Upper Salmon Basin Groundwater – Surface Water Interactions Study, Phase 3
Final Project Report

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PROJECT OVERVIEW

DOC, Award Number:	15NMF4380233
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CFDA Project Title:	Salmon Restoration, State of Idaho
Geographic Area:	Salmon River, above the Middle Fork Salmon River, Idaho
OSC Project Number:	004 15 SA
Project Sub-Grantee:	Idaho Department of Water Resources
Project Contact Information:	Ryan Warden Hydrogeologist 322 E. Front Street, P.O. Box 83720 Boise, ID 83720-0098
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Total Non-Federal Match:	$254,148.00
Primary PCSRF Objectives:	Salmon Research, Monitoring, and Evaluation (SRME)

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PROJECT OVERVIEW

In support of the Upper Salmon Basin Watershed Program (USBWP) and its collaborators, this project undertook a series of hydrologic field tests, research, and hydrologic modeling activities aimed at characterizing the relationships between groundwater and streamflows in the Lemhi River Basin (LRB). Understanding the groundwater – surface water interactions in the basin is important for assessing the contributions to streamflow from natural runoff, irrigation return flows, and groundwater. Work associated with this project was performed in a manner that considered the needs of irrigators, anadromous fish, and the local economy.

INTRODUCTION

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

Stakeholders in the LRB seek to achieve greater streamflows and stream connectivity to provide quality habitat for Endangered Species Act (ESA)-listed anadromous and resident fish spawning, rearing, and migration. The USBWP (previously referred to as the Model Watershed Project) was established in 1992 to protect and restore habitat for ecologically- and socially-important fish species in the Lemhi, Pahsimeroi, and East Fork Salmon Rivers while, "respecting and balancing the needs of irrigated agriculture and strengthening the local economy" (USBWP, 2018).

The USBWP Technical Team (Technical Team) is composed of various federal, state, and non-profit agency personnel and local landowners. The Technical Team plans and implements a variety of streamflow enhancement projects; however, the success of these projects depends on a detailed understanding of the complex basin hydrology. Furthermore, understanding the relationships between the basin's hydrologic processes, water resources, and water rights is required for the analysis of how proposed changes might affect both fish habitat and agricultural water supplies.

Primary drivers for this study include the need to better understand the following: 1) the role that flood irrigation plays in regulating streamflows throughout the basin, 2) the hydrologic costs and benefits of high flow irrigation, and 3) the impacts that changes in irrigation practices have on streamflows. According to long-time residents and landowners, flood irrigation was widely used to water the basin's collection of pasture and hay fields before the advent of commercial sprinkler systems. Irrigators developed a practice of applying this flood water during the peak runoff period in excess of that required for irrigation (i.e., high flow irrigation) to saturate the shallow aquifer in an attempt to maintain streamflows throughout the irrigation season. However, some irrigators switched to more efficient commercial sprinkler systems as the technology became available. Additionally, governmental, tribal, and private organizations began to financially incentivize the installation of sprinkler systems in an effort to bolster streamflows during critical fish migration periods. The relationship between irrigation practices and their impact on streamflows and water supplies is currently not well understood, and it is unclear how best to implement enhancement projects to ensure that desired streamflows are attained while minimizing the impacts to irrigators.

The USBWP, the Idaho Department of Water Resources (IDWR), and several collaborating agencies seek to better understand the physical processes governing the seepage of irrigation water into the subsurface, the residence time of this shallow groundwater, and the locations of its discharge to streams. This study is intended to develop this understanding through a series of hydrologic investigations.

Since 2002, IDWR and its contractors have worked to improve our understanding of the hydrologic system by developing and refining an empirical model using MIKE BASIN modeling framework (DHI, 2003). The model was designed to describe the distribution and use of surface water across the basin, accounting for all irrigation diversions and places of use (i.e., irrigated fields). The current version of the model is capable of estimating the potential impacts on streamflows from alterations to surface water rights, such as moving irrigation diversion locations from tributary streams to the Lemhi River. Although fairly robust in terms of surface water accounting, more defined information on groundwater – surface water interactions can increase the model's accuracy and functionality. Incorporating this information into Lemhi MIKE Basin Model (LMBM) would result in a more powerful tool capable of better assessing how irrigation practices affect streamflows and overall basin water supplies.

LOCATION AND BACKGROUND

The LRB encompasses 1,270 square miles in east-central Idaho, situated between the Lemhi Range and the Beaverhead Mountains (Figure 1). The LRB is part of the larger Upper Salmon River drainage basin (USB), which encompasses the Upper Salmon, Pahsimeroi, Lemhi, and Middle Salmon – Panther River basins, which historically supported critical habitat for vast numbers of anadromous fish. The USB, the Lemhi River in particular, has been a focal area for aquatic habitat restoration for the past 25 years because it contains the headwaters of some of the last remaining anadromous fish runs in Idaho.

The headwaters of the Lemhi River are formed by the confluence of several tributaries flowing from the surrounding mountains on the north side of Gilmore Summit (7,000 ft above mean sea level (amsl)). The main-stem valley floor ranges in elevation between 4,000 – 6,000 ft amsl and receives less than 10 in/yr of precipitation. Precipitation above the valley floor is strongly correlated with elevation, and the higher surrounding mountains (exceeding 10,000 ft amsl) can receive more than 40 in/yr of precipitation, primarily in the form of snowpack.

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

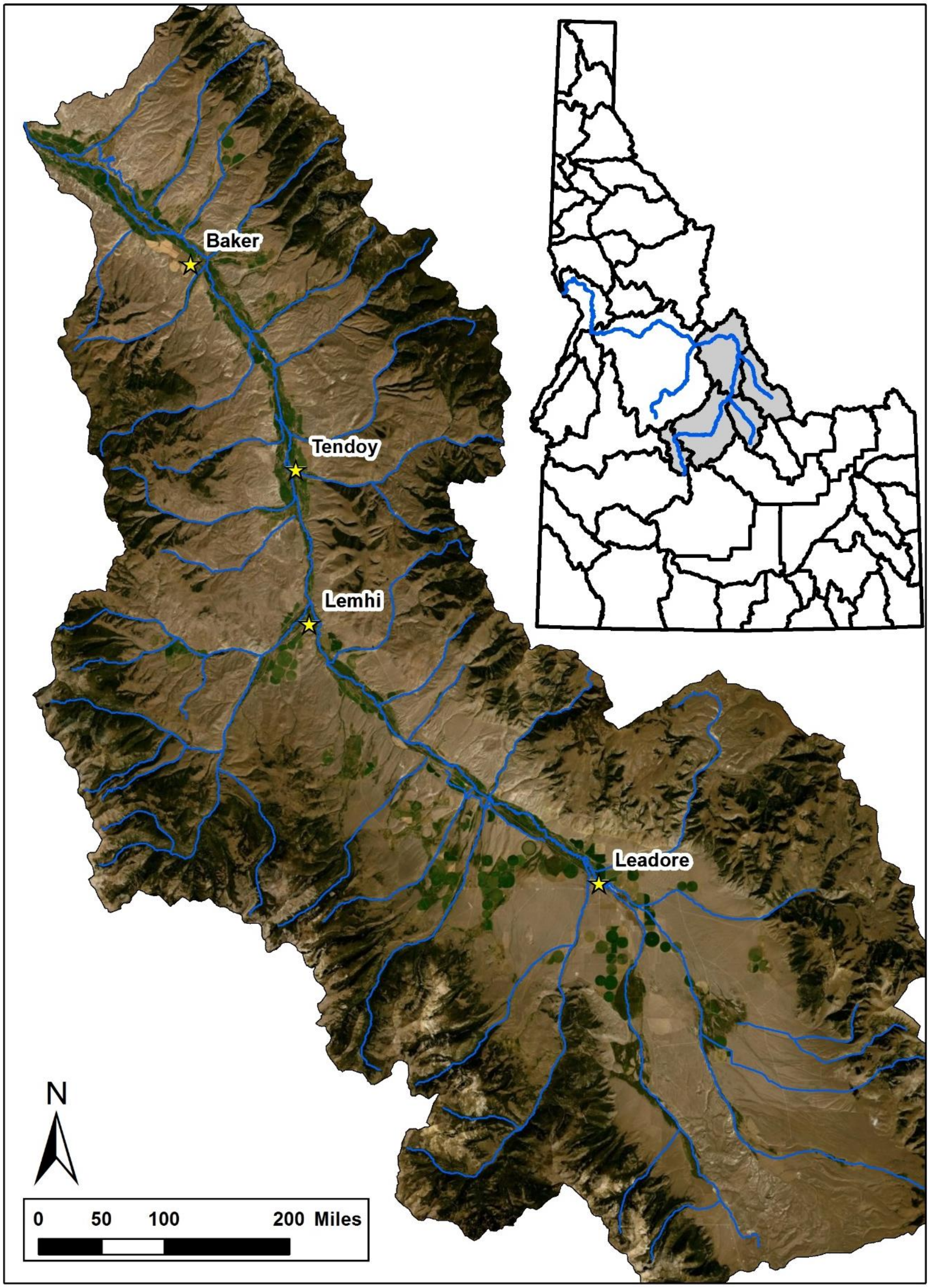

Figure 1. Location of the Upper Salmon Basin is shown in the grey inset, along with satellite imagery of the LRB portion of the Upper Salmon Basin.

IDWR estimates that approximately 120,000 acres of land are irrigated in the LRB, chiefly for alfalfa hay and pasture, based on the 2001 U.S. Geological Survey (USGS) National Land Cover Dataset. Water availability for irrigation is heavily dependent on snow melt from the surrounding mountains; consequently, landowners have created numerous earthen canals and ditches to intercept runoff. Water readily infiltrates the shallow alluvial sediments as it flows through the canals and is applied to fields, and returns to streams by both surface and groundwater flow paths (Donato 1998). After returning to streams, the water is available to be re-diverted and water in the basin is likely reused multiple times before exiting the basin as both streamflow and groundwater underflow.

Previous researchers have divided the LRB into two subbasins based on a geologic constriction (locally referred to as the "Narrows") that forces groundwater to discharge to the Lemhi River between the towns of Lemhi and Tendoy (Anderson, 1961; Dorratcaque, 1986; Spinazola, 1998). The boundary separating the upper and lower basins has been assigned to an arbitrary location within the constriction (Figure 1). The upper basin constitutes the majority of the total basin area, and the alluvium is thicker and more laterally-extensive than in the lower basin (Dorratcaque, 1986). Estimated aquifer thickness ranges from 20 to over 200 ft in the upper basin, and 27 to over 60 ft in the lower basin. Aquifer thickness in between Lemhi and Tendoy ranges from 16 to 42 ft, depending on how the Narrows is delineated.

The timing and delivery of water from the upper to the lower basin is affected potentially by both climatological factors (i.e., snow pack, rain, and temperature), and by irrigation practices upgradient of the groundwater constriction (DHI, 2006). For example, the practice of high flow irrigation may contribute significant recharge to the alluvial aquifer, and augment late season surface flows through gradual aquifer discharge (DHI, 2006). Because the upper basin comprises the majority of aquifer volume, surface water irrigation and the resulting groundwater recharge in the upper basin may be a significant component to streamflows in the lower basin. However, quantitative, temporally- and spatially-distributed data regarding the impacts on streamflows from irrigation practices are lacking.

OBJECTIVES AND TASK SUMMARIES

IDWR, as part of the USBWP Technical Team, collected data, analyzed data, and conducted modeling efforts to improve the hydrologic understanding of the LRB and the greater USB. Because most of the streamflow enhancement projects are located in the LRB, it was the primary focus of Phase 3. The main tasks conducted by IDWR included the following: 1) surface water and groundwater monitoring, 2) LMBM update and calibration, 3) aquifer characterization, 4) aerial analysis of irrigation practices, 5) evaluation of the potential for a groundwater flow model, and 6) assessment of data collection efforts.

1) Summary of Surface water and Groundwater Monitoring

   -Surface water

   IDWR managed 19 stream gages across the LRB and an additional seven gages across the greater USB. Two other gages in the LRB are monitored cooperatively with Water District 74. IDWR subcontracted with Idaho Water Engineers (IWE) to manage 11 of the 19 gages in the LRB and six gages in the USB. IDWR and IWE conducted measurements at each gage to develop rating curves, and the streamflow data were published to the IDWR public website (https://research.idwr.idaho.gov/apps/hydrologic/aquainfo/Home/Data#!/). Streamflow hydrographs are located in Appendix A.

-Groundwater

IDWR monitored 42 groundwater wells within the LRB; 24 were instrumented with data loggers and 18 were measured manually every two weeks between March and November. Groundwater data can be accessed from the IDWR website (https://data-idwr.opendata.arcgis.com/pages/popular-maps). Groundwater hydrographs are located in Appendix B.

-Soil Moisture Measurements

IDWR managed six soil moisture stations within the LRB to monitor soil moisture responses to changes in irrigation practice; two of the stations were installed during the prior phase of the project and monitoring continued throughout this phase. Four soil moisture stations were installed during May 2016 in the Pratt Creek drainage within the LRB.

Two stations were installed during September 2017 in the Hawley Creek drainage within the USB to monitor soil moisture changes associated with Beaver Dam Analog (BDA) structures. These stations were monitored cooperatively with the USBWP Technical Team. Soil moisture data are presented in the written project report. Soil moisture data are located in Appendix C.

-Isotopic Water Analysis

IDWR collected water samples from 13 surface water sites and three groundwater wells within the LRB and had them analyzed for oxygen and hydrogen isotopes. Isotope samples were collected on a quarterly basis to track seasonal changes across the whole LRB, with a total of 223 samples collected during the project period. Samples were analyzed for trends and correlations, and the results are located in Appendix D.

2) Summary of the Lemhi MIKE Basin Model (LMBM) Update and Calibration
   IDWR maintained and updated the LMBM by inputting diversion data, evapotranspiration (ET) data, and streamflow data for water years 2015, 2016, 2017, and 2018. The LMBM was re-calibrated using 2008 to 2017 water-year data. The updating, calibrating, and archiving procedures have been documented in the "Lemhi River Basin Annual Maintenance Guidance Document" located in Appendix E.

3) Summary of Aquifer Characterization
   IDWR used new and existing data to characterize the geology, hydrology, and hydrogeology of the LRB. IDWR developed a water budget for the LRB and compared it to the 1997 Donato water budget. A memo detailing the findings is located in Appendix I.

   IDWR helped to pay for a specific capacity pump test in the upper basin to better define aquifer characteristics. No other aquifer test opportunities were available during the grant period, but areas of interests were identified by IDWR to pursue in the future.

   IDWR investigated the groundwater-surface water interaction within the geologic constriction area located between the towns of Lemhi and Tendoy. IDWR initially proposed conducting a detailed seepage study, but concluded that the available hydrogeologic data explained the gains and losses along this stretch of the Lemhi River and that a seepage run was not needed at the current time. A memo detailing the findings is located in Appendix F.

4) Summary of Aerial Analysis of Irrigation Practices
IDWR initiated the aerial analysis of irrigation practices in the LRB, and is currently working to complete this task. The analysis will utilize aerial photography from 1992 as well as 2004, 2006, 2009, and 2013 NAIP datasets. Irrigated lands will be classified as: flood, sprinklers (hand lines or wheel lines), pivot system, non-irrigated, or undetermined.

5) Summary of Evaluation of the Potential for a Groundwater Flow Model
IDWR evaluated the potential for developing a groundwater flow model to represent the LRB. Data collection efforts by the USBWP Technical Team, Bureau of Reclamation (BOR), and USGS have provided sufficient data for developing a groundwater flow model of the LRB aquifer. Development of a physically-based, head-dependent groundwater flow model is expected to result in improved estimates of aquifer properties and improved ability to model streamflow responses to changes in irrigation practices. Time series outputs from groundwater-flow-model simulations could be input into the MIKE BASIN model as reach gains, and could replace the response-function time series and reach gain adjustments currently used to represent groundwater in the MIKE BASIN model.

6) Summary of the Assessment of Data Collection Efforts
Pratt Creek Drainage
An enhancement to data collection was identified by USBWP collaborators in the Pratt Creek Drainage within the LRB to help further understand the impact of changing irrigation practices on the groundwater system. Three dedicated monitoring wells were drilled and four new soil moisture measurement stations were installed to allow IDWR to monitor two conversion projects in fields that transitioned from flood to sprinkler irrigation. After installation of the wells and the soil moisture stations, both fields were then converted to sprinklers. Graphs of the soil moisture and groundwater elevation data are located in Appendix G.

Passive Integrated Transponder (PIT) Tag Arrays
IDWR investigated the feasibility of using the existing PIT tag arrays as surface water gaging stations. Quantitative Consultants, Inc. (QCI) managed and operated the PIT tag arrays in the LRB, and they reviewed the data for all array stations. QCI concluded that the pressure transducer (water depth) data was variably correlated to both temperature and barometric changes, and that a pressure-temperature relationship curve is necessary to normalize the data before the PIT tag arrays can be considered for use as gaging stations.

Hawley Creek Soil Moisture Stations
The USBWP staff needed assistance with a monitoring program that would monitor the effects of beaver dam analog (BDA) structures in Hawley Creek within the LRB. BDA monitoring usually involves measuring the groundwater levels in piezometers, but groundwater beneath the BDAs in Hawley Creek is approximately 120 feet below land surface. Therefore, soil moisture stations were installed instead. Each station consists of three sensors installed within the inundated area as well as three sensors installed on the bank of the inundated area. The sensors were installed at depths of 1, 3, and 5 feet below the surface. Piezometers were installed in 2018 next to the sensors within the inundated areas to confirm that the soil was saturated. Graphs of the soil moisture and temperature are located in Appendix H.

TASK DETAILS

IDWR conducted hydrologic investigations to gain additional information about groundwater and surface water interactions in the LRB (Main Task #1). IDWR and contractors monitored large surface water and groundwater networks that are described in detail below.

Surface Water and Groundwater Data Collection

1) *Surface Water Data Collection*

   Streamflow data are used to support planning, implementation, and monitoring of streamflow enhancements projects. IDWR has managed the collection of streamflow data for the Technical Team since 2004; gages managed by IDWR are those operated under PCSRF funding. IDWR managed 19 stream gages across the LRB and an additional seven gages across the greater USB. IDWR contracted with Idaho Water Engineers (IWE) to monitor 11 of the 19 gages in the LRB and six gages in the USB. IDWR monitored the remaining eight gages in the LRB and one gage in the USB. IDWR and IWE conducted measurements at each gage to develop rating curves. Aquarius software was used to generate rating curves for the 8 gages monitored by IDWR within the LRB.

   IDWR also contracted with Idaho Power Company (IPCo) to operate 10 gages throughout the USB that are funded through non-PCSRF sources. IWE supplied IDWR with daily and 15 minute data from the 17 stream gages they monitored, and IPCo supplied daily data from the 10 gages they monitored. Figure 2 illustrates gage locations within the greater USB that were operated during the 2015-2018 project period. Table 1 lists all of the stream gages operated within the USB. Gage locations in the LRB, the focus of this study, can be found in Figure 3.

   Two other gages in the LRB, Lemhi River L-1 and Lemhi River McFarland Campground, are monitored cooperatively by IDWR and Water District 74. IDWR developed rating curves for these two sites using data collected by WD 74. These rating curves were then used to generate daily time series of flow for these two gages; however, the data are considered provisional due to the scarcity of calibration measurements collected.

   IDWR supplemented the USB streamflow data set with downloaded daily flow data for the USGS Lemhi River-near-Lemhi and the above L-5 gages from the USGS WaterWatch website (USGS, 2018) during the 2015-2018 project period. Streamflow hydrographs for this project are included in Appendix A. All data pertaining to the IDWR managed gages (rating curves, daily mean flow, 15 minute stage, etc.) for the project period are compiled in IDWR's Aquarius database, where they are securely stored and can be rapidly queried for any request by the USBWP Technical Team or other organization. The data can also be accessed via the IDWR website at the following URL: https://research.idwr.idaho.gov/apps/hydrologic/aquainfo/Home/Data#!/.

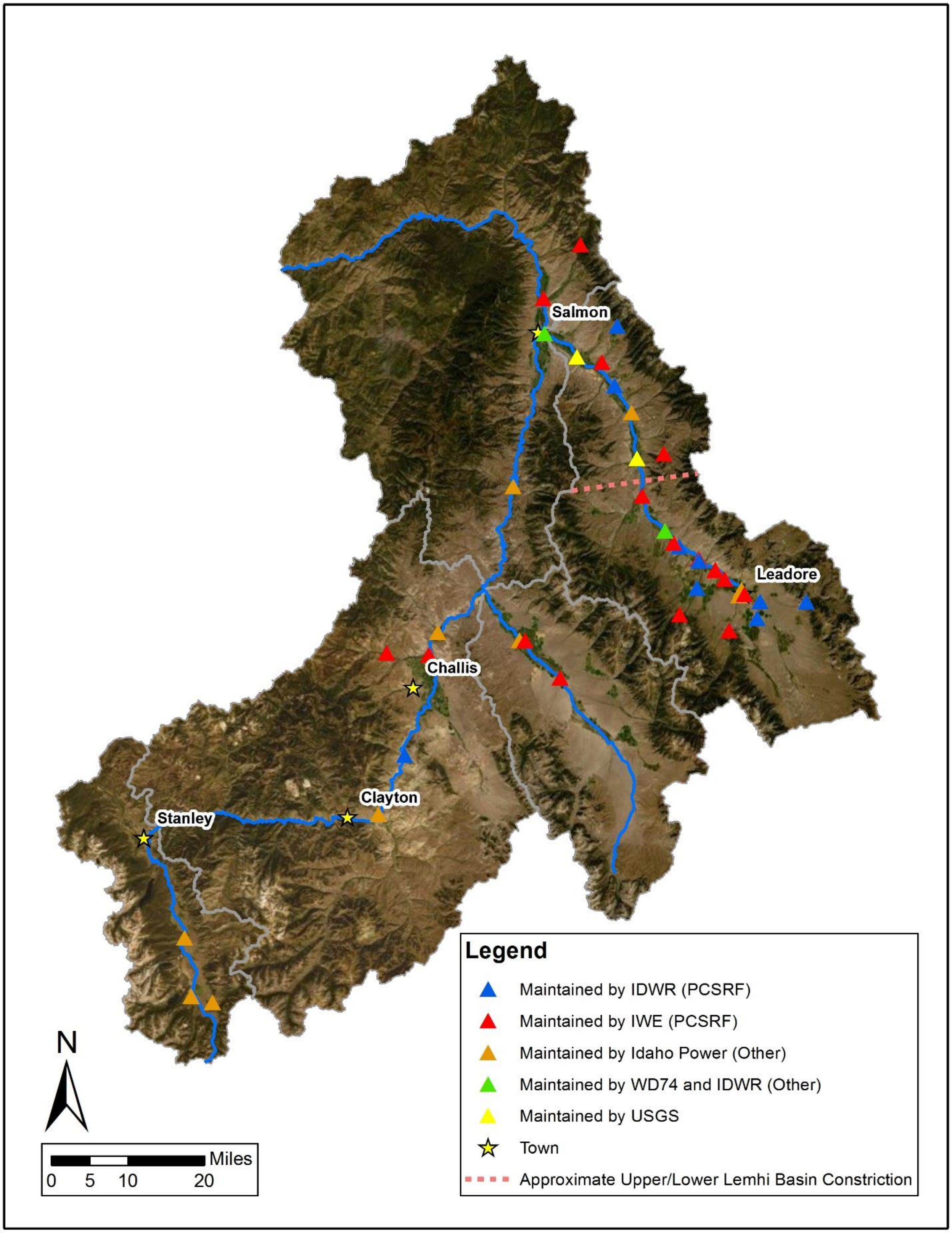

Figure 2. Stream gages within the USB. Funding sources are shown in parentheses.

Table 1. Stream gages within the USB.

Gage Name	Data Range	Status	Funding
Pole Creek below P-7	2005 - present	Operated by Idaho Power	CBWTP
Pahsimeroi River below P-9	2005 - present	Operated by Idaho Power	CBWTP
Iron Creek	2006 - present	Operated by Idaho Power	CBWTP
Beaver Creek	2004 - present	Operated by Idaho Power	CBWTP
Big Timber Creek	2004 - present	Operated by Idaho Power	IWTP
Kenney Creek	2004 - present	Operated by Idaho Power	IWTP
Fourth of July Creek	2004 - present	Operated by Idaho Power	CBWTP
Canyon Creek	2008 - present	Operated by Idaho Power	IWTP
Morgan Creek	2007 - present	Operated by Idaho Power	CBWTP
East Fork Salmon River	2004 - 2007, 2015 - present	Operated by Idaho Power	CBWTP
Eighteenmile Creek	2006 - present	Operated by IDWR	PCSRF
Hawley Creek	2008 - present	Operated by IDWR	PCSRF
Upper Little Springs Creek	2008 - 2016	Operated by IDWR	PCSRF
Lower Big Eightmile Creek	2008 - present	Operated by IDWR	PCSRF
Texas Creek	2008 - present	Operated by IDWR	PCSRF
Lee Creek	2009 - present	Operated by IDWR	PCSRF
Bohannon Creek	2013 - present	Operated by IDWR	PCSRF
Bayhorse Creek	2013 - present	Operated by IDWR	PCSRF
Pratt Creek	2017 - present	Operated by IDWR	PCSRF
Agency Creek	2005 - present	Operated by IWE	PCSRF
Big Timber Creek	2005 - present	Operated by IWE	PCSRF
Big Eightmile Creek	2005 - present	Operated by IWE	PCSRF
Big Springs Creek	2005 - present	Operated by IWE	PCSRF
Carmen Creek - Lower	2005 - present	Operated by IWE	PCSRF
Challis Creek - Lower	2005 - present	Operated by IWE	PCSRF
Lemhi River above Big Springs Creek	2005 - present	Operated by IWE	PCSRF
Lemhi River at Cottom Lane	2005 - present	Operated by IWE	PCSRF
Carmen Creek - Upper	2005 - present	Operated by IWE	PCSRF
Challis Creek - Upper	2005 - present	Operated by IWE	PCSRF
Pahsimeroi at Furey Lane	2004 - present	Operated by IWE	PCSRF
Bohannon Creek	2008 - present	Operated by IWE	PCSRF
Upper Big Springs Creek	2008 - present	Operated by IWE	PCSRF
Lemhi River above L-63	2008 - present	Operated by IWE	PCSRF
Lower Little Springs Creek	2008 - present	Operated by IWE	PCSRF
Upper Patterson-Big Springs Creek	2008 - present	Operated by IWE	PCSRF
Hayden Creek	1997 - present	Operated by IWE	PCSRF
Lemhi River at L-1	1997 - present	Operated by WD 74 and IDWR	Other
Lemhi River at McFarland Campground	1997 - present	Operated by WD 74 and IDWR	Other

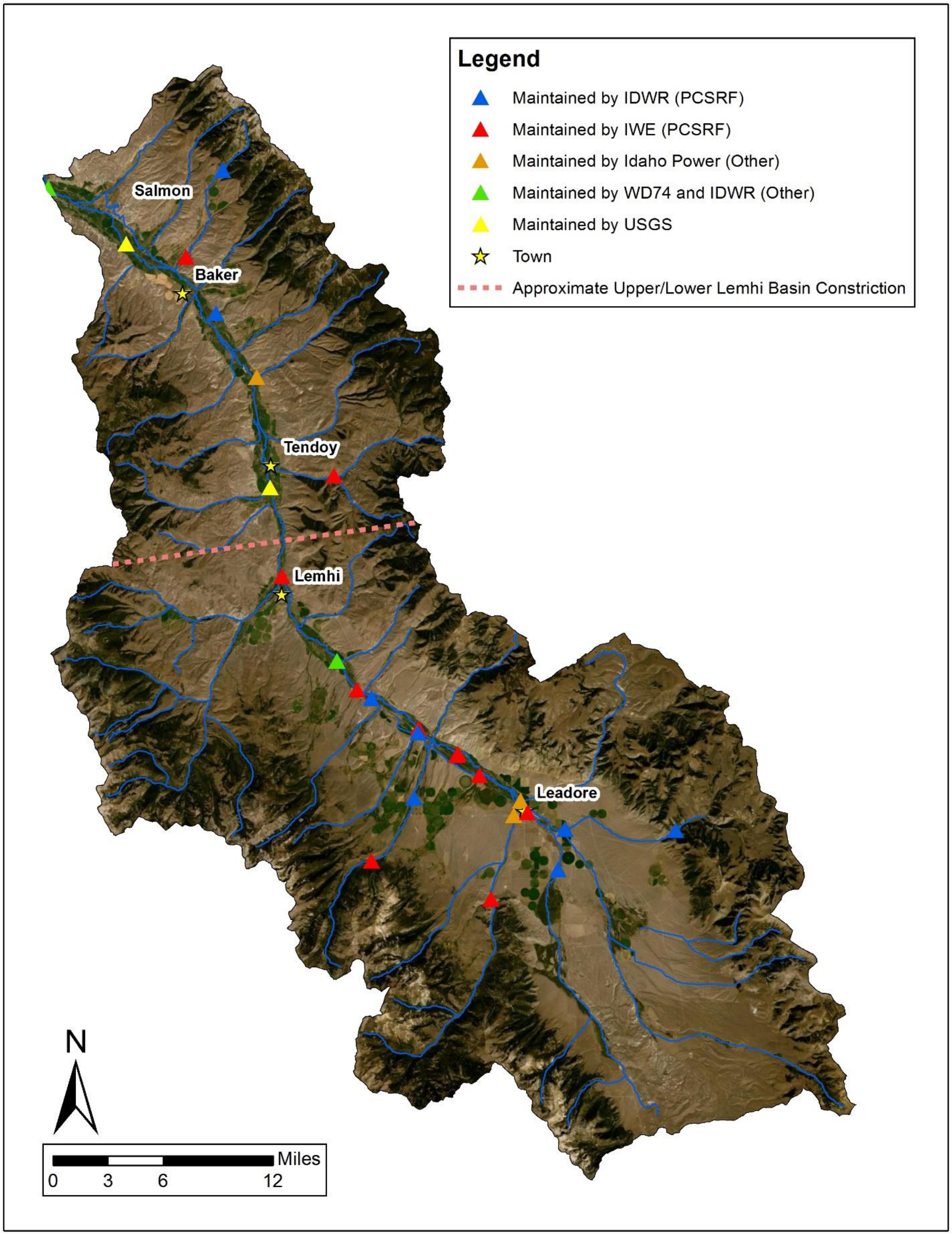

Figure 3. Stream gages located within the LRB.

2) *Groundwater Data Collection*

Irrigators and fish are both dependent on interactions between the LRB surface and groundwater systems. Groundwater level measurements are crucial in understanding surface water/groundwater interactions, and are used to support planning and implementation projects. The LRB groundwater monitoring network consists of 42 wells; thirty-eight wells were added to the LRB network during previous phases of the project (Phase 1 and 2), and four wells were added to the network during Phase 3 (Figure 4). Eighteen of the 42 wells are measured manually every two weeks between March and November by the WD 74 Water Master. The other 24 wells are equipped with non-vented, In-Situ Level Troll data loggers (Table 2). The data loggers are set to record the depth-to-water once every 6 to 12 hours, depending on the daily frequency and magnitude of water-level changes, and the loggers are left in the wells to collect data year-round. The water level data set for each well ranges from 1 to 8 years in duration, and 32 of the 42 wells also have two years of data collected from 1997 through 1998.

Seasonal water-level changes in LRB wells are greatly influenced by flood irrigation, which raises the groundwater levels anywhere from 5 to 25 ft. Therefore, long-term trends are most reliable when calculated using data collected during the non-irrigation season; non-irrigation data for all wells suggests that the aquifer has been stable with no increasing or decreasing trend from 2011-2018. However, it is difficult to determine statistically significant trends with the limited duration time-series datasets that are available. Table B1 in Appendix B lists the average groundwater elevations for the irrigation and non-irrigation seasons during the three phases of this project, and if available, for data collected by the USGS in 1997 and 1998. Comparing the averages of current water levels to the average 1997-1998 water levels indicates little to no change in groundwater levels over time; furthering the idea that aquifer levels are stable. Wells located in the upper basin have the highest seasonal water-level changes, and a few wells in the upper basin (Hayes, TylerS, England, and Beyeler Rental) also show larger water-level responses to climatic changes.

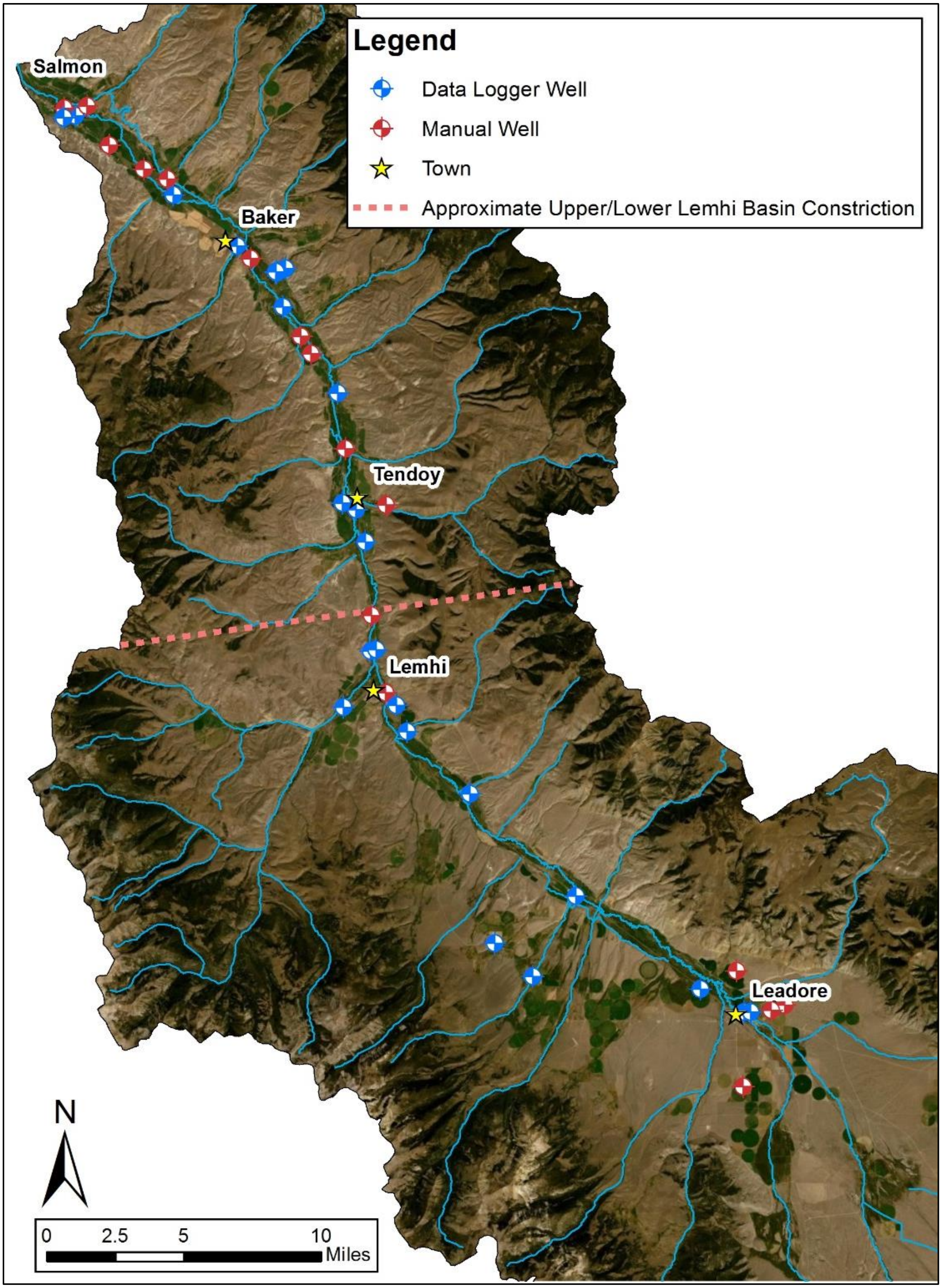

Figure 4. Groundwater well network within the LRB.

Table 2. Groundwater Well Network

	Name	Well Number	Monitoring	Start Year
Lower Lemhi Basin	Jackson	21N 22E 09DAB1	Manual Measurement	2011
	Thomas[1]	21N 22E 09DDB1	Data Logger Measurement	2011
	Cheney	21N 22E 10CCA1	Data Logger Measurement	2011
	Cockrell[1]	21N 22E 10ACD2	Manual Measurement	2011
	Fisher[1]	21N 22E 14CDD1	Manual Measurement	2015
	Richardson[1]	21N 22E 24DCA1	Manual Measurement	2015
	Stokes	21N 23E 30ABC1	Manual Measurement	2013
	Daniels[1]	21N 23E 30DAC1	Data Logger Measurement	2013
	Jordan[1]	20N 23E 03CBA2	Data Logger Measurement	2011
	Sager[1]	20N 23E 10ABA1	Manual Measurement	2015
	Pratt MW-1	20N 23E 11ADD1,2	Data Logger Measurement	2016
	Pratt MW-2	20N 23E 11DBB1	Data Logger Measurement	2016
	Pratt MW-3	20N 23E 11DBB2	Data Logger Measurement	2016
	SnookE[1]	20N 23E 14DDB1	Data Logger Measurement	2015
	SnookQ[1]	20N 23E 24CDD1	Manual Measurement	2015
	Luftkin	20N 23E 25DAB1	Manual Measurement	2015
	Probst[1]	20N 24E 31DDC1	Data Logger Measurement	2013
Mid Lemhi Basin	Sells[1]	19N 24E 17BBB1	Manual Measurement	2015
	Kesl[1]	19N 24E 30AAA2	Data Logger Measurement	2015
	Eastman[1]	19N 24E 29BDA1	Data Logger Measurement	2015
	Shuff[1]	19N 24E 28ABB2	Manual Measurement	2015
	Smith2[1]	19N 24E 32ADC1	Data Logger Measurement	2013
	Stout[1]	18N 24E 16BBB1	Manual Measurement	2011
	Kibbee	18N 24E 20ADD1	Data Logger Measurement	2011
	Whitson[1]	18N 24E 21BCD1	Data Logger Measurement	2011
	Playfair[1]	18N 24E 28DCC3	Manual Measurement	2015
	Adams[1]	18N 24E 31ACD1	Data Logger Measurement	2015
Upper Lemhi Basin	ShinerS[1]	17N 24E 04ADC1	Data Logger Measurement	2015
	ShinerD[1]	18N 24E 33ACB1	Data Logger Measurement	2013
	SnyderR[1]	17N 24E 13CBD1	Data Logger Measurement	2015
	TylerS[1]	16N 25E 18BBC1	Data Logger Measurement	2011
	Hayes[1]	16N 25E 03BCC1	Data Logger Measurement	2011
	England[1]	16N 25E 20BDD1	Data Logger Measurement	2015
	TylerK	16N 26E 20CDD1	Data Logger Measurement	2013
	Niebaur[1]	16N 26E 21ACA1	Manual Measurement	2015
	BeyelerRental[1]	16N 26E 21CAC1	Data Logger Measurement	2011
	Leatham	16N 26E 27CCB1	Data Logger Measurement	2015
	BeyelerIrr[1]	16N 26E 27CAC1	Manual Measurement	2012
	Tyler 3 (Isom3)	16N 26E 26CBC1	Manual Measurement	2018
	Isom1[1]	16N 26E 26ABB1	Manual Measurement	2015
	Isom2[1]	16N 26E 26DBB1	Manual Measurement	2015
	Dart[1,2]	15N 26E 09ADD2	Manual Measurement	2015

[1] Data set include measurements from 1997-1998.

[2] Well dropped from network.

Data logger readings were corrected for barometric pressure fluctuations using In-Situ Baro Merge software. Barometrically-corrected data are more representative of aquifer water levels (Figure 5). Hydrographs and trends are located in Appendix B, and data can be accessed through the IDWR website: https://data-idwr.opendata.arcgis.com/pages/popular-maps .

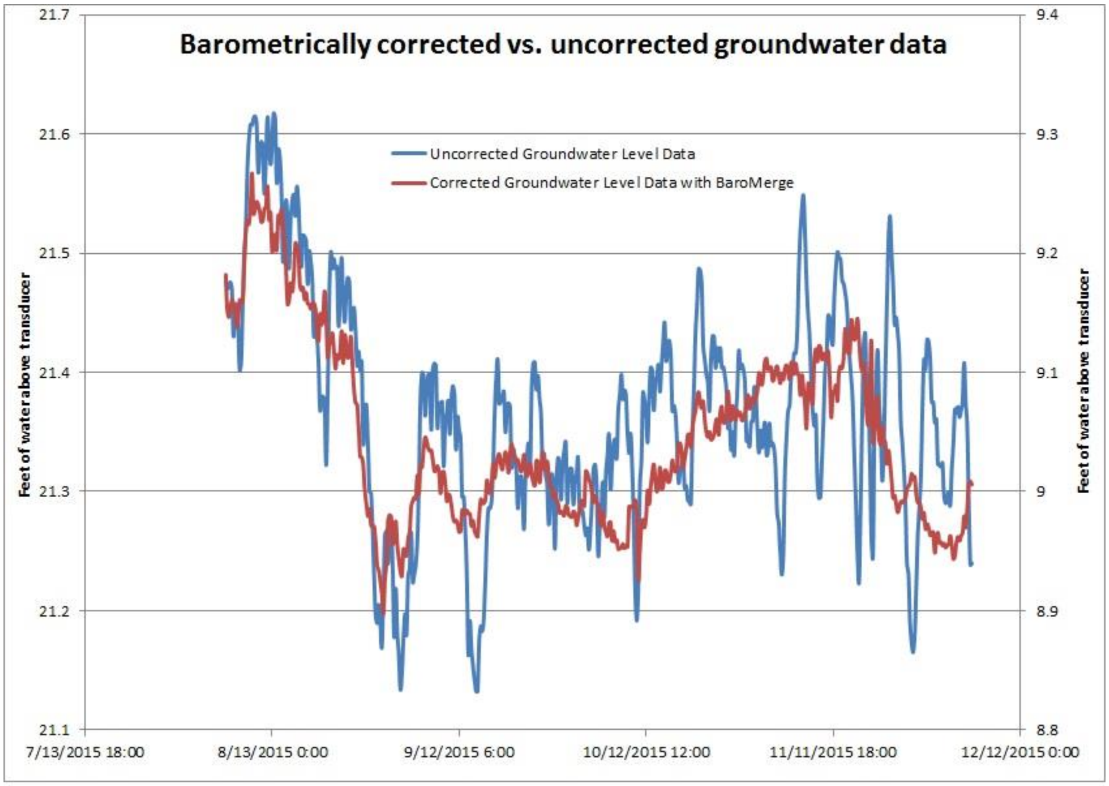

Figure 5. Example of raw versus barometrically corrected water level data.

3) *Soil Moisture Measurements*

IDWR managed six soil moisture stations within the LRB to monitor soil moisture responses to changes in irrigation practices (Figure 6 and Appendix C). Four soil moisture stations were installed in the Pratt Creek drainage during May 2016 to monitor the impacts of stream restoration and flood-to-sprinkler projects. Additionally, two stations were installed in the Hawley Creek drainage during September 2017 to monitor soil moisture changes associated with Beaver Dam Analog (BDA) structures. These stations were monitored cooperatively by IDWR and the Technical Team. The Pratt Creek and Hawley Creek stations are discussed in the Data Collection Assessment section.

The SnookQ and TylerK stations were installed during Phase 2, and monitoring continued throughout Phase 3.

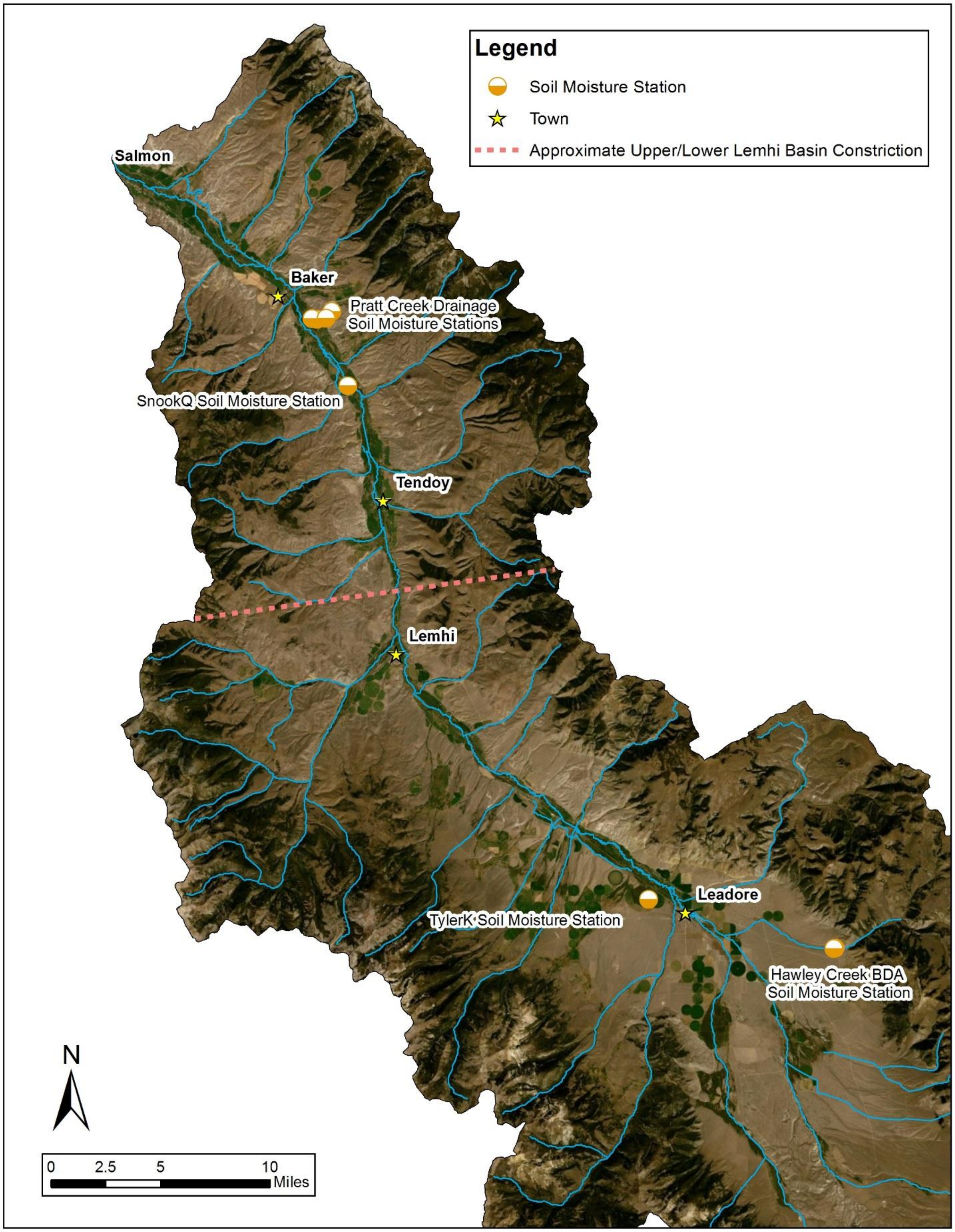

Figure 6. Location of soil moisture stations.

