surface and ground water passing through these locations. If at all possible, seepage runs will also be conducted in areas with upcoming flood to sprinkler conversion projects, even if outside of the focal areas, to supply baseline information (i.e. gains and losses associated with reaches downgradient of flood irrigated fields). Further, a handful of seepage runs may be performed during the high flow irrigation season to estimate the fraction of water used to flood irrigated fields that does not return directly to stream flow in the form of overland flow. This fraction will be a quantitative estimate of the amount of high flow irrigation that results in aquifer recharge.

2.1.3 Analysis of Previously Conducted Seepage Runs

Information from seepage studies conducted in the Lemhi Basin during the last 15 years will be analyzed and used to supplement the data collected in the field during this study. This includes the results of Donato (1998), where seepage runs were utilized along the mainstem Lemhi River during the late 1990’s. Additionally, IDWR performed seepage runs along several tributaries in the Basin, including Big Timber Creek, Hawley Creek, Little Springs Creek, Kenney Creek, and Bohannon Creek, during the late 2000's.

2.1.4 Well Level Measurements

Ground water levels will be measured periodically, either hourly or daily with installed pressure transducers or every other week with water level sounders, in selected existing wells throughout the irrigation season to assess the temporal fluctuations of ground water levels in each focus area and thus help correlate ground water level fluctuations with irrigation practices. Both wells above and below irrigated lands will be monitored to investigate the correlation of ground water recharge and irrigation vs. natural runoff processes. Additionally, wells equipped with pressure transducers recording water levels hourly will be used to estimate the lag time between when water is applied to the surface (i.e. either irrigation or precipitation) and when it recharges the aquifer. Further, periodic well level measurements will help provide estimates of the seasonal variability of ground water underflow/outflow through the mid-Basin divide and downgradient Basin boundary. Each depth to water (D_w) measurement will be converted to a ground water elevation by subtracting D_w, which will be corrected for the casing height above ground, from ground surface elevation.

2.1.5 Analysis of Previously Conducted Well Level Measurements

The well level measurements will be supplemented with data collected by Spinazola (1998) and the USGS, where possible, and used to estimate catchment-scale ground water elevation contours. This information will further aid in identifying ground water flow paths and recharge/discharge locations across each focus area, and will provide additional insight into estimating the seasonal variability of ground water underflow/outflow through the mid-Basin divide and downgradient Basin boundary.

2.1.6 Aquifer Tests

Aquifer tests will be utilized to quantitatively estimate K_{sat}, which in turn will be used to calculate the volume of ground water flowing through the mid-Basin divide and downgradient Basin boundary (and total flow when combined with surface water flow volumes). For each well chosen for water level measurements near the boundary and along the divide, step-rate pump tests will first be conducted to investigate the drawdown response at several pumping rates. This will provide pumping rates that will elicit a measurable drawdown response but will not result in dewatering to below the top of the pump. Step-rate and constant rate pumping test analyses (refer to Section 2.2.2) will be performed to characterize the average local T. This information will be used in conjunction with drill logs and existing geological surveys to quantitatively estimate K_{sat} and volumetric ground water flow quantities (Q_w). This information will be used in tandem with the water level measurements to estimate the variability of Q_w with time.

2.1.7 Collection of Stream Gauge Data

Stream gauging data will be used to quantitatively estimate the surface water flow rates (S_w) in each focus area and compare the ground and surface water flow rates through the mid-Basin divide and downgradient Basin boundary. Available gauge locations are shown in Figure 5. Gauge data will be collected during the periods when the tracer tests and aquifer tests are conducted. In conjunction with the aquifer tests, these data will provide snapshots of surface and ground water flow rates through these locations. Additionally, the variability of Q_w with time will be compared against the variability of S_w with time to help discern the relative significance of ground water underflow to total water flow through the mid-Basin divide and downgradient Basin boundary.

2.1.8 Soil Moisture Measurements

Soil moisture meters will be installed in selected flood and sprinkler irrigated fields to directly measure irrigation infiltration, which will be used to estimate the extent of ground water recharge. Soil moisture data will be collected throughout the irrigation season to help evaluate the significance of high flow irrigation in enhancing ground water recharge. This information will also be used to supplement that obtained through existing soil data analysis, specifically to gain site-specific information where it is lacking.

2.1.9 Analysis of Existing Soils Data

The Natural Resource Conservation Service (NRCS, formerly the Soil Conservation Service) is charged with keeping data relevant to soil types and properties, and has records of this information at the local scale for the Lemhi Basin. Specifically, soil moisture data and infiltration rates will be collected and analyzed to provide estimates of recharge associated with flood and sprinkler irrigation practices.

2.1.10 Incorporation of Measured/Collected Data into and Refinement of MIKE BASIN Model

Presently, the MIKE BASIN model is structured to reflect the surface flow paths of all major stream and irrigation diversion channels, and all catchments that supply flow to these channels, in the Lemhi Basin. The model is loaded with daily stream and diversion flow data, measured via stream gauges or local watermasters, and various physical and empirical characteristics of the catchments are calibrated to predict the measured stream flows from climatological data, accounting for the flows diverted through irrigation ditches. The model also accounts for the demand (i.e. water rights) associated with each irrigation water user. Thus, the model is currently capable of estimating the distribution of surface flows throughout the Basin, and predicting where and when demand shortages are encountered. However, because data on ground water – surface water interactions in the Basin is presently lacking, the model assumes the timing and locations of return flows, and does not account for the storage and movement of ground water, which likely accounts for a large proportion of hydrological processes in the Basin. Therefore, although the present model is useful in estimating how surface water is distributed and demanded across the Basin, and how basic alterations to surface water diversions (i.e. relocating a point of diversion or place of use, or reducing water demand) may impact downstream flows, it is not currently capable of assessing the more complex issues that are reflected in the objectives listed in Section 1.3.

Through this study, data on the physical timing and locations of irrigation return flows and extent and multi-scale roles of ground water in the Basin will be collected. This information will be incorporated into the model, which will be augmented with an available ground water package, as it is collected. Successive calibrations of the model will then provide a more physically-based tool capable of describing the Basin's hydrology, illustrating the local- and large-scale roles of irrigation practices in regulating water supplies, and guiding successful stream flow enhancement projects. Figure 6 plots an example output of an enhanced MIKE BASIN model (i.e. ground water characteristics assumed for illustrative purposes only). As shown, the model is capable of differentiating surface water contributions from ground water contributions to total stream flow. This capability would help irrigators and planners of stream flow enhancement projects delineate the hydrologic impacts of, for example, switching from flood to sprinkler irrigation practices.

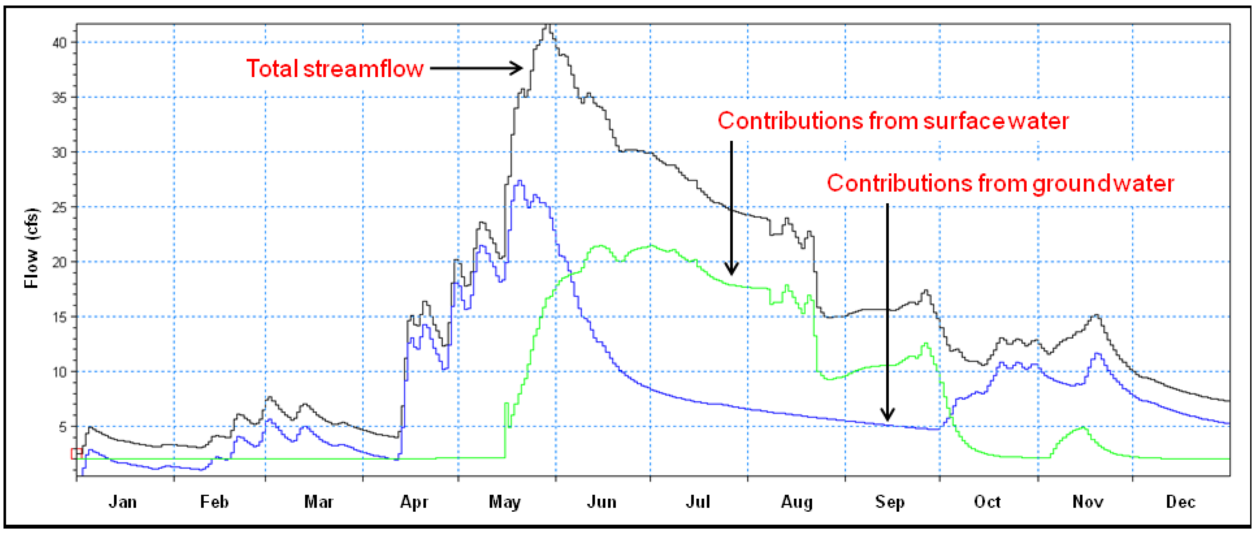

Figure 6. Example hydrograph generated with an enhanced MIKE BASIN model equipped with surface and ground water processes. This example illustrates how knowledge of the timing and locations of irrigation return flows, as well as aquifer capacity and ground water translation, can help water users and natural resource managers more fully understand the physical processes governing stream flows.

2.2 Analytical Methods

The primary analytical methods associated with the study are measuring tracer concentrations in charcoal packet and water samples, and analyzing aquifer test data to estimate hydraulic properties of the Basin's alluvial aquifer.

2.2.1 Fluorometric Determination of Tracer Concentrations

The experimental methods for fluorometric analysis that follow are referenced from Aley (2002, 2003), unless otherwise noted.

Upon field collection, the charcoal packets will be immediately placed in white Styrofoam coolers with 'blue ice' cold packs (i.e. non-dye containing), and subsequently transferred to a refrigerator for storage prior to analysis. The packets will not be rinsed prior to storage, as chlorinated water has been shown to result in tracer loss from activated charcoal. The packets will be transported for analysis in the containers mentioned above, and will be analyzed within 1 month of their collection.

Unfiltered water samples (50 ml) will be collected in screw-top polypropylene containers (pre-rinsed 3 times with sample water), and placed in white Styrofoam coolers with 'blue ice' cold packs immediately upon collection. The samples will be shipped overnight for analysis in the containers mentioned above. Upon delivery to IDWR, the samples will be placed in a refrigerator for 1 – 2 days for sediment to settle, and analyzed within 1 week of collection on a Turner Designs TD-700 laboratory fluorometer configured for fluorescein or rhodamine WT. Each sample will be adjusted to above pH 6 prior to analysis (Davis et al. 1985).

Prior to fluorometric analysis, the charcoal packets will be rinsed with a jet of deionized water to remove sediment, algae, or other materials that may be associated with the charcoal. Rinsing will mitigate background fluorescence and will aid in minimizing the detection limit for the tracer. The charcoal will then be emptied from the fiberglass packets into screw-top glass jars, and soaked in 50 ml of an eluent solution of 5% aqua ammonia (29% ammonia) and 95% isopropyl alcohol (70% alcohol, 30% water) for 24 hours (Farmer and Blew 2011). The resulting elutant solutions (i.e. eluent solution with dissolved tracer) will then be analyzed on a Turner Designs TD-700 laboratory fluorometer configured for fluorescein or rhodamine WT.

2.2.2 Analysis of Aquifer Test Data

The depth to water (D_w) in each well used for aquifer testing will be monitored with a Level TROLL 300 (In-Situ, Inc.) pressure transducer throughout the duration of the step-rate, constant rate, and recovery tests. For the constant rate and recovery tests, AQTESOLV software (HydroSOLVE, Inc.) will be used to plot D_w against time (i.e. time-drawdown data) and estimate transmissivity (T) and storativity (S) using a series of mathematical models that relate time-drawdown to aquifer hydraulic properties (Fetter 2001).

