Upper Salmon Basin Groundwater – Surface Water Interactions Study, Phase 4
Final Project Report

Prepared by

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PROJECT OVERVIEW

DOC, Award Number:	16NMF4380334
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:	020 16 SA
Project Sub-Grantee:	Idaho Department of Water Resources
Project Contact Information:	Ryan McCutcheon Hydrogeologist 322 E. Front Street, P.O. Box 83720 Boise, ID 83720-0098
Grant Period:	04/01/2019 – 09/30/2020
Total PCSRF Funds:	$247,878.00
Total Non-Federal Match:	$82,626.00
Primary PCSRF Objectives:	Salmon Research, Monitoring, and Evaluation (SRME)

This [report/video/etc.] was prepared by [recipient name] using Federal funds under award 17NMF4380178 from the National Marine Fisheries Service, U.S. Department of Commerce. The statements, findings, conclusions, and recommendations are those of the author(s) and do not necessarily reflect the views of the National Marine Fisheries Service or the U.S. Department of Commerce.

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INTRODUCTION

The Upper Salmon Basin (USB) and its tributaries have historically hosted large populations of anadromous fish such as Chinook salmon, sockeye salmon, and steelhead trout (USBWP, 2019). However, spawning returns in the USB have been greatly reduced over the past 150 years due to the placement of physical barriers (e.g., dams), changes to in-stream habitat, water quality degradation, and other factors (ISCC, 1995). A persistent decrease in anadromous fish returns has led to Chinook salmon, sockeye salmon, and steelhead trout being listed under the Endangered Species Act (ESA).

In response to decreased returns of salmonids, many stakeholders in the USB now seek to improve streamflow conditions and in-stream habitat in the hopes of increasing fish populations. The Upper Salmon Basin Watershed Program (USBWP) was established in 1992 as a group of stakeholders devoted to accomplishing this goal; namely, "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, 2018).

The USBWP Technical Team (Tech Team) is a group of federal, state, and nonprofit agency personnel that employ their technical expertise to accomplish the goals of the USBWP. Many local landowners are members of the USBWP, and have agreed to work with the Tech Team to implement water transactions and/or in-stream habitat improvement projects on their private property. This cooperation has led to the completion of many projects in the Upper Salmon Basin since the inception of the USBWP in 1992 (USBWP, 2019). The efficacy of these efforts relies on a detailed understanding of the hydrogeology of the Upper Salmon Basin, as well as predictions on how both fish habitat and water users might be impacted by changes to water management, land use, climate, etc. It is a goal of the Idaho Department of Water Resources (IDWR) to provide that expertise. The bulk of USBWP projects have focused on the Lemhi River Basin (LRB) in recent years. As a result, the primary focus Phase 4 of this study is the Lemhi Basin, which is home to both Chinook salmon and steelhead trout.

In support of the USBWP, this report details a series of hydrologic data collection efforts, analyses, and numerical modeling activities conducted by IDWR and collaborators during the Upper Salmon Basin Groundwater and Surface Water Interactions Study, Phase 4. The reported data and analyses are aimed at characterizing groundwater and surface water interactions within the LRB, as well as predicting the hydrologic impacts of proposed changes to land use, in-stream habitat, water management, etc. All data and interactive analytical tools produced during this study will be made available to the public via web portals when finalized, while additional, more robust hydrologic analyses will be reported on after the culmination of Phase 5, in the next report.

STUDY AREA AND BACKGROUND

The Lemhi River Basin is an approximately 1,270 mi^2 NNW trending watershed in east-central Idaho, situated between the Lemhi Range to the west and the Beaverhead Mountains to the east (Figure 1). The LRB is part of the larger USB, which encompasses the Lemhi, Upper Salmon, Pahsimeroi, and Middle Salmon river basins, and historically supported critical habitat for vast numbers of anadromous fish. The USB, and the LRB in particular, has been a focal area for in-stream habitat restoration for the past 25 years because it contains the headwaters of some of the last remaining anadromous fish runs in Idaho.

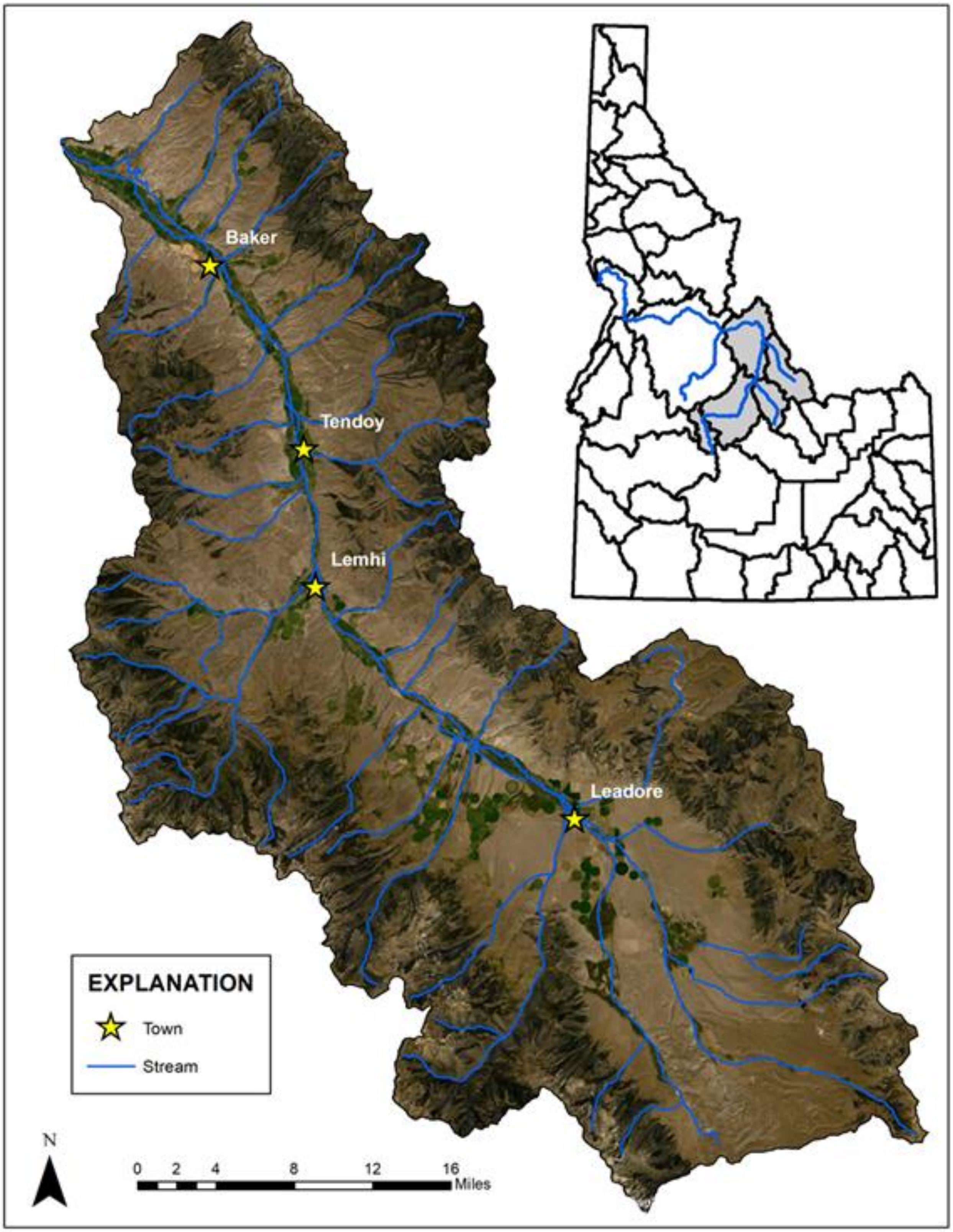

Figure 1. Lemhi River Basin

The headwaters of the Lemhi River are formed by the confluence of several tributaries that drain the surrounding mountains. Downstream of the confluence, the valley floor ranges in elevation between 4,000 and 6,000 ft above mean sea level, and receives less than 10 in/yr of precipitation. However, above the valley floor, precipitation is positively correlated with elevation, and the surrounding mountains (some exceeding 10,000 ft) can receive more than 40 in/yr of precipitation, primarily in the form of snow. As a result, the magnitude and timing of snowmelt and subsequent water storage dynamics play an important role in Lemhi Basin hydrogeology.

The Lemhi River flows approximately 60 miles from the town of Leadore to its confluence with the Salmon River near the town of Salmon. The river and associated tributaries are characterized by meandering channels that flow through rural rangeland, willow stands, and irrigated fields and pastures. The Lemhi River Valley, surrounding alluvial terraces, and tributary watersheds host productive agricultural businesses that support the local economy. IDWR estimates that approximately 120,000 acres of land are irrigated in the LRB, chiefly for alfalfa hay and pasture, based on the 2001 U.S. Geological Survey (USGS) National Land Cover Dataset. Landowners have created numerous earthen canals and ditches to intercept runoff. Water readily infiltrates into the shallow alluvial sediments as it flows through the canals and is applied to fields, later returning to streams by both surface and groundwater flowpaths (Donato, 1998). After returning to streams, the water is available to be re-diverted and water in the basin is likely reused multiple times before exiting the basin as both streamflow and groundwater underflow (Donato, 1998).

Previous researchers have divided the LRB groundwater system into two subbasins, which are separated by a bedrock constriction that is located between the towns of Lemhi and Tendoy and is locally referred to as “The Narrows” (Figure 2). This constriction in the low permeability bedrock forces groundwater flowing from the upper basin to the lower basin to discharge to the Lemhi River (Anderson, 1961; Dorratcaque, 1986; Spinazola, 1998). The alluvial aquifer of the upper basin is both wider and thicker than the alluvial aquifer of the lower basin (Dorratcaque, 1986). Estimated aquifer thickness ranges from 20 to over 200 ft in the upper basin, and 16 to 42 ft in the narrows, and 27 to over 60 ft in the lower basin (Donato, 1998).

The timing and quantity of water delivered from the upper basin to the lower basin is likely impacted by both climatological factors (e.g., snow pack, rain, and temperature) and irrigation practices up-gradient of the narrows (DHI, 2006). As an example of the latter, the practice of high flow irrigation may contribute significant recharge to the alluvial aquifer and augment late season streamflow through gradual aquifer discharge into the Lemhi River (DHI, 2006).

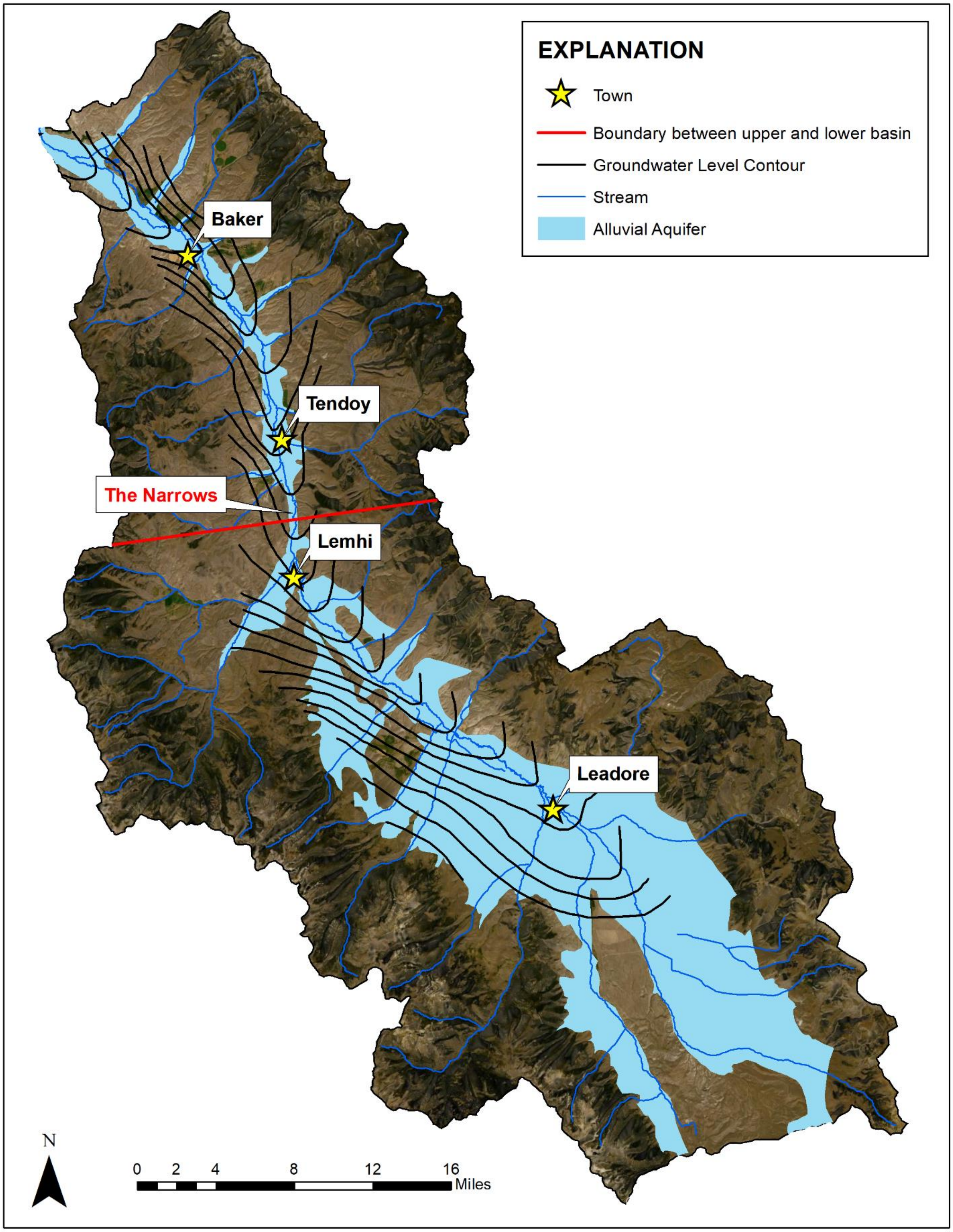

Figure 2. Lemhi River Basin Hydrogeology

OBJECTIVES

The following task list (Objectives) has been copied from the research proposal submitted to the Idaho Pacific Coastal Salmon Recovery Fund (2018, Round 21).