The 3 ft below ground surface (BGS) sensor at the TylerK site failed during Phase 3 of the project, providing only partial data in 2016 and 2017, and no data in 2018. The sensors installed at 0.5, 2, and 5 ft BGS operated throughout the project without any failures. Although the data from the sensor at 3 ft BGS contained data gaps, it is evident that conditions remained fairly wet prior to 2016, with periods of dryness during the irrigation season. No data was collected from the sensors installed at 1 and 4 ft BGS during the project. The sensor installed at 5 ft BGS has very little variability and measurements indicate the soil at that depth is wet and may be saturated. The sensor at 2 ft BGS indicates wet conditions during 2014, 2015, 2017, and 2018, but this sensor varies from wet to dry during 2012, 2013, and 2016; it is unclear if the differences are due to questionable data.

The station installed at the SnookQ site is installed under a pivot and on top of a slope that is marshy towards the bottom. All sensors show variability from wet to dry throughout the irrigation season; it is assumed this is due to a quick wetting from the pivot passing over the station followed by a slow drying period. The sensor installed at 5 ft BGS gradually wets up as irrigation season starts and then dries up at the end of irrigation each year.

4) *Isotope Analysis*

Water samples were collected in the basin from headwater-tributary streams, the main stem of the Lemhi River, and groundwater wells to analyze naturally-occurring oxygen-18 ($\delta^{18}O$) and deuterium ($\delta^{2}H$) values. Isotope values are reported in delta notation, as isotopic ratios 2H/1H and 18O/16O relative to Vienna Standard Mean Ocean Water (VSMOW), in units of per mil (‰). Deviations in $\delta^{18}O$ and $\delta^{2}H$ values from VSMOW are the result of isotopic fractionation processes that occur during phase changes (e.g., condensation and evaporation). This allows for the use of these isotope values as tracers to differentiate unique water sources. Figure 7 illustrates the sample locations. Samples were collected during spring (March-April), summer (June-August), fall (September-October), and winter (November-December) to capture any temporal changes that could influence isotope values.

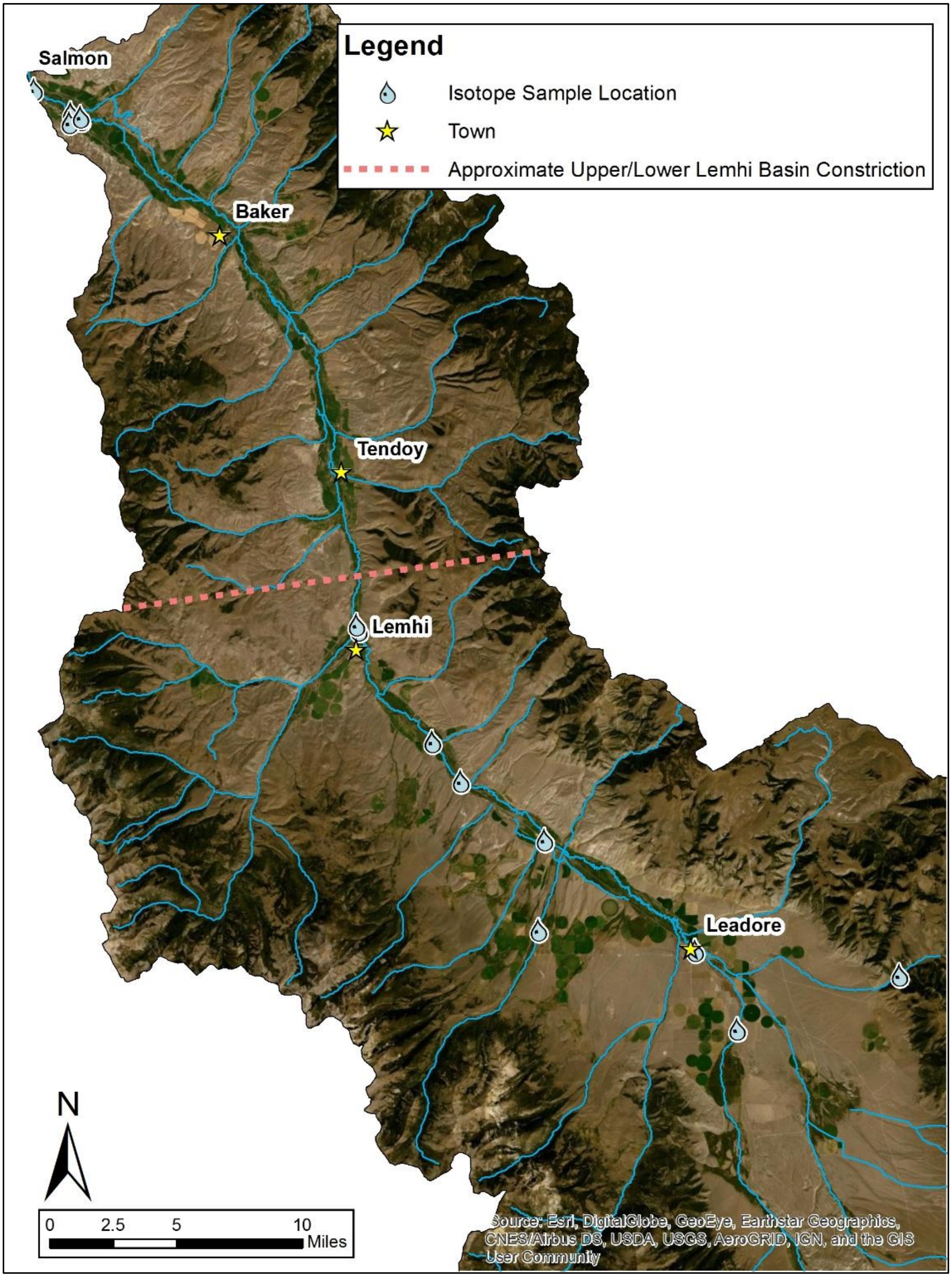

Figure 7. Locations of isotope sample collection points.

$\delta^{18}O$ versus δ^2H was plotted for all samples collected (Appendix D, Figure D-1). A global meteoric water line was used to compare sample $\delta^{18}O$ and δ^2H values to average global precipitation. Additionally, the data were compared to a local meteoric water line for the Pahsimeroi Basin (Hagedorn and Whittier, 2014) because it likely better represents precipitation $\delta^{18}O$ and δ^2H values of the LRB. The range in the isotope values collected was 17.75 for δ^2H and 2.02 for $\delta^{18}O$; no correlations or relationships were identified. Visually, there is no clear correlation or distinction (high scatter) in the isotope data even when grouped into patterns such as seasons or by locations (Appendix D). The lack of any isotopic signature in the location is indicative of a high degree of water interchanging and/or low variability in the source waters for the basin.

Lemhi MIKE Basin Model

The LMBM was used throughout the project to model the hydrologic system and support the Technical Team. The LMBM boundary was expanded in 2013 to include the whole basin, including pediment catchments representing irrigated land near the start of the alluvial aquifer system. In 2015 (Phase 2), the model was recalibrated and updated to water year (WY) 2014. The LMBM was subsequently calibrated and updated to WY 2017 during Phase 3. The 2017 version also added a simple groundwater flow component to account for recharge from irrigation practices, and utilized response curves (CH2M HILL, 2014) to represent the quantity and timing of the groundwater discharge back to the Lemhi River. Centered Consulting International (CCI) created wrote a report “Lemhi River Basin Model Supporting Documentation December 2015”, which documents the development of the LRMB and all of its components (Appendix K).

An Annual Maintenance Guidance Document was created during this project to document the upkeep of the LMBM (Appendix E). The document outlines how to update, calibrate, and archive the model for future versions. The document will be a living document that will be updated as needed.

Aerial Analysis of Irrigation Practices

IDWR initiated an analysis of irrigation practices in the LRB, and is currently working to complete this task. The analysis will utilize aerial photography from 1992, 2004, 2006, 2009, and 2013 NAIP datasets. Irrigated lands will be classified as: flood, sprinklers (hand lines or wheel lines), pivot system, non-irrigated, or undetermined. The analysis will continue into the next project phase.

Potential for a Groundwater Flow Model

IDWR evaluated the potential for developing a groundwater flow model to represent the LRB. This analysis is located in Appendix J. The analysis determined that there are sufficient data for developing a groundwater flow model, and that the development of a model is expected to result in improved estimates of aquifer properties and improved ability to model streamflow responses to changes in irrigation practices. Time series outputs from groundwater-flow-model simulations could be input into the LMBM model as reach gains, and could replace the response-function time series and reach gain adjustments currently used to represent groundwater.

DATA COLLECTION ASSESSMENT

Aquifer Tests

IDWR had planned to conduct aquifer tests to quantify aquifer properties; however, no opportunities were available during the grant period. Instead, IDWR provided financial support for specific capacity tests that the Lemhi Soil and Water Conservation District was conducting on the Isom #1 and Isom #2 wells (Figure 8). The specific capacity tests were not designed to determine aquifer properties, but to test the maximum pumping rate that would allow for a stable water level. Each well was tested two times at different RPMs to find the maximum stable pump rate. Table 3 shows the stable water levels as well as estimated transmissivity values from the test data.

Table 3. Specific capacity test information and calculated transmissivity.

Isom#1	Static WL = 148				
	Pumping Water Level (ft)	Drawdown (ft)	Flow (gpm)	Flow (ft^3/d)	Transmissivity (ft^2/d)
Test 1	164	16	850	163,636	16,326
Test 2	194	46	935	180,000	8,577

Isom#2	Static WL = 120				
	Pumping Water Level (ft)	Drawdown (ft)	Flow (gpm)	Flow (ft^3/d)	Transmissivity (ft^2/d)
Test 1	185	65	Cavitation - loss of flow		
Test 2	184	64	992	190,973	7,152

Because knowledge of aquifer properties is important for understanding the hydrologic system, an aquifer test designed and implemented by a professional hydrogeologist or engineer is recommended for the next phase of the project.

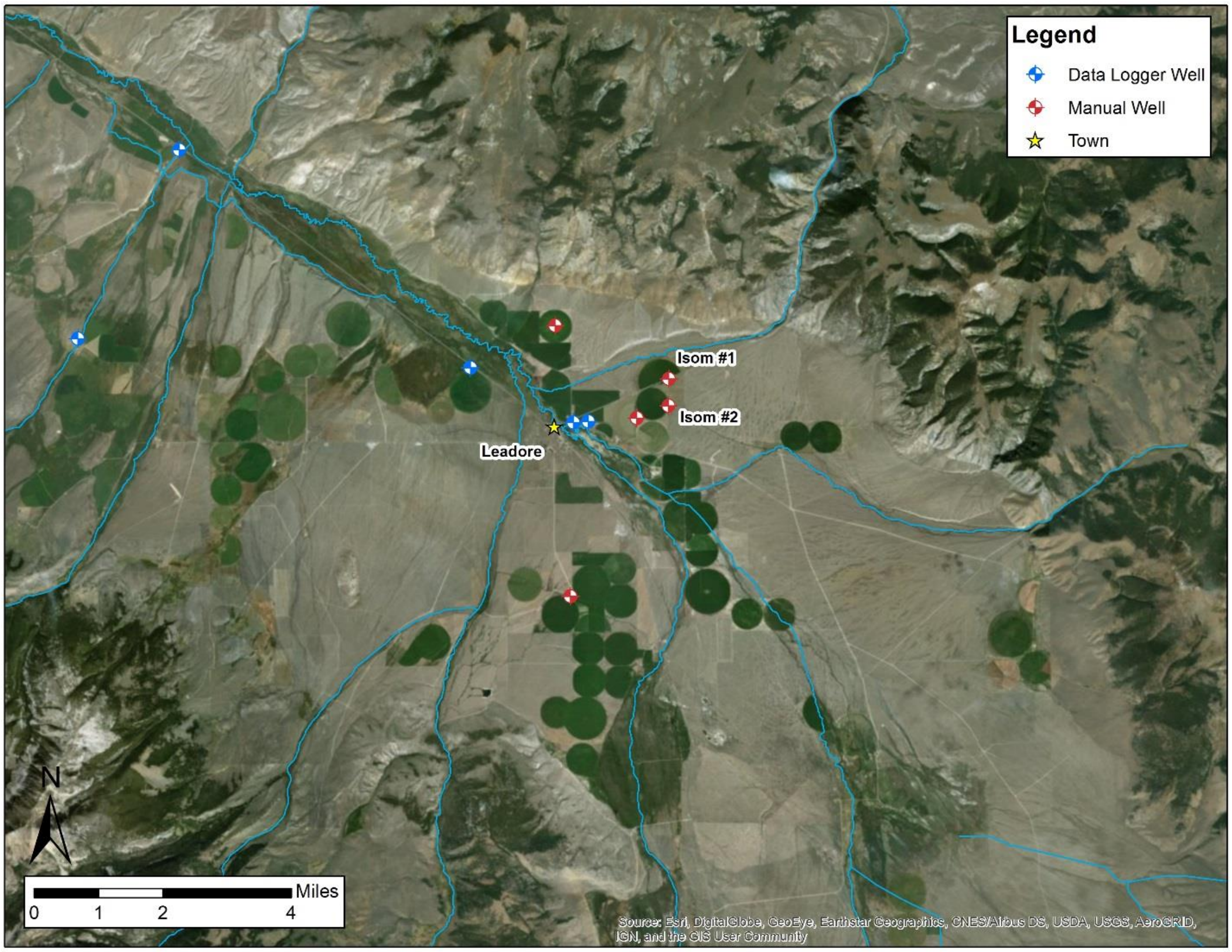

Figure 8. Location of test wells used for specific capacity tests.

Seepage Runs

A seepage run was conducted on the Lemhi River during Phase #2 of the project to duplicate the Donato (1998) study. The Phase #2 results indicated that this was a gaining stretch during irrigation season but losing during the non-irrigation season. Therefore, a Phase #3 seepage run along the stretch of the Lemhi River that passes though the constriction area was proposed to better understand the surface water – groundwater dynamics in the Narrows area. Prior to starting the seepage run, an analysis was done to investigate potential causes for loss in the river during the non-irrigation season. The analysis indicated that the gains and losses can be explained with available information (Appendix F).

PIT Tag Arrays

IDWR investigated the feasibility of using the existing PIT tag arrays as surface water gaging stations. Quantitative Consultants, Inc. (QCI) managed and operated the PIT tag arrays in the LRB (Figure 9). PIT tag arrays are a group of sensors that scan tagged fish as they pass the sensors. The arrays also collect data from the stream such as temperature and depth of water. It was proposed that it may be possible to utilize the array as a stream gage by using the pressure transducer data to develop a rating curve. QCI, who manages the data, reviewed the transducer data for all the stations in the LRB and found that pressure (water depth) was variably correlated to temperature and barometric pressure. QCI concluded that a pressure-temperature relationship curve is necessary to normalize the data before the PIT tag arrays can be considered for use as gaging stations. Another complication is the arrays are located to account for fish entering and exiting key parts of the streams, not in locations that provide good controls for developing stage-discharge relations.

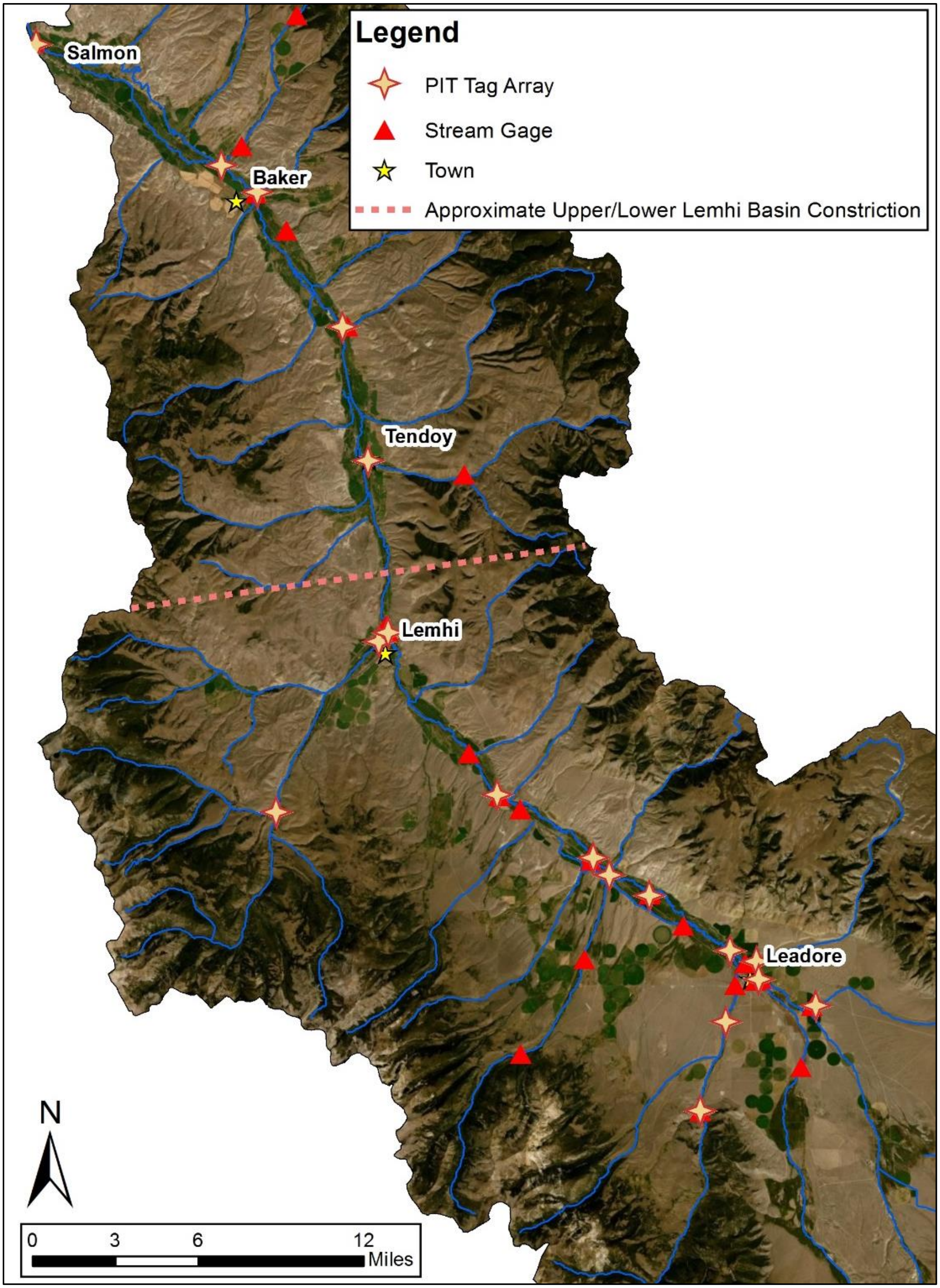

Figure 9. PIT tag array locations in the LRB.

Pratt Creek Drainage Study

An enhancement to data collection was identified by USBWP collaborators in the Pratt Creek Drainage to help further understand the impact of changing irrigation practices on the groundwater system, specifically from the conversion of flood to sprinkler irrigation and the re-channelization of Pratt Creek. Four soil moisture stations and three shallow wells were installed to monitor soil moisture and groundwater level changes due to conversion projects (Figure 10).

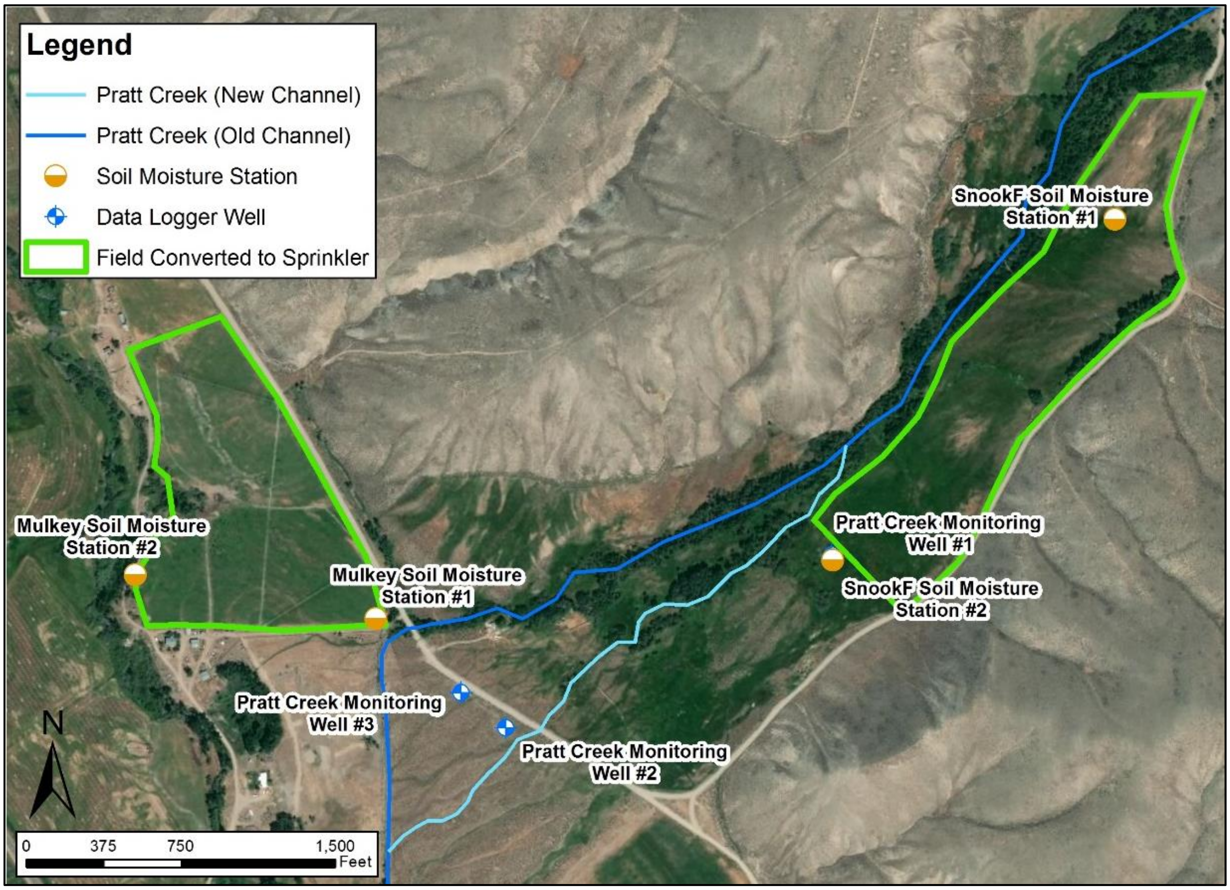

Figure 10. Pratt Creek soil moisture and water level monitoring sites.

Soil moisture and groundwater level data from the Pratt Creek Drainage study are located in Appendix G. The soil moisture stations were installed in May 2016, with each station comprised of five soil moisture probes, one thermistor, and a data logger. The loggers collected a reading every 8 hours, and the probes were buried at 0.5, 1, 2, 3, 4, and 5 feet below land surface. The Mulkey2 station sensors 1 and 4 malfunctioned in 2017; only sensors 2, 5 and 6 were operational in 2018. The SnookF2 data logger malfunctioned in 2018 and many of the data were lost. The Pratt Creek monitoring wells were completed in October 2016 and subsequently instrumented with data loggers.

The irrigation method for the SnookF fields was changed from flood irrigation to wheel-line sprinklers prior to the start of the 2018 irrigation season. The old Pratt Creek Channel was discontinued and the new channel began flowing in November 2018. Water levels in MW-1 responded within a week of the application of water to the SnookF fields. Water levels in MW-2 and MW-3 rose more than in MW-1, but took more than 2 weeks to respond (Appendix G). Water levels in MW-1 rose sooner than soil moisture at the SnookF2 station, despite being 25 feet away from each other. Once irrigation ceased, water levels receded to baseline levels in approximately two months. Soil started drying immediately after irrigation stopped, and was past the wilting point within six weeks. The impact to groundwater from converting from flood to sprinkler irrigation is not evident in either the water-level or moisture data. However, when the old Pratt Creek channel was abandoned and the new channel put into use, water levels in both MW-2 and MW-3 responded immediately. Water levels in the Pratt Creek study area appear to have been most impacted by channel realignment, with little impact from changing irrigation methods.

The irrigation method for the Mulkey fields was changed from flood irrigation to pivot sprinklers prior to the start of the 2017 irrigation season. Soil moisture data from the Mulkey fields show immediate responses to sprinkler irrigation. The deepest Mulky1 sensor (5 ft) reported consistently wet soil, but the deep sensor at the Mulkey2 station reached wilting point each year. A reason for the difference between Mulkey1 and Mulkey2 could be that the Mulkey1 station is under the pivot and Mulkley1 is outside of the pivot swing.

Hawley Creek Beaver Dam Analog Soil Moisture Monitoring

Beaver Dam Analog (BDA) structures were installed along stretches of Hawley Creek to increase moisture retention within the soil and improve the decimated wetland habitat from decades of dewatering. Five BDA complexes were installed in September 2017. BDA monitoring usually involves measuring the groundwater levels in piezometers, but groundwater beneath the location of the BDAs in Hawley Creek is approximately 120 feet below land surface. Therefore, two soil moisture stations were installed instead. Figure 11 shows the locations of the BDAs and the soil moisture stations.

Each station consists of three moisture sensors and a thermistor. One station was installed within the inundated area and one station was installed on the bank of the inundated area. The sensors are installed at depths of 1, 3, and 5 ft BGS, and the thermistors were installed at a depth of 1 ft BGS. Piezometers were installed in 2018 within the inundated areas to confirm that the soil was saturated. Hydrographs are located in Appendix H.

BDA 4 data indicate that the soil stays wet except for a drying event that appears to be the result of freezing temperatures in December 2018. However, the BDA 4 bank sensors respond very similarly to the BDA 5 inundated sensors, and the wiring and programming need to be examined to ensure they are set up correctly.

Hydrographs of BDA 5 in 2018 indicate two wetting periods with a drying period between. All bank and inundated sensors become wet in March and the piezometers indicate that soil in the inundated area is saturated. The soil starts to dry and the piezometers have no water by early July, presumably due to lower flows in Hawley Creek and a smaller inundation footprint in the BDAs. The sensors measure increasing soil moisture in September, but only the piezometer installed to 1 ft BGS is saturated (Appendix G).

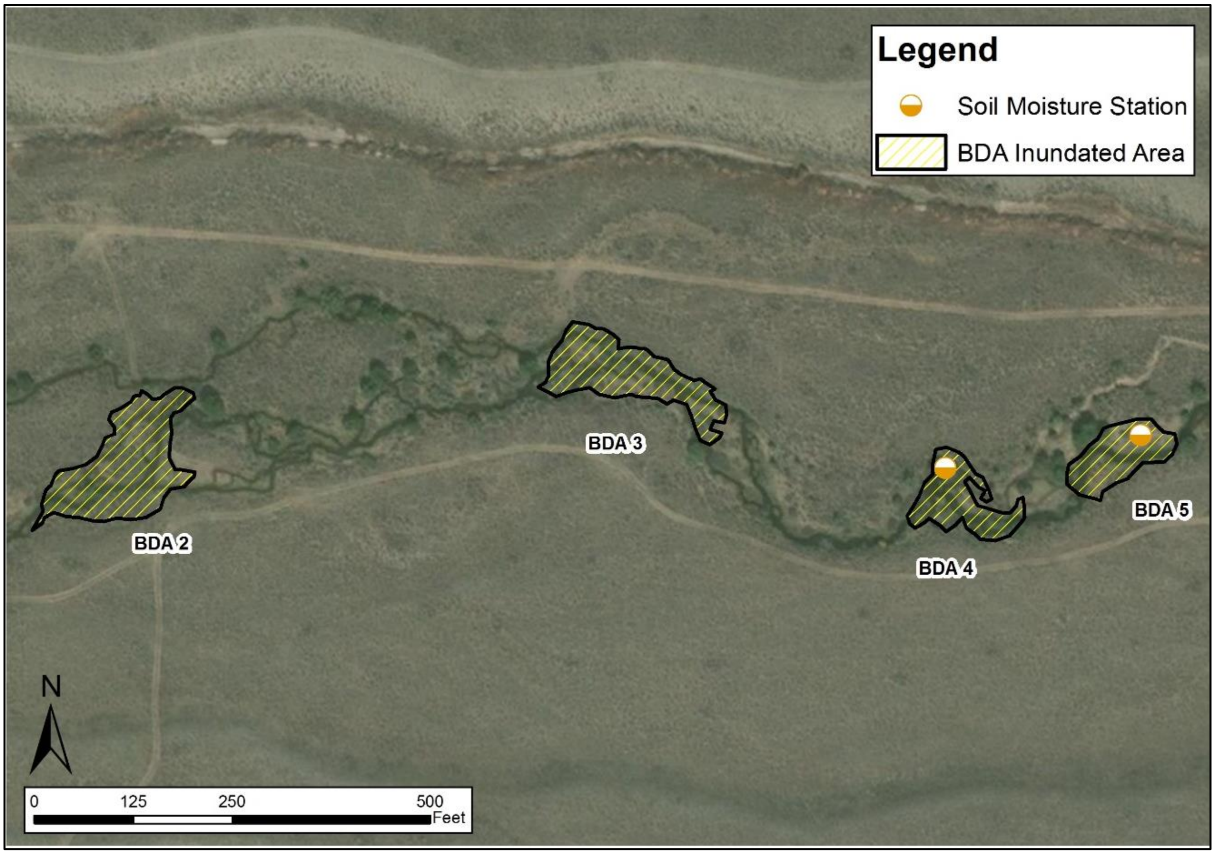

Figure 11. Location of beaver dam analog structures and soil moisture monitoring stations on Hawley Creek.

HYDROGEOLOGIC SETTING

The LRB is located within the Rocky Mountain physiographic province (Dorratcaque, 1986). The basin is bounded on the west by the Lemhi Mountain Range and on the east by the Beaverhead Mountain Range. The mountain ranges flanking the LRB consist primarily of volcanic, intrusive, metamorphic, and sedimentary rocks of Mesoproterozoic to Miocene age, and do not contribute significant volumes of water to the aquifer system (Anderson, 1961; Donato, 1998). Low-permeability sediments dating to the Eocene underlie all of the Lemhi Valley, and are characterized by shales with sandy lenses, silty shales, and conglomerates (Chapman, 1976).

The valley floor and adjacent terraces are composed of unconsolidated Holocene alluvial deposits associated with the Lemhi River and its tributaries, as well as older Quaternary alluvial terrace, alluvial fan, and glacial deposits. These sediments are the principal water-bearing units in the basin (Donato, 1998). Figure 12 illustrates the surficial geology of the LRB.

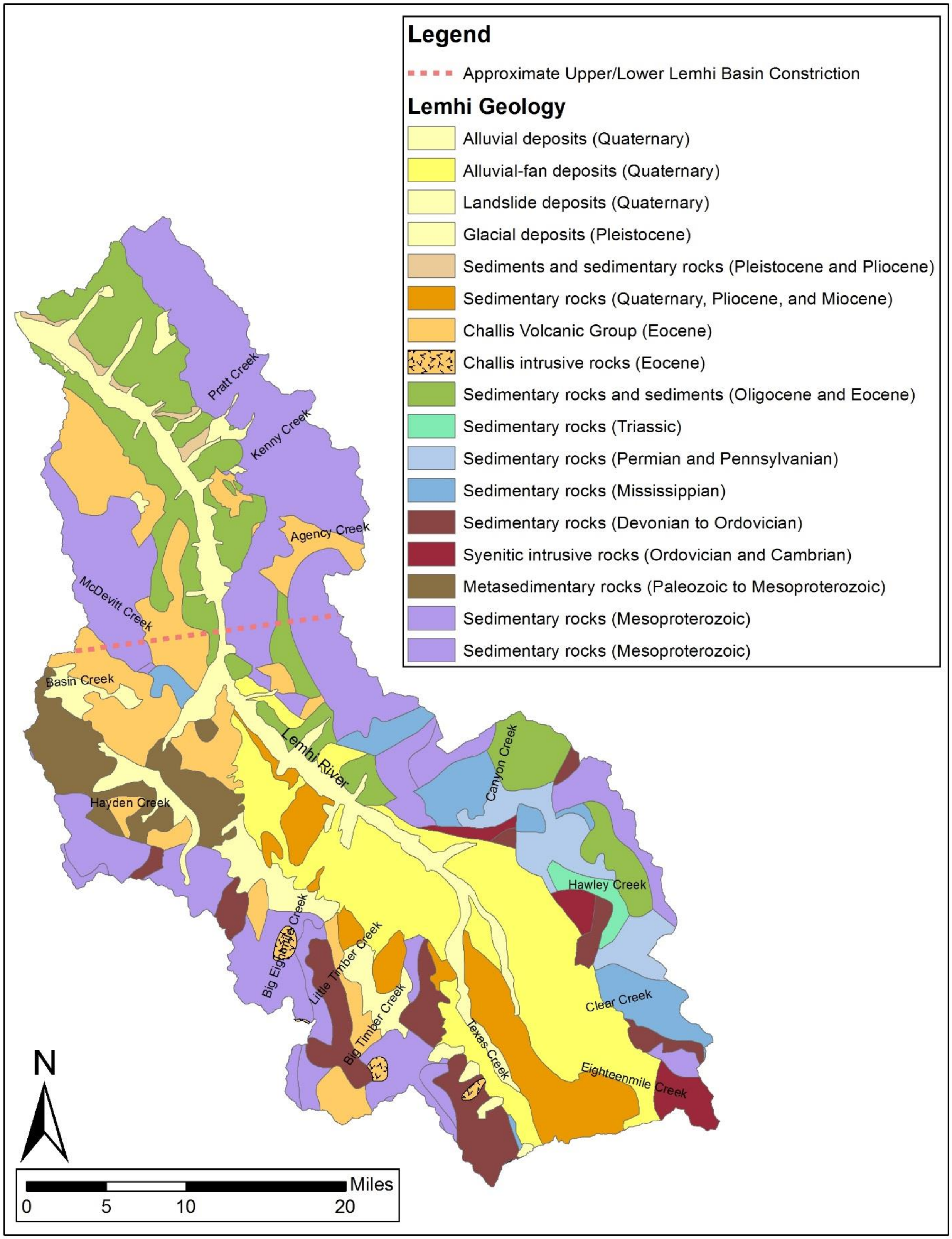

Figure 12. Surficial geology in the LRB.

Geologic History

Pre-Quaternary History

The oldest rocks in the basin are sedimentary rocks that have been dated to the Mesoproterozoic Era. These sediments were deposited in very shallow seas that covered a slowly-sinking geosyncline. The sedimentation during this time occurred at approximately the same rate as the subsidence which resulted in deposits that are up to 30,000 feet thick. Regional uplifts and marine regression halted the deposition of sediments in Late Precambrian time (Anderson, 1961).

During the Early Paleozoic Era, the basin experienced recurrent uplifts that led to extensive erosion. This erosion removed evidence of any deposition that may have occurred during the Cambrian, as well as the loss of a thick section of Mesoproterozoic rocks (Anderson, 1961). Uplift ceased during the Late Ordovician Period, and seas advanced across the area which resulted in renewed deposition through the Devonian Period. During the Mississippian Period, uplift resumed and erosion continued throughout the rest of the Paleozoic Era and the entire Mesozoic Era.

The Early and Middle Tertiary Era was characterized by orogenic periods that deformed and fractured the existing lithology, and the associated uplift led to erosion of the existing rocks and the deposition of new sedimentary rocks. Volcanic activity began during the Oligocene which resulted in the accumulation of volcanic rocks, and the associated crustal instability led to recurrent periods of uplift, erosion, and deposition. Sedimentation ceased in the Late Miocene, and erosion resumed due to a rapid, regional uplift (Chapman, 1976).

Quaternary History

Erosion due to the uplift at the end of the Tertiary initiated the creation of the dominant features of the LRB seen today – the Lemhi Valley flanked by the Beaverhead and Lemhi ranges. During the early stages of this re-sculpturing, glaciers formed and crept down-slope to the edges of the basin. Moraines were left on the flanks of the basin and the outwash was carried out onto the basin floor. Subsequent stream erosion carved the outwash deposits down to the elevations of the current valley floors.

A second period of glaciation did not extend as far down-slope as the earlier glaciers; however, the melt waters dropped most of the glacial debris on the valley floors. As the glaciers disappeared, the streams began eroding alluvial fill from the valley, leaving terraces bordering the valley floor. Erosion has been negligible since the disappearance of the glaciers, and there has been no appreciable deepening along the Lemhi River.

Hydrogeology

Quaternary-age unconsolidated sediments located on the valley floor, in terraces and moraines adjacent to the valley, and in alluvial fans at the mouths of tributary streams are the principal water-bearing materials in the basin (Figures 12 and 13; Donato, 1998). These sediments consist primarily of gravel with intercalated sand and silt. The gravel is generally well sorted and is derived mainly from resistant quartzite, dolomite, and volcanic rocks exposed in the vicinity. The finer-grained sand, silt, and clay are derived generally from poorly consolidated Tertiary sediments (Anderson; 1956, 1957, 1961).

The three-dimensional shape of the alluvium on the basin floor is not well defined (Donato, 1998). Wells for which drillers' lithologic logs encounter bedrock can be used to estimate alluvium thickness at the well locations; however, most wells are completed in alluvium and those logs give only an indication of minimum alluvium thickness (Figure 13; Donato, 1998).

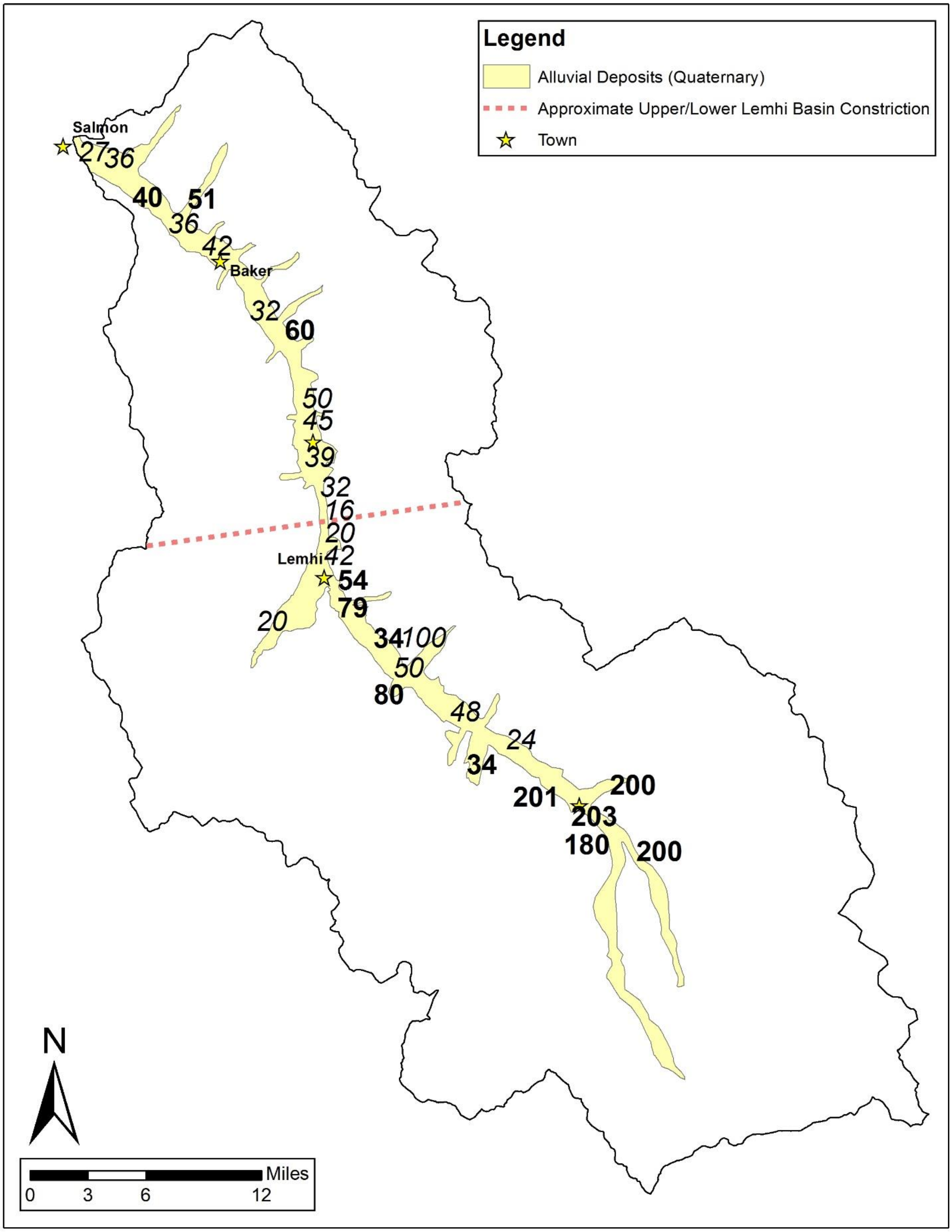

Figure 13. Alluvium thickness in the LRB aquifer. Bolded numbers represent minimum alluvium thickness and italicized numbers represent maximum alluvium thickness.

Previous researchers have generally divided the LRB into two basins, the upper basin and the lower basin, based on the presence of a geologic constriction. This constriction occurs immediately downstream from Lemhi where the alluvium appears to be less than 20 ft thick and about 2,300 ft wide. Because the aquifer becomes shallower and narrower, the majority of groundwater is forced to discharge into the Lemhi River, creating a hydraulic barrier to groundwater flow (Anderson, 1961; Donato, 1998). In other words, effectively all of the surface water and groundwater originating in the upper basin flows through the constriction as surface water in the Lemhi River as it enters the lower basin (Donato 1998). The exact location of the boundary is not known and has been assigned to the approximate location of the well with the shallowest depth to bedrock (Figure 13).

The upper basin constitutes the majority of the total basin area, and generally consists of thicker and more laterally-extensive alluvium deposits than the lower basin (Dorratcaque, 1986). Estimates of saturated aquifer thickness in the upper basin range from 5 – 50 ft along the Lemhi River corridor to greater than 100 ft along the terraces flanking the corridor and over 200 ft up-gradient of Leadore (Spinazola, 1998). Because the lower basin encompasses less area, is at a lower elevation, and is not receiving appreciable underflow from the upper basin, flows of the Lemhi River are largely fed by water originating in the upper basin (Appendix I; Donato 1998).

Little quantitative information is known about the alluvial aquifer properties because most existing information was estimated from driller's logs and general aquifer property literature. Quantitative information on aquifer properties is required to accurately account for the amount and timing of water transmitted through the aquifer, and will foster the development of a groundwater flow model.

Groundwater in the LRB occurs primarily in the Quaternary sediments (Figures 12 and 13). Depth-to-water during the irrigation season ranges from 10 to 30 feet BGS in the lower basin and constriction areas, and from 20 to 50 feet BGS in the upper basin (Donato, 1998). Groundwater flows from higher elevations to the Lemhi River and follows the river to the northwest until it exits the LRB as underflow (Figure 14). Although water levels fluctuate due to pumping, geologic conditions, proximity to surface water features, and long-term variation in precipitation, the primary driver for water level change is the application of irrigation water. Surface water irrigation creates water level changes on the order of 20 feet in many wells in the LRB (Donato, 1998).

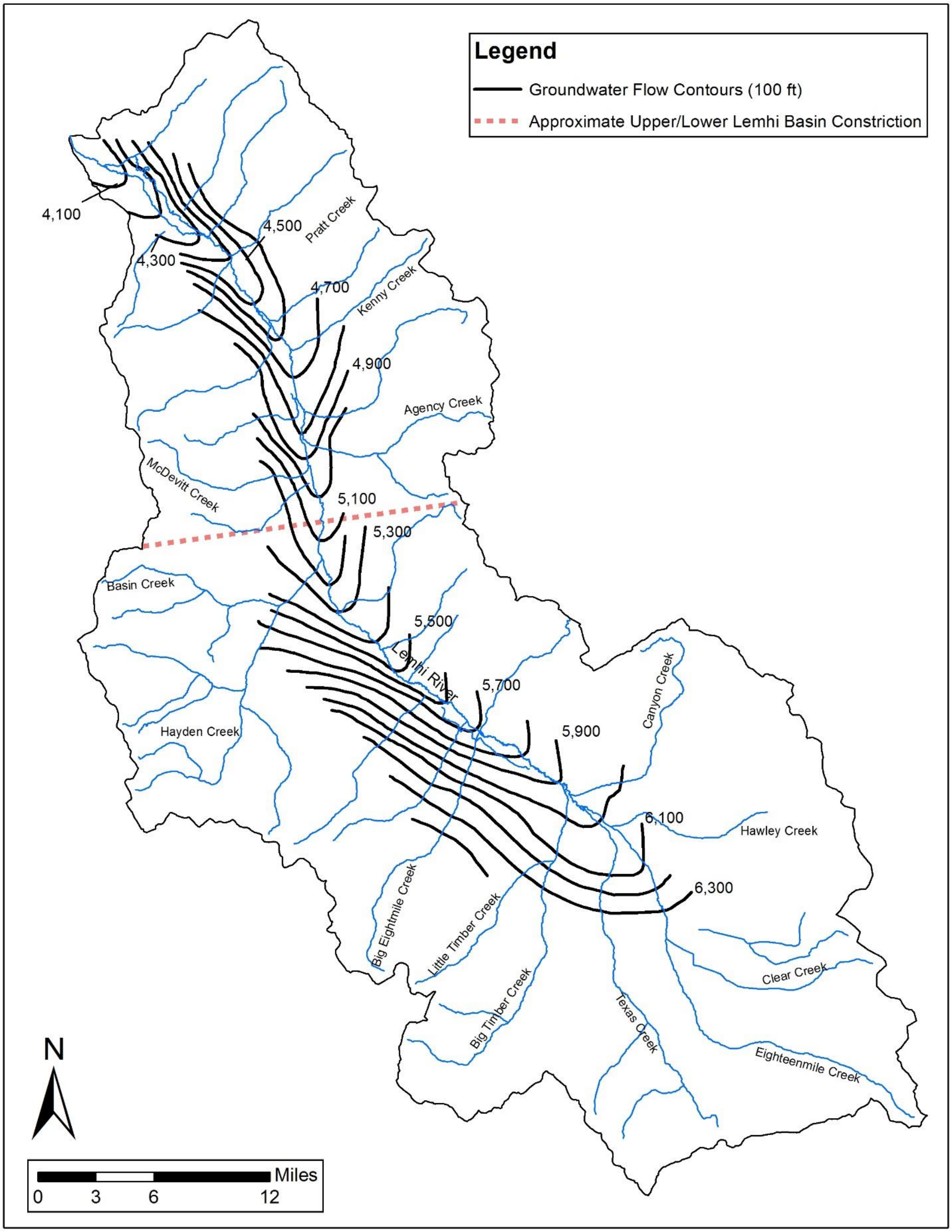

Figure 14. Water level elevation in the LRB.

