Upper Salmon Basin Groundwater – Surface Water Interactions Study, Phase 5
Final Project Report

Prepared by

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August 30, 2022

PROJECT OVERVIEW

DOC, Award Number:	19NMF4380205
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:	010 19 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:	07/01/2020 – 03/31/2022
Total PCSRF Funds:	$315,609.00
Total Non-Federal Match:	$105,203.00
Primary PCSRF Objectives:	Salmon Research, Monitoring, and Evaluation (SRME)

This report was prepared by Idaho Department of Water Resources 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 (salmonids) such as Chinook salmon, sockeye salmon, and steelhead trout (USBWP, 2019). However, spawning returns to the USB have been greatly reduced over the past 150 years due to the placement of physical barriers (e.g., dams), alteration of in-stream habitat, water quality degradation, and other factors (ISCC, 1995). A persistent decrease in the returns of salmonids has led to spring/summer Chinook salmon, fall 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 seek to improve streamflow conditions and in-stream habitat in the hopes of improving the abundance and health of these populations. A group of such individuals came together to form the Upper Salmon Basin Watershed Program (USBWP) in 1992, and this group still operates today. The mission statement of the USBWP is "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 consists of two focused working groups that employ their own unique sets of expertise in service of USBWP objectives. The Advisory Committee is composed of local landowners and stakeholders with a vested interest in the health of the salmonid runs. Members of this committee convey the wishes of the local community, provide local knowledge and expertise, and are often willing to allow for implementation of habitat improvement projects (HIPs) on their private property. The group that implements HIPs is known as the Technical Team (Tech Team), which is a diverse group of federal, state, and nonprofit agency personnel that cooperates to design, review, prioritize, and evaluate proposed and ongoing HIPs.

Development and evaluation of HIPs relies on a detailed understanding of the hydrogeology of the Upper Salmon Basin, as well as predictions on how both salmonid habitat and water users might be impacted by changes to water management, land use, climate, etc. As a member of the Tech Team, it is a goal of the Idaho Department of Water Resources (IDWR) to provide that expertise. Although IDWR is committed to advising projects throughout the Upper Salmon Basin, the primary focus of this report is the Lemhi River Basin (LRB), which hosts many HIPs requiring further development and evaluation.

In support of the USBWP, this report details collected hydrologic data, analyses, and numerical modeling activities conducted during the Upper Salmon Basin Groundwater and Surface Water Interactions Study, Phase 5. All data and products resulting from this study have been made available to the public within this report or via web portal.

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 (see Figure 1, upper right corner), which encompasses the Lemhi, Upper Salmon, Pahsimeroi, and Middle Salmon river basins, and historically supported critical habitat for vast numbers of anadromous fish. The LRB 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.

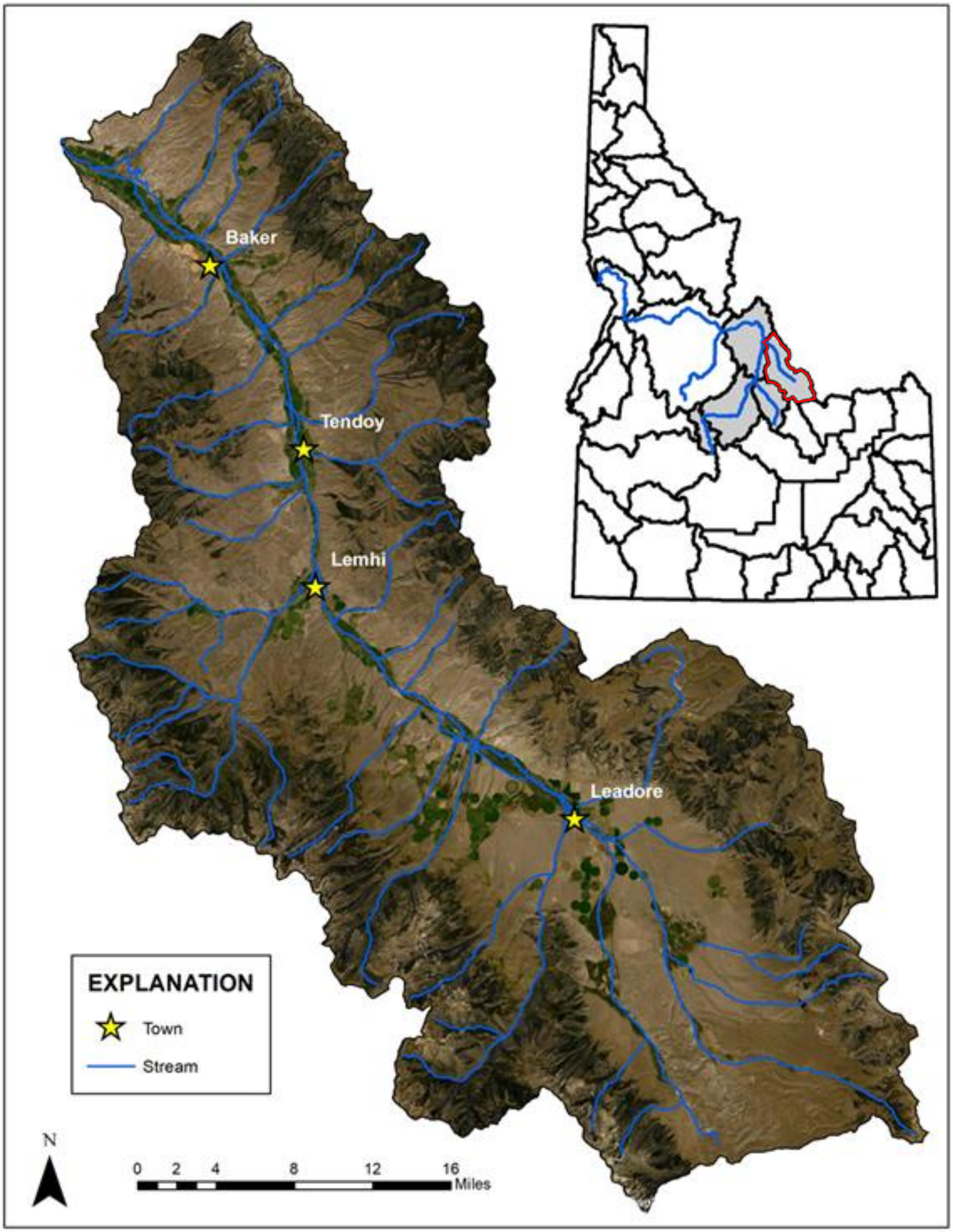

Figure 1. Lemhi River Basin

The headwaters of the Lemhi River are formed by the confluence of several tributaries flowing from the Beaverhead and Lemhi mountain ranges. 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 inches of precipitation per year. However, precipitation is positively correlated with elevation, and the surrounding mountains (some exceeding 10,000 ft) can receive more than 40 inches annually, primarily in the form of snow. As a result, the magnitude and timing of snowmelt and subsequent water storage and transport 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. 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 via 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). Estimated aquifer thickness ranges from 20 to over 200 ft in the upper basin, 16 to 42 ft within 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 impacted by both climatological factors (e.g., snowpack, 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).

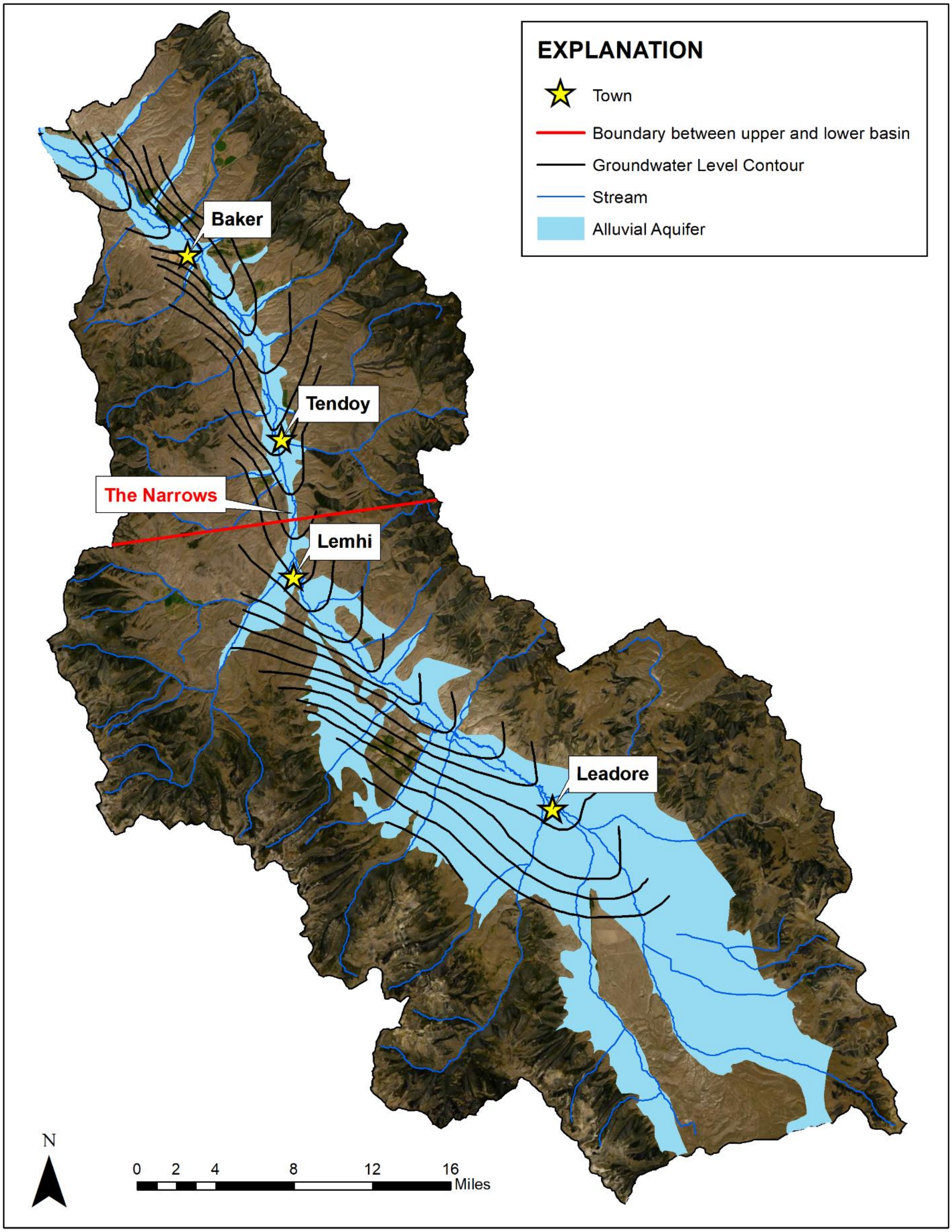

Figure 2. Lemhi River Basin Hydrogeology Overview

OBJECTIVES

The details of the following tasks were copied from the research proposal submitted to the Idaho Pacific Coastal Salmon Recovery Fund (2019, Round 22), while task numbering and titles were modified to match the structure of this report.

Task 1 - Surface Water and Groundwater Monitoring

a) Stream Gauging:

Streamflow data has been and will continue to be critical for project planning and evaluation and hydrologic modeling in the Upper Salmon Basin. The current streamflow monitoring network was created in 2005, with Idaho Power Company installing and operating the gages, the locations of which were determined through discussions with the USBWP Technical Team and collaborators. The streamflow monitoring network has changed periodically since 2005, reflecting USBWP and collaborator needs. However, starting on January 1, 2020, five stream gages will be subcontracted to another agency, while an additional 10 stream gages will continue to be operated by IDWR. All fifteen gages are expected to operate through the end of 2021, and the public streamflow database (https://research.idwr.idaho.gov/apps/hydrologic/aquainfo/Home/Data#!/) will be updated on a quarterly basis or upon request.

b) Groundwater Level Measurements:

A groundwater level monitoring network of 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 recorded using electronic pressure transducers in nine wells and biweekly manual measurements were made in the additional 12 wells. In May of 2015, the network was expanded to 41 wells; 24 continuously monitored by IDWR and 17 manually measured by Water District 74 (WD74) through a subcontract. Today, the network is 41 wells; 25 continuously monitored (IDWR) and 16 manually measured (WD74). This data provides information about the timing and magnitude of aquifer water level changes caused by pumping, natural recharge, and incidental recharge of water applied for irrigation. It is also used to investigate interactions between groundwater and surface water, as it provides a time series of distributed groundwater levels in the alluvial aquifer that underlies the Lemhi River. Under this task, IDWR and subcontracted WD74 staff will continue to monitor and maintain the expanded groundwater level network. IDWR will reprogram pressure transducers to record hourly groundwater levels instead of 6-hour readings, and update the public groundwater level database (https://maps.idwr.idaho.gov/agol/GroundwaterLevels/) on a quarterly basis or upon request.

c) Soil Moisture Measurements:

From 2014 to present, eight soil moisture monitoring sites, each containing moisture sensors at multiple depths, were installed to provide direct measurements of soil moisture storage and inform infiltration and groundwater recharge studies. Six sites are installed in agricultural fields where irrigation changed from flooding to sprinkler irrigation. In these locations, the soil moisture data allows IDWR to evaluate the hydrologic effects of changes to irrigation practice. The seventh and eighth sites are adjacent to Hawley Creek, next to a series of beaver dam analogues (BDAs) installed as part of a salmonid habitat restoration project. At this location, the soil moisture sensors allow IDWR to assess the hydrologic impact of BDAs by indirectly observing overbank flows and hyporheic exchange. All soil moisture sensors will be reprogrammed to record on an hourly basis rather than every eight hours. IDWR will also develop a new public database for soil moisture levels, which will be updated on a quarterly basis or upon request.

Task 2 - Aerial Photography Analysis of Changes in Irrigation Practices

IDWR and USBWP Technical Team collaborators are aiming to 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 by June 30, 2020. Other datasets may be added to this task if deemed helpful for long-term trend analyses. The aerial photography analysis will be performed using ArcGIS 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. Following the analysis of changes to irrigation practices, IDWR will investigate the hydrologic impacts of irrigation changes on the Lemhi River system. Analyses will include statistical comparisons of stream gage records before and after irrigation changes, as well as modeled scenarios in the LRBM.

Task 3 – Surface Water Quality Data

The Idaho DEQ (DEQ) has measured several water quality parameters, establishing total maximum daily load values in the Lemhi River and several of its tributaries, as is documented in reports including “Lemhi River Watershed TMDL” (1999) and “Lemhi River Subbasin Total Maximum Daily Loads and Five-Year Review” (2012). The DEQ (1999, 2012) concluded that several reaches of the Lemhi River and its major tributaries contain “Impaired Waters”, with listed pollutants of temperature, sedimentation/siltation, fecal coliform, and nutrients. Nevertheless, there are currently no long-term, coordinated water quality monitoring programs in the basin (Todd Blythe, USBWP, personal communication, 9/11/2019).

In the Lemhi River and its tributaries, limiting factors to salmonid habitat suitability include elevated summer water temperatures and winter freezing, as well as excess fine sediment (OSC et al., 2019; Mike Edmonson, personal communication, 8/7/2019). Additional water quality metrics of concern include pH and dissolved oxygen (DO), as unsuitable concentrations of H^+ or DO can result in diminished production, or even mortality of salmonids (Carter, 2008).

IDWR already manages stream gages, as well as groundwater level wells, groundwater quality wells, and soil moisture monitoring sites in the Lemhi Basin. As a result, adding a surface water quality monitoring program to the existing network would be more time and cost efficient than establishing an entirely new network. Given the potential for such efficiency and the importance of water quality to salmonids, IDWR proposes to monitor temperature, turbidity, specific conductivity, pH, and dissolved oxygen in the Lemhi River and its tributaries. The list of analytes and measurement sites (below) may be expanded upon request from the USBWP or collaborators.

Continuous Surface Water Temperature Data:
Temperature data from all Lemhi Basin temperature-recording gages maintained by IDWR and subcontractors will be made public. This includes six IDWR-managed gauges (one of which is in the Upper Salmon Basin) and up to ten additional subcontracted gages, depending on equipment used by the subcontractors. In addition, all IDWR-maintained and subcontracted gages located on stream segments listed as "Impaired Waters" due to temperature (DEQ, 2012) will be outfitted with temperature probes if they are not already recording temperature. This list includes gaging sites on the Lemhi River, Eighteenmile Creek, Hawley Creek, and Bohannon Creek. Continuous surface water temperature data will be uploaded to the database on a quarterly basis, or upon request.

Discrete Surface Water Quality Data:
This task involves recording monthly (weather permitting) measurements of temperature, specific conductivity, turbidity, pH, and dissolved oxygen levels. These water quality parameters will be measured using handheld multiparameter sondes while already on site for stream gauging at the 10 sites (9 sites in the Lemhi Basin and 1 in the Upper Salmon Basin) currently maintained by IDWR personnel. Water quality will also be measured at an additional 11 IDWR-subcontracted stream gauging sites on at least a quarterly basis (see attachments "PCSRF Location Map Lemhi" and "PCSRF Location Map Upper Salmon"), creating a total of 21 surface water quality sites. Water quality measurement frequency and locations may be changed as more is learned about water quality trends in the basin. Collecting water quality data at stream gaging sites allows for calculation of total load and may help characterize the relationships between streamflow and water quality in future analyses.

Task 4 - Lemhi River Basin Model (LRBM) Updates

IDWR has been responsible for the Lemhi River Basin Model (LRBM) from 2008 to present. The model has included the entire Lemhi River Basin since 2013, and is continuously updated and recalibrated with new data and hydrologic information to reflect the current state of the basin. Under this task, the LRBM will be updated with data and irrigation system configuration information for water year 2019. Modeled water use scenarios will be used by collaborators to determine the hydrologic impacts of water conservation and salmonid habitat restoration projects and predict the impacts of potential future projects. All hydrologic modeling activities are, and will continue to be, performed by IDWR with assistance from a Mike Hydro Basin Consultant on an as-needed basis.

LRBM Data Atlas:
Due to the inherent complexities of water transaction projects, thus far it has been difficult for collaborators to convey the information needed to run the desired LRBM water use scenarios. This shortcoming undermines IDWR's ability to aid in evaluation of such projects. 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 ultimate goal is to be able to run a model scenario and assess the hydrologic impacts of the proposed water use change within hours of receiving a model run request. IDWR is aiming to have this completed by June 30, 2020. Subsequent work (July 2020 – December 2021) will be done to refine the Data Atlas to further expedite model runs and better suit model user needs as new types of projects are developed in the Lemhi Basin.

LRBM Habitat:
Evaluating salmonid habitat suitability is a difficult proposition, as habitat health is reliant upon a myriad of factors. Recently, Lemhi Basin habitat quantity and quality was evaluated using an empirically-based quantile regression forest (QRF) model (OSC et al., 2019). The model estimated the number of redds and the number of juveniles that the Lemhi River and tributaries can support (OSC et al., 2019). The model results suggested that juvenile Chinook rearing capacity may be limited during both summer (parr) and winter (presmolt) months (OSC et al., 2019). However, analysis of the relationship between streamflow levels and habitat quantity and quality was limited.

IDWR aims to bolster the salmonid habitat modeling effort in the Lemhi River by coupling the LRBM with a fish habitat model, thereby allowing for the prediction of salmonid habitat suitability when streamflow behavior changes. In order to accomplish this, the fish habitat model must incorporate a high resolution digital elevation model of the streambed, and use flow rate and stage data inputs to calculate habitat suitability. Fortunately, Dr. Daniele Tonina of University of Idaho has already developed such a model, and IDWR and a MIKE Hydro consultant have begun working on coupling this model with the LRBM.

In this task, streamflow data output from the LRBM will be fed into the fish habitat model. The habitat model then uses the Instream Flow Incremental Methodology to calculate how much physical habitat is gained or lost as a result of gains or losses to streamflow. This will allow researchers to characterize seasonal and long-term variability in salmonid habitat suitability, and even run water use or climate change scenarios to assess hydrologic and biological impacts on the system. Future work will include working with Dr. Tonina, the USBWP Technical Team, and a MIKE Hydro Basin consultant to improve modeled salmonid habitat suitability estimates.

RESULTS

The work completed during phase 5 of this project was guided by the objectives outlined in the Pacific Coastal Salmon Recovery Fund (2019, Round 22) proposal submitted to the Idaho Governor's Office of Species Conservation (see "OBJECTIVES" in this report). However, minor changes were made to the data collection and analysis campaigns due to unanticipated complications and USBWP requests for changes to the project scope. The results section documents all work completed for this project, including additions, subtractions, and deviations from the original proposal.

Task 1a - Streamflow Data Collection and Analysis

Streamflow Data Collection

Streamflow data has been used to support the USBWP in planning, implementation, and monitoring of streamflow enhancement and in-stream habitat improvement projects (HIPs), and provides data needed to calibrate the Lemhi River Basin Model (LRBM). The data and LRBM have also been used to inform local stakeholders on basin hydrogeology and aid settlement negotiations which culminated in the completion and signing of the Lemhi River Basin Comprehensive Settlement Agreement on 2/24/2022. The settlement agreement allows for water users to attain high flow water rights, while also provisioning minimum streamflows to enable fish passage and maintain in-stream habitat health. IDWR managed gages will be used to enforce minimum streamflow provisions at the Lemhi River at McFarland, Lemhi River below L5 Diversion, Big Timber Creek Lower, Bohannon Creek Lower, Canyon Creek, and Hayden Creek.

With funding from the Pacific Coast Salmon Recovery Fund (PCSRF), the Columbia Basin Water Transactions Program (CBWTP), and the Idaho Water Transactions Program (IWTP), IDWR has managed streamflow data collection for the USBWP from 1997 to present (Table 1). In total, IDWR actively manages 35 USB stream gages, 16 of which are managed through this project using PCSRF funds (Table 1, Figure 3). Two of the 16 gages were added to the network on 1/1/2022 (Table 1) at the request of the USBWP. The two new gages are intended to aid in evaluation of the efficacy of a HIP on Hawley Creek.

Gages managed through the water transactions programs (CBWTP and IWTP) are included in this report (Table 1) because PCSRF personnel hours were used to serve this data to the public. For all IDWR managed gages, stage data was recorded using a pressure transducer or bubbler and on-site streamflow measurements were made every six weeks (conditions permitting) using an Acoustic Doppler Velocimeter, an acoustic Doppler current profiler, or dilution gaging techniques. The stage and streamflow data were then used to develop stage-discharge rating tables and compute daily mean streamflow values.

All streamflow data collected in the Upper Salmon Basin through the last week of September 2021 has been posted to the IDWR streamflow data web portal at (https://research.idwr.idaho.gov/apps/hydrologic/aquainfo/Home/Data#!/). Data from water year 2021 (October 1, 2020, to September 30, 2021) and prior may be considered finalized, while data from water year 2022 should be considered preliminary until 2/1/2023 unless otherwise specified by IDWR.

Table 1. IDWR Stream Gages within the Upper Salmon Basin

Gage 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 USGS	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 - present	Transferred to BOR	None
Challis Creek, Upper	44.572	-114.305	2005 - 2019	Discontinued	None
East Fork Salmon River	44.267	-114.325	2004 – 2018, 2022	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	PCSRF
Hawley Creek Below Diversions	44.659	-113.216	2020 - present	Operated by SPF	PCSRF
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 - present	Operated by USGS	IDWR
Lemhi River nr Lemhi	44.940	-113.639	1938 – present	Operated by USGS	IDWR
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 - 2021	Discontinued	None
North Fork Salmon River	45.406	-113.994	2005 - 2007	Discontinued	None
Pahsimeroi at Ellis	44.692	-114.047	1984 – present	Operated by USGS	IDWR
Pahsimeroi at Furey Lane	44.526	-113.848	2004 - present	Transferred to BOR	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