<u>On-going Tasks:</u>

Task 1 - Surface Water and Groundwater Monitoring

Stream gaging:

The current streamflow monitoring network was created in 2005 with Idaho Power Company installing and operating the gauges. The locations of these gauges were determined through discussions with the USBWP Technical Team and other collaborators. Streamflow data in the basin has been and will continue to be critical for project planning, monitoring, and prediction of project outcomes via numerical modeling. It is used for the assess projects including water management, streamflow enhancement, and in-stream habitat restoration.

Currently, via a subcontract with Idaho Water Engineering (IWE), 17 stream gauges are operated across the USB. An additional seven stream gauges are operated by IDWR. For 2019, at least 17 stream gauges will be subcontracted to IWE, and seven will continue to be operated by IDWR. The adequacy of the streamflow monitoring network for project planning is being evaluated by the USBWP Technical Team to see if new gauges are needed or if current gauges need to be relocated or are no longer needed.

Groundwater level measurements:

A groundwater level monitoring network comprising 21 wells was established in May of 2011 based on review of the water level monitoring efforts conducted in the late 1990's by Spinazola (1998). Until May of 2015, continuous water level measurements were measured using electronic pressure transducers in nine wells and biweekly manual measurements were made in the remaining 12 wells.

In May of 2015, the network was expanded to the current total of 41 wells; 24 continuously measured and 17 manually measured. These data provide information about the timing and magnitude of aquifer water level changes caused by pumping, natural recharge, and incidental recharge of water applied for irrigation. Under this task, the Water District 74 Watermaster and IDWR staff will continue to maintain the expanded water level monitoring network.

Soil moisture measurements:

During this phase of the project, soil moisture sensors that were previously installed beneath four fields will continue to be monitored in order to provide ongoing, direct measurements of irrigation-induced aquifer recharge. The resulting data will be used to evaluate the hydrologic impacts of the change in irrigation practice.

Task 2 - Lemhi River Basin Model (LRBM)

IDWR is responsible for the Lemhi River Basin Model (LRBM). Under this task, the LRBM will be continually maintained with the most up to date hydrologic data and irrigation system configuration information for water year 2017. The model will be used to determine the hydrologic impacts of previous projects performed in the past and to help plan for future projects.

Skeleton MIKE BASIN models have been developed for the Pahsimeroi and East Fork Salmon River basins, as well as for the Carmen Creek and Morgan Creek drainages. Hydrologic data collection and modeling may also be performed for these areas if the USBWP and/or its collaborators request these efforts.

All hydrologic modeling activities are, and will continue to be, performed by the IDWR with assistance from a Mike Basin Consultant on an as-needed basis.

Task 3- Aerial Photography Analysis of Changes in Irrigation Practices

IDWR will analyze changes in irrigation practices using aerial photography from the Idaho Soil Conservation flight in 1992, and the NAIP datasets for 2004, 2006, 2009, and 2013. The aerial photography analysis will be performed using ArcMap Geographic Information System software. For each year, all irrigated lands will be assigned one of the following irrigation practice classifications: flood irrigation, hand-lines, wheel-lines, center-pivot, or undetermined. A comparison of the shapefiles for each year will facilitate determination of how irrigation practices have changed over time.

New Proposed Tasks:

Task 4- Conversion from MIKE BASIN to MHB

This task involves: 1) determining if the LRBM should be converted from the currently used version of the Mike Basin computer program (MIKE BASIN v2012) to the most current version (MHB), and if it is decided to proceed, 2) starting the process of converting the model into MHB. In the case of the latter, all of the supporting tools will also be updated so there will be no loss of functionality. Carter Borden from Centered Consulting International, LLC will be contracted to assist IDWR with this task.

Task 5- MIKE BASIN Integration Tool

To date, it has been difficult for evaluators of potential water transaction projects to convey the associated water use scenarios to the MIKE BASIN modelers. Under this task, scenario evaluation will be made more straightforward by creating a suite of MS Excel-based pre- and post-processing tools that expedite the submittal, simulation, and evaluation of a water use scenario. The goal is to have an assessment of the hydrologic impacts set up and ran within hours of receiving a submittal from the evaluators. Carter Borden from Centered Consulting International, LLC will be contracted to assist IDWR with this task.

Task 6- Compile and publish current and historical streamflow data

Currently only streamflow data from active gauges are made available to the public via contractor's websites. Thus, the historical streamflow data are no longer accessible when a gauge is discontinued. Under this task, IDWR will compile all current and historical streamflow data in a central database and make the data publicly available via the IDWR website.

Task 7 – Data Collection Assessment

Modification to Data Collection:

If any data sources are found to be lacking or insufficient, IDWR will modify the data collection process to support the USBWP, the LRBM or development of another model, and future research needs for the overarching objective to support salmonid recovery efforts. Possible enhancements to existing data collection efforts include: 1) adding more existing wells to the monitoring network, 2) increasing the number of surface water measurements and gaging sites, 3) conducting more seepage runs, and 4) identifying locations for drilling dedicated monitoring wells.

Project Milestones and Timelines

- April 2019 – June 2020: Collect surface water measurements at stream gauges for site 1 and site 2 post to the IDWR website.
- April 2019 – June 2020: Collect groundwater levels at site 1 and post to Department hosted site for the public.
- September 2019: Semi-Annual Progress report
- March 2020: Semi-Annual Progress report
- September 2020: Final Project Report which will include
    1. Streamflow data
    2. Groundwater level measurements
    3. Soil moisture measurements
    4. Status of the MIKE BASIN Model
    5. Status of the aerial photography analysis

RESULTS

Phase 4 of this project was focused primarily on data collection and the development of modelling tools that will enable a more robust data analysis that will be presented in the Upper Salmon Basin Groundwater – Surface Water Interactions Study, Phase 5 Final Project Report. The work completed generally adhered to the objectives outlined in the Pacific Coastal Salmon Recovery Fund (2018, Round 21) grant proposal submitted to the Idaho Governor's Office of Species Conservation (see "OBJECTIVES"), although minor changes were made to the data collection and analysis campaigns in order to meet the ever-changing needs of stakeholders.

Streamflow, groundwater levels, and soil moisture data were all collected during this project phase. Minor changes to these monitoring networks were necessitated as a result of changing data demands and the development of in-stream habitat and water-related projects. In addition, the Lemhi River Basin

Model was maintained and upgraded in order to run scenarios for stakeholders upon request. Conversion of the model to use the new MIKE Hydro Basin Software has begun, and a suite of interactive tools was developed to increase the ability of stakeholders to interact with model data.

It is worth noting that the headings within the results section of this report were labelled differently than the "Tasks" outlined in the objectives section of the report. This format was used to better convey the individual data and analysis products that were produced during this project phase. However, information regarding the work completed on the proposed tasks can be found under the following headings in the results section:

- Streamflow Data Collection – Tasks 1, 6, and 7
- Groundwater Level Data Collection – Tasks 1 and 6
- Soil Moisture Data Collection – Tasks 1 and 6
- Status of the Lemhi River Basin Model – Tasks 2 and 4
- Aerial Photography Analysis of Changes in Irrigation Practices – Task 3
- Lemhi River Basin Model Interactive Tools – Task 5

Streamflow Data Collection

Streamflow data has been used to support the USBWP in planning, implementation, and monitoring of streamflow enhancement and salmonid habitat restoration projects, and provides integral calibration data to the Lemhi River Basin Model (LRBM). The data has also been used to inform water users on basin hydrogeology and aid in water right settlement negotiations that impact the quantity and quality of water available to salmonids. With funding from the Pacific Coast Salmon Recovery Fund (PCSRF), the Columbia Basin Water Transactions Program (CBWTP), the Idaho Water Transactions Program (IWTP), and the Bonneville Environment Foundation (BEF), IDWR has managed streamflow data collection for the USBWP from 1997 to present (Table 1).

In total, IDWR has managed 54 stream gauges within the USB, 34 of which are still active data collection sites as of the publication of this report (Table 1, Figure 3). IDWR personnel monitored 12 stream gauges throughout this project phase, while IDWR subcontractors monitored the rest. Prior to 3/15/2020, Idaho Water Engineering (IWE) was subcontracted to monitor 17 gauges. However, following 3/15/2020, all subcontracted gauges were awarded to SPF Water Engineering (SPF), who currently monitors 22.

Of the 34 USB gauges currently managed by IDWR, 16 exist within the LRB (Figure 4). IDWR manages 13 of the 16 LRB gauges using PCSRF funds, while the rest are funded by other sources (Table 1). It's also important to note that IDWR monitors one gauge on Bayhorse Creek outside of the LRB using PCSRF funds (Table 1, Figure 3). Both IDWR and subcontractors developed stage-discharge rating tables by measuring streamflow every six weeks (when possible) using an Acoustic Doppler Velocimeter, an acoustic Doppler current profiler, or dilution gauging. The stream gauge stage data and stage-discharge rating tables were used to calculate streamflow values.

All streamflow data collected through the last week of September, 2019 has been posted to the IDWR streamflow data web portal, Aqua Info, where all data is made freely available to the public (https://research.idwr.idaho.gov/apps/hydrologic/aquainfo/Home/Data#!/). This is the case for both PCSRF-funded gauges and other IDWR USB gauges, as one of the proposed project Objectives (Task 6) was to compile and publish current and historical streamflow data, and that task has been completed. All data from water year 2019 (October 1, 2018 to September 30, 2019) and prior may be considered finalized, while all posted data from water year 2020 should be considered preliminary until it is finalized on February 1, 2021.

Table 1. IDWR Stream Gauges within the Upper Salmon Basin

Gauge Name	Latitude	Longitude	Data Range	Status	Funding
Agency Creek	44.949	-113.568	2005 - present	Operated by SPF	PCSRF
Alturas Lake Creek	43.982	-114.846	2006 - 2015	Discontinued	None
Bayhorse Creek	44.378	-114.257	2013 - present	Operated by IDWR	PCSRF
Beaver Creek	43.919	-114.814	2004 - present	Operated by SPF	CBWTP
Big Eightmile Creek, Lower	44.694	-113.482	2008 - present	Operated by IDWR	PCSRF
Big Eightmile Creek, Upper	44.644	-113.529	2005 - present	Operated by IDWR	PCSRF
Big Hat Creek	44.818	-114.111	2004 - 2005	Discontinued	None
Big Springs Creek, Lower	44.728	-113.433	2005 - present	Operated by SPF	IWTP
Big Springs Creek, Upper	44.711	-113.409	2008 - present	Operated by SPF	PCSRF
Big Timber Creek, Lower	44.689	-113.370	2004 - present	Operated by SPF	IWTP
Big Timber Creek, Upper	44.614	-113.397	2005 - present	Operated by IDWR	PCSRF
Bohannon Creek, Lower	45.122	-113.732	2008 - present	Operated by SPF	IWTP
Bohannon Creek, Upper	45.191	-113.691	2013 - present	Operated by IDWR	PCSRF
Canyon Creek	44.691	-113.364	2008 - present	Operated by SPF	IWTP
Carmen Creek, Lower	45.246	-113.893	2005 - present	Operated by SPF	CBWTP
Carmen Creek, Upper	45.345	-113.789	2005 - 2018	Discontinued	None
Challis Creek, Lower	44.569	-114.194	2005 - 2019	Transferred	None
Challis Creek, Upper	44.572	-114.305	2005 - 2019	Discontinued	None
Eighteenmile Creek	44.668	-113.314	2006 - present	Operated by IDWR	PCSRF
Eighteenmile Creek Mouth	44.683	-113.352	2008 - 2009	Discontinued	None
Falls Creek	44.583	-113.766	2005 - 2007	Discontinued	None
Fourth of July Creek	44.030	-114.834	2004 - present	Operated by SPF	CBWTP
Garden Creek	44.511	-114.203	2005 - 2007	Discontinued	None
Goat Creek	44.219	-114.952	2018 - present	Operated by SPF	CBWTP
Hawley Creek	44.667	-113.192	2008 - present	Operated by IDWR	PCSRF
Hawley Creek at Bridge Near Leadore	44.672	-113.302	2020 - present	Operated by SPF	BEF
Hawley Creek Below Diversions	44.659	-113.216	2020 - present	Operated by SPF	BEF
Hayden Creek	44.870	-113.627	1997 - present	Operated by SPF	PCSRF
Herd Creek	44.117	-114.262	2005 - 2007	Discontinued	None
Iron Creek	44.888	-113.971	2006 - present	Operated by SPF	CBWTP
Kenney Creek	45.027	-113.654	2004 - present	Operated by SPF	IWTP
Lee Creek	44.746	-113.476	2009 - present	Operated by IDWR	PCSRF
Lemhi River above Big Springs	44.729	-113.433	2005 - present	Operated by SPF	PCSRF
Lemhi River above Hayden Creek	44.867	-113.625	2004 - 2009	Discontinued	None
Lemhi River above L-63	44.682	-113.356	2008 - 2019	Discontinued	None
Lemhi River at Baker	45.098	-113.722	2004 - 2009	Discontinued	None
Lemhi River at Cottom Lane	44.749	-113.476	2005 - present	Operated by SPF	PCSRF

Lemhi River at L-1	45.177	-113.886	1997 - present	Operated by IDWR	Other
Lemhi River at McFarland	44.803	-113.566	1997 - 2019	Transferred	None
Little Morgan Creek	44.653	-113.932	2005 - 2007	Discontinued	None
Little Springs Creek, Lower	44.779	-113.544	2008 - present	Operated by IDWR	CBWTP
Little Springs Creek, Upper	44.773	-113.528	2008 - 2016	Discontinued	None
Meadow Creek	44.218	-114.944	2018 - present	Operated by SPF	CBWTP
Morgan Creek	44.612	-114.170	2006 - present	Operated by SPF	CBWTP
North Fork Salmon River	45.406	-113.994	2005 - 2007	Discontinued	None
Pahsimeroi at Furey Lane	44.526	-113.848	2004 - 2020	Transferred	None
Pahsimeroi River below P-9	44.597	-113.953	2005 - present	Operated by SPF	IWTP
Patterson - Big Springs, Lower	44.606	-113.951	2009	Discontinued	None
Patterson - Big Springs, Upper	44.596	-113.938	2008 - present	Operated by SPF	IWTP
Pole Creek	43.909	-114.759	2005 - present	Operated by SPF	CBWTP
Pratt Creek	45.078	-113.699	2017 - present	Operated by IDWR	IWTP
Salmon River near Obsidian	44.001	-114.833	2004 - 2009	Discontinued	None
Salmon River near Stanley	44.257	-114.833	2004 - 2009	Discontinued	None
Texas Creek	44.636	-113.323	2008 - present	Operated by IDWR	PCSRF