Hydrology

The LRB is an elongate valley that encompasses approximately 1,270 square miles. The headwaters of the Lemhi River originate at the southeastern end of the valley and the river flows northwest to the confluence with the Salmon River (Figure 2). Elevation ranges from approximately 3,900 feet amsl at the confluence with the Salmon River to over 11,000 feet amsl in the Lemhi and Beaverhead Mountain Ranges; precipitation is positively correlated with elevation (Chapman, 1976; Donato, 1998). An average of 950,000 acre-ft/year of precipitation fell from 2008-2017 on the LRB (Appendix I), with approximately 88% of the precipitation occurring (mostly as snow) in the surrounding mountains (Donato, 1998).

IDWR manages 22 surface water gages within the LRB and USB (Table 1; Figure 3). Hydrographs for these gages are located in Appendix A. Additionally, the USGS operates two gages on the Lemhi River: the Lemhi River near Lemhi ID gage (#13305000) and the Lemhi River below L5 near Salmon ID gage (#13305310). The Lemhi River below L5 near Salmon ID is approximately seven miles upstream of the confluence with the Salmon River; therefore, the drainage area contributing to the gage encompasses approximately 96% of the total LRB. The drainage area contributing flow to the Lemhi River near Lemhi gage is approximately 897 square miles which is approximately 71% of the total LRB, and is an approximate representation of the upper basin (CH2M HILL, 2014). Hydrographs for the USGS gages are located in Figure 15.

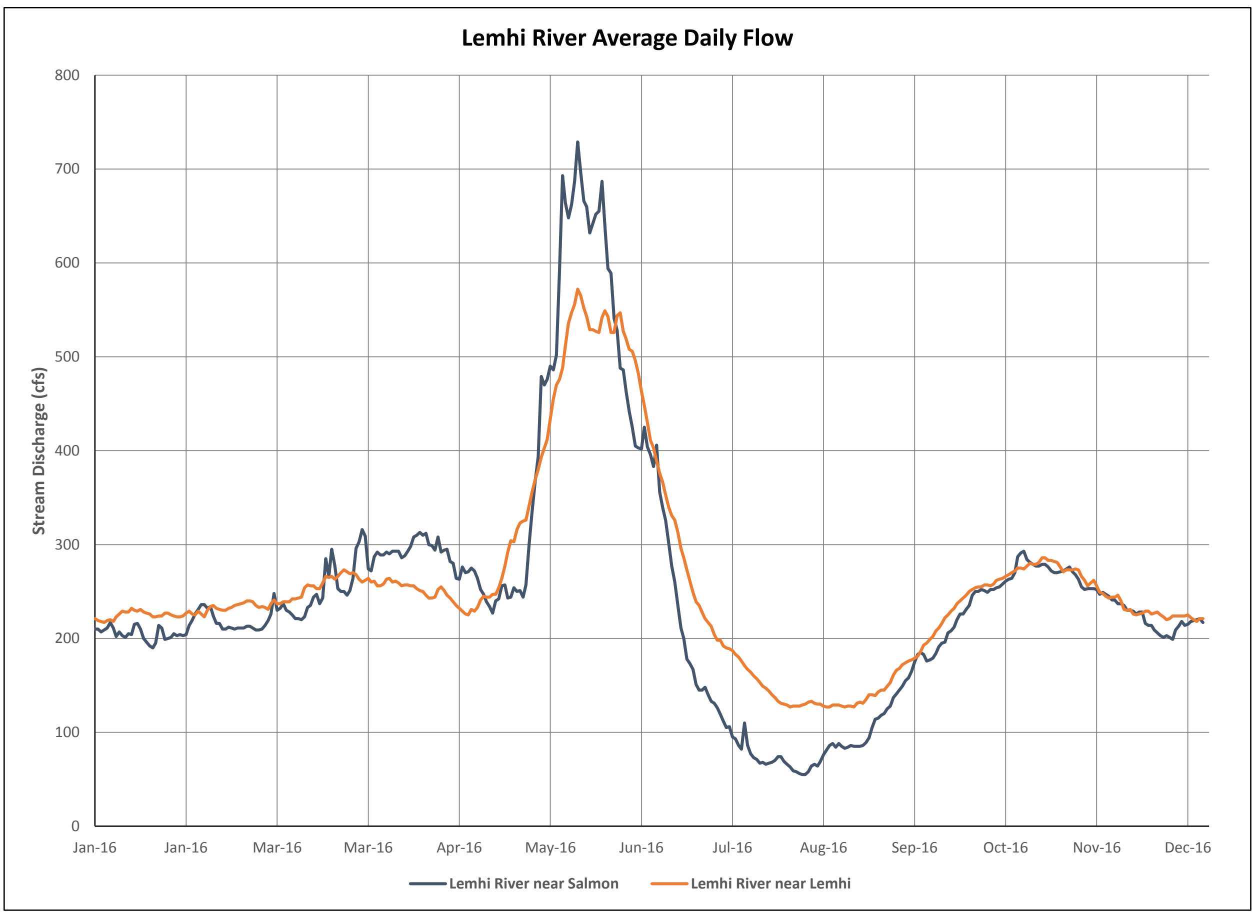

Figure 15. Hydrographs of average daily flow for the two USGS gages in the LRB.

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Appendix A – Streamflow Hydrographs

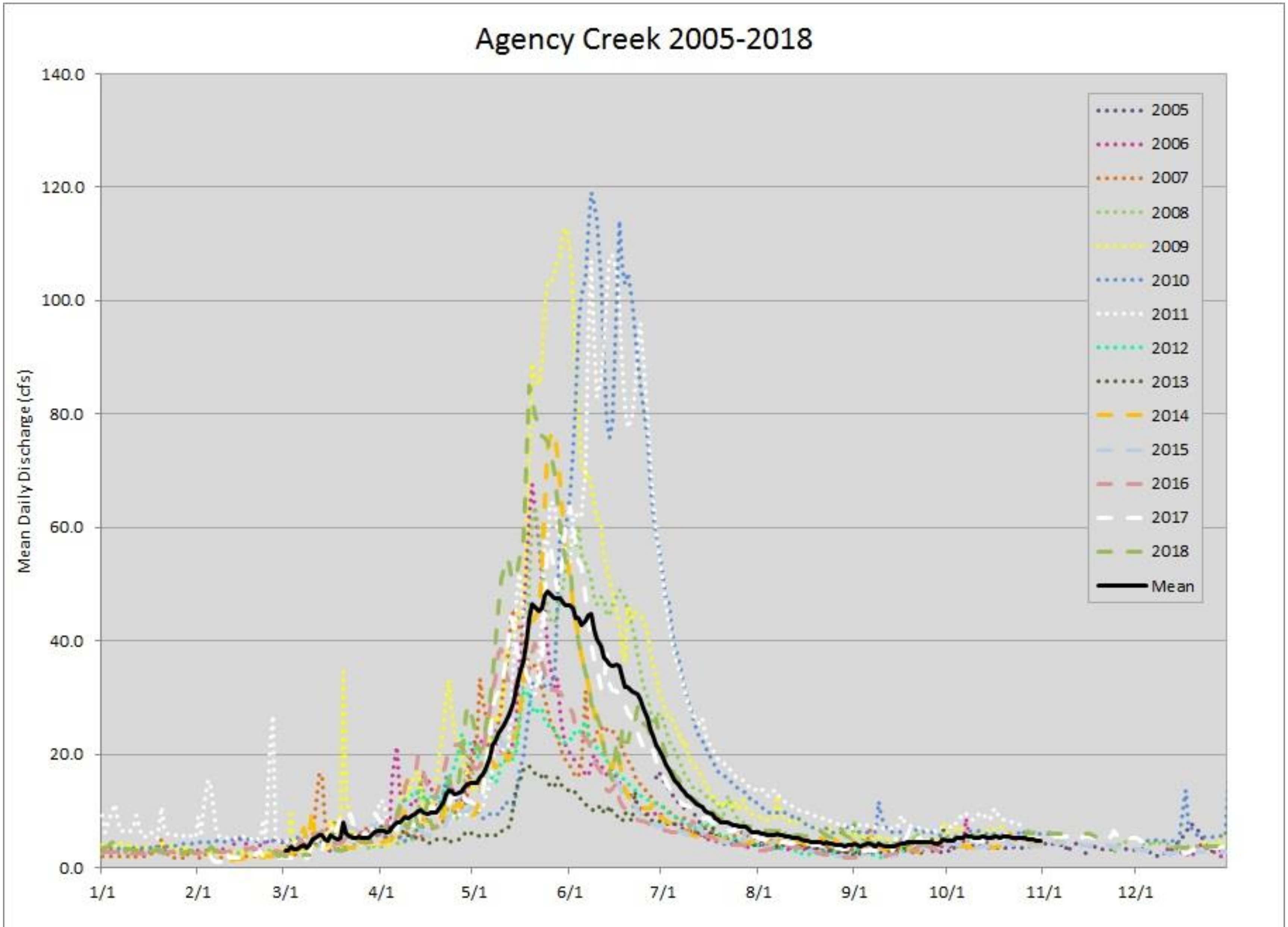

Agency Creek 2005-2018
Mean Daily Discharge (cfs)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-1

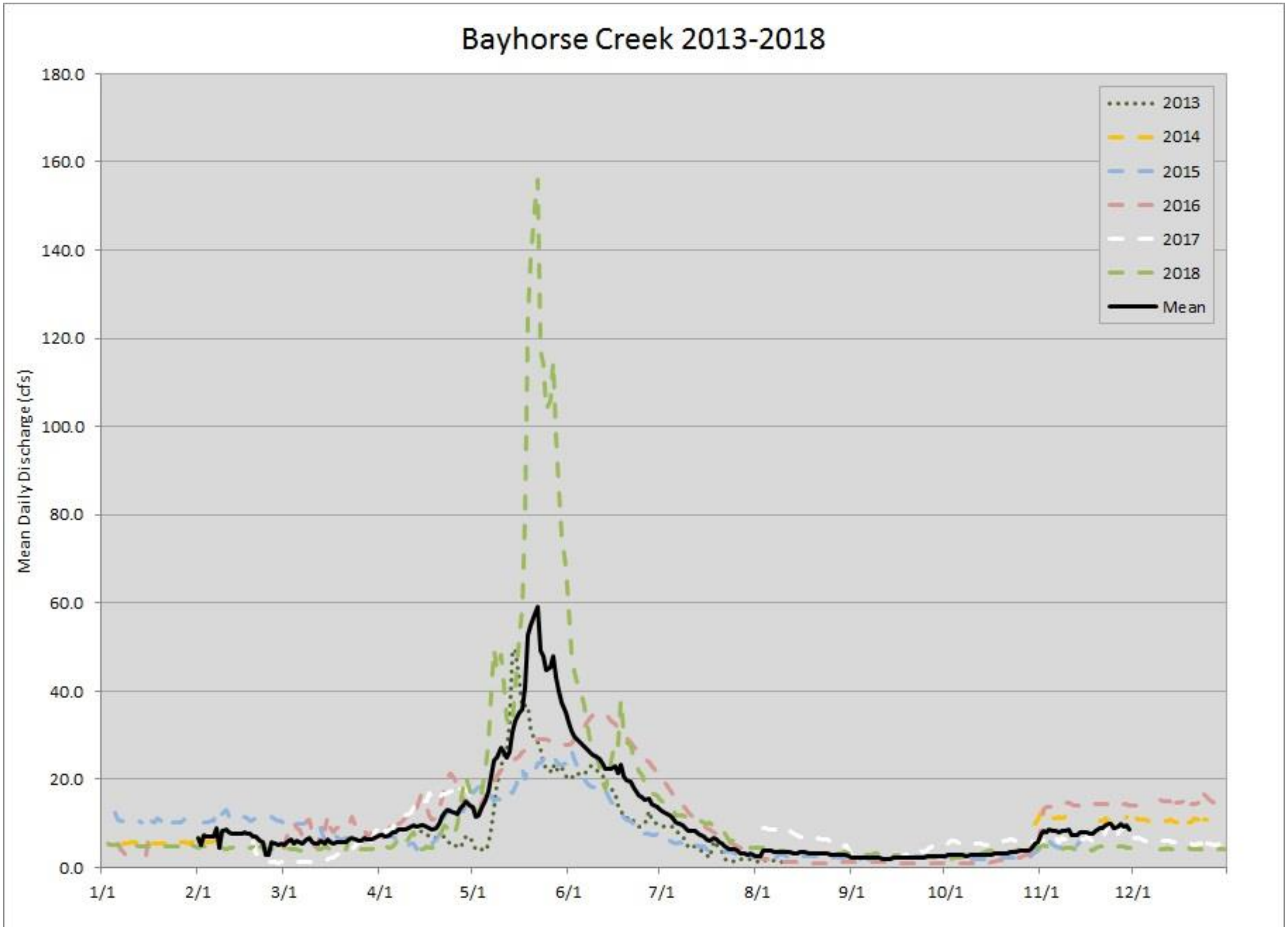
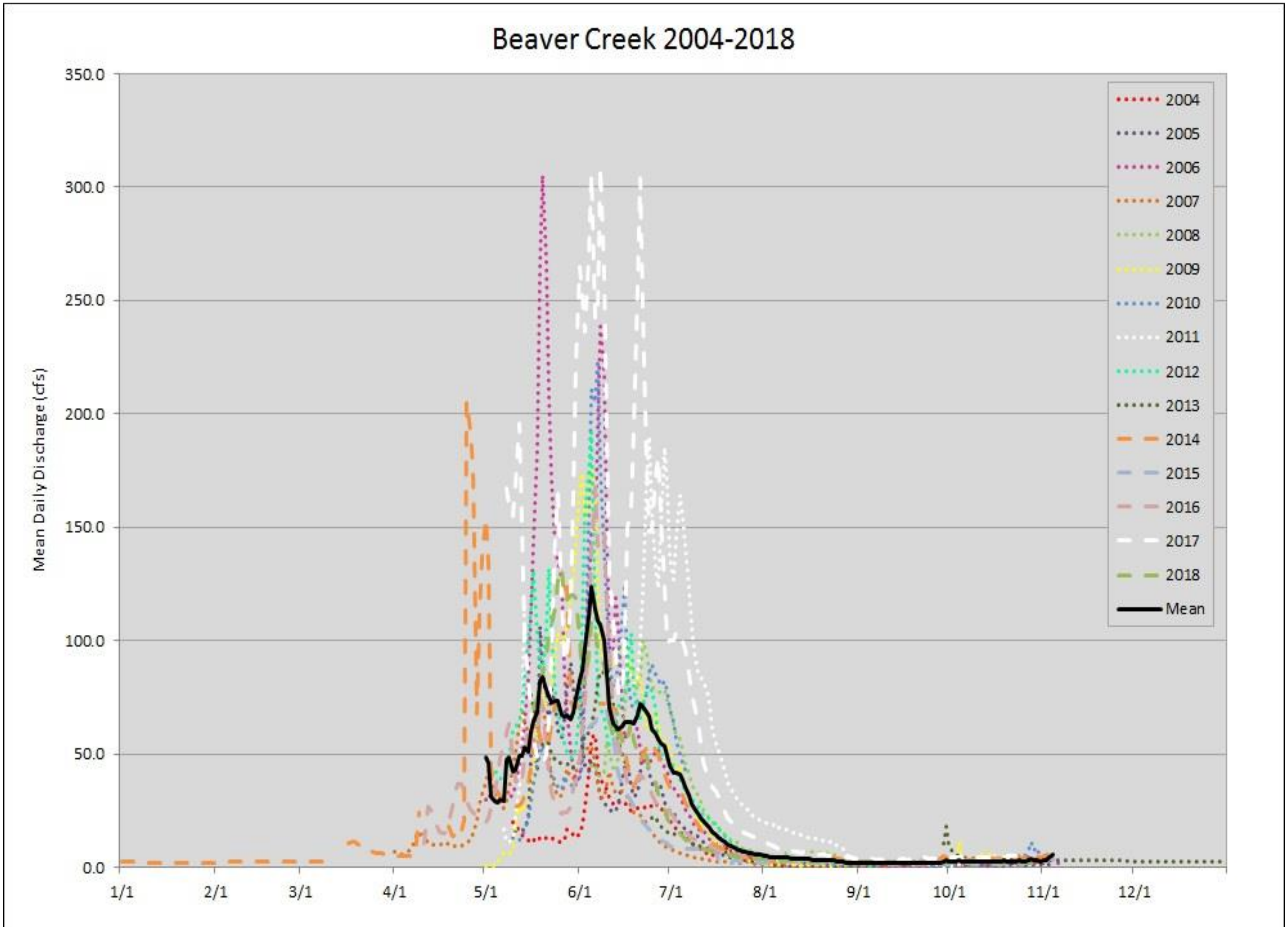

Bayhorse Creek 2013-2018
Mean Daily Discharge (cfs)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2013
2014
2015
2016
2017
2018
Mean

Figure A-2



Beaver Creek 2004-2018
Mean Daily Discharge (cfs)
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-3

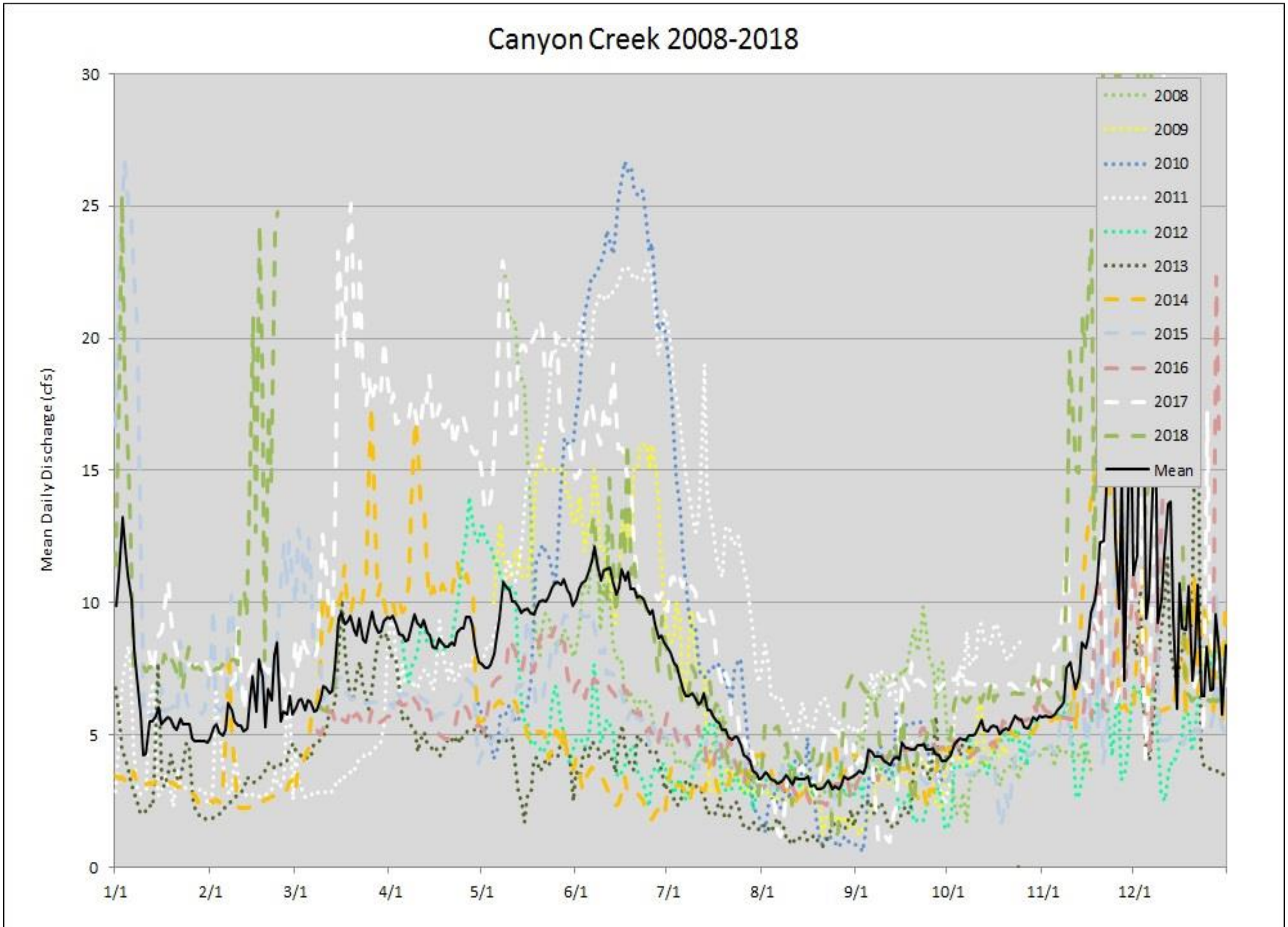

Canyon Creek 2008-2018
Mean Daily Discharge (cfs)
30
25
20
15
10
5
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-4

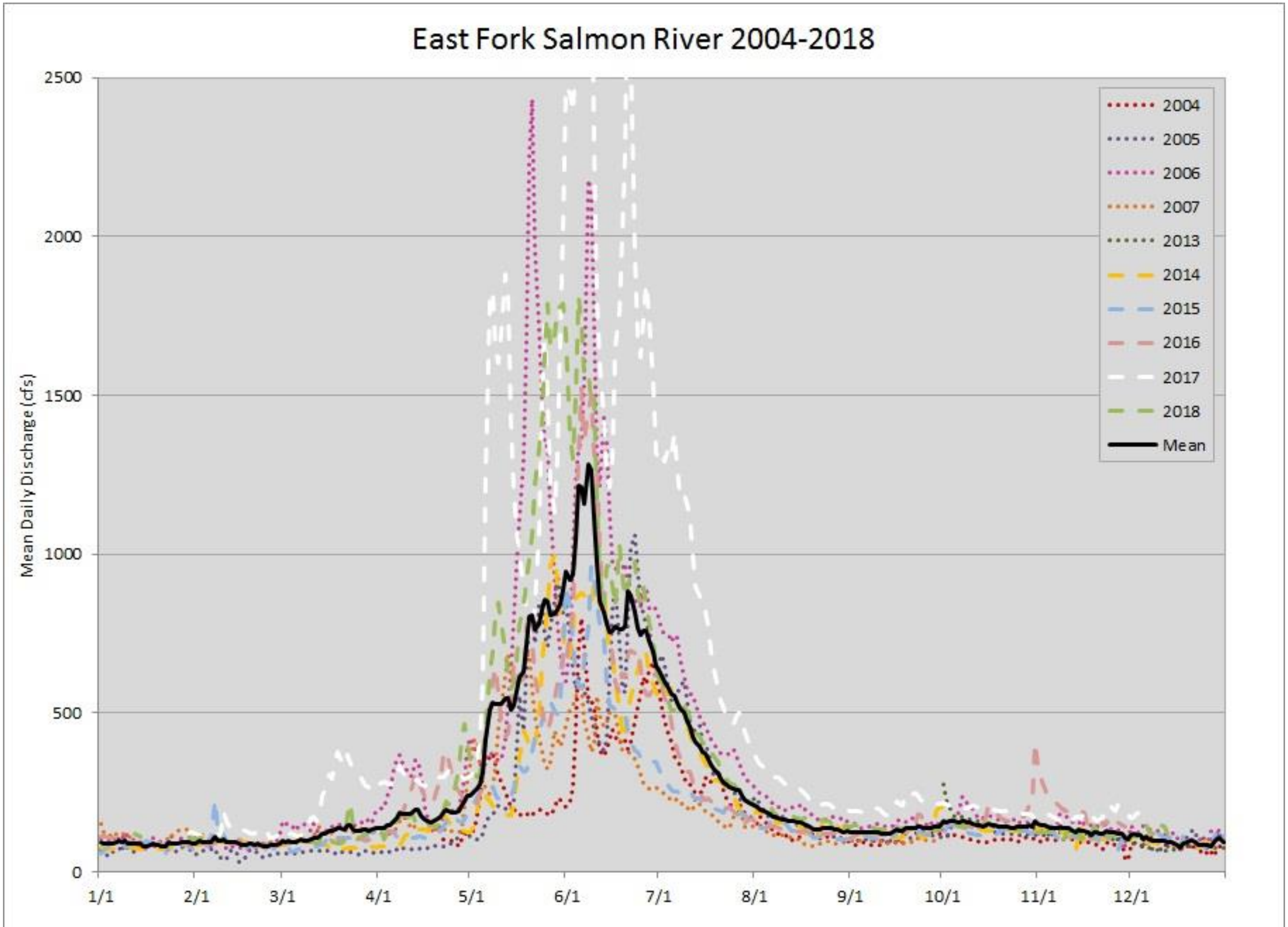

East Fork Salmon River 2004-2018
Mean Daily Discharge (cfs)
2500
2000
1500
1000
500
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2004
2005
2006
2007
2013
2014
2015
2016
2017
2018
Mean

Figure A-5

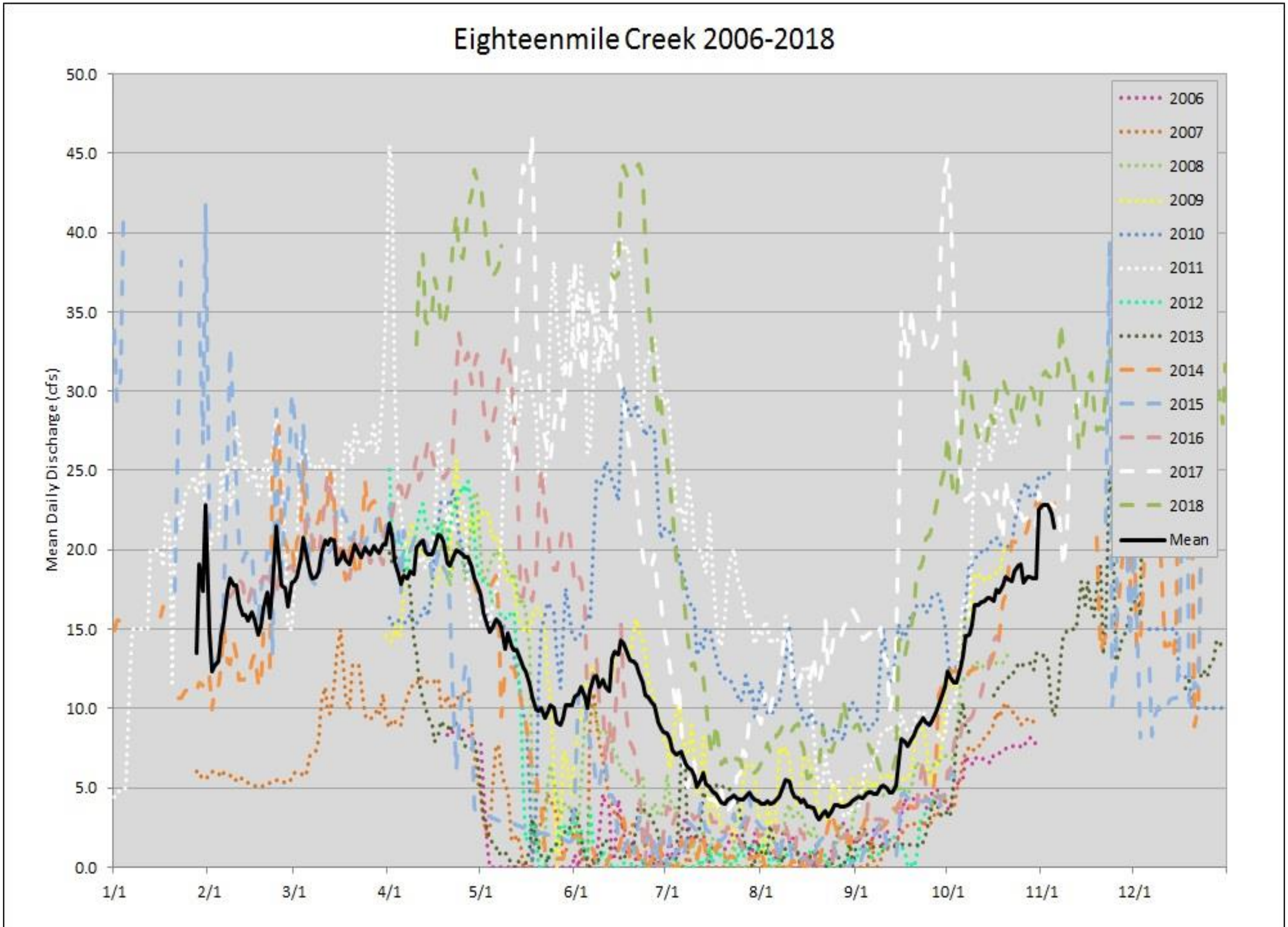
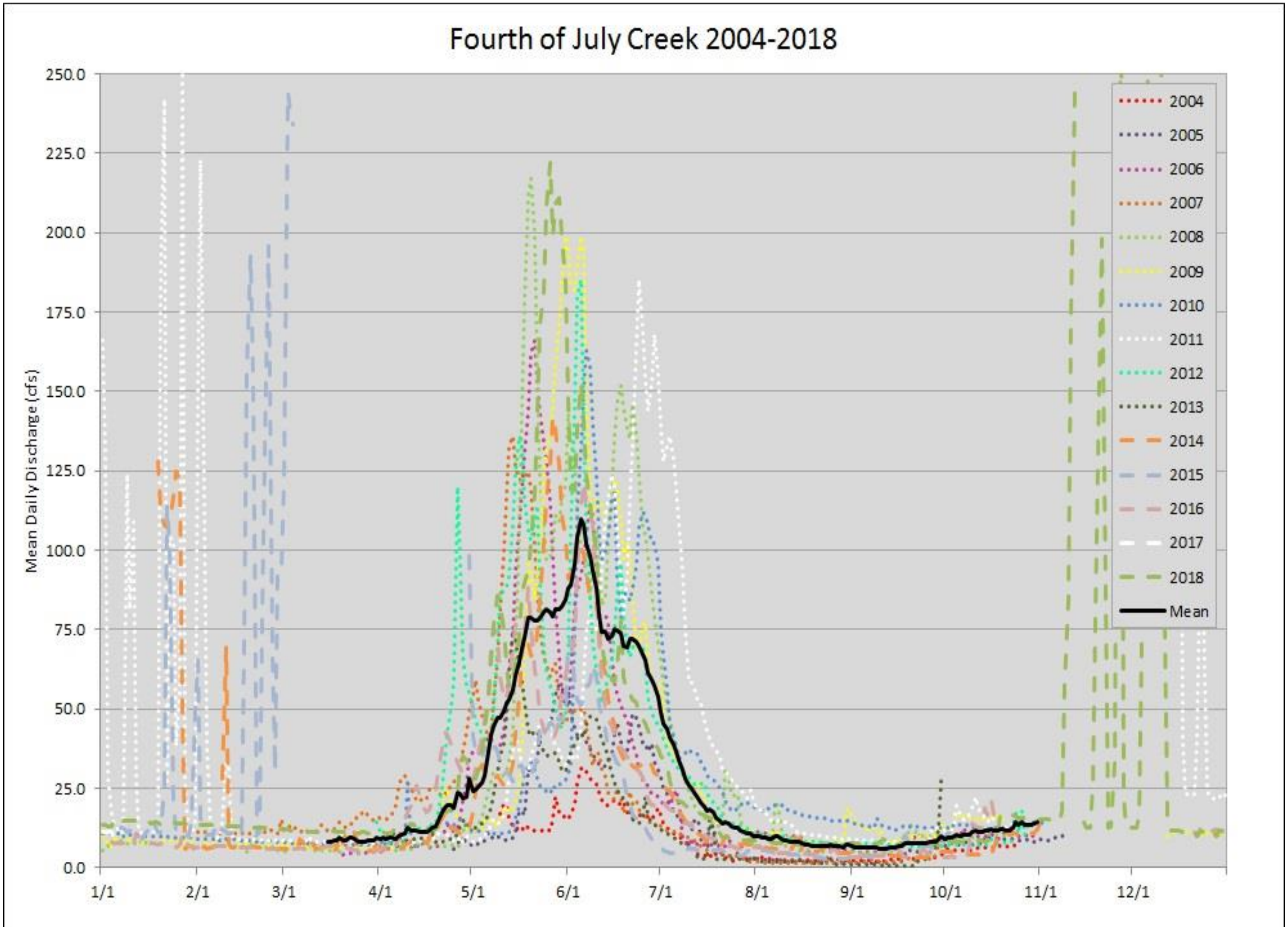

Eighteenmile Creek 2006-2018
Mean Daily Discharge (cfs)
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-6



Fourth of July Creek 2004-2018
Mean Daily Discharge (cfs)
250.0
225.0
200.0
175.0
150.0
125.0
100.0
75.0
50.0
25.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-7

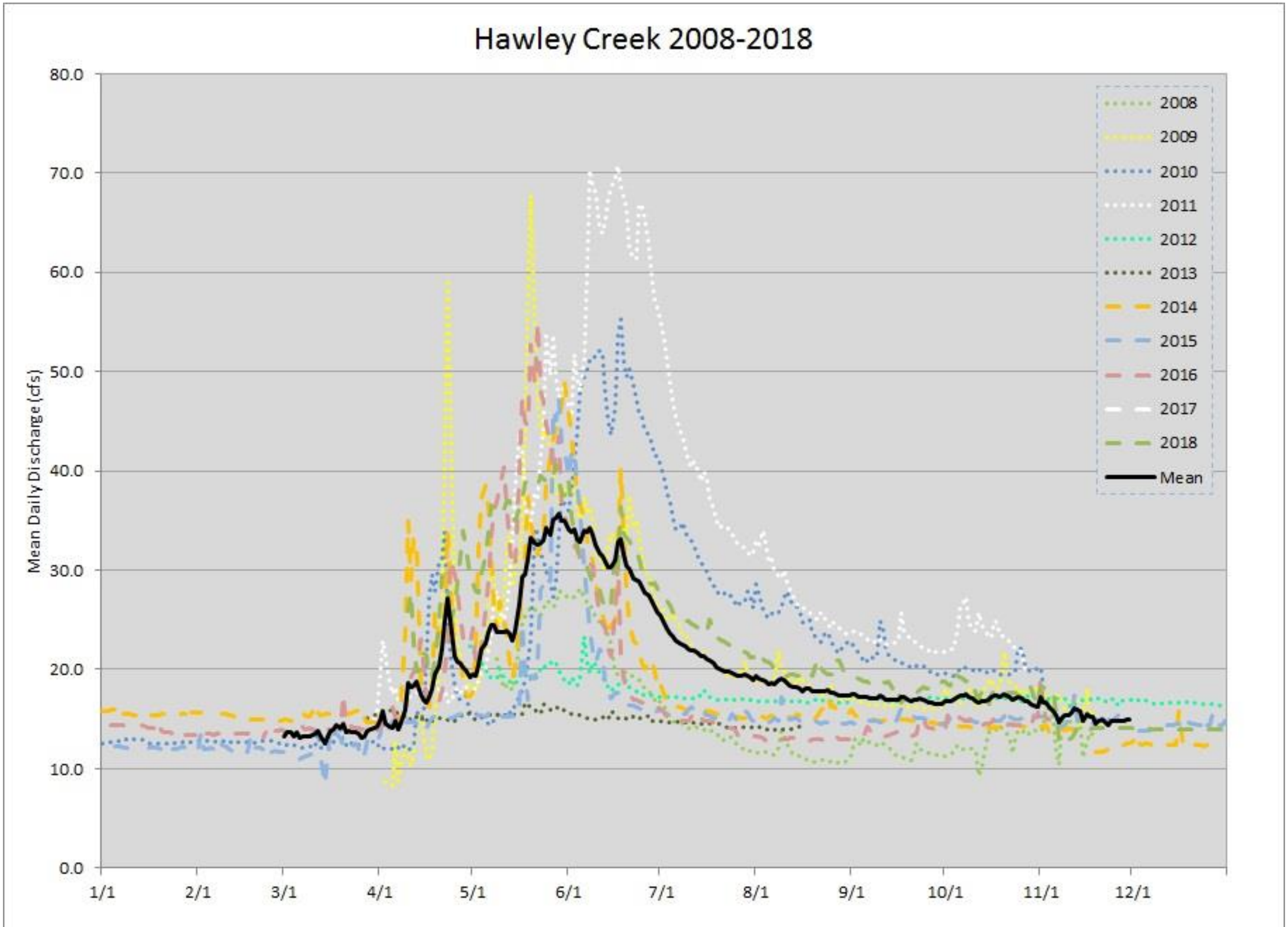

Hawley Creek 2008-2018
Mean Daily Discharge (cfs)
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-8

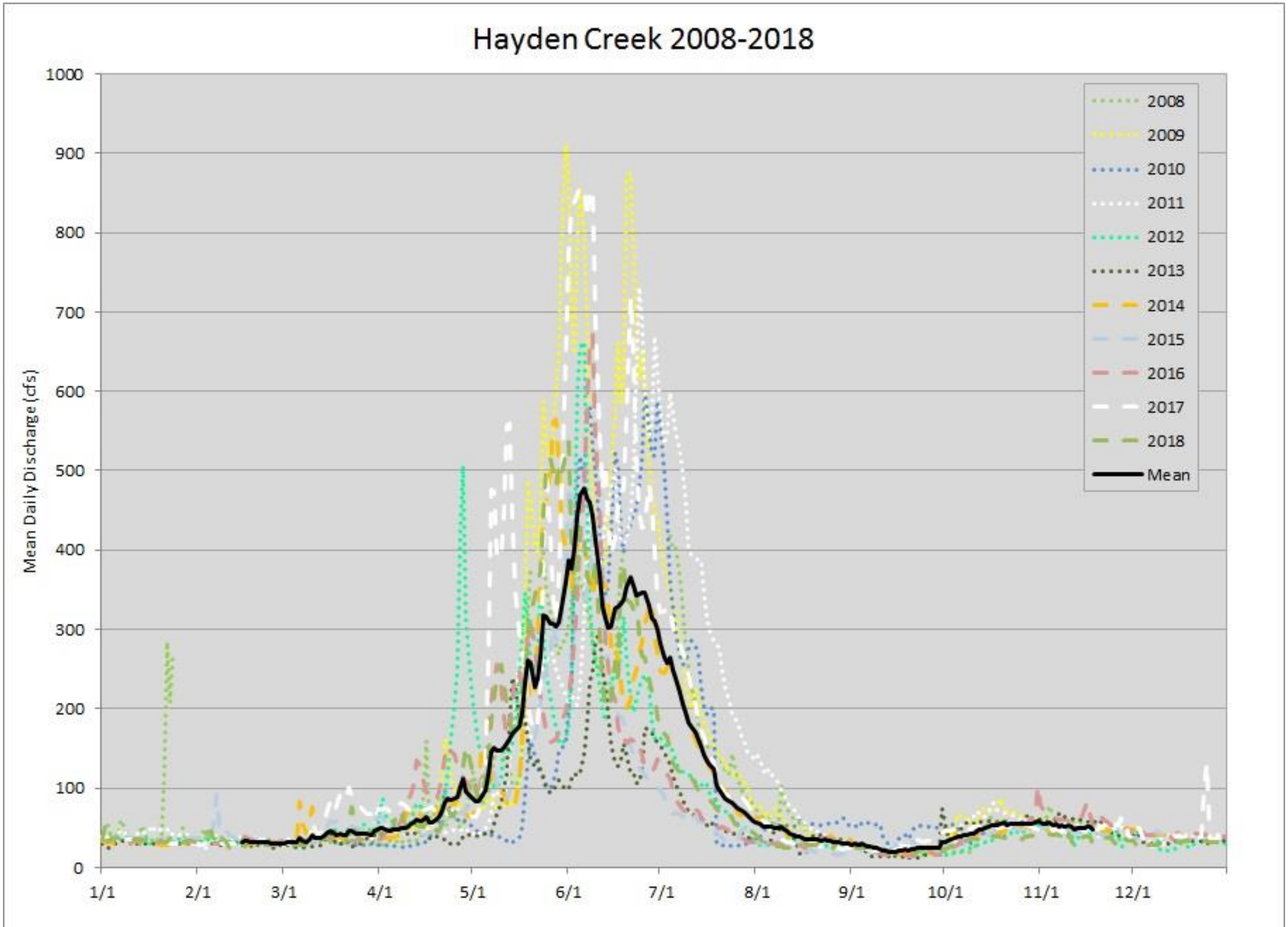

Hayden Creek 2008-2018
Mean Daily Discharge (cfs)
1000
900
800
700
600
500
400
300
200
100
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-9

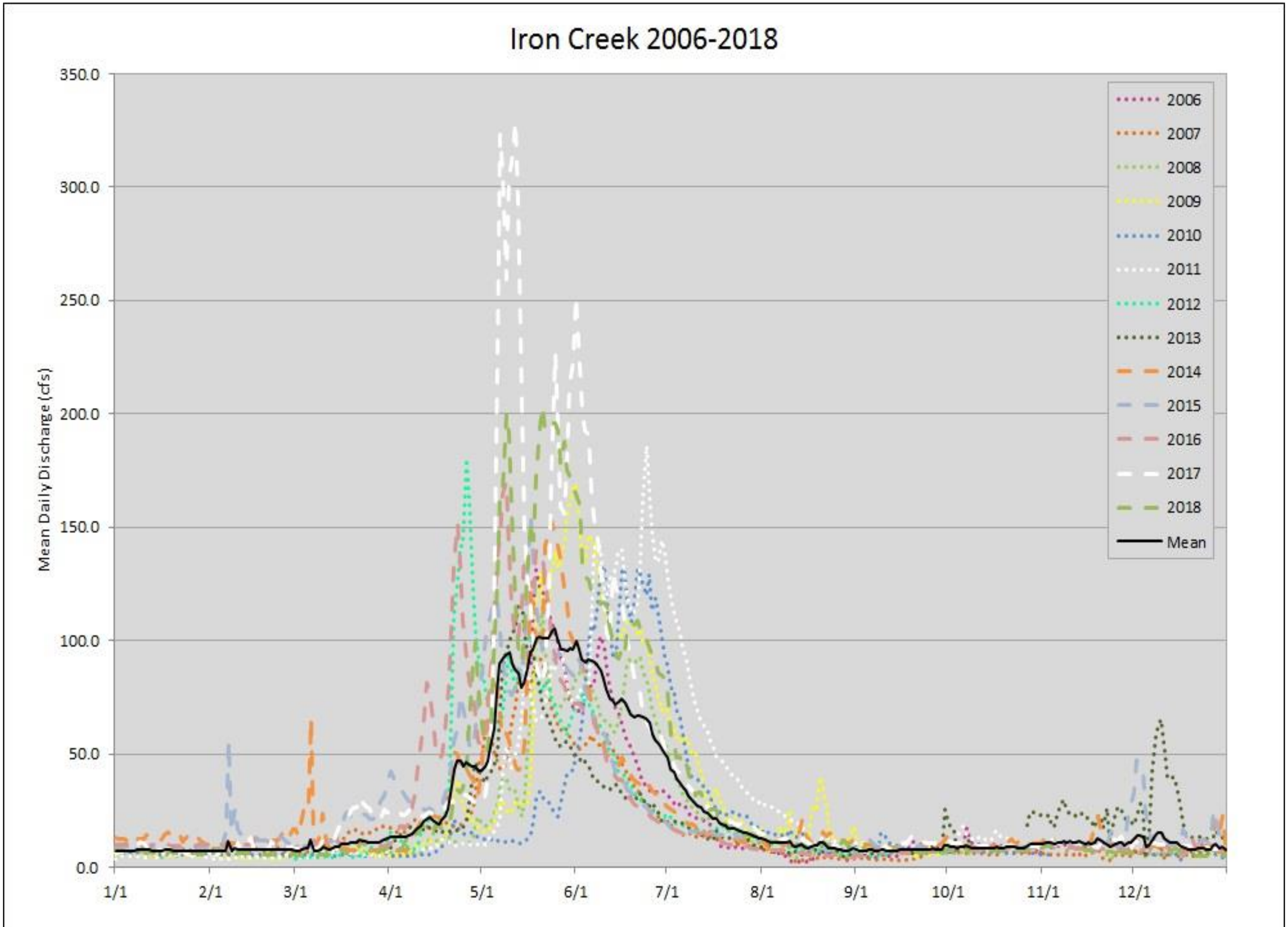
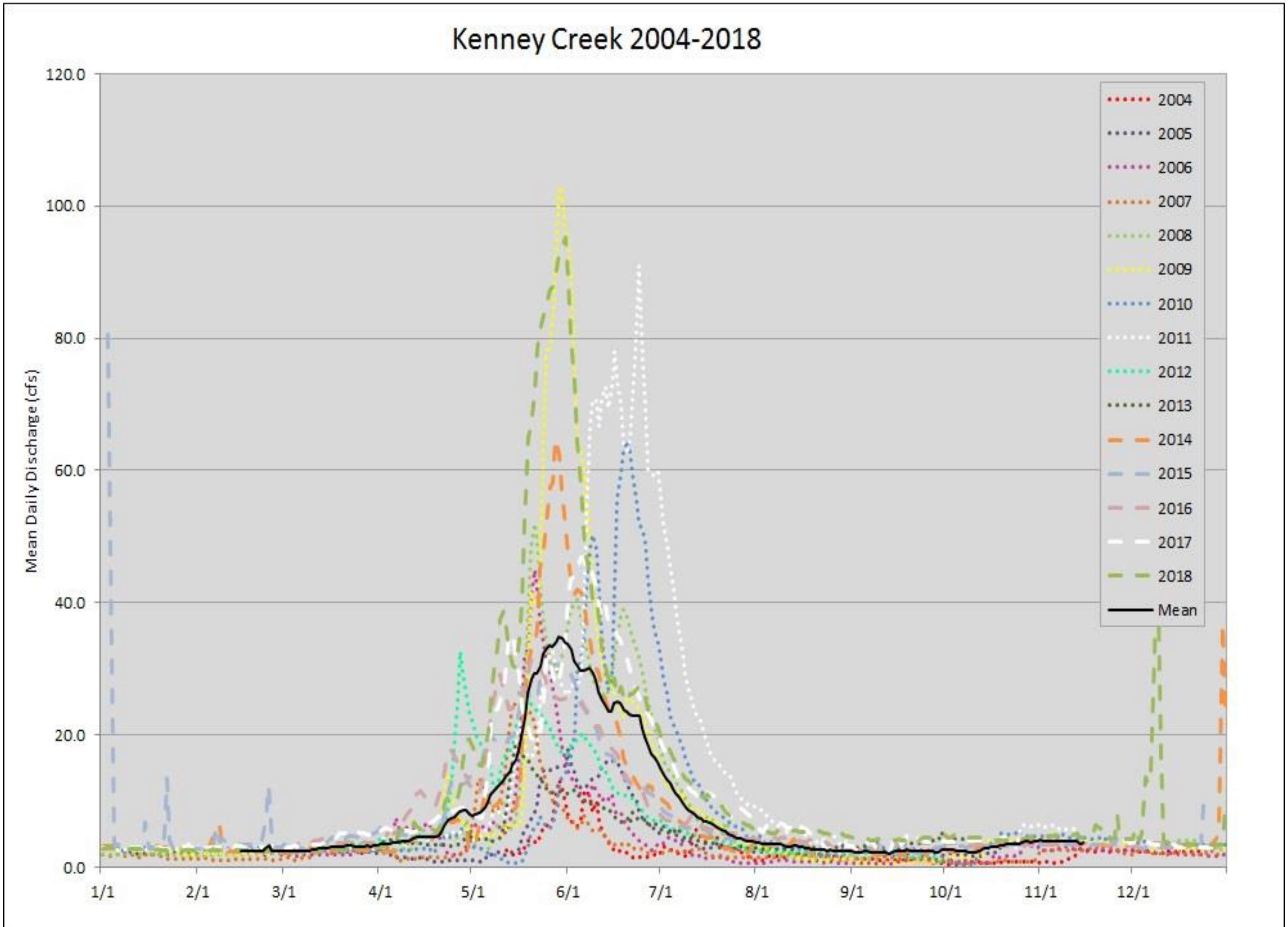