Subsequent hydrologic computations using the test-derived values of T and S, as well as data provided on drill logs (i.e. saturated aquifer thickness, b_{sat}, and open interval of well) and from field measurements (i.e. hydraulic gradient, i), will then be performed to estimate saturated hydraulic conductivity (K_{sat}) and ground water flow rate (Q_{gw}). Refer to Appendix A for details associated with the computations mentioned above.

2.3 Quality Assurance and Quality Control

A variety of activities will be incorporated into the field, laboratory, and data review/analysis practices of this study to produce high quality results.

- Several schemes will be employed to ensure the charcoal packets accurately reflect tracer concentrations. This includes placing packets in duplicate on periodic occasions to examine any variability in tracer adsorption between packets. Additionally, for some sets of duplicate packets, one will be retrieved for analysis one or two weeks prior to the other. The concentrations in both packets will be compared against neighboring packets and will help assess the field longevity of the packets (i.e. if the tracer begins to degrade in the packets after some time). Some packets will also be positioned upgradient of the expected tracer discharge locations to assess the background fluorescence associated with any natural organic matter present in the surface waters (Aley 2002).

- Most of the charcoal packets will be analyzed by IDWR, but some will be sent to Ozark Underground Laboratory (OUL), a professional laboratory with significant, specific experience analyzing dye tracer samples, for comparative analysis.

- Periodic measurements of depth to water (D_w) using a water level sounder will be performed as a calibration check in wells outfitted with a pressure transducer.

- Prior to conducting aquifer tests, each candidate well will be outfitted with a Level TROLL 300 (In-Situ, Inc.) pressure transducer to record D_w measurements every minute for several weeks to identify the drawdown and recovery characteristics of each well during normal domestic water usage. This practice, which is essentially a preliminary short-duration pumping test, will determine whether a well may be tested with the existing installed pump (i.e. if it experiences a notable drawdown using pumping rates available through the existing pump). Because large pumps cannot be used in small diameter (i.e. 6 in) wells, like this study's candidate domestic wells, this preliminary investigation of drawdown and recovery responses will guide the selection of wells for aquifer tests, and thus prevent unnecessary testing of unsuitable wells (Sukow 2011).

- Lastly, periodic review of the hydrologic tests and results of this study will be provided by various staff of IDWR with specific experience in one or more hydrologic fields reflected in each activity.

3.0 Phase 1 – 2011

Due to the inherent breadth and complexity of this project, as well as the currently limited number of field and laboratory personnel, field activities will be staggered over three years, or phases. Phase 1 goals are to run hydrologic tests (i.e. tracer tests, seepage runs, and well level measurements) at one trial site, apply and refine the field protocols developed to one focus area, experiment with investigating ground water sources and alluvial aquifer properties in the upper Basin, and begin examining the total water flow through the mid-Basin divide and downgradient Basin boundary during the 2011 irrigation season. Because Phases 2 and 3 are contingent upon the successes of Phase 1, as well as continued funding, detailed plans for hydrologic testing for these phases will be completed during and/or following Phase 1.

3.1 Lower Basin: Olson Property

Phase I goals include developing specific experimental procedures required for successful hydrologic tests throughout the Lemhi Basin. Thus, 2011 field activities will be focused, in part, on performing trial tests in a location known to have extensive ground water – surface water interactions, and applying the knowledge gained in the trial tests to one focus area. Detailed field protocols will first be developed and refined by investigating the ground water – surface water interactions on a property located in the lower Basin just downgradient of lower Geertson Creek. This property, owned by V. Don Olson, has several spring systems likely fed, at least in part, by many nearby irrigated areas. Additionally, the water table in this area is typically less than 20 ft below land surface (bls) according to drill logs, thus allowing tracer to more rapidly reach the ground water table.

Because ground water tracer testing is complex, this methodology is expected to require some fine-tuning prior to application across the Basin. The physical characteristics of Mr. Olson's property present an ideal opportunity to run trial field tests. These initial activities are required to ensure subsequent efforts in the identified focal areas are successful. Mr. Olson provided a tour of his property for IDWR in November 2010 to showcase its many ground water discharge locations, including small ditch/spring channels, the L-8A ditch, and a large pond (Figure 7).

Based on the local topography and Mr. Olson's accounts, the ground water emerging on this property is likely fed by seepage from the L-9 ditch, irrigation applied to land upstream along the Lemhi River corridor and along lower Geertson Creek, and lower Basin ground water underflow. At least one tracer test will be performed on this property to estimate the local ground water velocity and general flow paths. Based on preliminary analysis of 27 drill logs in the vicinity of Mr. Olson's property, the average saturated aquifer thickness (b_{sat}) is 28 ft, the average depth to water (D_w) is 12 ft bls, and the geometric mean saturated hydraulic conductivity (K_{sat}) is 19 ft/d. Refer to Appendix A for example calculations involved in estimating K_{sat} from drill logs.

In addition, seepage runs and well level measurements will be conducted in tandem with the tracer tests on and near Mr. Olson's property. Seepage runs along the L-9 ditch, the L-8A ditch, and lower Geertson Creek will provide estimates of the source(s) of water emerging from the spring systems. Further, periodic well level measurements will be performed in several wells that together encompass ground directly to the north and upslope of the property, near lower Geertson Creek, and along the lower Lemhi River corridor. This information will be supplemented with data collected by Spinazola (1998), and used to estimate the local ground water elevation contours and seasonal variability in water levels.

Figure 7 illustrates the key field sites for hydrologic tests in the vicinity of Mr. Olson's property, and Table 2 lists the locations where well level measurements and tracer injections will occur.

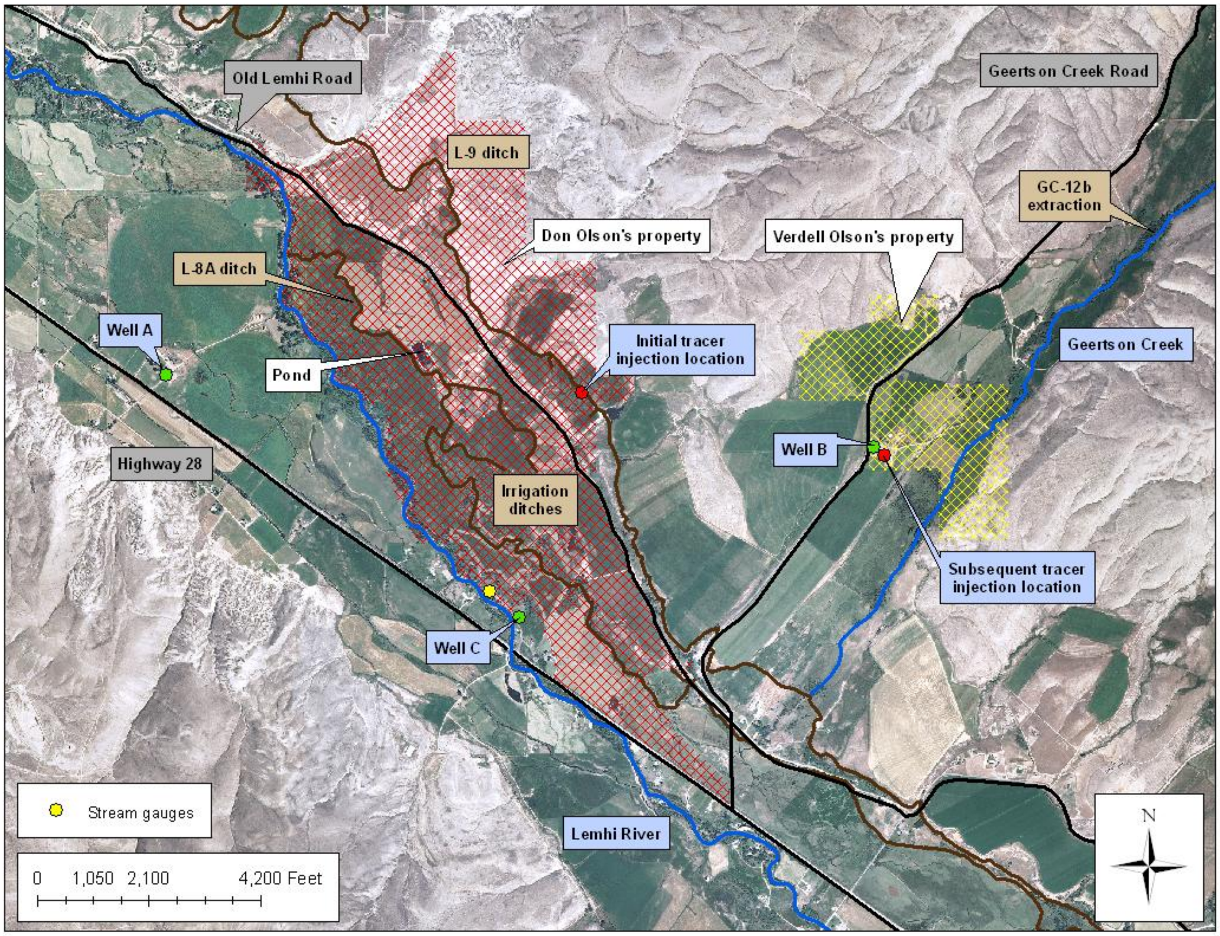

Figure 7. Mr. V. Don Olson's property details with key field sites for hydrologic tests identified.

Tracer Tests

Based on Mr. Olson's accounts and the local topography, the springs on and near this property are likely, at least partially, fed by seepage from the L-9 ditch which runs parallel to the property, directly to the north. In order to investigate the likely ground water flow paths connecting the L-9 ditch to the springs on Mr. Olson's property, we propose to excavate a trench of 10 – 15 ft depth on the ground between the L-9 ditch and the Old Lemhi Road, deploy a concentrated solution of fluorescein tracer in the trench, and flush the tracer into the subsurface with water from the ditch. The tracer deployment location is approximately 1000 ft upgradient from the spring systems on Mr. Olson's property. Based upon the estimated K_{sat} in this area, and assuming an average hydraulic gradient of 0.02 (Donato 1998) and an average porosity of 0.30 typical of unconsolidated alluvial sediments (Dingman 2002), the average linear ground water velocity is 1.3 ft/d. This estimate suggests the tracer will require approximately 2 years to travel from the injection location to the spring systems. Please refer to Appendix A for example hydrologic calculations that can be used to calculate the above parameters. However, Mr. Olson has observed several of these springs to run dry 2 – 6 mo following the irrigation season, suggesting return times on the order of months.

Activated charcoal packets will be positioned along the north banks of several small irrigation channels that flow northwest across Mr. Olson's property, downgradient from the Old Lemhi Road. Additionally, packets will be placed along the north banks of the L-8A ditch, from directly south of the injection location to the confluence with the Lemhi River. Because any tracer that reached the lower Lemhi River would be rapidly diluted to very low concentrations, no packets will be positioned in the river during the initial test. The packets will be collected and replaced by fresh packets every other week until confirmation that peak tracer discharge to the surface has occurred, which will be assessed by collecting manual water samples for analysis. The water samples will be collected from multiple locations coinciding with the packet placements.

If results from the initial tracer test suggest a return time on the order of months, as suggested by Mr. Olson's accounts, an additional test will not be conducted during 2011. However, if the tracer returns to the surface in the spring systems within weeks, an additional test with greater separation between tracer deployment and expected emergence locations will be performed. Because the spring systems on Mr. Olson's property may also be fed by irrigation seepage from fields farther east, tracer may be deployed on land located directly west of lower Geertson Creek. One possibility is deploying tracer in a constructed trench (equivalent to that which will be utilized during the initial test) on Verdell Olson's property, approximately 1.5 mi east of the springs on Mr. V. Don Olson's property.