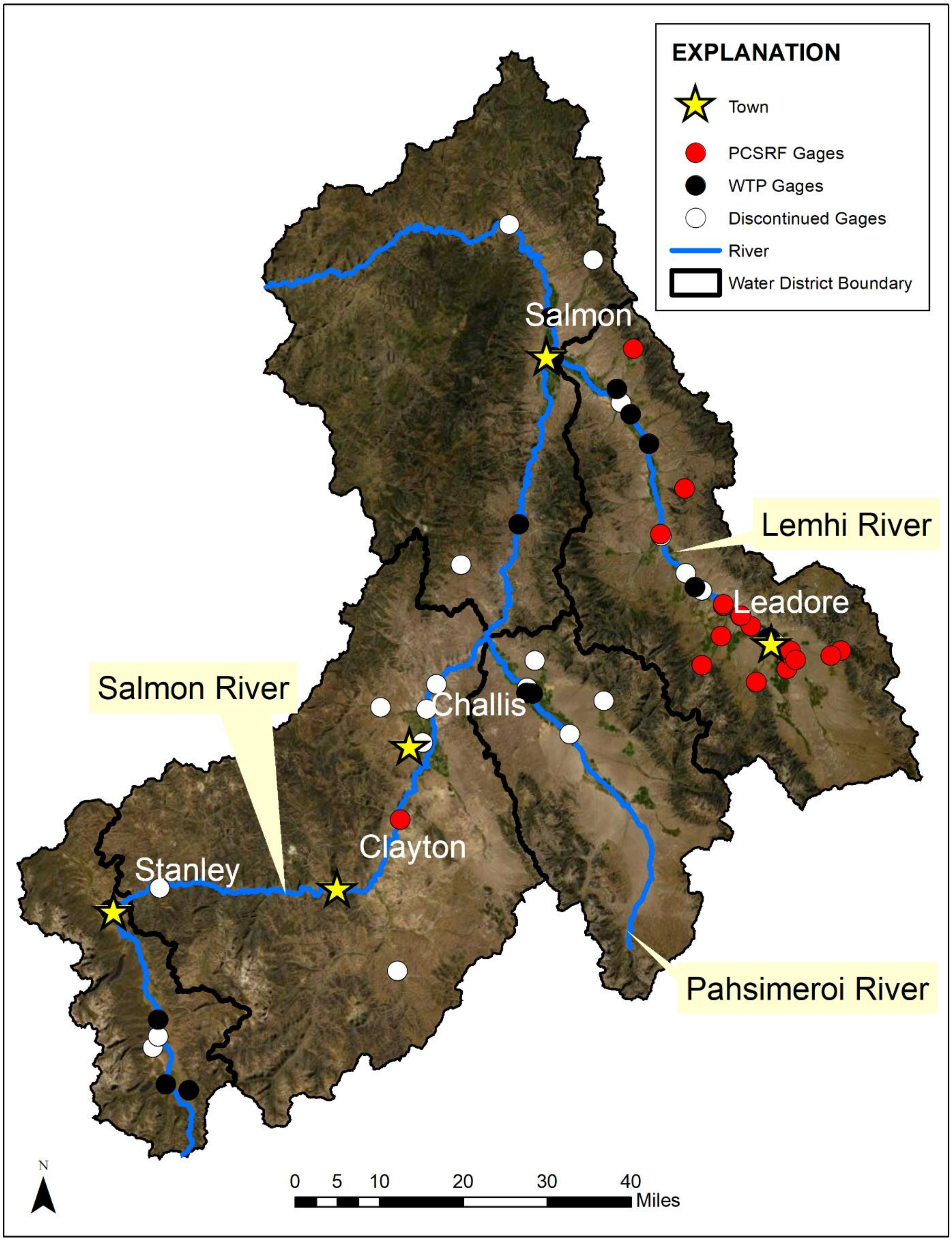

Figure 3. Upper Salmon Basin Streamflow Monitoring Network

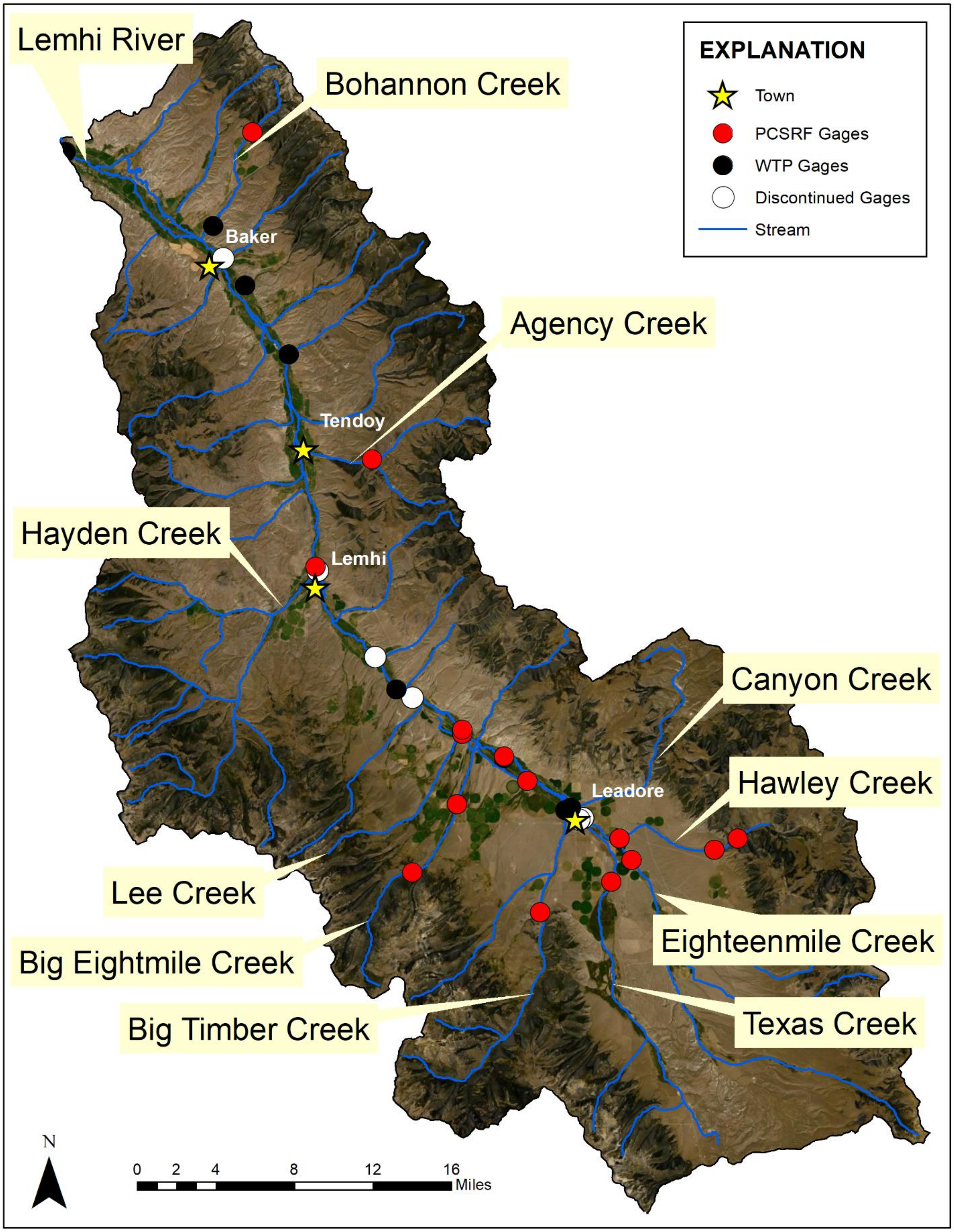

Figure 4. Lemhi River Basin Streamflow Monitoring Network

Streamflow Trend Analysis

Over the period of record, it is likely that mean annual streamflow has changed at some gage sites (see Table 1 for geographic coordinates) due to water management decisions, altered irrigation practices, habitat improvement projects, climatic fluctuations, etc. Trend analyses were conducted on the full streamflow datasets collected by IDWR using the Mann-Kendall trend test. Mann Kendall analyses typically utilize at least 30 years of data to decrease uncertainty introduced by climatic variability, measurement uncertainty, and other factors. Nevertheless, IDWR deemed it appropriate to complete preliminary trend analyses on all 34 stream gages with ten or more years of data (includes discontinued gages) and encourages the reader to consider the period of record when interpreting the results. Five additional USGS gages funded by other agencies were also analyzed, all of which were labeled with "USGS" after the appropriate gage names in the Mann Kendall Test tables (Table 2, Table 3, Table 4).

The Mann Kendall Tests determined if there are statistically significant trends in mean annual streamflow (Table 2), minimum annual streamflow (Table 3), or maximum annual streamflow (Table 4). Note that years with missing streamflow data were removed from the analyses. Kendall's tau shows the strength of correlation (e.g. 0 = no correlation and 1 = perfect correlation), while the p-value shows the probability that the null hypothesis of no trend in streamflow was rejected, and Sen's Slope depicts the rate of change in streamflow (e.g. Sen's Slope of 2 means that streamflow increased by 2 CFS per year). Tests with p-values less than 0.05 were considered to be gaging stations with trending streamflow (95% confidence). Also of note is that the higher the p-value, the greater the uncertainty in Sen's Slope (e.g. tests with p-values < 0.05 generally yield more accurate Sen's Slope estimates).

Table 2. Mann-Kendall Test: Mean Annual Streamflow

Gage	Start Year	End Year	Kendall's tau	p-value	Sen's Slope
Agency Creek	2006	2020	0.150	0.444	-0.215
Beaver Creek	2005	2020	0.100	0.620	0.186
Big Eightmile Creek Upper	2006	2020	0.055	0.827	-0.259
Big Eightmile Creek Lower	2009	2020	0.333	0.127	-0.523
Big Springs Creek Upper	2009	2020	0.212	0.373	-0.245
Big Springs Creek Lower	2009	2020	0.417	0.027	-0.416
Big Timber Creek Upper	2006	2020	0.067	0.753	-0.625
Big Timber Creek Lower	2007	2020	0.200	0.300	0.822
Bohannon Creek Lower	2009	2020	0.011	1.000	-0.048
Canyon Creek	2009	2020	0.282	0.200	-0.220
Carmen Creek Upper	2006	2017	0.026	0.951	-0.114
Carmen Creek Lower	2006	2020	0.324	0.077	1.265
Challis Creek Upper	2006	2018	0.205	0.360	0.840
Challis Creek Lower	2006	2018	0.253	0.228	0.810
East Fork Salmon River	2005	2017	0.103	0.669	1.111
Eighteenmile Creek	2007	2020	0.560	0.006	1.317
Fourth of July Creek	2005	2020	0.143	0.488	0.350
Hawley Creek	2009	2020	0.212	0.373	-0.407
Hayden Creek	2008	2020	0.333	0.127	-3.389

Iron Creek	2007	2020	0.538	0.012	1.367
Kenney Creek	2005	2020	0.516	0.012	0.506
Lee Creek	2010	2020	0.091	0.755	-0.169
Lemhi River at Big Springs	2006	2020	0.067	0.767	1.014
Lemhi River at L63	2009	2018	0.018	1.000	0.075
Lemhi River at Cottom Ln	2006	2020	0.105	0.621	1.352
Lemhi River at L1	2011	2020	0.022	1.000	3.521
Lemhi River at McFarland	1998	2018	0.438	0.006	4.109
Lemhi River below L5 UGSS	1992	2021	0.009	0.967	-0.246
Lemhi River nr Lemhi	1938	2021	0.130	0.130	-0.698
Little Springs Creek Lower	2009	2020	0.152	0.537	0.265
Morgan Creek	2007	2020	0.026	0.951	0.012
Pahsimeroi River at Ellis	1987	2021	0.086	0.478	0.309
Pahsimeroi River at Furey Ln	2005	2018	0.451	0.029	1.814
Pahsimeroi River at P9	2010	2020	0.055	0.827	-0.476
Patterson Big Springs Upper	2009	2020	0.333	0.150	-1.045
Pole Creek	2006	2020	0.051	0.855	0.038
Salmon River at Salmon USGS	1987	2020	0.209	0.085	17.660
Salmon River nr Shoup USGS	2003	2021	0.181	0.294	47.011
Texas Creek	2009	2020	0.018	1.000	-0.149
Valley Creek at Stanley USGS	1993	2021	0.020	0.896	-0.265
Yankee Fork Salmon R. USGS	2012	2021	0.333	0.210	-8.495

Table 3. Mann-Kendall Test: Minimum Annual Streamflow

Gage	Start Year	End Year	Kendall's tau	p-value	Sen's Slope
Agency Creek	2006	2020	0.326	0.087	-0.046
Beaver Creek	2005	2020	NA	NA	NA
Big Eightmile Creek Upper	2006	2020	0.429	0.037	0.385
Big Eightmile Creek Lower	2009	2020	0.282	0.200	-0.149
Big Springs Creek Upper	2009	2020	0.615	0.004	1.004
Big Springs Creek Lower	2009	2020	0.276	0.149	-0.124
Big Timber Creek Upper	2006	2020	0.572	0.004	0.117
Big Timber Creek Lower	2007	2020	0.045	0.868	0.000
Bohannon Creek Lower	2009	2020	0.061	0.837	0.019
Canyon Creek	2009	2020	0.154	0.502	-0.104
Carmen Creek Upper	2006	2017	0.062	0.769	0.000
Carmen Creek Lower	2006	2020	0.282	0.200	-0.272
Challis Creek Upper	2006	2018	0.199	0.351	-0.012
Challis Creek Lower	2006	2018	0.282	0.200	1.367
East Fork Salmon River	2005	2017	NA	NA	NA
Eighteenmile Creek	2007	2020	0.096	0.656	0.110

Fourth of July Creek	2005	2020	0.000	1.000	0.002
Hawley Creek	2009	2020	0.179	0.428	-0.225
Hayden Creek	2008	2020	0.658	0.002	0.233
Iron Creek	2007	2020	0.544	0.008	0.188
Kenney Creek	2005	2020	0.164	0.533	-0.029
Lee Creek	2010	2020	0.067	0.767	-0.366
Lemhi River at Big Springs	2006	2020	0.309	0.213	-0.527
Lemhi River at L63	2009	2018	0.105	0.621	0.405
Lemhi River at Cottom Ln	2006	2020	0.244	0.371	-2.947
Lemhi River at L1	2011	2020	0.057	0.740	-0.107
Lemhi River at McFarland	1998	2018	0.107	0.680	0.062
Lemhi River below L5 Div USGS	1992	2021	0.037	0.802	-0.050
Lemhi River nr Lemhi	1938	2021	0.094	0.273	-0.237
Little Springs Creek Lower	2009	2020	0.026	0.951	-0.012
Morgan Creek	2007	2020	0.144	0.510	0.015
Pahsimeroi River at Ellis	1987	2021	0.074	0.541	0.208
Pahsimeroi River at Furey Ln	2005	2018	0.066	0.784	0.227
Pahsimeroi River at P9	2010	2020	0.455	0.047	-0.778
Patterson Big Springs Upper	2009	2020	0.308	0.161	0.449
Pole Creek	2006	2020	0.236	0.350	-0.274
Salmon River at Salmon USGS	1987	2020	0.279	0.022	7.00
Salmon River nr Shoup USGS	2003	2021	0.206	0.234	13.750
Texas Creek	2009	2020	0.018	1.000	-0.149
Valley Creek at Stanley USGS	1993	2021	0.249	0.061	0.439
Yankee Fork Salmon R. USGS	2012	2021	0.067	0.858	-0.333

Table 4. Mann-Kendall Test: Maximum Annual Streamflow

Gage	Start Year	End Year	Kendall's tau	p-value	Sen's Slope
Agency Creek	2006	2020	0.167	0.392	-2.347
Beaver Creek	2005	2020	0.048	0.843	-2.033
Big Eightmile Creek Upper	2006	2020	0.436	0.044	-5.754
Big Eightmile Creek Lower	2009	2020	0.364	0.115	-5.092
Big Springs Creek Upper	2009	2020	0.487	0.024	-3.912
Big Springs Creek Lower	2009	2020	0.033	0.893	-0.852
Big Timber Creek Upper	2006	2020	0.100	0.620	1.100
Big Timber Creek Lower	2007	2020	0.033	0.913	-0.086
Bohannon Creek Lower	2009	2020	0.323	0.142	-0.890
Canyon Creek	2009	2020	0.000	1.000	-0.122
Carmen Creek Upper	2006	2017	0.309	0.091	11.159
Carmen Creek Lower	2006	2020	0.179	0.428	7.021
Challis Creek Upper	2006	2018	0.121	0.584	4.100

Challis Creek Lower	2006	2018	0.077	0.760	38.409
East Fork Salmon River	2005	2017	0.604	0.003	2.100
Eighteenmile Creek	2007	2020	0.048	0.843	0.786
Fourth of July Creek	2005	2020	0.242	0.304	-2.210
Hawley Creek	2009	2020	0.154	0.502	-11.006
Hayden Creek	2008	2020	0.538	0.012	6.865
Iron Creek	2007	2020	0.165	0.443	1.560
Kenney Creek	2005	2020	0.018	1.000	0.217
Lee Creek	2010	2020	0.067	0.767	-2.178
Lemhi River at Big Springs	2006	2020	0.236	0.350	2.590
Lemhi River at L63	2009	2018	0.257	0.198	-7.696
Lemhi River at Cottom Ln	2006	2020	0.289	0.283	33.989
Lemhi River at L1	2011	2020	0.362	0.024	9.971
Lemhi River at McFarland	1998	2018	0.273	0.244	-0.829
Lemhi River below L5 Div USGS	1992	2021	0.191	0.169	-28.786
Lemhi River nr Lemhi	1938	2021	0.099	0.251	-3.460
Little Springs Creek Lower	2009	2020	0.154	0.502	-4.453
Morgan Creek	2007	2020	0.331	0.112	2.900
Pahsimeroi River at Ellis	1987	2021	0.052	0.670	0.556
Pahsimeroi River at Furey Ln	2005	2018	0.033	0.913	-0.988
Pahsimeroi River at P9	2010	2020	0.242	0.304	-2.786
Patterson Big Springs Upper	2009	2020	0.026	0.951	-0.293
Pole Creek	2006	2020	0.164	0.533	-1.062
Salmon River at Salmon USGS	1987	2020	0.226	0.062	128.571
Salmon River nr Shoup USGS	2003	2021	0.047	0.806	-58.333
Texas Creek	2009	2020	0.018	1.000	-0.149
Valley Creek at Stanley USGS	1993	2021	0.086	0.524	-6.983
Yankee Fork Salmon R. USGS	2012	2021	0.467	0.074	-156.667

In the Lemhi Basin, significant trends in mean annual streamflow (95% confidence) occurred at four gages (highlighted in Table 2): Lemhi River at McFarland (+4.1 cfs/yr), Eighteenmile Creek (+1.3 cfs/yr), Big Springs Creek Lower (-0.4 cfs/yr), and Kenney Creek (+0.5 cfs/yr). Significant trends in minimum annual streamflow occurred at four gages (highlighted in Table 3): Big Eightmile Creek Upper (+0.385 cfs/yr), Big Timber Creek Upper (0.117 cfs/yr), Big Springs Creek Upper (+1.004 cfs/yr), and Hayden Creek (+0.233 cfs/yr). Significant trends in maximum streamflow occurred at four gages (highlighted in Table 4): Big Eightmile Creek Upper (-5.754 cfs/yr), Big Springs Creek Upper (-3.912), Hayden Creek (+6.865 cfs/yr), and Lemhi River at L1 (9.971 cfs/yr). Figure 5 shows the locations and streamflow trend directions for gages in the Lemhi basin.

Outside the Lemhi basin, in the greater USB, significant trends in mean annual streamflow occurred at two gages (highlighted in Table 2): Pahsimeroi River at Furey Ln (+1.814 cfs/yr) and Iron Creek (+1.367 cfs/yr). Trends in minimum annual streamflow occurred at three gages (Table 3): Iron Creek (+0.188 cfs/yr), Pahsimeroi River at P9 (-0.778 cfs/yr), and Salmon River at Salmon USGS (+7.00 cfs/yr). Trends in maximum streamflow occurred at the East Fork Salmon River (2.100 cfs/yr). Figure 6 shows the locations and trend direction for gages in the USB basin.

Catchment-Scale Analyses

Lemhi River Basin

Starting in the Upper Lemhi Basin, mean annual streamflow is trending upward at the Lemhi River at McFarland Gage (Figure 5). This may be caused, at least in part, by USBWP efforts to reconnect headwater tributaries to the Lemhi River and the trend of irrigators converting from flood to sprinkler irrigation (see "Aerial Photograph Analysis of Changes in Irrigation Practices)". The upward trend in mean annual streamflow at Eighteenmile Creek is also encouraging, as Eighteenmile Creek is a headwater tributary to the Lemhi River, and the USBWP has implemented multiple projects to reconnect Hawley Creek to Eighteenmile Creek. If the upwards trend in streamflow at the Lemhi at McFarland Gage persists, it could bode well for water users, managers, and salmonid habitat health, as the Lemhi Settlement Agreement has provisioned a minimum streamflow requirement (420 CFS at McFarland Gage for three consecutive days without two out of every five years) in an effort to maintain quality in-stream habitat within the Upper Lemhi River.

With regards to minimum annual streamflow, the USBWP has spent significant resources on projects intended to maintain connection between the Lemhi River and its tributaries. As such, it is encouraging to see annual minimum streamflow trending upward at Hayden Creek, Big Timber Creek Lower, Lee Creek, Hayden Creek, and Kenney Creek. In the cases of Big Timber Creek Lower, Lee Creek, and Kenney Creek, higher minimum flows yield more opportunities for fish passage, and more suitable in-stream habitat for salmonids during periods of low flow. In the case of Hayden Creek, higher minimum flows increase the available in-stream salmonid habitat during periods of low flow, as well as within the Lemhi River downstream of the confluence. The flow contributions of Hayden Creek are crucial to the lower Lemhi River ecosystem, as flow at Hayden Creek Gage is approximately 30% of that at the Lemhi River nr Lemhi USGS Gage just downstream of the confluence with Hayden Creek. Higher minimum streamflow at Hayden Creek also serves irrigators who are subject to a minimum streamflow provision of 35 CFS at the Lemhi River below L5 Diversion Gage.

More concerning streamflow trends included decreasing mean streamflow at Big Springs Creek Lower. Flow at this gage is roughly 42% of flow at the Lemhi River at Big Springs Gage on average, so it comprises a large percentage of total surface water flow in the Upper Lemhi Basin. Given that both of these gages are located just above the confluence of Big Springs Creek and the Lemhi River, decreasing flow within Big Springs Creek may result in significant decreases in flow within the Lemhi River itself. Big Springs Creek also provides habitat for salmonids; however, temperatures within Big Springs Creek were often elevated relative to the Lemhi River and many of its tributaries (see "Surface Water Quality Data Collection and Analysis"). Given these baseline conditions, further reduction in flow may result in greater seasonal fluctuations in water temperature that would provide less suitable habitat for salmonids in Big Springs Creek.

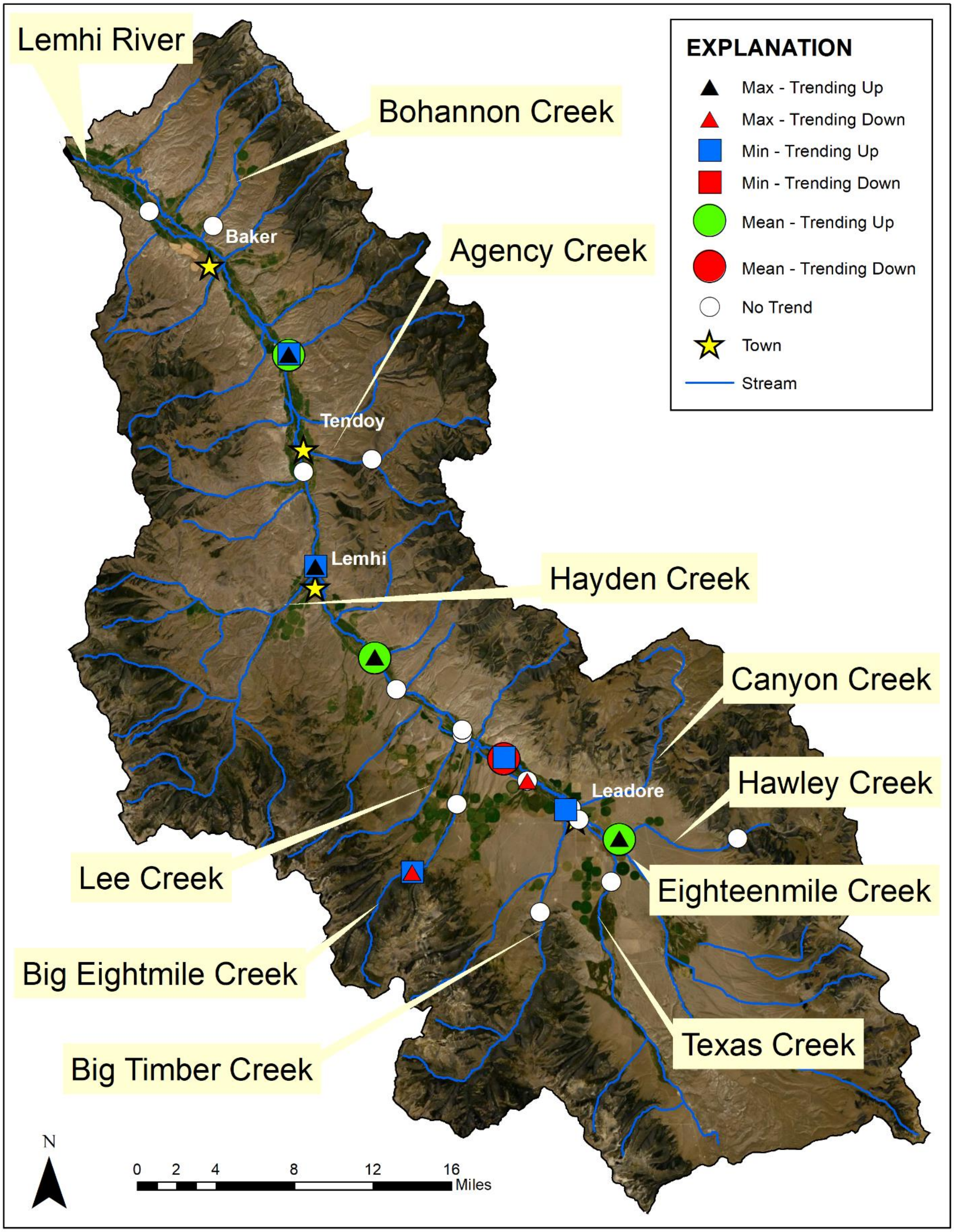

Figure 5. Streamflow trends within the Lemhi Basin

Pahsimeroi River Basin

Starting in the Upper Pahsimeroi Basin, the Pahsimeroi River at Furey Ln Gage has showed increasing mean annual streamflow, while the Pahsimeroi River at P9 Gage showed decreasing minimum streamflow (Figure 6). The Pahsimeroi River at Furey Ln Gage showing increasing mean flow is encouraging because it is near the headwaters of the Pahsimeroi River, and increased flow in the headwaters can help to mitigate any losses to flow further downstream. However, the decreasing minimum streamflow at the Pahsimeroi River at P9 Gage is discouraging because flow sometimes decreases to levels near fish passage thresholds at this location (e.g. minimum flow of < 5 CFS 4 out of 17 years) before the Pahsimeroi River and Patterson Big Springs Creek converge. As a result, downward trending minimum streamflow in this location may result in more frequent blockages to fish passage in addition to decreased availability of suitable in-stream habitat.

There were no discernible trends in flow at Patterson Big Springs Creek, nor the Pahsimeroi at Ellis, which is the gage nearest to the confluence of the Pahsimeroi and Salmon rivers. The increased mean annual streamflow at the Pahsimeroi River at Furey Ln Gage may be helping to slow the downward trend in streamflow at the Pahsimeroi River at P9 Gage and maintain stable flows near the mouth of the Pahsimeroi River at Ellis Gage. Gains in streamflow from groundwater sources or other factors (e.g. changes to irrigation practices or water management) may also help to stabilize flows between the Pahsimeroi River at P9 and the Pahsimeroi River at Ellis gages.

Upper Salmon Basin

Few gages within the Upper Salmon Basin (upstream of the Salmon River confluence with the Pahsimeroi River) showed discernible trends in streamflow (Figure 6). Minimum flow trended upwards at the Salmon River at Salmon Gage. This trend may serve to increase in-stream habitat for salmonids during periods of low flow, as well as decrease curtailment for irrigators, as there is a minimum streamflow provision at the Salmon River nr Shoup USGS Gage downstream of this location. Other trends included increasing maximum annual streamflow at the East Fork Salmon River Gage and increases in both minimum and mean streamflow in Iron Creek. Though Iron Creek is not a major tributary to the Salmon River in terms of flow, it does provide salmonid habitat, and given that minimum streamflow values in Iron Creek often approach fish passage thresholds (< 5 CFS for 9 out of 16 years), the upward trend in minimum annual flow is beneficial.

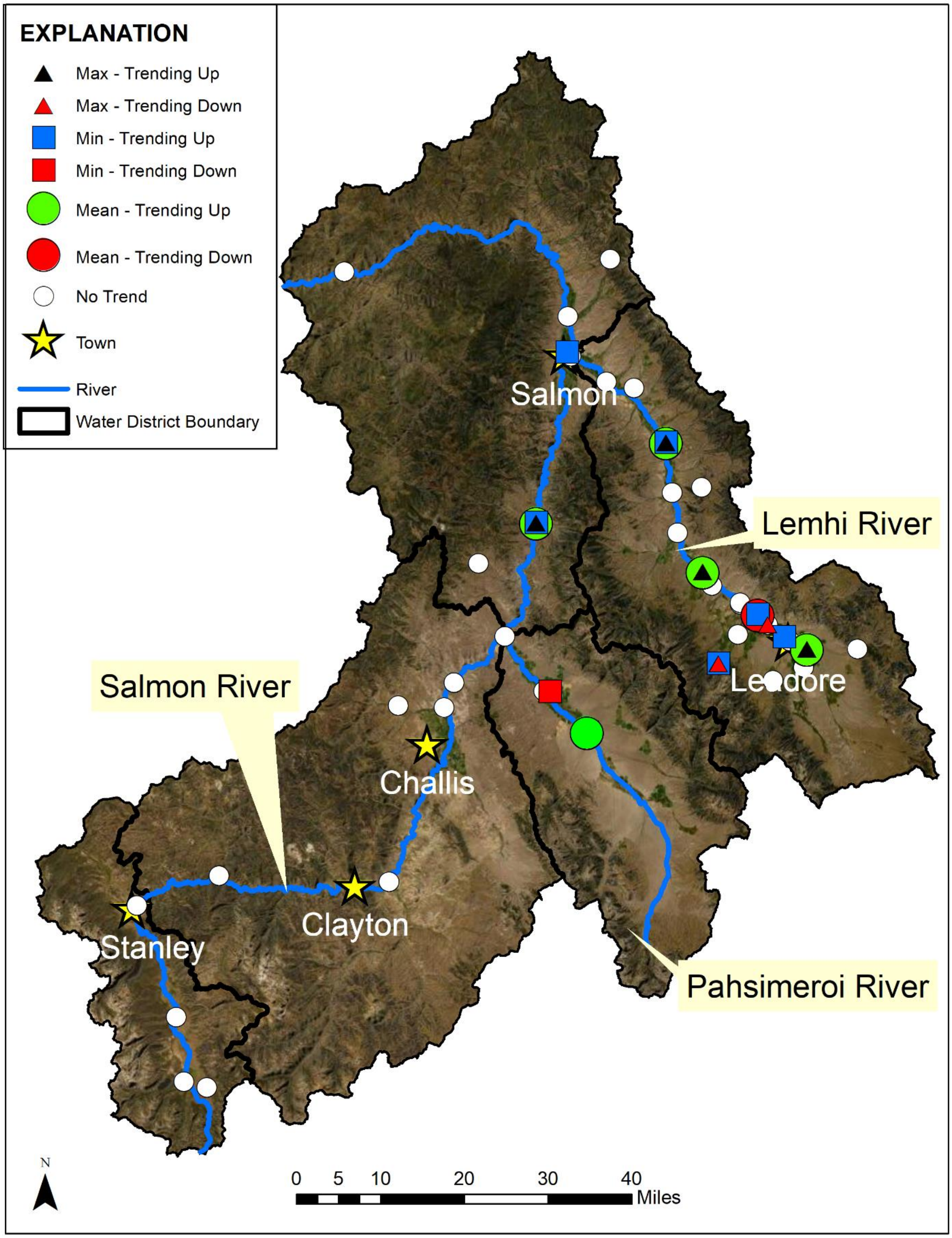

Figure 6. Streamflow trends within the Upper Salmon Basin

Task 1b - Groundwater Level Data Collection and Analysis

Groundwater Data Collection

Groundwater level data is required to determine how changes to land use, stream channel morphology, water management, and climate impact both groundwater and surface water resource availability in the Lemhi River Basin. Understanding interactions between groundwater and surface water is especially important in Idaho where water resources are subject to conjunctive management. As such, groundwater levels and streamflow data have been used to characterize these interactions, and to help water managers and habitat improvement projects to make informed decisions when considering alterations to basin hydrogeology.