Iron Creek 2006-2018
Mean Daily Discharge (cfs)
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-10



Kenney Creek 2004-2018
Mean Daily Discharge (cfs)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-11

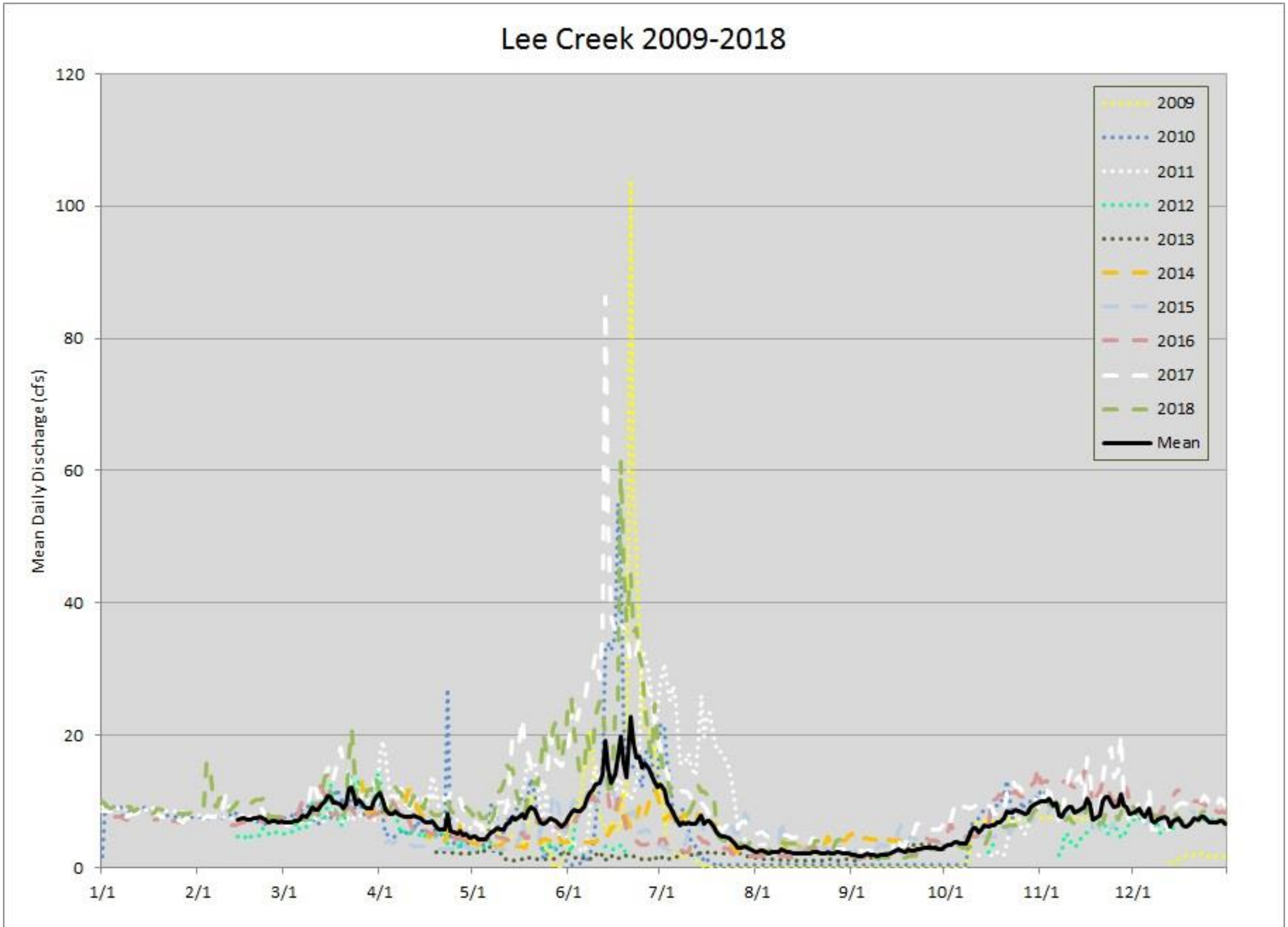
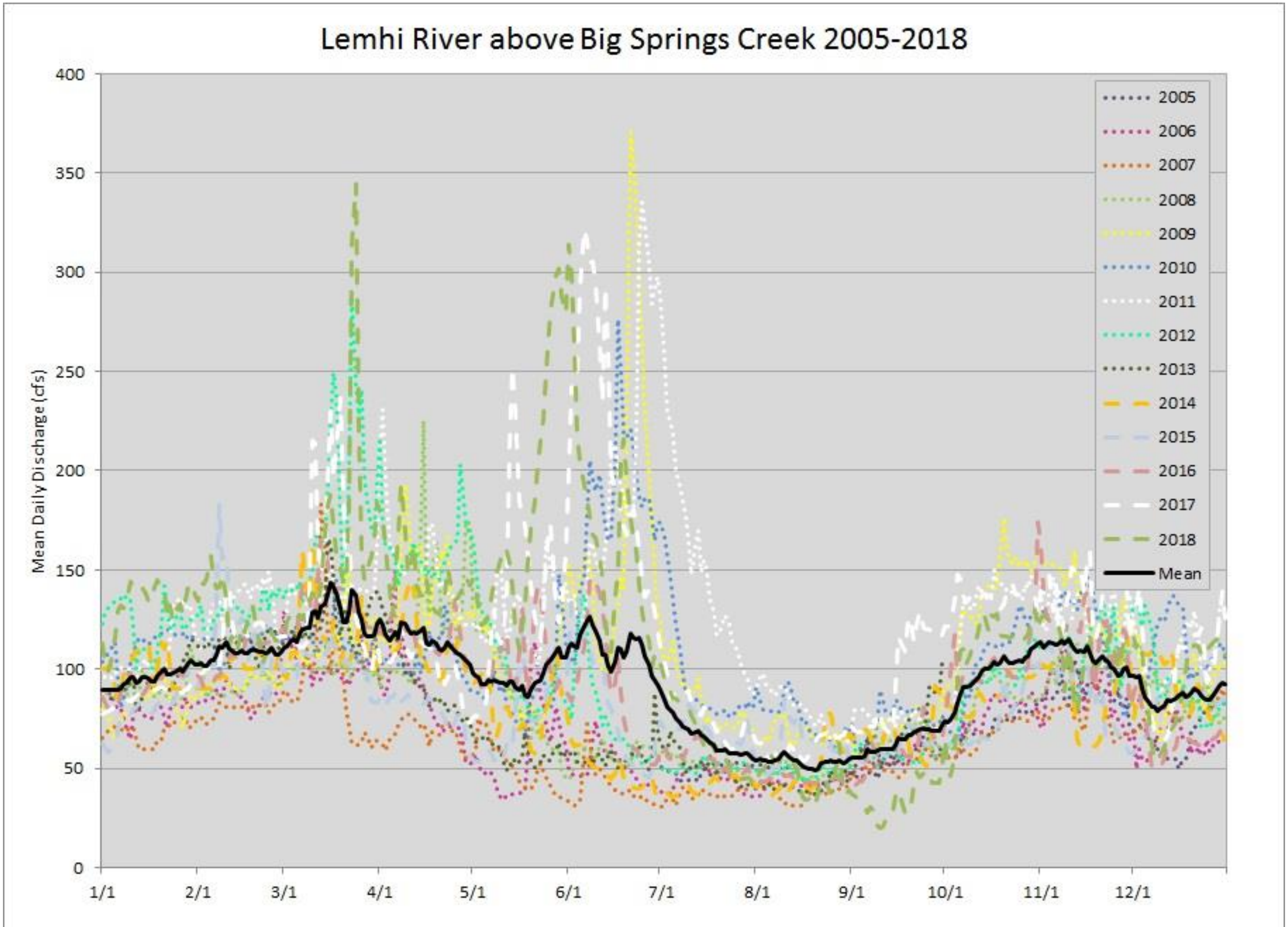

Lee Creek 2009-2018
Mean Daily Discharge (cfs)
120
100
80
60
40
20
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-12



Lemhi River above Big Springs Creek 2005-2018
Mean Daily Discharge (cfs)
400
350
300
250
200
150
100
50
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-13

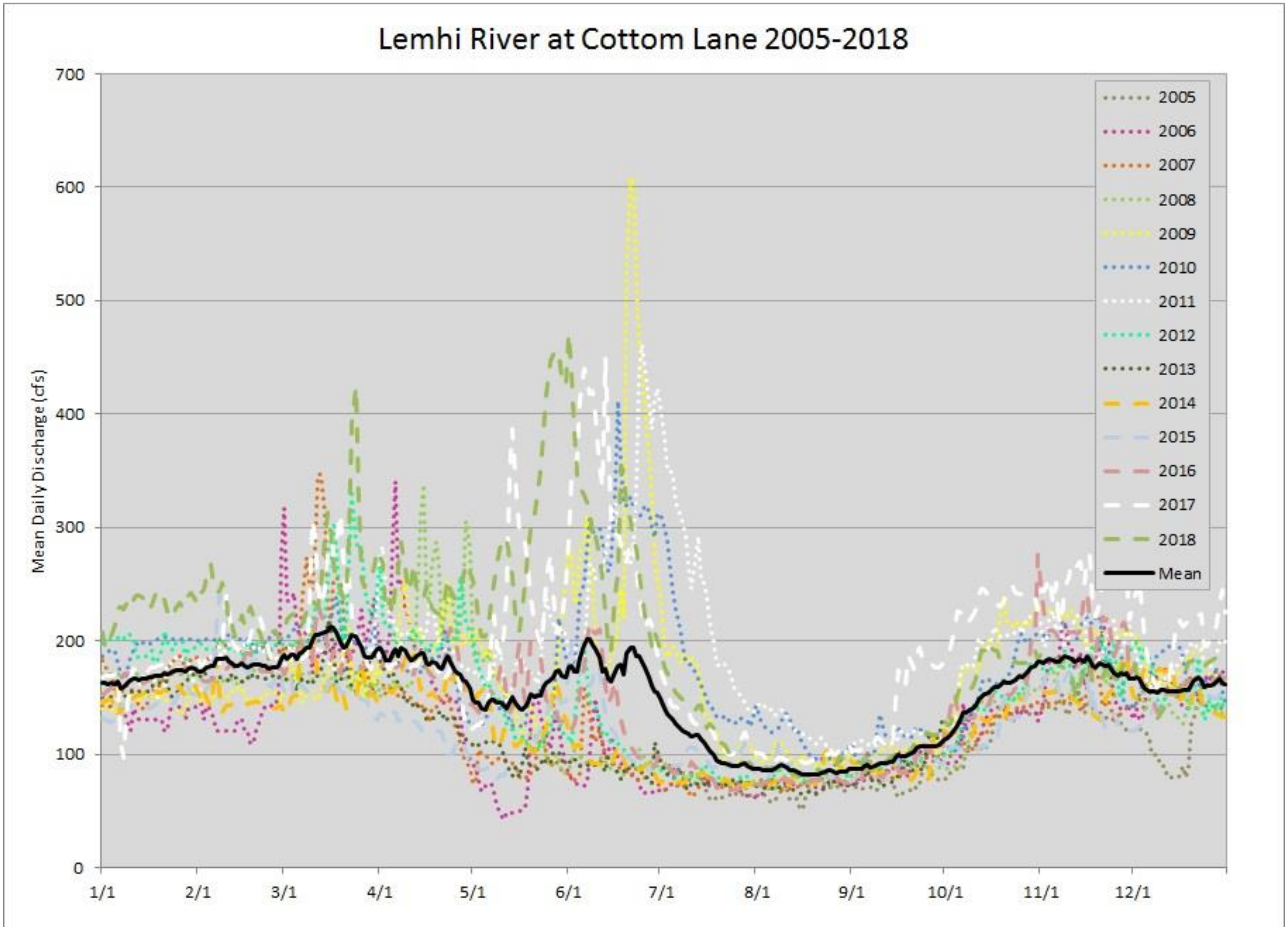

Lemhi River at Cottom Lane 2005-2018
Mean Daily Discharge (cfs)
700
600
500
400
300
200
100
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-14

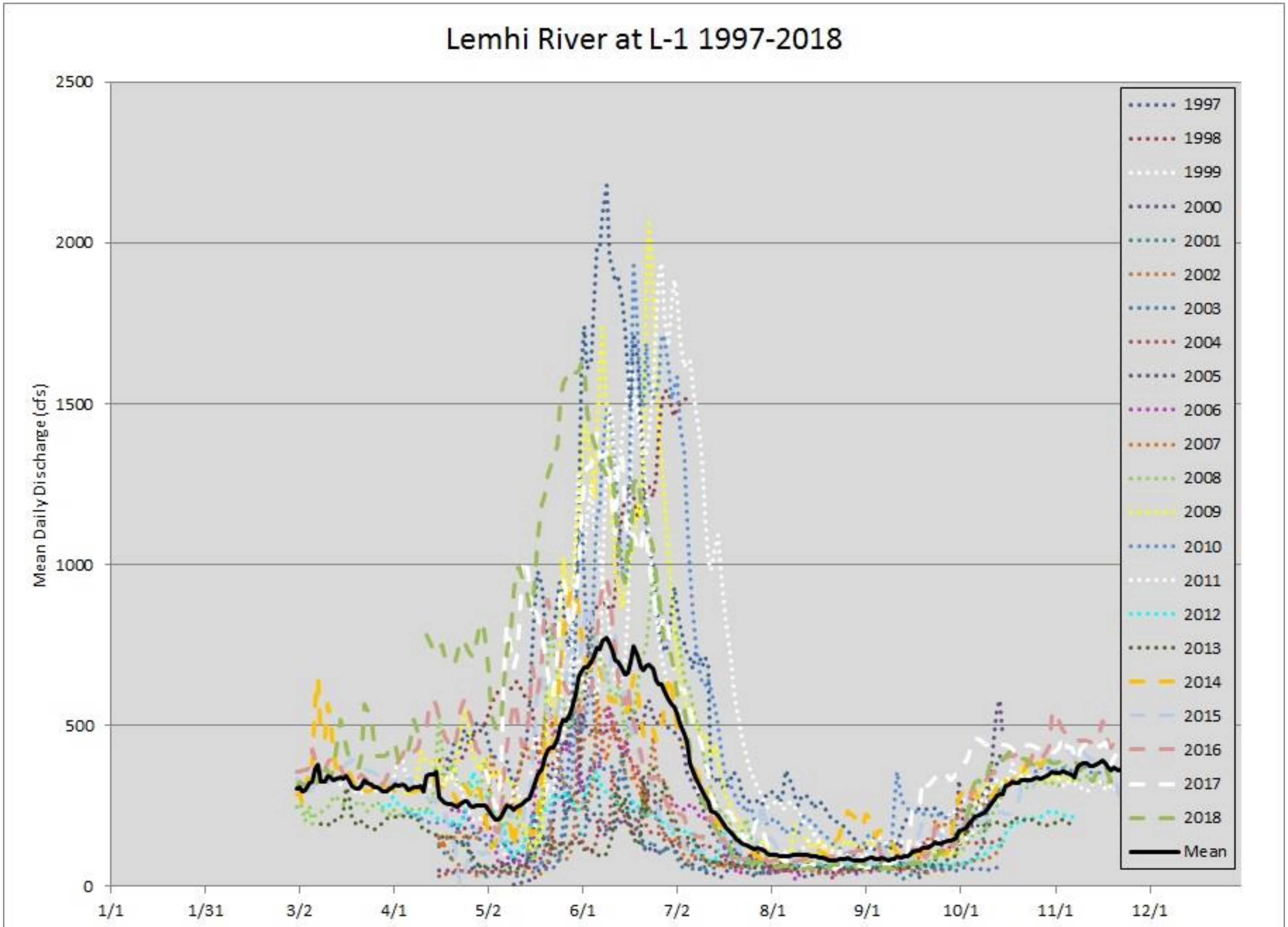

Lemhi River at L-1 1997-2018
Mean Daily Discharge (cfs)
2500
2000
1500
1000
500
0
1/1
1/31
3/2
4/1
5/2
6/1
7/2
8/1
9/1
10/1
11/1
12/1
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-15

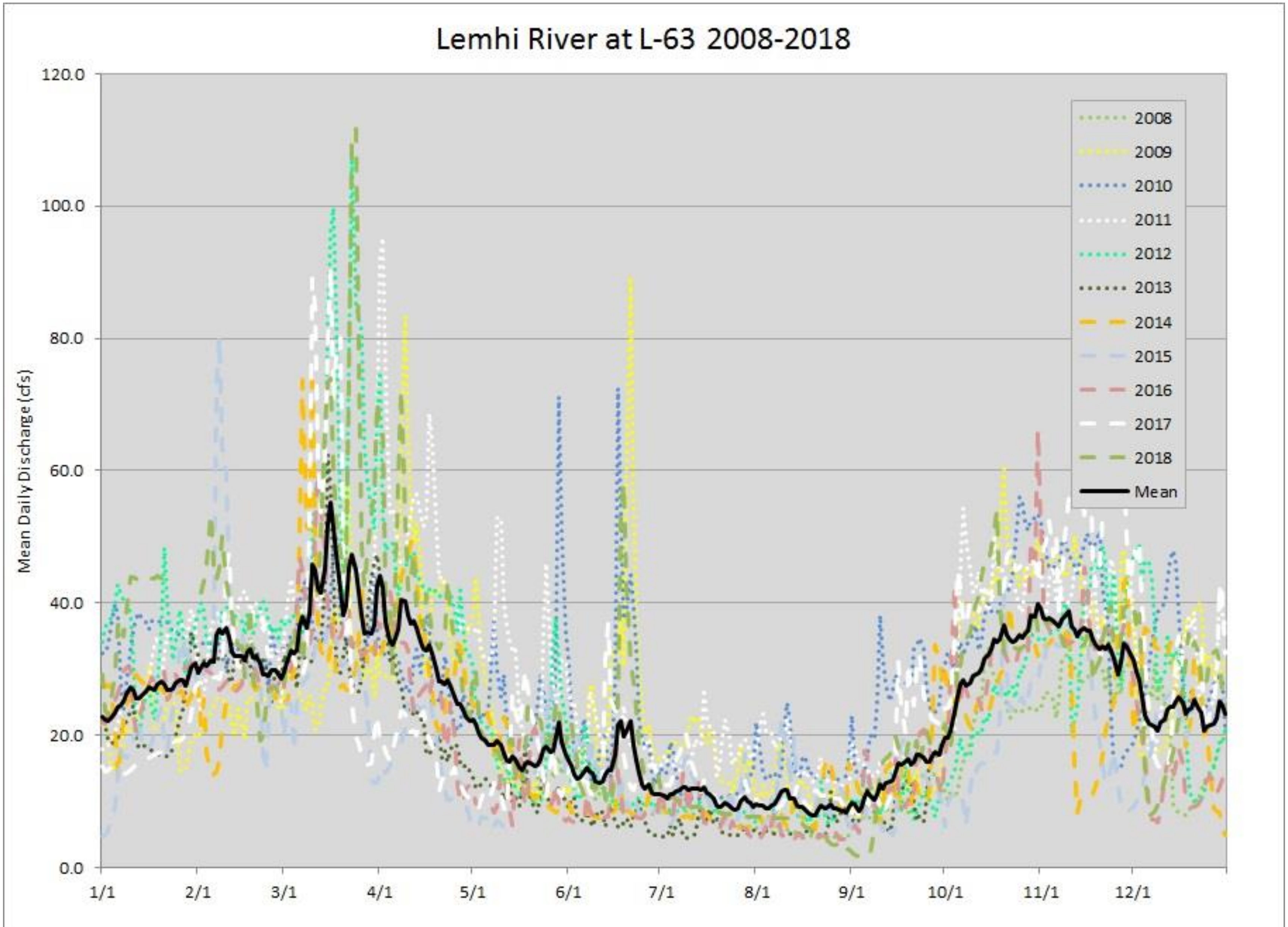
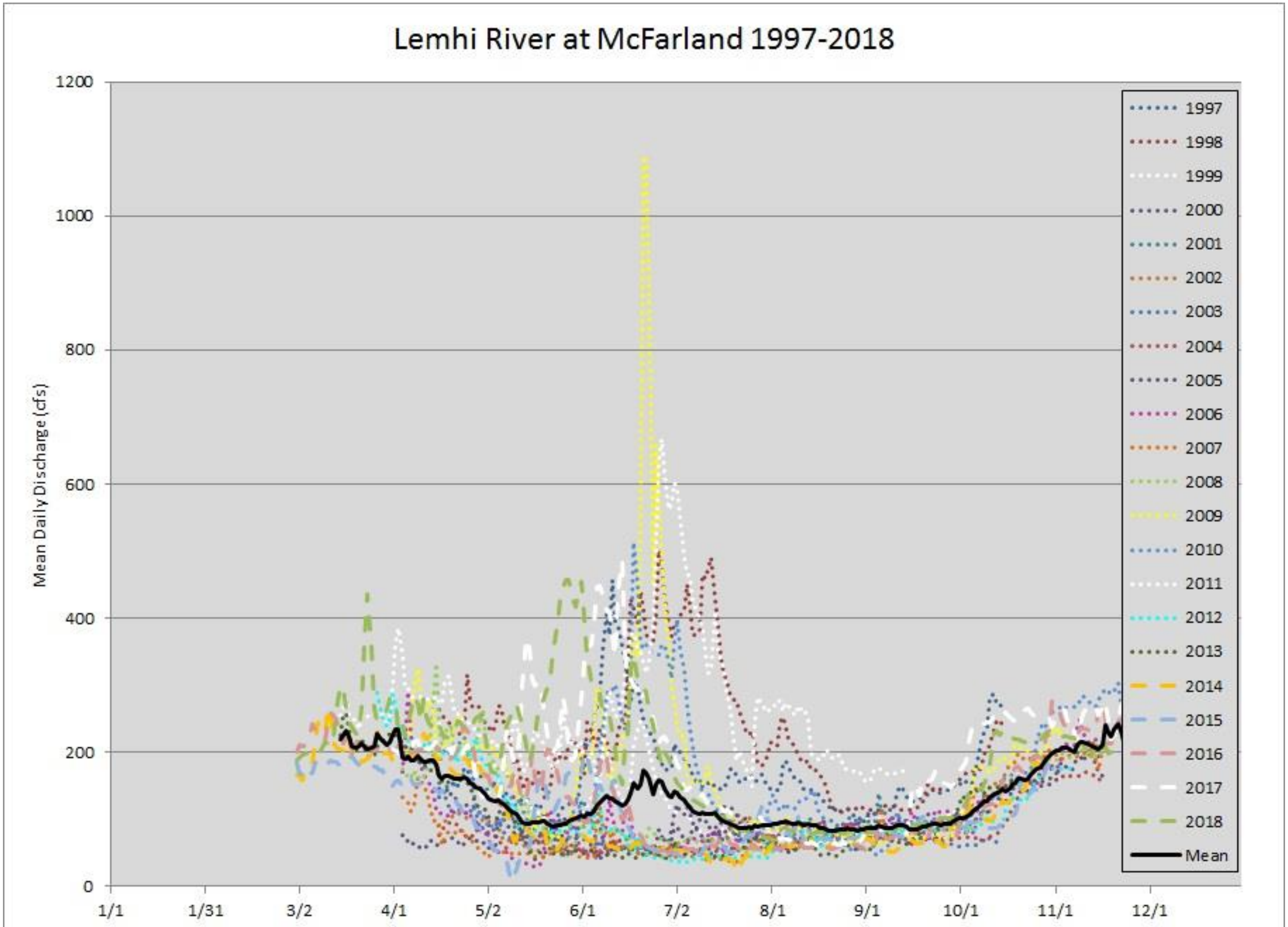
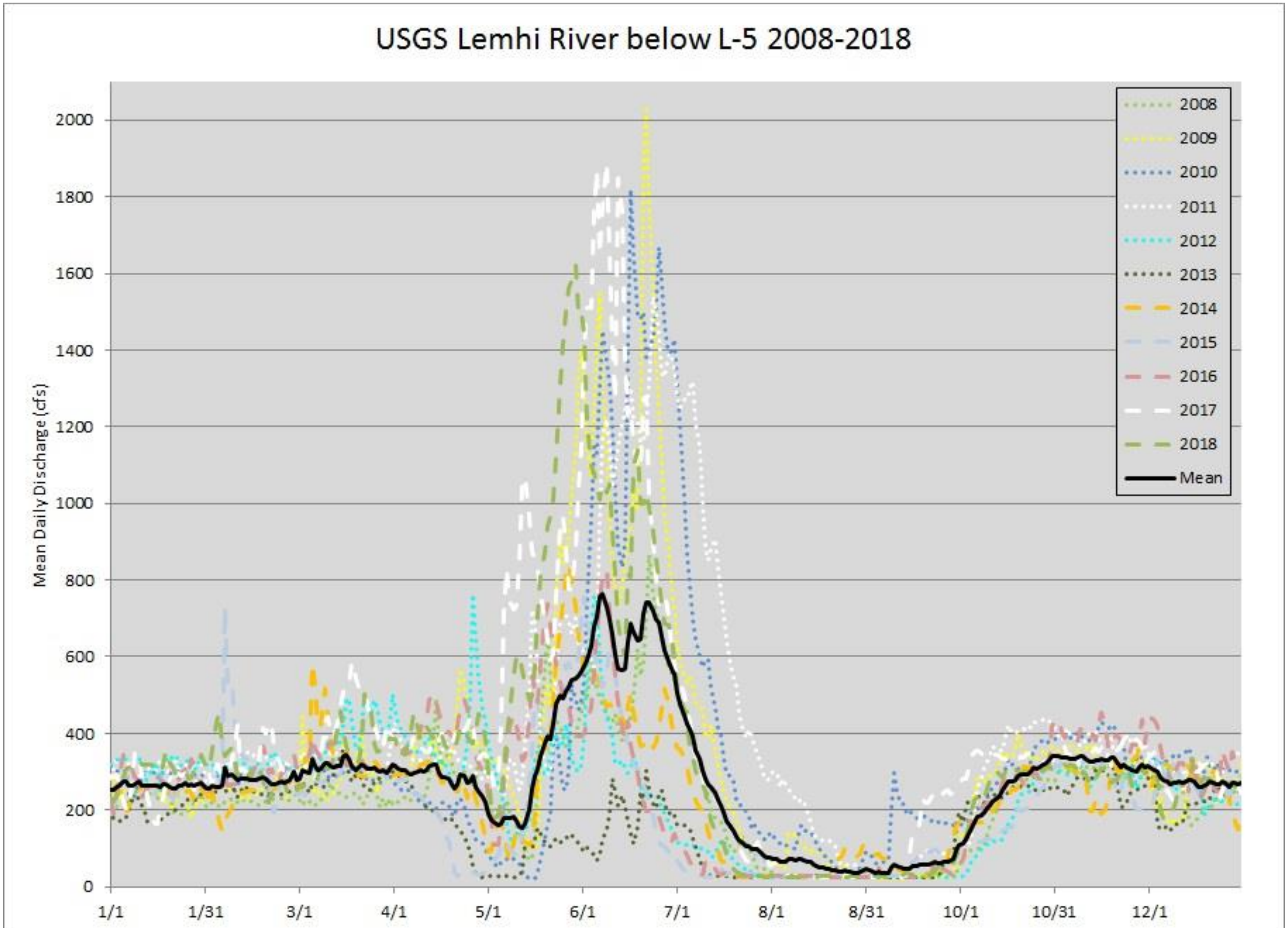

Lemhi River at L-63 2008-2018
Mean Daily Discharge (cfs)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-16



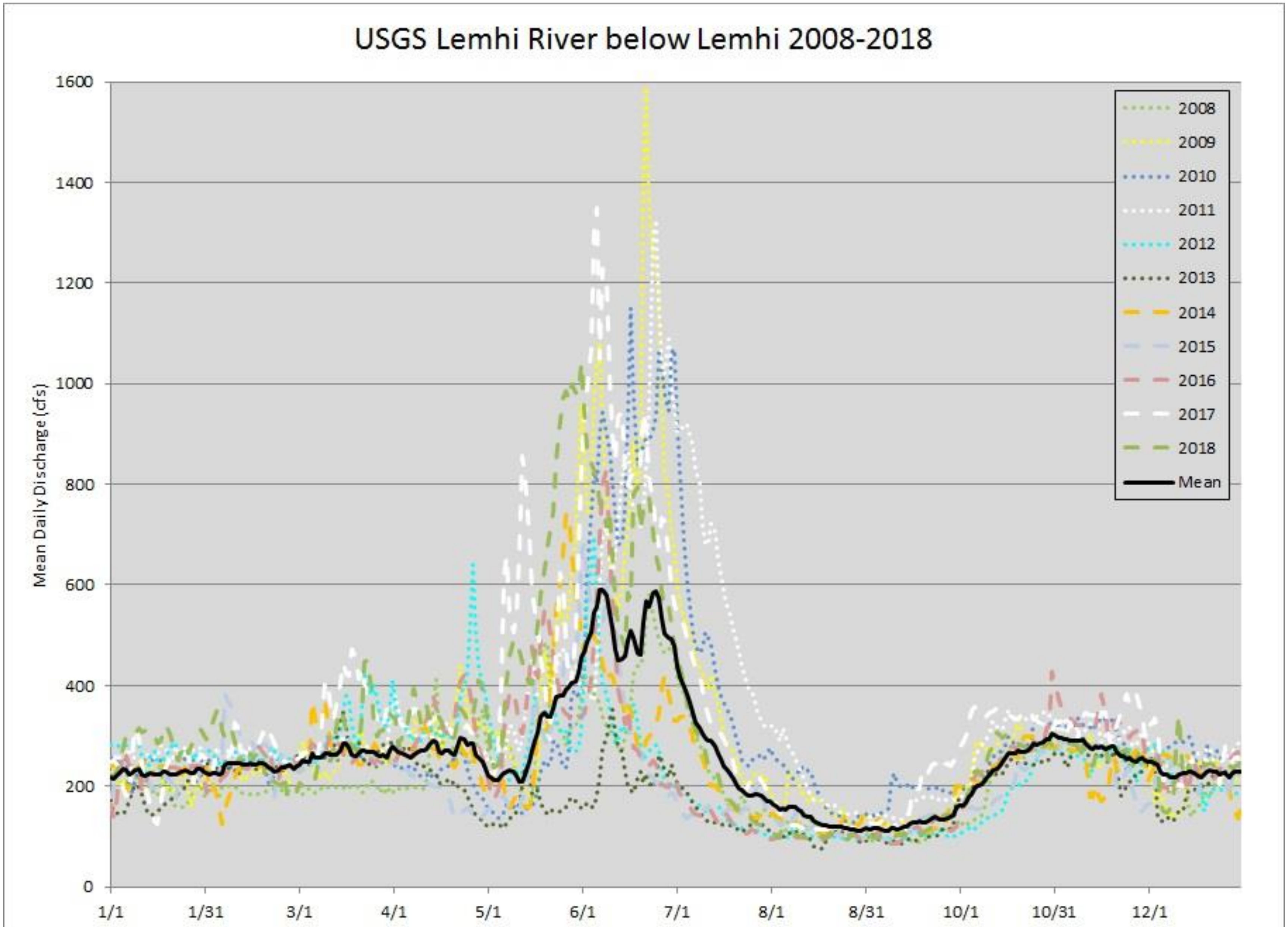
Lemhi River at McFarland 1997-2018
Mean Daily Discharge (cfs)
1200
1000
800
600
400
200
0
1/1
1/31
3/2
4/1
5/2
6/1
7/2
8/1
9/1
10/1
11/1
12/1
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-17



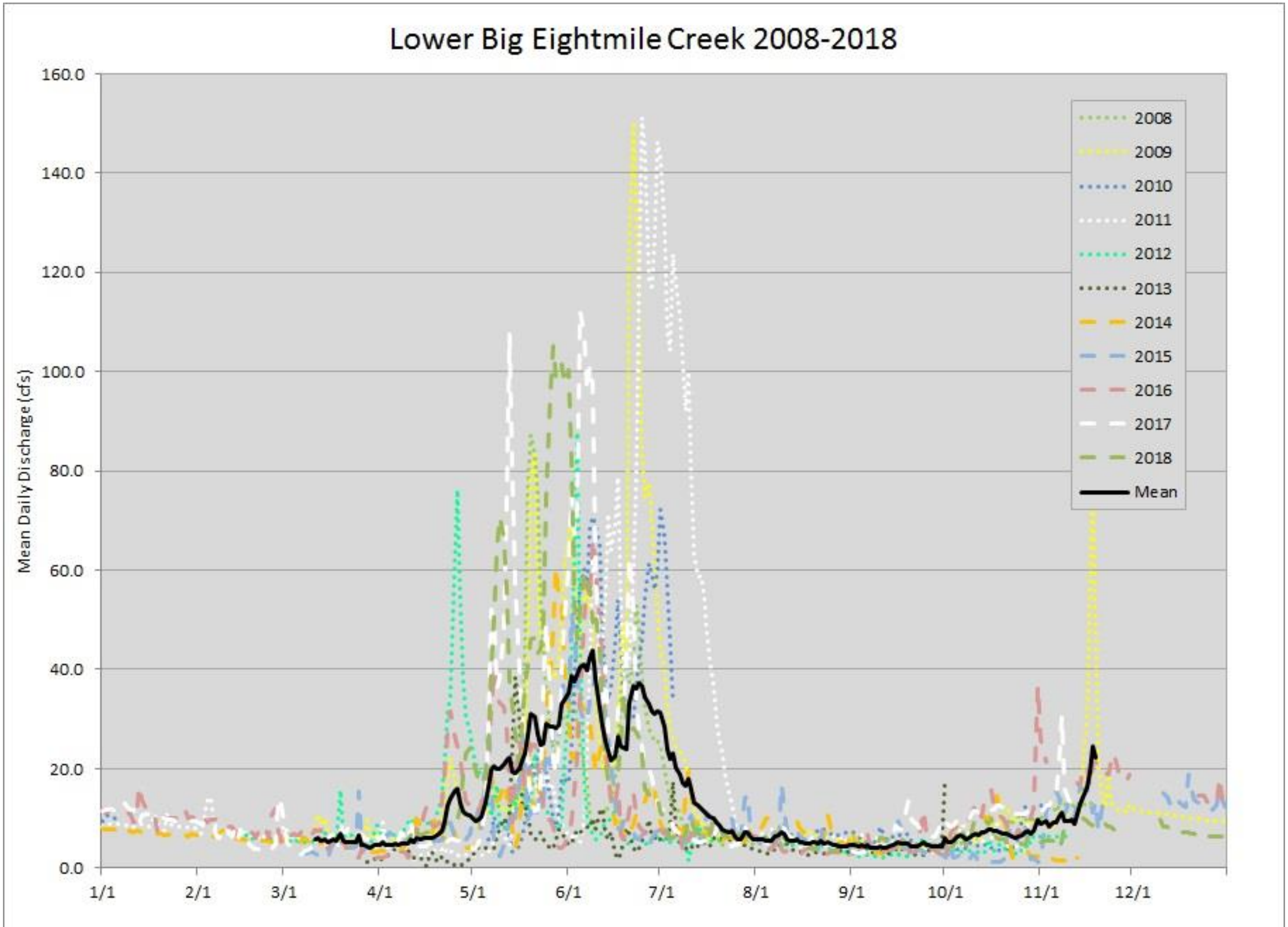
USGS Lemhi River below L-5 2008-2018
Mean Daily Discharge (cfs)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
1/1
1/31
3/1
4/1
5/1
6/1
7/1
8/1
8/31
10/1
10/31
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-18



USGS Lemhi River below Lemhi 2008-2018
Mean Daily Discharge (cfs)
0
200
400
600
800
1000
1200
1400
1600
1/1
1/31
3/1
4/1
5/1
6/1
7/1
8/1
8/31
10/1
10/31
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-19



Lower Big Eightmile Creek 2008-2018
Mean Daily Discharge (cfs)
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-20

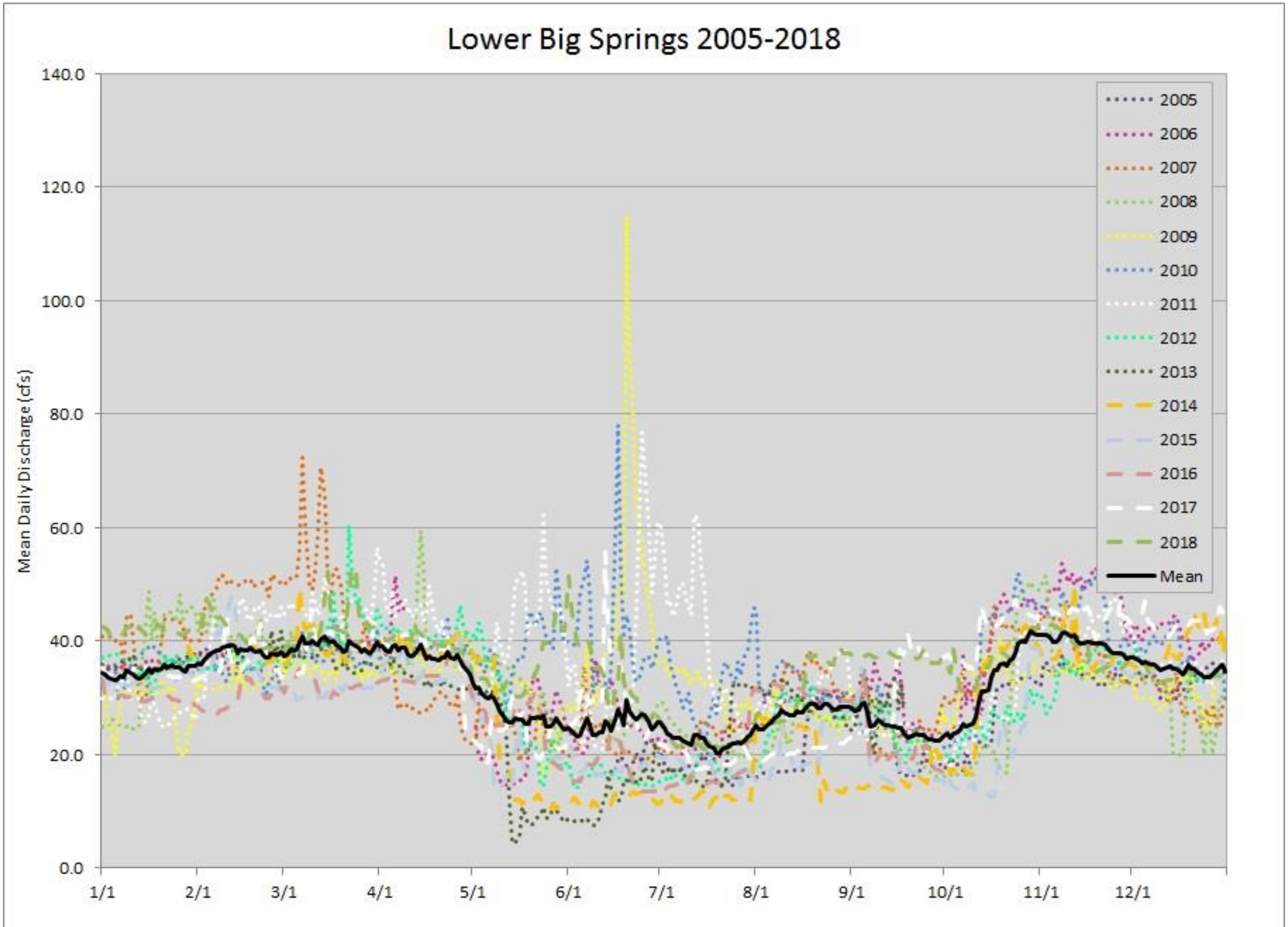

Lower Big Springs 2005-2018
Mean Daily Discharge (cfs)
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-21

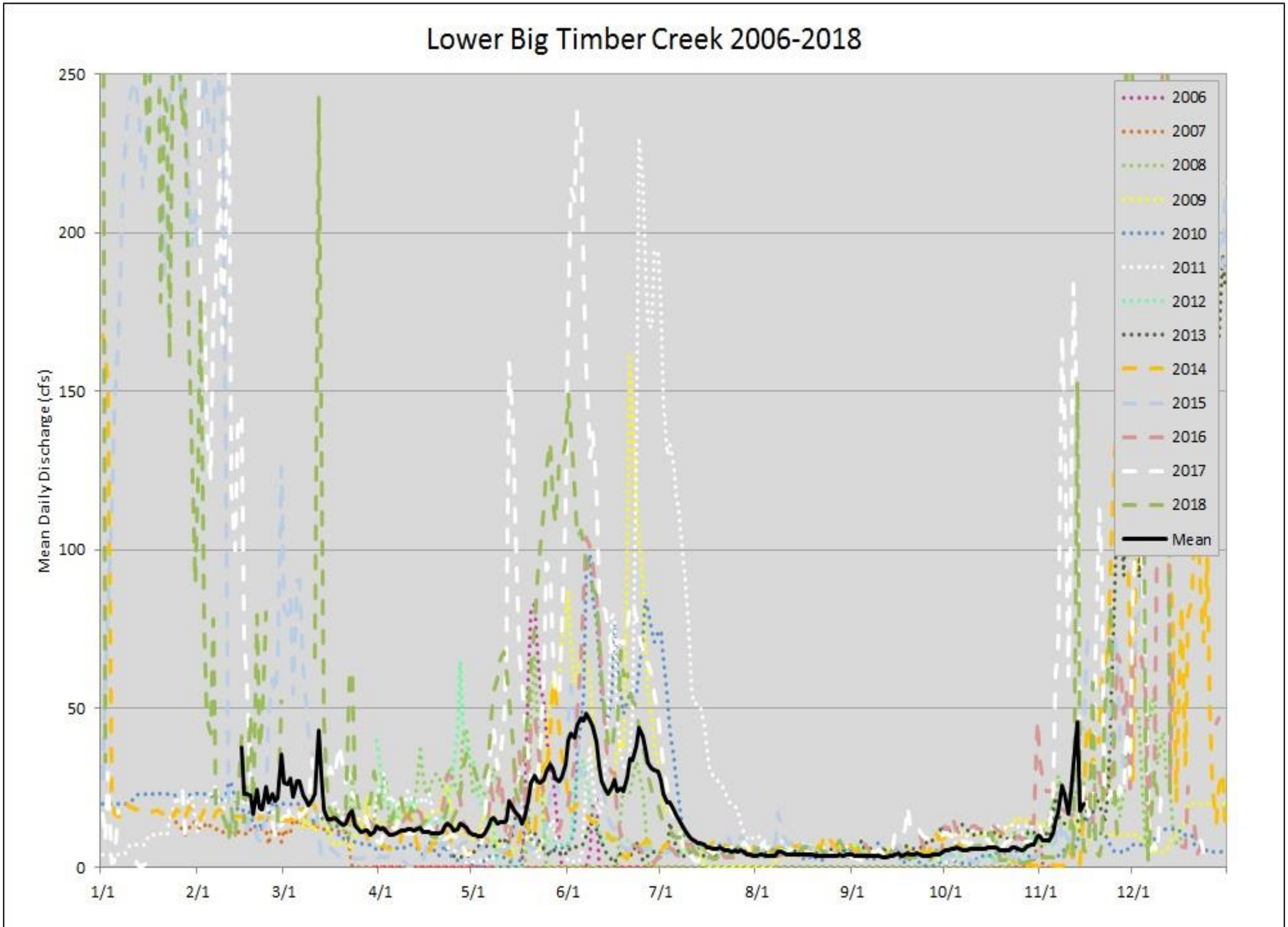
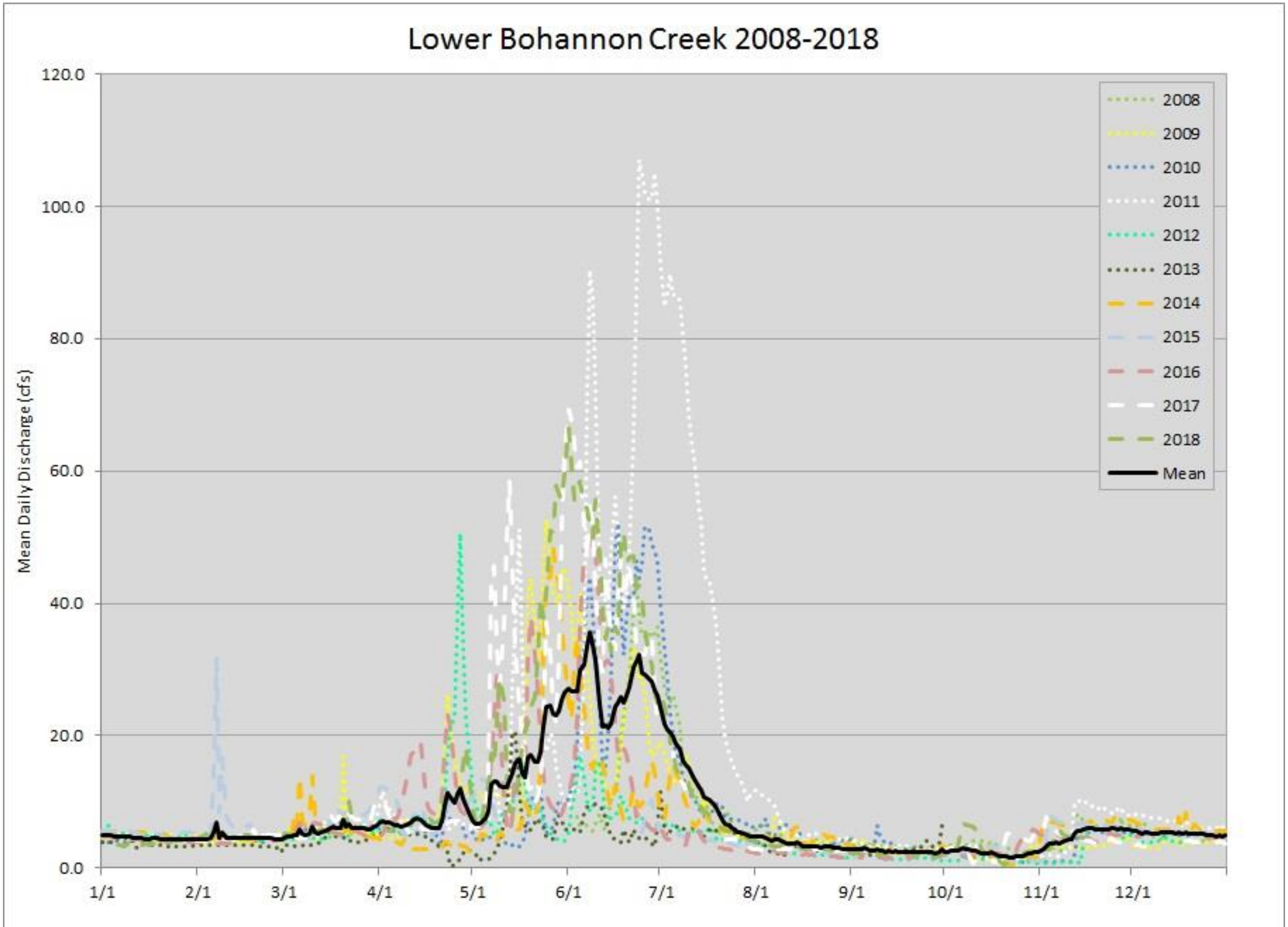