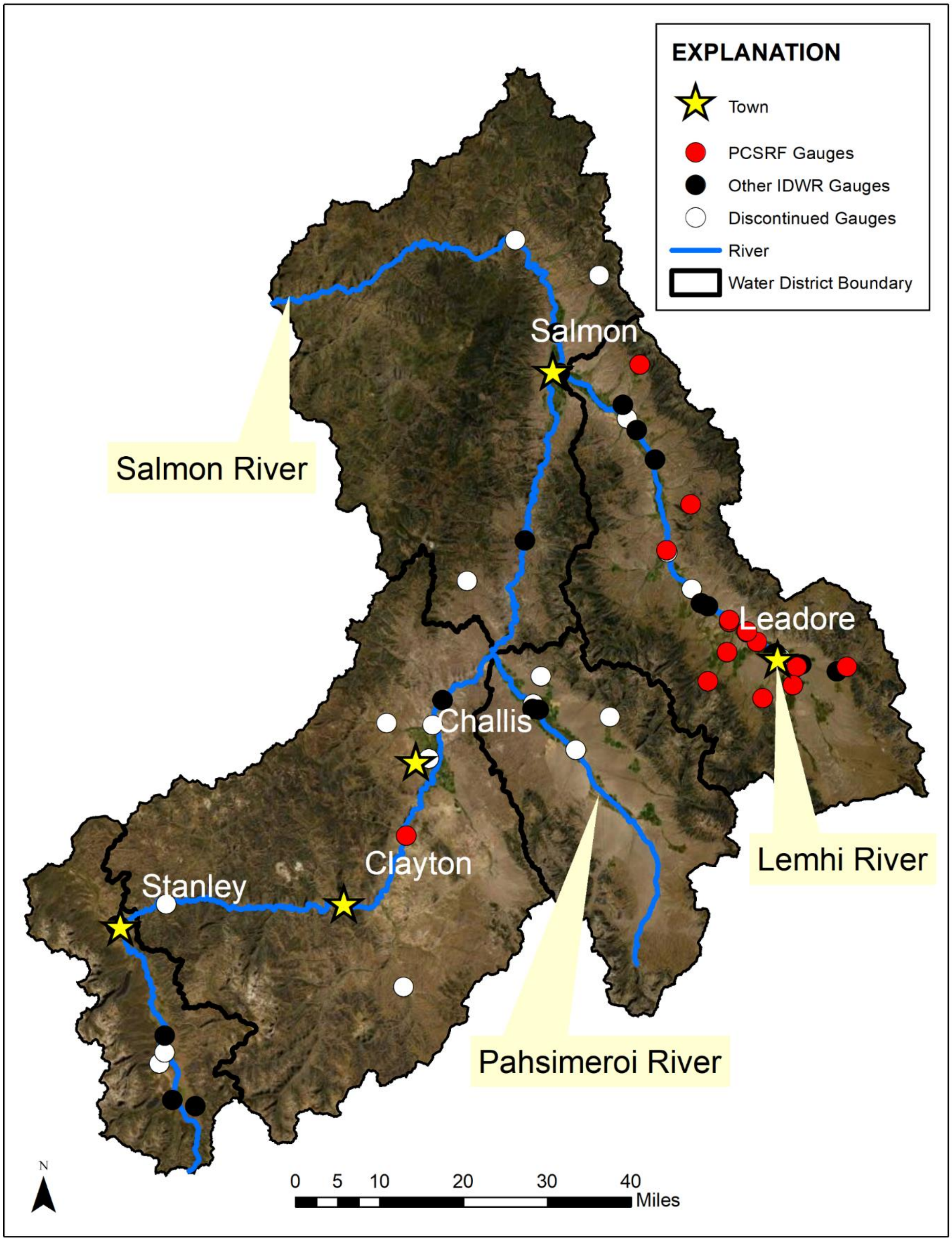

Figure 3. Upper Salmon Basin Streamflow Monitoring Network

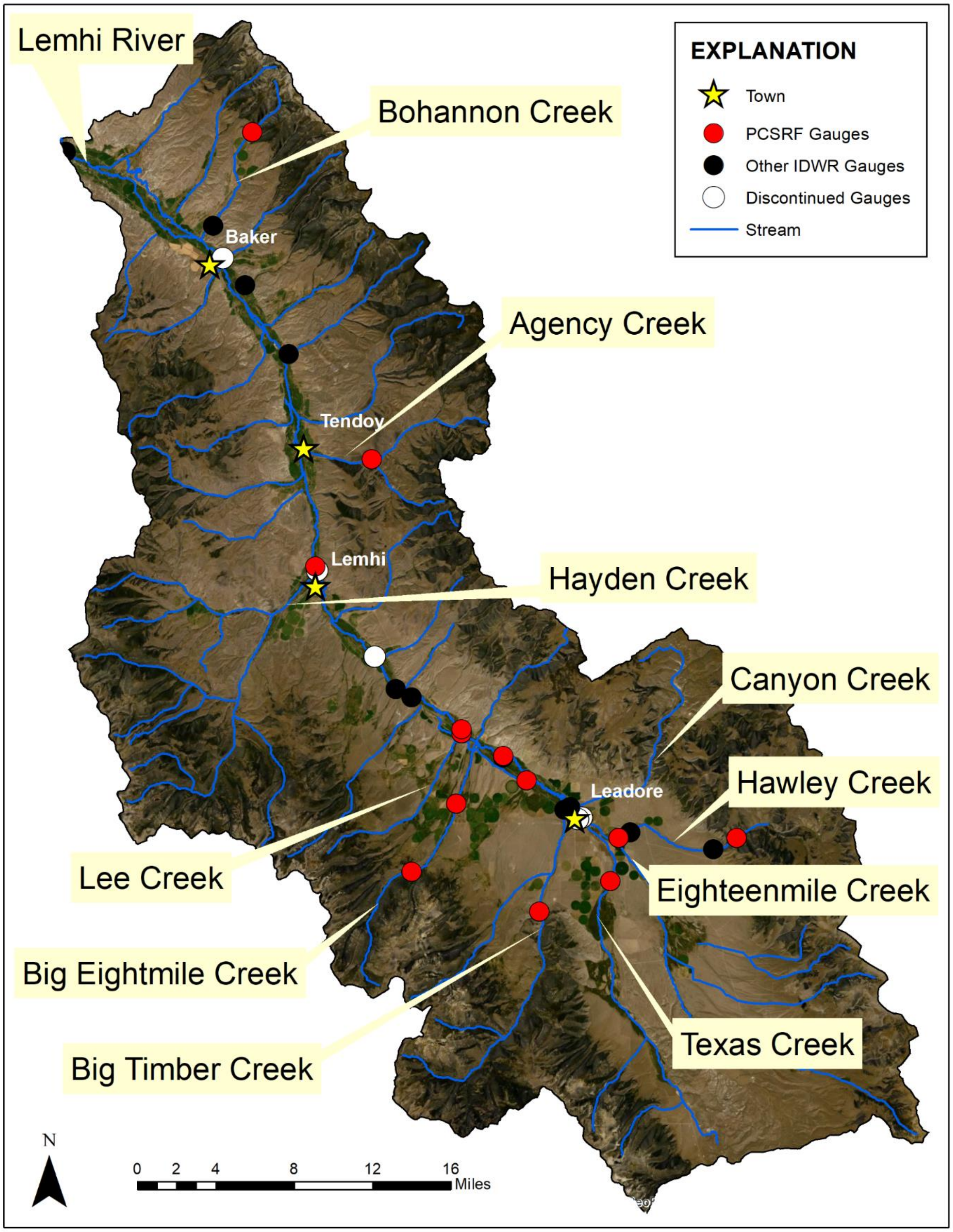

Figure 4. Lemhi River Basin Streamflow Monitoring Network

Groundwater Level Data Collection

Groundwater level data are required to determine how changes to water management, land use, and climate impact streamflow and groundwater resource availability in the LRB. These data have been used to determine the nature of groundwater and surface water interactions, and to help water managers and salmonid habitat project planners make better informed decisions when considering potential alterations to basin hydrogeology. The data are also set to be added to the LRBM at a future date to better account for the impacts of groundwater fluctuations on streamflow within the numerical model.

The Lemhi River Basin Groundwater Monitoring Network consists of 41 wells (Table 2, Figure 5). The network started with 38 wells during project Phase 1 and Phase 2, while four wells were added during Phase 3, and one well was removed during Phase 4. During this phase, Water District 74 was subcontracted to manually measure depth to water using an electric tape measure at 17 wells (Non-Instrumented Wells, Figure 5) every two weeks between March and November. IDWR equipped an additional 24 wells with non-vented In-Situ Level Troll data loggers (Instrumented Wells, Figure 5), which monitored water levels and temperature year-round, recording every twelve hours. A calibrated electric tape was used to manually measure groundwater levels at the instrumented wells on a bi-annual basis in order to ensure the accuracy of the recorded pressure transducer data. The water level dataset for each well in the monitoring network ranges from two to nine years in duration, and 32 of the 41 wells also had two years of data collected during the Donato (1998) study (Table 2).

Both manual (Non-Instrumented Wells) and continuous (Instrumented Wells) groundwater level measurements for water year 2019 have been posted to the IDWR Groundwater Levels Data Portal at https://maps.idwr.idaho.gov/agol/GroundwaterLevels/. However, IDWR is currently transitioning to a new Groundwater Levels Data Portal, which is not yet available to the public. As a result, water year 2020 data will be temporarily posted to the project website at https://idwr.idaho.gov/water-data/projects/upper-salmon/references.html before February 1, 2021. The USBWP and others will be notified when the new data portal begins serving data.

Table 2. IDWR Groundwater Level Monitoring Sites within the Lemhi River Basin

Well Number	Latitude	Longitude	Instrumentation	Data Range	Status
21N 22E 10ACD2[1]	45.16505	-113.83914	Non-Instrumented	2011 - present	Operated by WD74
21N 22E 09DAB1	45.16368	-113.85635	Non-Instrumented	2011 - present	Operated by WD74
21N 22E 10CCA1	45.15980	-113.84790	Instrumented	2011 - present	Operated by IDWR
21N 22E 09DDB1[1]	45.15888	-113.85682	Instrumented	2011 - present	Operated by IDWR
21N 22E 14CDD1[1]	45.14410	-113.82265	Non-Instrumented	2015 - present	Operated by WD74
21N 22E 24DCA1[1]	45.13138	-113.79678	Non-Instrumented	2015 - present	Operated by WD74
21N 23E 30ABC1	45.12622	-113.77948	Non-Instrumented	2013 - present	Operated by WD74
21N 23E 30DAC1[1]	45.11773	-113.77499	Instrumented	2013 - present	Operated by IDWR
20N 23E 03CBA2[1]	45.09077	-113.72743	Instrumented	2011 - present	Operated by IDWR
20N 23E 10ABA1[1]	45.08403	-113.71750	Non-Instrumented	2015 - present	Operated by WD74
20N 23E 11ADD1,2	45.07869	-113.69151	Instrumented	2016 - present	Operated by IDWR
20N 23E 11DBB2	45.07689	-113.69850	Instrumented	2016 - present	Operated by IDWR
20N 23E 11DBB1	45.07641	-113.69766	Instrumented	2016 - present	Operated by IDWR

20N 23E 14DDB1[1]	45.05836	-113.69347	Instrumented	2015 - present	Operated by IDWR
20N 23E 24CDD1[1]	45.04268	-113.68028	Non-Instrumented	2015 - present	Operated by WD74
20N 23E 25DAB1	45.03343	-113.67259	Non-Instrumented	2015 - present	Operated by WD74
20N 24E 31DDC1	45.01276	-113.65267	Instrumented	2013 - present	Operated by IDWR
19N 24E 17BBB1[1]	44.98321	-113.64745	Non-Instrumented	2015 - present	Operated by WD74
19N 24E 30AAA2[1]	44.95454	-113.64964	Instrumented	2015 - present	Operated by IDWR
19N 24E 28ABB2[1]	44.95342	-113.61718	Non-Instrumented	2015 - present	Operated by WD74
19N 24E 29BDA1[1]	44.95087	-113.63946	Instrumented	2015 - present	Operated by IDWR
19N 24E 32ADC1[1]	44.93372	-113.63255	Instrumented	2013 - present	Operated by IDWR
18N 24E 16BBB1[1]	44.89499	-113.62826	Non-Instrumented	2011 - present	Operated by WD74
18N 24E 20ADD1	44.87690	-113.62498	Instrumented	2011 - present	Operated by IDWR
18N 24E 21BCD1[1]	44.87607	-113.62916	Instrumented	2011 - present	Operated by IDWR
18N 24E 28DCC3[1]	44.85399	-113.61804	Non-Instrumented	2015 - present	Operated by WD74
17N 24E 04ADC1[1]	44.84722	-113.61015	Instrumented	2015 - present	Operated by IDWR
18N 24E 31ACD1[1]	44.84654	-113.64959	Instrumented	2015 - present	Operated by IDWR
18N 24E 33ACB1[1]	44.83354	-113.60230	Instrumented	2013 - present	Operated by IDWR
17N 24E 13CBD1[1]	44.80042	-113.55596	Instrumented	2015 - present	Operated by IDWR
16N 25E 03BCC1[1]	44.74601	-113.47765	Instrumented	2011 - present	Operated by IDWR
16N 25E 18BBC1[1]	44.72115	-113.53810	Instrumented	2011 - 2019	Discontinued
16N 26E 21ACA1[1]	44.70572	-113.35900	Non-Instrumented	2015 - present	Operated by WD74
16N 25E 20BDD1[1]	44.70349	-113.51018	Instrumented	2015 - present	Operated by IDWR
16N 26E 21CAC1[1]	44.69963	-113.36721	Instrumented	2011 - present	Operated by IDWR
16N 26E 20CDD1	44.69631	-113.38594	Instrumented	2013 - present	Operated by IDWR
16N 26E 26ABB1[1]	44.69349	-113.32314	Non-Instrumented	2015 - present	Operated by WD74
16N 26E 26DBB1[1]	44.68739	-113.32330	Non-Instrumented	2015 - present	Operated by WD74
16N 26E 26CBC1	44.68470	-113.33335	Non-Instrumented	2018 - present	Operated by WD74
16N 26E 27CAC1[1]	44.68399	-113.34880	Non-Instrumented	2012 - present	Operated by WD74
16N 26E 27CCB1	44.68380	-113.35352	Instrumented	2015 - present	Operated by IDWR
15N 26E 09ADD2[1]	44.64458	-113.35482	Non-Instrumented	2015 - 2016	Discontinued

[1]Data set includes 1997 - 1998 measurements from Donato (1998) study.