The Lemhi River Basin Groundwater Monitoring Network currently consists of 41 wells (Table 5, Figure 7). The network started with 38 wells during project Phase 1 and Phase 2, while five wells were added during Phase 3, and two wells were discontinued during phases 4 and 5. The period of record for wells in the network ranges from three to nine years in duration. Additional data was collected at 32 of the 41 wells during a study in 1995 to 1997 (Donato 1998; Table 5).

IDWR equipped 24 wells with non-vented In-Situ Level Troll data loggers (Instrumented Wells, Figure 7), which monitored water levels and temperature year-round, recording data every twelve hours. A calibrated electric tape was used to manually measure groundwater levels at the instrumented wells on a bi-annual basis and ensure the accuracy of the pressure transducer data. In addition, Water District 74 was subcontracted to manually measure depth to water at 18 wells on a bi-weekly basis from March through November of 2020 and 2021 (Non-Instrumented Wells, Figure 7). Instrumented Well 16N 25E 20 BDD1 was discontinued in late 2021, as the owner removed the monitoring equipment when a new pump was installed. Monitoring may continue at this well at a future date if the landowner permits.

Groundwater levels from both instrumented and non-instrumented wells for water years 2020 and 2021 have been posted to the IDWR Groundwater Levels Data Portal at https://idwr-groundwater-data.idaho.gov/applications/public.html?publicuser=public#waterdata/stationoverview. All published data may be considered finalized.

Table 5. 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	45.07869	-113.69151	Instrumented	2016 - present	Operated by IDWR
20N 23E 11ADD2	45.07869	-113.69151	Instrumented	2016 - present	Operated by IDWR
20N 23E 11DBB1	45.07641	-113.69766	Instrumented	2016 - present	Operated by IDWR
20N 23E 11DBB2	45.07689	-113.69850	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
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 04ADC1[1]	44.84722	-113.61015	Instrumented	2015 - 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 - 2021	Discontinued
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[1]	44.68380	-113.35352	Instrumented	2015 - present	Operated by IDWR
15N 26E 09ADD2[1]	44.64458	-113.35482	Non-Instrumented	2015 - 2016	Discontinued

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

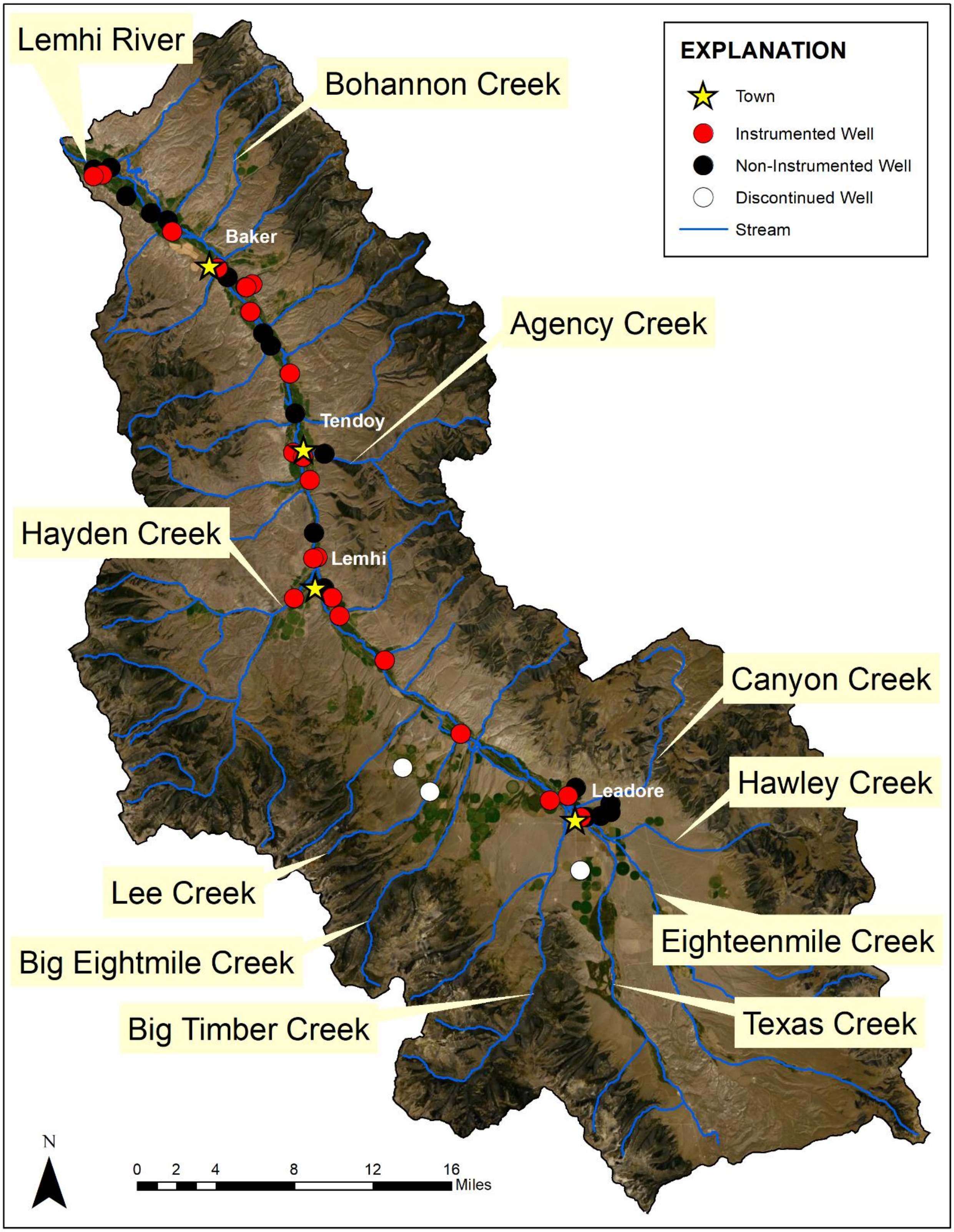


Figure 7. Lemhi River Basin Groundwater Level Monitoring Network

Groundwater Levels Analysis

Out of the 43 wells that IDWR has monitored for groundwater levels in the past six years, 33 were previously measured for groundwater levels from early 1995 through 1997 (sometimes early 1998) during the Donato (1998) study. As a result, it is possible to compare groundwater levels from Donato (1998) to those recorded more recently to determine if there have been any significant changes in depth to water over time. A summary of all collected data as well as depth to water summary statistics are depicted in Table 6. Mann-Whitney U Tests (Table 7) were performed to determine if there were any differences between the 1995-1997 groundwater levels and more recent water levels (varying record between 2011-2021). Well sites with Mann-Whitney p-values less than 0.05 were determined to have different water levels in recent times than they did in 1995-1997 (95% confidence), while the null hypothesis that water levels have not changed over time cannot be rejected at well sites with p-values greater than 0.05.

Table 6. Summary Statistics - All Groundwater Level Data

Well Number	Record	Instrumentation	n	Min	Max	Mean	Std. dev.
15N 26E 09ADD2	1996-1998	Non-Instrumented	32	133.20	157.20	143.49	5.23
	2015-2016	Non-Instrumented	37	155.17	161.17	158.91	1.70
16N 25E 03BCC1	1996-1997	Non-Instrumented	41	15.30	25.00	21.41	2.98
	2011-2021	Instrumented	25516	13.55	26.95	24.62	1.46
16N 25E 18BBC1	1996-1998	Non-Instrumented	40	12.45	45.80	24.60	5.84
	2011-2019	Instrumented	5007	22.22	52.79	29.49	3.17
16N 25E 20BDD1	1996-1997	Non-Instrumented	41	0.00	41.50	28.54	10.33
	2015-2021	Instrumented	17719	21.07	53.88	44.40	4.70
16N 26E 21ACA1	1996-1998	Non-Instrumented	43	100.25	121.50	104.86	5.62
	2011-2021	Non-Instrumented	128	103.90	140.60	112.77	9.94
16N 26E 21CAC1	1996-1998	Non-Instrumented	41	14.56	26.91	23.46	3.31
	2011-2021	Instrumented	34243	28.39	31.86	29.96	0.61
16N 26E 26ABB1	1995-1997	Non-Instrumented	40	139.10	161.10	145.77	6.99
	2015-2021	Non-Instrumented	124	141.27	191.27	151.83	9.41
16N 26E 26DBB1	1995-1997	Non-Instrumented	40	113.10	136.00	118.74	6.91
	2015-2021	Non-Instrumented	124	118.00	157.64	126.07	9.57
16N 26E 27CAC1	1996-1998	Non-Instrumented	43	16.95	34.90	20.11	4.58
	2015-2021	Non-Instrumented	187	17.70	47.60	23.20	6.68
16N 26E 27CCB1	1996-1998	Non-Instrumented	33	4.80	9.30	6.10	0.96
	2015-2021	Instrumented	25440	5.97	28.65	7.25	0.45
17N 24E 04ADC1	1995-1997	Non-Instrumented	43	6.85	21.70	15.97	4.03
	2013-2021	Instrumented	21230	2.75	36.24	19.84	7.27
17N 24E 13CBD1	1995-1997	Non-Instrumented	43	7.30	19.80	16.18	3.37
	2015-2021	Instrumented	22276	5.42	21.07	17.42	3.72
18N 24E 16BBB1	1995-1997	Non-Instrumented	44	5.75	11.30	8.07	1.05

	2011-2021	Non-Instrumented	206	1.45	11.95	7.32	1.68
18N 24E 20ADD1	1995-1997	Non-Instrumented	44	3.75	27.05	15.07	9.21
	2015-2021	Instrumented	25451	11.18	41.79	26.84	9.39
18N 24E 21BCD1	1995-1997	Non-Instrumented	44	3.75	27.05	15.07	9.21
	2011-2021	Instrumented	27026	2.62	29.40	16.45	8.96
18N 24E 28DCC3	1995-1997	Non-Instrumented	43	2.65	19.20	11.88	5.38
	2015-2021	Non-Instrumented	129	0.92	27.10	13.02	4.81
18N 24E 31ACD1	1996-1998	Non-Instrumented	41	4.00	22.65	14.92	5.69
	2015-2021	Instrumented	22253	3.23	24.62	17.67	6.24
18N 24E 33ACB1	1995-1997	Non-Instrumented	42	54.40	84.65	69.90	10.95
	2015-2021	Instrumented	21919	68.19	87.70	78.68	5.45
19N 24E 17BBB1	1996-1997	Non-Instrumented	42	3.05	5.50	4.63	0.69
	2015-2021	Non-Instrumented	112	2.55	6.10	4.34	0.73
19N 24E 28ABB2	1996-1997	Non-Instrumented	27	40.15	42.65	41.15	0.84
	2015-2021	Non-Instrumented	129	35.72	41.98	38.14	0.75
19N 24E 29BDA1	1996-1997	Non-Instrumented	43	10.50	17.15	14.40	2.27
	2015-2021	Instrumented	25461	10.37	18.04	14.72	1.85
19N 24E 30AAA2	1996-1997	Non-Instrumented	43	14.60	30.20	19.60	3.44
	2015-2021	Instrumented	25459	9.30	38.29	15.85	5.71
19N 24E 32ADC1	1995-1997	Non-Instrumented	44	1.30	15.05	9.55	5.29
	2013-2021	Instrumented	28009	1.65	37.17	11.04	4.99
20N 23E 03CBA2	1995-1997	Non-Instrumented	40	-1.40	13.80	5.54	4.20
	2011-2021	Instrumented	33540	-1.31	26.21	6.88	5.92
20N 23E 10ABA1	1995-1997	Non-Instrumented	42	1.05	3.60	2.85	0.54
	2015-2021	Non-Instrumented	128	0.42	5.50	2.71	0.66
20N 23E 14DDB1	1995-1997	Non-Instrumented	44	2.05	8.70	5.52	1.72
	2015-2021	Instrumented	25487	0.74	13.08	4.01	2.29
20N 23E 24CDD1	1995-1997	Non-Instrumented	37	1.65	2.80	2.28	0.33
	2015-2021	Non-Instrumented	129	2.00	6.62	3.07	0.67
20N 24E 31DDC1	1995-1997	Non-Instrumented	43	3.00	6.50	4.80	1.14
	2013-2021	Instrumented	23788	2.67	7.90	6.15	1.11
21N 22E 09DDB1	1995-1997	Non-Instrumented	44	1.55	15.75	8.20	5.39
	2011-2021	Instrumented	17653	2.40	18.08	10.08	4.66
21N 22E 10ACD2	1995-1998	Non-Instrumented	46	4.40	24.40	6.58	3.44
	2011-2021	Non-Instrumented	206	3.00	7.95	5.20	1.36
21N 22E 14CDD1	1995-1997	Non-Instrumented	44	0.00	20.40	10.88	5.08
	2011-2021	Non-Instrumented	205	4.25	17.75	9.25	2.71
21N 22E 24DCA1	1995-1997	Non-Instrumented	42	3.85	9.25	5.94	1.00
	2011-2021	Non-Instrumented	206	3.73	7.63	5.82	0.63
21N 23E 30DAC1	1995-1997	Non-Instrumented	39	0.90	5.40	3.61	0.95
	2013-2021	Instrumented	12281	0.97	20.45	4.58	1.42

Table 7. Mann-Whitney Test - All Groundwater Level Data

Well Number	U	U (standardized)	Expected value	Variance (U)	p-value
15N 26E 09ADD2	8	0.000	592	6905.1526	<0.0001
16N 25E 03BCC1	182673.5	-7.211	523078	2228119410	<0.0001
16N 25E 18BBC1	15576.5	-9.213	100140	84249468.48	<0.0001
16N 25E 20BDD1	28331	-10.213	363239.5	1075248440	<0.0001
16N 26E 21ACA1	521.5	-7.941	2752	78869.55569	<0.0001
16N 26E 21CAC1	0	-11.084	701981.5	4011123902	<0.0001
16N 26E 26ABB1	841	-6.274	2480	68193.69146	<0.0001
16N 26E 26DBB1	817	-6.366	2480	68195.36136	<0.0001
16N 26E 27CAC1	1338.5	-6.817	4020.5	154736.8087	<0.0001
16N 26E 27CCB1	86340	-7.898	419760	1782062433	<0.0001
17N 24E 04ADC1	263622.5	-4.793	456445	1618397686	<0.0001
17N 24E 13CBD1	310227.5	-3.997	478934	1781610168	<0.0001
18N 24E 16BBB1	5040.5	1.167	4532	189499.9924	0.243
18N 24E 20ADD1	254888	-6.254	559922	2379294195	<0.0001
18N 24E 21BCD1	506809.5	-1.694	594572	2682607769	0.090
18N 24E 28DCC3	2441.5	-1.172	2773.5	79967.26974	0.241
18N 24E 31ACD1	301063	-3.768	456186.5	1695109869	0.000
18N 24E 33ACB1	257558.5	-4.939	460299	1684846701	<0.0001
19N 24E 17BBB1	2916.5	2.289	2352	60731.85027	0.022
19N 24E 28ABB2	3452	8.013	1741.5	45546.13083	<0.0001
19N 24E 29BDA1	519133.5	-0.586	547411.5	2326944906	0.558
19N 24E 30AAA2	881017	6.917	547368.5	2326587252	<0.0001
19N 24E 32ADC1	488609	-2.377	616198	2881132605	0.017
20N 23E 03CBA2	655019	-0.258	670800	3754334224	0.797
20N 23E 10ABA1	3168.5	1.736	2688	76491.89112	0.083
20N 23E 14DDB1	801408.5	4.928	560692	2385819913	<0.0001
20N 23E 24CDD1	556.5	-7.101	2386.5	66374.23719	<0.0001
20N 24E 31DDC1	193710	-7.049	511420.5	2031251850	<0.0001
21N 22E 09DDB1	254828.5	-3.945	388366	1145545370	<0.0001
21N 22E 10ACD2	6391	3.698	4738	199736.0784	0.000
21N 22E 14CDD1	5142	1.457	4510	187899.6497	0.145
21N 22E 24DCA1	4038	-0.679	4326	179390.0872	0.497
21N 23E 30DAC1	136700	-4.635	239480	491766368.4	0.000

Inspecting Table 7, 25 of the 33 wells showed statistically significant changes in groundwater levels between the 1995-1997 measurements (Donato, 1998) and the more recent measurements (2011-2021). Coupling this data with Table 6, one can see that 20 of the 33 wells had a significantly greater mean depth to water from 2011 to 2021 than they did from 1995 to 1997, while eight wells had decreased depth to water, and five had change in depth to water. These results suggest that the majority of the Lemhi River Basin has experienced a decline in groundwater levels over the past 20 to 25 years.

Given that groundwater and surface water resources are connected, one might expect that decreasing groundwater levels would have led to decreased streamflow. However, this has generally not been the case in the Lemhi River, nor most of its tributaries (see “Streamflow Data Collection and Analysis”). Further investigation would be needed to determine why correlation is poor. Potential studies include more detailed temporal analysis of groundwater levels, characterizing climatic trends, quantifying groundwater usage for irrigation, and lastly, an analysis of trends in natural streamflow (e.g. modelled flows with zero water extraction). Though many of these analyses are beyond the scope of this study, a map was created to visually inspect the spatial distribution of changes to groundwater levels (Figure 8). The Lemhi River at McFarland Gage, as well as the Lemhi River at Lemhi and Lemhi River below L5 (USGS) were included on the figure as points of reference. These gages were chosen for inclusion because they have periods of record dating back to 1998, 1992, and 1938, respectively, and can therefore be used to evaluate correlation between changes to groundwater levels and streamflow.

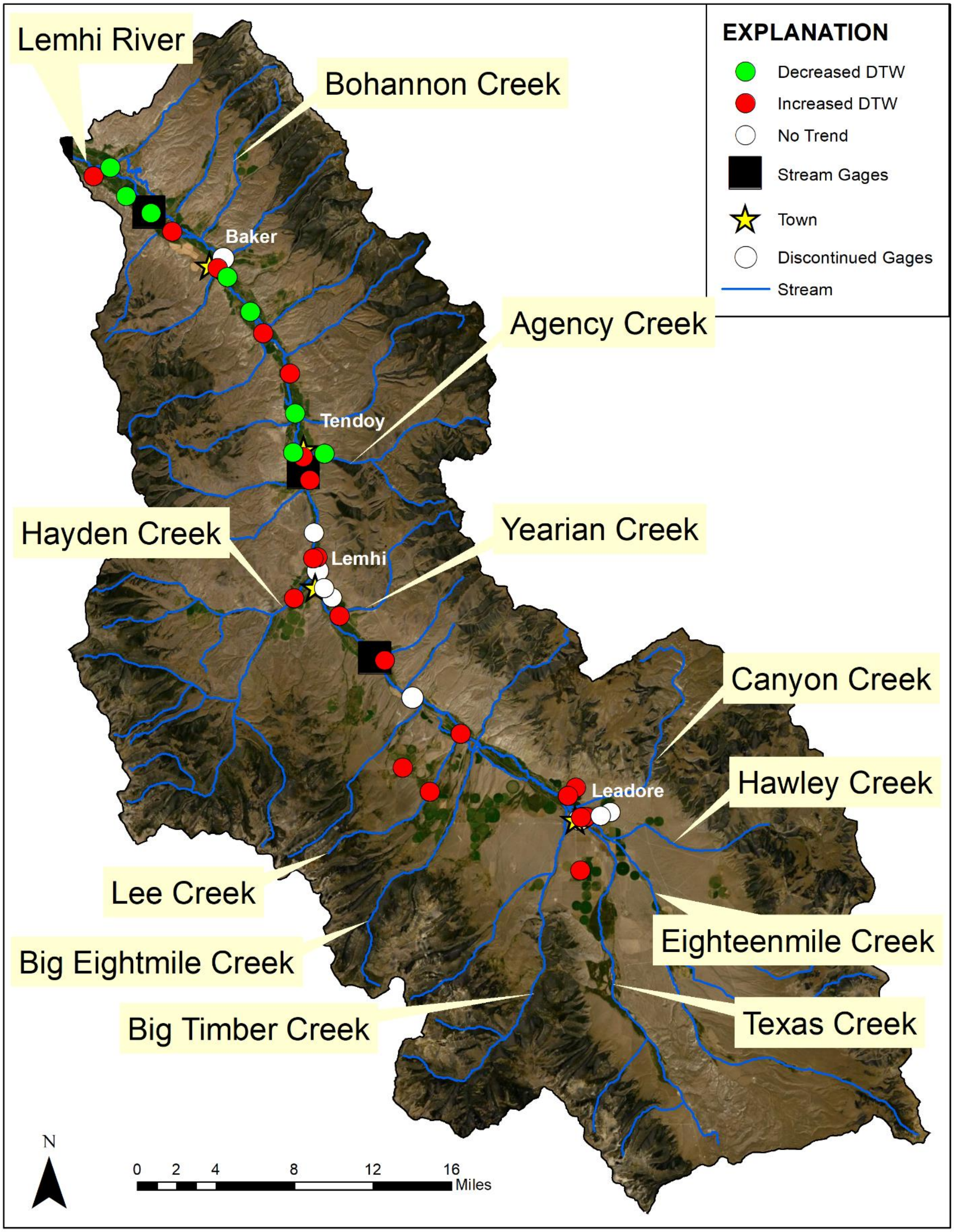


Figure 8. Changes to Groundwater Levels within the Lemhi Basin

Beginning at the Lemhi River headwaters near Leadore, five of seven wells saw increased depth to water between the two periods of record. Moving down gradient (northwest), the next five wells located between the confluences of Big Timber Creek and Yearian Creek all saw increased depth to water. Altogether, ten out of twelve wells in the Upper Lemhi Basin (up-gradient of Yearian Creek) had increased depth to water relative to the 1995 to 1998 period of record.

The three wells between Yearian Creek and Hayden Creek within the alluvial aquifer adjacent to the Lemhi River (Figure 2) had no significant change in groundwater levels. This is the area just upstream of "The Narrows" (see "Study Area and Background"), where groundwater from the deeper and wider alluvial aquifer of the Upper Lemhi Basin is squeezed into a shallow and narrow region (The Narrows), resulting in much of the groundwater being pushed to the surface to flow down the Lemhi River. This region has maintained stable groundwater levels, which could bode well for sustaining streamflow in the lower Lemhi River despite the increased depth to water in much of the upper basin.

Within The Narrows between the Hayden Creek Confluence and the Lemhi River nr Lemhi USGS Gage, four out of five wells had increased depth to water, which is very similar to changes in groundwater levels in the Upper Lemhi Basin. However, changes to groundwater levels were much more variable in the Lower Lemhi Basin (from Tendoy to the outlet of the Lemhi River) than they were upstream. One well adjacent to Agency Creek had decreased depth to water, as did seven wells within the Lemhi River Valley. Through the same stretch, five wells had increased depth to water, and one well had no discernible change.

Despite the increased depth to groundwater in the upper basin, mean annual flow at the Lemhi River at McFarland Gage trended upwards, while minimum and maximum flows show no discernible trend (Figure 5, Figure 8). Moving downstream to the Lemhi River nr Lemhi USGS Gage and the Lemhi River nr L5 USGS Gage, there were no discernible trends in mean, minimum, or maximum streamflow. These results suggest that annual Lemhi River streamflow has remained relatively consistent, regardless of fluctuations in groundwater levels. Changes to water management, irrigation practices, climate, and other factors may have helped to mitigate the impact of declining groundwater levels on streamflow. An analysis of natural streamflow in the Lemhi Basin will be conducted and reported on for the upcoming "Upper Salmon Basin Hydrologic Monitoring and Analyses" project, and these results may help to better characterize the sensitivity of streamflow to changes in groundwater levels.

Task 1c - Soil Moisture Data Collection and Analysis

During previous phases of this investigation, IDWR installed soil moisture stations in agricultural fields where irrigation practices were being altered, as well as adjacent to in-stream habitat improvement projects known as beaver dam analogues (BDAs). The agricultural soil moisture stations are being used to improve our understanding of infiltration dynamics before and after conversion from flood to sprinkler irrigation, while the stations installed adjacent to BDAs are used to characterize the impacts of these habitat projects on local water resources.

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 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 much less likely when only the first couple feet of soil wet up, but 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 8, Figure 9). Two active Stations are located within agricultural fields near Pratt Creek, while the other two are located adjacent to BDAs on Hawley Creek. The agricultural stations contain one soil moisture pit each, while both BDA stations contain two soil moisture pits (one nearer to the stream channel and one further away). Each Station has been visited biannually to download data and maintain the equipment. All recorded data will be posted to the project website at https://idwr.idaho.gov/water-data/projects/upper-salmon/references/. Additional data visualization for some of the Hawley Creek BDA Soil Moisture Stations and the Pratt Creek Agricultural Soil Moisture Stations are available below (Figure 10, Figure 11).