Lower Big Timber Creek 2006-2018
Mean Daily Discharge (cfs)
250
200
150
100
50
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-22



Lower Bohannon Creek 2008-2018
Mean Daily Discharge (cfs)
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-23

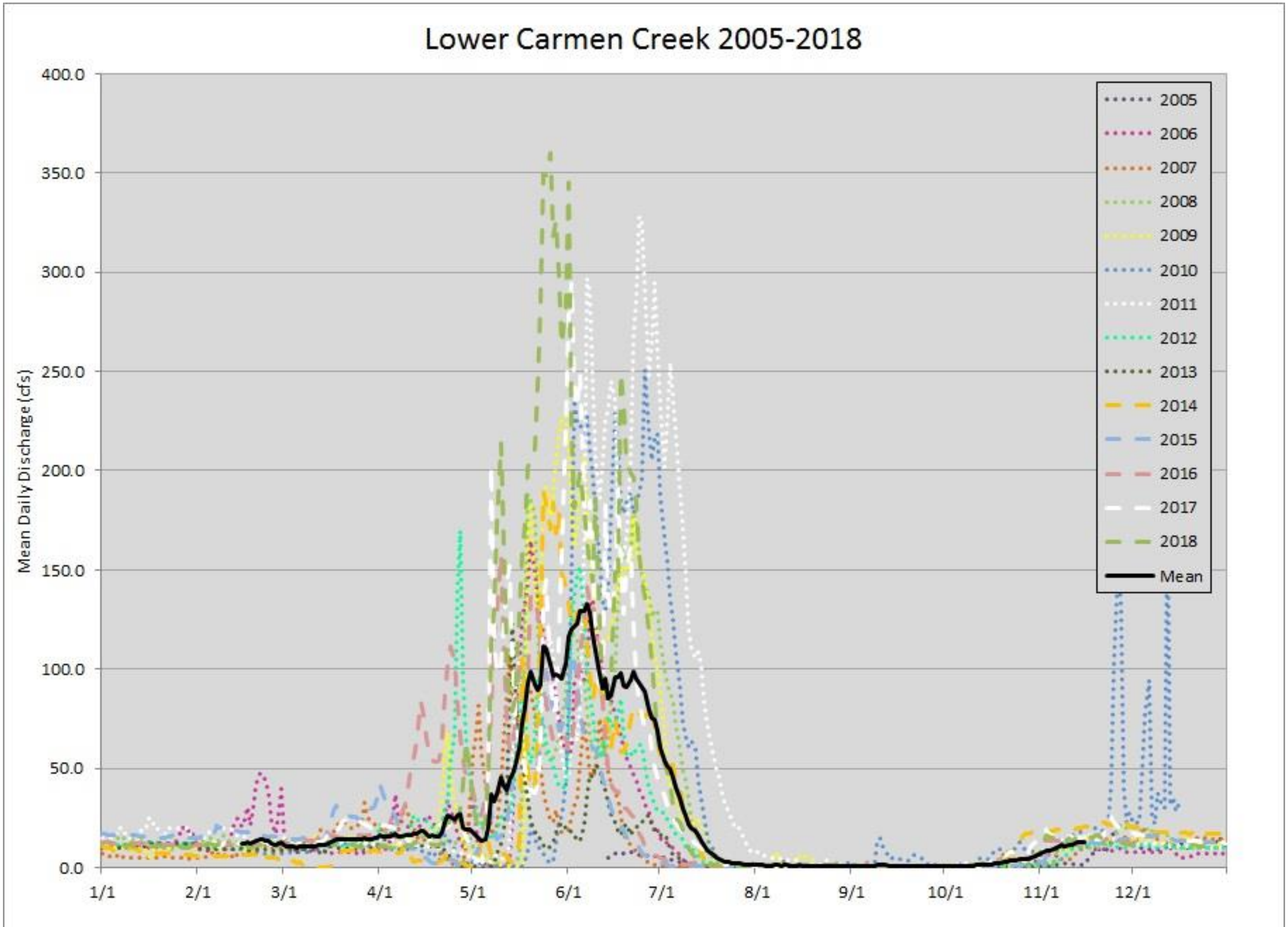

Lower Carmen Creek 2005-2018
Mean Daily Discharge (cfs)
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-24

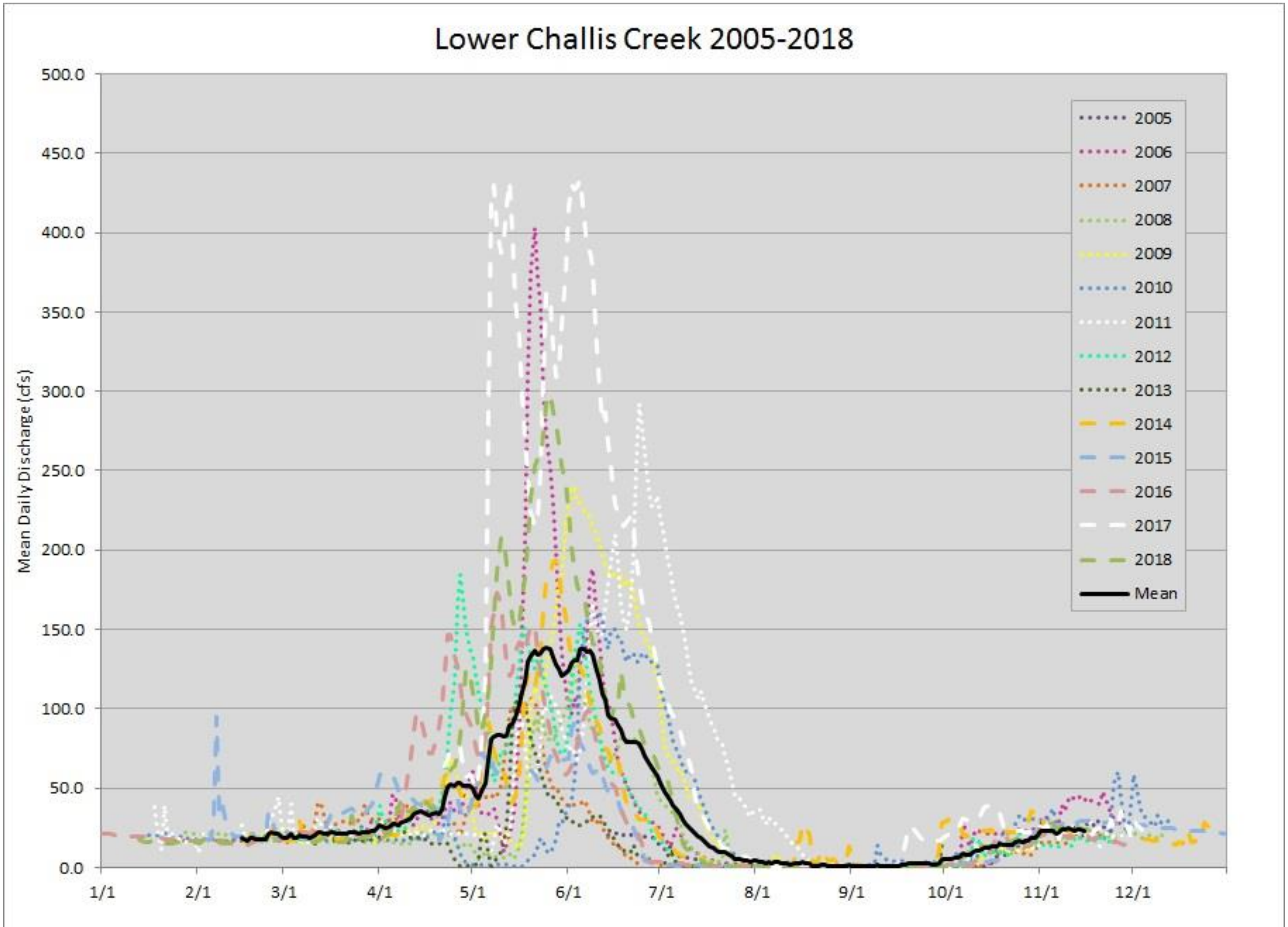
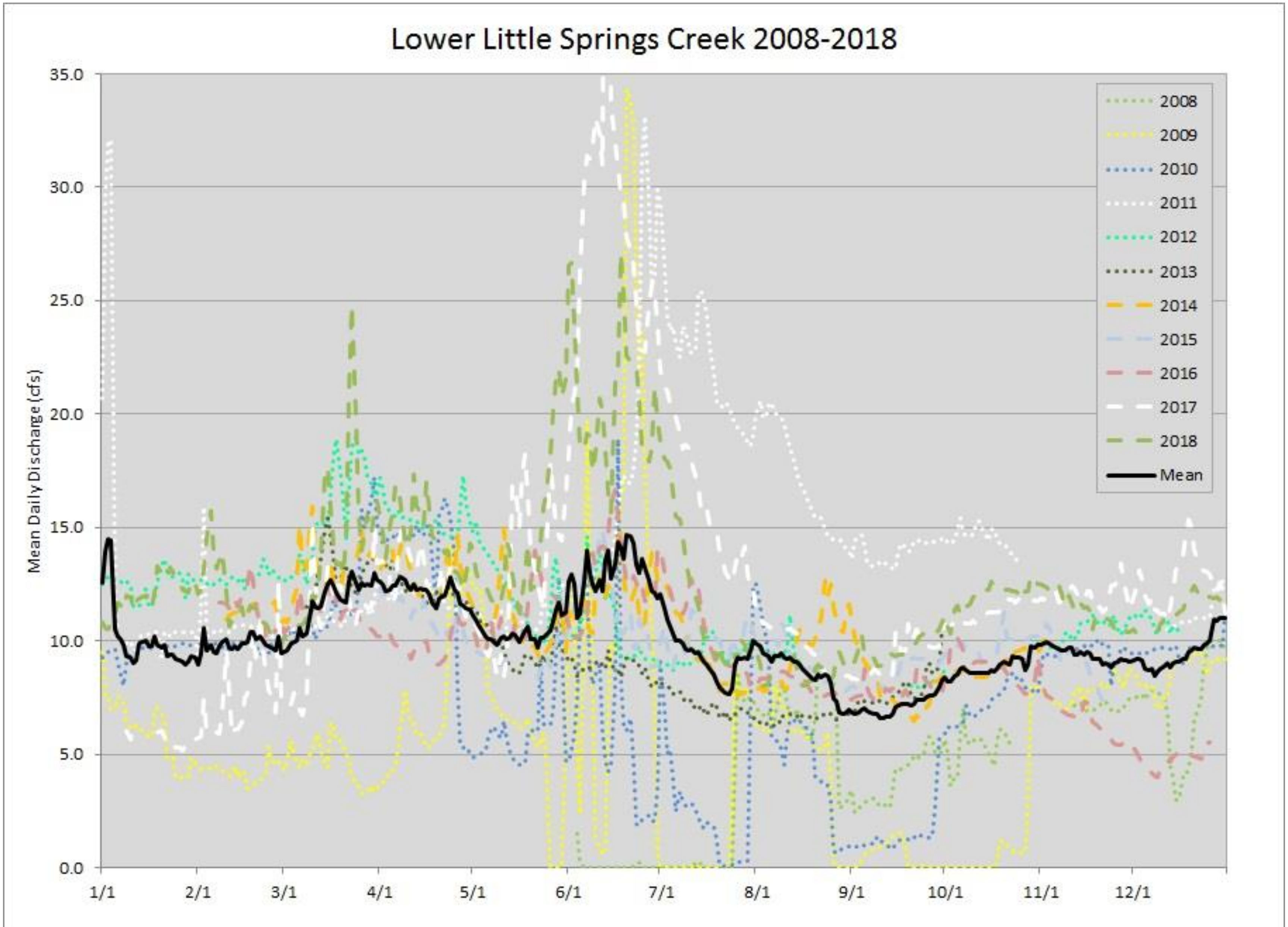

Lower Challis Creek 2005-2018
Mean Daily Discharge (cfs)
500.0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-25



Lower Little Springs Creek 2008-2018
Mean Daily Discharge (cfs)
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-26

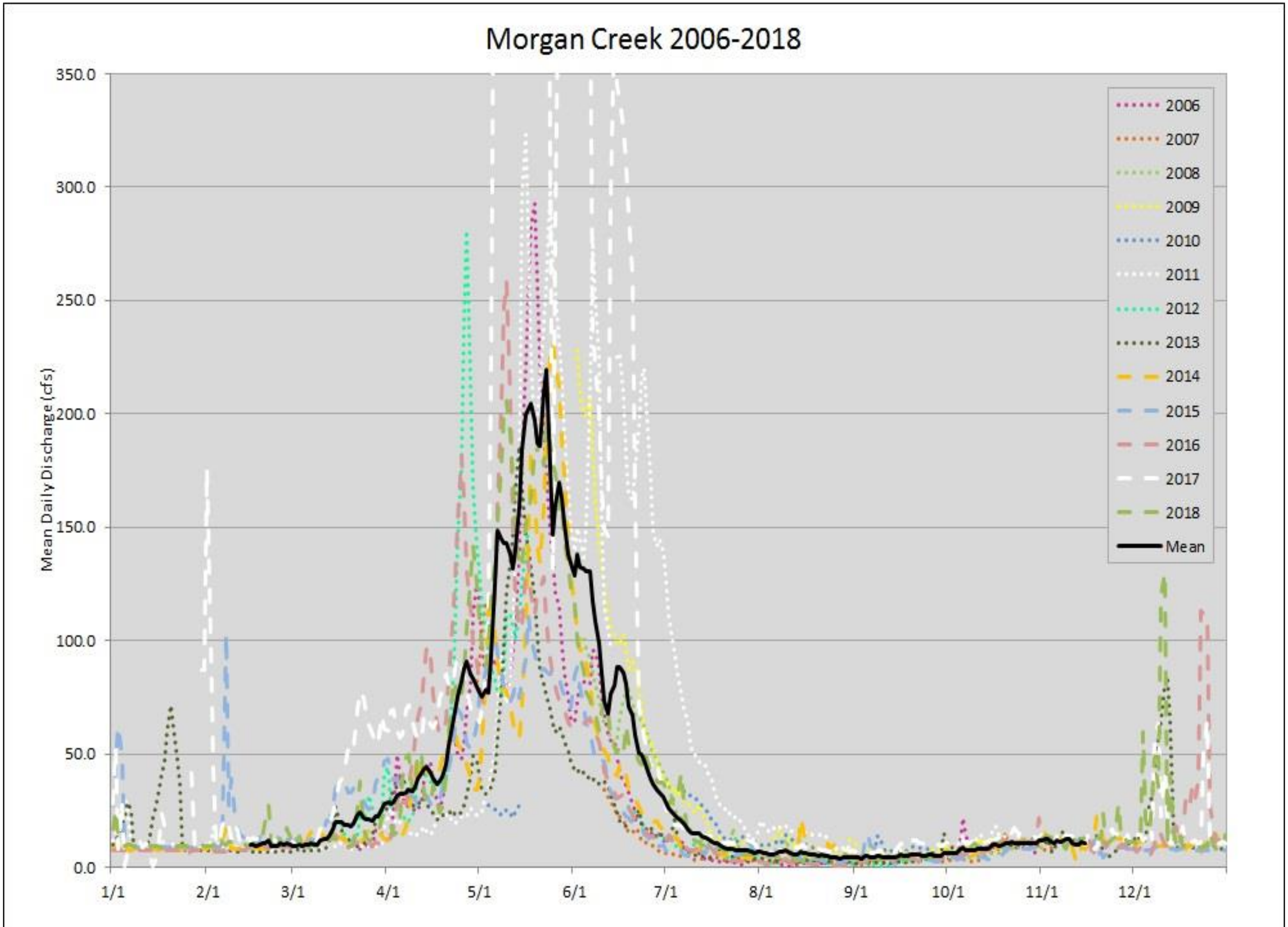

Morgan Creek 2006-2018
Mean Daily Discharge (cfs)
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-27

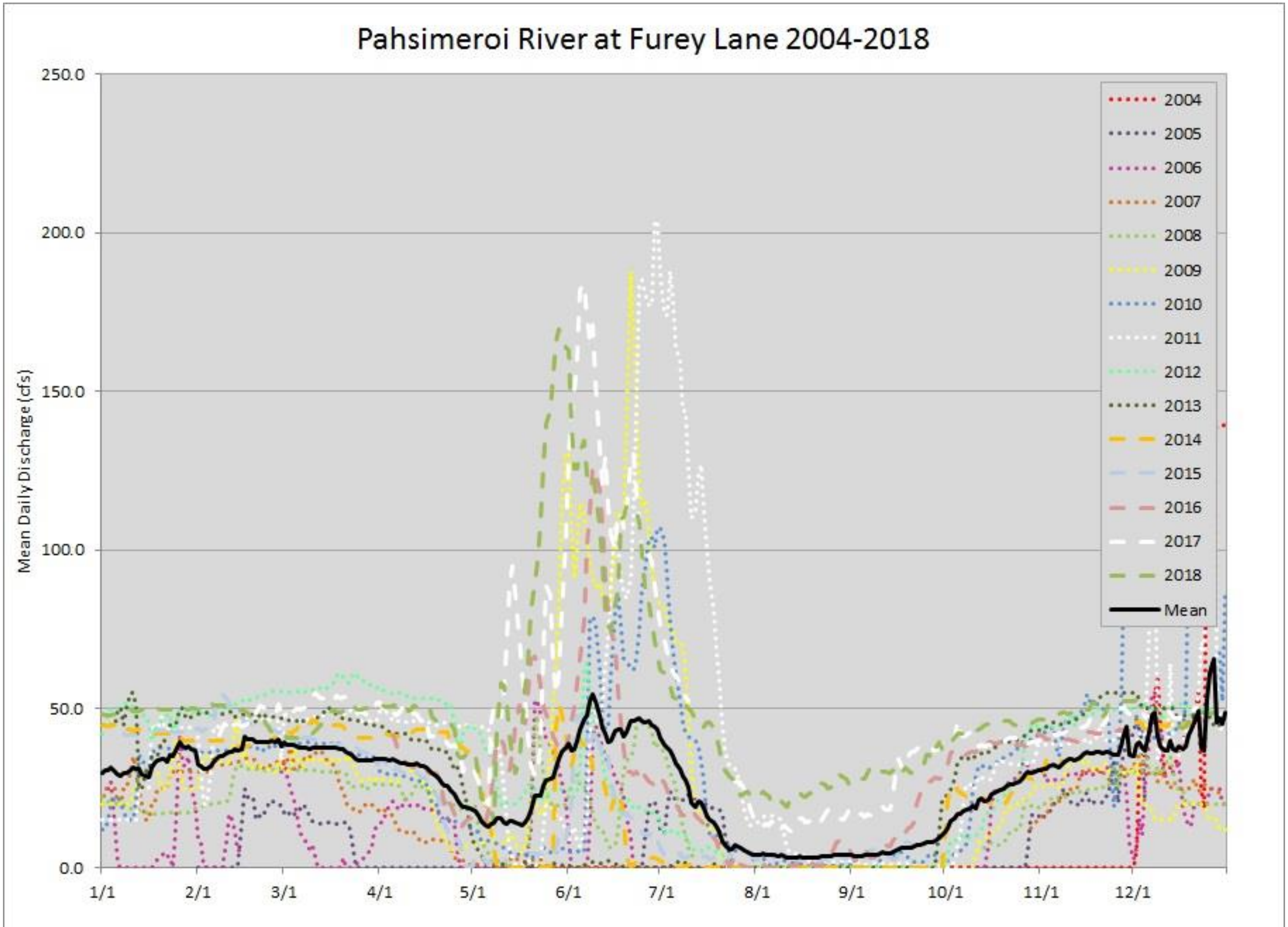

Pahsimeroi River at Furey Lane 2004-2018
Mean Daily Discharge (cfs)
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-28

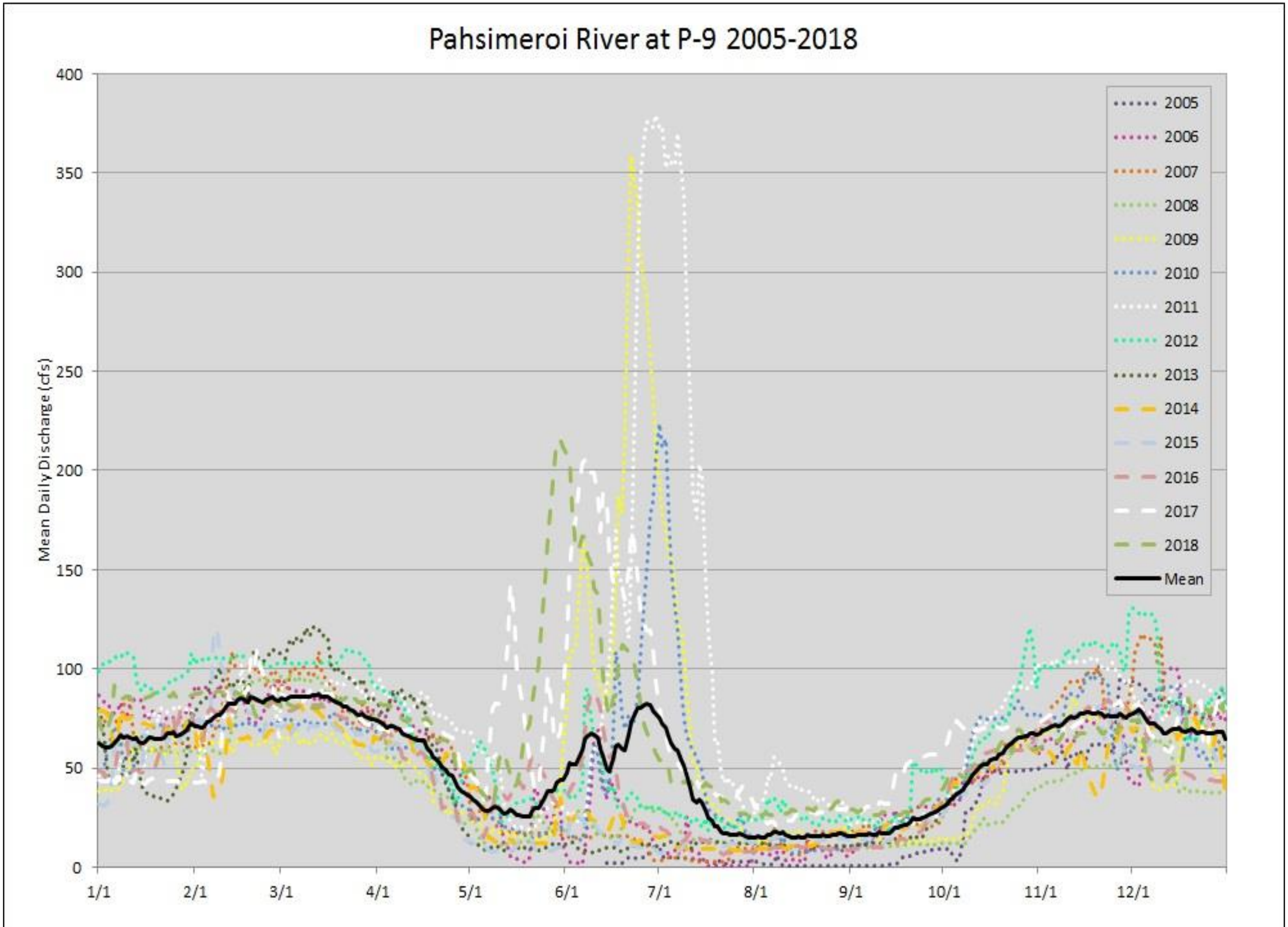

Pahsimeroi River at P-9 2005-2018
Mean Daily Discharge (cfs)
400
350
300
250
200
150
100
50
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-29

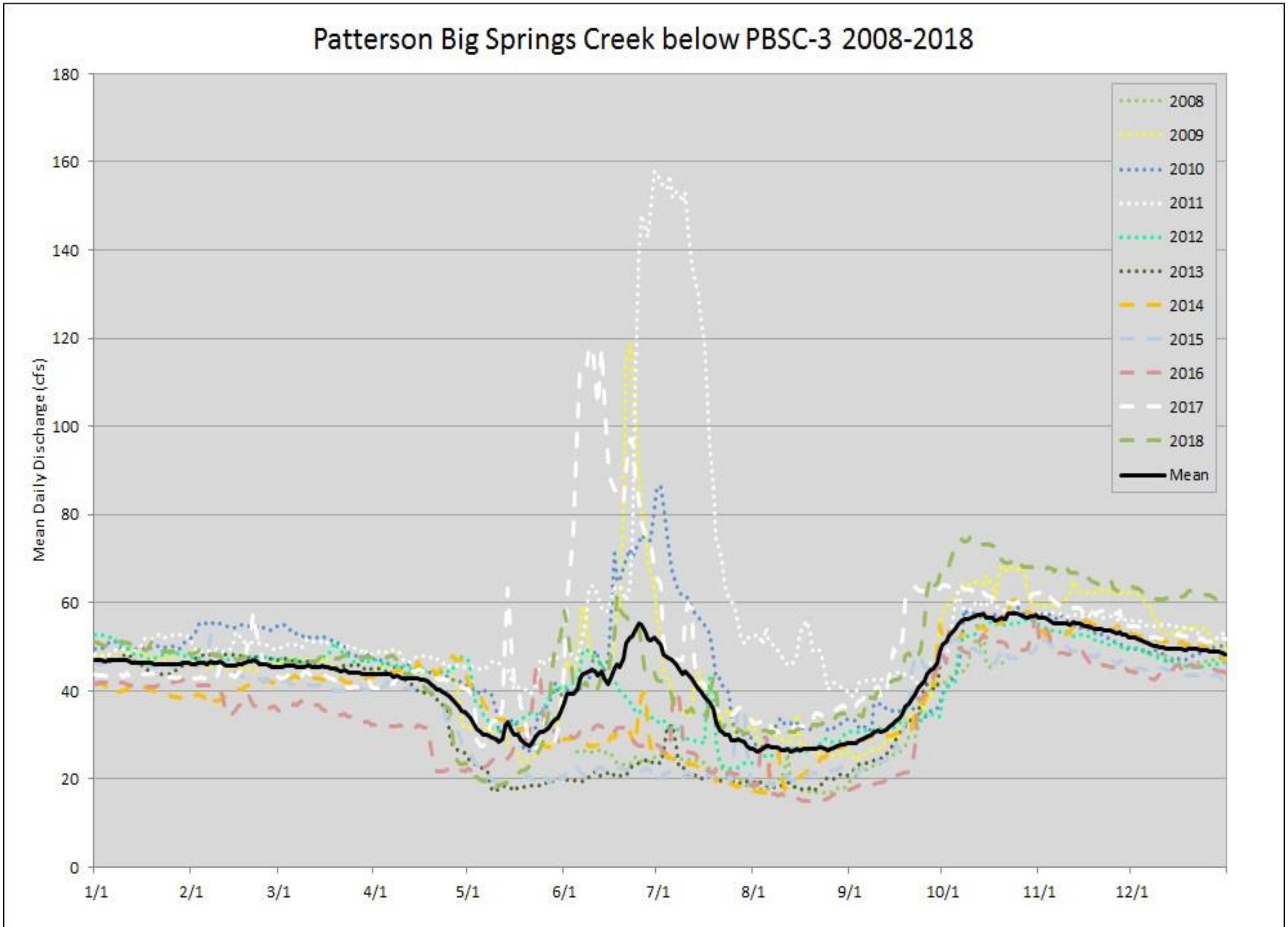

Patterson Big Springs Creek below PBSC-3 2008-2018
Mean Daily Discharge (cfs)
180
160
140
120
100
80
60
40
20
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-30

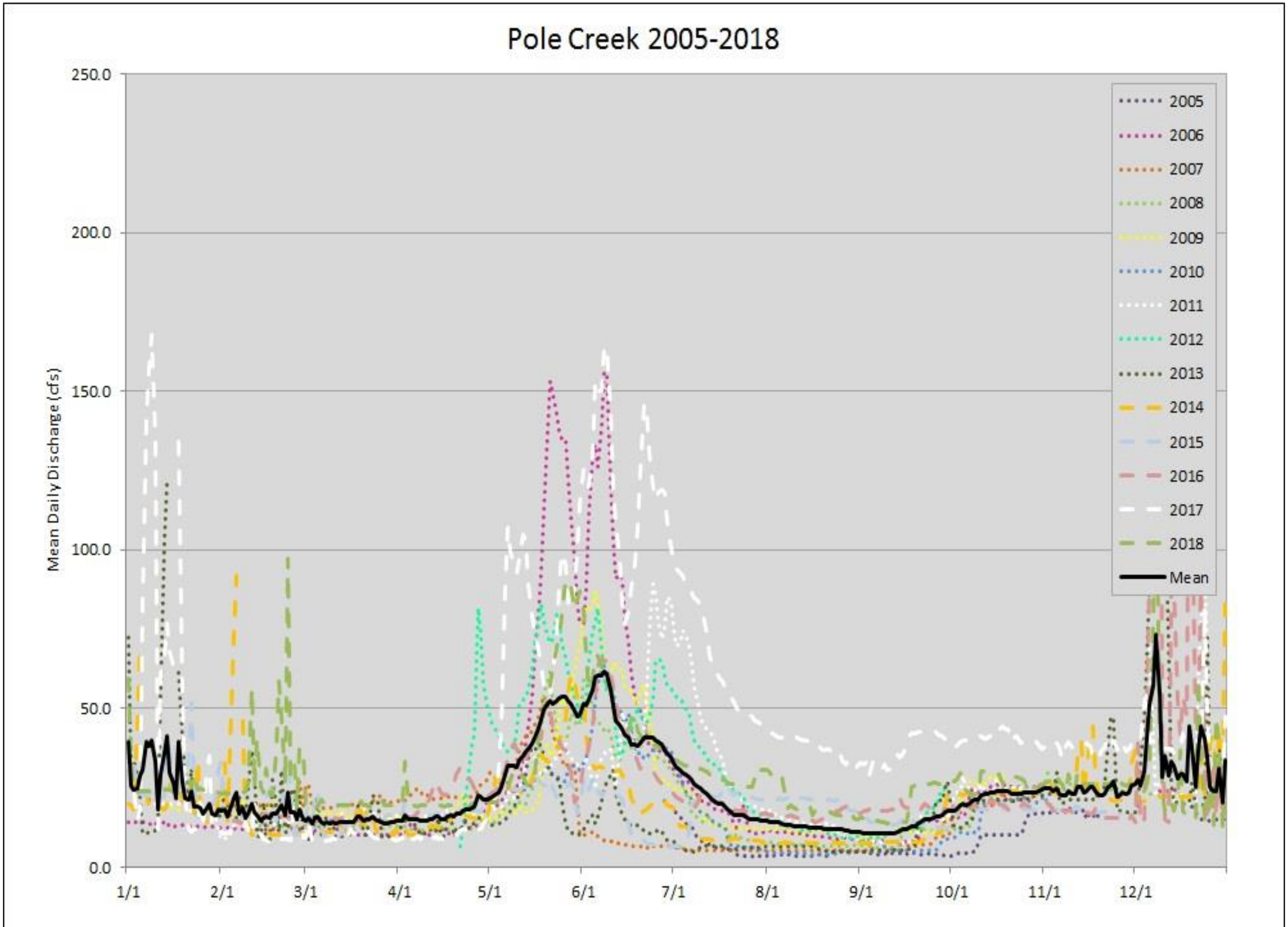
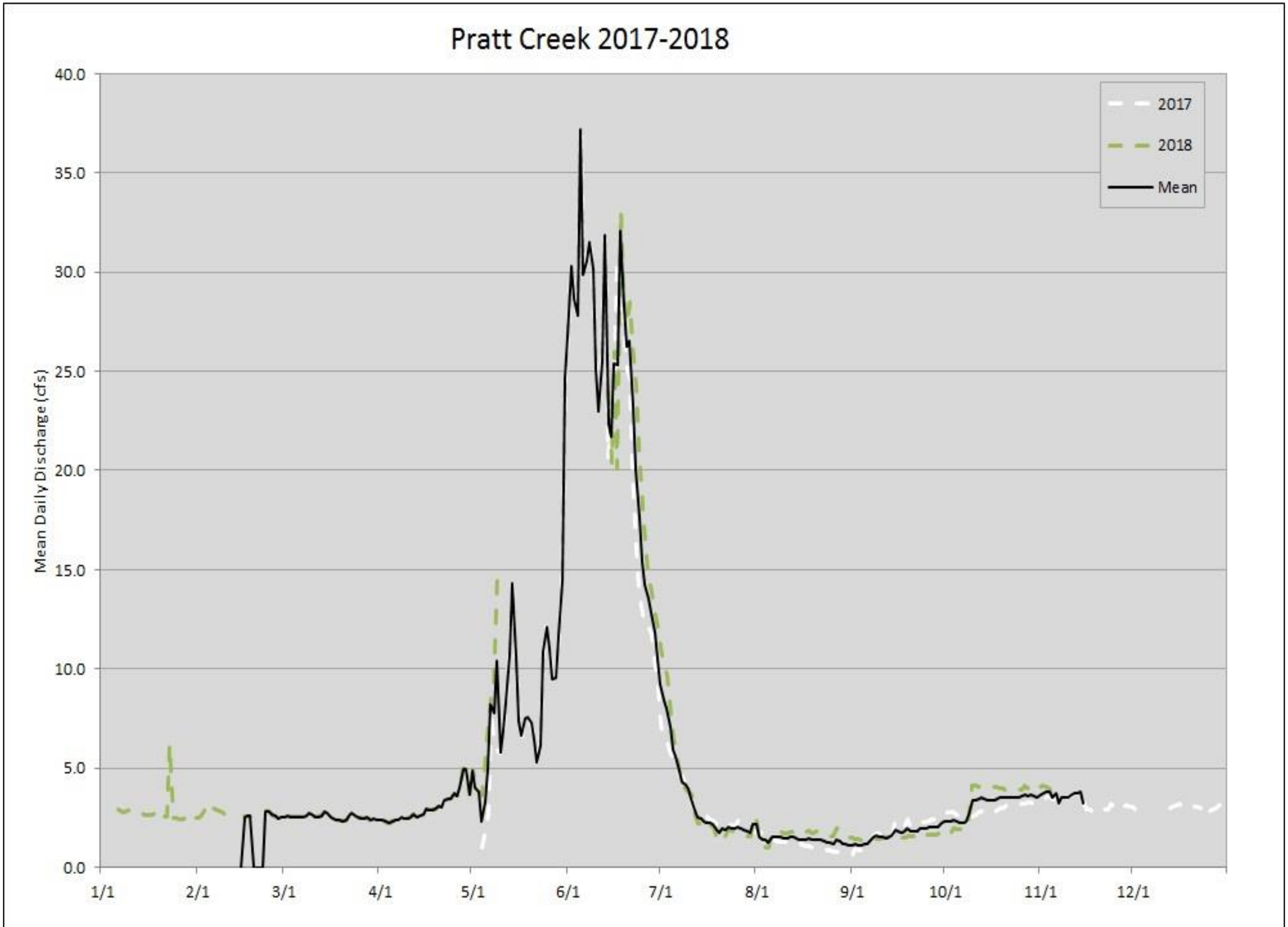

Pole Creek 2005-2018
Mean Daily Discharge (cfs)
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-31



Pratt Creek 2017-2018
Mean Daily Discharge (cfs)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2017
2018
Mean

Figure A-32

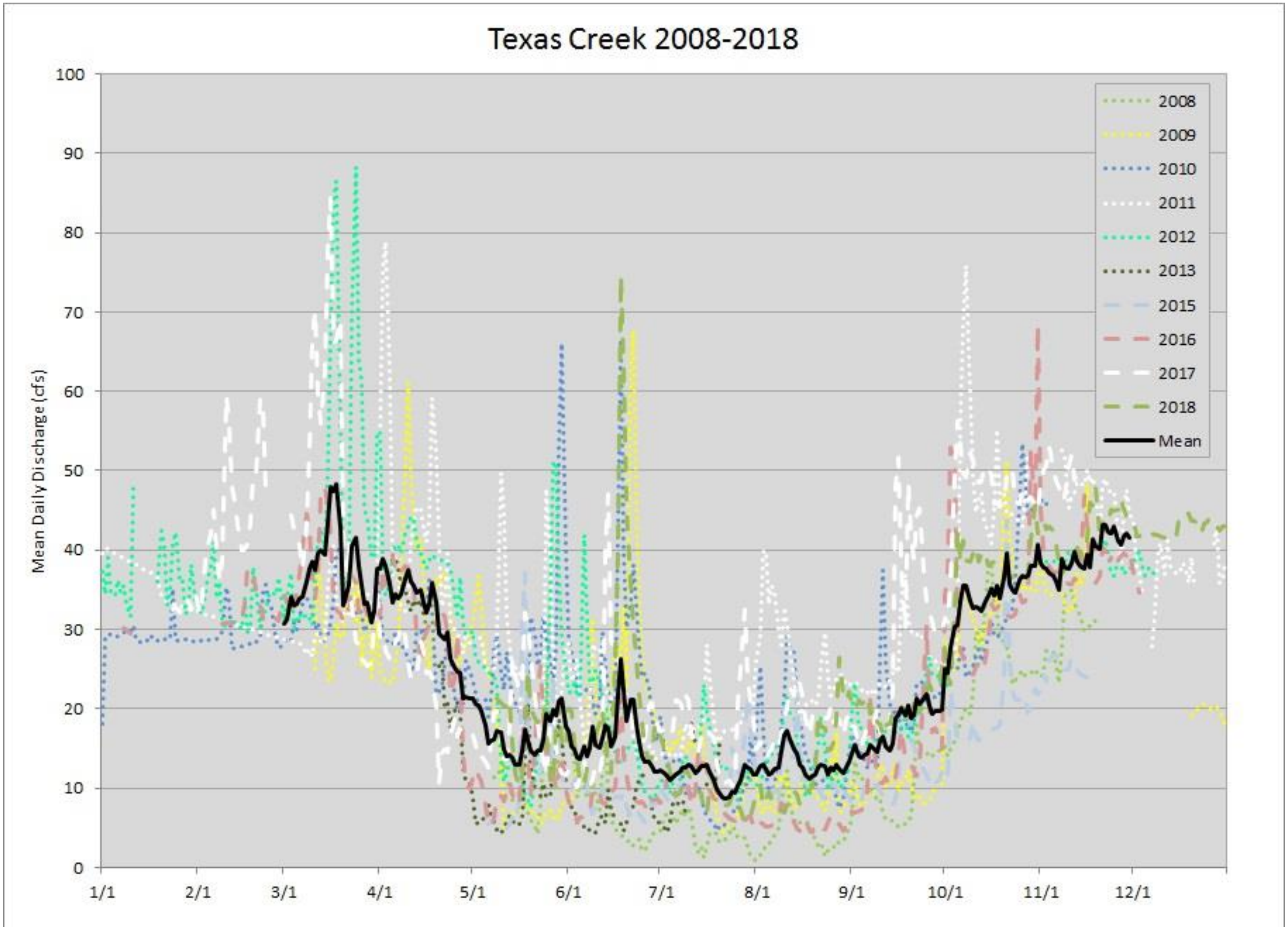

Texas Creek 2008-2018
Mean Daily Discharge (cfs)
100
90
80
70
60
50
40
30
20
10
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2015
2016
2017
2018
Mean

Figure A-33

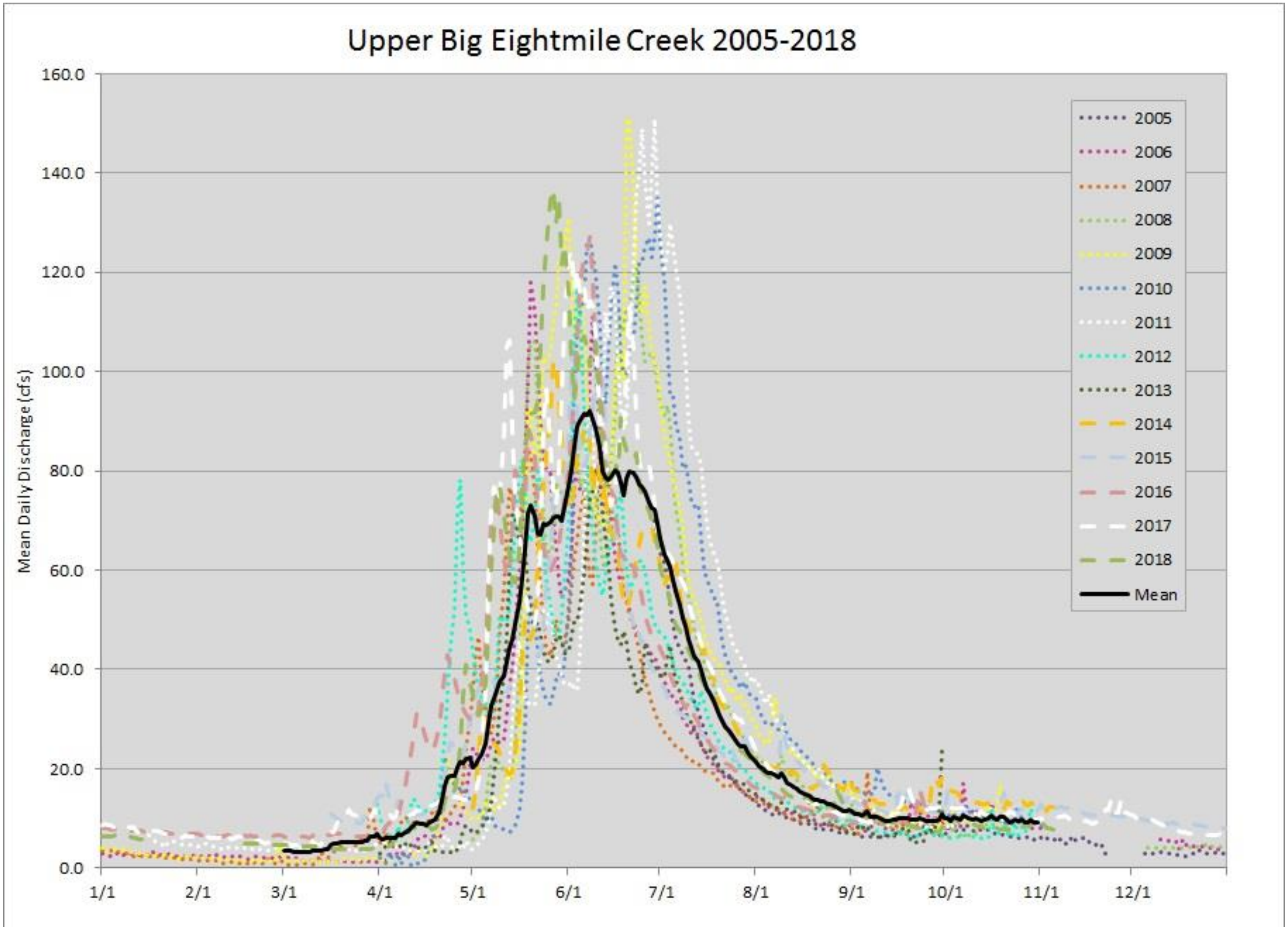

Upper Big Eightmile Creek 2005-2018
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Mean Daily Discharge (cfs)
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-34

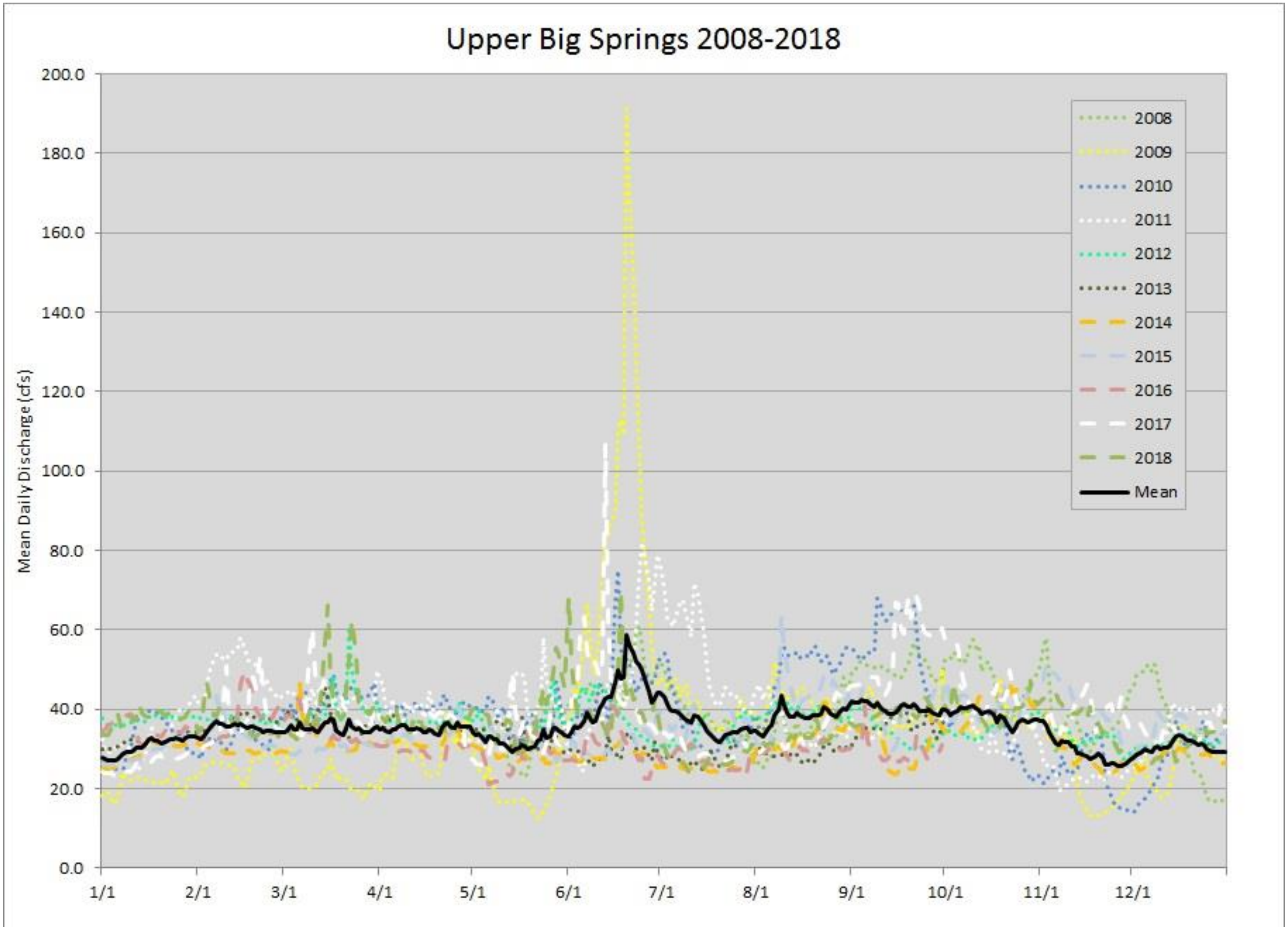

Upper Big Springs 2008-2018
Mean Daily Discharge (cfs)
200.0
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-35