Verdell Olson owns a well on his property that was previously monitored by Spinazola (1998). This domestic well is drilled to a depth of 65 ft bls through a gravel/sand water-bearing zone at approximately 20 ft bls, and bottoms in a clay layer. According to the results of Spinazola, the depth to water (D_w) in this well rises from approximately 20 ft bls prior to the irrigation season to just a few feet bls during the season. Thus, due to the shallow D_w of this well during the irrigation season, trench-deployment of tracer on Verdell Olson's property, likely just downgradient of his well, should rapidly introduce tracer into the aquifer. Water to flush the tracer into the subsurface will be supplied by pumping the nearby well. The drill log indicates this well can be pumped at 10 gallons per minute (gpm) for greater than 3 hrs without going dry. At this rate, enough flush water (i.e. 2000 gal, refer to Section 2.1.1) will be supplied within 2 hrs.

This subsequent trench injection will employ an alternate tracer, rhodamine WT, to avoid potential overlap with any residual tracer from the initial test on Mr. Olson's property. Otherwise, the general experimental procedures mentioned above will be followed during this subsequent test. However, additional packets and/or water samples might be utilized to account for the expected increased lateral dispersion of the tracer and the potential flow paths towards lower Geertson Creek and the L-9 ditch, and slight modifications to the experimental procedures may also be made, if deemed necessary.

Seepage Runs

During the initial tracer test on Mr. Olson's property, two seepage runs will be performed: one on a 1.5 mi stretch of the L-9 ditch directly north of the property, and the other on a 1.5 mi stretch of the L-8A ditch that runs through the property and connects to the Lemhi River. Both seepage runs will be conducted during the same day. Several measurements will be collected along each channel. Measurement locations will be chosen based either on equal spacing with other measurements or on the locations of surface inflows and outflows, which will also be accounted for. If the subsequent tracer test is performed, the same seepage runs mentioned above will be conducted again, and an additional seepage run will be performed on a 2 mi reach of lower Geertson Creek extending upstream from its interception by the L-9 ditch to above the Geertson Creek-12b extraction. This latter seepage run will consist of several flow measurements in Geertson Creek located above and below the main diversions, as well as several measurements to assess the flows through these diversions. All seepage runs will be conducted during the associated tracer test, and will occur during the same day or during two consecutive days.

Well Level Measurements

The depth to water (D_w) in three wells in the vicinity of Mr. Olson's property will be measured periodically, beginning prior to the 2011 irrigation season and extending into November 2011. The first, well A, is owned by Paul Fisher, Jr. and is located approximately 1 mi west of the pond on Mr. Olson's property, near the lower Lemhi River. According to the drill log, this domestic well is drilled to a depth of 37 ft bls through a cobble/gravel/sand water-bearing zone, bottoms in a clay layer, and has an approximate D_w of 12 ft bls. The second, well B, is owned by Verdell Olson and was previously mentioned in the plans for tracer tests on Mr. V. Don Olson's property. The third, well C, is owned by Bill Richardson and is located just south of Mr. Olson's property, near the lower Lemhi River. According to the drill log, this domestic well is drilled to a depth of 42 ft bls through a cobble/gravel/sand water-bearing zone, bottoms in sandstone, and has an approximate D_w of 4 ft bls. All three wells were previously monitored by Spinazola (1998), and all have been field-verified. All are surrounded by various irrigated fields; however, unlike wells A and C which will be impacted by local irrigation and Lemhi River corridor ground water underflow, well B is only downgradient of irrigated fields along upper Geertson Creek.

Landowner Permission
Mr. Olson has expressed his approval for all hydrologic tests on his property. Additionally, Mr. Fisher, Verdell Olson, and Mr. Richardson have agreed to allow periodic well level measurements for this study. Verdell Olson has also expressed his approval for tracer testing on his property. Permissions along lower Geertson Creek will be obtained prior to conducting the seepage run.

Site	Owner	Coordinates (NAD 1983, meters)		Spinazola (1998)
		Longitude	Latitude	
Initial tracer injection location	Olson	2516341	1549081	NA
Subsequent tracer injection location	Verdell Olson	2518077	1548721	NA
Well A	Fisher	2513957	1549180	Yes
Well B	Verdell Olson	2518018	1548767	Yes
Well C	Richardson	2515983	1547793	Yes

Table 2. Summary of field sites planned for hydrologic tests in the vicinity of Mr. Don Olson's property.

3.2 Upper Basin: Little Springs Creek

The second Phase I test area will be Little Springs Creek, and hydrologic tests will begin in this area following and/or during the initial trial tracer test on Mr. Olson's property. Due to flow enhancement projects currently underway or planned for the near future, the vicinity of Little Springs Creek has been identified by USBWP personnel and affiliates as an area of priority for 2011. It must be noted that Phase 1 hydrologic tests in this focus area are not expected to provide a comprehensive assessment of ground water – surface water interactions. The expected outcome is a better understanding of the local ground water table elevation contours, flow paths, and ground water velocity, which will be critical to assessing the ground water – surface water interactions during Phase 2.

Little Springs Creek is a spring-fed system that flows along the upper Lemhi River corridor. Similar to the conditions present on Mr. Olson's property, the area surrounding Little Springs Creek also appears to exhibit a high degree of ground water – surface interaction. The headwaters are located on the south side of Highway 28, just to the north and downslope of the bar ground separating the channels of Mill and Lee Creeks (Figure 8).

Irrigation applied to and underflow beneath this bar ground, as well as upper Basin ground water underflow, appears to feed the spring systems that form Little Springs Creek. At least two tracer tests are planned for this area, and are expected to provide an estimate of the local ground water velocity and general flow paths. Based on preliminary analysis of 50 drill logs in the vicinity of Little Springs Creek, the average b_{sat} is 47 ft, the average D_w is 31 ft bls, and the geometric mean K_{sat} is 22 ft/d. Refer to Appendix A for example calculations involved in estimating K_{sat} from drill logs.

Similar to the experimental scheme planned for Mr. Olson's property, seepage runs and well level measurements will be conducted in tandem with the tracer tests near Little Springs Creek. Seepage runs will be conducted along Little Springs Creek and lower Mill Creek to provide estimates of the source(s) of water feeding Little Springs Creek. Additionally, data collected by IDWR during seepage runs conducted in 2007 and 2008 along Little Springs Creek, and by Donato (1998) during seepage runs conducted in 1997 along the upper Lemhi River, will be analyzed and used to supplement the data collected during 2011. Periodic ground water level measurements will be collected from three wells located in the bar ground to the southwest, near lower Lee Creek to the east, and along the upper Lemhi River corridor. This information will be supplemented with data collected by Spinazola (1998), and used to estimate the local ground water elevation contours and seasonal variability in ground water levels.

Figure 8 illustrates the key field sites for hydrologic tests in the vicinity of Little Springs Creek, and Table 3 lists the locations where well level measurements and tracer injections will occur.

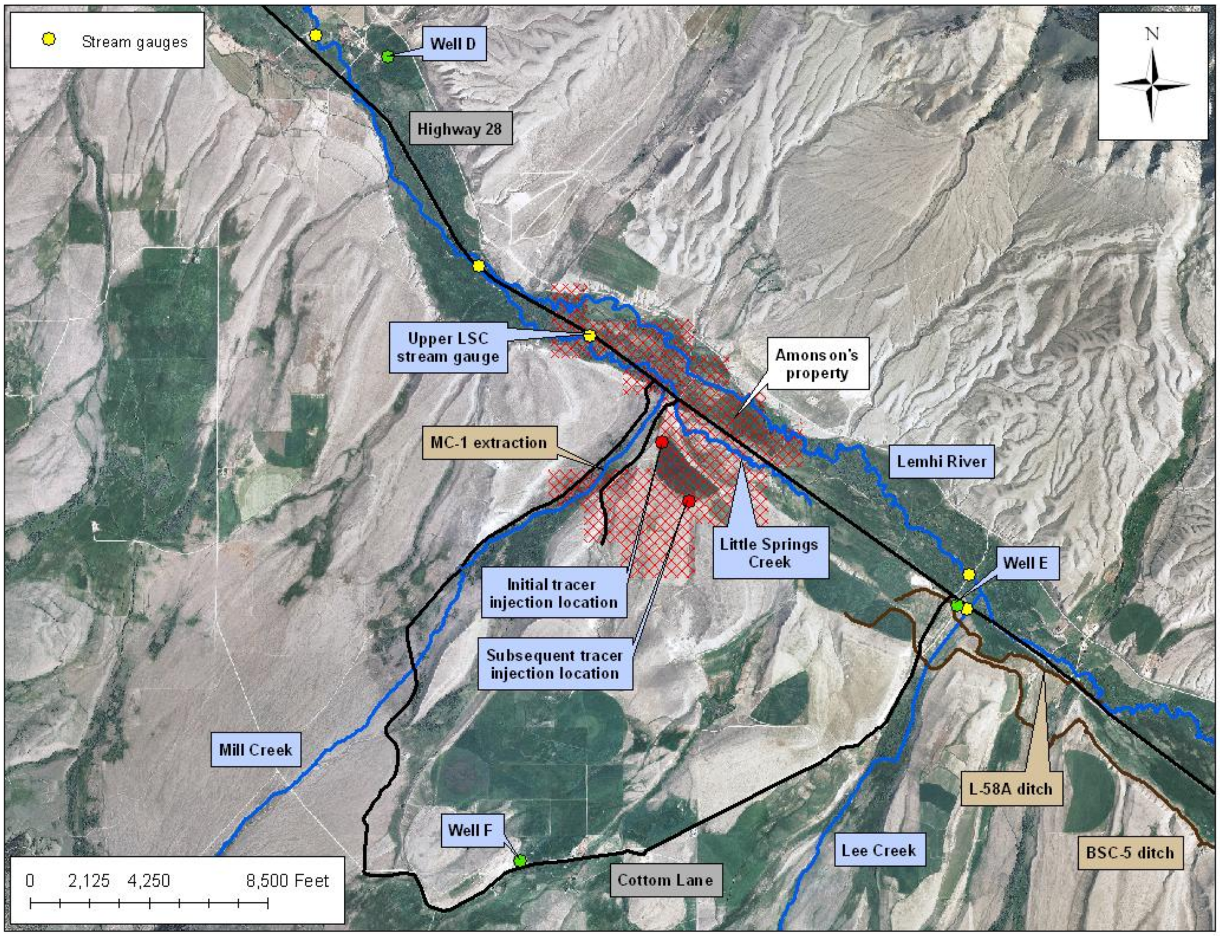

Figure 8. Little Springs Creek area details with key field sites for hydrologic tests identified.

Tracer Tests

Based on the local topography and landowner accounts, Little Springs Creek is likely, at least partially, fed by ground and surface water associated with the bar ground directly to the southwest. Merrill Beyeler, who leases the land encompassing most of Little Springs Creek and the nearby bar ground from Bob Amonson, has suggested deploying hydrologic tracer near the north corner of the wiper pivot field (located on the Hansen bar). This location is advantageous because seepage runs conducted during 2007 and 2008 by IDWR indicate the reach of Little Springs Creek directly downgradient of the Hansen bar is a gaining system. A shallow trench was recently excavated in the proposed injection location, and is equipped with a water delivery pipe and spigot. We propose to excavate this trench to a slightly greater depth (i.e. 10 – 15 ft bls), apply a concentrated solution of fluorescein tracer to the trench, and flush the tracer into the ground with water supplied by the existing pipe and spigot. The tracer deployment location is 1000 ft upgradient from Little Springs Creek. Based upon the estimated K_{sat} in this area, and again assuming an average hydraulic gradient of 0.02 (Donato 1998) and an average porosity of 0.30 (Dingman 2002), the average linear ground water velocity is estimated at 1.5 ft/d. This estimate suggests the tracer will require nearly 2 years to travel from the injection location to Little Springs Creek. Please refer to Appendix A for example hydrologic calculations that can be used to calculate the above parameters. However, based on Mr. Beyeler's accounts of the effects of nearby irrigation practices on the seasonal flows of springs in the area, we expect the travel time to be much less.