Table 8. 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

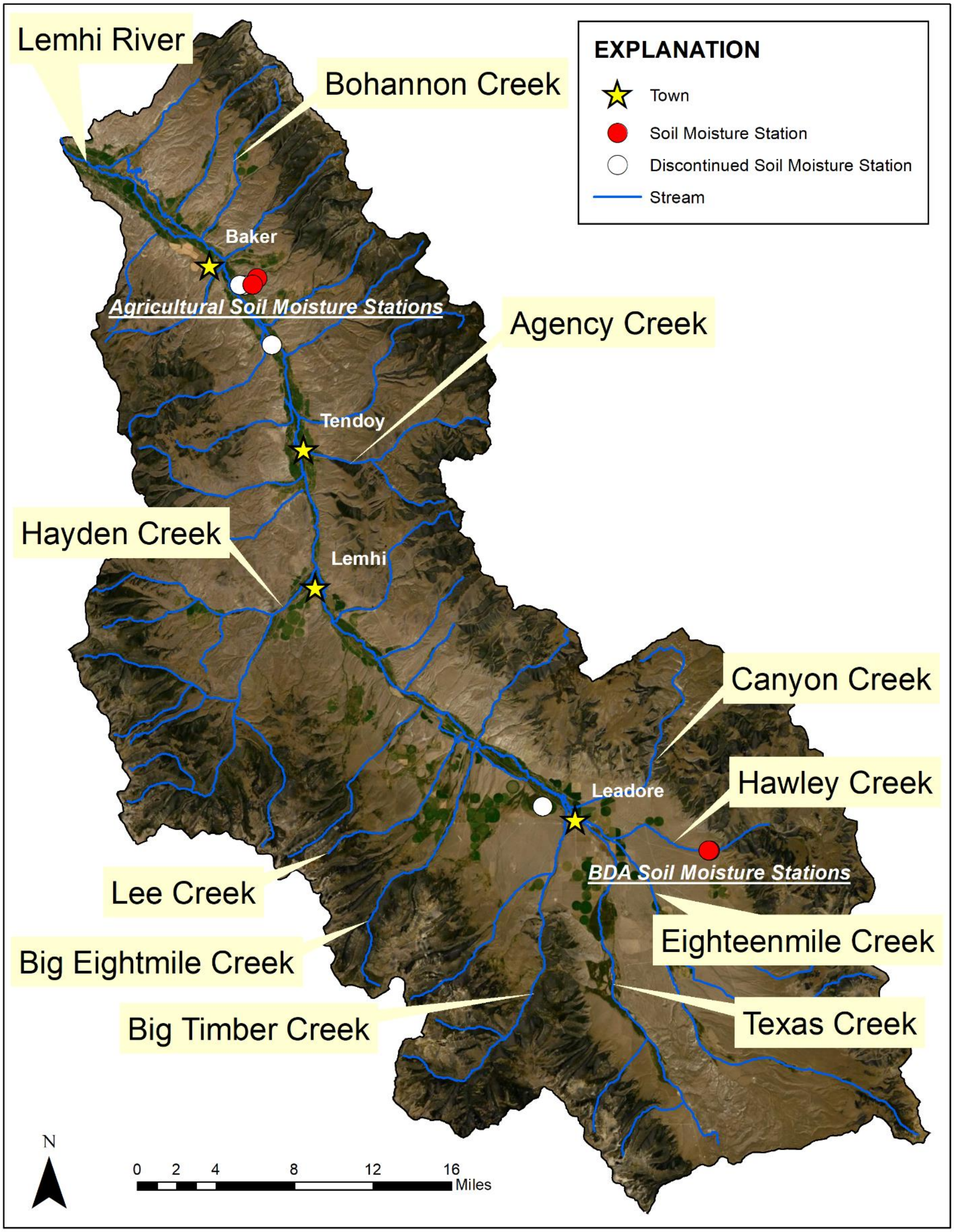


Figure 9. Lemhi River Basin Soil Moisture Monitoring Network

Soil Moisture Data Analyses

Soil Moisture near Hawley Creek (Table 8 - BDA5):

Beaver Dam Analogue (BDA) 5 was installed along Hawley Creek in September, 2017. This BDA is one of a series of BDAs that were installed to improve in-stream habitat for salmonids and to increase moisture retention within stream-adjacent soils. Additional soil moisture would allow for growth of more riparian vegetation, which provides coverage for fish and habitat for other wildlife. Riparian vegetation also produces shade which reduces daily streamwater temperature fluctuations, stabilizes streambank soils, absorbs excess nutrients (e.g. from irrigated agriculture), allows for natural placement of woody debris (increases in-stream habitat diversity), and slows the velocity of over-bank flow during floods, causing greater floodplain deposition of fine soils. Following completion of the BDA, soil moisture sites were installed to evaluate local soil moisture retention.

Two soil moisture pits were dug, one in an often inundated area, and one on the streambank, which was slightly elevated relative to the inundated area (see IDWR, 2019 for diagrams of the BDA locations). In each pit, soil moisture sensors were installed at 1, 3, and 5 feet below the ground surface, along with a temperature sensor at 1 foot below ground surface. The sensors record water tension in centibars. All else being equal (e.g. consistent soil texture), the higher the tension, the less water is contained in the soil pores, and the less water is available for usage by plants and other organisms. Monthly mean soil moisture tension timeseries were plotted (Figure 10, Figure 11), and lines were included to indicate the thresholds at which point soil has likely reached the wilting point (when soil water is held too tightly within the soil for plants roots to extract water), field capacity (when excess soil moisture has drained away and the rate of water movement has decreased to near zero), and saturation (when soil pores are full of water). Note that there was a data gap between August, 2019 and June, 2020 when visually inspecting Figure 10 and Figure 11.

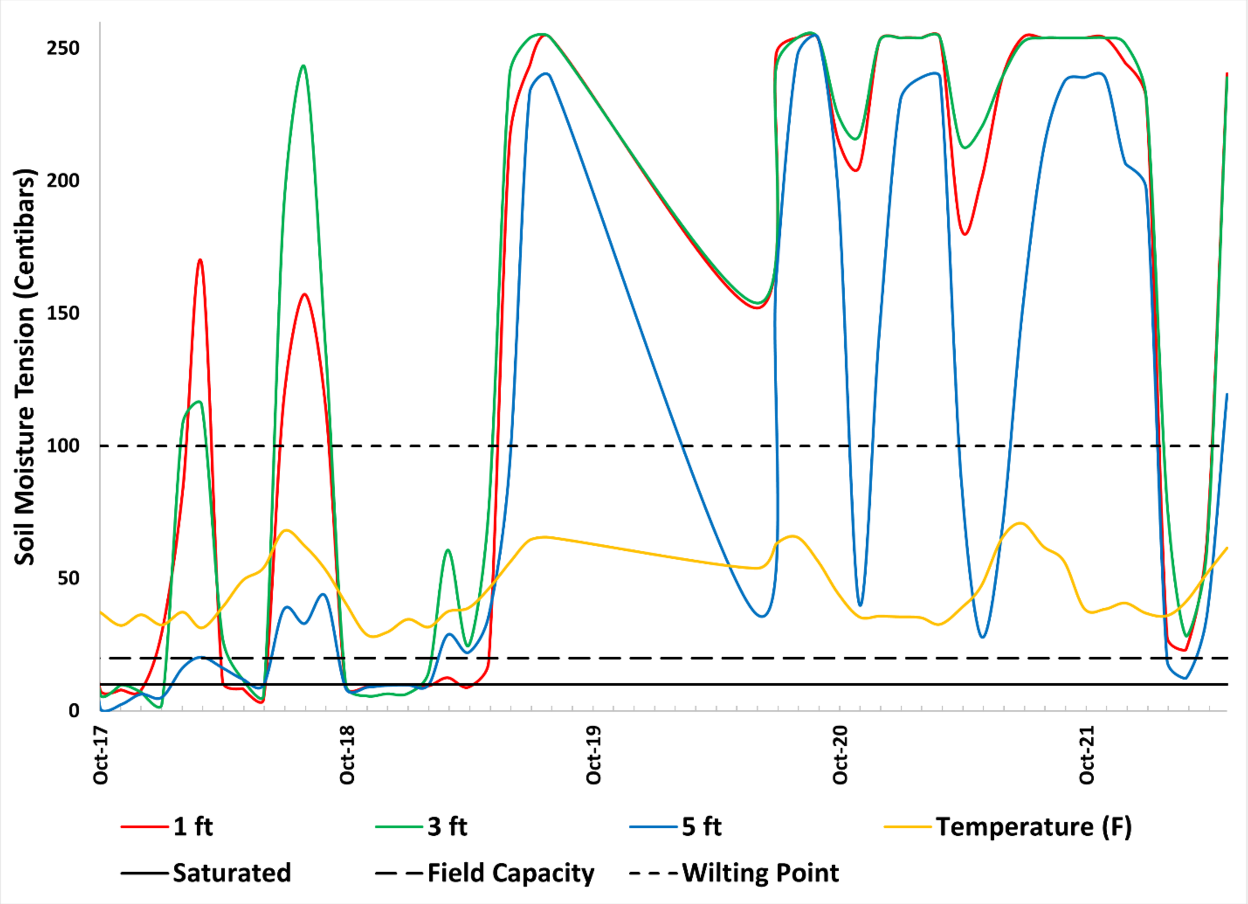


Figure 10. Average Monthly Soil Moisture Tension at Beaver Dam Analogue 5 – Inundated Site

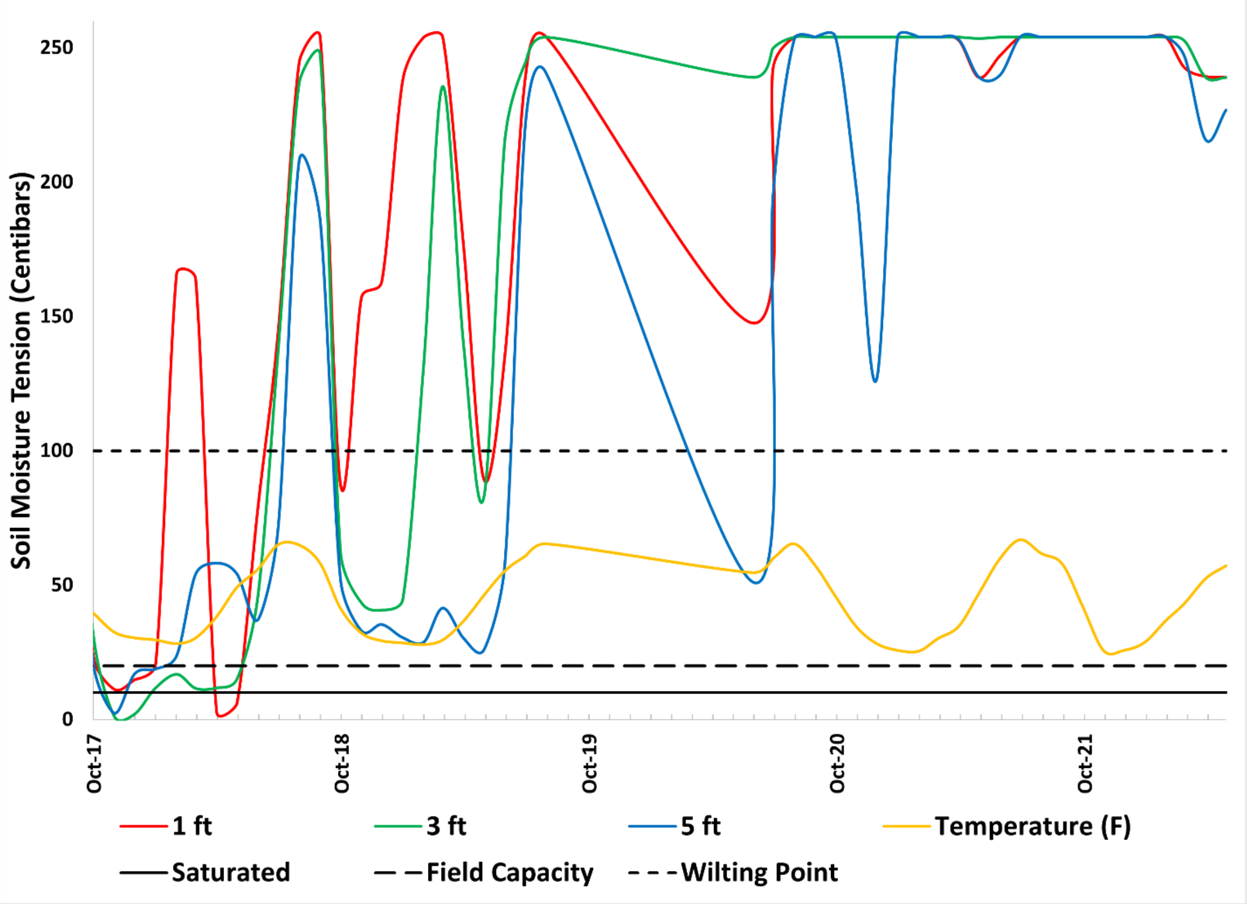


Figure 11. Average Monthly Soil Moisture Tension at Beaver Dam Analogue 5 – Streambank Site

Reviewing soil moisture data at the inundated and streambank pits (Figure 10, Figure 11), an annual cycle of rising and falling soil moisture tension is observed. Tension at both sites and at all depths typically spiked at some point between December and February, and again at some point between June and September, though deeper soil remained wetter (lower soil moisture tension) throughout the cycle. In the summer months, this spike in tension (decrease in soil moisture content) is likely caused by both natural drying of the soil column and decreasing streamwater stage within Hawley Creek, while freezing of the ground surface and/or Hawley Creek itself may be a factor during the winter months. As might be expected, the inundated site shows lower soil moisture tension than the streambank site on average. However, both sites also had increasing soil moisture tension year over year, excluding a return to lower tension levels at the inundated site in spring, 2022. Of note is that the nearby beaver dam analogues were breached in 2021, so the spike in soil moisture levels seen in spring, 2022 was likely caused by natural rainfall and runoff, rather than a pool of water behind the BDA.

One possible explanation for the upward trend in annual mean soil moisture tension is that the BDAs slowed the rate of water transport to the point that clay and silt settled out and were deposited on the ground surface, thereby making the soil above the sensors less permeable. This would cause a decrease in soil moisture (increase in tension) primarily in two ways. First, the clayey soils have finer pores, and therefore water is naturally held at higher tension levels. And second, the decreased permeability of the finer grained shallow soil may cause more water to pool near the ground surface, rather than infiltrate into the ground. It is likely that riparian vegetation would still utilize this water, as the roots may extract more water from increasingly shallow depths. The fact that water was allowed to flow more freely in late 2021 and early 2022 (due to the BDA being breached), and spring, 2022 saw an increase in wet up in the inundated soil moisture pit supports this thesis. The faster flow rates may have removed some of the fine sediment, thereby restoring greater permeability to the upper portion of the soil column. Further research is needed to determine whether this was the cause of the observed changes in soil moisture tension or if other factors were responsible.

Soil Moisture in an agricultural field adjacent to Pratt Creek (Table 8 - SnookF1 and SnookF2):

Two soil moisture stations were installed in an agricultural field adjacent to Pratt Creek. SnookF1 is further upstream, and SnookF2 is roughly ½ mile down-gradient in the same field. SnookF1 is displayed here (Figure 12) because both soil moisture pits displayed similar trends and there were less data gaps in the SnookF1 dataset. The irrigation method for this agricultural field was changed from flooding to wheel-line sprinklers prior to the start of the 2018 irrigation season.

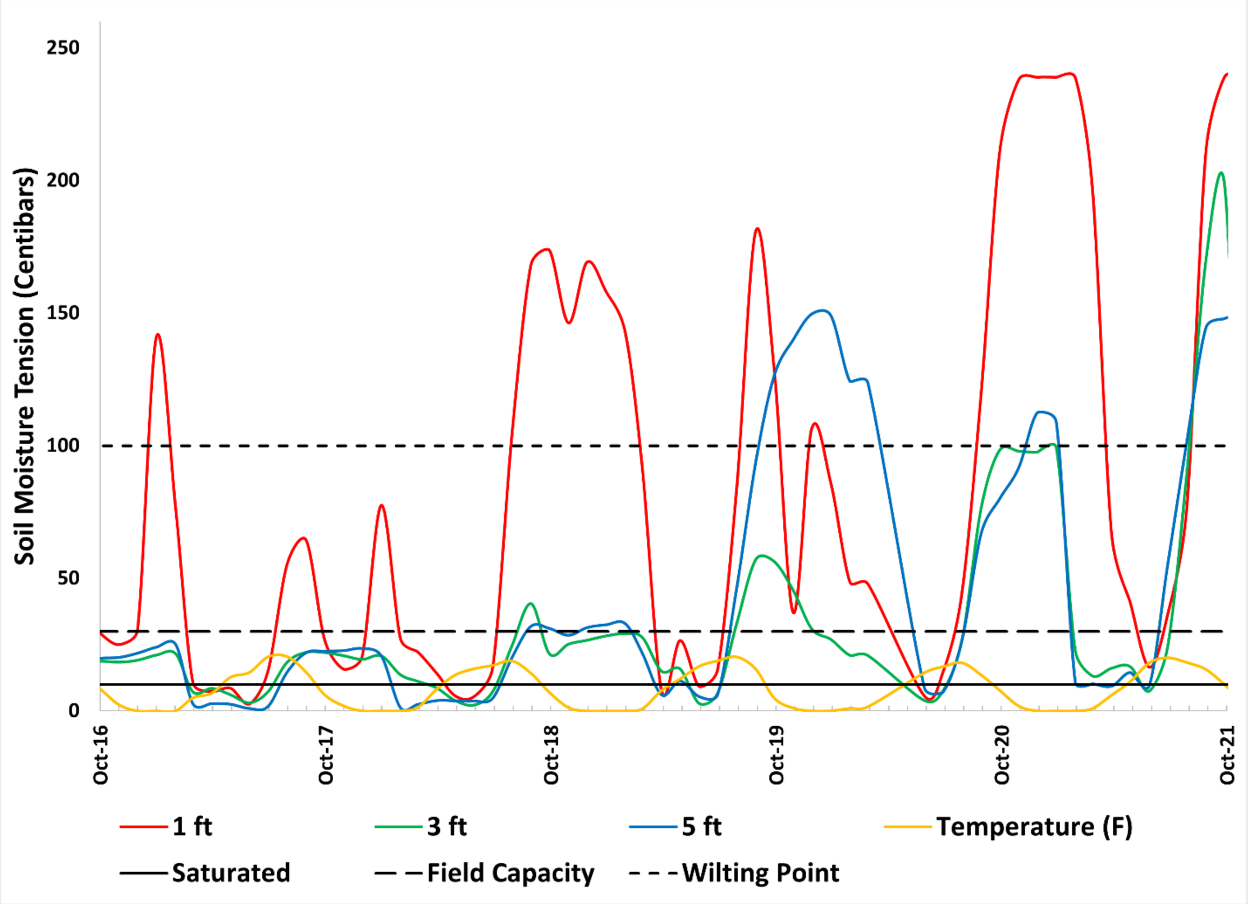


Figure 12. Average Monthly Soil Moisture Tension in an agricultural field (SnookF1)

When evaluating soil moisture at SnookF1, it is clear that there was a change to average monthly soil moisture after the transition from flood to sprinkler irrigation in early 2018. Soil moisture at all depths is decreased (tension increased). Prior to 2018, only the sensor at one foot depth ever exceeded field capacity. However, beginning in 2018, tension at one, three, and five foot depths began exceeding field capacity on occasion. By 2019, soil moisture tension three feet below ground surface began exceeding wilting point during the non-irrigation season. By 2022, soil moisture tension down to five feet began exceeding wilting point during the non-irrigation season. This trend is not surprising, as sprinkler irrigation is typically more efficient than flood irrigation from a water usage perspective, and there is no financial incentive for a farmer to keep soil wetted up during the non-irrigation season. Soil moisture tension at each depth was driven down to below field capacity during each irrigation season. Given this trend in declining soil moisture with the transition from flood to sprinkler irrigation, a common question amongst water users, managers, and conservationists is whether this causes a net decrease to groundwater levels or streamflow. Groundwater level data from nearby monitoring wells will be used to address this question during the next study.

Task 2. Aerial Photograph Analysis of Changes in Irrigation Practices

The scope of the aerial photograph analysis was modified from the scope detailed in the project proposal due to time constraints and other considerations. Nevertheless, an analysis of changes to irrigation practices was conducted and may serve to inform future habitat work and streamflow modelling investigations.

Aerial imagery of the Lemhi Basin was downloaded from the National Agriculture Imagery Program (NAIP) for the growing seasons of 2004 and 2021. These datasets were selected because they are the oldest (2004) and the youngest (2021) NAIP imagery available to IDWR, and as such, can provide information on changes to irrigation over the longest possible time period. Imagery from both years was analyzed to quantify irrigated lands and to differentiate between agricultural plots irrigated via flood and sprinkler systems.

Irrigated lands were delineated by manually drawing polygons around every plot of land that appeared to be irrigated. The imagery was then visually inspected with the aid of the Data Atlas (see “Status of the Lemhi River Basin Model”) which contains diversion, water rights, water use, and other pertinent information, to determine if the irrigation method was flood or sprinkler irrigation (including pivot systems, hand lines, wheel lines, etc.). Areas irrigated by sprinkler were shaded red on the generated maps (Figure 13, 14), while areas irrigated via flood were shaded blue. All sprinkler systems were displayed as one color to simplify visualization, and because the type of sprinkler system is seen as much less consequential to the impact of irrigation practices on hydrogeology than the distinction between flood and sprinkler. Both visualization and computation of changes to irrigation practices were completed with the primary inquiries of the USBWP and other stakeholders in mind. First, how much land has changed from flood to sprinkler irrigation? If changes have occurred, to what degree might the change in irrigation practices impact basin hydrogeology?

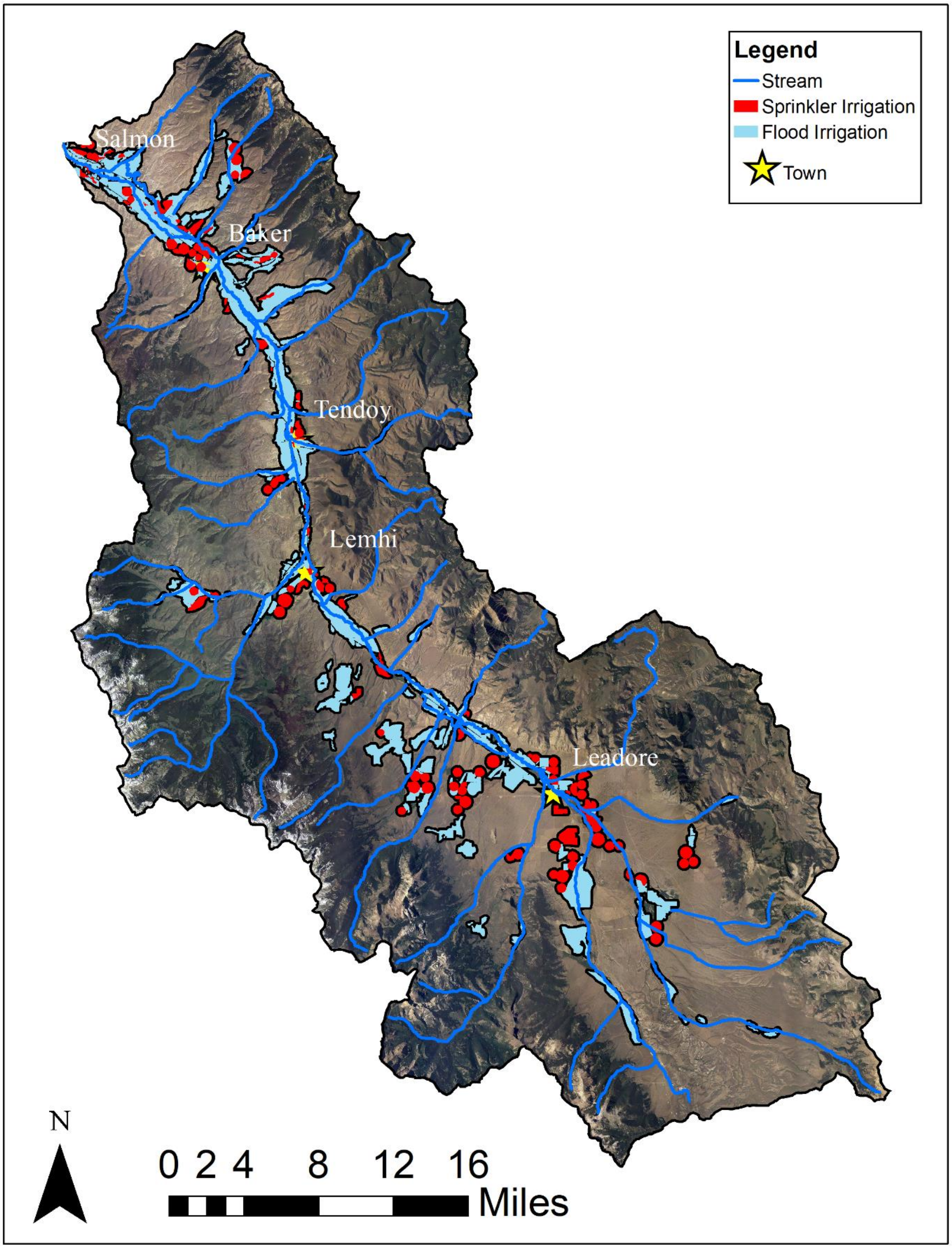


Figure 13. Delineation of lands irrigated by flood and sprinkler irrigation in 2004

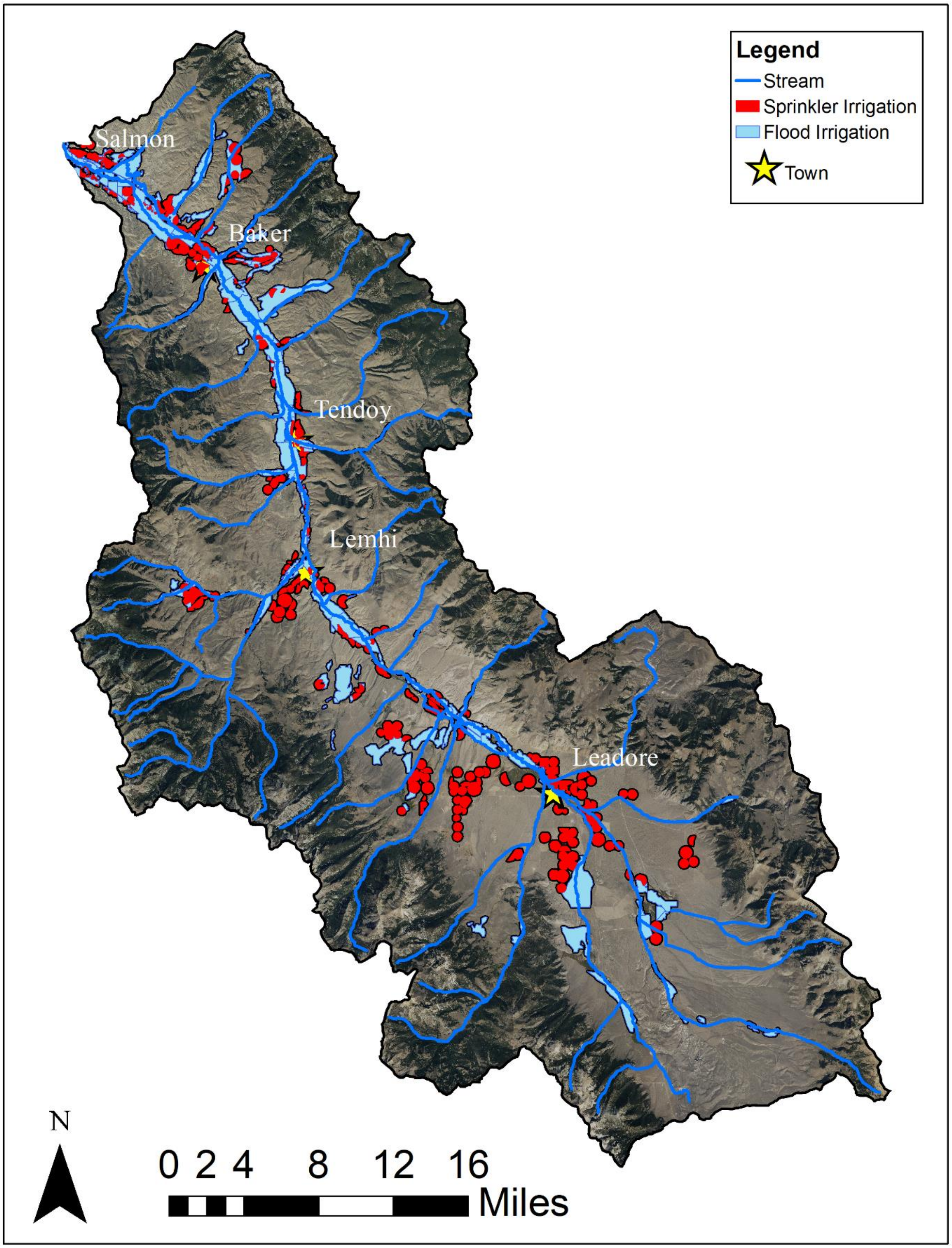


Figure 14. Delineation of lands irrigated by flood and sprinkler irrigation in 2021

From visual inspection of Figures 13 and 14, it appears that the total amount of irrigated lands in the basin has remained relatively stable from 2004 to 2021. Indeed, summing all irrigated lands in 2004 yielded 52,733 acres, while the same analysis yielded 51,636 acres in 2021 (Table 9). However, these maps also show that there was a net migration from flood to sprinkler irrigation over the same period, as sprinkler-irrigated acreage increased from 13,601 acres to 21,386 acres from 2004 to 2021 (Table 9). In percentage terms, Lemhi Basin sprinkler usage per unit irrigated area increased from 25.8% to 41.4%.