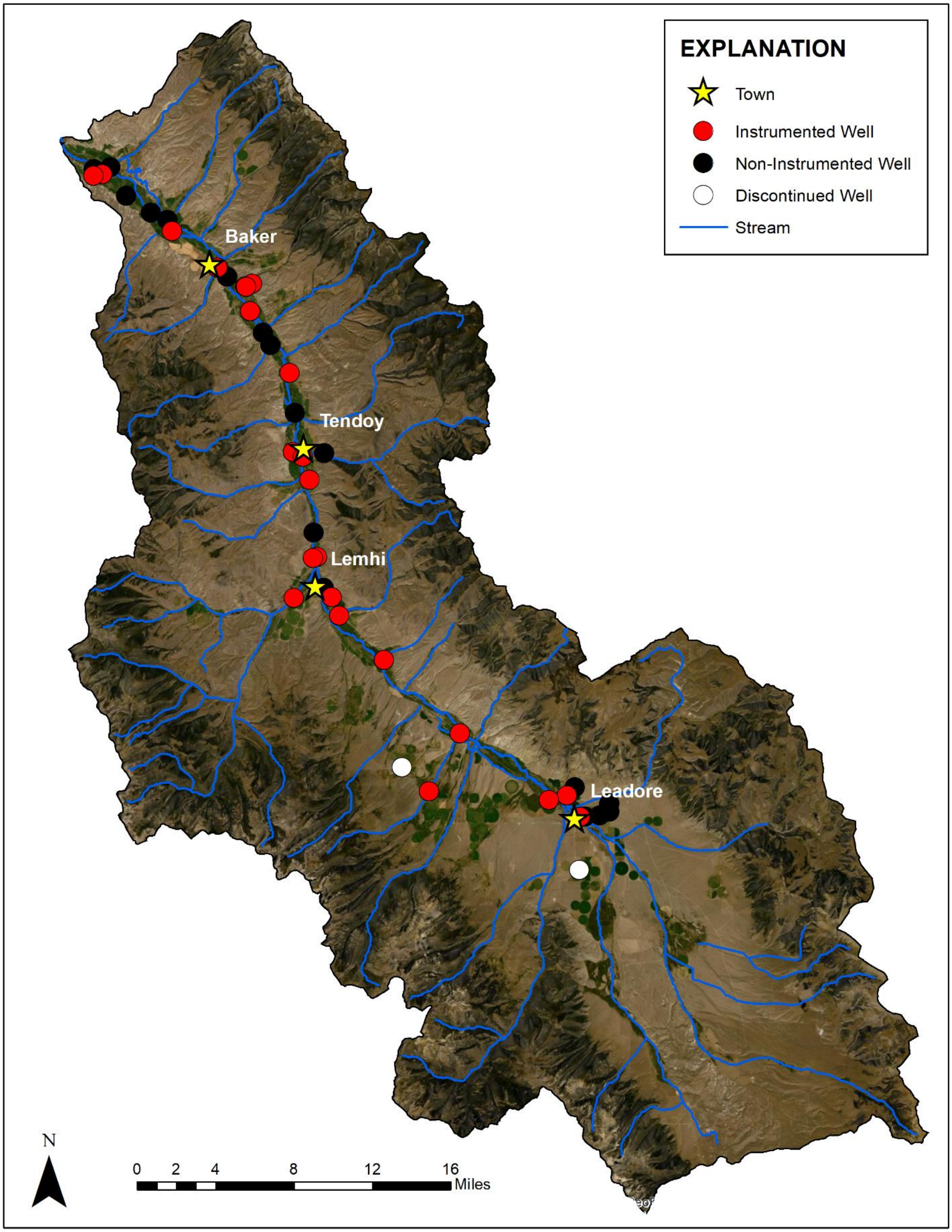

Figure 5. Lemhi River Basin Groundwater Level Monitoring Network

Soil Moisture Data Collection

During previous phases of this investigation, IDWR installed soil moisture stations in agricultural fields undergoing changes to irrigation practices, as well as adjacent to in-stream habitat improvement projects known as beaver dam analogues (BDAs). The soil moisture stations in agricultural fields are being used to improve our understanding of infiltration dynamics before and after conversion from flood to sprinkler irrigation. The stations installed adjacent to BDAs help us to understand the impacts of these projects on streamflow, as well as exchanges between groundwater and surface water.

Soil moisture sensors were placed at multiple depths (and sometimes multiple locations) at each soil moisture station. This was done to enable future spatiotemporal analysis of the nature of infiltration and potential for groundwater recharge in the basin. For example, groundwater recharge may be occurring in instances when every soil moisture sensor at a station (up to 5 ft deep) shows saturated conditions. Conversely, groundwater recharge is less likely in instances when only the first couple feet of soil wet up and deeper soil remains dry.

The Lemhi River Basin Soil Moisture Monitoring Network consists of four active soil moisture monitoring stations, and four discontinued stations (Table 3, Figure 6). Two active Stations are located within agricultural fields near Pratt Creek, while the other two are located adjacent to BDAs on Hawley Creek (Table 3, Figure 6). The Agricultural Stations contain one soil moisture pit each, while both of the BDA Stations contain two soil moisture pits (one near the stream and one further away). Each Station has been visited within the past six months to download data and maintain the equipment. None of the public IDWR databases currently support soil moisture data; however, it is available upon request. In addition, IDWR will make soil moisture data available to the public by February 1, 2021 via the project website at https://idwr.idaho.gov/water-data/projects/upper-salmon/references.html.

Table 3. IDWR Soil Moisture Stations within the Lemhi River Basin

Soil Moisture Stations	Latitude	Longitude	Data Range	Status	Sensor Depths (ft)
Hawley Creek BDA5	44.65845	-113.22092	2017 - present	Active	1, 3, 5
Hawley Creek BDA4	44.65838	-113.22190	2017 - present	Active	1, 3, 5
SnookF1	45.08319	-113.68627	2016 - present	Active	0.5, 1, 2, 3, 4, 5
SnookF2	45.07860	-113.69111	2016 - present	Active	0.5, 1, 2, 3, 4, 5
TylerK	44.69187	-113.39346	2012 - 2018	Discontinued	0.5, 1, 2, 3, 4, 5
SnookQ	45.03385	-113.67143	2014 - 2018	Discontinued	0.5, 1, 2, 3, 4, 5
Mulkey1	45.07788	-113.70005	2016 - 2018	Discontinued	0.5, 1, 2, 3, 4, 5
Mulkey2	45.07818	-113.70452	2016 - 2018	Discontinued	0.5, 1, 2, 3, 4, 5

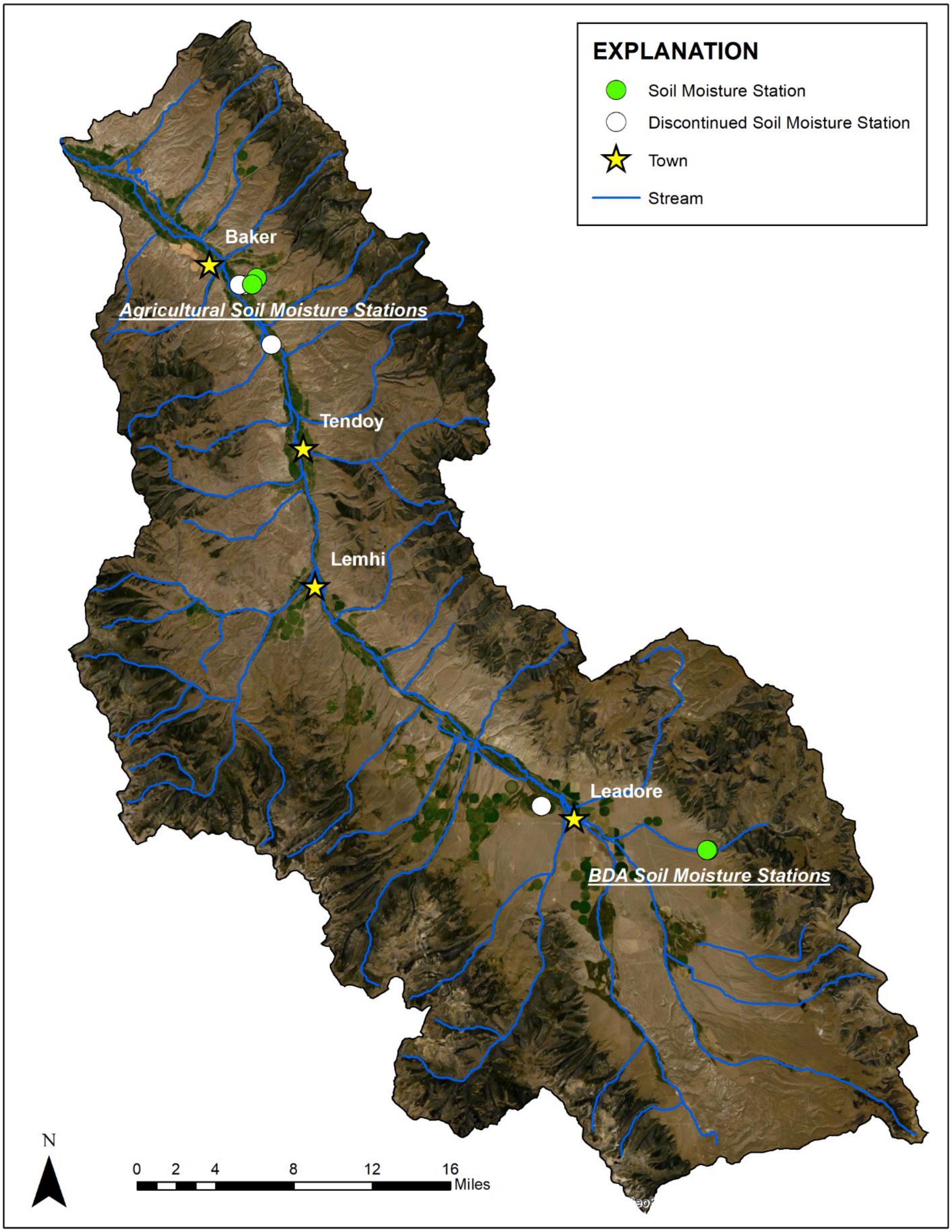

Figure 6. Lemhi River Basin Soil Moisture Monitoring Network

Aerial Photograph Analysis of Changes in Irrigation Practices

Many irrigators in the Lemhi Basin have been transitioning from flood to sprinkler irrigation in recent years as a result of increased crop growth efficiency and additional financial incentives. Due to significant changes in total application of water and associated changes to evapotranspiration, infiltration, and return flows, it is known that conversion from flood to sprinkler irrigation (or vice versa) has significant impacts on the hydrogeology of the basin. However, the scope of the impacts to basin hydrology and in-stream habitat are as of yet poorly understood.

During this project phase, data on acreage of flood/sprinkler irrigation was manually updated within the Lemhi River Basin Model database to include the changes that are known to have occurred over the past five years. Information on the location and acreage of lands irrigated via flood and sprinkler methods is now available in the LRBM Diversion Atlas (see "Lemhi River Basin Model Interactive Tools"). Although this analysis does not provide a thorough understanding of historical irrigation practices, it does inform us of recent changes, as well as the current state of irrigation practices.

In addition to updating information on irrigation practices, Dr. Carter Borden of Centered Consulting International, LLC (CCI) and IDWR completed preliminary hydrologic modeling analyses to begin to determine the impacts of irrigation conversions on upper Lemhi River streamflow. The Lemhi River Basin Model was used to generate two modelled scenarios: one featuring baseline conditions (2020 irrigation practices) and one featuring conversion of all flood irrigation to sprinkler irrigation. The analysis assumed that all sprinkler irrigation is 100% consumptive.

The output LRBM Lemhi River streamflow values were then plotted on a longitudinal profile of the Lemhi River stemming from the headwaters to Hayden Creek (Figure 7). The preliminary results suggest that the early irrigation season (May) sees additional streamflow when only sprinkler irrigation is used, while late irrigation streamflow (October) is reduced. This trend is not ideal, as the late irrigation season typically produces less streamflow in the Lemhi River. Not only is this detrimental to salmonids in instances when lower basin streamflow (e.g. L-1 diversion) is greatly reduced, but minimum streamflow requirements may be breached more frequently, leading to increased curtailment of water rights. Conversations with water users and the USBWP Tech Team, as well as research efforts regarding how to mitigate for the potentially undesirable late irrigation season impacts of flood to sprinkler conversions are ongoing.

Due to unforeseen issues, IDWR was not able to complete the originally proposed aerial photograph analysis during the current project period. Although the analyses completed during this phase lead to a better understanding of current irrigation practices, a more robust depiction of historical changes in irrigation practices is necessary to improve our understanding of LRB hydrogeology. IDWR will complete the remaining analyses during Phase 5 of this project, and report on the results in the final report.