Activated charcoal packets will be positioned along the south bank of the creek channel, from just downgradient of the trench to the upper Little Springs Creek stream gauge. A pond is also situated directly downgradient of the injection location and one or more packets will be positioned to capture any tracer migration into the pond.

Additionally, to account for ground water flow paths not directed towards Little Springs Creek, packets will also be positioned along lower Mill Creek, extending downstream to its confluence with Little Springs Creek. Lastly, one or more packets will be placed in locations exhibiting springs seeping to the surface (i.e. at the downgradient base of the bar ground). Because any tracer that reached the upper Lemhi River would be rapidly diluted to very low concentrations, no packets will be positioned in the river during the initial test. The packets will be collected and replaced by fresh packets every other week until confirmation that peak tracer discharge to the surface has occurred, which will be assessed by collecting manual water samples for analysis. The water samples will be collected from multiple locations coinciding with the packet placements.

Following analysis of the data collected from this initial experiment, a subsequent tracer test will be initiated. If the initial test provides data that are questionable, it will be repeated; however, adjustments in packet and/or water sample locations, timing of packet rotation and/or water sampling, or other experimental procedures might be made, if deemed necessary. Additionally, an alternate tracer, rhodamine WT, will be used in place of fluorescein to avoid potential overlap with any residual tracer from the initial test.

If initial data are sufficient to determine the primary ground water flow paths and approximate subsurface travel times, the subsequent test will deploy tracer farther upgradient along the Hansen bar, at a distance of 0.5 mi from Little Springs Creek. Again, the tracer will be deployed in a constructed trench, equivalent to that which will be utilized for the initial tracer test in this area. Water to flush the tracer into the subsurface will be supplied by a local water truck. This subsequent trench injection will employ an alternate tracer, rhodamine WT, again to avoid potential overlap with any residual tracer from the initial test. Otherwise, the general experimental procedures mentioned above will be followed during this subsequent test. However, additional packets and/or water samples might be utilized to account for the expected increased lateral dispersion of the tracer, and slight modifications to the experimental procedures may also be made, if deemed necessary.

Seepage Runs

During the initial tracer test in the Little Springs Creek vicinity, three seepage runs will be performed: on the 2 mi stretch of Little Springs Creek from directly downgradient of the eastern edge of Mr. Beyeler's wiper pivot to the upper Little Springs Creek stream gauge, on the 1 mi stretch of lower Mill Creek from just above the Mill Creek-1 extraction to its confluence with Little Springs Creek, and on the 1 mi reach of lower Lee Creek extending upstream from its confluence with the Lemhi River. All seepage runs will be conducted during the same day. Measurement locations will be chosen based either on equal spacing with other measurements or on the locations of surface inflows and outflows, which will also be accounted for. These seepage runs will be repeated during the course of either the repeat of the initial tracer test or the subsequent tracer test (i.e. with injection location farther upgradient on the Hansen bar). Again, all measurements will be collected during the same day. Lastly, additional seepage runs along the Big Springs Creek-5 and L-58A ditches may be conducted by Rick Sager, watermaster for the Lemhi River, during 2011. Data from these measurements will be incorporated into this study.

Well Level Measurements

The depth to water (D_w)in three wells in the vicinity of Little Springs Creek will be measured periodically, beginning prior to the 2011 irrigation season and extending into November 2011. The first, well D, is owned by Rick Snyder and is located approximately 1.5 mi northwest of the confluence of Little Springs Creek and the upper Lemhi River. According to the drill log, this domestic well is drilled to a depth of 31 ft bls through a clay/gravel water-bearing zone, bottoms in this clay/gravel layer, and has an approximate D_w of 20 ft bls. The second, well E, is owned by Frances Ellsworth Hays and is located near the confluence of Lee Creek and the upper Lemhi River. The drill log indicates this domestic well is drilled to a depth of 42 ft bls through a gravel/sand water-bearing zone, bottoms in this gravel/sand layer, and has an approximate D_w of 18 ft bls. The third well, well F, is owned by Scott Tyler and is located approximately 3 mi upgradient and to the southwest of Little Springs Creek. The drill log indicates this domestic well is drilled to a depth of 60 ft bls through a silt/gravel water-bearing zone, bottoms in this silt/gravel layer, and has an approximate D_w of 30 ft bls. All three wells were previously monitored by Spinazola (1998), and all have been field-verified. Both wells D and E are surrounded by various irrigated fields and will likely be impacted by Lemhi River corridor ground water underflow. Well F is located downgradient of a few small, flood-irrigated fields, but is upgradient and far-removed of the corridor ground water underflow.

Landowner Permission
Mr. Amonson and Mr. Beyeler have expressed their approval for all hydrologic tests on Mr. Amonson's property. Additionally, Mr. Snyder, Mr. Tyler, and Carl Ellsworth, who owns the property where well E is located, have agreed to allow well level measurements for this study. Permissions along lower Mill and Lee Creeks will be obtained prior to conducting the seepage runs.

Site	Owner	Coordinates (NAD 1983, meters)		Spinazola (1998)
		Longitude	Latitude	
Initial tracer injection location	Amonson	2538128	1506879	NA
Subsequent tracer injection location	Amonson	2538417	1506232	NA
Well D	Snyder	2535122	1511102	Yes
Well E	Hays	2541350	1505098	Yes
Well F	Tyler	2536580	1502306	Yes

Table 3. Summary of field sites planned for hydrologic tests in the vicinity of Little Springs Creek.

3.3 Upper Basin: Aquifer Recharge and Ground Water Velocity

The third Phase I activity aims to begin characterizing the sources of ground water and alluvial aquifer properties in the portion of the upper Basin where much of the Basin's ground water originates. This area is located near and upgradient of the town of Leadore (Figure 9). Based on the saturated aquifer thickness (i.e. exceeding 100 ft according to several drill logs) and areal extent of the aquifer in this portion of the Basin (Spinazola 1998), a significant proportion of the Basin's ground water is supplied in this area. Thus, to begin developing an understanding of the large-scale role of ground water in the Basin, it is critical to determine how and when the aquifer is recharged and how fast ground water travels in this portion of the Basin. Two types of hydrologic tests are planned to help develop an understanding of the characteristics of ground water in the upper Basin: high resolution water level measurements in selected wells to measure the lag time between surface application of water (either irrigation or precipitation) and aquifer recharge, and a well-deployed tracer test to estimate ground water velocity.

Figure 9 illustrates the field sites for additional hydrologic tests in the upper Basin, and Table 4 lists the locations where well level measurements and tracer injection will occur.

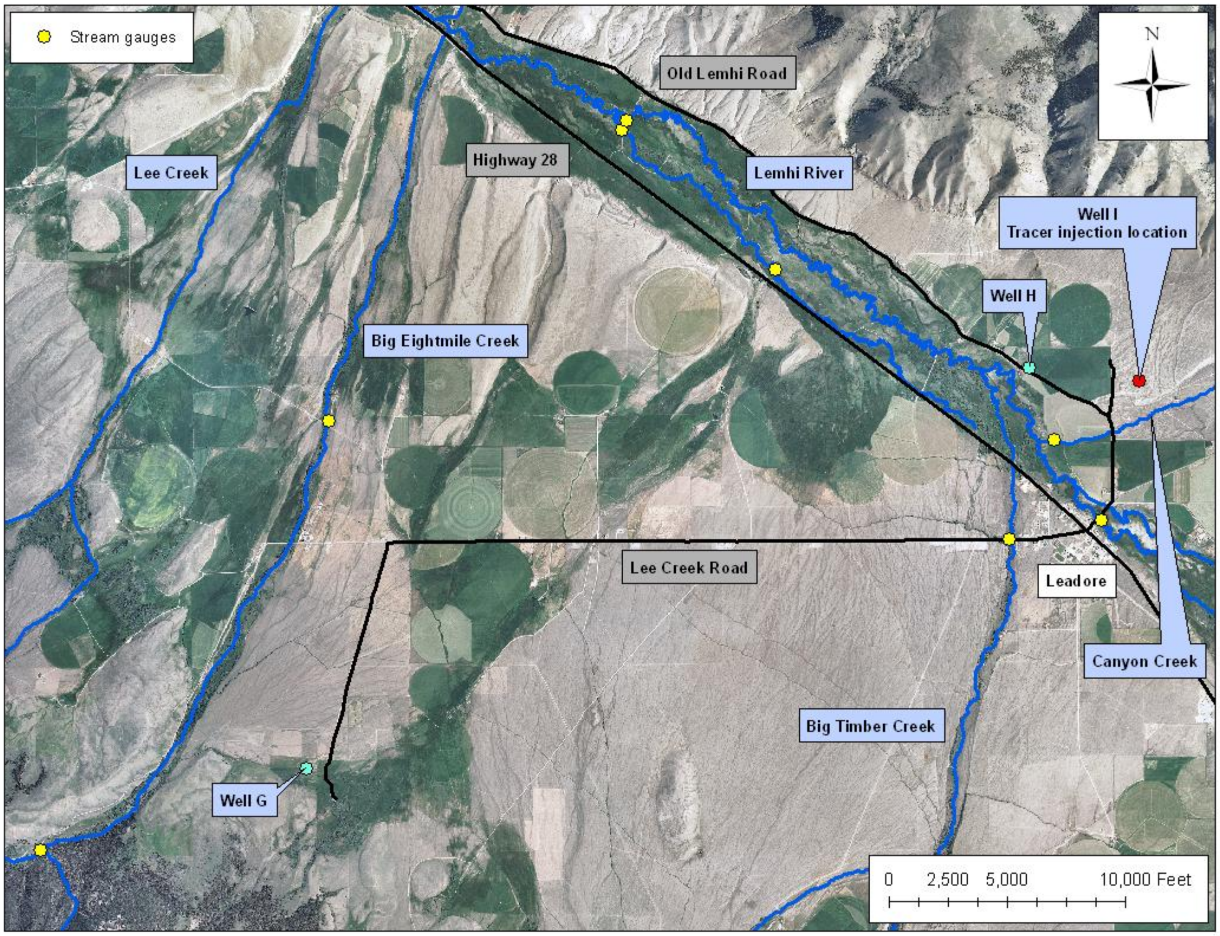

Figure 9. Locations of field sites for additional upper Basin hydrologic tests.

Well Level Measurements

Two wells in this portion of the upper Basin have been equipped with pressure transducers to measure ground water levels on an hourly basis. The first, well G, is owned by Merrill Beyeler and is located approximately 2000 ft east of the headwaters of the Lemhi River. This well is just downgradient of a few fields irrigated primarily through sprinkler systems; otherwise, only non-irrigated sagebrush and forested lands sit upgradient of this well. The second, well H, is owned by Earl McRea and is located on the opposite side of the upper Basin, approximately 1 mi east of upper Big Eightmile Creek. This well is just downgradient of a small, flood irrigated field; otherwise, only non-irrigated sagebrush and forested lands sit upgradient of this well. No drill logs have yet been identified for either of these wells; however, IDWR visited both in April 2011 and noted well G has a depth to water (D_w) of 30 ft bls, and well H has a D_w of 36 ft bls. Additionally, both wells were chosen for monitoring by Spinazola (1998).

Because the amount of irrigated land upgradient from both of these wells is limited, and the timing of irrigation in these limited locations will be monitored, it is anticipated that the influence of natural runoff and/or heavy rainstorms vs. irrigation on rises in the ground water table will be distinguished by the high resolution measurements. Further, by accounting for the timing of irrigation and natural events, these measurements are expected to provide an estimate of the lag time between surface application of water and aquifer recharge.