Given that the Lemhi Basin can be separated into two distinct hydrogeologic zones as a result of the hydrologic constriction known as The Narrows (see "Study Area and Background"), the areas irrigated by flood and sprinkler are also detailed for the regions characterized as the Upper Lemhi Basin and Lower Lemhi Basin (see Figure 2 for the dividing line between the two subbasins). Both the Upper and Lower Lemhi Basin saw increases to the total acreage of sprinkler irrigation and the percentage sprinkler irrigation relative to total irrigated area. The percentage of irrigated area serviced by sprinkler systems increased from 30.6% to 52.2% in the Upper Lemhi Basin, making the majority of the irrigated area in this region serviced by sprinkler systems. At the same time, the Lower Lemhi Basin saw an increase in sprinkler usage from 19.5% to 27.9%.

Table 9. Changes to Lemhi Basin Irrigation Practices from 2004 to 2021

Region	Year	Irrigated (Acres)	Flood Irrigation (Acres)	Sprinkler Irrigation (Acres)	Flood Irrigation (%)	Sprinkler Irrigation (%)
Lemhi Basin	2004	52733	39132	13601	74.2%	25.8%
Lemhi Basin	2021	51636	30250	21386	58.6%	41.4%
Upper Lemhi Basin	2004	29754	20637	9117	69.4%	30.6%
Upper Lemhi Basin	2021	28717	13714	15003	47.8%	52.2%
Lower Lemhi Basin	2004	22979	18495	4484	80.5%	19.5%
Lower Lemhi Basin	2021	22919	16536	6383	72.1%	27.9%

The results displayed in figures 13 and 14, as well as table 9 serve to quantify the net rate of conversion from flood to sprinkler irrigation within the Lemhi Basin from 2004 to 2021. In the next study, these results will be used in conjunction with the Lemhi River Basin Model (see "Status of the Lemhi River Basin Model") to estimate the hydrologic impacts of converting this amount of irrigation from flood to sprinkler systems.

Task 3. Surface Water Quality Data Collection and Analysis

IDWR began a water quality study during this project phase. The goal of this study was to measure water quality field parameters throughout the Lemhi Basin and identify areas where salmonid habitat may be degraded due to poor water quality. The data provides baseline water quality information and was used to aid the design of the next study that will include the collection and analysis of grab samples. Data was collected and analyzed as outlined in the original project proposal, with a few modifications.

The proposed scope was to collect data at 10 stream gage locations on a monthly basis (conditions permitting), as well as at 11 additional gages on a quarterly basis. That plan was modified to allow for less frequent monitoring at the 10 stream gage sites (to align with regular IDWR visits to the Lemhi Basin approximately every six weeks), extra measurements at the additional 11 gage sites, and varied measurements at 20 extra sites that were discovered when searching for easily accessible monitoring locations. In total, water quality field parameters were measured at 42 sites during 10 separate field visits between 7/21/2020 and 12/3/2021 (Table 9, Figure 15).

Table 9. Lemhi Basin Surface Water Quality Measurement Sites

Water Quality Measurement Site	Latitude	Longitude	Measurements
Agency Creek at Old 28	44.959	-113.644	8
Bayhorse Creek Gage	44.379	-114.257	8
Big Eightmile Creek Lower Gage	44.694	-113.482	7
Big Eightmile Creek Upper Gage	44.644	-113.529	7
Big Springs Creek Lower Gage	44.728	-113.433	7
Big Springs Creek Upper Gage	44.712	-113.411	1
Big Timber Creek Lower Gage	44.687	-113.367	6
Big Timber Creek Upper Gage	44.614	-113.397	7
Bohannon Creek at Lemhi Rd	45.114	-113.744	7
Bohannon Creek Upper Gage	45.191	-113.691	7
Canyon Creek at Old 28	44.692	-113.354	7
Eighteenmile Creek at Old 28	44.683	-113.355	7
Eighteenmile Creek Gage	44.668	-113.313	6
Hawley Creek BDA4	44.658	-113.221	4
Hawley Creek BDA5	44.658	-113.222	4
Hawley Creek Upper Gage	44.667	-113.192	9
Hawley Creek Middle Gage	44.659	-113.216	4
Hayden Creek Gage	44.868	-113.628	6
Haynes Creek at Price Creek Rd	45.030	-113.679	3
Kenney Creek at Back Rd	45.027	-113.654	7
Kirtley Creek at Old 28	45.165	-113.841	5
Lee Creek Gage	44.746	-113.476	10
Lemhi above Big Springs Gage	44.729	-113.433	8
Lemhi above Hayden	44.868	-113.624	6
Lemhi above L-63 Gage	44.682	-113.356	8

Lemhi at Baker Gage	45.097	-113.721	8
Lemhi at Cottom Ln Gage	44.749	-113.476	7
Lemhi at L-1 Gage	45.178	-113.887	7
Lemhi at McFarland Gage	44.803	-113.566	8
Lemhi River nr Lemhi USGS Gage	44.940	-113.639	8
Little Eightmile Creek at Old 28	44.743	-113.459	4
Little Sawmill Creek at 28	44.849	-113.620	8
Little Springs Creek Lower Gage	44.780	-113.544	8
McDevitt Creek at Mabey Ln	44.933	-113.640	2
Mill Creek at 28	44.767	-113.516	5
Muddy Creek at McDevitt Creek Rd	44.933	-113.638	3
Pattee Creek at Lemhi Rd	44.981	-113.640	6
Pratt Creek at Lemhi Rd	45.076	-113.697	8
Sandy Creek at Lemhi Rd	45.050	-113.670	7
Texas Creek Gage	44.632	-113.325	9
Wimpey Creek at Old 28	45.098	-113.720	8
Withington Creek at 28	45.092	-113.724	3

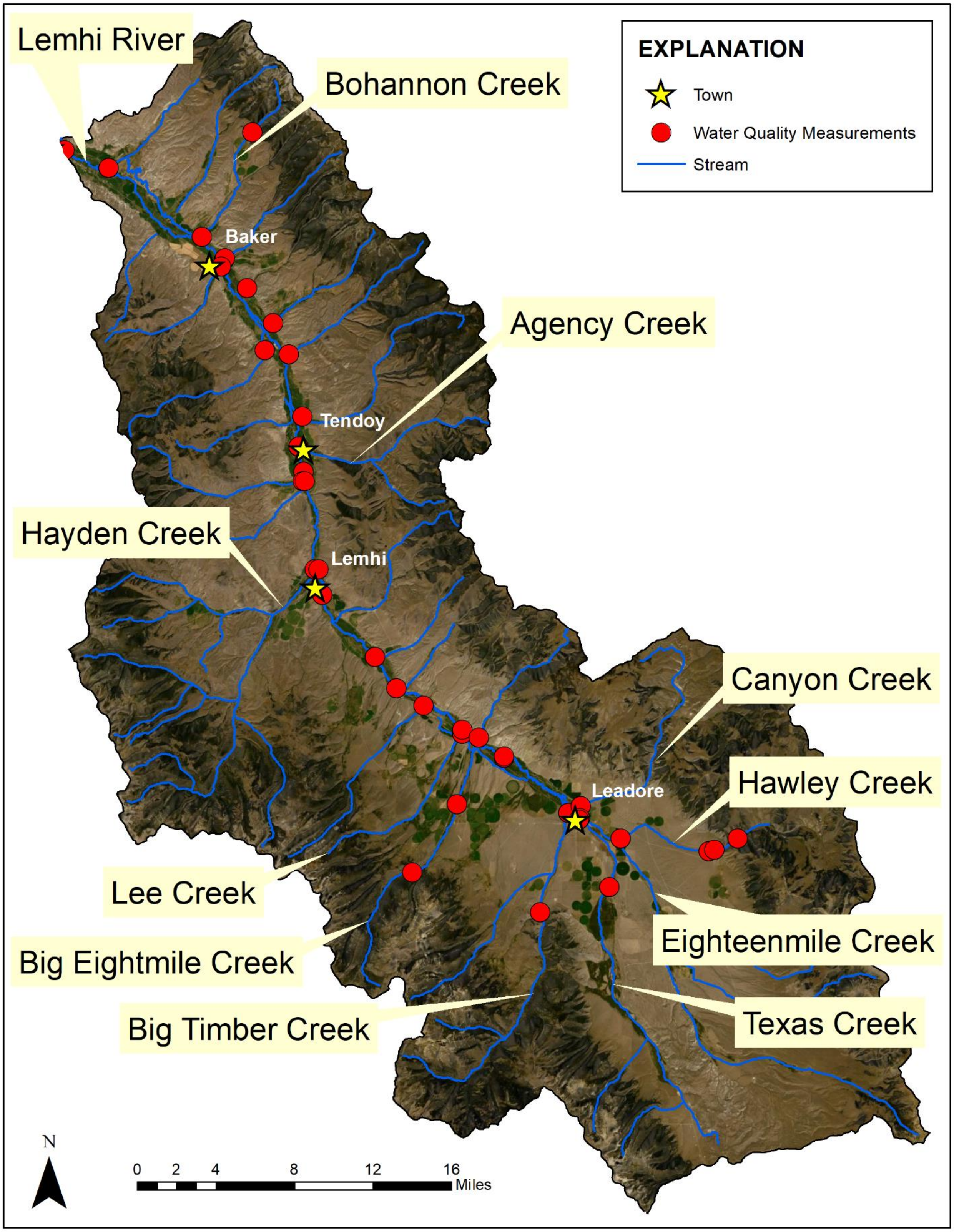


Figure 15. Lemhi River Basin Surface Water Quality Monitoring Sites

Surface Water Quality Analyses

Measured surface water quality parameters included dissolved oxygen (DO), temperature, pH, and turbidity. The data was compared to ranges of water quality values considered suitable for salmonid habitat. Values for each parameter were compiled into tables and highlighted different colors to indicate varying degrees of habitat suitability. Instances of poor water quality for each parameter were also mapped to visualize the geographic extent of water quality issues. Water quality data for DO, pH, and turbidity were collected via discrete, manual measurements (Tables 10-13, Figure 15), while temperature was recorded via both continuous measurements (Table 14) and discrete measurements (available upon request).

All manual measurements were recorded using an In-Situ Aqua Troll 500 Multiparameter Sonde equipped with sensors to measure DO, pH, turbidity, and temperature. Each sensor was calibrated once before data collection on each day that measurements were taken. Data was collected by placing the sonde near the streambed and within water estimated to be flowing at an average rate within a stream cross section. Alternatively, continuous water temperature measurements were recorded every 15 minutes at IDWR managed stream gages (Figure 6) using In-Situ Level Troll Data Loggers or HOBO Pendant Temperature Data Loggers. The continuous temperature data loggers were placed near the streambed and typically nearer to the streambank, along with the stream gaging equipment.

DO suitability levels (Table 10) were defined relative to the requirements of incubating salmonid eggs, as eggs require more oxygen than other life stages, and the eggs of Chinook or Steelhead may be incubating year-round outside of August (Carter, 2005). DO concentrations above 9.75 mg/L are considered optimal (green shading), while 8 - 9.75 mg/L is suitable (yellow shading), less than 8 mg/L is poor because it results in oxygen distress for average eggs (red shading), and less than 6.5 mg/L is very poor because it results in oxygen distress for a large percentage of eggs (dark red shading; Davis, 1975). However, it is important to note that the DO measurements presented here were taken from the water column, while incubating salmonid eggs reside in the inter-gravel space in the streambed. Furthermore, DO concentrations within the inter-gravel space are estimated to be 1 to 3 mg/L less than in the water column (WDOE, 2002). As a result, DO levels are likely to be less suitable to salmonid eggs than is presented here.

Table 6. Surface Water Quality Data - Dissolved Oxygen (mg/L)

Site	Jul-20	Sep-20	Dec-20	Mar-21	Apr-21	Jun-21	Jul-21	Aug-21	Oct-21	Dec-21
Agency Creek at Old 28	8.40	9.41	10.06	11.44	8.84	8.39	8.07	9.22		
Bayhorse Creek Gage		9.65		10.69	8.26	8.86	6.95	8.12	8.53	10.00
Big Eightmile Creek Lower Gage	8.40	9.74	11.55	10.43		8.17	7.77	8.31	10.06	10.36
Big Eightmile Creek Upper Gage	8.20	8.92			9.89	8.21	8.25		9.81	10.23
Big Springs Creek Lower Gage	7.90	10.04		9.19	8.09	9.42	9.29	9.51		
Big Timber Creek Lower Gage	7.30	9.68			8.52	8.48	7.59	8.12		
Big Timber Creek Upper Gage	7.50	9.07			10.30	8.31	8.24	8.77	9.55	
Bohannon Creek at Lemhi Rd	8.90	8.99	11.29	11.91	8.38	8.83	8.07	7.91		
Bohannon Creek Upper Gage		9.72			10.41	9.22	9.06		9.30	10.06
Canyon Creek at Old 28	7.30	9.27	11.36	11.39	9.32	7.40	7.56	8.25		

Eighteenmile Creek at Old 28	9.60	9.68		11.22	9.42	8.55	7.86	10.04		
Eighteenmile Creek Gage	7.00	10.58		10.58	9.93	9.39				11.12
Hawley Creek BDA4				9.37		7.54	7.99		9.90	
Hawley Creek BDA5				9.33			8.11	8.02	9.87	
Hawley Creek Upper Gage	8.00	10.01	11.31	9.30		7.71	8.28	8.89	9.39	
Hawley Creek Middle Gage					10.53	7.81	8.45	9.15	9.67	
Hayden Creek Gage	8.70	9.52		10.95	8.78	9.36	8.25	8.57		
Haynes Creek at Price Creek Rd	9.10					9.22	7.91			
Kenney Creek at Back Rd	9.10	9.98		11.97	8.78	9.34	8.53	9.11		
Kirtley Creek at Old 28	8.40	7.91		11.81	7.68	9.64				
Lee Creek Gage	9.20	8.51	12.25	9.76	8.67	6.84	8.65	8.43	9.49	10.11
Lemhi above Big Springs Gage	8.80	10.01	11.85	10.18	9.09	9.70	10.21	9.88		
Lemhi above Hayden	10.90		11.50	11.89	9.37	9.33		9.88		
Lemhi above L-63 Gage	8.70	9.09	9.49	9.86	9.03	8.98	6.77	9.45		
Lemhi at Baker Gage	9.00	8.69	12.51	12.83	8.92	8.62	7.60	9.33		
Lemhi at Cottom Ln Gage	8.80	9.61	11.62	10.62		7.77	8.51	9.38		
Lemhi at L-1 Gage	8.60	9.78		11.93		7.46	8.65		9.54	11.79
Lemhi at McFarland Gage	10.40	9.68	12.17	12.05	9.54	9.39	8.41	10.39		
Lemhi River nr Lemhi USGS Gage	10.10	8.99	11.46	11.28	9.76	9.24	8.08	8.45		
Little Eightmile Creek at Old 28	9.70					8.51	9.20	10.49		
Little Sawmill Creek at 28	9.50	9.38	8.93	8.37	12.46	9.64	7.87	8.82		
Little Springs Creek Lower Gage		10.81								
McDevitt Creek at Mabey Ln	7.70	10.14								
Mill Creek at 28	11.50	10.84			9.95		8.20	11.69		
Muddy Creek at McDevitt Creek Rd	6.50	9.47					6.19			
Pattee Creek at Lemhi Rd	8.50	9.90		12.00	8.34		7.31	8.44		
Pratt Creek at Lemhi Rd	8.60	10.17	12.16	12.51	9.59	8.85	8.36	8.79		
Sandy Creek at Lemhi Rd	7.70	9.50		12.18	8.28	8.11	7.95	8.26		
Texas Creek Gage	7.60	10.05	11.98	10.62	9.08	7.66	8.15		9.33	10.53
Wimpey Creek at Old 28	9.20	10.51	12.05	12.16	8.83	9.43	8.32	8.63		
Withington Creek at 28	7.20					8.13	7.66			

DO concentrations were optimal at most measurement sites in December and March, while they were merely suitable, or in some cases poor, from June through August (note that neither Chinook, nor Steelhead eggs are typically incubating in August; Table 10). DO concentrations at most sites were suitable in September and October as well, as there was only one instance of poor DO concentrations during this time. Poor DO conditions were most common in June and July, which is likely due to both higher water temperatures (warmer water can't retain as much oxygen) and increased in-stream plant respiration and decomposition, which consumes oxygen.

The incubation phase for Chinook eggs is from September to April, while Steelhead is from April to July. Given this information, it appears that DO conditions are more problematic for Steelhead than Chinook (Table 10). DO was more suitable during April than in June or July. July DO levels in the upper Lemhi River and Hayden Creek were also generally more suitable to Steelhead in 2020 than in 2021. This was likely caused, at least in part, by lower streamflow during much of 2021, as low flow often leads to increased water temperature, which decreases DO concentrations.

While none of the recorded DO levels are acutely harmful to juvenile or adult salmonids, DO below 8 mg/L can reduce swimming speeds, as well as growth rates (WDOE, 2002). Reducing DO levels to 7 mg/L causes a decrease in swimming speeds by 3.2 – 6.4% (Davis et al., 1963) and a reduction in growth rate by up to 20% (WDOE, 2002). Refuge for oxygen-stressed salmonids may be found in the upper Lemhi River (above Hayden Creek) and Hayden Creek, which are also the locations of most Chinook redds. Additional DO refuge may be found in Pratt Creek, Wimpey Creek, Mill Creek, Agency Creek, Upper Big Eightmile, and Upper Bohannon, as DO levels were greater than 8 mg/L during every measurement at these sites (Figure 16).

Table 11 depicts continuous mean monthly water temperature measurements (recorded every 15 minutes from an in-stream, fixed, temperature sensor at x depth) over the period of record (in years) and compares them to optimal conditions for Chinook. Temperatures below 4.5 °C were considered below the minimum for all life stages (blue shading; Carter, 2005). Optimal temperatures were defined as 7.2 - 14.5 °C from April to September and 5 – 11 °C from October through March (green shading; Carter, 2005). Maximum temperatures were defined as 18 °C from April to August and 14 °C from September to March (yellow shading; Carter, 2005). Finally, acute temperatures were defined as greater than 20 °C from April to September and greater than 17.5 °C from October to March (red shading; Carter, 2005). These thresholds were simplified from those documented in Carter (2005), as Chinook life stages overlap with one another, and optimal conditions vary amongst life stages. As such, the defined temperature thresholds were selected based on conditions considered suitable for all Chinook life stages that might be present at a given time.

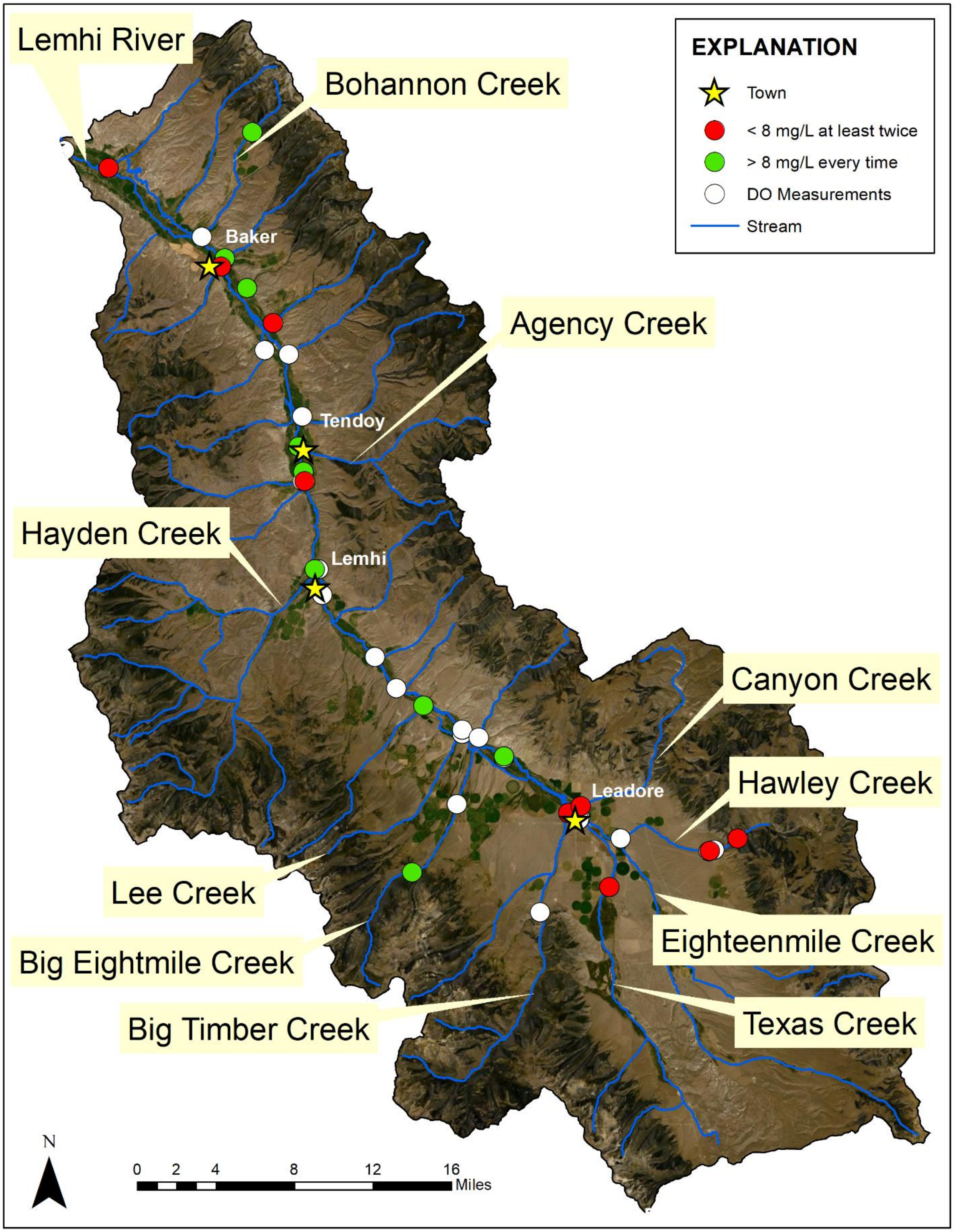


Figure 16. Lemhi River Basin Surface Water Quality – Dissolved Oxygen Measurements

Table 11. Surface Water Quality - Average Monthly Temperature (°C) and Optimal Conditions for Chinook

Stream Gage	Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agency Creek	20-21	0.1	0.2	1.0	3.8	7.2	10.7	13.8	13.7	10.1	5.6	0.8	0.0
Beaver Creek	20-21	0.0				6.3	7.4	12.5	13.5	8.9	3.3	0.0	0.0
Big Eightmile Creek Lower	21				3.3	6.2	10.5	14.2	12.4	9.0	4.6	1.1	1.8
Big Eightmile Creek Upper	17-21	0.4	0.4	1.0	2.4	4.0	6.2	9.6	10.0	7.2	3.0	1.0	0.4
Big Springs Creek Lower	20-21	2.5	3.2	5.5	6.9	10.4	13.5	14.4	13.3	10.7	7.7	4.9	2.9
Big Springs Creek Upper	20-21	4.0	4.3	5.7	7.2	9.2	11.4	12.2	11.7	10.1	8.1	5.6	4.3
Big Timber Creek Lower	20-21	0.0	0.0	0.5	3.5	8.3	11.7	15.0	14.4	10.1	5.0	0.7	0.0
Big Timber Creek Upper	18-21	0.2	0.2	0.7	4	6.1	8.6	12	13	9.4	3.7	0.7	0.2
Bohannon Creek Lower	20-21	0.3	0.5	1.8	6.0	8.0	10.1	12.7	13.1	10.5	7.3	1.9	0.3
Bohannon Creek Upper	14-21	1.3	1.3	2.2	3.6	4.7	6.1	7.9	8.2	7.0	4.8	2.7	1.4
Canyon Creek	20-21	0.2	0.5	1.3	4.7	9.0	13.3	14.8	13.6	9.5	4.9	0.8	0.1
Carmen Creek Lower	20-22	0.0	0.3	2.8	5.9	8.9	11.3	17.2	17.2	12.9	8.3	3.2	0.8
Eighteenmile Creek	21				6.7	5.9	DRY	DRY	DRY	DRY	DRY	DRY	0.6
Fourth of July Creek	20-21	0.1	0.1	0.6	3.2	5.4	8.8	12.3	12.3	9.2	4.6	0.9	0.2
Goat Creek	20-21	1.6	2.0	2.3	3.1	6.7	8.6	12.0	11.9	8.6	5.4	1.6	1.5
Hawley Creek Lower	20-22	0.0	1.4	5.0	6.1	8.1		11.6	11.2	9.3	6.5	1.5	0.0
Hawley Creek Middle	20-21	3.9	3.9	5.0	6.1	8.1	12.0	12.0	11.2	9.4	6.6	4.3	3.9
Hawley Creek Upper	21				4.7	6.9	10.3	10.4	9.4	7.5	5.1	3.2	3.8
Hayden Creek	20-21	1.3	1.4	2.9	5.4	6.5	8.7	12.1	13.4	11.3	8.1	3.8	1.8
Iron Creek	20-21	0.2	0.5	2.8	6.0	7.5	10.8	14.8	14.7	11.6	7.3	1.5	0.1
Kenney Creek	20-21	0.5	1.0	3.2	4.5	6.7	8.9	11.1	11.7	9.5	6.7	2.8	1.1
Lee Creek	15-21	1.0	1.0	2.3	5.4	9.0	12.3	13.2	12.5	9.7	6.1	2.6	0.9
Lemhi River abv Big Springs	20-21	1.9	2.2	4.3	7.2	9.8	12.9	14.4	13.4	10.6	7.4	3.5	1.9
Lemhi River at Cottom Ln	20-21	1.3	1.8	4.2	7.1	10.1	13.1	14.6	13.9	10.8	7.5	3.2	1.3
Meadow Creek	20-21	0.8	1.2	2.7	5.2	8.6	12.9	16.7	16.8	13.1	7.9	1.8	0.6
Pahsimeroi River below P9	20-21		4.4	6.1	7.5	10.7	13.3	14.2	14.0				
Patterson Big Springs Creek	20-21	3.7	4.4	6.3	8.1	10.3	12.4	13.0	12.8	10.9	8.7	5.5	3.8
Pole Creek	20-21	0.5	0.8	2.0	4.1	6.2	8.0	9.7	9.2	7.1	4.4	1.5	0.5
Pratt Creek	20-21	0.4	0.6	1.9		8.9	11.0	14.0	14.0	11.3	7.3	1.8	0.3

Average temperature conditions at most sites were optimal for Chinook from May through October (Table 11), while most sites were colder than optimal in January through March and again in November through December. These findings align with the modelled Lemhi River water temperature results reported in Carter (2005), suggesting that wintering conditions in the Pahsimeroi and Lemhi Rivers are often colder than optimal for Chinook, while warmer than optimal conditions are less common in the summer. The data suggests that thermal refuge for wintering fish may include Big Springs Creek, the Pahsimeroi below P9, and Patterson Big Springs Creek. The Lemhi River and Hayden Creek also provided additional thermal refuge, as they were warmer than most of their tributaries during the winter, in addition to hosting deeper pools and greater interaction with groundwater.