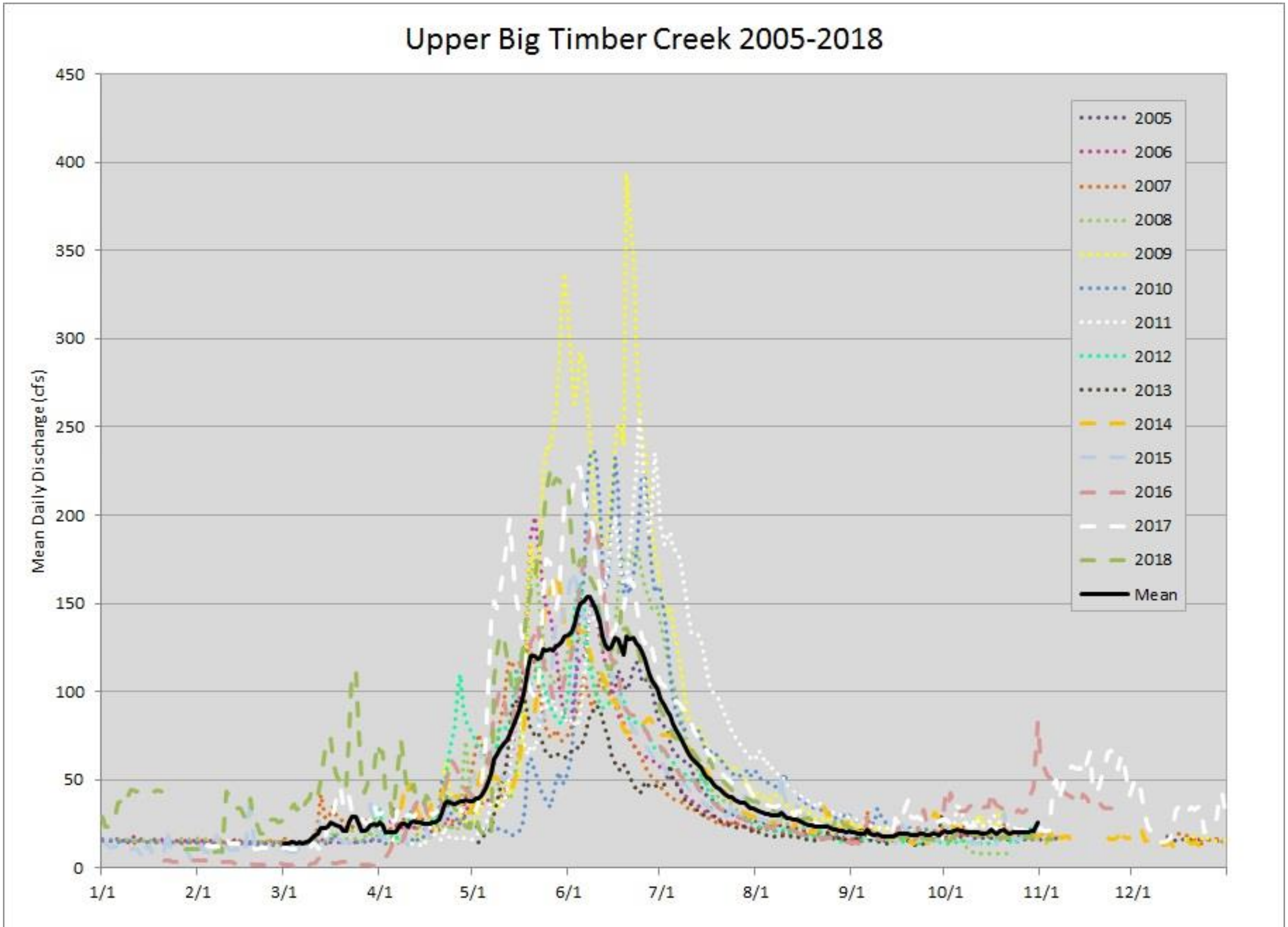

Upper Big Timber Creek 2005-2018
Mean Daily Discharge (cfs)
450
400
350
300
250
200
150
100
50
0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-36

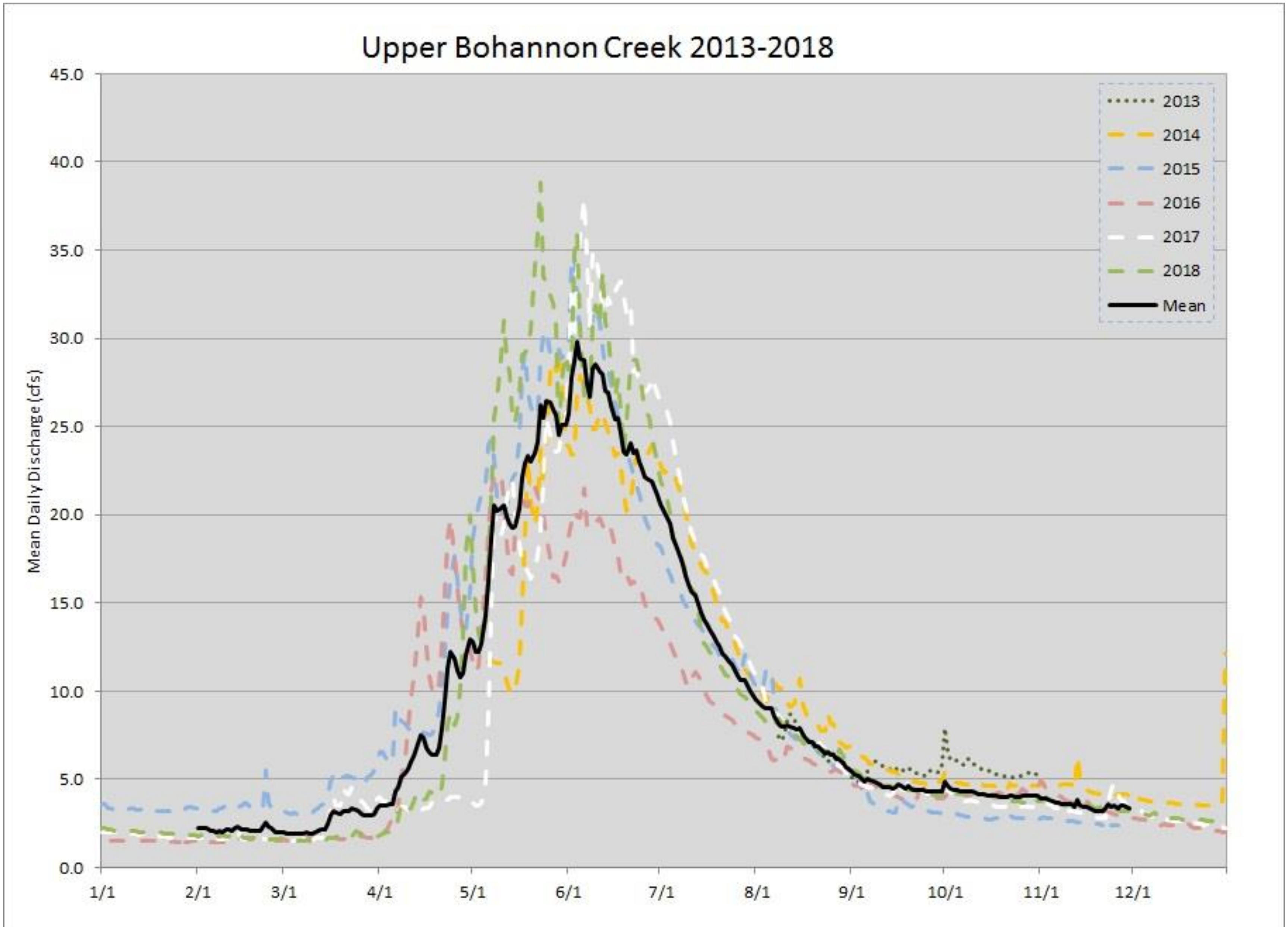

Upper Bohannon Creek 2013-2018
Mean Daily Discharge (cfs)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2013
2014
2015
2016
2017
2018
Mean

Figure A-37

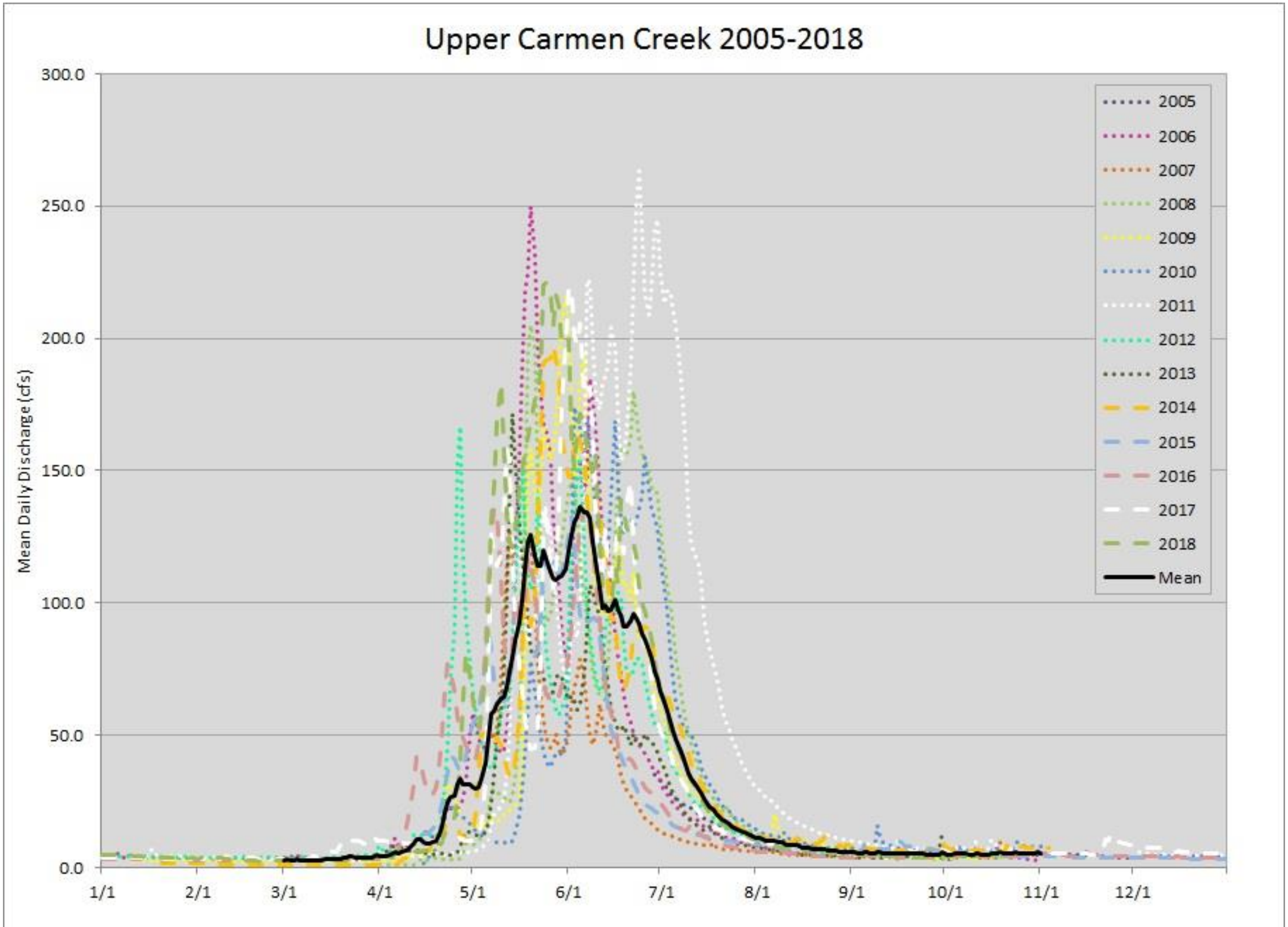

Upper Carmen Creek 2005-2018
Mean Daily Discharge (cfs)
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-38

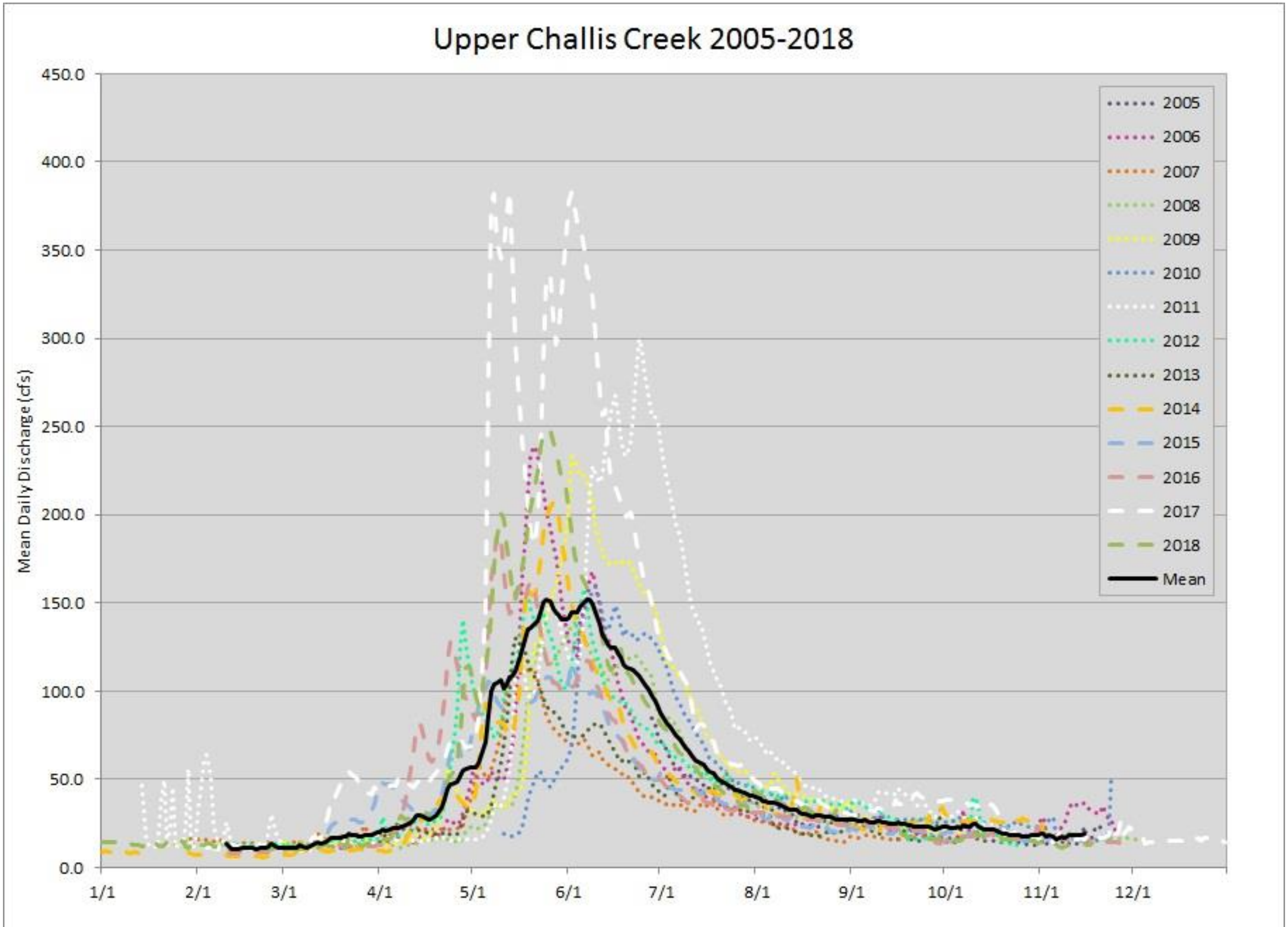
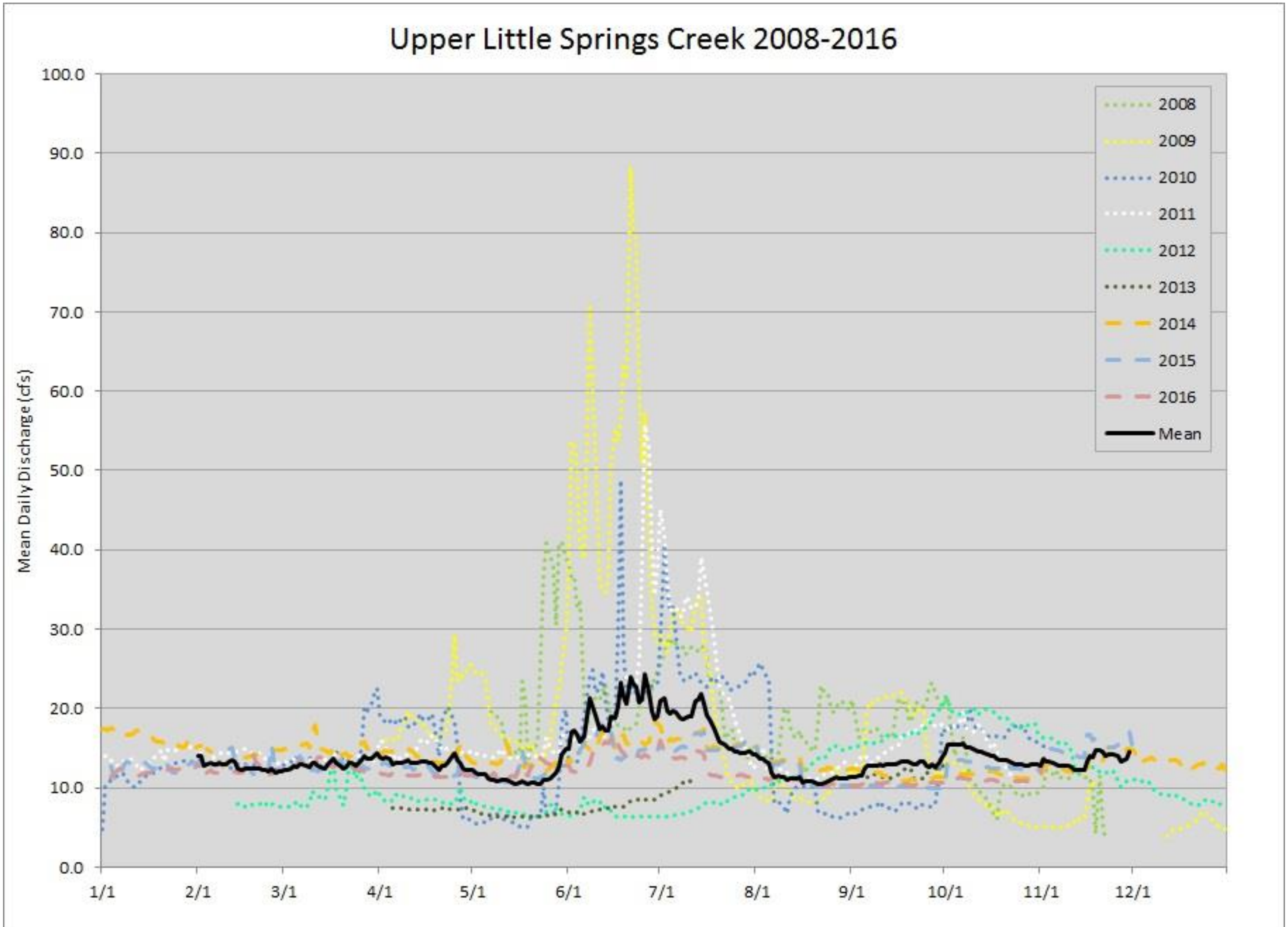

Upper Challis Creek 2005-2018
Mean Daily Discharge (cfs)
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Mean

Figure A-39



Upper Little Springs Creek 2008-2016
Mean Daily Discharge (cfs)
100.0
90.0
80.0
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
1/1
2/1
3/1
4/1
5/1
6/1
7/1
8/1
9/1
10/1
11/1
12/1
2008
2009
2010
2011
2012
2013
2014
2015
2016
Mean

Figure A-40

Appendix B – Groundwater Hydrographs

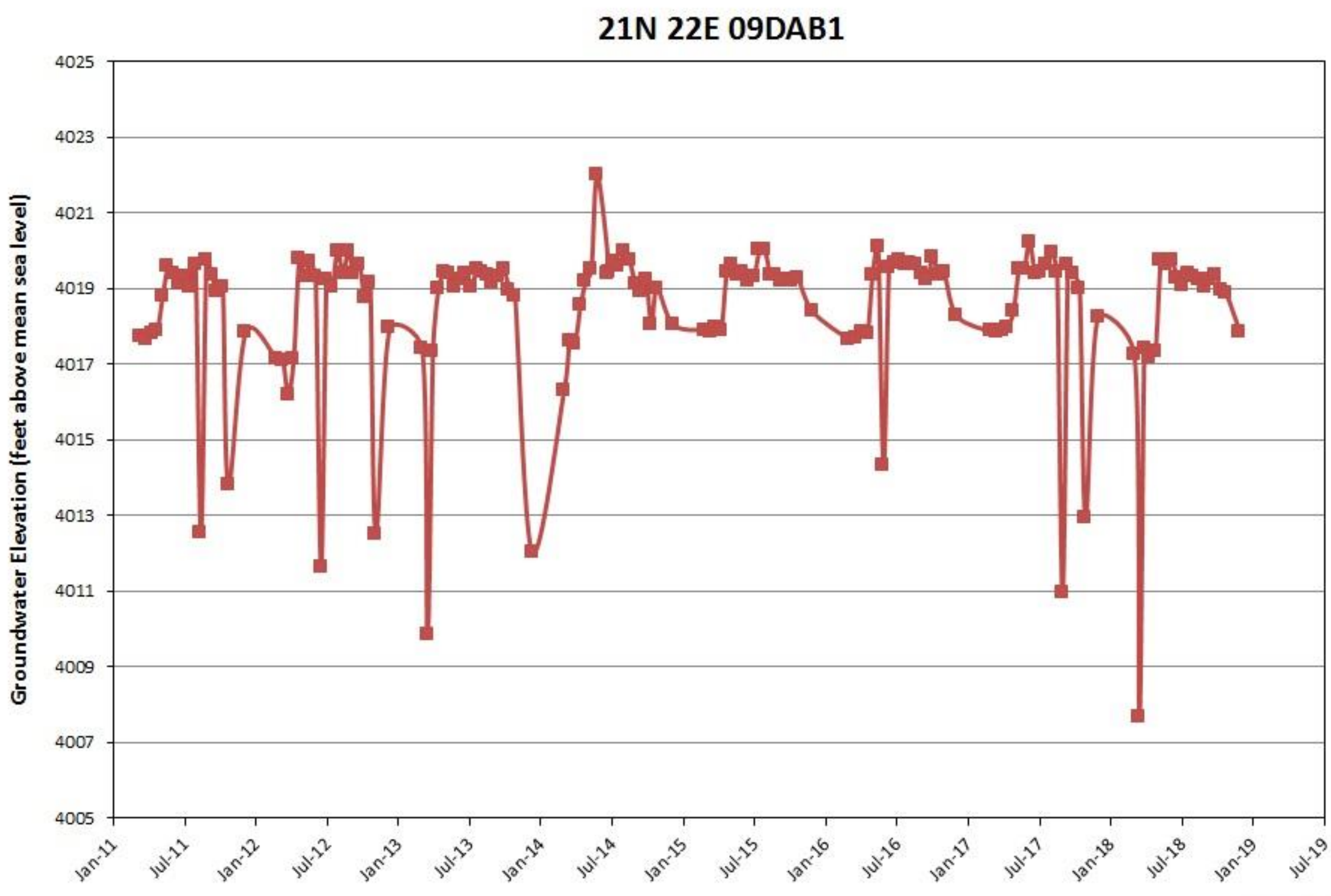


FIGURE B-1
Jackson Well
Lower Lemhi Basin
SW - GW Interactions P.III

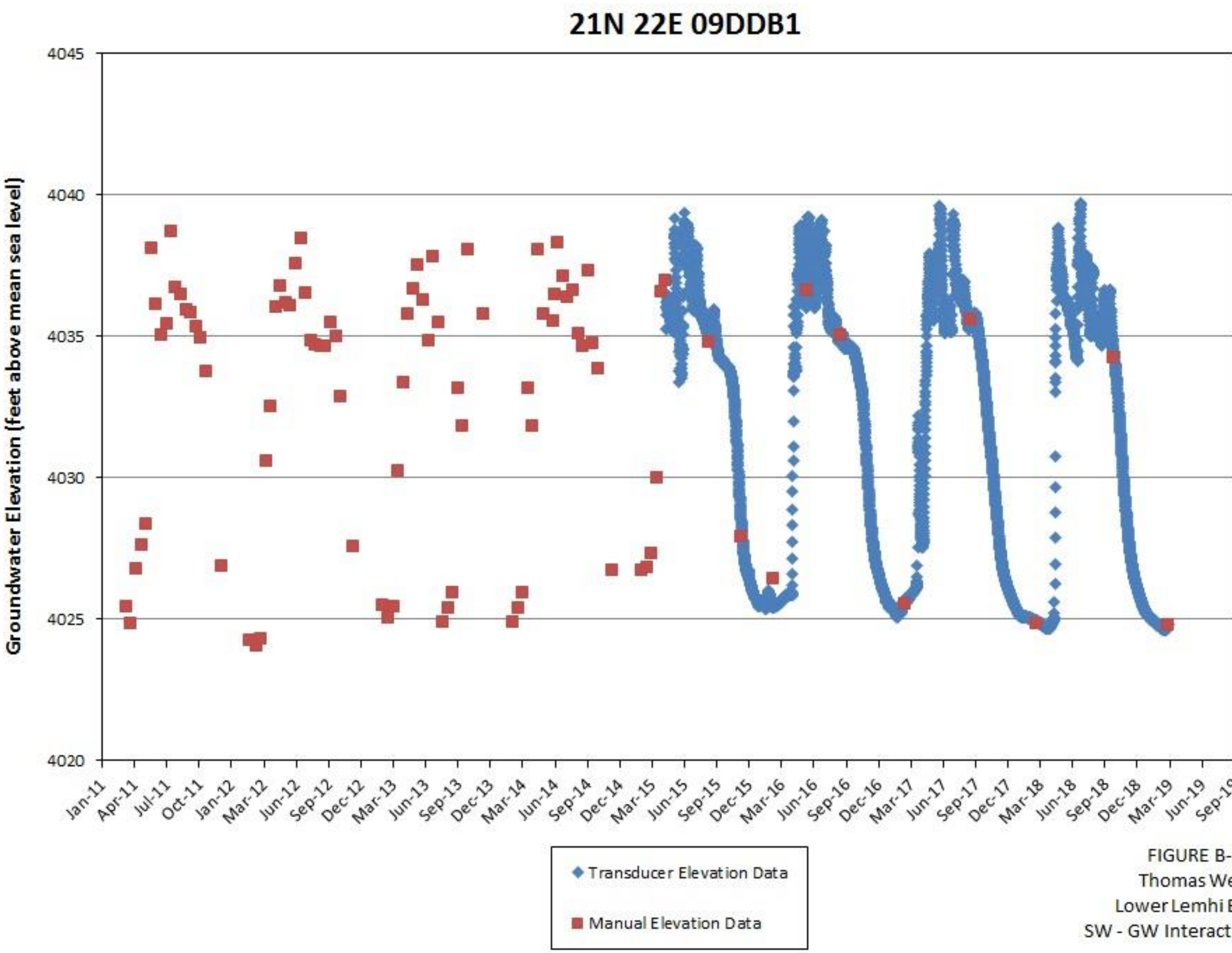
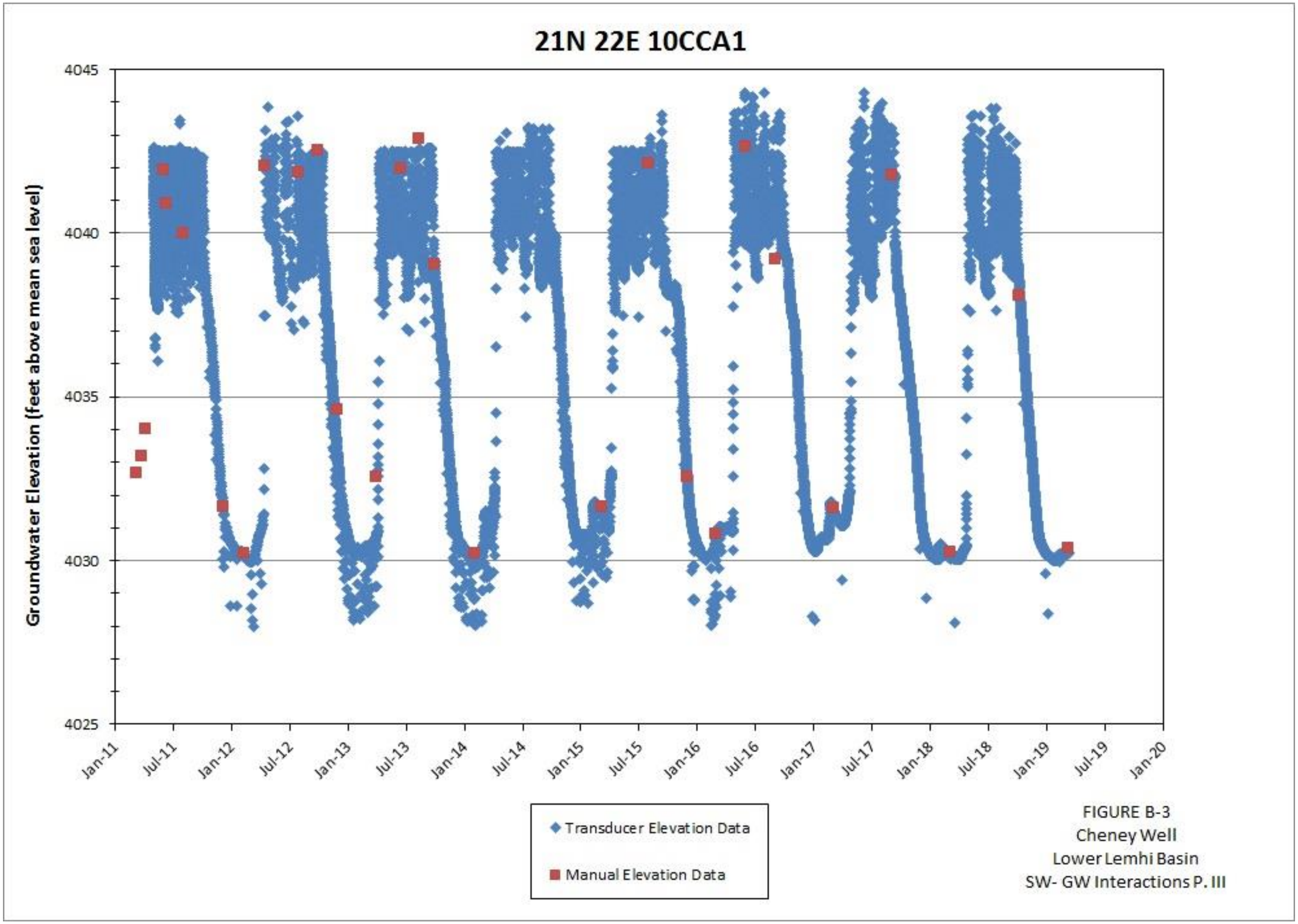


FIGURE B-2
Thomas Well
Lower Lemhi Basin
SW - GW Interactions P.III


21N 22E 10CCA1
Groundwater Elevation (feet above mean sea level)
4045
4040
4035
4030
4025
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Jan-20
Transducer Elevation Data
Manual Elevation Data
FIGURE B-3
Cheney Well
Lower Lemhi Basin
SW- GW Interactions P. III