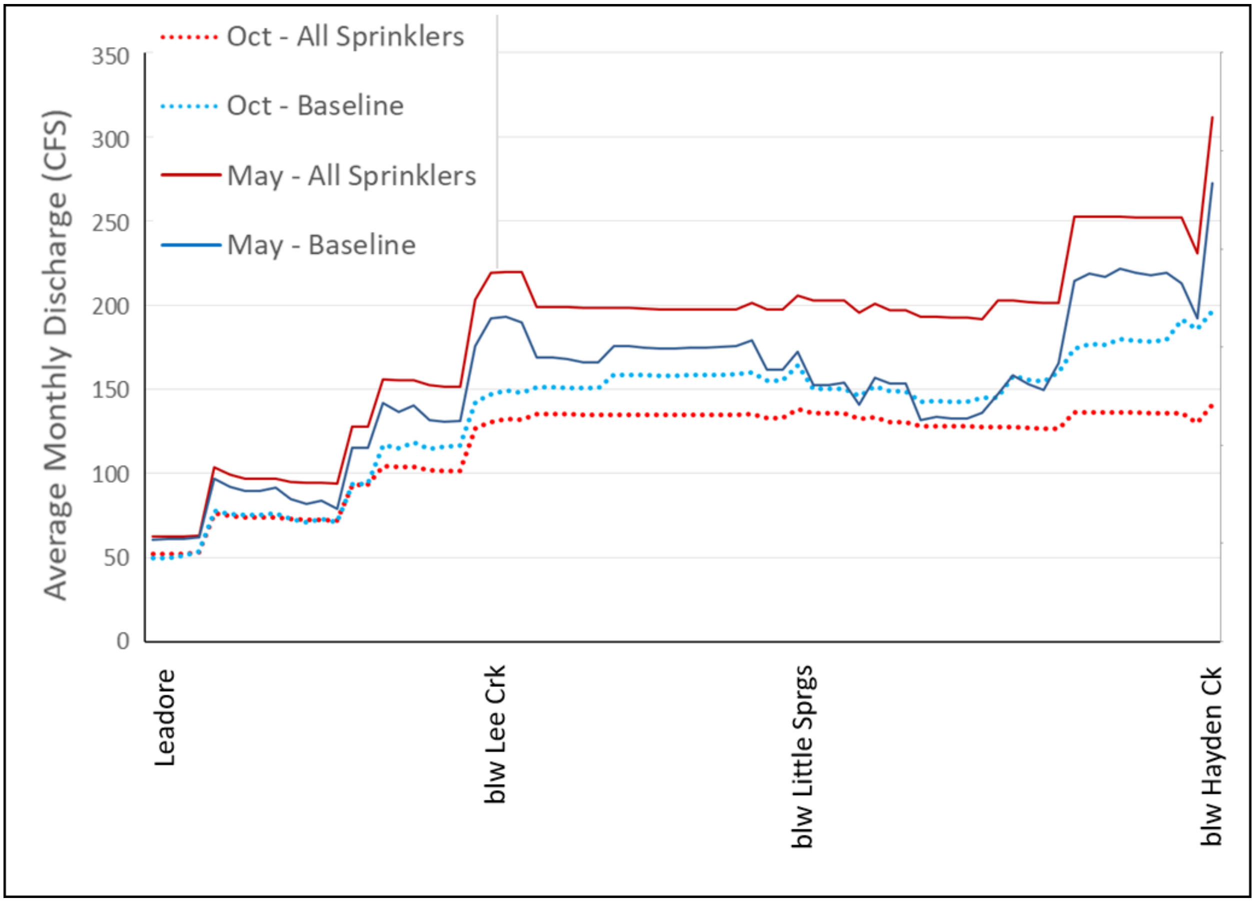

Figure 7. Streamflow profiles for preliminary LRBM irrigation practice scenarios.

Status of the Lemhi River Basin Model

The Lemhi River Basin Model (LRBM) has been maintained by IDWR and Centered Consulting International, LLC (CCI) from 2006 to present. A summary of updates includes

1. Updated NAM Rainfall-Runoff model to include data through water year 2019
2. Began migrating the LRBM from the DHI's MIKE BASIN (v2012) (MB) to DHI's MIKE HYDRO BASIN (v2020) (MHB)
3. Consulted with stakeholders to assess model user needs and aid development of modelling tools
4. Developed public modelling tools to aid stakeholders in project development and assessment
    a. LRBM Diversion Atlas
    b. LRBM Scenario Submission Form
    c. LRBM Scenario Report
    d. LRBM Habitat Tool
    e. LRBM Streamflow Threshold Calculator

Background

The LRBM was developed by the IDWR for evaluating diversion operations and tributary reconnections in the Lemhi River Basin (DHI, 2006). The LRBM includes a rainfall-runoff model to predict inflow to the system and a river basin model to route water in the stream network and account for irrigation. Supporting the LRBM are several MS EXCEL workbooks that aid in inputting time series data for catchments and irrigation nodes as well as extracting, analyzing, and reformatting simulation output results for evaluating water management scenarios. Collectively, the LRBM and ancillary tools are used by the Upper Salmon Basin Watershed Program and other stakeholders as a common framework for understanding the hydrology and water allocation in the basin.

The LRBM was developed using MIKE HYDRO BASIN (MHB): a geographic information systems (GIS) based water allocation software package developed by the DHI Water and Environment (DHI) to support water management planning in river basins. MHB uses polygons to represent catchment inflow and groundwater storage (lumped conceptual), branches to route water, and nodes to account for water as well as represent different uses of water. The software simulates the system's performance by calculating water mass balance at every node and routing water between nodes via branches. Results from the model are viewed as a time series of any computational component (e.g. river flows, groundwater storage volumes, deficits for water users). Though conceptually simple, river basin accounting models allow water managers to rapidly investigate management alternatives associated with different diversion operations, crop irrigation/rotation methods, and an understanding of how return flows influence stream flows in response to irrigation practices.

In the LRBM, catchment runoff is represented by 85 subcatchment polygons (Figure 8) that require a catchment runoff time series. As the majority of the tributary streams in the model are ungauged, DHI's Nedbør-Afstrømnings-Model (NAM) which is a module within MHB, was used to estimate inflow into ungauged tributaries. NAM is a lumped conceptual rainfall-runoff model for simulating streamflow based on precipitation and evapotranspiration at a catchment scale. NAM operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow, and baseflow (DHI, 2003). As NAM is a lumped model, it treats each subcatchment as one unit thus parameters are considered to represent average values for the entire subcatchment. Precipitation in the form of snow is modelled as a fourth storage unit. For catchments with snow falling over a wide elevation range, the storage unit representing snow can be divided up into subunits to represent different elevation zones. The result is a continuous time series of the runoff from the catchment throughout the modelling period. Thus, the NAM model provides both peak and base flow conditions that account for soil moisture conditions over the simulation period. The LRBM-NAM modelled catchment inflow is calibrated to measured streamflow at gauged locations (Table 1, Figure 4), and streamflow on ungauged streams is calibrated using information from nearby and/or hydrologically similar streams. Finally, LRBM-NAM streamflow values in ungauged locations were compared to monthly streamflow values computed using the U.S. Geological Survey StreamStats tool (https://streamstats.usgs.gov/ss/) as a quality check.

NAM Rainfall-Runoff Model Update

As stated, NAM is a lumped conceptual model of the hydrologic system with 9 state parameters representing the storage in the surface zone, root zone, and groundwater as well as the rate and timing of exchange between these storage reservoirs. Required time series input includes precipitation, temperature, and potential evapotranspiration and, for calibration, stream gauge data. In the LRBM, these parameters are typically derived from empirically-based approximations, and then tweaked during calibration until modelled streamflow values reasonably approximate measured streamflow values (Table 1, Figure 4). For ungauged catchments, parameters from a gauged catchment of similar physical characteristics and land use are used in combination with catchment specific precipitation, temperature, and potential evapotranspiration. The result of the calibration process is a time series of runoff for each catchment through the simulation period.

Methods for deriving the LRBM NAM input data have varied considerably over the years. Previously, Snotel snowpack and PRISM precipitation data were combined to create the input data (IDWR, 2019). While that method represented the headwater stream catchments well, it poorly accounted for the valley catchments (IDWR, 2019). In an effort to improve the pediment and valley catchment inflow estimations, the climate input data has been updated to use the PRISM and gridMET databases from the Climate Engine (app.climatechange.org/climateEngine) for each of the 85 individual catchments within the LRBM. The datasets were significantly different from the older datasets; however, efforts to evaluate the resultant differences in NAM streamflows are ongoing.

The new NAM input data was used to update the NAM model through water year 2019 (previously 2005 through 2017), and to enable the model to run scenarios back to 1981 (1981 to 2019 in total). Despite the increased temporal scope of the model, it is important to note that it is likely to produce less accurate results when measured streamflow and diversion data is lacking, as this data is needed for calibration. Unfortunately, there are few streamflow measurements on Lemhi tributaries (Table 1) or recorded diversion rates predating 2005. Nevertheless, there is a U.S. Geological Survey stream gauge near Lemhi, Idaho (USGS 13305000 LEMHI RIVER NR LEMHI ID) that could be used to calibrate the model back to 1981 if a stakeholder needed to analyze a longer time series.

Although the new NAM input datasets appear to improve NAM model performance in some cases, efforts to further improve calibration are ongoing. For example, Dr. Borden recently noted that changing the size and shape of some of the catchments (Figure 8) may be in order. While the headwater catchments were drawn to accurately reflect the surface water drainage characteristics of the Lemhi Basin, it appears as though some of the pediment (e.g., rock debris slope) catchments were not. The sizes and shapes of some of the pediment catchments will be altered within the next project phase, and it is believed that this will improve the performance of the NAM Rainfall-Runoff model, and therefore the LRBM as a whole.

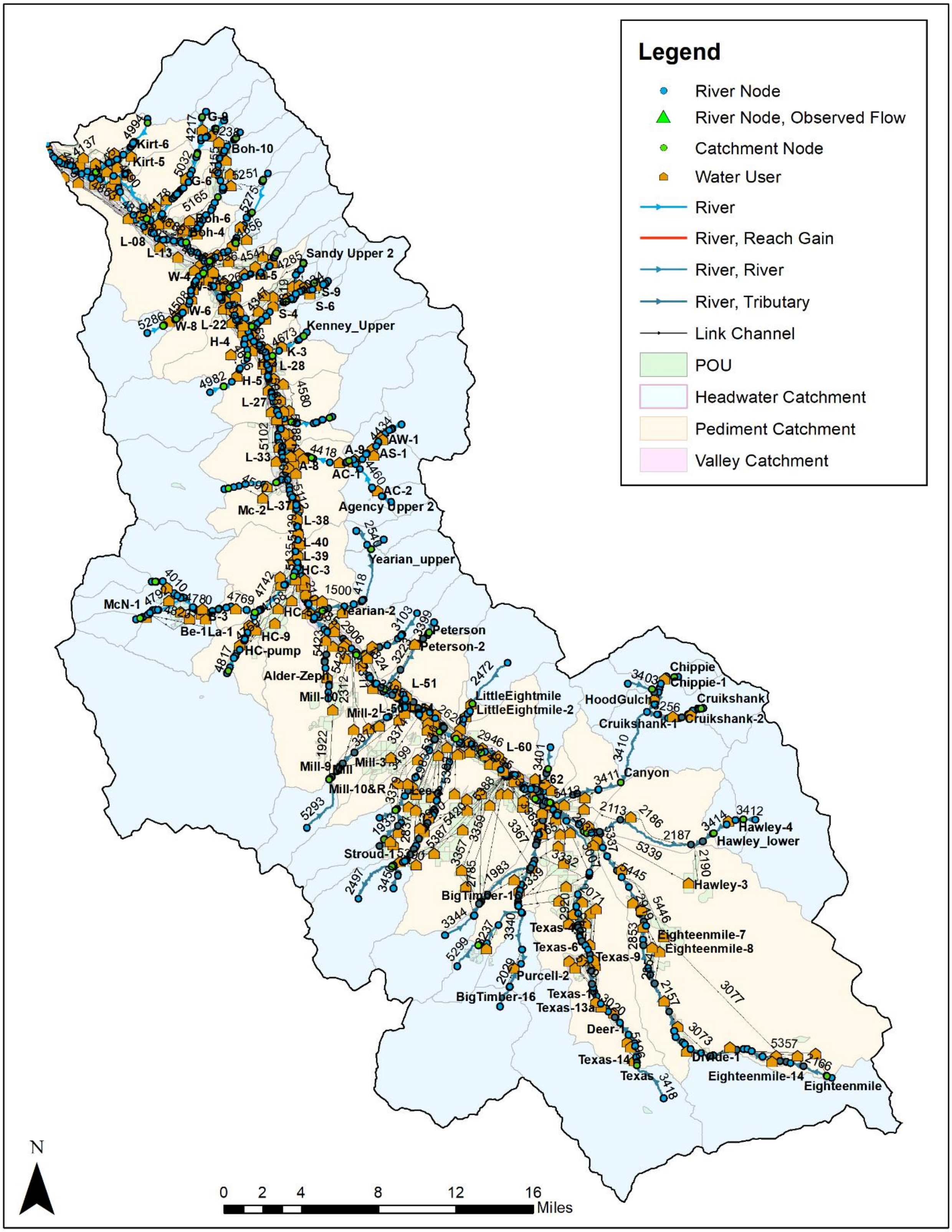

Figure 8. Node-Link Diagram of the Lemhi River Basin Model

Migration of the LRBM to MIKE HYDRO BASIN

The MIKE BASIN (v2012) (MB) software being used by CCI and IDWR at the onset of this project phase was outdated and no longer supported by DHI. Based on an evaluation of MIKE HYDRO BASIN (MHB) v2020, it was recommended that the LRBM should be migrated to the current software (see “Task 4” in “OBJECTIVES”). Below are a few of the reasons for this migration:

1) Danish Hydrologic Institute (DHI), the developers of MIKE modelling software, no longer support MIKE BASIN v2012, but they do support MHB v2020. Using MHB allows CCI and IDWR to take advantage of the increased functionality of the new modelling software, and also program the LRBM to interact with newer versions of external software (e.g. MS Excel Workbook files). Use of MHB also allows for DHI technical support.
2) MHB has embedded GIS features/functionalities, while MIKE BASIN is a module build in ArcGIS v10.1. These features may expedite the creation of LRBM model visualization tools, and they also remove the need for stakeholders to pay for a separate ArcGIS license.
3) MHB comes equipped with a Stakeholder Add-on that allows for the creation of an interactive layer on top of the LRBM that would allow interested parties to interact directly with model outputs without the need for technical support from a modeler. This feature may be used to improve the functionality of the MIKE BASIN Integration Tool (see “Task 4” in “OBJECTIVES”) moving forward.