Table 12 depicts continuous water temperature measurements and compares them to optimal conditions for Steelhead. Temperatures below 4.5 °C were considered below the minimum for all life stages (blue shading; Carter, 2005). Optimal temperatures were defined as 4.5 - 10 °C from April to July and 10 – 18 °C otherwise (green shading; Carter, 2005). Maximum temperatures were defined as 12 °C from April to July and 18 °C otherwise (yellow shading; Carter, 2005). Finally, acute temperatures were defined as greater than 14 °C from March to June and greater than 20°C otherwise (red shading; Carter, 2005). These results also align with those of Carter (2005), as that study showed that temperatures often exceeded optimal conditions during Steelhead incubation (April - June) and emergence (June 15 – July 15).

Table 12. Surface Water Quality - Average Monthly Temperature (°C) and Optimal Conditions for Steelhead

Stream Gage	Record	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agency Creek	20-21	0.1	0.2	1.0	3.8	7.2	10.7	13.8	13.7	10.1	5.6	0.8	0.0
Beaver Creek	20-21	0.0				6.3	7.4	12.5	13.5	8.9	3.3	0.0	0.0
Big Eightmile Creek Lower	21				3.3	6.2	10.5	14.2	12.4	9.0	4.6	1.1	1.8
Big Eightmile Creek Upper	17-21	0.4	0.4	1.0	2.4	4.0	6.2	9.6	10.0	7.2	3.0	1.0	0.4
Big Springs Creek Lower	20-21	2.5	3.2	5.5	6.9	10.4	13.5	14.4	13.3	10.7	7.7	4.9	2.9
Big Springs Creek Upper	20-21	4.0	4.3	5.7	7.2	9.2	11.4	12.2	11.7	10.1	8.1	5.6	4.3
Big Timber Creek Lower	20-21	0.0	0.0	0.5	3.5	8.3	11.7	15.0	14.4	10.1	5.0	0.7	0.0
Big Timber Creek Upper	18-21	0.2	0.2	0.7	3.6	6.1	8.6	12.3	12.8	9.4	3.7	0.7	0.2
Bohannon Creek Lower	20-21	0.3	0.5	1.8	6.0	8.0	10.1	12.7	13.1	10.5	7.3	1.9	0.3
Bohannon Creek Upper	14-21	1.3	1.3	2.2	3.6	4.7	6.1	7.9	8.2	7.0	4.8	2.7	1.4
Canyon Creek	20-21	0.2	0.5	1.3	4.7	9.0	13.3	14.8	13.6	9.5	4.9	0.8	0.1
Carmen Creek Lower	20-22	0.0	0.3	2.8	5.9	8.9	11.3	17.2	17.2	12.9	8.3	3.2	0.8
Eighteenmile Creek	21				6.7	5.9	DRY	DRY	DRY	DRY	DRY	DRY	0.6
Fourth of July Creek	20-21	0.1	0.1	0.6	3.2	5.4	8.8	12.3	12.3	9.2	4.6	0.9	0.2
Goat Creek	20-21	1.6	2.0	2.3	3.1	6.7	8.6	12.0	11.9	8.6	5.4	1.6	1.5
Hawley Creek Lower	20-22	0.0	1.4	5.0	6.1	8.1		11.6	11.2	9.3	6.5	1.5	0.0
Hawley Creek Middle	20-21	3.9	3.9	5.0	6.1	8.1	12.0	12.0	11.2	9.4	6.6	4.3	3.9
Hawley Creek Upper	21				4.7	6.9	10.3	10.4	9.4	7.5	5.1	3.2	3.8
Hayden Creek	20-21	1.3	1.4	2.9	5.4	6.5	8.7	12.1	13.4	11.3	8.1	3.8	1.8
Iron Creek	20-21	0.2	0.5	2.8	6.0	7.5	10.8	14.8	14.7	11.6	7.3	1.5	0.1
Kenney Creek	20-21	0.5	1.0	3.2	4.5	6.7	8.9	11.1	11.7	9.5	6.7	2.8	1.1
Lee Creek	15-21	1.0	1.0	2.3	5.4	9.0	12.3	13.2	12.5	9.7	6.1	2.6	0.9
Lemhi River abv Big Springs	20-21	1.9	2.2	4.3	7.2	9.8	12.9	14.4	13.4	10.6	7.4	3.5	1.9
Lemhi River at Cottom Ln	20-21	1.3	1.8	4.2	7.1	10.1	13.1	14.6	13.9	10.8	7.5	3.2	1.3
Meadow Creek	20-21	0.8	1.2	2.7	5.2	8.6	12.9	16.7	16.8	13.1	7.9	1.8	0.6
Pahsimeroi below P9	20-21		4.4	6.1	7.5	10.7	13.3	14.2	14.0				
Patterson Big Springs Creek	20-21	3.7	4.4	6.3	8.1	10.3	12.4	13.0	12.8	10.9	8.7	5.5	3.8
Pole Creek	20-21	0.5	0.8	2.0	4.1	6.2	8.0	9.7	9.2	7.1	4.4	1.5	0.5
Pratt Creek	20-21	0.4	0.6	1.9		8.9	11.0	14.0	14.0	11.3	7.3	1.8	0.3

Table 12 shows that Upper Salmon Basin water temperature suitability is relatively similar for Steelhead as it is for Chinook. The primary difference is that temperatures were often higher than optimal for Steelhead in June and early July. This discrepancy is primarily a result of the Steelhead incubation and emergence life stages occurring at a different time than Chinook incubation and emergence. As a result of differing temperature requirements for the two species, in-stream habitat improvement projects in areas hosting Steelhead should be cognizant of both winter and summer water temperatures.

Collectively, Table 11 and Table 12 show that water temperatures modelled by Carter (2005) in the Lemhi and Pahsimeroi rivers were relatively accurate. The dataset provided in this report both ground truths the modelled dataset and expands our knowledge of stream temperatures to the fish-bearing tributaries of the Lemhi, Pahsimeroi, and Salmon Rivers. These tributaries host important salmonid habitat, as they can provide additional food, as well as refuge from suboptimal streamflow conditions, water temperatures, water quality disturbances, and other factors. The continuous water temperature dataset provides baseline water temperatures that can be used to better estimate the habitat impacts of climate change, water management, and in-stream habitat improvement projects (e.g. Hawley Creek BDAs or Pratt Creek channel restoration).

In Table 13, pH values of 7 to 8 were considered optimal (green shading), 8 to 9 were considered suitable (yellow shading; Muan and Moulton, 2011), and values less than 5 or greater than 9 were considered poor (red shading). Values of pH less than 5 or greater than 9 can sometimes result in degraded productivity or even partial mortality of all life stages of salmonids (Muan and Moulton, 2011). The severity of the impact of pH levels below 5 or above 9 depends on the length of exposure, the rate of change to pH, and other environmental factors (Colt et al. 1979). Locations where pH was measured are mapped in Figure 17, with high pH sites marked in red.

Table 13. Surface Water Quality Data - pH Values

Site	Jul-20	Sep-20	Dec-20	Mar-21	Apr-21	Jun-21	Jul-21	Aug-21	Oct-21	Dec-21
Agency Creek at Old 28	8.53	7.78	7.79	7.83	8.10	7.83	7.80	8.11		
Bayhorse Creek Gage		8.45		8.38	6.50	8.30	8.25	8.58	8.33	8.41
Big Eightmile Creek Lower Gage	7.27	7.56	8.77	8.14		7.32	7.82	8.12	7.77	7.98
Big Eightmile Creek Upper Gage	7.41	8.06			7.49	7.77	7.71		8.19	7.98
Big Springs Creek Lower Gage	8.72	8.95		8.38	8.60	8.35	8.66	9.17		
Big Timber Creek Lower Gage	7.71	8.27			8.65	8.19	8.07	8.25		
Big Timber Creek Upper Gage	7.49	8.24			8.19	7.46	7.89	8.29	8.23	
Bohannon Creek at Lemhi Rd	8.72	7.76	8.15	8.31	7.90	8.07	7.91	8.21		
Bohannon Creek Upper Gage		7.44			8.17	7.65	7.67		8.03	8.04
Canyon Creek at Old 28	8.03	8.55	8.49	8.57	8.84	8.27	8.51	8.68		
Eighteenmile Creek at Old 28	7.89	8.35		8.48	8.55	7.83	8.14	8.43		
Eighteenmile Creek Gage	8.29	8.63		8.72	8.74	9.02				8.60
Hawley Creek BDA4				8.40		8.64	8.46		8.59	
Hawley Creek BDA5				8.30			8.42	8.43	8.57	
Hawley Creek Upper Gage	7.55	8.51	8.58	8.66		8.59	8.31	8.36	8.57	
Hawley Creek Middle Gage					8.46	8.68	8.27	8.28	8.51	
Hayden Creek Gage	7.47	8.41		8.65	8.37	7.74	8.14	8.49		

Haynes Creek at Price Creek Rd	7.06					8.19	8.03			
Kenney Creek at Back Rd	8.34	7.65		8.27	7.74	7.62	7.70	8.02		
Kirtley Creek at Old 28	7.38	8.00		7.76	7.80	8.35				
Lee Creek Gage	8.68	8.48	8.76	8.63	8.71	8.86	9.10	8.94	8.55	8.71
Lemhi above Big Springs Gage	8.25	8.58	8.66	8.53	8.62	8.20	8.70	8.98		
Lemhi above Hayden	8.61		8.38	8.60	8.83	8.02		8.58		
Lemhi above L-63 Gage	7.58	8.08	8.09	8.18	8.18	7.76	7.89	8.14		
Lemhi at Baker Gage	8.30	7.97	8.44	8.68	8.67	8.02	7.89	8.29		
Lemhi at Cottom Ln Gage	8.56	8.62	8.54	8.44		8.57	8.57	8.97		
Lemhi at L-1 Gage	7.53	8.20		8.08		8.19	7.97		7.99	8.66
Lemhi at McFarland Gage	8.51	8.68	8.57	8.71	8.87	8.19	8.46	8.96		
Lemhi River nr Lemhi USGS Gage	8.98	8.45	8.53	8.64	8.74	8.14	7.51	8.77		
Little Eightmile Creek at Old 28	8.74					8.82	8.93	9.11		
Little Sawmill Creek at 28	8.45	8.27	7.97	8.41	8.25	8.04	7.92	8.23		
Little Springs Creek Lower Gage	8.34	8.79	8.50	8.61	8.74	8.32	8.62	8.88		
McDevitt Creek at Mabey Ln	9.13	8.58								
Mill Creek at 28	8.39	8.55			8.45		8.19	8.80		
Muddy Creek at McDevitt Creek Rd	7.37	8.31					7.67			
Pattee Creek at Lemhi Rd	8.63	7.69		8.45	8.72		8.67	8.51		
Pratt Creek at Lemhi Rd	8.27	7.96	7.66	8.59	8.40	8.31	8.24	8.49		
Sandy Creek at Lemhi Rd	7.05	8.19		8.26	7.62	8.10	7.99	8.35		
Texas Creek Gage	7.87	8.54	8.47	8.45	8.59	8.73	8.71		8.51	8.47
Wimpey Creek at Old 28	6.98	10.83	8.25	8.68	8.31	8.08	8.12	8.55		
Withington Creek at 28	7.00					8.00	7.80			

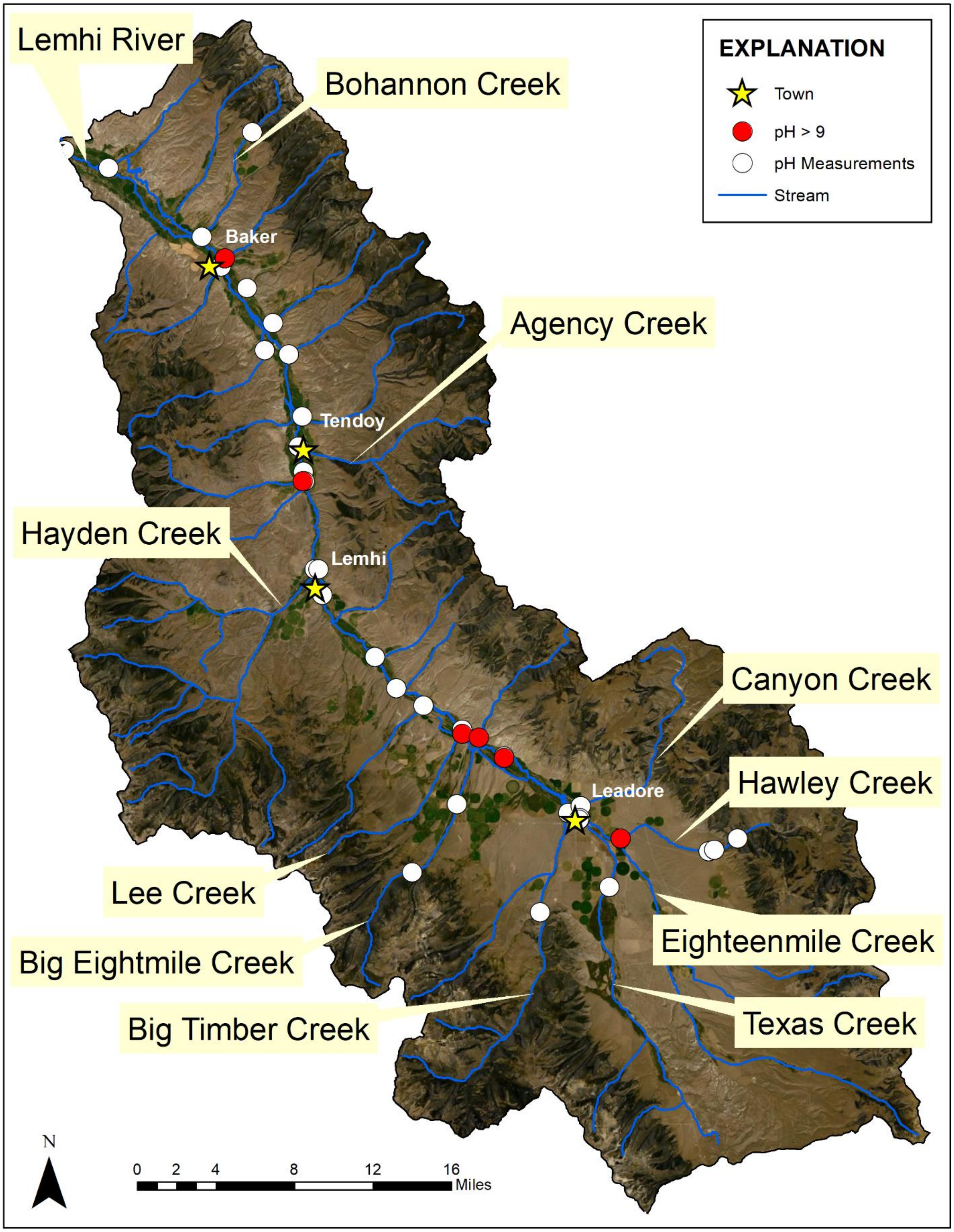


Figure 17. Lemhi River Basin Surface Water Quality – pH Measurements

Zero pH measurements were recorded below 6.5, while six measurements exceeded a pH of 9 (Table 13). Though a pH of 7 to 8 is characterized as optimal, a range of 8 to 9 is suitable, as the health and behavior of most salmonids is relatively normal until the pH exceeds 9 (Muan and Moulton, 2011). As a result, it is unlikely that pH is a major factor in degrading salmonid habitat outside of occasional spikes above a pH of 9 (Table 13, Figure 12). The only salmonid-bearing streams that had recorded instances of pH greater than 9 were Big Springs, Eighteenmile Creek, Lee Creek, and Wimpey Creek, and all pH spikes were less than 9.2 except for one outlier measurement of 10.83 at Wimpey Creek.

In this study, a threshold of 20 NTUs was used to define whether optimal or suboptimal habitat conditions existed at each measurement site (Muan and Moulton, 2011). Turbidity levels above 20 NTUs (Table 14, red shading) that lead to suboptimal conditions were measured in six salmonid-bearing streams, as well as at multiple locations within the Lemhi River (Figure 18). None of the observed turbidity levels are likely to result in partial fatality for healthy adult salmonids, though during times of high turbidity those fit to flee to less turbid waters would likely do so (Carter, 2005). Nevertheless, turbidity is an important analyte because 1) salmonids rely heavily upon their vision to feed and will typically seek the clearest water all else being equal, and 2) salmonids require exposed and well-aerated streambed gravels to lay their eggs and produce healthy hatchlings (Carter, 2005). As a result, excessive fine sediment transport and deposition into areas containing redds (salmonid eggs) can result in decreased health or even mortality of salmonid eggs and hatchlings. This is a known issue in the Upper Lemhi Basin, and while turbidity is not a direct measure of fine sediment transport, it does spike when excessive fine sediment is being transported.

Table 14. Surface Water Quality - Turbidity (NTUs)

Site	20-Sep	20-Dec	21-Mar	21-Apr	21-Jun	21-Jul	21-Aug	21-Oct	21-Dec
Agency Creek at Old 28	0	8.42	252.7	1174	0.02	0	0		
Bayhorse Creek Gage	0		0	1.52	0	0	1.45	0	0
Big Eightmile Creek Lower Gage	0	2.82	0.42		0	0.03	0	0	0.17
Big Eightmile Creek Upper Gage	0			0	0	0		0	0
Big Springs Creek Lower Gage	0		5.49	2.26	0.49	0.02	0		
Big Timber Creek Lower Gage	0			15.73	2.87	0	0		
Big Timber Creek Upper Gage	0			0	0	0	0	6.14	
Bohannon Creek at Lemhi Rd	0	0	1.24	0.7	5.7	0.19	0.1		
Bohannon Creek Upper Gage	0			0	0	0		0	0
Canyon Creek at Old 28	12.42	0	22.97	0	4.9	4.8	1550		
Eighteenmile Creek at Old 28	20.54		16.39	14.78	17.71	0.43	0		
Eighteenmile Creek Gage	2.61		34.19	53.88	0				25.32
Hawley Creek BDA4			97.95		0	0.71		0	
Hawley Creek BDA5			0			0	0	0	
Hawley Creek Upper Gage	0	0	0		0	0	0	0	
Hawley Creek Middle Gage				0	0	0	0	0	

Hayden Creek Gage	0		0	0	0	0	0		
Haynes Creek at Price Creek Rd					2.96	0			
Kenney Creek at Back Rd	0.14		0	0	0.26	0	0		
Kirtley Creek at Old 28	0.39		31.31	11.23	0				
Lee Creek Gage	57.47	0	58.9	0.07	4.06	0	0	0	0.03
Lemhi above Big Springs Gage	1.07	1.6	9.91	4.81	0.11	0	0.26		
Lemhi above Hayden		9.23	7.94	6.31	0.06		0.57		
Lemhi above L-63 Gage	0	0	33.54	50.89	79.05	0.77	0.11		
Lemhi at Baker Gage	0	0	5.01	2.9	0.76	17.94	0		
Lemhi at Cottom Ln Gage	0.04	4.51	9.1		1.24	0	0		
Lemhi at L-1 Gage	0		4.95		1.94	0		3.35	0
Lemhi at McFarland Gage	60.94	10.23	6.58	5.93	0	0.34	4.45		
Lemhi River nr Lemhi USGS Gage	0.01	8.54	6.31	1.48	0.69	24.84	0.4		
Little Eightmile Creek at Old 28					1.91	0	0		
Little Sawmill Creek at 28	12.4	54.06	10.86	3.56	7.35	0	23.33		
Little Springs Creek Lower Gage	4.16	27.66	7.08	0.39	10.79	0.42	0.1		
McDevitt Creek at Mabey Ln	17.76								
Mill Creek at 28	0.04			0.26		0	0.02		
Muddy Creek at McDevitt Creek Rd	1.24					36.29			
Pattee Creek at Lemhi Rd	0		12.7	0.23		0.53	3.63		
Pratt Creek at Lemhi Rd	0	0	0	0	0	0	0.07		
Sandy Creek at Lemhi Rd	0		0.01	0	0	0	0		
Texas Creek Gage	0	0	0.65	7.04	0	0.92		0.27	4.54
Wimpey Creek at Old 28	0	6.77	0	0	0.01	0	0		
Withington Creek at 28					0.01	0			

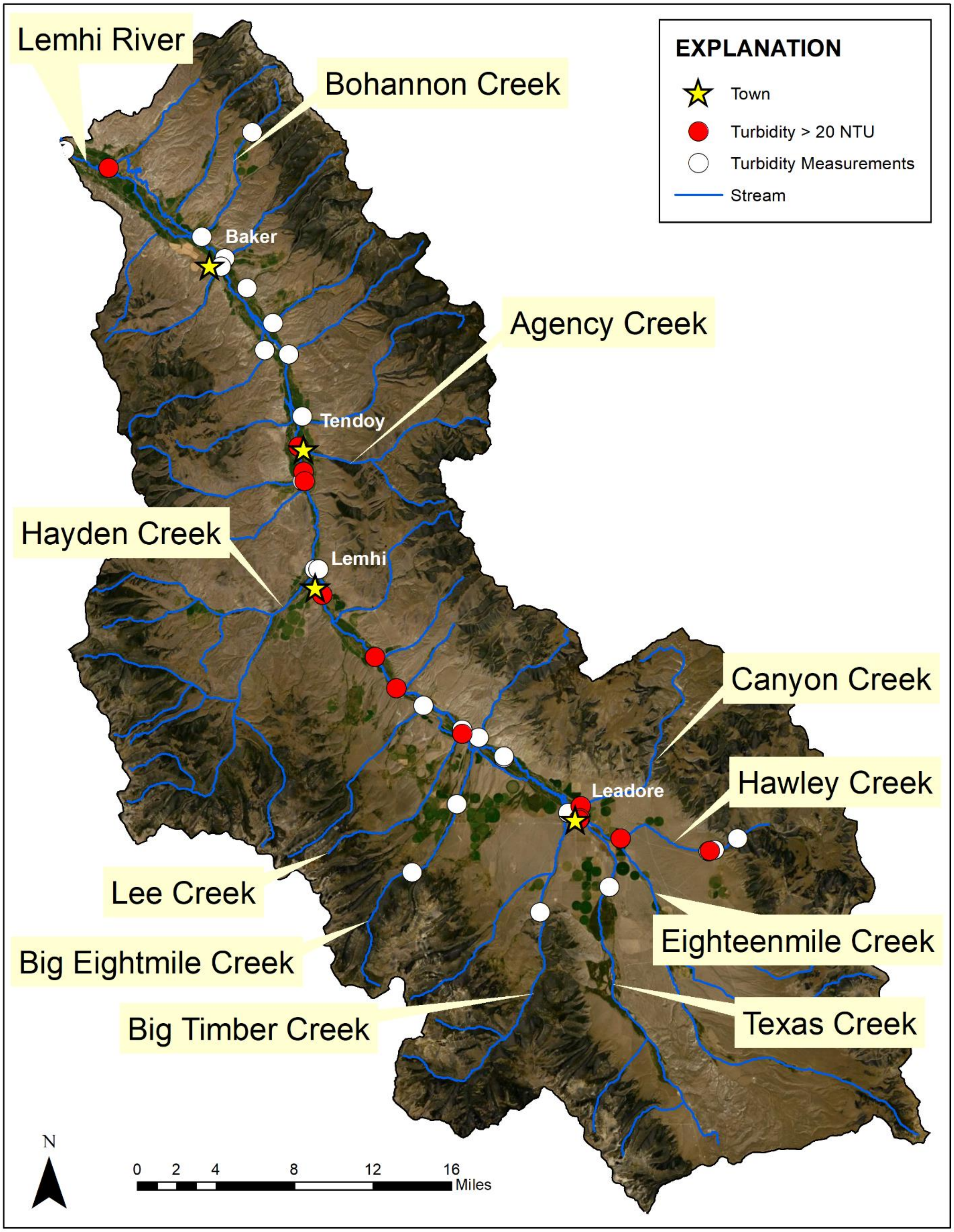


Figure 18. Lemhi River Basin Surface Water Quality – Turbidity Measurements

Turbidity spikes in March and April, 2021, appeared to be primarily caused by sediment transport, while spikes in September 2020 and July to August, 2021, were likely caused by agricultural runoff, as these were periods of low flow and little precipitation within the basin.

High turbidity readings at Canyon Creek, Eighteenmile Creek, Lee Creek, and Lemhi above L-63 in March are particularly problematic, as these readings are indicative of excessive fine sediment being transported into the Upper Lemhi River, which is the location of many Chinook redds. High turbidity readings throughout the rest of the year may degrade the ability of salmonids to feed and can delay migration in some cases.

Task 4. Lemhi River Basin Model Updates

Background

The LRBM was developed by IDWR to evaluate the hydrogeologic impacts of diversion operations, tributary reconnections, and other changes to 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 through the stream network, as well as account for irrigation practices and in-channel gains and losses to streamflow. Supporting the LRBM are several Microsoft Excel (Excel) workbooks that aid in inputting timeseries data for catchments and irrigation nodes (see "Data Atlas" below) as well as extracting, analyzing, and reformatting model simulation results for evaluating scenarios (e.g. potential changes to water management, irrigation methods, crop types, climate, etc.). Collectively, the LRBM, Data Atlas, and associated tools are used by the Upper Salmon Basin Watershed Program and other stakeholders as a common framework for understanding the hydrology and water allocation of the basin.

The LRBM was developed using MIKE HYDRO BASIN (MHB), a geographic information systems (GIS) based water allocation software package developed by 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 model), 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 timeseries 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 including diversion operations, crop irrigation/rotation methods, reconnection of tributaries, etc. Modelled streamflow outputs from the LRBM are also used to help evaluate the viability of potential in-stream habitat projects.

In the LRBM, catchment runoff is computed for 80 subcatchment polygons (Figure 19). Runoff was computed for each catchment using DHI's Nedbør-Afstrømnings-Model (NAM) which is a module within MHB. NAM is a lumped conceptual rainfall-runoff model for simulating streamflow at a catchment scale based on precipitation, temperature, evapotranspiration, and other factors. NAM computes total runoff on a daily timestep by accounting for the moisture content in three distinct, yet interconnected storage zones that represent overland flow, interflow, and baseflow (DHI, 2003). As NAM is a lumped model, it treats each subcatchment as one unit, thus input parameters are considered to represent average values for each individual 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 is divided up into subunits to represent different elevation zones. The result is a continuous timeseries 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 gaged locations (Table 1, Figure 3), and streamflow on ungaged streams is calibrated using information from nearby streams within subcatchments featuring similar hydrologic properties. LRBM-NAM streamflow values in ungaged 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. Usage of parameters from alternative subcatchments were explored in instances where LRBM-NAM and StreamStats flow values differed significantly.