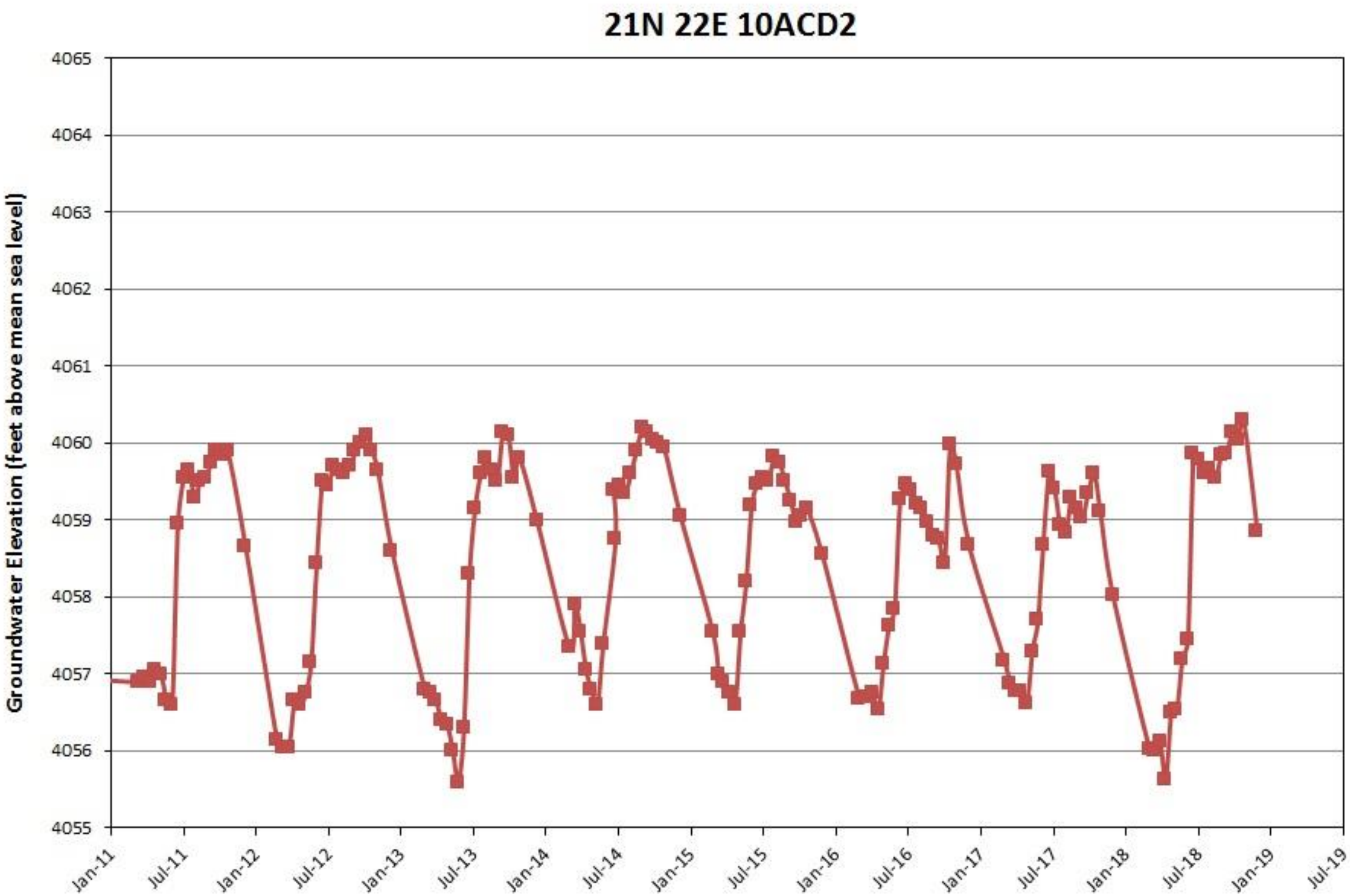


FIGURE B-4
Cockrell Well
Lower Lemhi Basin
SW - GW Interactions P.III

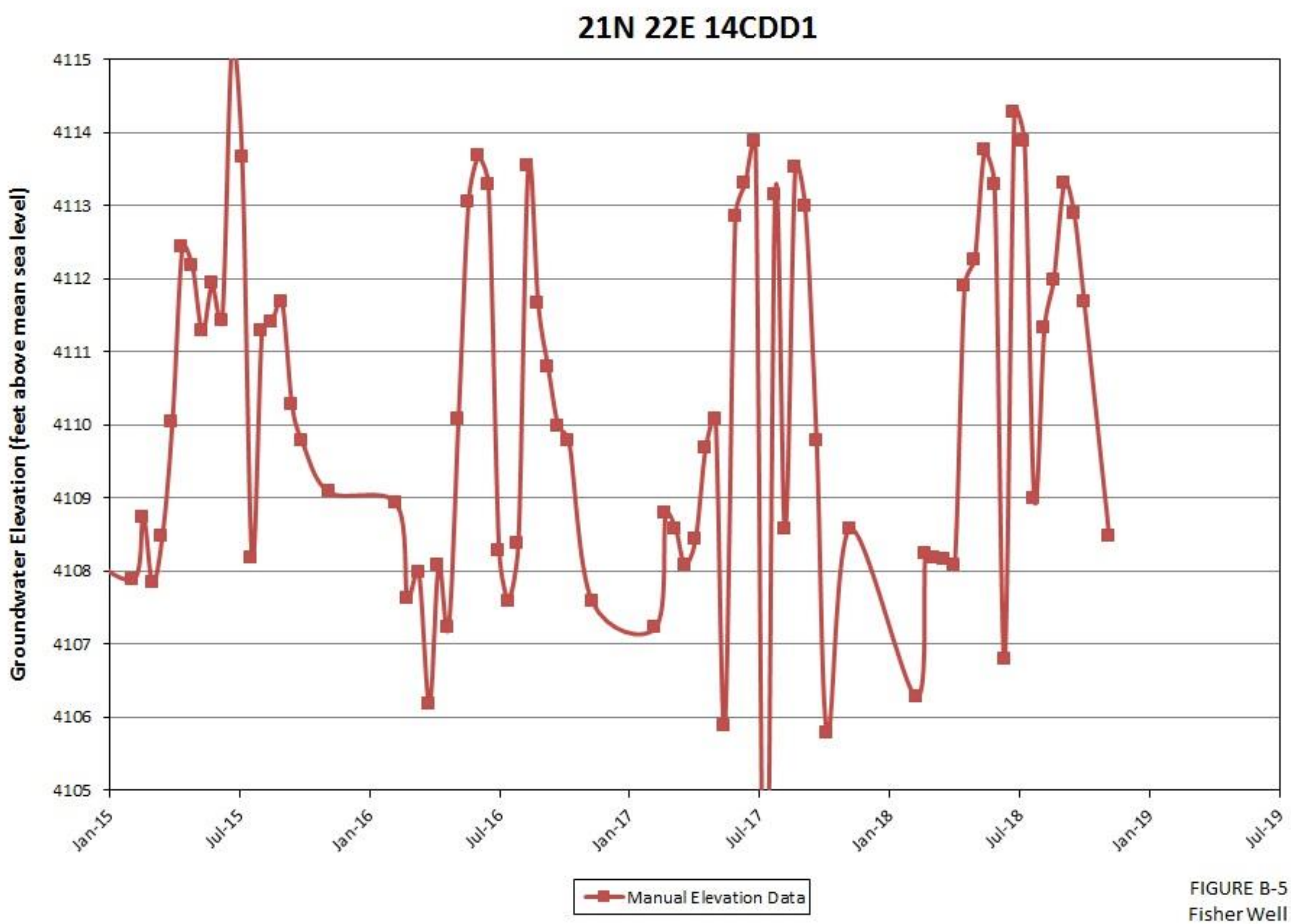


FIGURE B-5
Fisher Well
Lower Lemhi Basin
SW - GW Interactions P.III

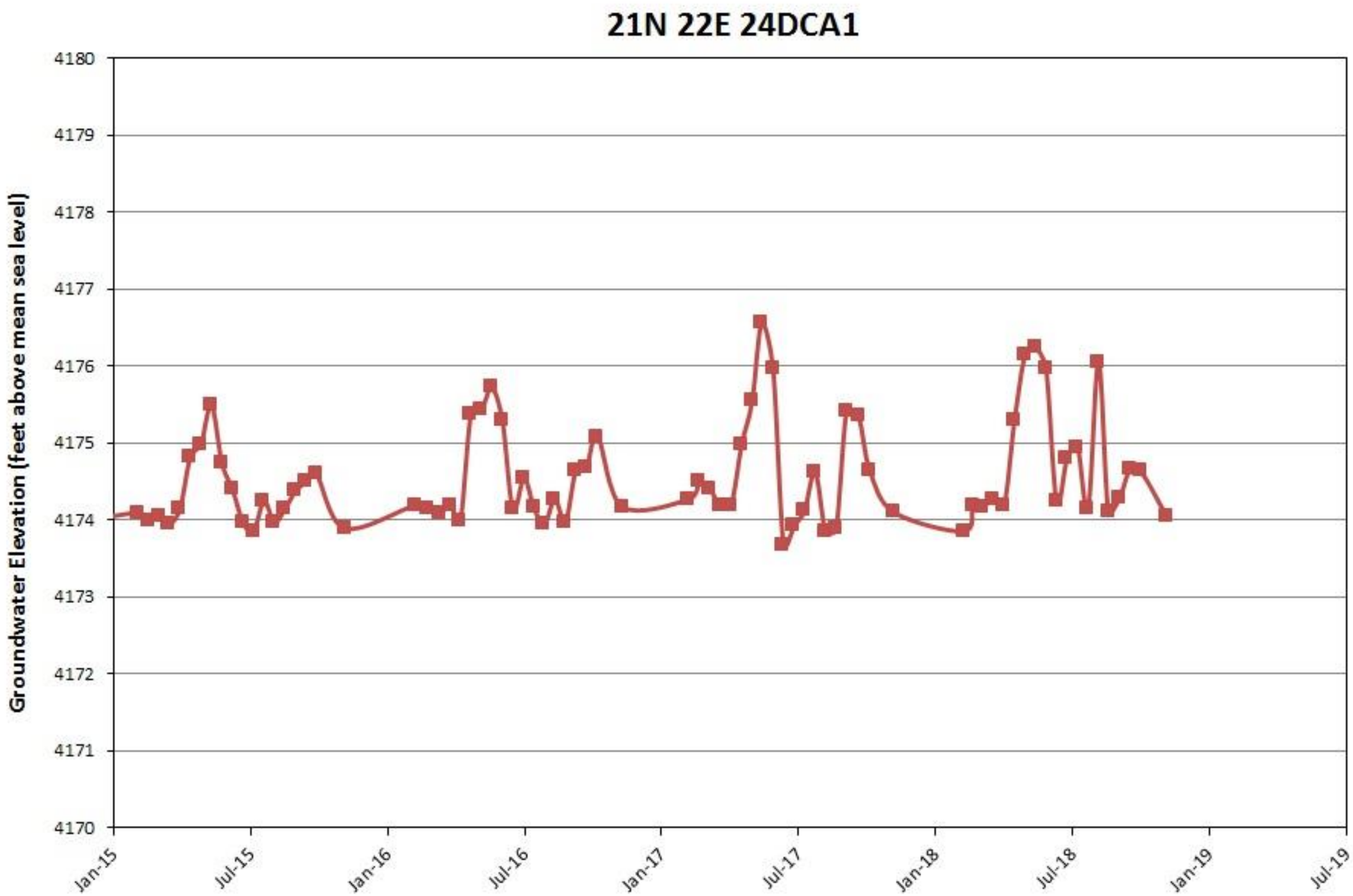


FIGURE B-6
Richardson Well
Lower Lemhi Basin
SW - GW Interactions P.III

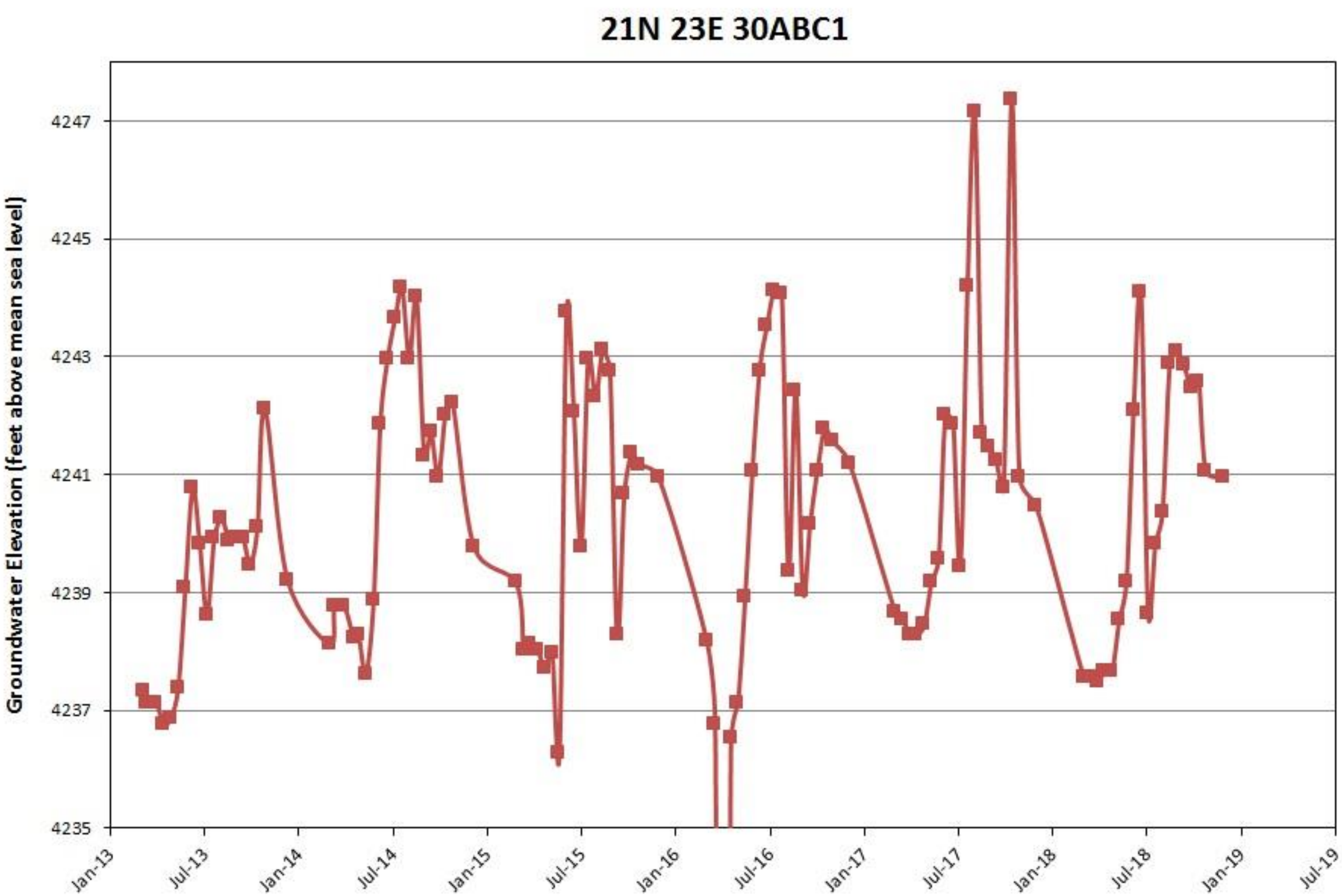


FIGURE B-7
Stokes Well
Lower Lemhi Basin
SW - GW Interactions P.III

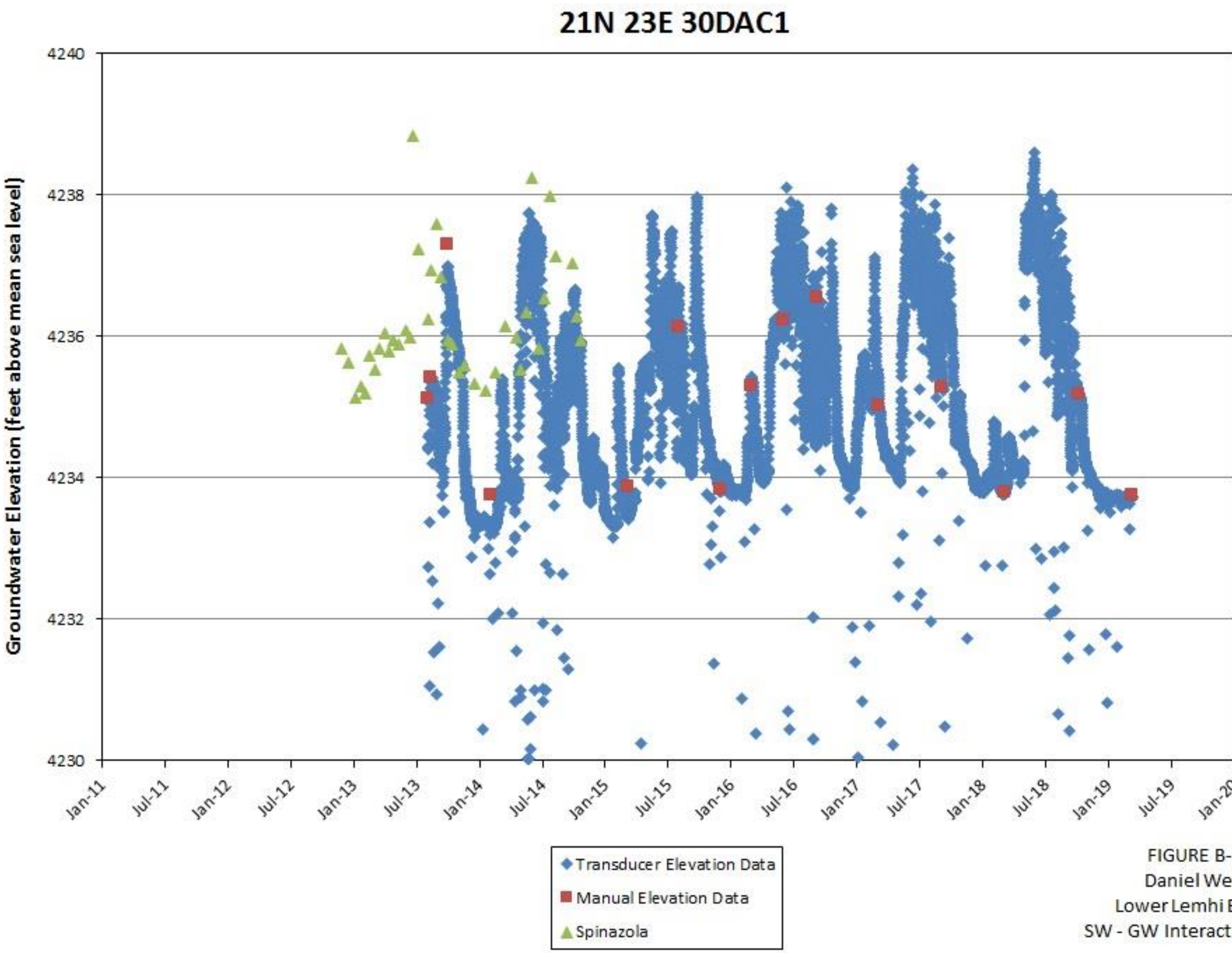


FIGURE B-8
Daniel Well
Lower Lemhi Basin
SW - GW Interactions p.III

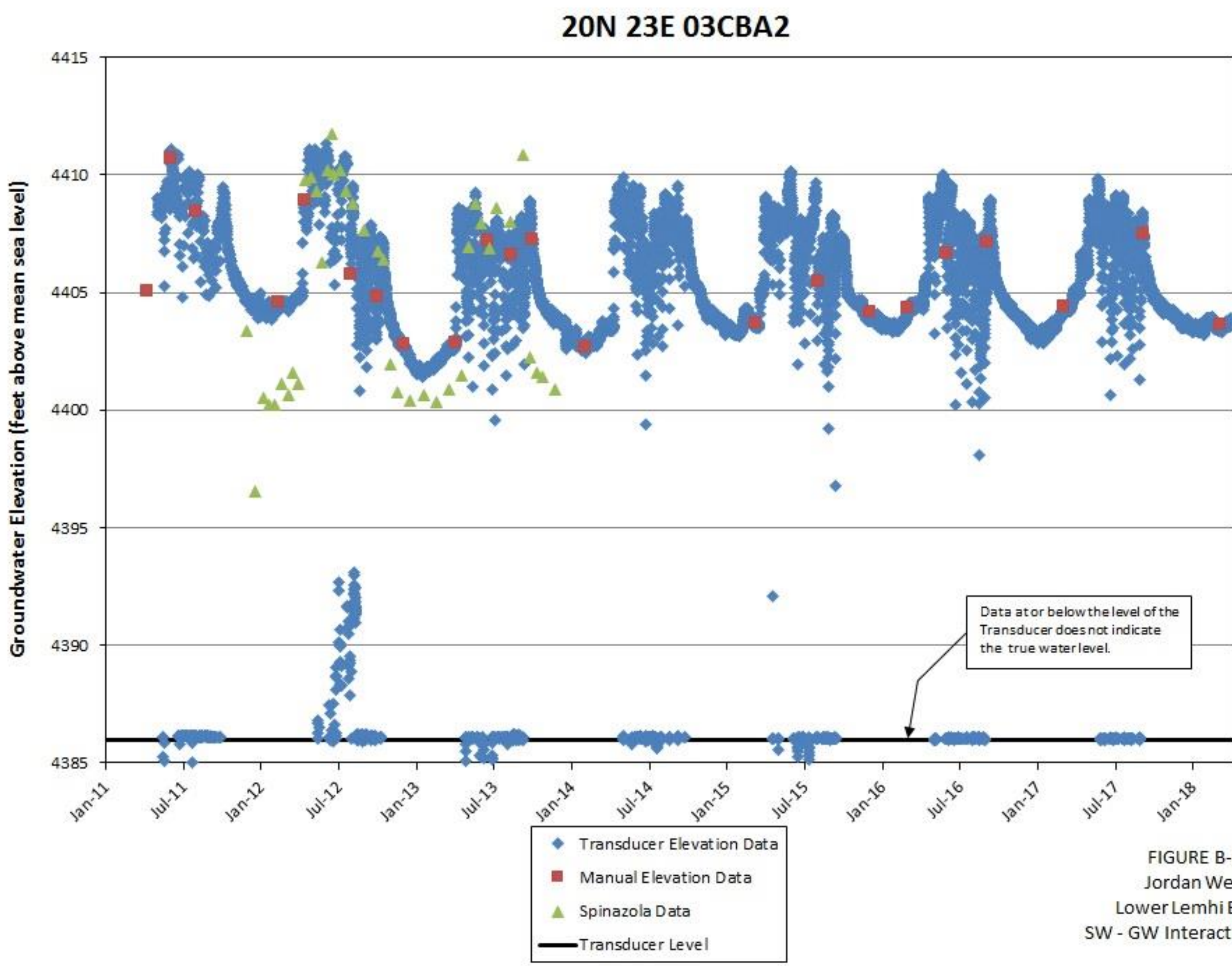


FIGURE B-9
Jordan Well
Lower Lemhi Basin
SW - GW Interactions P.III

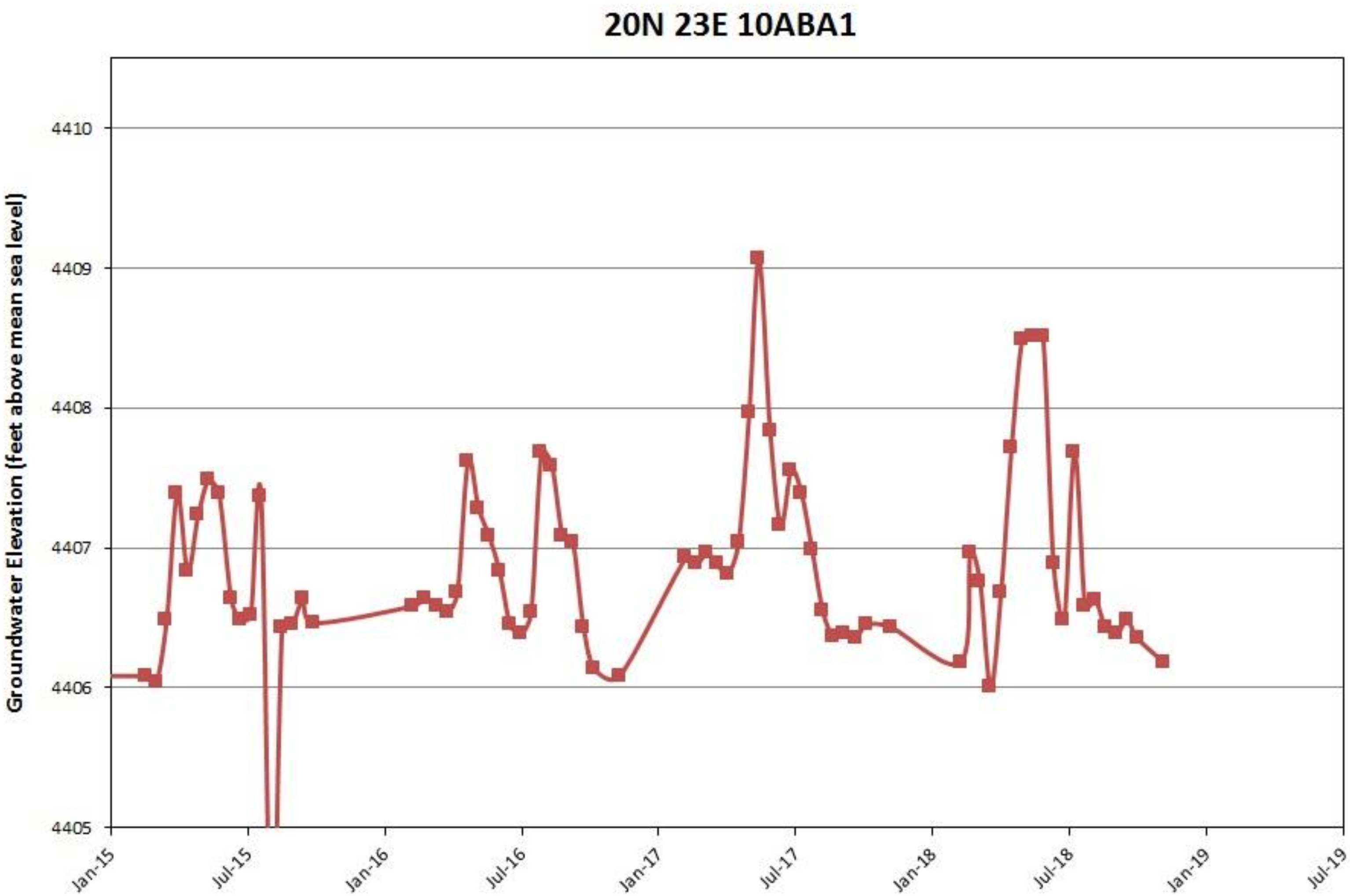


FIGURE B-10
Sager Well
Lower Lemhi Basin
SW - GW Interactions P.III

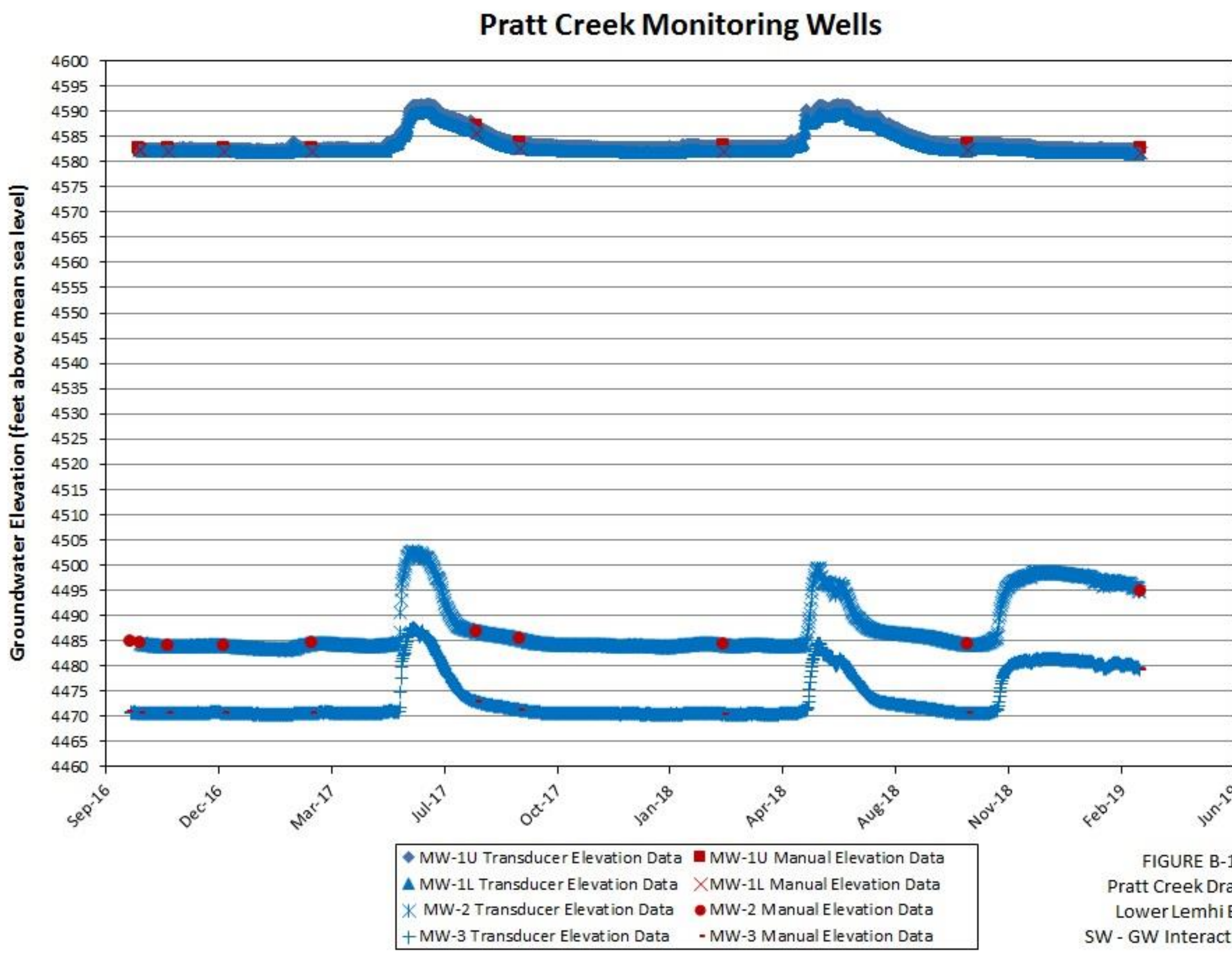


FIGURE B-11
Pratt Creek Drainage
Lower Lemhi Basin
SW - GW Interactions P.III

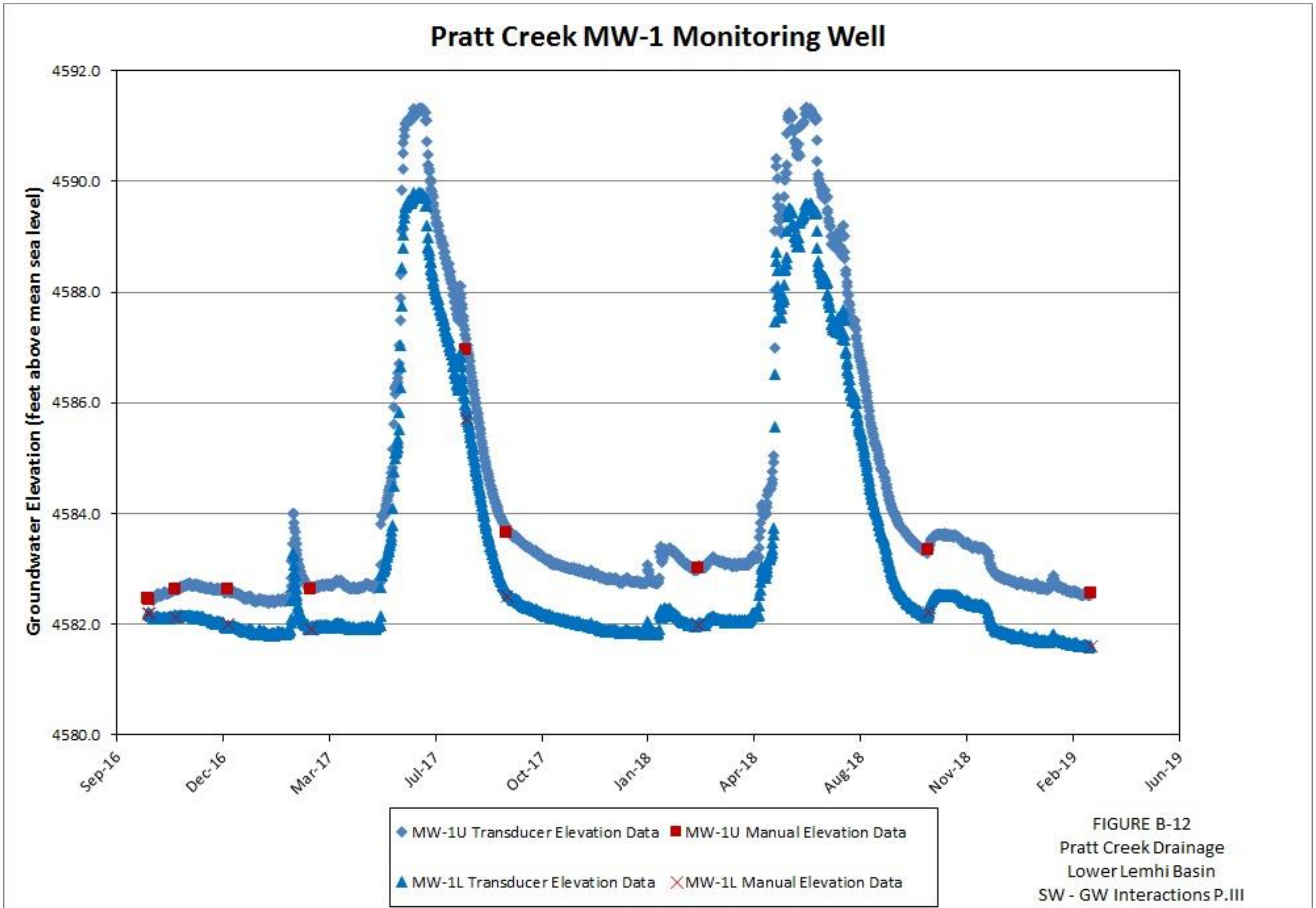


FIGURE B-12
Pratt Creek Drainage
Lower Lemhi Basin
SW - GW Interactions P.III

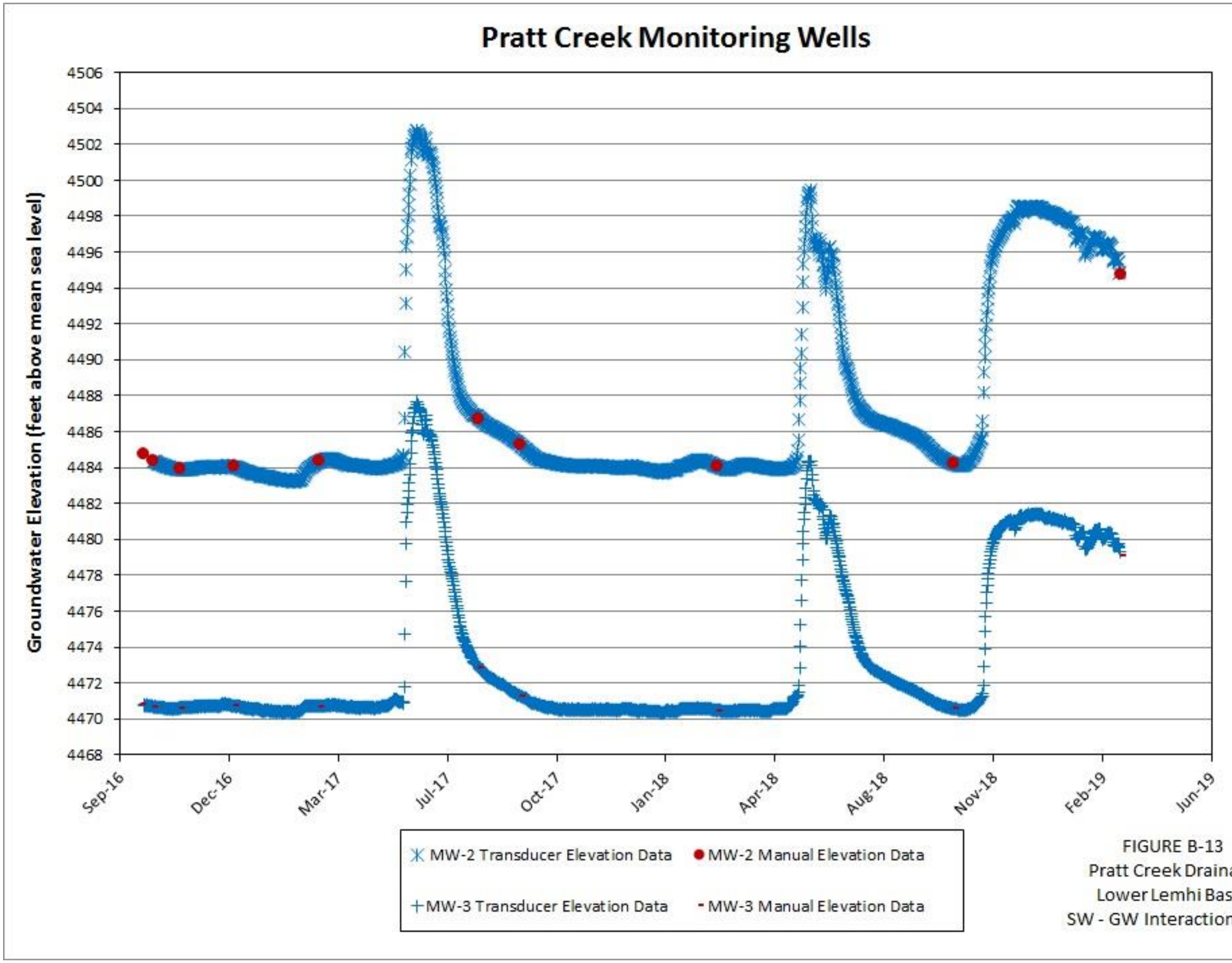


FIGURE B-13
Pratt Creek Drainage
Lower Lemhi Basin
SW - GW Interactions P.III

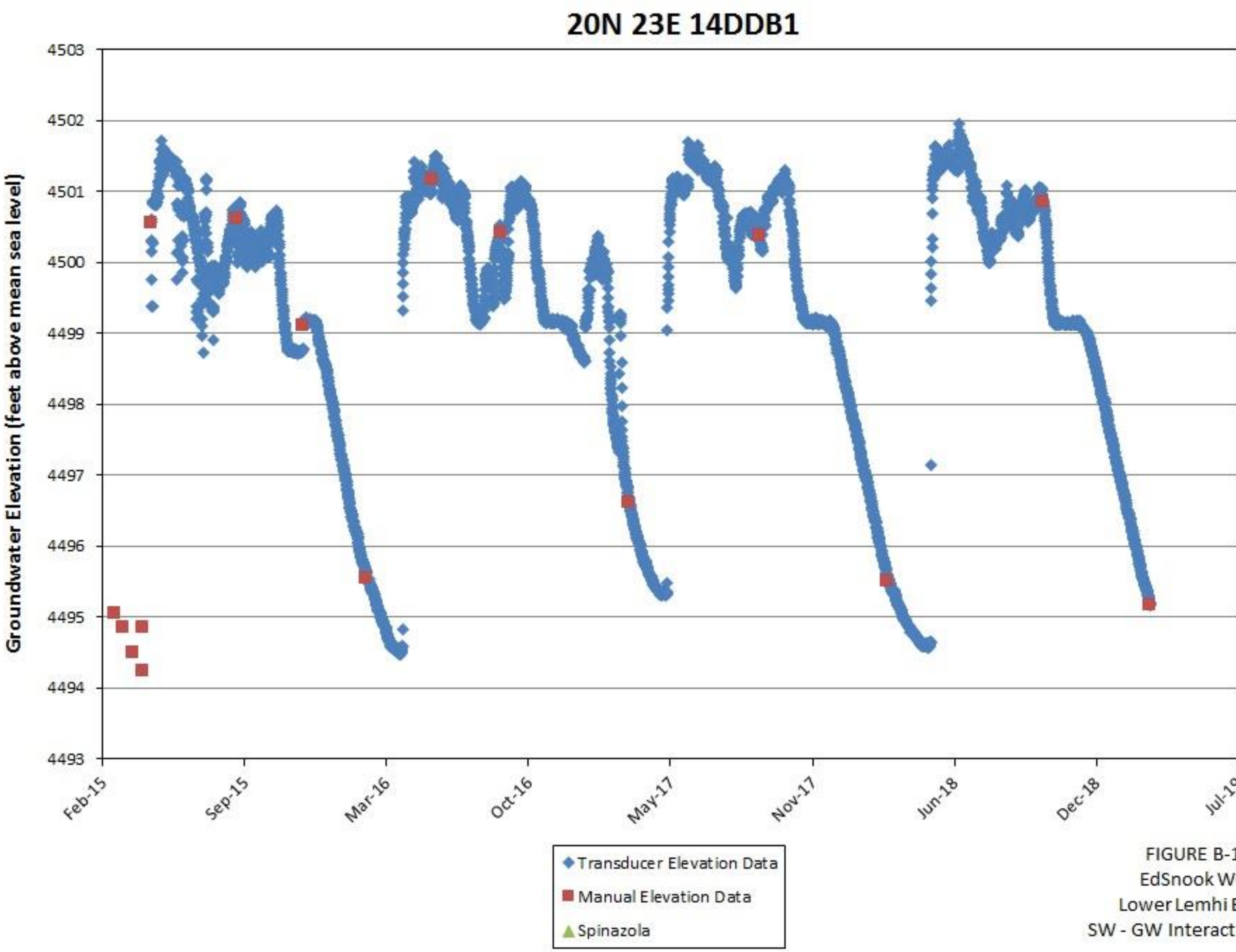


FIGURE B-14
EdSnook Well
Lower Lemhi Basin
SW - GW Interactions P.III

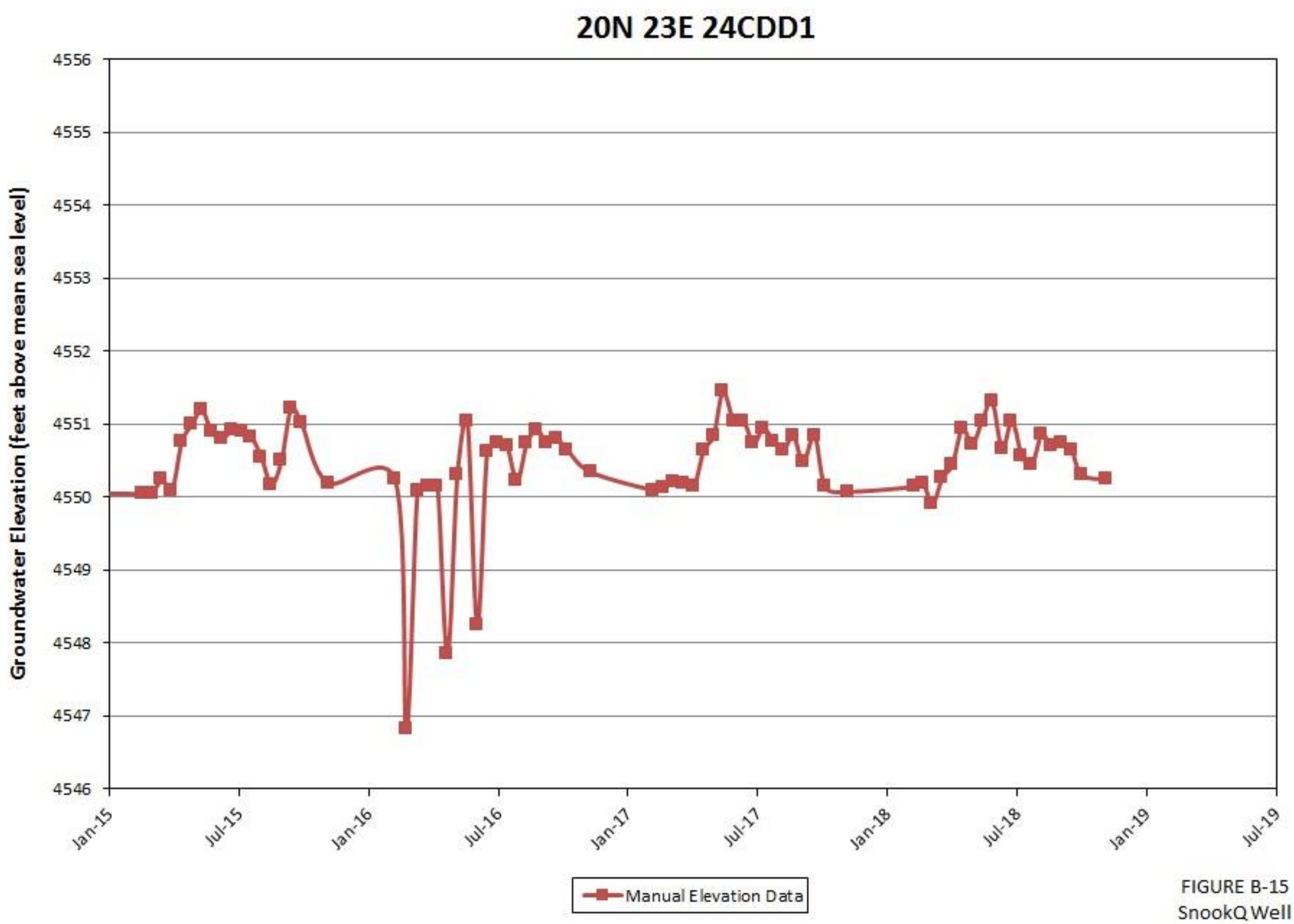


FIGURE B-15
SnookQ Well
Lower Lemhi Basin
SW - GW Interactions P.III

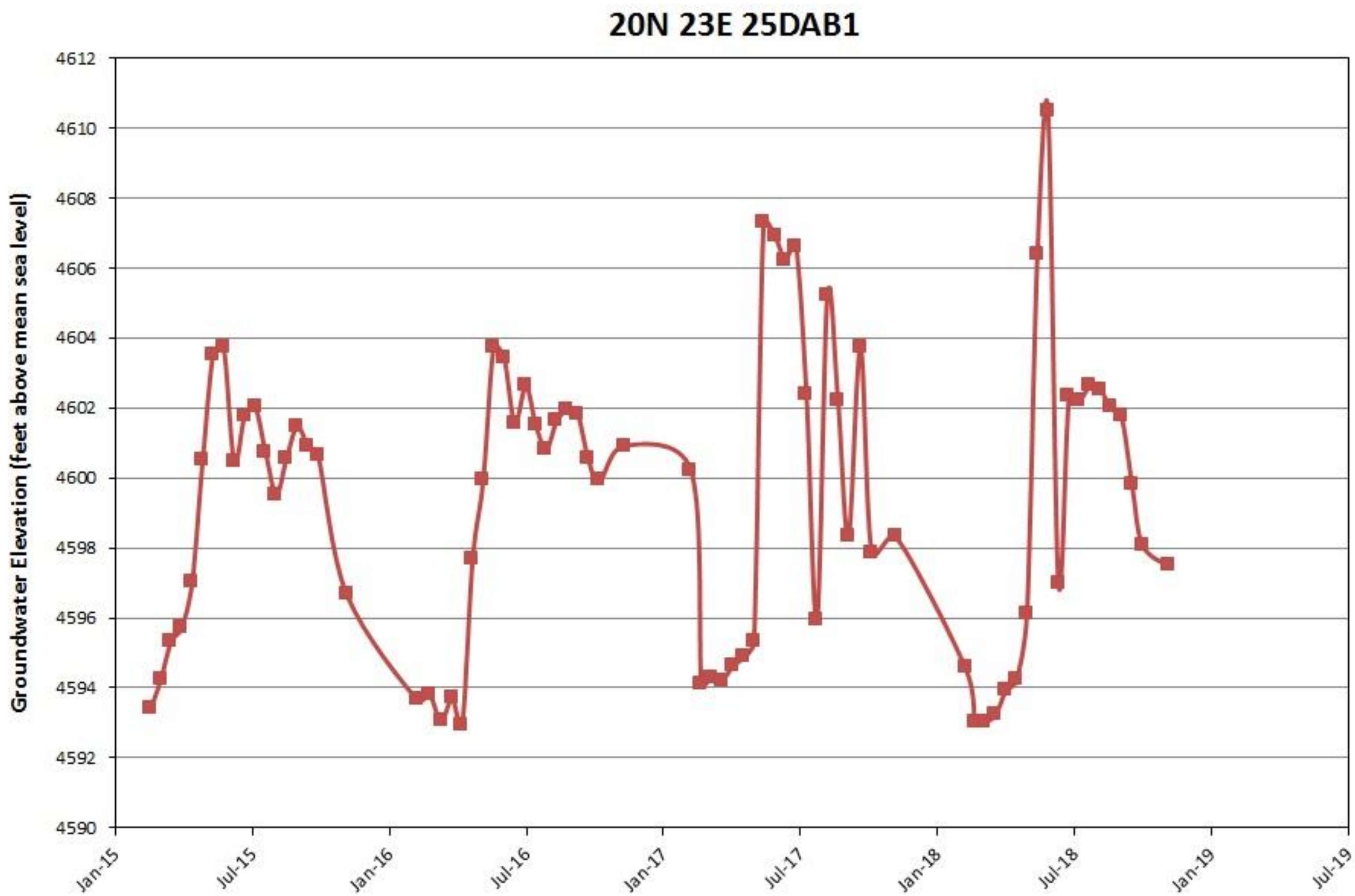


FIGURE B-16
Lufkin Well
Lower Lemhi Basin
SW - GW Interactions P.III

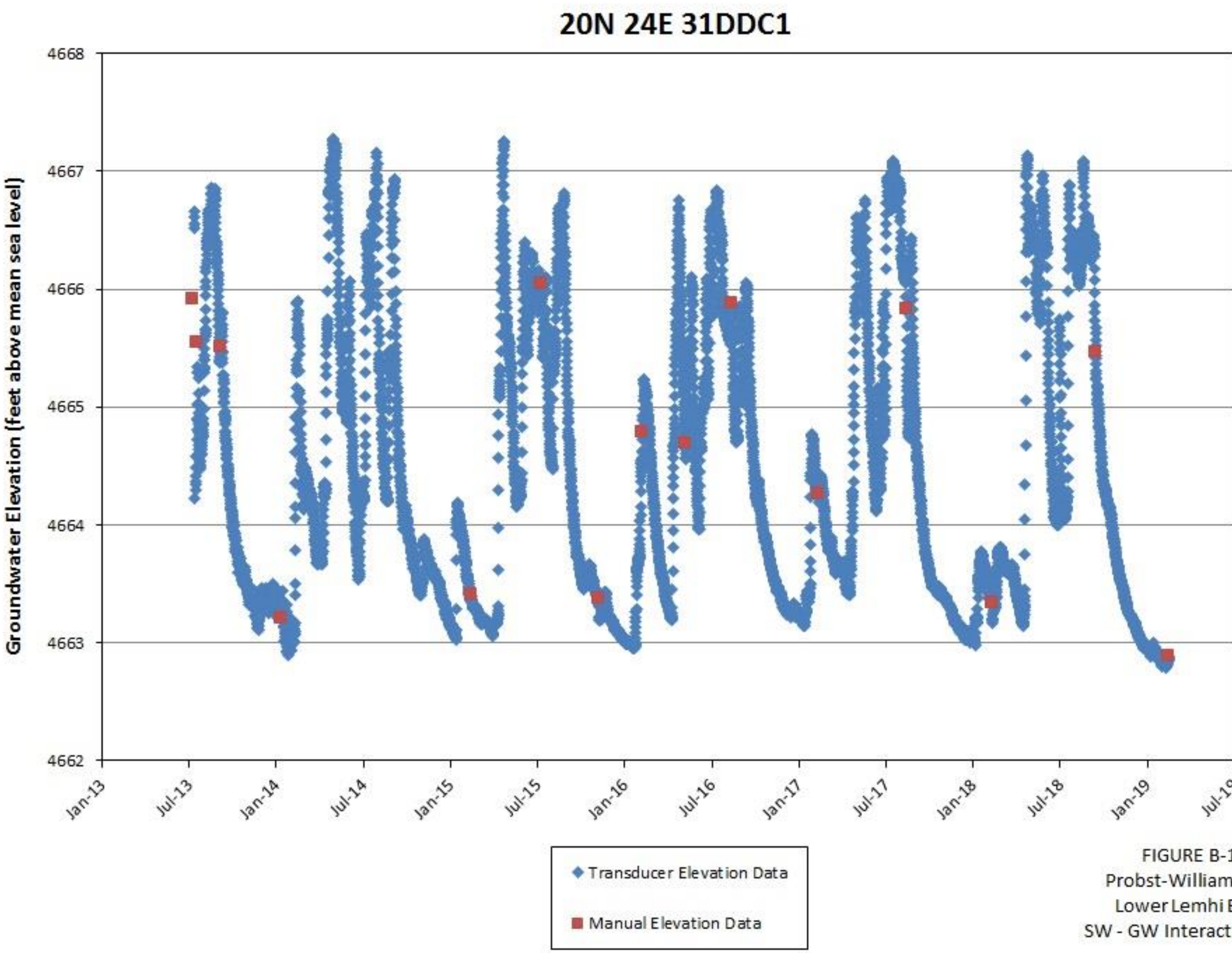


FIGURE B-17
Probst-Williams Well
Lower Lemhi Basin
SW - GW Interactions P.III

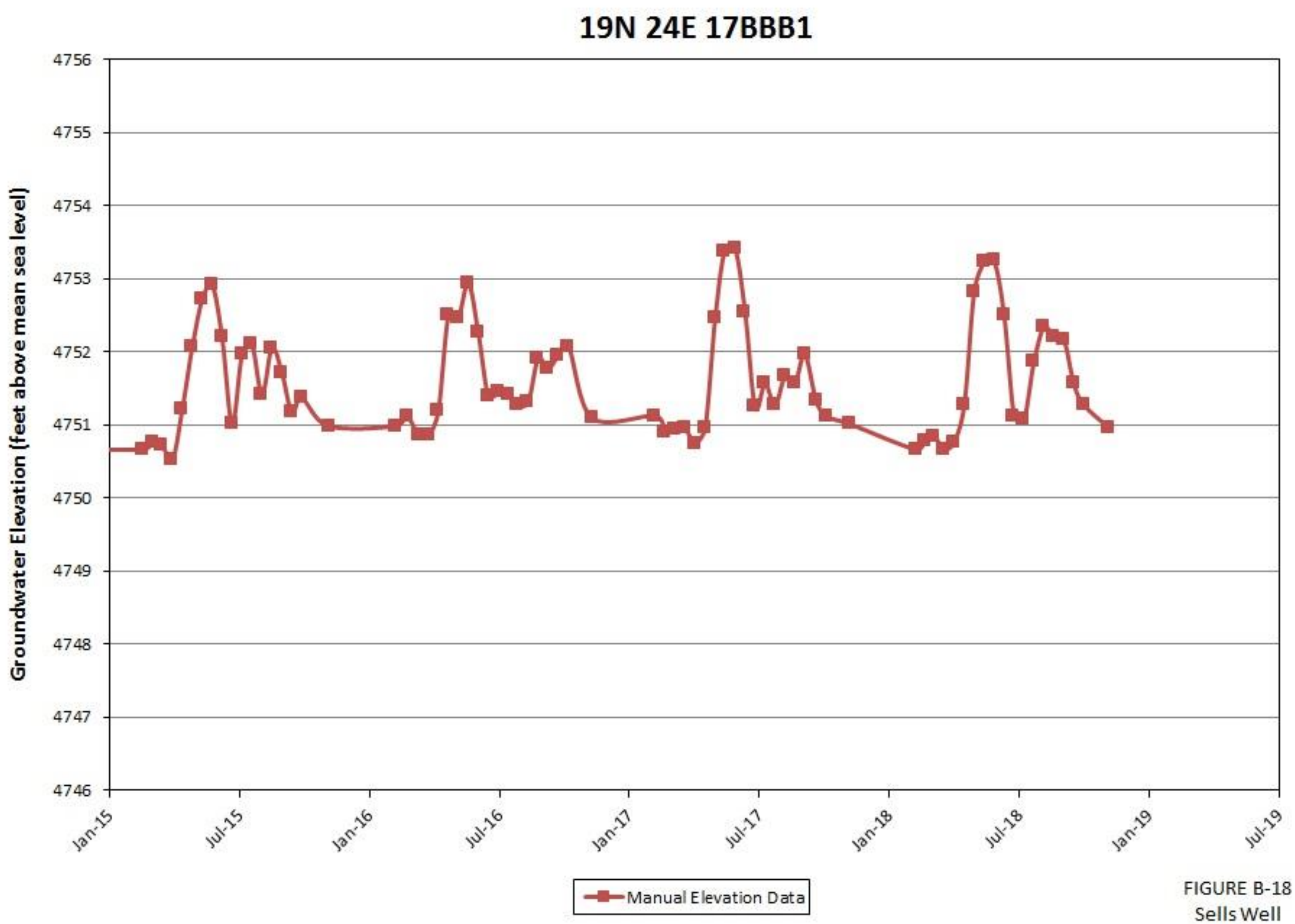


FIGURE B-18
Sells Well
Mid Lemhi Basin
SW - GW Interactions P.III

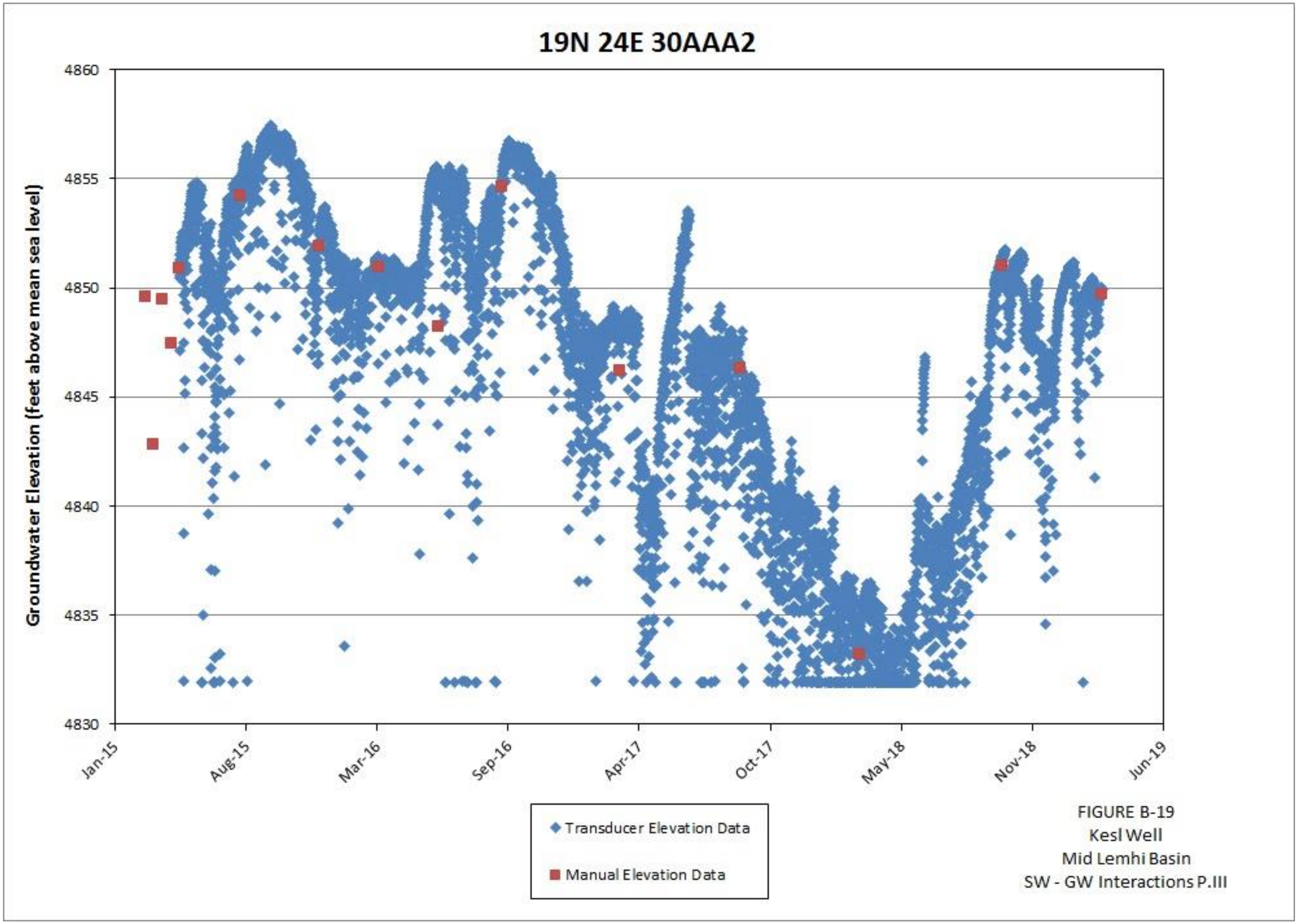


FIGURE B-19
Kesl Well
Mid Lemhi Basin
SW - GW Interactions P.III

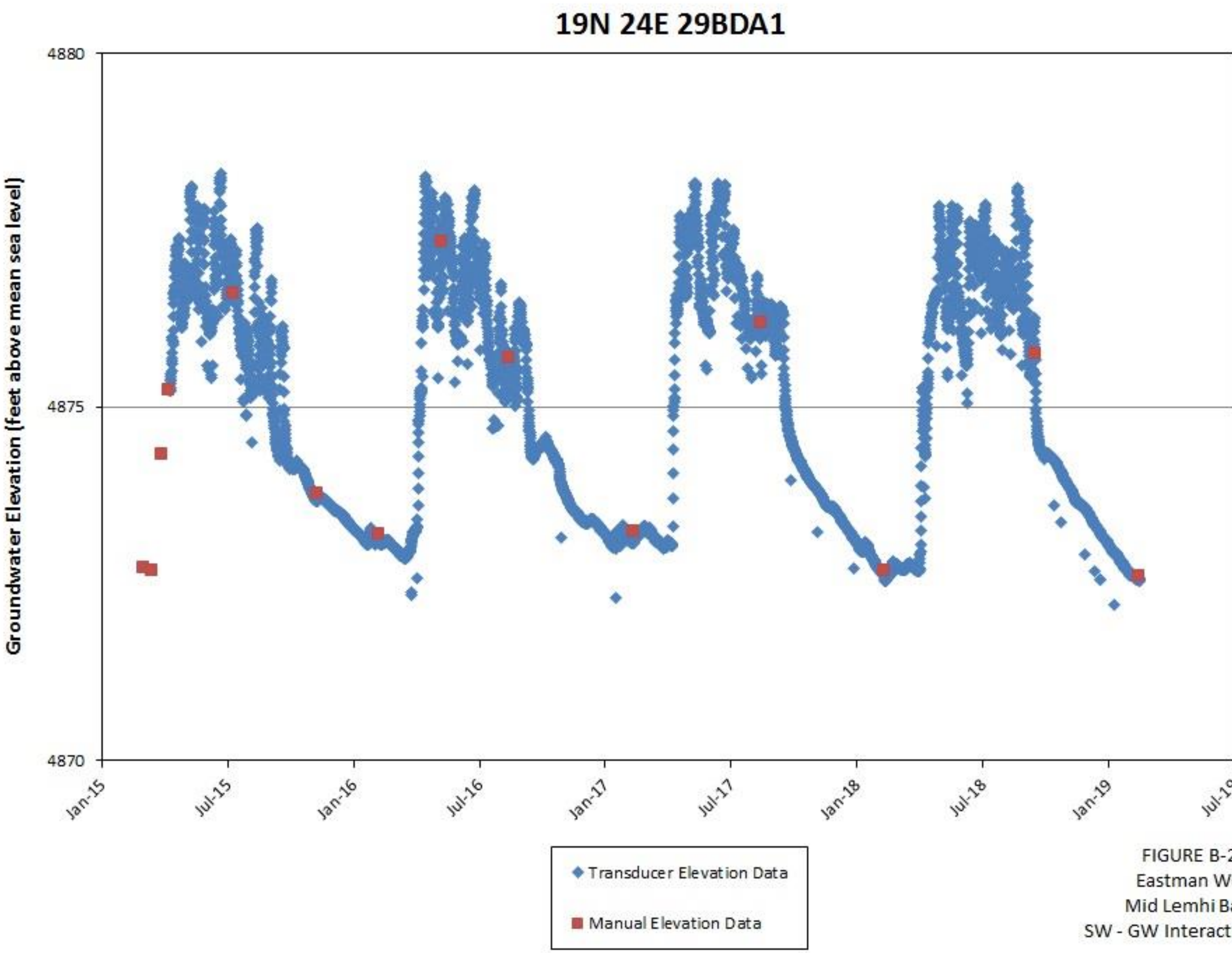


FIGURE B-20
Eastman Well
Mid Lemhi Basin
SW - GW Interactions P.III

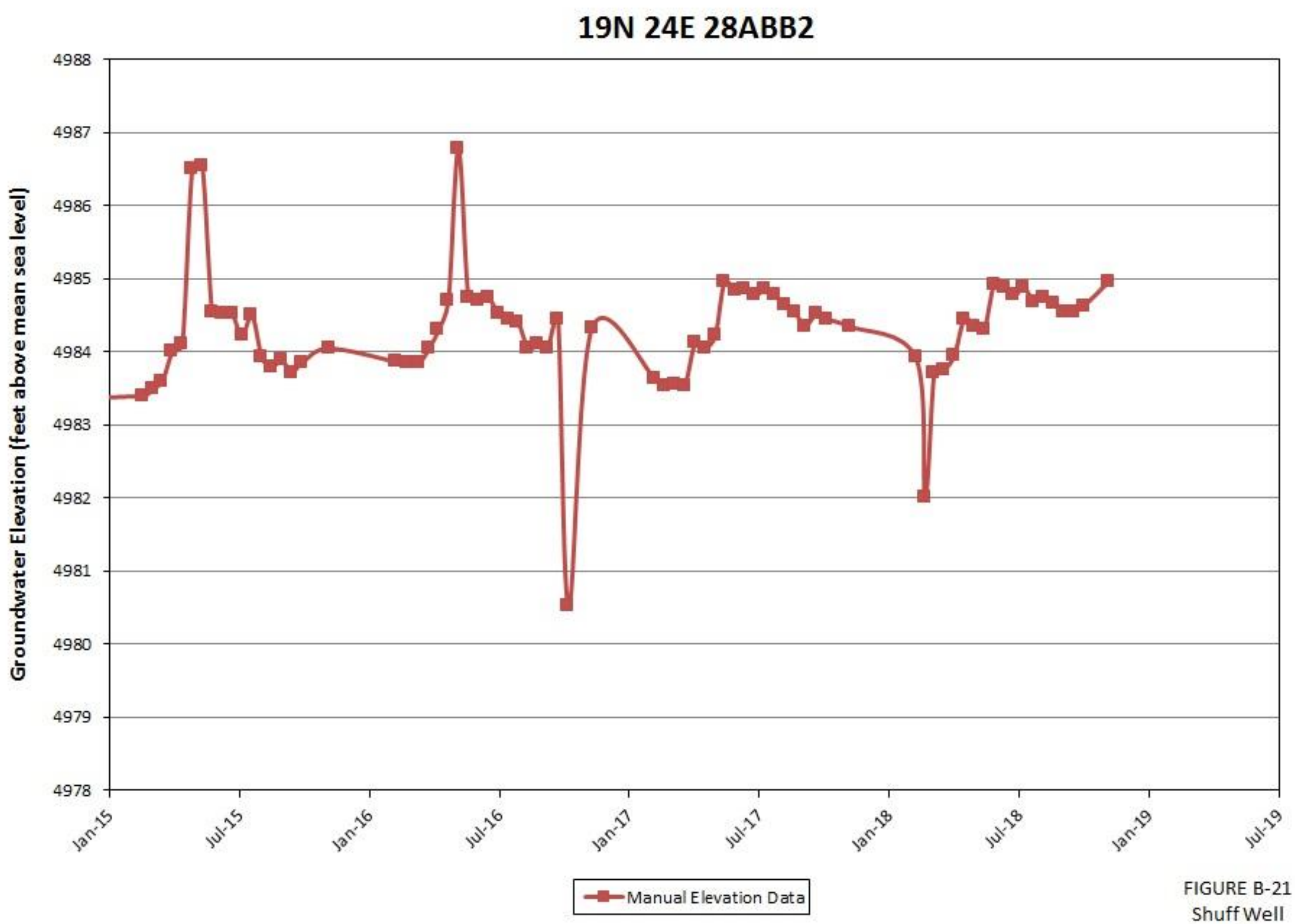


FIGURE B-21
Shuff Well
Mid Lemhi Basin