The task of migrating the LRBM to the MHB platform is now approximately 50% complete, so work on this task will continue into the next project phase. At present, the iteration of the LRBM that exists within MIKE BASIN v2012 is fully operational and has been used to run all model scenarios requested to date. The current state of the LRBM migration is further detailed below.

MHB licenses were purchased and keys were distributed to CCI and IDWR personnel in August, 2020. This step was necessary to allow for testing of model migration methods. Following the purchase of MHB software, methods for migrating models were investigated, and the Carmen Creek River Basin Model (CCRBM) was migrated to MHB. The CCRBM is a simpler model than the LRBM, and provided a case study to help identify and troubleshoot issues that may arise during migration of the more robust LRBM. Unfortunately, MHB no longer supports the DHI dfs0 (DHI’s proprietary data storage files) to MS Excel links that were developed for the LRBM within the older MIKE BASIN v2012 software. Without these links, it was impossible for the new MHB software to read/write to and from the MS Excel spreadsheets that housed both the LRBM input data and the automated data and analysis tools that had been developed for LRBM output data. To overcome this issue, CCI and IDWR developed a data transfer bridge (by merging VBA and Python codes) to embed in the LRBM input and output Excel files. During this process, the MS Excel files for water user model input were streamlined and combined with the return flow calculator for diversions using the CH2M analytical solutions (CH2MHill, 2014). This effort decreased the file size, made it easier to modify and view input time series, and consolidated the water demand and return flow MS Excel files into a single file.

Lemhi River Basin Model Interactive Tools

A series of interactive tools were created to enable stakeholders to interact directly with LRBM input and output data, as well as generate data analyses and visualizations without the need for modelling or programming skills. Each of the tools consists of MS Excel spreadsheets containing a variety of check boxes and/or drop down menus to facilitate the selection of options by stakeholders. At the conclusion of this project phase, all of the tools are ready for use, albeit in prototype form. Increasingly robust versions of these tools will be released during the next project phase to better match stakeholder needs.

LRBM User Needs Assessment

In December, 2019, CCI and IDWR conducted a series of interviews with members of the Tech Team to better assess their data and analysis needs. Following the meeting, a working group was formed to foster more frequent discussion of the ever-changing needs of stakeholders and the development of publically-available interactive modelling tools that would aid in-stream habitat and water-related project development and assessment. Since then, lessons learned from working group discussions have informed the build out of several interactive modelling tools. The tool suite now includes the LRBM Diversion Atlas (view LRBM input data), the LRBM Scenario Submission Form (rapidly submit LRBM scenarios and the desired outputs), and the LRBM Scenario Report (presents data, analyses, and data visualizations from submitted model scenarios). Additional, more specialized tools include the LRBM Habitat Tool and the LRBM Streamflow Threshold Calculator. A brief description of each component of the tool suite is provided below.

LRBM Diversion Atlas

Based on data in the updated water user input file (see "Migration of the LRBM to MIKE Hydro Basin" in "Status of the Lemhi River Basin Model"), the LRBM Diversion Atlas was created. This database is intended to act as a common platform for researchers and stakeholders to view, retrieve, and update Lemhi Basin hydrologic information (Figure **9.** Lemhi River Basin Model Diversion Atlas (Page One)
9, Figure 10). For all diversions in the LRBM, the Atlas provides the following:

A) Diversion name, LRBM ID, point of diversion location, water district, and tributary.
B) Water rights information.
C) Ditch capacity (where known), as well as the maximum and average diversion rate.
D) Consumption calculation parameters including irrigated area, crop type (grass, alfalfa, pasture), and irrigation method (sprinkler versus flood).
E) Water demand time series, consumption rate, and return flow lag factor for the LRBM.
F) LRBM water demand and return flow time series file names.
G) Miscellaneous notes on diversion operations and requirements.

The LRBM Diversion Atlas Page One (Figure 9) provides dropdown menus for user input (data source and diversion of interest) at the top of the MS Excel Sheet. Once the user has made their selections, the sheet automatically generates hydrographs and exceedance probability curves to inform the user about historical diversion rates, water consumption, water right information, and water right amounts. The LRBM Diversion Atlas Page Two (Figure 10) provides the user with additional information about the irrigation type, land cover type, irrigated area, diversion ditch capacity, historic diversion records, days in operation, and more in the form of tables and a figure.

Though the LRBM Diversion Atlas is largely complete, a few items require additional attention. The Atlas currently presents the LRBM water right and agricultural practices from the 2010 data collection effort; thus it will need to be updated to include more current data. The Atlas is also being reviewed by several Tech Team members, and further modifications may be required to meet stakeholder needs.

Lemhi River Basin Model - Diversion Atlas

Diversion Summary

Summary

Source	Upper Lemhi River	Local Name	Ditch: W972	LRBM POU Nodes	N15	
Diversion	L-51	IDWR Ref No.	13304640	LRBM POD Nodes	W972	L-51
Tributary To	Lemhi River	POD Latitude	45.1111N			
Water District	WD74	POD Longitude	118.2222W			

Update Diversion Information

Operational Overview

Water Rights [cfs]	6	High Water Right [cfs]	6	Ave. Diversion Rate [cfs]	2.60	Max. Diversion Rate [cfs]	6.00

Water Rights

No. of Water Rights	2	Total Irrigated Area [ac]	39	Total Max Diversion Rates [cfs]	6

	No.	Owner	Priority Date	Max Rate [cfs]	Irrigated Area [ac]	Notes
1	74-1632	ROBERT B AMONSON	1885.11.23	1.17	0	
2	74-15159	LEMHI IRRIGATION DISTRICT	1966.03.15	3.4	0	
3						
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Page 1

Figure 9. Lemhi River Basin Model Diversion Atlas (Page One)

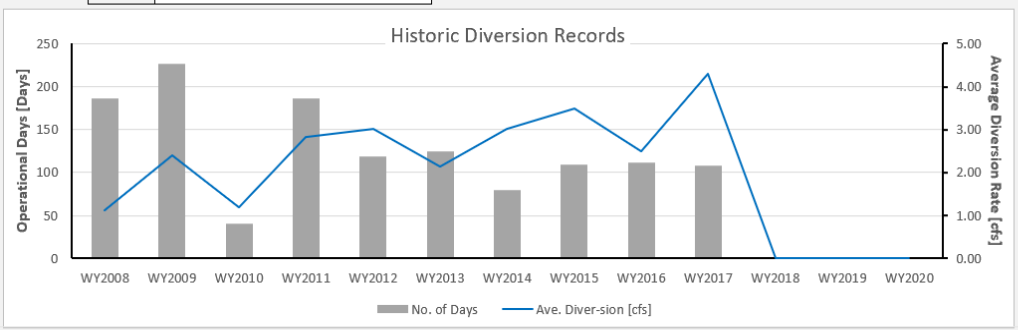
Lemhi River BASIN Model - Diversion Atlas

Diversion: L-51

Agricultural Practices

Irrigated Area [ac]	39	Ditch Capacity [cfs]/Source		6.12	Screen			Note	0		
Method	Flood	Alfalfa	Pasture	Grass		Sprinkler	Alfalfa	Pasture	Grass		
LRBM	100%	0%	100%	0%	[%]	0%	0%	0%	0%	[%]	

Demand Record	Data Type	No. of Days	Ave. Diver-sion [cfs]	ET [mm]	Flood	Flood: Alfalfa	Flood: Grass	Flood: Pasture	Sprinkler	Sprinkler : Alfalfa	Sprinkler : Grass	Sprinkler : Pasture
WY2008	Data	186	1.13	186	100%	0%	100%	0%	0%	0%	0%	0%
WY2009	Data	227	2.40	227	100%	0%	100%	0%	0%	0%	0%	0%
WY2010	ND	41	1.18	41	100%	0%	100%	0%	0%	0%	0%	0%
WY2011	Data	186	2.83	186	100%	0%	100%	0%	0%	0%	0%	0%
WY2012	Data	119	3.01	119	100%	0%	100%	0%	0%	0%	0%	0%
WY2013	Data	125	2.14	125	100%	0%	100%	0%	0%	0%	0%	0%
WY2014	Data	80	3.02	80	100%	0%	100%	0%	0%	0%	0%	0%
WY2015	Data	109	3.49	109	100%	0%	100%	0%	0%	0%	0%	0%
WY2016	Data	112	2.49	112	100%	0%	100%	0%	0%	0%	0%	0%
WY2017	Data	108	4.31	108	100%	0%	100%	0%	0%	0%	0%	0%
WY2018		0		0	100%	0%	100%	0%	0%	0%	0%	0%
WY2019		0		0	100%	0%	100%	0%	0%	0%	0%	0%
WY2020		0		0	100%	0%	100%	0%	0%	0%	0%	0%
Average	0.00	99.46	2.60	99.46								
Max.	0.00	227.00	4.31	227.00								



Days in Operation

Month	2008	2009	2010	2011	2012	2013	2014	2015	2015	2016	2018	2019	2020	Average
Jan	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Feb	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Mar	3	3	0	3	0	0	0	0	0	0	0	0	0	0.7
Apr	30	30	0	30	0	0	0	0	0	0	0	0	0	6.9
May	31	31	0	31	0	0	0	0	0	0	0	0	0	7.2
Jun	30	30	0	30	27	23	10	18	25	20	0	0	0	16.4
Jul	31	31	0	31	31	31	31	31	31	31	0	0	0	21.5
Aug	31	31	0	31	31	31	31	31	31	31	0	0	0	21.5
Sep	30	30	0	30	30	30	3	29	25	26	0	0	0	17.9
Oct	0	31	31	0	0	10	5	0	0	0	0	0	0	5.9
Nov	0	10	10	0	0	0	0	0	0	0	0	0	0	1.5
Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Average	26.1	30.6	4.4	26.1	17.0	17.9	11.4	15.6	16.0	15.4	0.0	0.0	0.0	13.9

Average Monthly Diversion Rate

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Average
Jan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feb	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mar	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Apr	0.3	1.2	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
May	0.8	3.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Jun	1.2	3.5	0.0	3.4	4.2	4.1	2.0	3.4	3.8	3.8	0.0	0.0	0.0	2.3
Jul	1.7	3.4	0.0	4.2	3.3	2.4	4.2	4.8	2.6	5.1	0.0	0.0	0.0	2.4
Aug	1.7	3.3	0.0	3.6	2.3	1.3	1.6	3.0	1.5	3.9	0.0	0.0	0.0	1.7
Sep	1.1	2.9	0.0	3.1	1.9	0.9	0.1	1.2	1.3	2.4	0.0	0.0	0.0	1.1
Oct	0.0	0.5	1.5	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Nov	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Dec	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Average	1.0	2.5	0.2	2.5	1.7	1.3	1.1	1.8	1.3	2.2	0.0	0.0	0.0	1.2

Page 2

Figure 10. Lemhi River Basin Model Diversion Atlas (Page Two)

LRBM Scenario Submission Form

Historically, the process of requesting that hydrologic scenarios be run on the LRBM has been lengthy (weeks), as LRBM functionality has been poorly understood by stakeholders (Tech Team, state agencies, federal agencies, nonprofits) and model outputs had to be customized to match each request. However, certain aspects of the scenario request process could be modified to increase the efficiency of this process and deliver more useful LRBM outputs. The LRBM Scenario Submission Form is part of an effort to do just that.

The LRBM Scenario Submission Form is a MS Excel spreadsheet that is intended to streamline the process by which stakeholders convey information to the modelers about what sort of changes to the system are being proposed (e.g. new diversion or water transaction), and what sort of data and analyses are needed to evaluate the impacts of the proposed changes (Figure 11). The LRBM Scenario Submission Form is a simple form, but the process of filling it out helps with both stakeholder-to-modeler communication and stakeholder understanding of the types of scenarios that can be evaluated using the LRBM (e.g., what types of input data can be tweaked to run altered state scenarios) and what sorts of LRBM results and analyses can be produced. Given this information, it's easier for stakeholders to submit LRBM scenario requests that match their needs, resulting in time and energy savings for both the modelers and the model users.

LRBM Scenario Input Form					
	Scenario:	Transfer of water rights from Hawley-4 to Big Timber Creek - 5			
	Requested By	Ryan Warden			
	Date:	17-Aug-18	**Date Returned**	23-Aug-18	
	Description:	Proposed is the transfer of water rights from Hawley-4 to Big Timber-5. Of interest is the impact to flow reliablity and impact to bull trout migration and steel head rearing and migration			
Scenarios					
Proposed Actions		**Name**	**LRBM Name**	**Alteration**	
A1	**Transfer**	Bear Creek - 1	Hawley-4	Eliminate	✔
A2	**Transfer**	Big Timber -5	Big Timber -6	Increase diversion rate by 2 cfs	✔
A3					
A4					
A5					
Climate		**Conditions**		**Description**	
	Climate Type	Average			✔
Output Format					
Hydrology		**Start**	**End**		
L1	**Longitudinal Profile 1**	u/s Bear Creek-1	Confl w/		✔
	LRBM Equivalent	E435	E447		
L2	**Longitudinal Profile 2**		Confl w/		
	LRBM Equivalent				
L3	**Longitudinal Profile 3**	u/s Bear Creek-3	Confl w/		
	LRBM Equivalent				
		Name	**LRBM Name**		
D1	**Discharge Freq. 1**	u/s Bear Creek-1	E435		✔
D2	**Discharge Freq. 2**	d/s Bear Creek-1	E436		✔
D3	**Discharge Freq.3**				
Fish Output		**Species**	**Life Stage**		
S1	**Species 1**	Bull trout	Rearing		✔
S2	**Species 2**	Bull trout	Migration		✔
S3	**Species 3**	Steelhead	Migration		✔
S4	**Species 4**				
		Start	**End**		
F1	**Longitudinal Profile 1**	u/s Bear Creek-1	Confl w/		✔
	LRBM Equivalent	E435	E447		
F2	**Longitudinal Profile 2**		Confl w/		
	LRBM Equivalent				
F3	**Longitudinal Profile 3**	u/s Bear Creek-3	Confl w/		
	LRBM Equivalent				
		Name	**LRBM Name**		
H1	**Habitat Reliablity 1**	u/s Bear Creek-1	E435		✔
H2	**Habitat Reliablity 2**	d/s Bear Creek-1	E436		✔
H3	**Habitat Reliablity 3**				

Figure 11. Lemhi River Basin Model Scenario Submission Form

LRBM Scenario Report

The LRBM Scenario Report is a suite of MS Excel spreadsheets designed to automate conveyance of the most commonly requested LRBM output data and analyses to stakeholders. It is also an interactive tool that allows stakeholders to modify the LRBM scenarios of interest, the timeline of interest, and the stream reach or diversion of interest. Model users can explore the breadth of LRBM output results, without employing modeling or programming skills. For example, a stakeholder may use this tool to evaluate the result of a requested LRBM scenario and discover an unexpected issue with the implementation of their in-stream habitat project. In this example, because the issue wasn't previously considered, it is unlikely that the stakeholder would've requested that the modelers conduct the analyses necessary to discover the issue. However, because the LRBM Scenario Report is interactive, the stakeholder had an opportunity to further explore the hydrologic implications of their proposed project. This is an example of why an interactive tool may be more effective at aiding in planning and evaluation of projects than a simple suite of analyses deemed most important by the modelers. After all, modelers are bound to be less familiar with the intricacies of the project than the project planner/manager requesting the LRBM scenario.