Updates to 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 that were made to the LRBM during this project phase include:

1. Migrated the LRBM from MIKE BASIN v2012 to MHB v2020 software. Due to the complexity of the LRBM network, the transfer utility in MHB only migrated the channel network and river nodes. Thus, the 348 water user nodes representing diversions and the Lemhi Basin catchments were recreated and input timeseries attached manually (Figure 19).
2. Updated the NAM Rainfall-Runoff Model (computes catchment inflow values) to include data from water years (WY) 1981 – 2020 (previously 2005 – 2017).
    a. Replaced and extended the precipitation and temperature timeseries for each catchment with records from WRI's Climate Engine (Huntingdon et al., 2017) from 1981 - 2020. Previously, precipitation and temperature were extrapolated by extending meteorologic records over PRISM surfaces (IDWR, 2019). Use of the Climate Engine precipitation and temperature datasets expedites future data preparation.
    b. Replaced and extended the potential evapotranspiration (PET) timeseries with Gridmet average PET (Alfalfa reference) data from Climate Engine. In previous LRBM versions, PET was equal to the METRIC Actual ET and scaled to represent PET. As with precipitation and temperature, use of the Climate Engine PET dataset expedites future data preparation.
3. Upgraded NAM modeling for the LRBM inflow timeseries for 80 catchments within the LRBM.
    a. Re-delineated the LRBM catchment network and reduced the total number of catchments from 85 to 80, which better represents outflow at the catchment pour points (Figure 20). Elevation bands were also recalculated to apply the appropriate precipitation and temperature correction factors to the Climate Engine NAM input datasets, which allowed for a better characterization of snowmelt.
    b. Recalibrated the NAM model for gaged catchments. Transferred the gaged catchment NAM parameters to ungaged catchments with similar physical and land use characteristics. Monthly accumulated precipitation and runoff averages were compared against USGS StreamStats values to ensure that modeled estimates were within reason.
4. Expanded and updated LRBM water demand input timeseries from WY2017 to WY2020. Using the watermaster records posted in the IDWR database in water districts 74, 74A, 74B, 74C, 74F,

74G, 74J, 74M, 74Q, 74W, and 74Z, extended the water demand input time series to include WY2018 - WY2020. While a few watermaster annual reports were submitted in an electronic format that can be readily incorporated into the model, many water master reports were submitted as handwritten documents in PDF format and thus had to be manually entered. If reported by water right, the proper point of diversion (POD) also needed to be identified, which required additional data preparation. For water user nodes without a diversion record, the water right was used as the diversion rate throughout the irrigation season: April 15 – Oct 15. Once entered, all records were gap filled using the existing methodology (DHI, 2003; Borden, 2014) and uploaded to the LRBM input files (DFS0). All water rights, PODs, etc. were documented in the Data Atlas and incorporated into the LRBM (Figure 21).

5. Modified the supporting catchment runoff Excel file with the updated catchment runoff timeseries (Figure 21)
6. Recalibrated the LRBM using records at 10 stream gages, allowing for the calculation of reach gains or losses.

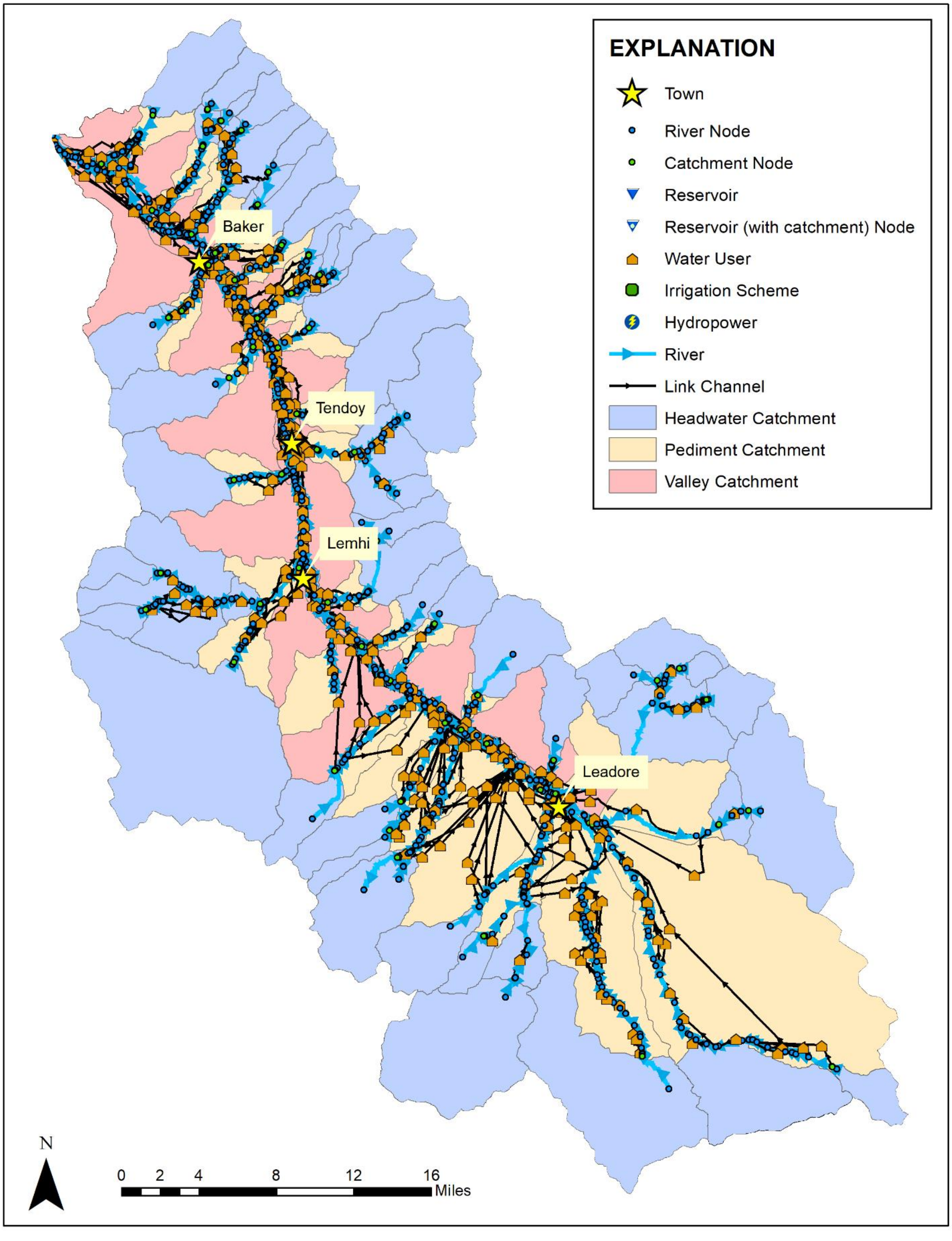


Figure 19. Node-Link Diagram of the Lemhi River Basin Model

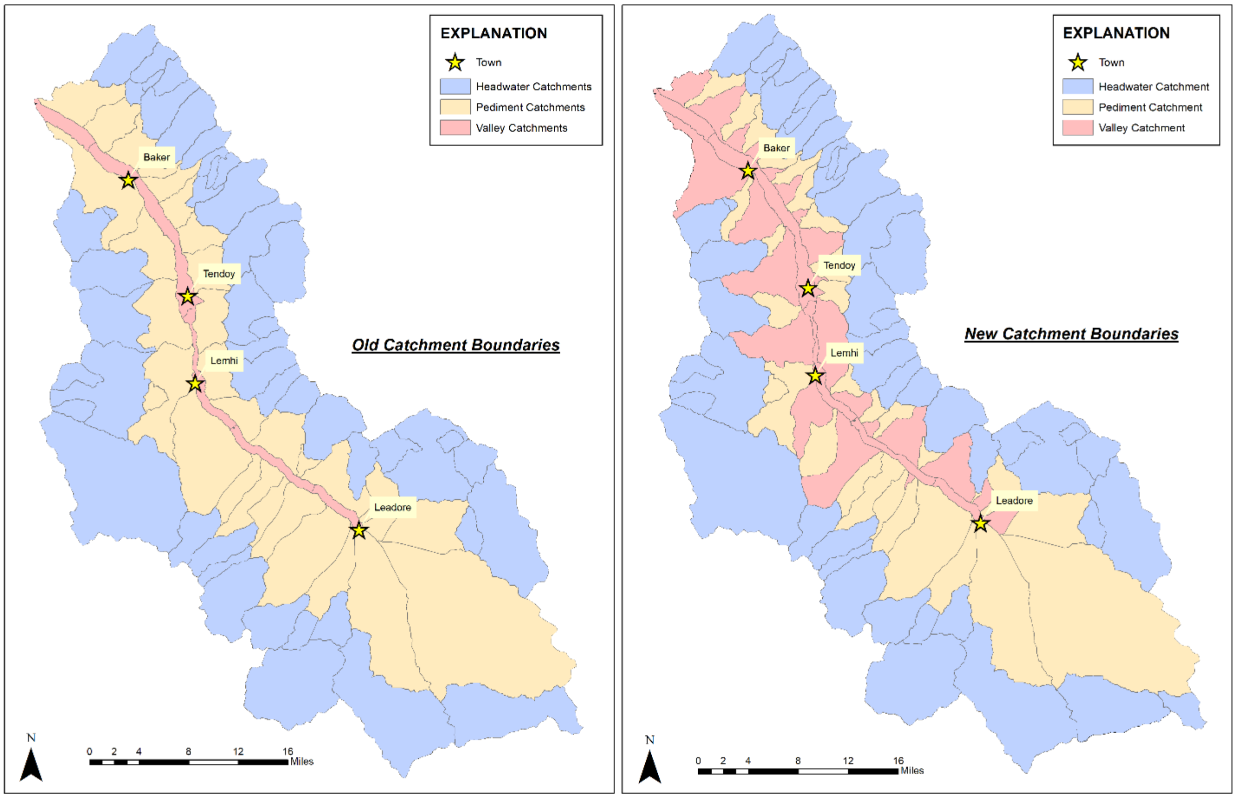


Figure 20. Re-delineation of Catchment Boundaries

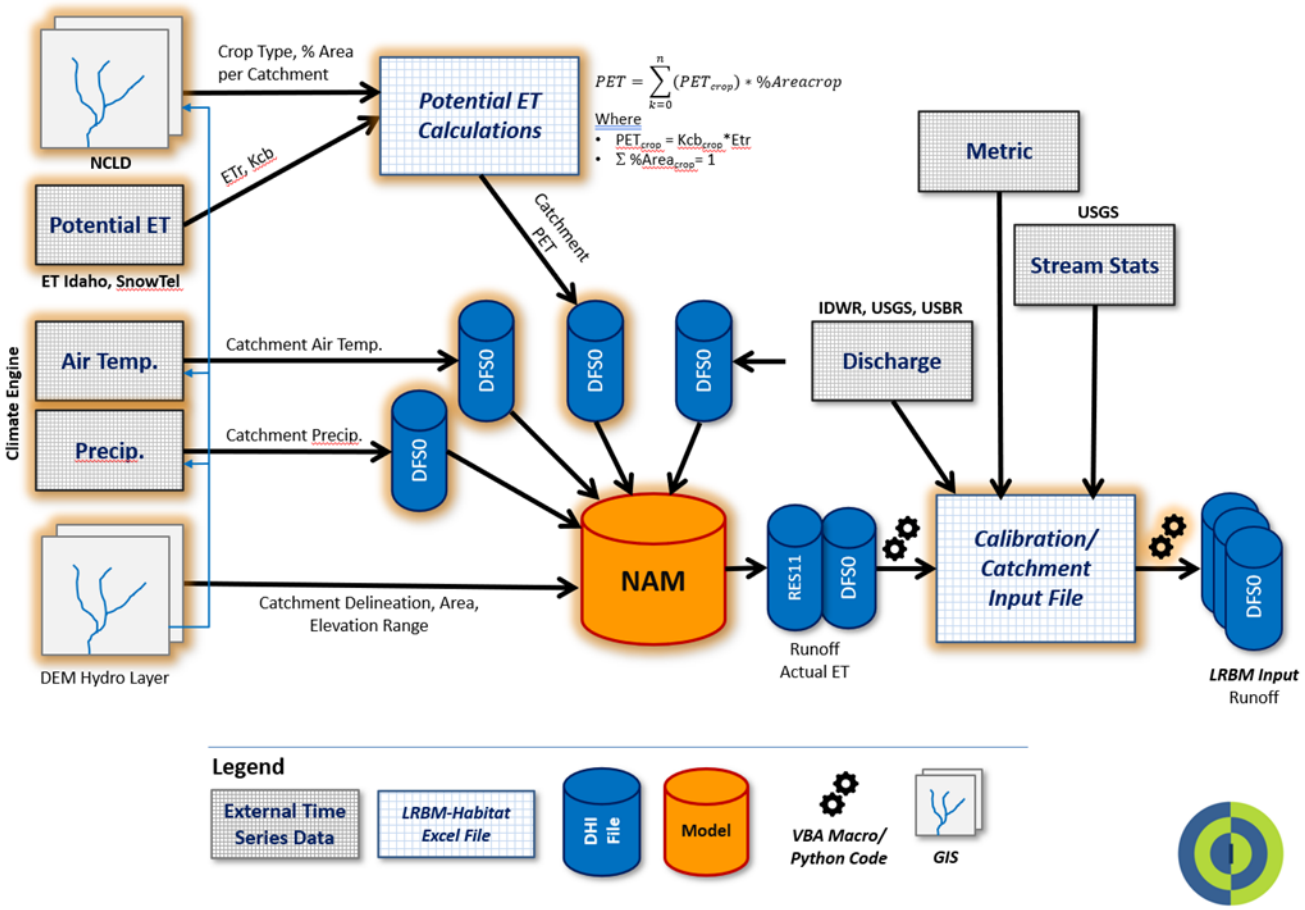


Figure 21. Rainfall-Runoff modeling components and data flow supporting the catchment inflow calculations. Orange highlighted elements were updated during the LRBM update.

Updates to LRBM Support Files

Data Atlas: For the 348 diversions, the Data Atlas provides a single location to process, store, plot, display, and programmatically upload diversion and return flow timeseries and other salient data (e.g., POD location, water rights, irrigation methods). Significant effort has gone into developing a single file that holds all the information needed to characterize each diversion, containing a timeseries of diversion rates, delivery of water to PODs, computing return rates, etc. Updates to the Data Atlas included:

- Consolidated the upper and lower Lemhi Basin Diversion workbooks into a single Excel Workbook (a.k.a., the Data Atlas). This involved a total overhaul of the input sheets and accompanying macros as well as populating the new input sheets with existing data from older workbooks.
- Extended the water demand input timeseries to include WY2018 - WY2020 (see “Updates to the Lemhi River Basin Model” above) using water master records from basins 74, 74A, 74B, 74C, 74F, 74G, 74J, 74M, 74Q, 74W, and 74Z. A macro was coded to gap fill missing daily data (daily values are required in MHB, even during the winter months) and the gap filled data was uploaded to the LRBM input file format (DFS0).

- Developed additional input demand and return flow timeseries to support base water rights (excluding high flow water rights). These base water rights scenarios can be used to quickly evaluate potential changes to the system (e.g. new water rights) and to plan for the implementation of streamflow maintenance water rights (see “Summary of Lemhi Settlement Agreement”).
- Developed a reference list of the diversion identification information, POD location, irrigation/return flow calculation data, base and high-water rights, historic diversion statistics, diversion data source (by year), return flow computation method, ditch capacity, and comments.
- Developed the Diversion Summary sheet to include high water right listing, aerial photo image of the POD location, and other salient information (Figure 22, Figure 23). Plots diversion record and predicted consumption rate.
- Incorporated the deep return flow computations into the sheet. This eliminates the external file that made these computations for the LRBM in MHB.
- A series of macros were written to programmatically process data, calculate return flow time series, transfer information, evaluate data quality, and populate the diversion sheet.
- A python script was created to automatically upload input time series. This is to eventually be embedded into the file using VBA.

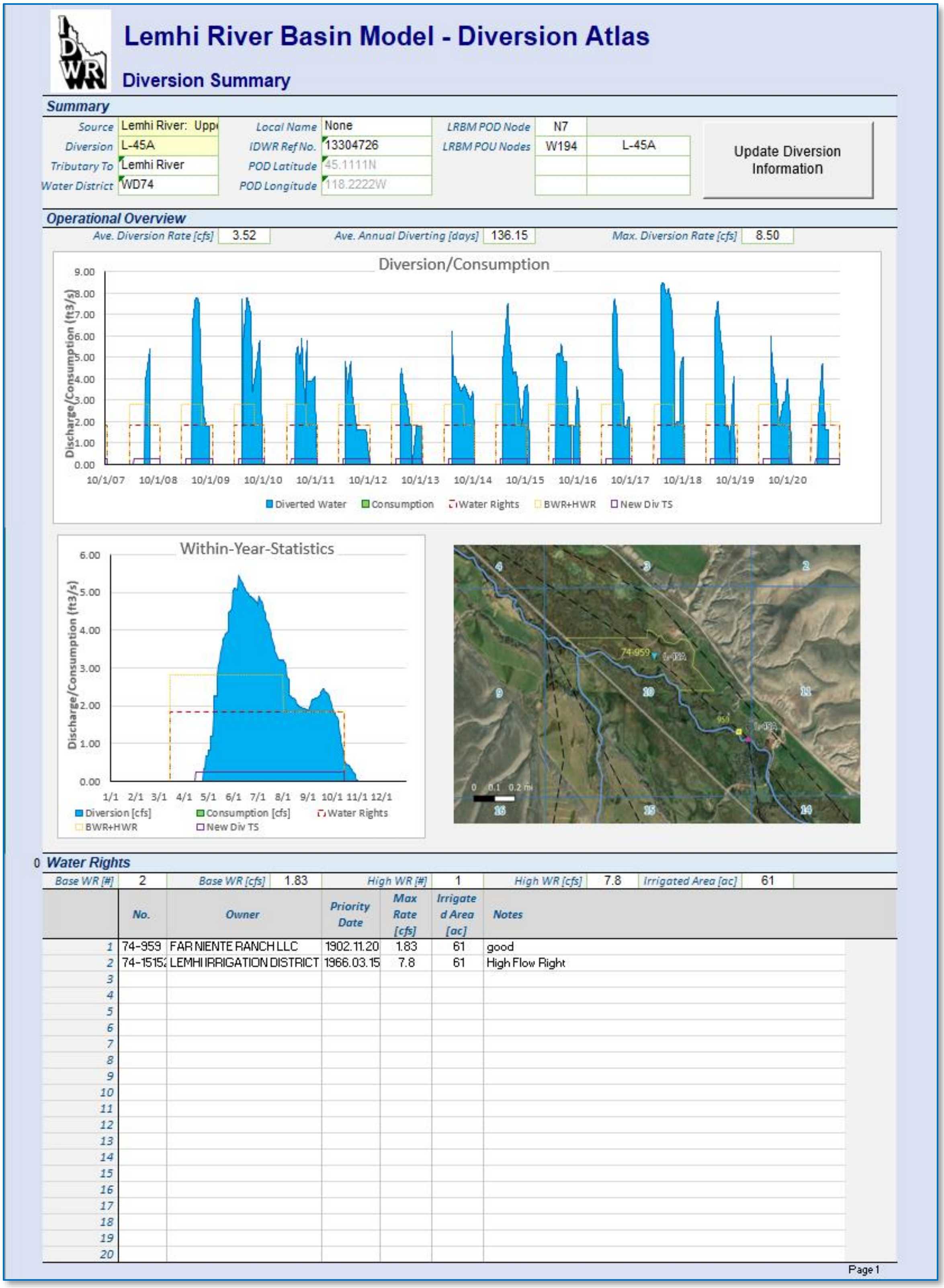
The document serves three purposes:

1. Holding and organizing the historic input data for the LRBM.
2. Saved separately, acts as an archive for model scenario inputs.
3. Community tool for investigating diversions. The tool allows USBWP Tech Team members and other interested parties to quickly review and visualize information about any diversion, POD, etc.

Catchment Inflow File: Organizes the catchment runoff timeseries for 80 catchments and loads them into the LRBM DFS0 input files. Specific updates from the previous versions:

- Incorporated new catchment list and modified timeseries references to new list.
- Extended catchment runoff timeseries from WY2008-WY2017 to WY1981-WY2020.
- Updated comparison NAM results with USGS StreamStats to validate.
- Coupled file with data transfer python code for rapid loading of catchment conditions.

Data Transfer Python Code: In MHB, transfer of time series information between Excel and the DFS0 files could be programmatically performed in VBA. Unfortunately, this functionality is no longer available with MHB, so a utility was written in Python to perform the transfer. While the data transfer code is an external tool that needs to be modified, the next step is to embed the python utility in the Excel workbooks and be able to call upon it from a VBA prompt.



Lemhi River Basin Model - Diversion Atlas

Diversion Summary

Summary

Source	Lemhi River: Upp	Local Name	None	LRBM POD Node	N7	
Diversion	L-45A	IDWR Ref No.	13304726	LRBM POU Nodes	W194	L-45A
Tributary To	Lemhi River	POD Latitude	45.1111N			
Water District	WD74	POD Longitude	118.2222W			

Update Diversion Information

Operational Overview

Ave. Diversion Rate [cfs]	3.52	Ave. Annual Diverting [days]	136.15	Max. Diversion Rate [cfs]	8.50

0 Water Rights

Base WR [#]	2	Base WR [cfs]	1.83	High WR [#]	1	High WR [cfs]	7.8	Irrigated Area [ac]	61

	No.	Owner	Priority Date	Max Rate [cfs]	Irrigated Area [ac]	Notes
1	74-959	FAR NIENTE RANCH LLC	1902.11.20	1.83	61	good
2	74-1515	LEMHI IRRIGATION DISTRICT	1966.03.15	7.8	61	High Flow Right
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
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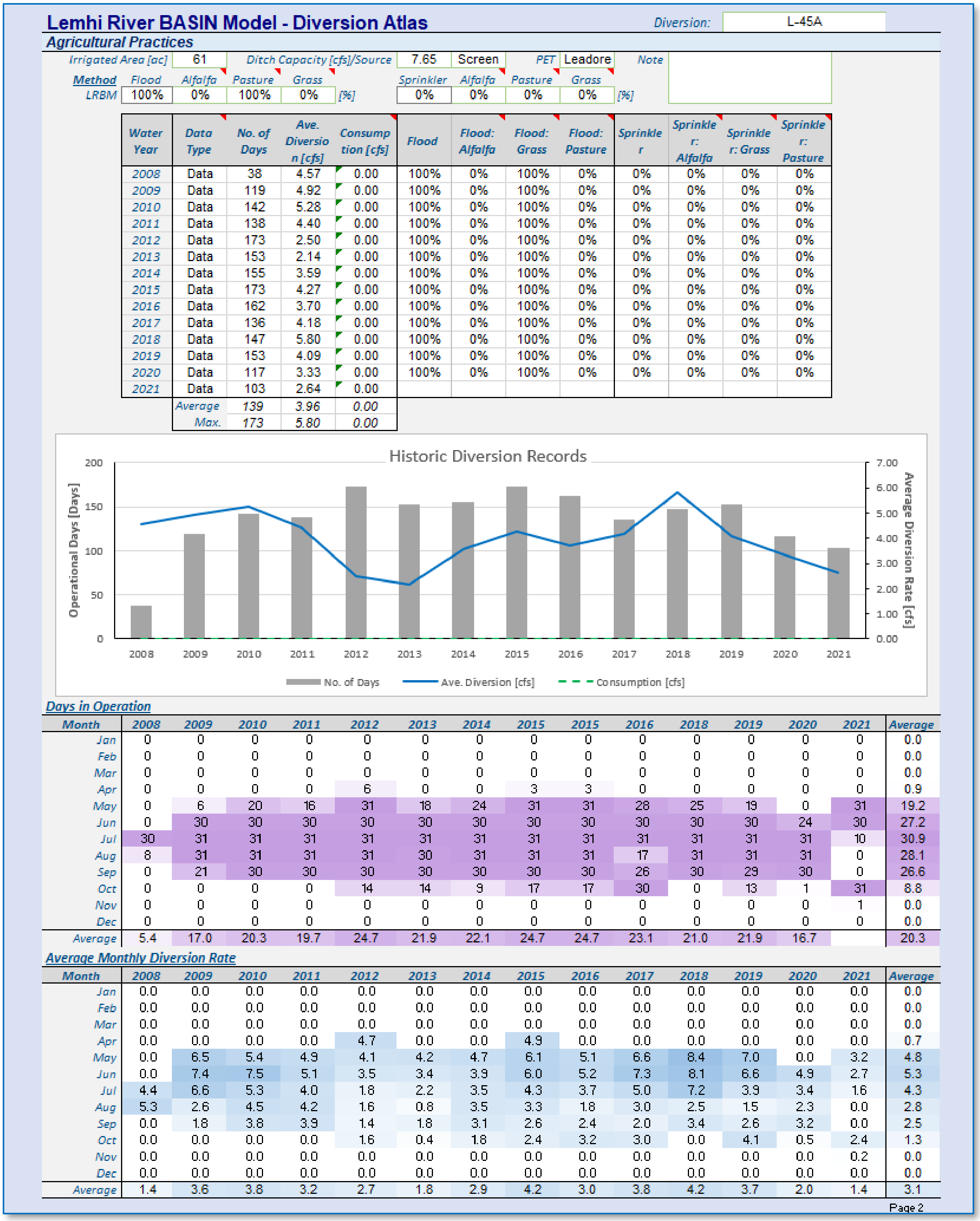
Page 1

Figure 22. First page of the Diversion Summary Sheet within the LRBM Diversion Atlas



Lemhi River BASIN Model - Diversion Atlas

Diversion: L-45A

Agricultural Practices

Irrigated Area [ac] 61

Ditch Capacity [cfs]/Source 7.65 Screen

PET Leadore

Note

Method	Flood	Alfalfa	Pasture	Grass		Sprinkler	Alfalfa	Pasture	Grass	
LRBM	100%	0%	100%	0%	[%]	0%	0%	0%	0%	[%]

Water Year	Data Type	No. of Days	Ave. Diversion [cfs]	Consumption [cfs]	Flood	Flood: Alfalfa	Flood: Grass	Flood: Pasture	Sprinkler	Sprinkler: Alfalfa	Sprinkler: Grass	Sprinkler: Pasture
2008	Data	38	4.57	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2009	Data	119	4.92	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2010	Data	142	5.28	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2011	Data	138	4.40	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2012	Data	173	2.50	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2013	Data	153	2.14	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2014	Data	155	3.59	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2015	Data	173	4.27	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2016	Data	162	3.70	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2017	Data	136	4.18	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2018	Data	147	5.80	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2019	Data	153	4.09	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2020	Data	117	3.33	0.00	100%	0%	100%	0%	0%	0%	0%	0%
2021	Data	103	2.64	0.00								
	Average	139	3.96	0.00								
	Max.	173	5.80	0.00								

Days in Operation

Month	2008	2009	2010	2011	2012	2013	2014	2015	2015	2016	2018	2019	2020	2021	Average
Jan	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
Mar	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Apr	0	0	0	0	6	0	0	3	3	0	0	0	0	0	0.9
May	0	6	20	16	31	18	24	31	31	28	25	19	0	31	19.2
Jun	0	30	30	30	30	30	30	30	30	30	30	30	24	30	27.2
Jul	30	31	31	31	31	31	31	31	31	31	31	31	31	10	30.9
Aug	8	31	31	31	31	30	31	31	31	17	31	31	31	0	28.1
Sep	0	21	30	30	30	30	30	30	30	26	30	29	30	0	26.6
Oct	0	0	0	0	14	14	9	17	17	30	0	13	1	31	8.8
Nov	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0
Dec	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Average	5.4	17.0	20.3	19.7	24.7	21.9	22.1	24.7	24.7	23.1	21.0	21.9	16.7		20.3

Average Monthly Diversion Rate

Month	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	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	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	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	0.0
Apr	0.0	0.0	0.0	0.0	4.7	0.0	0.0	4.9	0.0	0.0	0.0	0.0	0.0	0.0	0.7
May	0.0	6.5	5.4	4.9	4.1	4.2	4.7	6.1	5.1	6.6	8.4	7.0	0.0	3.2	4.8
Jun	0.0	7.4	7.5	5.1	3.5	3.4	3.9	6.0	5.2	7.3	8.1	6.6	4.9	2.7	5.3
Jul	4.4	6.6	5.3	4.0	1.8	2.2	3.5	4.3	3.7	5.0	7.2	3.9	3.4	1.6	4.3
Aug	5.3	2.6	4.5	4.2	1.6	0.8	3.5	3.3	1.8	3.0	2.5	1.5	2.3	0.0	2.8
Sep	0.0	1.8	3.8	3.9	1.4	1.8	3.1	2.6	2.4	2.0	3.4	2.6	3.2	0.0	2.5
Oct	0.0	0.0	0.0	0.0	1.6	0.4	1.8	2.4	3.2	3.0	0.0	4.1	0.5	2.4	1.3
Nov	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	0.2	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	0.0
Average	1.4	3.6	3.8	3.2	2.7	1.8	2.9	4.2	3.0	3.8	4.2	3.7	2.0	1.4	3.1

Page 2

Figure 23. Second page of the Diversion Summary Sheet within the LRBM Diversion Atlas

Connections/Applications: The LRBM has been the basis for a series of applications that provide insight into water movement in support of the Upper Salmon Basin Watershed Project and the Lemhi Settlement Working Group. The below applications post-process the LRBM output to provide information for Lemhi River Basin management.