Tracer Test

Because the D_w in this portion of the upper Basin can exceed 100 ft bls, trench-deployment of tracer is not reasonable (i.e. travel times through the thick vadose zone are not presently known and could be very long, and tracer adsorption onto the dry aquifer materials could be excessive). Thus, an unused domestic well has been identified and field-verified for tracer injection. This well, hereafter referred to as well I, is owned by Earl McRea, and is located approximately 0.25 mi north of lower Canyon Creek (which runs just north and parallel to lower Hawley Creek) and approximately 1 mi east of the headwaters of the Lemhi River. According to the drill log, this well has a 6 in diameter, is drilled to a depth of 142 ft bls through a sand/gravel water-bearing unit, bottoms in this sand/gravel layer, and has an approximate D_w of 120 ft bls.

Because a well offers a direct route for the tracer to enter the aquifer, large volumes of flush water are not required to conduct a well-deployment tracer test. However, introducing some volume of water in addition to that present in the well column is desired, as the added water pressure should help induce tracer migration into the aquifer. Thus, a volume to nearly fill the well column of fluorescein tracer solution in potable water will be added to the well. Based on preliminary analysis of the specific capacity test listed on the drill log (discussed in Appendix A), the saturated hydraulic conductivity (K_{sat}) in this area is estimated at 17 ft/d. Again assuming an average hydraulic gradient of 0.02 (Donato 1998) and an average aquifer porosity of 0.30 (Dingman 2002), the average linear ground water velocity is estimated at 1.1 ft/d. This estimate suggests the tracer will require several years to travel from the injection well to a reach of lower Canyon Creek at the same elevation as the ground water (i.e. approximately 0.5 mi downgradient). However, it is anticipated that the results of the tracer test(s) along Little Springs Creek will be available prior to conducting this well-deployment test, and will help in planning the length of time required for this test.

Activated charcoal packets will be positioned along the north bank of lower Canyon Creek. Packets will also be positioned along the north bank of the upper Lemhi River, from its confluence with lower Canyon Creek downgradient to its confluence with lower Big Timber Creek. Lastly, charcoal packets will be deployed in Mr. Beyeler's well, which is located approximately 1 mi west of the injection well. The packets will be collected and replaced by fresh packets every other week until confirmation that peak tracer discharge to the surface has occurred, which will be assessed by periodically analyzing the packets for tracer concentrations.

Because this tracer test is expected to be longer in duration than the trench-deployment tests, it will be initiated near the end of the 2011 irrigation season.

Landowner Permission
Both Mr. Beyeler and Mr. McRea have agreed to allow well level measurements and tracer test activities for this study.

Site	Owner	Coordinates (NAD 1983, meters)		Spinazola (1998)
		Longitude	Latitude	
Well I, tracer injection location	McRea	2551549	1499830	No
Well G	Beyeler	2550129	1500006	Yes
Well H	McRea	2540797	1494829	Yes

Table 4. Summary of field sites planned for additional hydrologic tests in the upper Basin.

3.4 Lower and Upper Basin: Total Water Flow

The remaining Phase I activities include aquifer tests and water level measurements to begin characterizing the total water flow through the mid-Basin divide and downgradient Basin boundary. Because the aquifer tests will require funding in addition to that already secured, some or all of these tests may not begin until Phase 2. However, water levels in several wells in both areas (Figures 10 and 11) will be periodically measured during Phase 1 to collect data on the seasonal fluctuations of ground water levels. Data from Donato (1998) and Spinazola (1998) will be analyzed and used to supplement the 2011 measurements.

What is important to the local irrigators and natural resource managers is the relative significance of ground water flow to the total flow through boundary and divide. For instance, when considering how much water flows into and out of the Lemhi Basin, and how irrigation practices affect the distribution and timing of water flow, should ground water be accounted for? Preliminary estimates of aquifer properties in these key areas have been obtained by analyzing well drill logs, many in addition to those examined by Spinazola (1998). Near the boundary (Figure 10), based on information for 14 wells, the average depth to water (D_w) is 12 ft bls and the average saturated aquifer thickness (b_{sat}) is 25 ft. Along the divide (Figure 11), based on information for 8 wells, the average D_w is 14 ft bls and the average b_{sat} is 21 ft. This information suggests that in these areas the aquifer might interact strongly with surface water (i.e. shallow depths to water) and act as a limited conduit for ground water flow, as underlying bedrock restricts the aquifer to shallow depths (Anderson 1956, 1961). The results of Donato (1998) support these assumptions, as reaches flowing though the boundary and divide were observed to gain ground water input in the summer and fall of 1997.

Although Donato (1998) and Spinazola (1998) concluded that the amount of ground water underflow at these locations is insignificant to total water flow, as most flow is in the Lemhi River, these conclusions were largely based on estimates of aquifer properties obtained from drill logs, which cannot be considered quantitative. Thus, it is necessary to perform aquifer tests in these areas to provide more quantitative estimates of aquifer hydraulic properties to be used in estimating the volumetric ground water flow rate and ground water velocity.

Step-rate and constant rate pumping tests will be performed to characterize the average local transmissivity (T) in each area. This information will be used in conjunction with drill logs and existing geological surveys to quantitatively estimate K_{sat} and volumetric ground water flow rates (Q_{gw}). Surface flow rates (S_w) in the Lemhi River at these locations will also be obtained from existing stream gauges, and compared against the estimated ground water Q_{gw} estimates. These efforts will provide quantitative estimates of ground water underflow at the divide and ground water outflow at the boundary, and the relative contributions of each to total water flow through these locations.

Ground water levels will be measured in several wells near the downgradient Basin boundary and along the mid-Basin divide to capture any temporal trends in water table fluctuations in these areas, and help provide seasonal estimates of ground water underflow/outflow at these locations. Spinazola (1998) conducted periodic measurements of water levels in these areas during the late 1990's, and observed a seasonal trend in depths to water in several of these wells. Spinazola observed the water levels in most wells rose several feet from spring baseline levels by the month of June, remained elevated through September, and receded down to baseline levels during the fall and winter. The data collected will be assessed to confirm these trends and help provide seasonal estimates of ground water underflow at these important locations.

Figures 10 and 11 illustrates the field sites for well level measurements and aquifer tests near the boundary and along the divide, and Table 5 provides this information in tabular form.

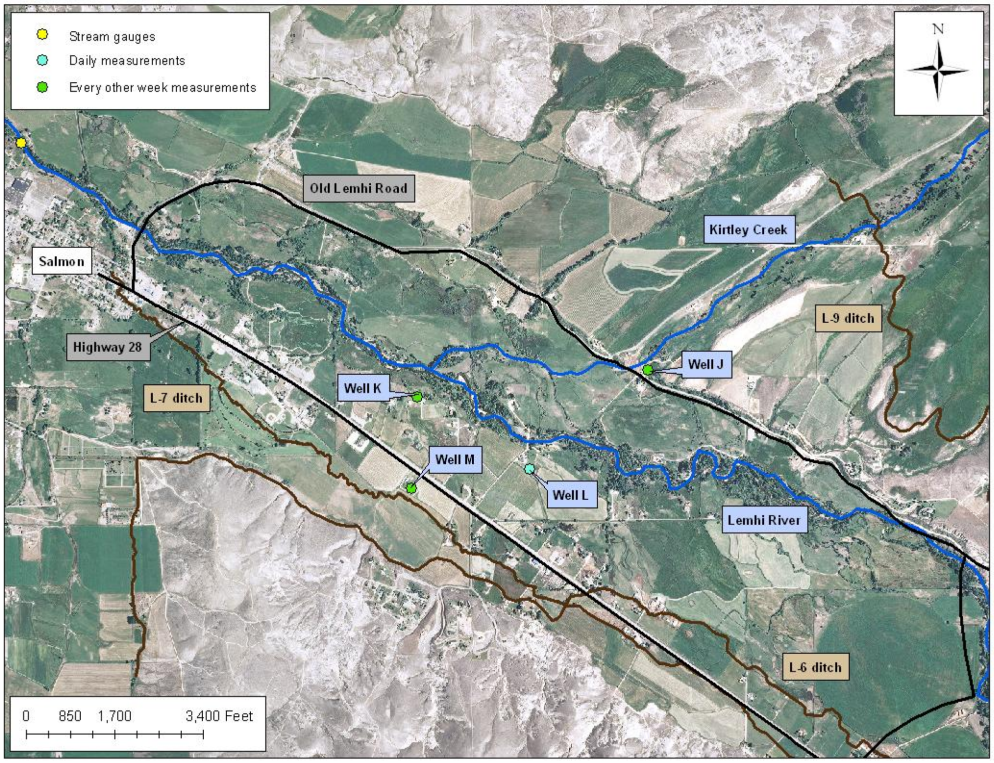

Figure 10. Locations of wells for periodic ground water elevation measurements and aquifer tests near the downgradient Basin boundary.

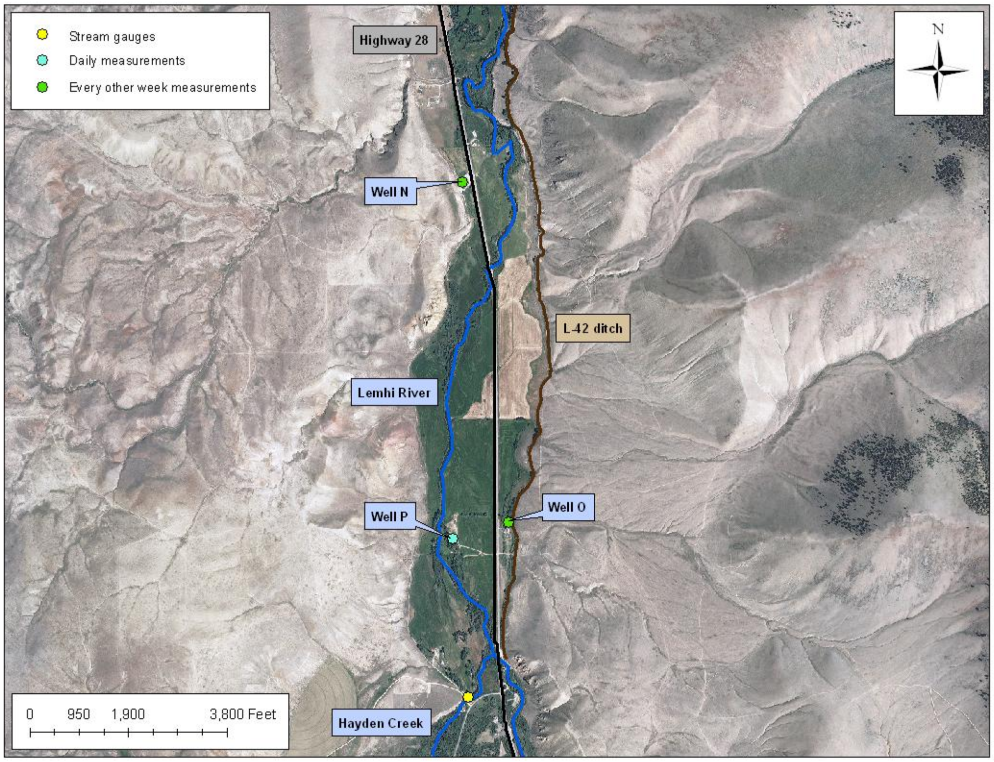

Figure 11. Locations of wells for periodic ground water elevation measurements and aquifer tests along the mid-Basin divide.

Well Level Measurements

The D_w in several wells near the downgradient Basin boundary and along the mid-Basin divide will be measured periodically, either daily with an installed pressure transducer or every other week with a water level sounder, beginning prior to the 2011 irrigation season and extending into November 2011. The goal is to estimate the seasonal ground water underflow through these key areas.