The LRBM Scenario Report has been initially developed for Big Timber Basin, a subcatchment of the Lemhi River Basin; however, the same suite of tools can be ported to other basins upon request. LRBM Scenario Report tools currently include the following:

A) Hydrographs of NAM Rainfall-Runoff Model generated inflows (Figure 12), LRBM modelled streamflow, historical cumulative diversion amounts, and cumulative water right amounts.
B) Water right curtailment calculator that indicates the delivery/deficit for each point of diversion.
C) Longitudinal profiles of modelled streamflow (streamflow plotted at each node along a stream, including tributary intersections and diversions), as well as longitudinal profiles of U.S. Bureau of Reclamation physical habitat simulation (PHABSIM) minimum streamflow targets (Sutton and Morris, 2004) for Chinook salmon, steelhead, and bull trout habitat during spawning, juvenile, rearing, and adult life stages (Figure 13). This tool features a slide bar to adjust the timeline.
D) Monthly streamflow exceedance probability hydrographs and longitudinal profiles with a dropdown menu to select the month of interest.
E) LRBM outflow hydrographs displaying discharge and water delivery/deficit for each point of diversion (drop down menu to select diversion of interest) along the stream (Figure 14).
F) Water rights compliance calculators that use minimum and maximum streamflows at all stream gauge locations impacting a water right to calculate and visualize the days in compliance.
G) A salmonid habitat evaluation tool that plots streamflow (baseline or scenario) against PHABSIM minimum streamflow targets (suitable for a variety of salmonid life stages) and informs when those flow targets are met.

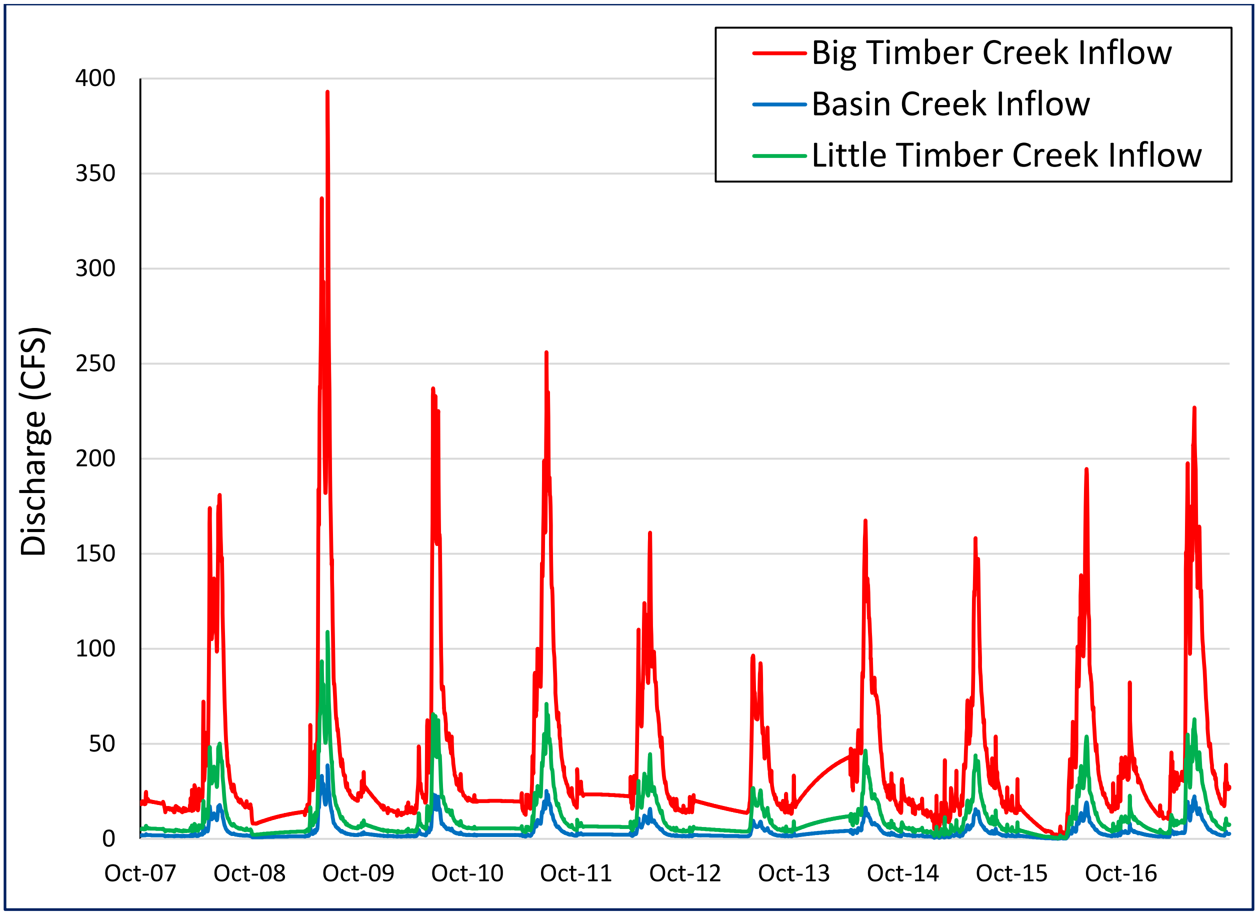


Figure 12. NAM Rainfall-Runoff Model inflows (generated using the LRBM Scenario Report)

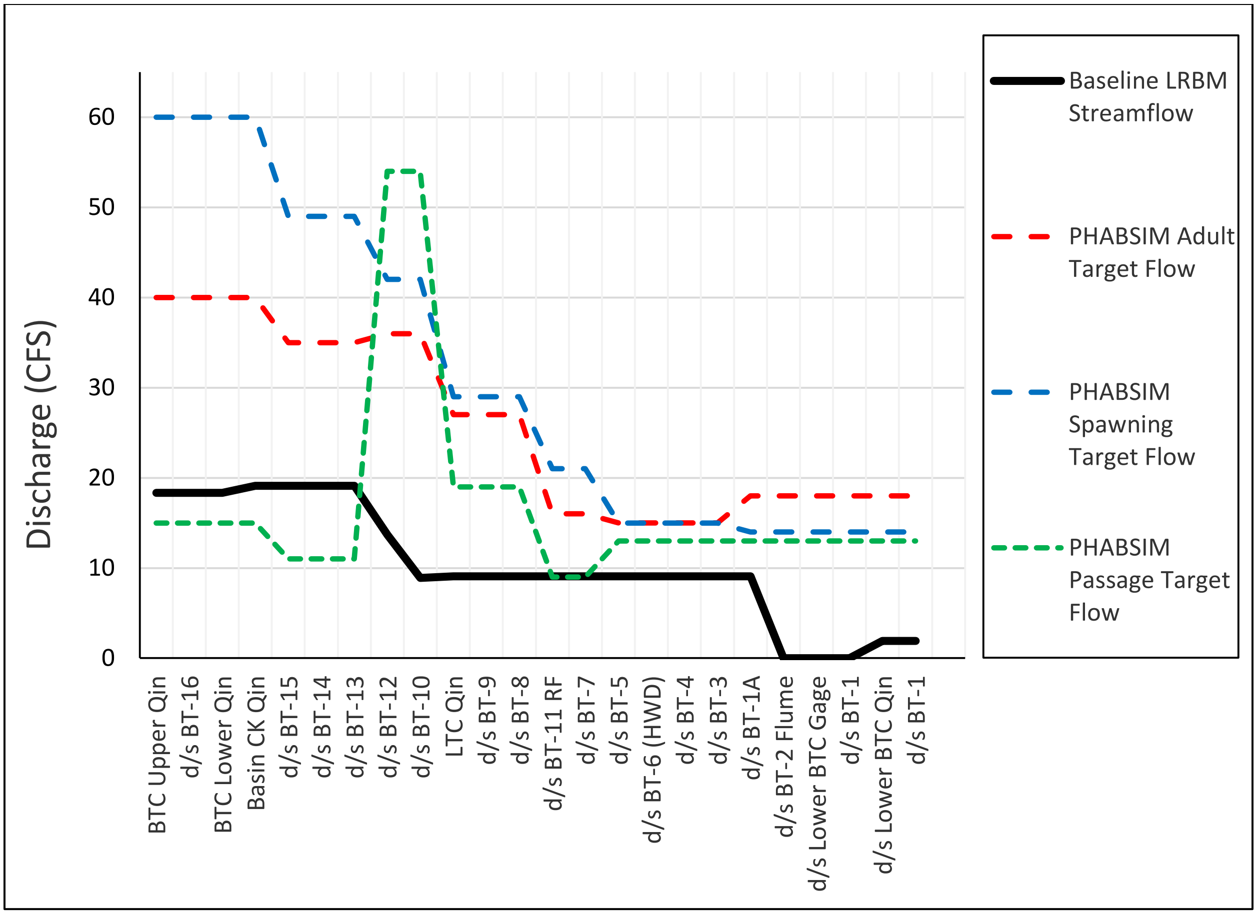


Figure 13. LRBM streamflow and PHABSIM target flows along longitudinal profile on 8/17/2016, which is an example of a low flow day (generated using the LRBM Scenario Report)

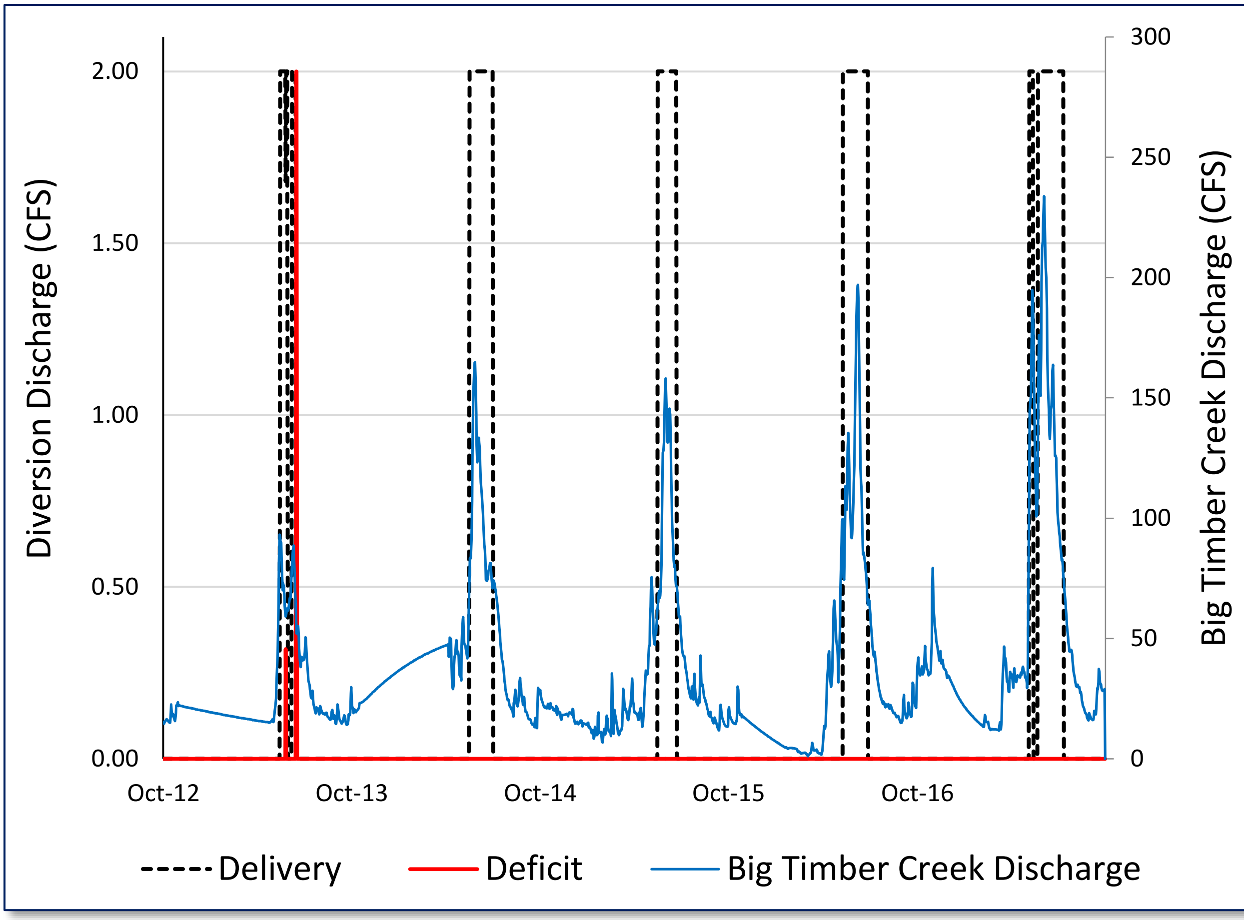


Figure 14. Water user delivery and deficit hydrograph for BT-4 Diversion (generated using the LRBM Scenario Report)

The LRBM Habitat Tool

CCI and IDWR collaborated with Dr. Daniele Tonina of the University of Idaho Center for Ecohydraulics Research to compute salmonid habitat suitability indices (HSIs) using LRBM-generated streamflow values. The goal of this effort was to empower stakeholders to evaluate the impacts to salmonid habitat that might result from the implementation of new habitat or water allocation projects. For example, the modelling team might run the LRBM to compute streamflow values for two scenarios, one being a scenario in which a new water transaction was introduced, and one being a baseline (unaltered) scenario. Both sets of LRBM-generated streamflow values could then be used to compute HSIs along the Lemhi River. The HSIs for the water transaction and baseline scenarios could then be compared with one another to assess the habitat impacts of the potential new water transaction.