1. **LRBM Data Atlas:** See Above for description.
2. **LRBM Aquatic Habitat Tool (LRBM Habitat):** calculates habitat suitability along the mainstem Lemhi River from LRBM discharge output and the UICER habitat suitability curves (co-funded by OSC Contract BRH004 20).
3. **LRBM Pulse Calculator:** computes the favorable periods and conditions to conduct flushing flows in the upper Lemhi River from the cessation of high-water diversions. (IWRB/OSC-PCSRF funded) – see the Lemhi River Basin Settlement for details on the specifics of this water right (https://idwr.idaho.gov/legal-actions/settlements/lemhi-settlement/)
4. **LRBM BTC:** provides statistical analysis and habitat quality data along Big Timber and Little Timber creeks.

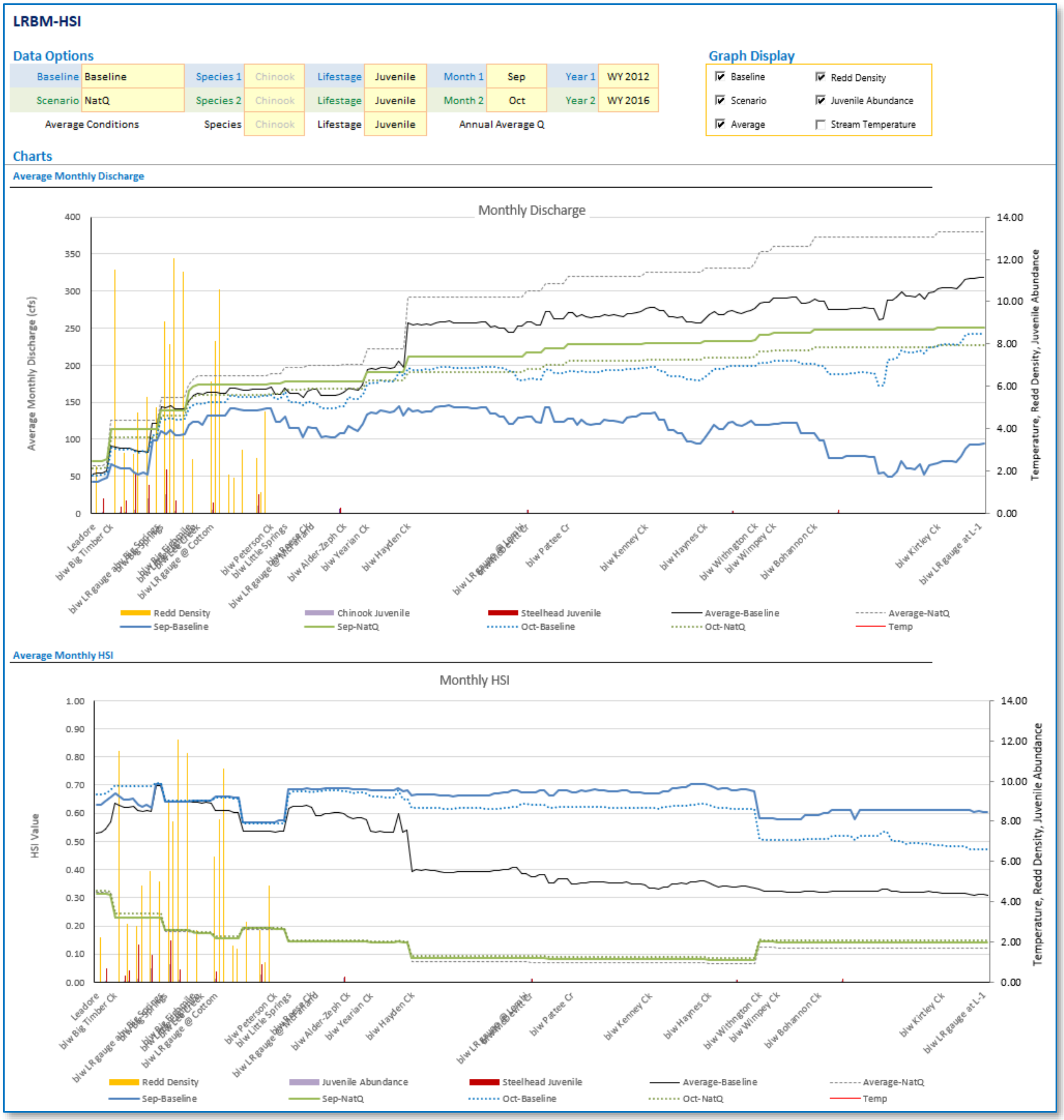
LRBM Habitat: This tool computes habitat quality along the mainstem Lemhi River by combining the LRBM discharge timeseries output with the habitat suitability indices (HSI) developed by UICER 2D modeling (Figure 24). The tool computes and displays:

- Month/year longitudinal display of discharge and HSI values.
- Redd density and juvenile abundance from historic data.
- Comparisons of annual discharge vs redd density and juvenile abundance
- Comparisons of annual HSI vs redd density and juvenile abundance

Through checkboxes, LRBM Habitat users can turn on/off the elements in the graphs and choose time periods to evaluate. Users can choose the year, month, species (Chinook only at present), and life stage from multiple hydrologic scenarios. Macros were developed to enable automated uploading and processing of new LRBM scenarios and UICER HSI curves.

Since the LRBM Habitat's development, the LRBM and UICER analysis have been updated and improved. Future developments involve updating the LRBM-Habitat by:

- Implementing stream temperatures into the reporting interface.
- Redefining reaches and introducing new HSI curves from the updated University of Idaho CER 2D modeling.
- Expanding to include other species/life-stages as the analysis is produced.
- Extending the period of analysis to WY 2020 corresponding with the updated LRBM.
- Embedding a code bridge in Python to automatically load results from MIKE Hydro Basin (MHB) model runs to the LRBM Habitat. MHB no longer supports the VBA bridge connecting Excel and DFS0 files (DHI time series file format).



LRBM-HSI

Data Options

Baseline	Baseline	Species 1	Chinook	Lifestage	Juvenile	Month 1	Sep	Year 1	WY 2012
Scenario	NatQ	Species 2	Chinook	Lifestage	Juvenile	Month 2	Oct	Year 2	WY 2016
Average Conditions		Species	Chinook	Lifestage	Juvenile	Annual Average Q			

Graph Display

☑ Baseline ☑ Redd Density
☑ Scenario ☑ Juvenile Abundance
☑ Average ☐ Stream Temperature

Charts

Average Monthly Discharge

Average Monthly HSI

Figure 24. Longitudinal discharge and Chinook salmon HSI, redd density, and juvenile abundance within the Lemhi River on a given month/year.

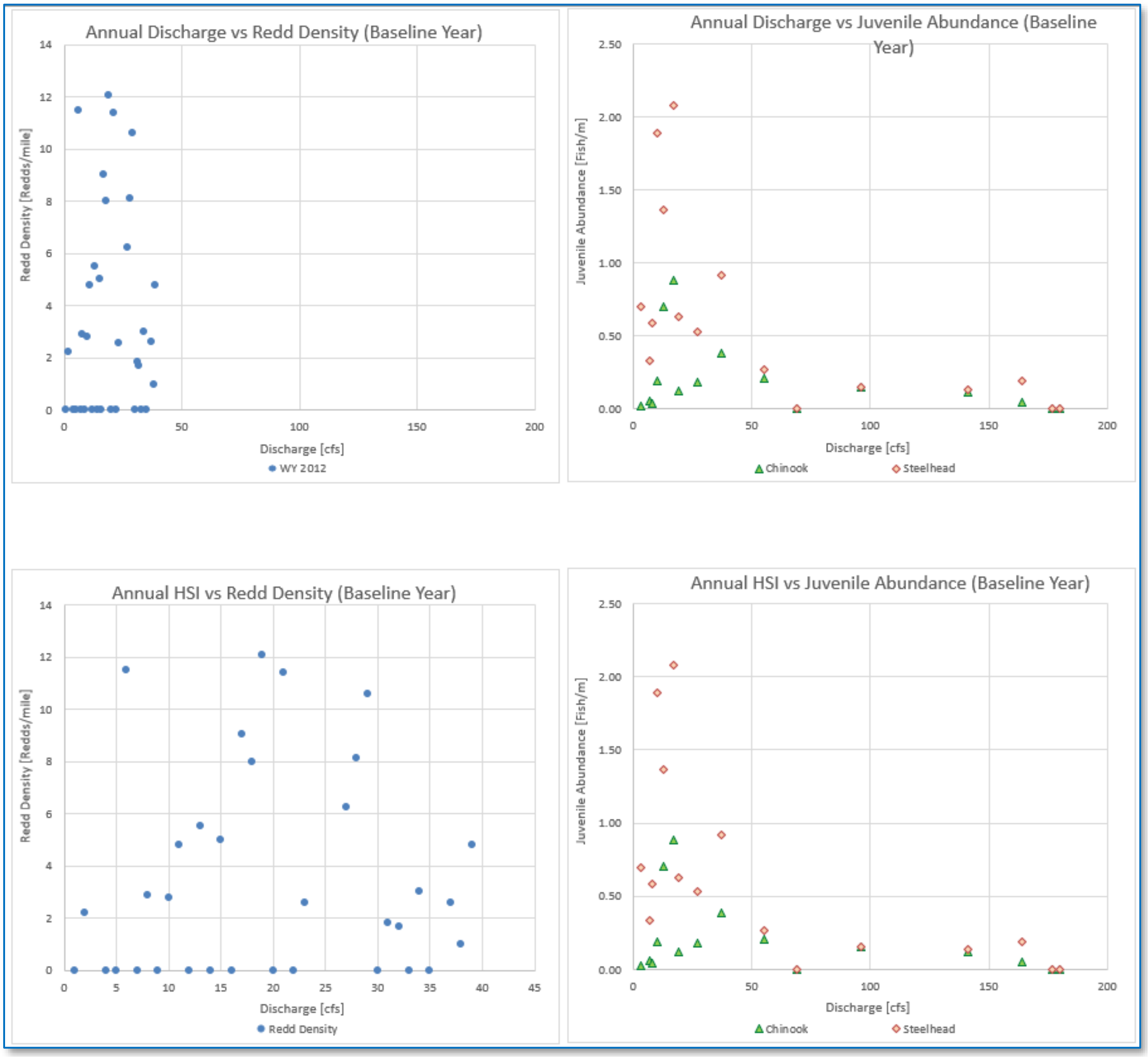


Figure 25. Annual discharge and HSI compared to redd density and juvenile abundance

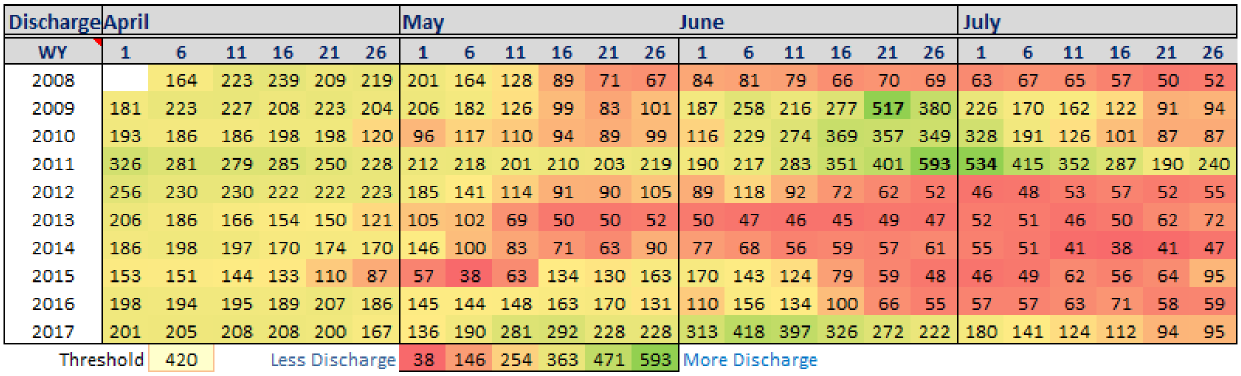
LRBM Pulse Calculator: The LRBM Pulse Calculator tested the feasibility of a flushing flow (to scour entrained sediment and restore/maintain quality in-stream habitat) and established criteria to determine favorable periods for its implementation. The steps to evaluating and formulating a flushing flow implemented in the LRBM Pulse Calculator include the following.

- Determine the flow target to improve ecological conditions,
- Calculate the water required to reach the flow target (aka. flow deficiency),
- Determine the source and quantity of water available to satisfy the flow deficiency,
- Match the timing of the water deficit with the water availability, and
- Determine downstream flooding potential/risk of implementing a flushing flow.

Specifically, the LRBM Pulse Calculator computes:

1. Setting a target flow: As the Lemhi River is heavily influenced by diversions, channel maintaining flow is best determined by computing the discharge necessary to move streambed material. Using pebble count data (Daniele Tonina, University of Idaho CER, personal communication 2020) and 2-D hydraulic modeling output (Rohan Benjankar, SIU, personal communication 2020), the calculator computes the discharge required for gravels mobilization (incipient motion) for five study reaches in the upper Lemhi River. From all the reaches, a flow target of 420 CFS was set for Lemhi River at McFarland Campground gage. The calculator also computes the effective discharge for each reach, though no mobilization of the substrate D50 was computed for discharges simulated by the 2-D hydraulic model. For reference, the calculator also computes flow frequency metrics including the 200% mean annual discharge, 17% discharge flow exceedance), and flood frequency of the 1.5-year, 2-year, and 25-years event. This analysis has been performed for the historic conditions as well as natural flows (no diversions) as calculated by the LRBM.
2. Flow deficiency: Subtracts the flow target from the historic gage records to derive the deficiency. Note, without a flushing flow provision, the 420 CFS flow target at Lemhi River at McFarland Campground gage naturally occurs two out of every ten years (Table 15, Figure 26).

Table 15. Discharge Exceedance of 420 CFS at the Lemhi at McFarland Gage



Discharge	April						May						June						July					
WY	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26
2008		164	223	239	209	219	201	164	128	89	71	67	84	81	79	66	70	69	63	67	65	57	50	52
2009	181	223	227	208	223	204	206	182	126	99	83	101	187	258	216	277	517	380	226	170	162	122	91	94
2010	193	186	186	198	198	120	96	117	110	94	89	99	116	229	274	369	357	349	328	191	126	101	87	87
2011	326	281	279	285	250	228	212	218	201	210	203	219	190	217	283	351	401	593	534	415	352	287	190	240
2012	256	230	230	222	222	223	185	141	114	91	90	105	89	118	92	72	62	52	46	48	53	57	52	55
2013	206	186	166	154	150	121	105	102	69	50	50	52	50	47	46	45	49	47	52	51	46	50	62	72
2014	186	198	197	170	174	170	146	100	83	71	63	90	77	68	56	59	57	61	55	51	41	38	41	47
2015	153	151	144	133	110	87	57	38	63	134	130	163	170	143	124	79	59	48	46	49	62	56	64	95
2016	198	194	195	189	207	186	145	144	148	163	170	131	110	156	134	100	66	55	57	57	63	71	58	59
2017	201	205	208	208	200	167	136	190	281	292	228	228	313	418	397	326	272	222	180	141	124	112	94	95
Threshold		420				Less Discharge	38	146	254	363	471	593	More Discharge											

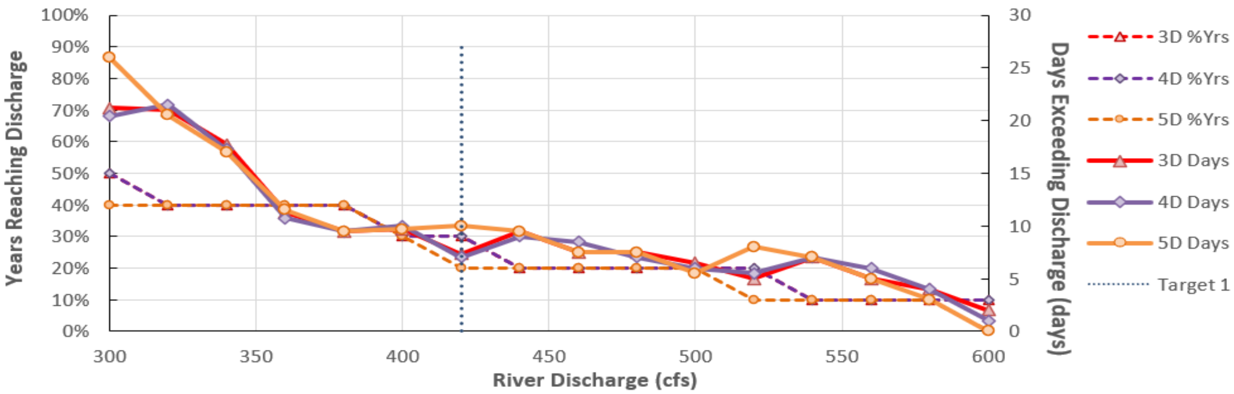
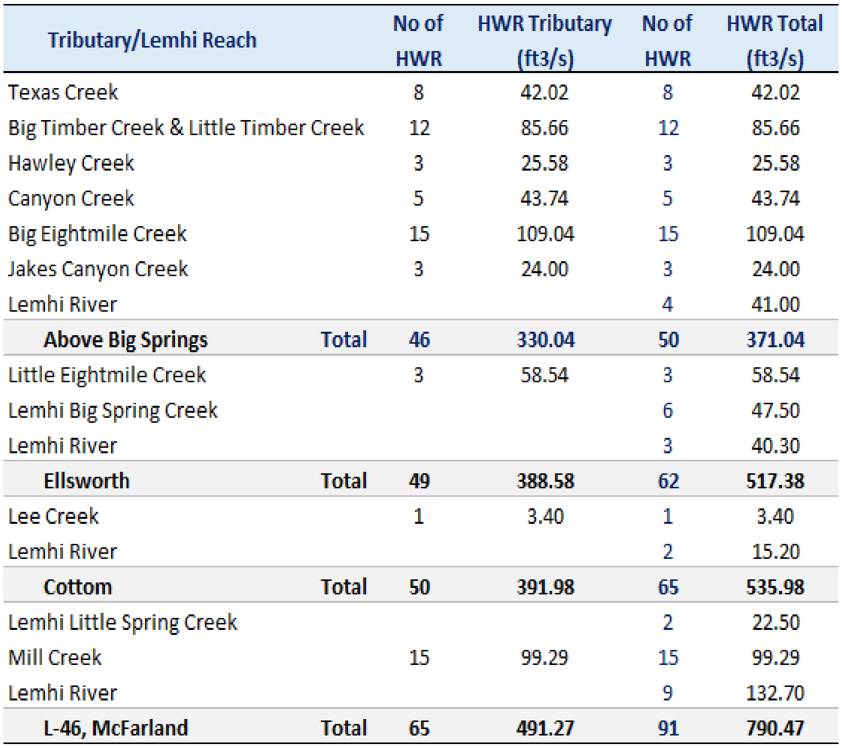


Figure 26. Discharge Exceedance of 420 CFS at the Lemhi at McFarland Gage

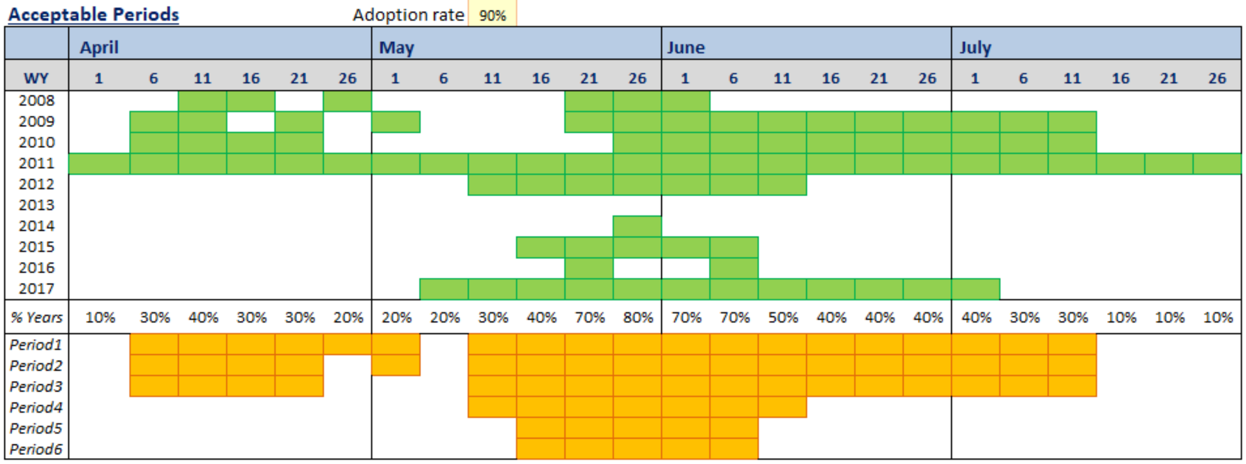
3. Available water for a flushing flow. Identifies and quantifies the diversions that divert high water. The tool maps these diversions against the historic catchment inflow from gage and LRBM rainfall-runoff modeling to determine the high water for a flushing flow. Available high-water discharge from tributaries and the mainstem Lemhi River are presented in Table 16.

Table 16. High-water rights per tributary and study reach



Tributary/Lemhi Reach	No of HWR	HWR Tributary (ft3/s)	No of HWR	HWR Total (ft3/s)
Texas Creek	8	42.02	8	42.02
Big Timber Creek & Little Timber Creek	12	85.66	12	85.66
Hawley Creek	3	25.58	3	25.58
Canyon Creek	5	43.74	5	43.74
Big Eightmile Creek	15	109.04	15	109.04
Jakes Canyon Creek	3	24.00	3	24.00
Lemhi River			4	41.00
Above Big Springs Total	**46**	**330.04**	**50**	**371.04**
Little Eightmile Creek	3	58.54	3	58.54
Lemhi Big Spring Creek			6	47.50
Lemhi River			3	40.30
Ellsworth Total	**49**	**388.58**	**62**	**517.38**
Lee Creek	1	3.40	1	3.40
Lemhi River			2	15.20
Cottom Total	**50**	**391.98**	**65**	**535.98**
Lemhi Little Spring Creek			2	22.50
Mill Creek	15	99.29	15	99.29
Lemhi River			9	132.70
L-46, McFarland Total	**65**	**491.27**	**91**	**790.47**

4. Favorable periods for conducting a flushing flow. Based on historic and modeled runoff, historic diversion records, and Lemhi River at McFarland Campground gage records, acceptable periods for reaching the 420 cfs flow target over a 3-day sustained period (the provision decided upon in the Lemhi Settlement Agreement) are presented (Figure 27, Top). Figure 27 (bottom) indicates when the “2 events in 5 years” criteria is satisfied.



Acceptable Periods

Adoption rate 90%

	April						May						June						July					
WY	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26	1	6	11	16	21	26
2008			🟩	🟩		🟩					🟩	🟩	🟩											
2009		🟩	🟩		🟩		🟩				🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			
2010		🟩	🟩	🟩	🟩							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			
2011	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩
2012									🟩	🟩	🟩	🟩	🟩	🟩	🟩									
2013																								
2014												🟩												
2015										🟩	🟩	🟩	🟩	🟩										
2016											🟩			🟩										
2017								🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩					
% Years	10%	30%	40%	30%	30%	20%	20%	20%	30%	40%	70%	80%	70%	70%	50%	40%	40%	40%	40%	30%	30%	10%	10%	10%
Period1		🟧	🟧	🟧	🟧	🟧	🟧		🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧			
Period2		🟧	🟧	🟧	🟧		🟧		🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧			
Period3		🟧	🟧	🟧	🟧				🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧	🟧			
Period4									🟧	🟧	🟧	🟧	🟧	🟧	🟧									
Period5										🟧	🟧	🟧	🟧	🟧										
Period6										🟧	🟧	🟧	🟧	🟧										

Figure 27. Favorable periods to conduct a Lemhi River flushing flow event (5-day intervals) for the upper Lemhi River

5. Identify flooding potential: Increasing discharge associated with the proposed Lemhi River flushing flow has potential flooding risk in Lemhi and Salmon, Idaho. The flooding risk has been estimated using the flood frequency return period of 50-year and 100-year flow events at USGS Gages Lemhi River at Lemhi (13305310) and Lemhi River at Lemhi (13305000). No flooding will occur during favorable flushing flow periods at either location. Note, the 50-year event is exceeded during June 2009 at Lemhi, but the corresponding flow at McFarland Campground is 517 CFS, which is above the target flow so no flushing flow would occur.

Though started under this project, the LRBM-Pulse Calculator has been further developed under contracts with IWRB and OSC-PCSRF 2021 funding. Future developments involve updating the LRBM-Pulse Calculator by:

- Characterizing criteria for the implementation of flushing flows
- Creating organizational infrastructure to support the implementation of flushing flows

LRBM BTC: The tool provides a detailed view of historic flow conditions; diversion water rights, historic flows, and consumptive rates (modeled); and how discharges along the creek impact aquatic habitat as determined by the PHABSIM studies (U.S. Bureau of Reclamation, 2004). This flow analysis tool in Excel uses water right information, LRBM modeling results, and USBR PHABSIM studies to describe how water discharge and habitat conditions vary along Big Timber Creek (BTC). To support the Lemhi Settlement, the tool was used to:

- Evaluate the frequency that flows will occur under current conditions,
- Test terms of the Bird water right application,
- Test the Bird terms under the Lemhi Settlement,
- Evaluate alternatives for Whittaker proposed terms, and
- Compute the cost estimate of conducting a 3-, 4-, and 5-day flushing flow event under different annual frequencies (e.g., 2-in-5 years, 5-in-10 years).

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