Four wells near the boundary have been identified and field-verified. All are located approximately 2 mi upgradient of the town of Salmon, near the confluence of Kirtley Creek with the lower Lemhi River, and together span the cross-section perpendicular to ground water flow. Based on Spinazola (1998), Donato (1998), and available drill logs, the alluvial aquifer in this region near the boundary is relatively homogeneous, and should thus provide reasonable conditions for estimating aquifer hydraulic properties. Further, this region is located between two stream gauges on the lower Lemhi River, one downgradient of the confluence of Geertson Creek and one near the town of Salmon (Figure 5), which will be critical in assessing the relative contributions of ground water underflow to total water flow through the Basin boundary.

The first well, well J, is owned by Lamar Cockrell and is located on the northeast side of the lower Lemhi River valley, near Kirtley Creek. According the drill log, this stock well has a 6 in diameter, is drilled to a depth of 45 ft bls through a clay/gravel water-bearing zone, bottoms in a conglomerate layer, and has an approximate D_w of 3 ft bls. The second, well K, is owned by Dean Jackson and is located just south of the lower Lemhi River. The drill log indicates this domestic well has a 6 in diameter, is drilled to a depth of 40 ft bls through a sand/gravel water bearing zone, bottoms in a clay layer, and has an approximate D_w of 4 ft bls. The third, well L, is owned by Ray Cheney and is located on the south side of the lower Lemhi River, approximately 0.5 mi upgradient of well K. The drill log indicates this domestic well has a 6 in diameter, is drilled to a depth of 35 ft bls through a sand/gravel layer, bottoms in a clay layer, and has an approximate D_w of 12 ft bls. The fourth, well M, is owned by Kim Thomas and is located on the southwest side of the lower Lemhi River valley. According to the drill log, this domestic well has a 6 in diameter, is drilled to a depth of 34 ft through a clay/sand/gravel water-bearing zone, bottoms in a gravel hardpan layer, and has an approximate D_w of 6 ft bls. Wells J and M were previously monitored by Spinazola (1998). All are surrounded by various irrigated fields and will likely be impacted by Lemhi River corridor ground water underflow.

Along the mid-Basin divide, three wells have been identified according to proximity to the upgradient end of the divide. This region of the divide is of interest because, according to Spinazola (1998) and Donato (1998), the upper half of the aquifer is thought to discharge nearly all of its water to the Lemhi River in this region. Additionally, three stream gauges are located near this region: one along the upper Lemhi River near McFarland Campground, one along lower Hayden Creek, and one along the lower Lemhi River near the town of Tendoy (Figure 5). Together, these stream gauges will supply the total amount of surface water flow through the divide, which will be critical in assessing the relative contributions of ground water underflow to total water flow.

The first well, well N, is owned by Clyde Stout and is located approximately 2 mi downgradient of the confluence of Hayden Creek with the upper Lemhi River. The drill log indicates this domestic well has a 6 in diameter, is drilled to a depth of 120 ft bls through a shallow gravel water-bearing zone, bottoms in bedrock, and has an approximate D_w of 12 ft bls. The second, well O, is owned by Janet Kibbee and is located near the eastern boundary of the divide, approximately 0.5 mi downgradient of the Hayden Creek confluence. According to the drill log, this domestic well has a 12 in diameter, is drilled to a depth of 72 ft bls in a sand/gravel water-bearing zone, bottoms in this sand/gravel layer, and has an approximate D_w of 46 ft bls. The third, well P, is owned by Walter Whitson and is located 0.25 mi west of well O, across the divide. The drill log indicates this domestic well has a 6 in diameter, is drilled to a depth of 35 ft bls through a sand/gravel water-bearing zone, bottoms in a clay layer, and has an approximate D_w of 17 ft bls. Wells N and P were previously monitored by Spinazola (1998), and all three have been field-verified. All are surrounded by various irrigated fields and will likely be impacted by Lemhi River corridor ground water underflow.

Aquifer Tests

Step-rate pumping tests will be conducted in several wells chosen for water level measurements near the downgradient Basin boundary and along the mid-Basin divde to investigate the drawdown response to several pumping rates. This will provide pumping rates that will create a measurable drawdown response but will not result in pulling the water below the top of the pump during the constant rate test. The subsequent constant rate pumping tests will be planned for 24 hours; however, if a well reaches a stable drawdown level (i.e. no additional drawdown) prior to 24 hours, the test may be shortened. Immediately upon pump shutoff at the end of the constant rate pumping, each well's water level will be monitored for an additional 12 hours for recovery data. A Level TROLL 300 (In-Situ, Inc.) pressure transducer will be deployed in each pumping well to provide continuous measurements of water levels throughout the durations of the step-rate, constant rate, and recovery tests.

Landowner Permission
The owners of wells J, K, L, M, N, O, and P have agreed to allow well level measurements for this study. Permissions for the aquifer tests will be obtained prior to conducting the tests.

Site ID	Owner	Coordinates (NAD 1983, meters)		Spinazola (1998)
		Longitude	Latitude	
Well J	Cockrell	2512648	1551523	Yes
Well K	Jackson	2511288	1551367	No
Well L	Cheney	2511951	1550940	No
Well M	Thomas	2511253	1550830	Yes
Well N	Stout	2529350	1521576	Yes
Well O	Kibbee	2529622	1519570	No
Well P	Whitson	2529292	1519473	Yes

Table 5. Summary of field sites planned for hydrologic tests near the downgradient Basin boundary and the mid-Basin divide.

4.0 Phases 2 and 3 – 2012 and 2013

Because of the uncertainty in the results of Phase 1, the Phase 2 – 2012 and Phase 3 – 2013 work cannot be rigorously detailed at this time. Additionally, it is anticipated that USBWP collaborators will help direct the focus of Phases 2 and 3 following the 2011 field season. Thus, the plans outlined below are suggestions assuming generally successful Phase I results, as well as continued funding.

- For the Little Springs Creek focus area, tracer will be trench-deployed near the downgradient reaches of the L-58A and/or BSC-5 ditches. Additionally, seepage runs will be conducted on these ditches, as well as along lower Lee Creek and the upper Lemhi River adjacent to the vicinity of Little Springs Creek. Seepage run data collected by IDWR during 2007 and 2008 and by Donato (1998) will be used to supplement this information. Well level measurements will also be continued; however, additional and/or different wells may be identified for measurements. Again, data from Spinazola (1998) will be used to supplement these measurements.

- Hydrologic tests and activities in the vicinity of Little Springs Creek will be spatially extended to encompass more of the Mill Creek focus area. This will include additional wells for monitoring, and conducting a seepage run on upper reaches of Mill Creek. Again, data from Spinazola (1998) will be used to supplement these measurements. Further, tracer may be deployed in one or more trenches or ditches, or in well F (Figure 7) and/or an additional well located near upper Mill Creek.

- Additional hydrologic tests and activities in the upper Basin will be continued. This will include deploying pressure transducers in well I (Figure 8) and/or wells near Big Timber Creek or Hawley Creek. Data from Spinazola (1998) will be used to guide the placement of pressure transducers. Also, depending on the results obtained through Phase I, the well-deployed tracer test in well I (Section 3.3) may be repeated. Conversely, one or more additional wells, or surface locations, may be identified for tracer deployment. The tracer deployment locations of Haws et al. (1977) will be used to guide these tracer tests.

- Near the downgradient Basin boundary, well level measurements will be continued, and aquifer tests in at least two of these wells will be conducted. Additionally, seepage runs along the lower Lemhi River near the boundary, as well as along the L-6, L-7, and L-9 ditches, and along lower Kirtley Creek, will be conducted. The well level measurements of Spinazola (1998) and seepage run data of Donato (1998) will be used to augment the 2012 – 2013 measurements.

- Along the mid-Basin divide, well level measurements will be continued, possibly including additional wells farther downgradient. Aquifer tests will be conducted in wells O and P, and possibly in one or more additional wells farther downgradient. Additionally, seepage runs will be conducted along reaches of the Lemhi River flowing through the divide and along the L-42 ditch. The well level measurements of Spinazola (1998) and seepage run data of Donato (1998) will be used to augment the 2012 – 2013 measurements.

- Comprehensive hydrologic tests (i.e. tracer tests, seepage runs, and well level measurements) will be conducted in either the Bohannon Creek or Kenney Creek focus area during 2012 and in the other during 2013. Existing data from IDWR seepage runs conducted in 2008, and from Spinazola (1998) and Donato (1998), will be used to guide and/or supplement these activities.

- Comprehensive hydrologic tests (i.e. tracer tests, seepage runs, and well level measurements) will be conducted in either the Hawley Creek or Big Timber Creek focus area during 2012 and in the other during 2013. Existing data from IDWR seepage runs conducted in 2008, and from Spinazola (1998) and Donato (1998), will be used to guide and/or supplement these activities.

- Comprehensive hydrologic tests (i.e. tracer tests, seepage runs, and well level measurements) will be conducted in the Withington Creek focus area. Existing data from IDWR seepage runs conducted in 2008, and from Spinazola (1998) and Donato (1998), will be used to guide and/or supplement these activities.

- Soil moisture meters will be deployed in a minimum of three focal areas, together encompassing both the lower and upper halves of the Basin, and preferably beneath both flood and sprinkler irrigated fields. Existing soils data (i.e. soil types, properties, and infiltration rates) from NRCS will be utilized to guide and or supplement these measurements.

5.0 Project Costs

In Table 5.1, the cost estimates for conducting the hydrologic tests and activities of Phase 1 are summarized, and the Phase 1 estimates are extrapolated to approximate the costs associated with Phases 2 and 3. The provided costs do not account for personnel and travel costs, as many of this study's logistics will not become firm until hydrologic tests and activities begin. Additionally, the involvement of IDWR in Phases 2 and 3 of this study is completely dependent on additional funding. Refer to Table C.1 for an itemized cost breakdown for Phase 1.

	Activity/Item	Cost	Notes (Refer to Table A1 for more detail)
Phase 1	Tracer tests	$ 6,500	Durations of tests assumed based on estimated aquifer properties and flow paths; performed by IDWR and USBWP
	Well measurements	$ 15,000	Nearly $7,000 of this is not a recurring cost for Phases 2 and 3 (equipment purchased); performed by IDWR and USBWP
	Seepage runs	$ -	Performed by IDWR and covered under other funding
	Stream gauging	$ -	Performed by IDWR and covered under other funding
	Existing and collected data analysis	$ -	Performed by IDWR and covered under other funding
	Incorporate data into MIKE BASIN model	$ -	Performed by IDWR and covered under other funding
	Other costs	$ -	Personnel and travel costs covered under other funding
	Miscellaneous supplies	$ 2,000	
	Subtotal	*$ 23,500*	
Phases 2 & 3	Tracer tests	$ 24,000	Assumes a maximum of 8 tests per year at an average cost of $1,500 per test; performed by IDWR and USBWP
	Well measurements	$ 16,000	Based on Phase 1 costs for every other week measurements; performed by IDWR and USBWP
	Aquifer tests	$ 30,000*	Assumes a maximum of 6 tests at an average cost of $5,000 per test; performed by IDWR
	Soil moisture measurements	$ -	Performed by IDWR with existing moisture meters
	Seepage runs	$ -	Performed by IDWR and USBWP and covered under other funding
	Stream gauging	$ -	Performed by IDWR and covered under other funding
	Existing and collected data analysis	$ -	Performed by IDWR and covered under other funding
	Incorporate data into MIKE BASIN model	$ -	Performed by IDWR and covered under other funding
	Other costs	$ -	Personnel and travel costs not known at present time
	Miscellaneous supplies	$ 5,000	
	Subtotal	*$ 75,000*	
	Total	***$ 98,500****	*The involvement of IDWR in Phases 2 and 3 is completely dependent on **additional** funding*

Table 5.1. Cost summary for this study. *Costs for aquifer tests may be less if one or more candidate wells is deemed unsuitable (refer to Section 2.3).