The LRBM Habitat Tool was developed for the Lemhi River, from headwaters to outlet. Additional Lidar remote sensing data would be required to expand similar analyses to Lemhi River tributaries; however, the Lemhi River itself provides critical habitat to Chinook salmon, steelhead trout, and bull trout (USBWP, 2019). As a result of stakeholder interest in the LRBM Habitat Tool, a working group was formed to ensure that the product would suit the needs of salmonid habitat project planners and managers. Aided by insights from the group, CCI and IDWR developed an interactive MS Excel spreadsheet that allows stakeholders to automatically plot longitudinal profiles of Lemhi River discharge and Chinook (rearing life stage) habitat suitability (as well as temperature, measured redd density, and measured juvenile abundance).

In its current state, the LRBM Habitat Tool allows stakeholders to choose a LRBM scenario of interest, timeline of interest, and the variables they would like to visualize. After the desired LRBM outputs are selected, figures within the spreadsheets are automatically populated with the requested LRBM streamflow and/or HSI data. The LRBM Habitat Tool comes equipped with a baseline (unaltered) streamflow scenario and a natural flow (no anthropogenic water use) scenario. The stakeholder can choose to compare between different months, years, and/or streamflow scenarios. An example figure generated using the LRBM Habitat Tool is presented below (Figure 15).

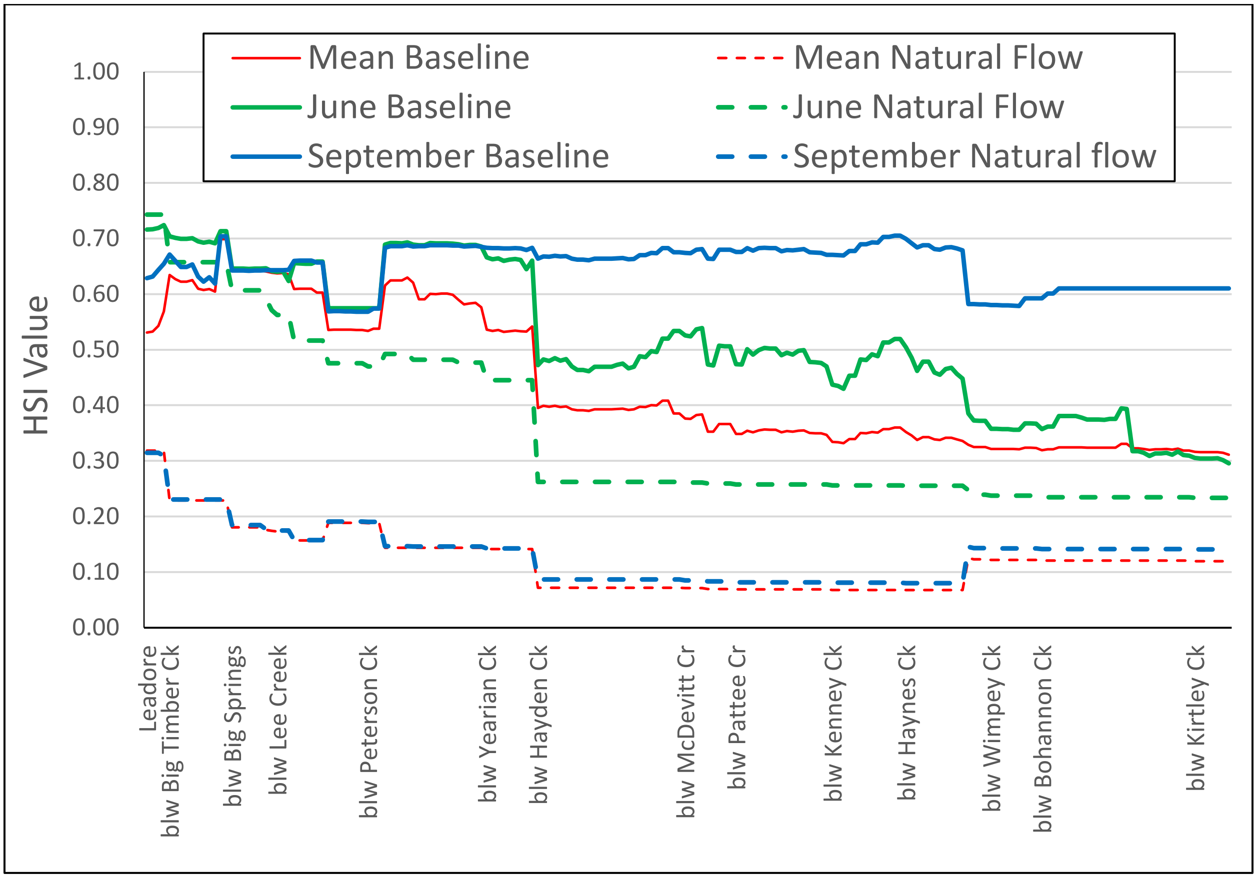


Figure 15. Chinook rearing habitat suitability profiles generated with the LRBM Habitat Tool

The LRBM Streamflow Threshold Calculator

Ongoing Lemhi Basin water rights settlement negotiations have led to increased discussion amongst Lemhi Basin stokeholders about the benefits to salmonids of “pulse flows” in the Lemhi River and its tributaries. In the context of this report, a pulse flow is defined as a streamflow event with enough energy to dislodge entrained fine sediments and debris from the stream channel. Such events help maintain equilibrium channel shape and bed material particle size.

The potential benefits of pulse flows are significant in the Lemhi Basin, as many of the tributaries (McDevitt Creek, Eighteenmile Creek, Sandy Creek, Wimpey Creek, Bohannon Creek, Geertson Creek, and Kirtley Creek) are listed as category 5 impaired waters for sediment (IDEQ, 2012). Category 5 impairment applies to “Waters not meeting applicable water quality standards for one or more beneficial uses by one or more pollutants and an EPA-approved TMDL is needed. Sedimentation is particularly destructive to salmonid habitat, as the excessive deposition of fine sediment causes losses of spawning habitat due to abrasion and/or suffocation of the eggs and trapping fry in the gravels” (USBWP, 2019).

The pulse frequency, duration, and peak flow rate necessary to maintain channel morphology and particle size on the Lemhi River and its tributaries have yet to be determined. However, there is a precedent for conditioning a high flow water right in the Lemhi Basin with a pulse flow provision (Order on Exceptions; Final Order in the matter of application for permit no. 74-16187). In this water right order, it was determined that “it is in the local public interest to preserve the periodic high flow events that maintain the Big Timber Creek stream channel morphology”. The streamflow threshold used for this order was the 20% annual exceedance rate for daily streamflow, though it is worth noting in this case that there were 67 CFS of preexisting water rights upstream of the aforementioned application. The Final Order stipulates “The right holder shall cease diversion under this right when the flow at the Bird Gauge is greater than 217 cfs. Diversion under this right may resume when the flow at the Bird Gauge drops below 217 cfs or has exceeded 217 for at least ten days in the current irrigation season."

Given this precedent, the LRBM Streamflow Threshold Calculator was developed as a tool to automatically determine the weeks during which defined streamflow thresholds are met. Thus far, the LRBM Streamflow Threshold Calculator has been developed for the Lemhi River at McFarland Campground, Big Timber Creek, Big Eightmile Creek, Eighteenmile Creek, and Mill Creek. Similar to the other interactive tools, the LRBM Streamflow Threshold Calculator is a suite of MS Excel spreadsheets. As such, it is readily accessible to stakeholders, as well as modelers. It is also worth noting that the ability of a LRBM Streamflow Threshold Calculator user to define any streamflow threshold opens up a wide variety of potential applications beyond pulse flows. For example, the potential for minimum streamflow values could also be evaluated.

The LRBM Streamflow Threshold Calculator features individual MS Excel sheets for each stream, which contain datasets for measured/modelled weekly streamflow values, as well as NAM-generated runoff inflows, and modelled catchment outflows. The streamflow threshold can be adjusted to any discharge of interest by simply typing a number into a defined cell. For example, if one wanted to test when the 20% annual exceedance rate for daily streamflow was exceeded, then that value could be entered as the threshold of interest. Table 4 presents an example of LRBM Streamflow Threshold Calculator output for a location on the Lemhi River. The table uses a streamflow threshold of 478 CFS, which is the 20% annual exceedance rate for daily streamflow at the Lemhi River at McFarland Campground Gauge (Table 1, Figure 4). Cells shaded in green exceed the flow threshold, while cells shaded in yellow are moderately below the threshold, and cells shaded in red are far below the threshold.

Table 4. LRBM Streamflow Threshold Calculator output for the Lemhi River at McFarland Campground Gauge

	May				June				July				
WY	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**
2008	100	105	58	234	233	173	60	95	185	128	105	107	84
2009	91	59	34	29	55	106	136	300	168	196	196	143	147
2010	97	105	111	163	208	171	277	269	274	288	196	162	172
2011	105	179	220	267	261	353	359	445	**676**	**550**	**488**	331	260
2012	216	246	162	106	115	75	50	68	75	95	95	90	103
2013	77	69	41	30	30	53	20	4	14	14	45	54	54
2014	101	25	46	79	30	26	21	16	19	39	56	42	63
2015	61	28	37	22	23	16	13	11	12	22	31	34	48
2016	160	83	94	102	36	16	13	9	5	7	22	33	42
2017	166	98	109	196	232	153	88	105	58	71	80	68	63
Streamflow Threshold: 478													

FUTURE WORK RECOMMENDATIONS

While work slated to be completed from October 1, 2020 to December 31, 2021 has been outlined in a now-funded proposal (2019 PCSRF Application – Round 22), additional data and analysis needs have been identified during this project period. IDWR recommends that the following tasks be completed in a future project phase to support the USBWP in its efforts to improve the health of salmonid populations.

Future Data Collection

The USBWP currently has significant interest in evaluating the hydrologic impacts of in-stream habitat projects in Hawley Creek. To further these efforts, two additional stream gauges have been installed on Hawley Creek in 2020, bringing the total to three (Table 1, Figure 3). IDWR also maintains soil moisture stations adjacent to some of the projects (Table 3, Figure 5). However, additional monitoring is likely needed based on input from the USBWP Tech Team (Tulley Mackey and Daniel Bertram, personal communication, 2020).

The USBWP has been installing BDAs in Hawley Creek since 2018, and continue to do so today. The USBWP has also recently asked Tulley Mackey, a USBWP employee and prospective graduate student, to evaluate the impacts of the BDAs on local hydrogeology, in-stream habitat, and riparian zone revegetation. IDWR is assisting Mr. Mackey and the USBWP in developing an appropriate environmental monitoring program to evaluate the effectiveness of the beaver dam analogues in achieving the desired hydrological and habitat-related transformations. The monitoring program is being designed to enable a thorough analysis of the results of the habitat program upon completion of the data collection campaign. As research and conversations continue with Mr. Mackey and the USBWP, IDWR offers its technical support and expertise, as well as assistance with installing new monitoring equipment as long as funding is available.

Future Data Analysis Efforts

IDWR has determined that appendices C and D from Phase 3 of the Upper Salmon Basin Groundwater and Surface Water Interactions project should be expounded upon. These appendices contain novel datasets that were collected with the intention of analyzing different aspects of Lemhi Basin hydrogeology, though such analyses are lacking in rigor to date.

Appendix C contains an abundance of soil moisture and temperature data. This data was collected to evaluate the conversion of irrigated plots from flood to sprinkler. However, little work has been done to analyze this data. IDWR would like to conduct further analyses, because details regarding changes in infiltration dynamics as a result of changes to irrigation would greatly benefit the ongoing evaluation of the hydrologic impacts of such changes.

Appendix D hosts a dataset containing the naturally-occurring ratios of the stable isotopes of water relative to Vienna Standard Mean Ocean Water ($\delta^{18}O$ and $\delta^{2}H$) throughout the Lemhi Basin. These isotope ratios are often used a tracers to determine the source waters contributing to the sampled water bodies. Although Phase 3 of this study plotted the isotope data in two-dimensional space and compared it to the global and meteoric water lines, there was no further attempt to evaluate the dataset. IDWR intends to critically evaluate this data using the analysis techniques developed in McCutcheon (2017) to recover any useful information the dataset may contain.

Future LRBM Modelling Efforts

Some of the LRBM modelling efforts proposed for this project phase require further efforts to complete, while additional modelling efforts not outlined in the proposal for Phase 5 of the project (2019 PCSRF Application – Round 22) would also be beneficial to the USBWP and other stakeholders. Altogether, modelling efforts requiring future work include the migration of the LRBM from MIKE BASIN v2012 to MHB 2020, further development of the LRBM Habitat Tool, and further development of the LRBM Streamflow Threshold Calculator.

Completing the migration of the LRBM to the MHB 2020 platform requires that the diversion and gauge data are updated and the supporting time series files are implemented into the new platform using the data transfer bridge that has been developed to communicate between MS Excel and DHI dfs0 files. The LRBM-Habitat Tool can be further improved by analyzing and displaying both monthly and annual statistics, completing quality assurance and quality control by comparing the HSI values with other ecological data, and expanding the analysis to different life stages (other than Chinook salmon rearing stage) and other ecological data sets. The LRBM Streamflow Threshold Calculator can be improved by calculating the streamflow thresholds required to achieve pulse flows, and then using those values as inputs to determine the weeks during the year when pulse flows are most likely to be achieved. This information can then be used by water users, water managers, salmonid habitat project managers, and others to determine location-specific discharge, frequency, and duration requirements for maintaining the stream channel for salmon rearing.

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