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Appendix A: Hydrologic Computations

Saturated Hydraulic Conductivity and Ground Water Velocity:
Upon completing a well, drillers will conduct a production test to assess the ground water yield of the well. During this test, the driller pumps water out of the well at a constant rate (Q) for a given time period (t), which can vary from less than 1 hr to more than 24 hrs. The driller records the static water level (h_0) before the test, and the water level after t (h). Hydrologists can utilize this information to estimate the specific capacity (S_c) of a well:

$$S_c = \frac{Q}{h_0 - h}$$

Because true aquifer test data is usually lacking (i.e. fairly expensive and time consuming to conduct), hydrologists have developed empirical equations that relate S_c obtained from drill logs to true aquifer properties, such as transmissivity (T) and saturated hydraulic conductivity (K_{sat}). In estimating upper Lemhi Basin aquifer properties from drill logs, Spinazola (1998) utilized the Theis (1963) method:

$$T = S_c \times \frac{2.3}{4\pi} \times log\left(\frac{2.25Tt}{r^2 S}\right)$$

Where r = the radius of the well and S = aquifer storativity. Because T appears on both sides of the equation, it is solved for iteratively by initially estimating values of T and S, and adjusting these values until the left and right sides of the equation are approximately equal. Note that other methods exist for estimating T from S_c; the Theis method is listed above for illustrative purposes because it was the method employed by Spinazola.

The aquifer's average K_{sat}, which is useful for estimating average linear ground water velocity (v_{gw}), can then be estimated by:

$$K_{sat} = \frac{T}{b_{sat}}$$

Where b_{sat} = saturated aquifer thickness, which is approximated by the open interval of the well (i.e. uncased length of well and/or length of well screen) where the true saturated thickness of the aquifer is unknown.

Following, v_{gw} can then be calculated from K_{sat} (Fetter 2001):

$$v_{gw} = K_{sat} \times \frac{i}{\varphi}$$

Where i = average ground water gradient and φ = aquifer porosity. According to water table contours in Donato (1998), a reasonable i in the Basin is 0.02, and φ can be approximated at 0.30 which is typical of unconsolidated alluvial sediments (Dingman 2002).

Lastly, the return time (t_r) of water seeping into the subsurface and traveling some distance (d) underground before discharging to a stream can be calculated as:

$$t_r = \frac{d}{t_r}$$

Ground Water Underflow:
Ground water flow (Q_{gw}) through a plane can be estimated using Darcy's Law:

$$Q_{gw} = K_{sat} \times A \times i$$

Where A = cross-sectional area of the plane and i = the average hydraulic gradient.
Donato (1998) employed Darcy's Law to estimate the yearly volume of ground water leaving the Lemhi Basin through the downgradient Basin boundary. Using K_{sat} = 40 ft/d (based on literature values for comparable sand and

gravel aquifers), i = 0.01 to 0.02 (based on ground water elevation contours drawn from well level measurements), and A = 143,000 ft^2, Donato calculated a maximum Q_{gw} through the downgradient Basin boundary of approximately 3,000 acre-ft/yr. Comparing this value to calculations of annual surface water outflow (> 200,000 acre-ft/yr), Donato concluded that ground water outflow is negligible in terms of the Basin's water budget.

Donato states, however, that this estimation of ground water outflow is based on many assumptions of aquifer properties. For example, the cross-section was modeled as an upside-down triangle, with a maximum thickness of 40 ft (based on drill logs). This representation may underestimate the extent of the aquifer near the boundary. Additionally, although K_{sat} = 40 ft/d falls within the range estimated by Spinazola, and is a reasonable value for silty sands and gravels (Fetter 2001), additional IDWR analyses of drill logs have suggested K_{sat} near the boundary could be up to an order of magnitude higher. Thus, additional hydrologic tests and computations are required to more accurately assess the significance of ground water outflow to the Basin's water budget.

Tracer Concentrations:

Fluorescein will be transported to the field in a plastic 5 gal carboy filled approximately 80% full with potable water. Trench-deployment of tracer will utilize a minimum of 1000 gal of irrigation water to dilute the tracer and flush it into the subsurface. Accounting for a maximum of 4 lbs of solid fluorescein (75% w/w) in the small carboy, the trench-deployment concentration of tracer (C_t) is calculated as:

$$C_t = \frac{M_t}{V_t} = \frac{(4lbs \times 0.75)\left(\frac{453.6g}{lb}\right)\left(\frac{1000mg}{g}\right)}{(1004gal)\left(\frac{3.785L}{gal}\right)} \approx 400ppm$$

Where M_t = mass of tracer, V_t = volume of tracer deployment solution, and parts per million (ppm) is equivalent to mg/L.

Upon deployment, the tracer solution will begin mixing with ground water present in the immediate zone of the aquifer, forming a tracer plume. Assuming a minimum saturated thickness (b_{sat}) of 5 ft, which is a very conservative estimate in both trench-deployment locations, the downgradient area (A_{dt}) required to dilute the trench-deployed tracer plume to the suggested safe limit (C_s) of 1 ppm (Field et al. 1995) is calculated as:

$$A_{dt} = \frac{\frac{C_t}{C_s} \times V_t}{\varphi \times b_{sat}} = \frac{\left(\frac{400ppm}{1ppm}\right) \times (1004gal)\left(\frac{ft^3}{7.48gal}\right)\left(\frac{acre \cdot ft}{43{,}560ft^2}\right)}{(0.30) \times (5ft)} = 0.8acre$$

Where φ = aquifer porosity, which accounts for the proportion of aquifer material available for ground water storage (i.e. pore space). This has been estimated at 0.30, which is representative of unconsolidated alluvial sediments (Dingman 2002).

Well-deployment of fluorescein will involve diluting the concentrated solution in the 5 gal carboy in an additional 150 gal of potable water in a larger plastic tank directly prior to injection. The resulting solution will be added to the 6 in diameter well, mixing with the approximately 20 ft column of water present in the well. Refer to Section 3.3 for a description of the well considered for tracer injection. Considering these conditions, the well-deployment concentration of tracer (C_w) is calculated as:

$$C_w = \frac{M_t}{V_t} = \frac{(4lbs \times 0.75)\left(\frac{453.6g}{lb}\right)\left(\frac{1000mg}{g}\right)}{(V_k + V_w)} \approx 2000ppm$$

Where V_k = volume of large plastic tank and V_w = volume of water in well. These quantities are calculated as:

$$V_k = (150gal)\left(\frac{3.785L}{gal}\right) = 568L$$

$$V_w = A_w \times L_w = (\pi \times (0.25ft)^2) \times (20ft) \times \left(\frac{7.48gal}{ft^3}\right)\left(\frac{3.785L}{gal}\right) = 111L$$

Where A_w = cross-sectional area of the well column, and L_w = length of the column of water in the well.

Upon deployment, the tracer solution will begin mixing with ground water present in the immediate vicinity of the aquifer, forming a tracer plume. Assuming a minimum saturated thickness of 20 ft, which is a very conservative estimate in the well-deployment location, the downgradient area (A_{dw}) required to dilute the well-deployed tracer plume to the C_s of 1 ppm is calculated as:

$$A_{dw} = \frac{\frac{C_w}{C_s} \times V_t}{\varphi \times b_{sat}} = \frac{\left(\frac{2000ppm}{1ppm}\right) \times (V_k + V_w)\left(\frac{gal}{3.785L}\right)\left(\frac{ft^3}{7.48gal}\right)\left(\frac{acre \cdot ft}{43{,}560ft^2}\right)}{(0.30) \times (20ft)} = 0.2acre$$

The above equations can be applied to calculate equivalent values for the trench- and well-deployments of rhodamine WT. The only modification that needs to be accounted for is rhodamine WT is sold in liquid form at 20% w/w. Thus, to attain concentrations similar to those employed with fluorescein, more "as sold" rhodamine must be used. Assuming a maximum of 12 lbs of liquid rhodamine:

$C_t \approx 300$ ppm
$A_{dt} \approx 0.6$acre
$C_w \approx 1600$ ppm
$A_{dw} \approx 0.2$ acre

Appendix B: Tracer Test Permit Requirements

Tracer tests in Idaho are regulated under two programs: the Underground Injection Control (UIC) program through the Idaho Department of Water Resources (IDWR) and the Idaho Department of Environmental Quality (DEQ), and the Land Application program through DEQ. The flow chart below (Figure A1) describes how to determine which program each Lemhi tracer test falls under.

IDWR and the Idaho Governor's Office of Species Conservation (OSC), which oversees the Upper Salmon Basin Watershed Program (USBWP), have consulted with DEQ on the trench-deployed tracer tests, which fall under the Land Application program. DEQ has granted approval for these tests. Approval from IDWR and DEQ under the UIC program will be sought as planned commencements for tracer well-deployments near.

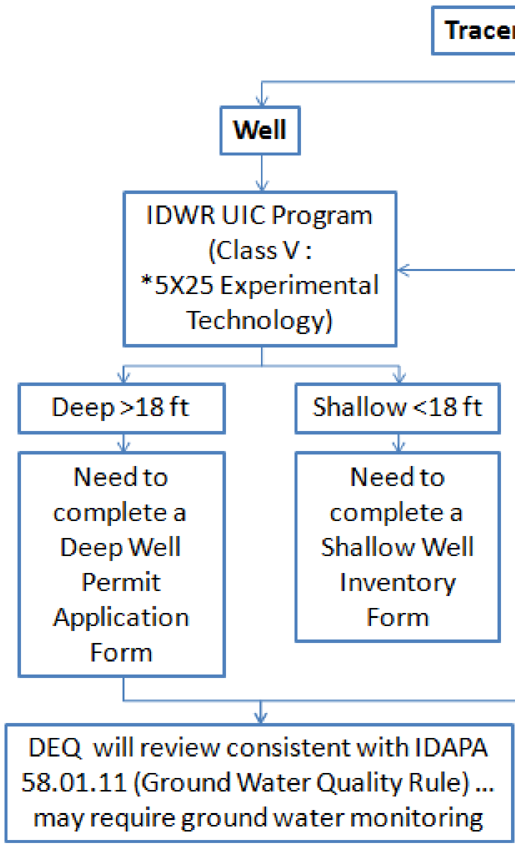

Figure B.1. Flow chart summarizing the process for tracer test deployment in Idaho.

Appendix C: Cost Breakdown

The anticipated costs for Phase 1 are itemized in Table C.1. Because many of the logistics of this study will not become firm until hydrologic tests and activities begin, personnel and travel costs are not presently included.

Test	Item	Quantity	Unit cost	Total cost	Notes
Olson **Initial trench injection**	Dye (lbs)	4	$ 50	$ 200	Fluorescein
	Dye carboys	1	$ 50	$ 50	
	Delivery water (gal)	1000	$ -	$ -	From L-9 ditch
	Packets	60	$ 2	$ 120	Rotated biweekly for 12 weeks
	Packet analysis	10	$ 40	$ 400	Majority performed by IDWR, some performed by OUL
	Vials	60	$ 2	$ 120	Collected from packet locations throughout test
	Vial analysis	0	$ -	$ -	Performed by IDWR
	Shipping for analysis	2	$ 35	$ 70	Assuming IDWR picking up majority
Olson **Subsequent trench injection**	Dye (lbs)	12	$ 50	$ 600	Rhodamine WT
	Dye carboys	2	$ 50	$ 100	
	Delivery water (gal)	1000	$ -	$ -	From Verdell Olson's well
	Packets	144	$ 2	$ 288	Rotated biweekly for 16 weeks
	Packet analysis	10	$ 40	$ 400	Majority performed by IDWR, some performed by OUL
	Vials	48	$ 2	$ 96	Collected from three locations, once per week, for 16 weeks
	Vial analysis	0	$ -	$ -	Performed by IDWR
	Shipping for analysis	4	$ 35	$ 140	Assuming IDWR picking up majority
Little Springs **Initial trench injection**	Dye (lbs)	2	$ 50	$ 100	Fluorescein
	Dye carboys	1	$ 50	$ 50	
	Delivery water (gal)	1000	$ -	$ -	From existing drain pipe
	Packets	40	$ 2	$ 80	Rotated biweekly for 8 weeks
	Packet analysis	10	$ 40	$ 400	Majority performed by IDWR, some performed by OUL
	Vials	40	$ 2	$ 80	Collected from two locations, twice per week, for 8 weeks
	Vial analysis	0	$ -	$ -	Performed by IDWR
	Shipping for analysis	2	$ 35	$ 70	Assuming IDWR picking up majority

Test	Item	Quantity	Unit cost	Total cost	Notes
Little Springs Subsequent trench injection	Dye (lbs)	12	$ 50	$ 600	Rhodamine WT
	Dye carboys	2	$ 50	$ 100	
	Delivery water (gal)	1000	$ -	$ -	From existing pivot system
	Packets	98	$ 2	$ 196	Rotated biweekly for 12 weeks
	Packet analysis	10	$ 40	$ 400	Majority performed by IDWR, some performed by OUL
	Vials	24	$ 2	$ 48	Collected from two locations, once per week, for 12 weeks
	Vial analysis	0	$ -	$ -	Performed by IDWR
	Shipping for vial analysis	3	$ 35	$ 105	Assuming IDWR picking up majority
Upper Basin Well injection	Dye (lbs)	8	$ 50	$ 400	Fluorescein
	Dye carboys	1	$ 50	$ 50	
	Delivery water (gal)	150	$ -	$ -	Potable water in plastic tank borrowed from landowner
	Mixing/delivery water container	1	$ -	$ -	Assuming can be borrowed from landowner
	Packets	120	$ 2	$ 240	Rotated biweekly for 8 weeks
	Packet analysis	10	$ 40	$ 400	Majority performed by IDWR, some performed by OUL
	Shipping for analysis	8	$ 35	$ 280	Assuming IDWR picking up some
Well level measurements	Well water level loggers	6	$ 810	$ 4,858	
	Well barometric pressure loggers	2	$ 810	$ 1,619	
	Well monitoring equipment installation	8	$ -	$ -	Performed by IDWR
	Manual water level measurements	231	$ 35	$ 8,085	Mid-March through mid-November
Other activities	Seepage runs	Various	$ -	$ -	Performed by IDWR, possibly assisted by collaborators
	Stream gauging	Various	$ -	$ -	Performed by IDWR
	Existing and collected data analysis	Various	$ -	$ -	Performed by IDWR
	Incorporate data into MIKE BASIN model	Various	$ -	$ -	Performed by IDWR
Miscellaneous	Generator	1	$ -	$ -	Assuming can be borrowed from IDWR or landowner
	Water pump	1	$ -	$ -	Assuming can be borrowed from landowner
	Miscellaneous supplies	Various	$ -	$ 2,000	General and laboratory supplies for hydrologic tests

Table C.1. Itemized costs for Phase 1 hydrologic tests and activities.

Appendix D: Project Schedule

Tables D.1, D.2, and D.3 illustrate the anticipated schedule of hydrologic tests and activities for Phases 1, 2, and 3, respectively.

Phase 1										
Olson - initial tracer test, seepage runs										
Little Springs - initial tracer test, seepage runs										
Olson - subsequent tracer test, seepage runs										
Little Springs - subsequent tracer test, seepage runs										
Upper Basin - well-deployed tracer test										
Well level measurements										
Stream gauging										
Existing and collected data analysis										
Phase 2										
Little Springs - tracer test, seepage runs										
Mill - tracer tests, seepage runs										
Bohannon or Kenney - tracer tests, seepage runs										
Hawley or Big Timber - tracer tests, seepage runs										
Upper Basin - tracer test										
Boundary - seepage runs										
Divide - seepage runs										
Well level measurements										
Aquifer tests										
Stream gauging										
Soil moisture measurements										
Existing and collected data analysis										
Phase 3										
Bohannon or Kenney - tracer tests, seepage runs										
Hawley or Big Timber - tracer tests, seepage runs										
Withington - tracer tests, seepage runs										
Boundary - seepage runs										
Divide - seepage runs										
Well level measurements										
Stream gauging										
Soil moisture measurements										
Existing and collected data analysis										
Update and refine MIKE BASIN model										
	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	2011									

Table D.1. Proposed project schedule during Phase 1.

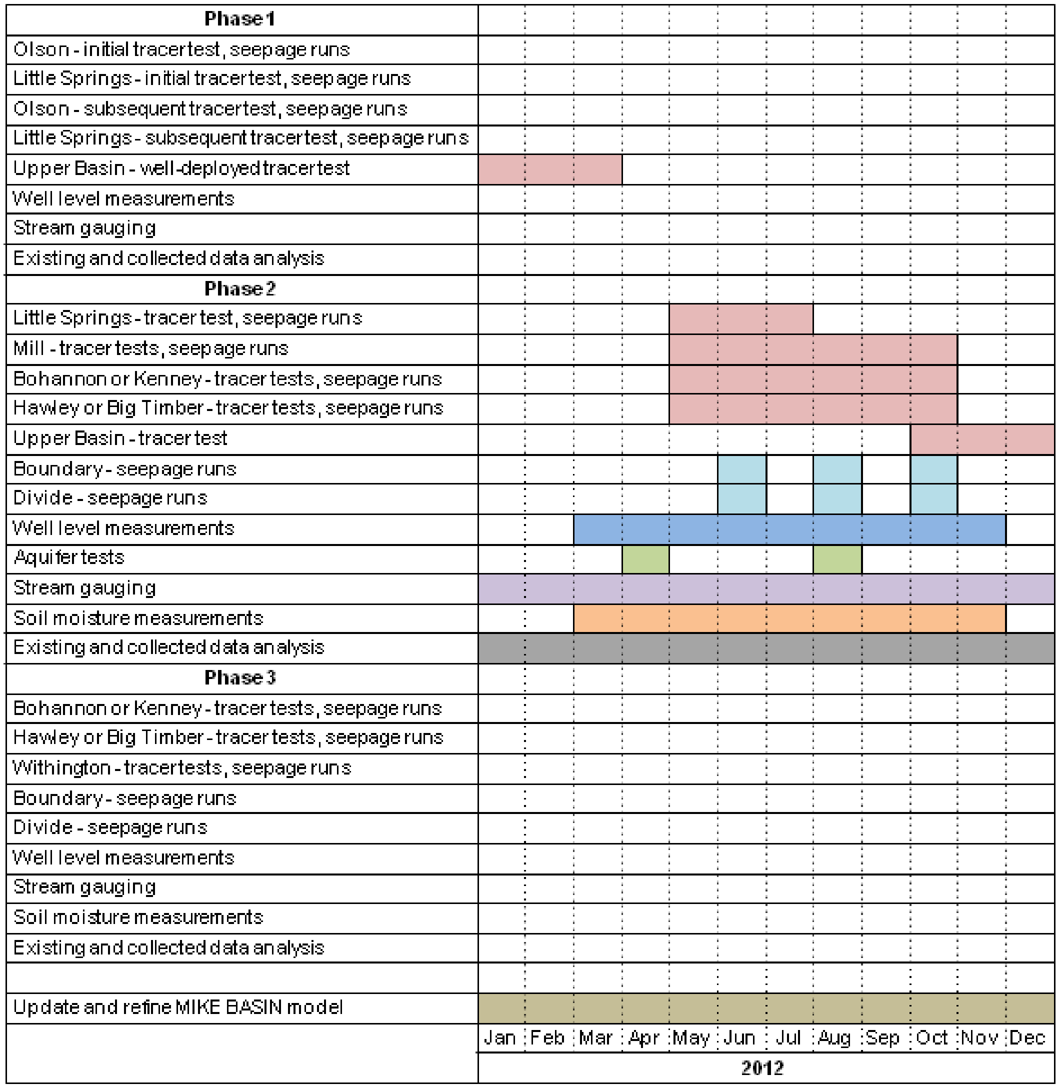

Table D.2. Proposed project schedule during Phase 2.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
Phase 1											
Olson - initial tracer test, seepage runs											
Little Springs - initial tracer test, seepage runs											
Olson - subsequent tracer test, seepage runs											
Little Springs - subsequent tracer test, seepage runs											
Upper Basin - well-deployed tracer test											
Well level measurements											
Stream gauging											
Existing and collected data analysis											
Phase 2											
Little Springs - tracer test, seepage runs											
Mill - tracer tests, seepage runs											
Bohannon or Kenney - tracer tests, seepage runs											
Hawley or Big Timber - tracer tests, seepage runs											
Upper Basin - tracer test											
Boundary - seepage runs											
Divide - seepage runs											
Well level measurements											
Aquifer tests											
Stream gauging											
Soil moisture measurements											
Existing and collected data analysis											
Phase 3											
Bohannon or Kenney - tracer tests, seepage runs											
Hawley or Big Timber - tracer tests, seepage runs											
Withington - tracer tests, seepage runs											
Boundary - seepage runs											
Divide - seepage runs											
Well level measurements											
Stream gauging											
Soil moisture measurements											
Existing and collected data analysis											
Update and refine MIKE BASIN model											
	2013										

Table D.3. Proposed project schedule during Phase 3.

Appendix E: Acronyms/Abbreviations

General abbreviations

amsl	Above mean sea level
bls	Below land surface

Agencies/organizations

BOR	U.S. Bureau of Reclamation
DEQ	Idaho Department of Environmental Quality
IDWR	Idaho Department of Water Resources
NRCS	Natural Resource Conservation Service
OSC	Idaho Governor's Office of Species Conservation
OUL	Ozark Underground Laboratory
UIC	Underground Injection Control program
USBWP	Upper Salmon Basin Watershed Program
USGS	U.S. Geological Survey

Hydrologic quantities

A	Cross-sectional area
A_{dt}	Downgradient area required to dilute the trench-deployed tracer plume to Cs
A_{dw}	Downgradient area required to dilute the well-deployed tracer plume to Cs
A_w	Cross-sectional area of well column
b_{sat}	Saturated aquifer thickness
C_s	Suggested safe concentration of tracer in natural waters, 1 ppm (Field et al. 1995)
C_t	Trench-deployment tracer concentration
C_w	Well-deployment tracer concentration
D_w	Depth to water
h	Water level after pumping
h_0	Static water level
i	Hydraulic gradient
K_{sat}	Saturated hydraulic conductivity
L_w	Length of water column in well
M_t	Mass of tracer
Q	Pumping rate
Q_{gw}	Ground water flow rate
Q_{sw}	Surface water flow rate
r	Well radius
S	Storativity
S_c	Specific capacity

T	Transmissivity
t	Time
v_{gw}	Average linear ground water velocity
V_k	Volume of large plastic tank
V_t	Volume of tracer deployment solution
V_w	Volume of water in well
φ	Porosity

Units

cfs	Cubic feet per second
d	Days
ft	Feet
g	Grams
gal	Gallons
gpm	Gallons per minute
hrs	Hours
in	Inches
L	Liter
lbs	Pounds
mg	Milligram
mi	Mile
ml	Milliliter
ppm	Parts per million, equivalent to mg/L