SW - GW Interactions P.III

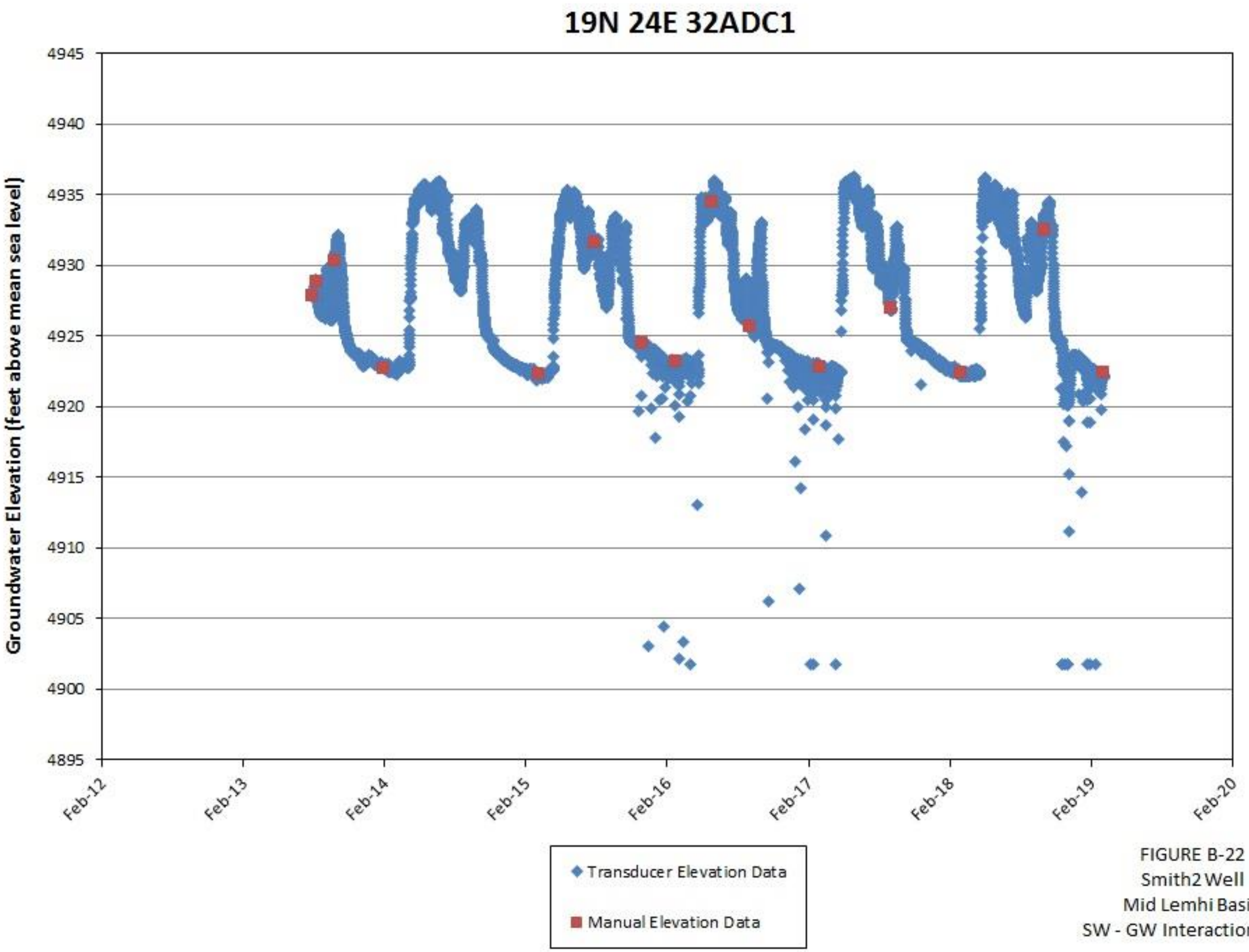


FIGURE B-22
Smith2 Well
Mid Lemhi Basin
SW - GW Interactions P.III

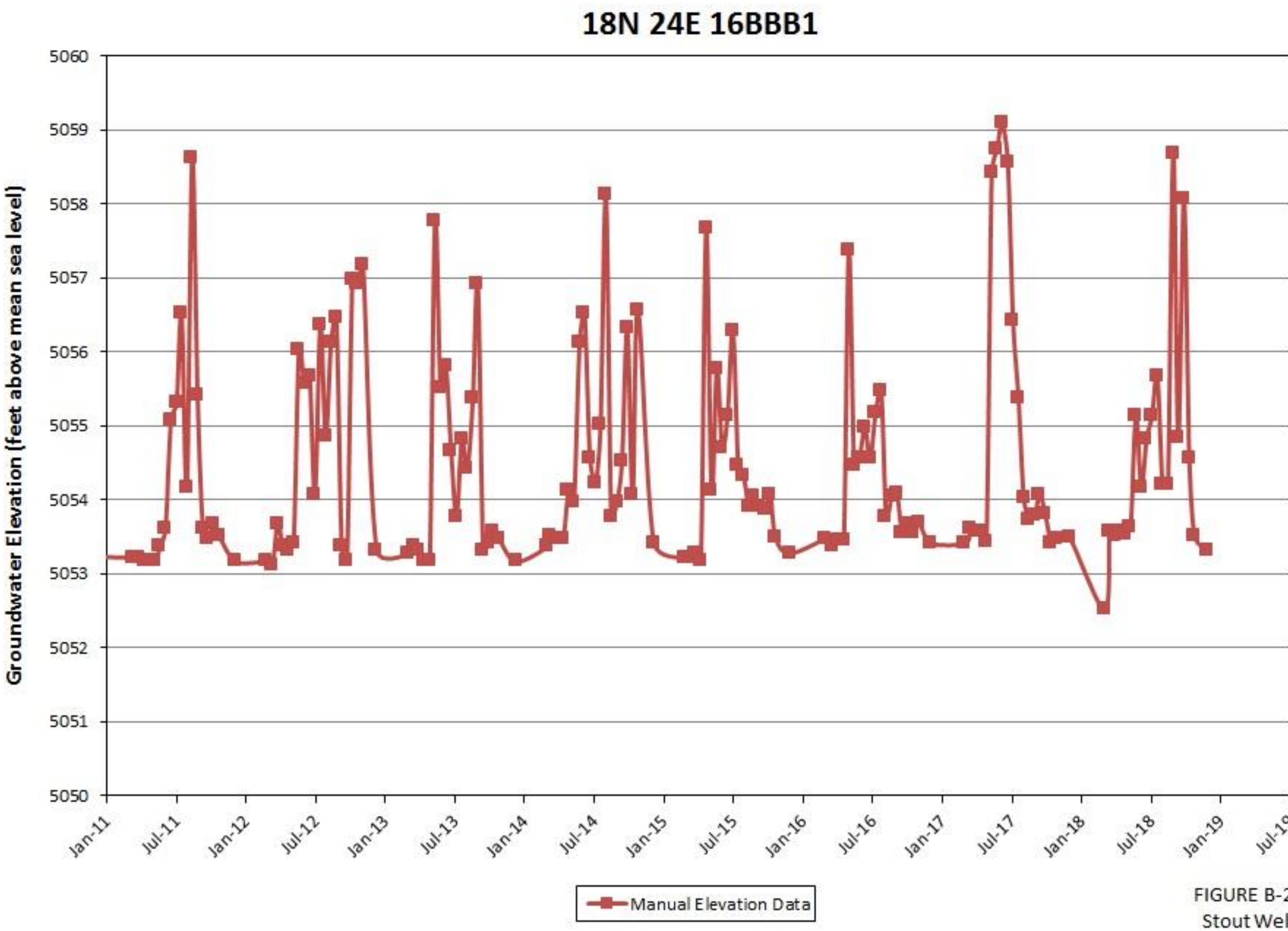
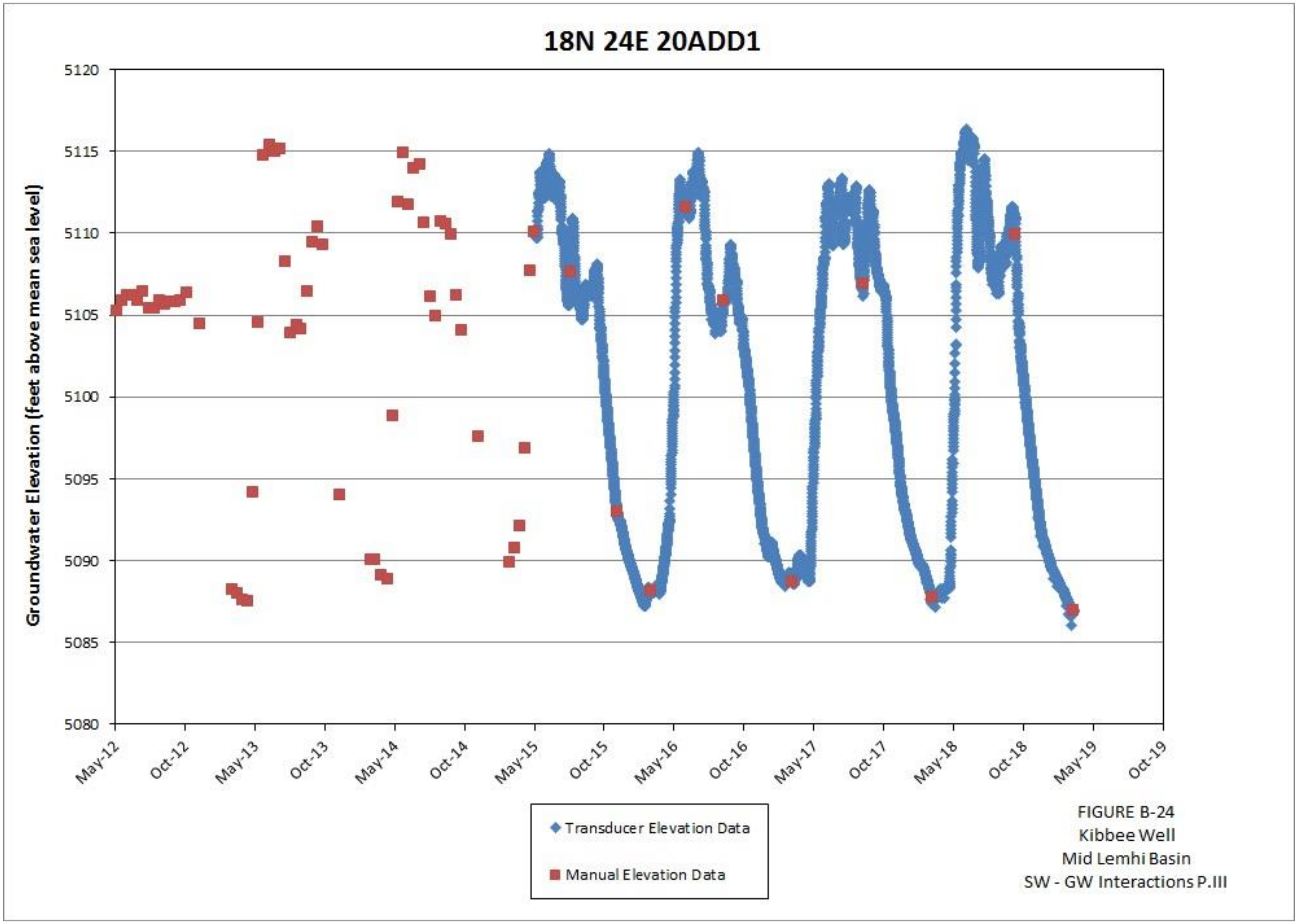


FIGURE B-23
Stout Well
Mid Lemhi Basin
SW - GW Interactions P.III


18N 24E 20ADD1
Groundwater Elevation (feet above mean sea level)
5120
5115
5110
5105
5100
5095
5090
5085
5080
May-12
Oct-12
May-13
Oct-13
May-14
Oct-14
May-15
Oct-15
May-16
Oct-16
May-17
Oct-17
May-18
Oct-18
May-19
Oct-19
Transducer Elevation Data
Manual Elevation Data
FIGURE B-24
Kibbee Well
Mid Lemhi Basin
SW - GW Interactions P.III

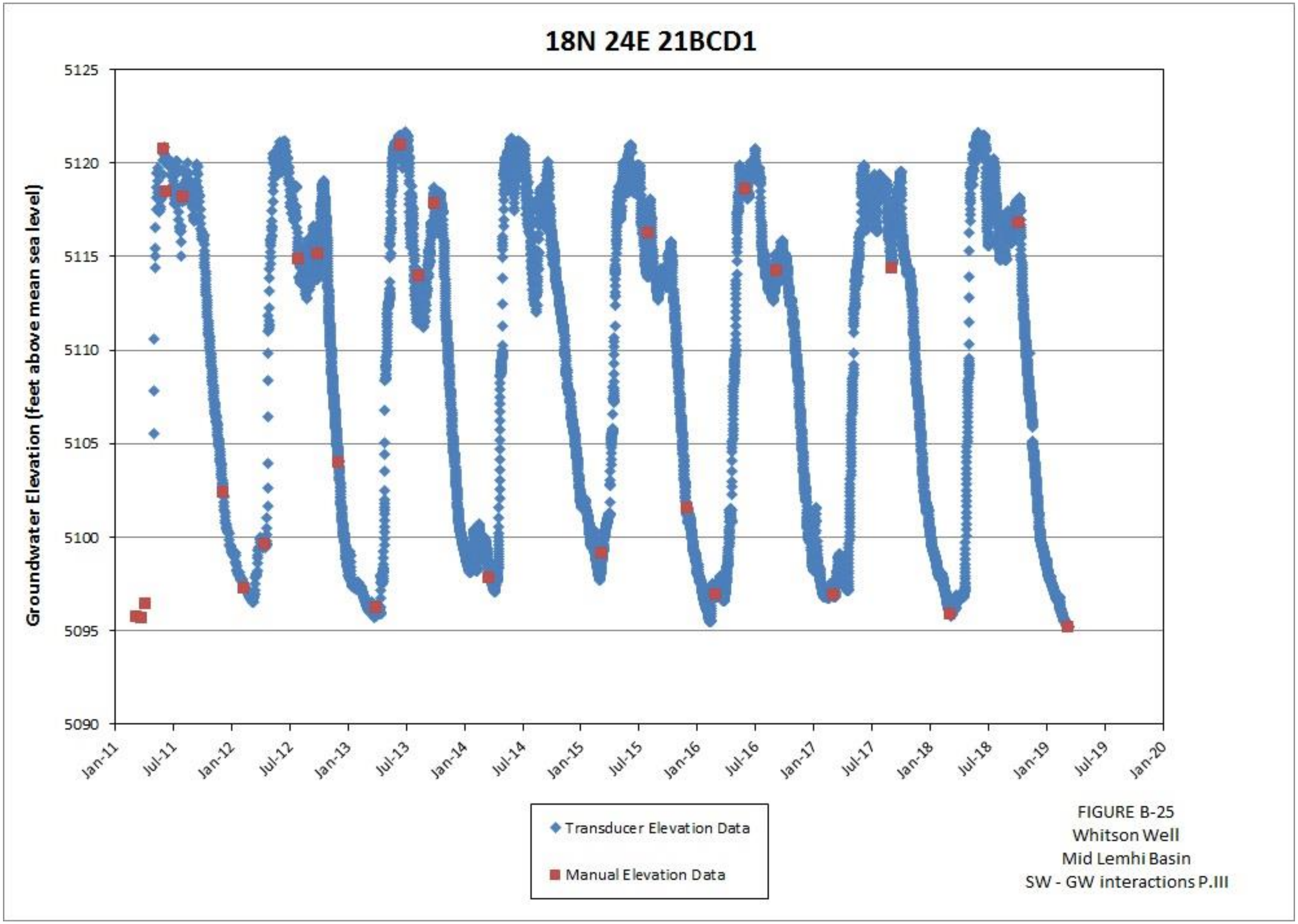
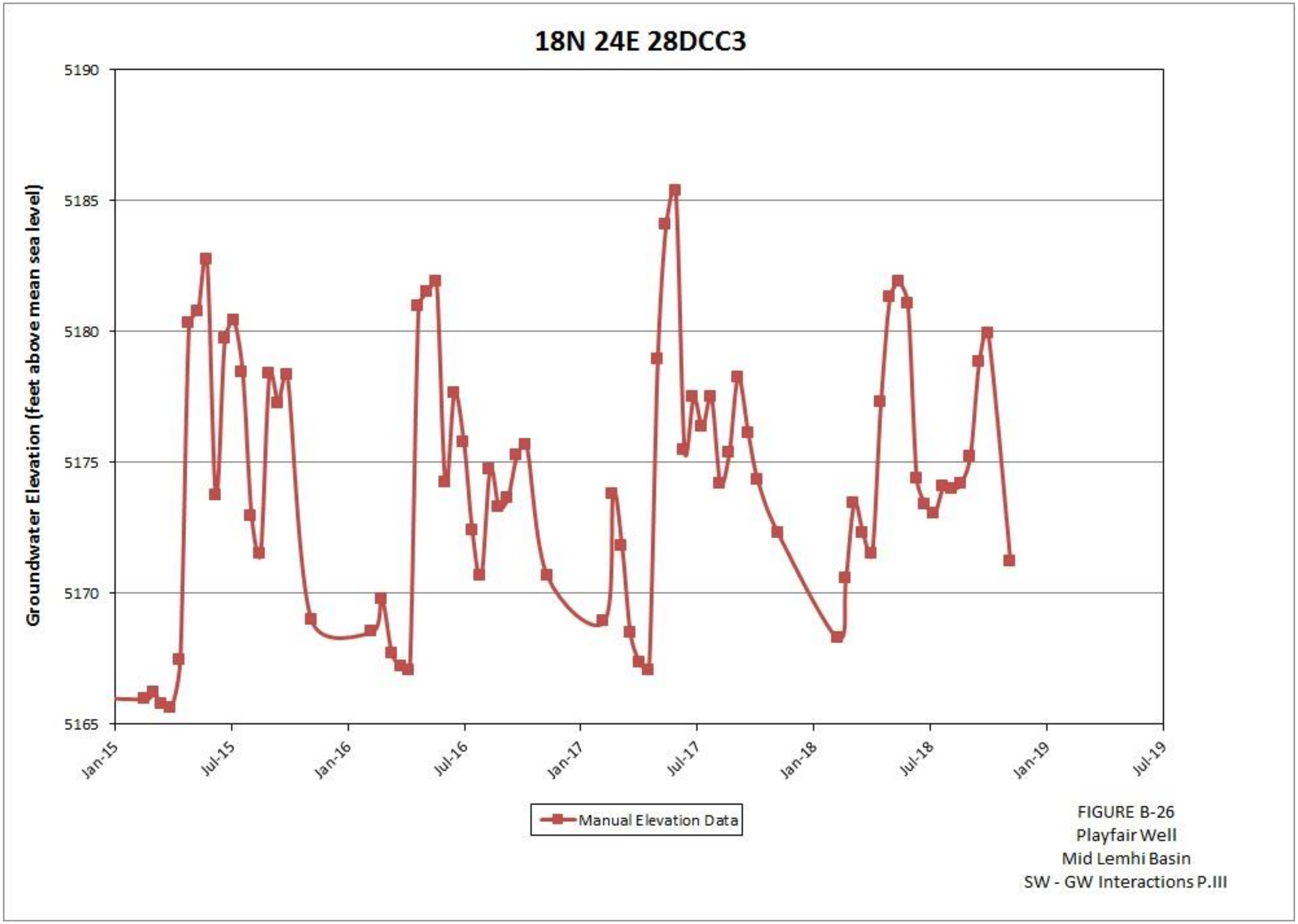
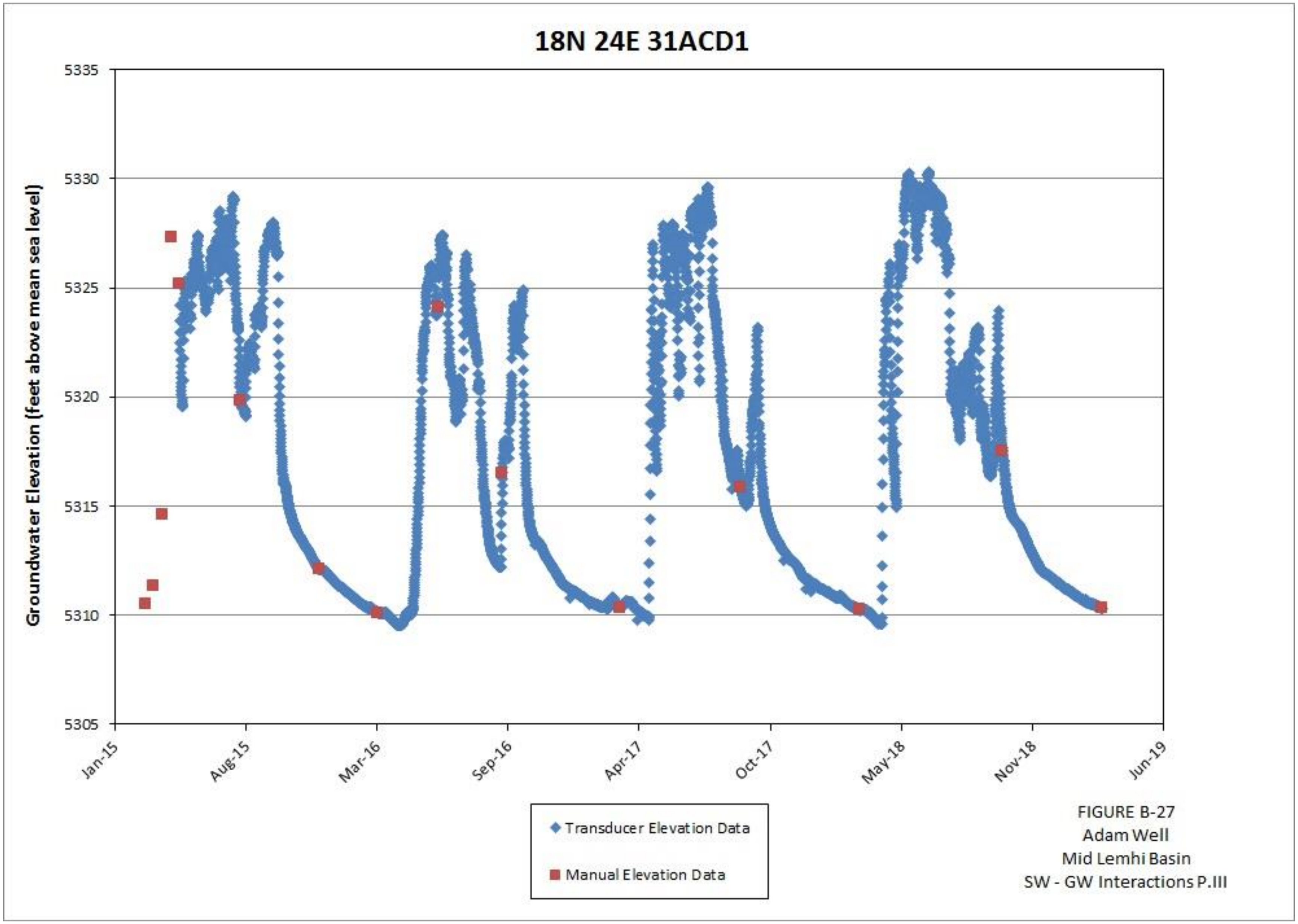


FIGURE B-25
Whitson Well
Mid Lemhi Basin
SW - GW interactions P.III


18N 24E 28DCC3
Groundwater Elevation (feet above mean sea level)
5190
5185
5180
5175
5170
5165
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Manual Elevation Data
FIGURE B-26
Playfair Well
Mid Lemhi Basin
SW - GW Interactions P.III


18N 24E 31ACD1
Groundwater Elevation (feet above mean sea level)
5335
5330
5325
5320
5315
5310
5305
Jan-15
Aug-15
Mar-16
Sep-16
Apr-17
Oct-17
May-18
Nov-18
Jun-19
Transducer Elevation Data
Manual Elevation Data
FIGURE B-27
Adam Well
Mid Lemhi Basin
SW - GW Interactions P.III

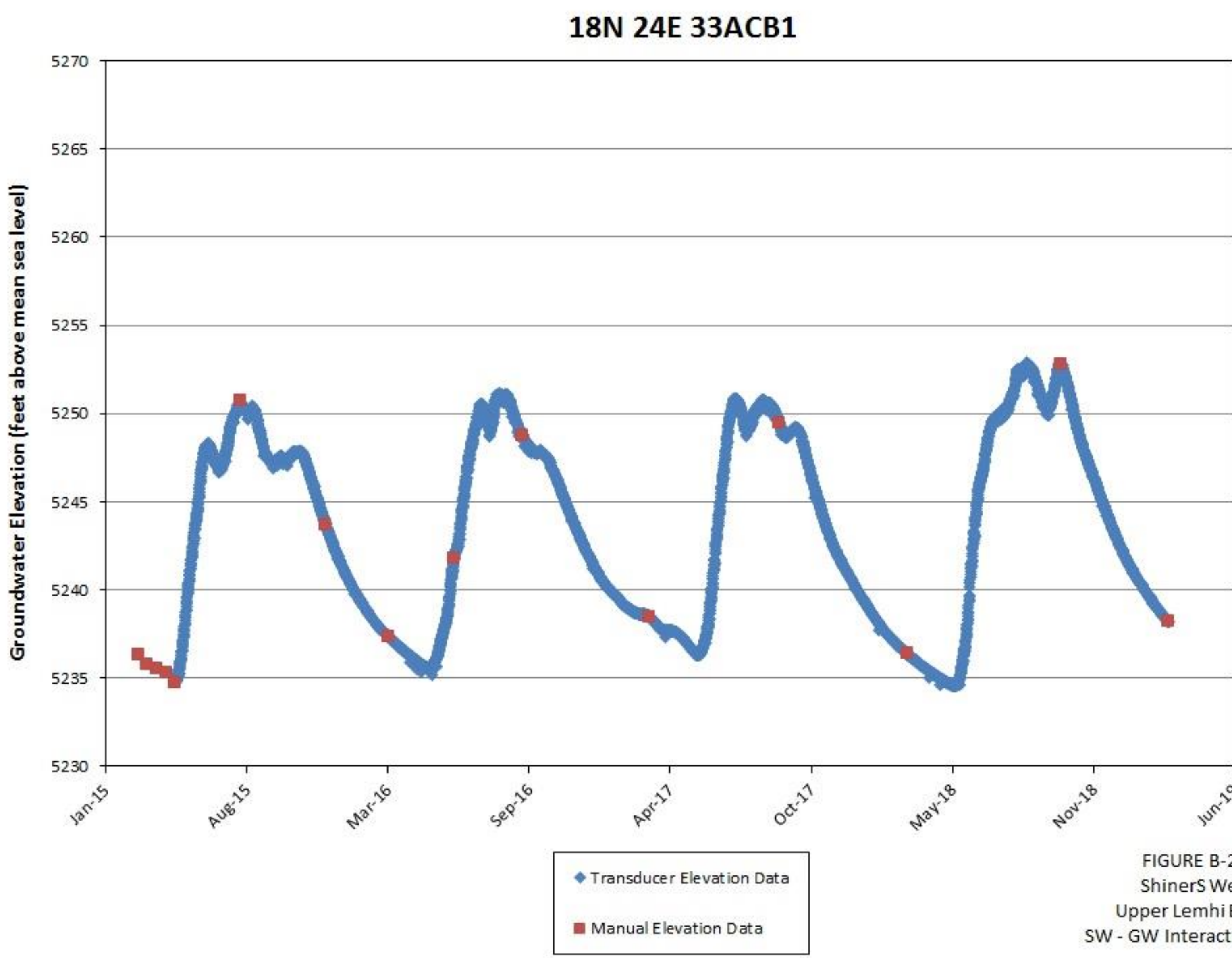
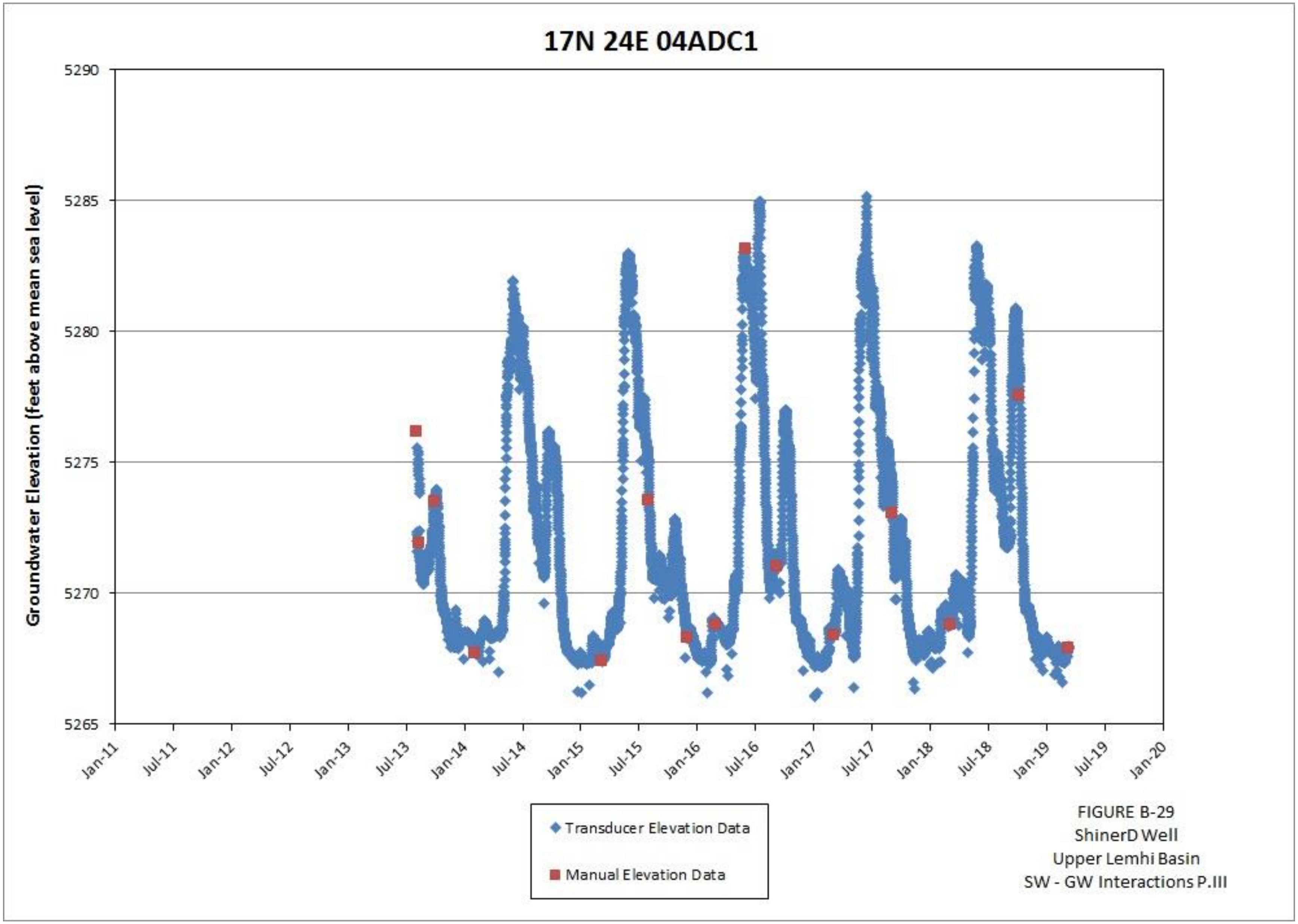


FIGURE B-28
ShinerS Well
Upper Lemhi Basin
SW - GW Interactions P.III


17N 24E 04ADC1
Groundwater Elevation (feet above mean sea level)
5290
5285
5280
5275
5270
5265
Jan-11
Jul-11
Jan-12
Jul-12
Jan-13
Jul-13
Jan-14
Jul-14
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Jan-20
Transducer Elevation Data
Manual Elevation Data
FIGURE B-29
ShinerD Well
Upper Lemhi Basin
SW - GW Interactions P.III

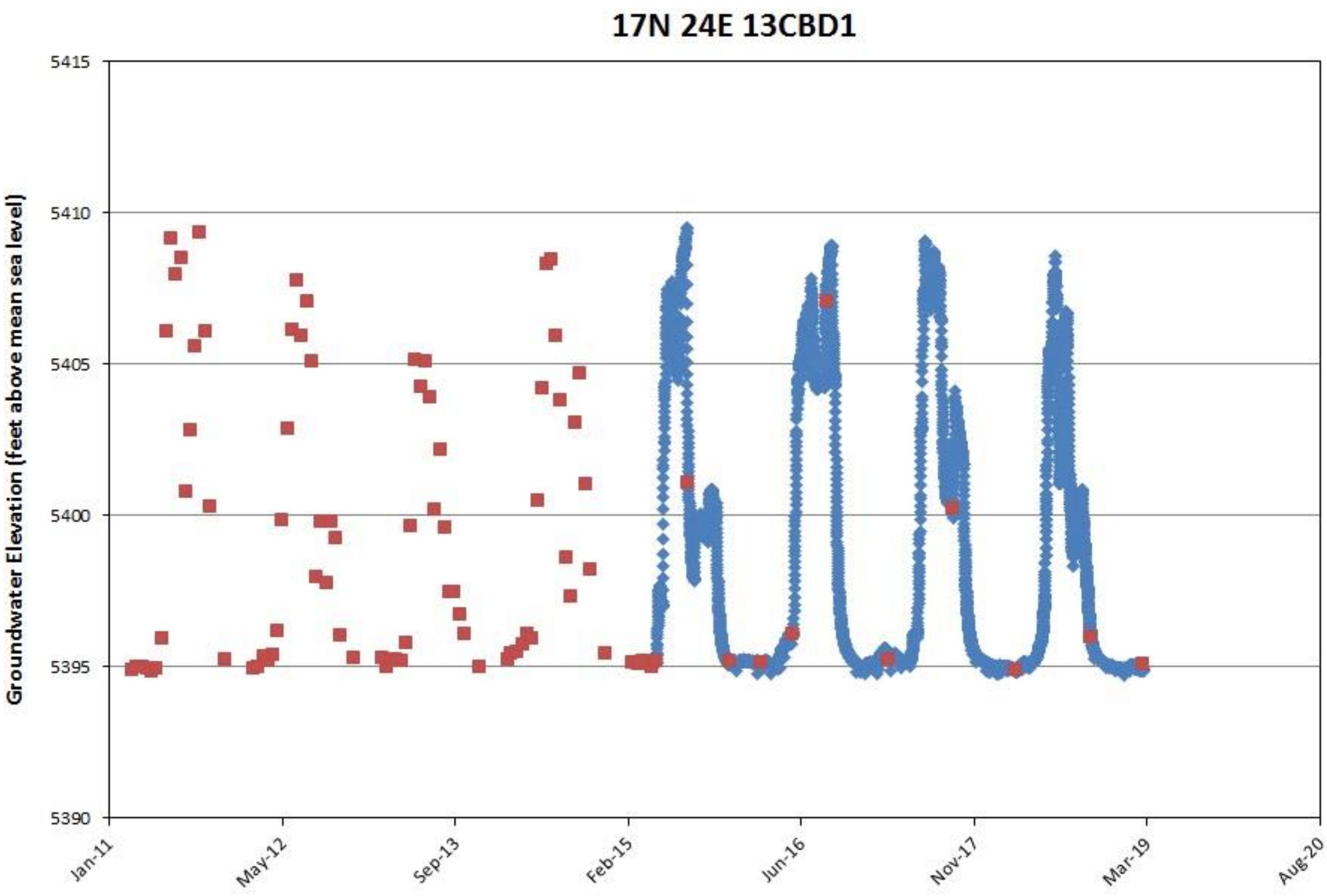


FIGURE B-30
SnyderR Well
Upper Lemhi Basin
SW - GW Interactions P.III

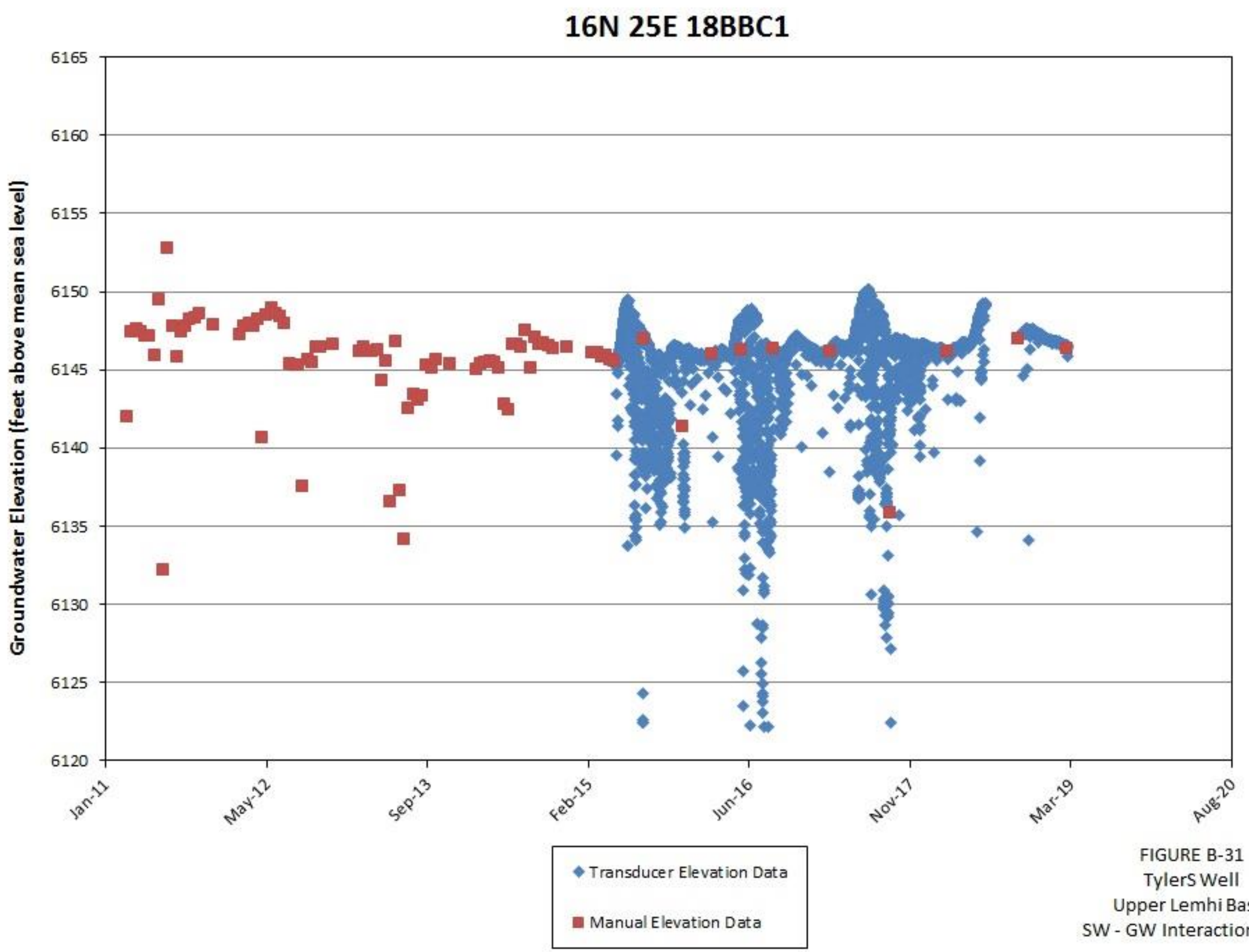


FIGURE B-31
TylerS Well
Upper Lemhi Basin
SW - GW Interactions P.III

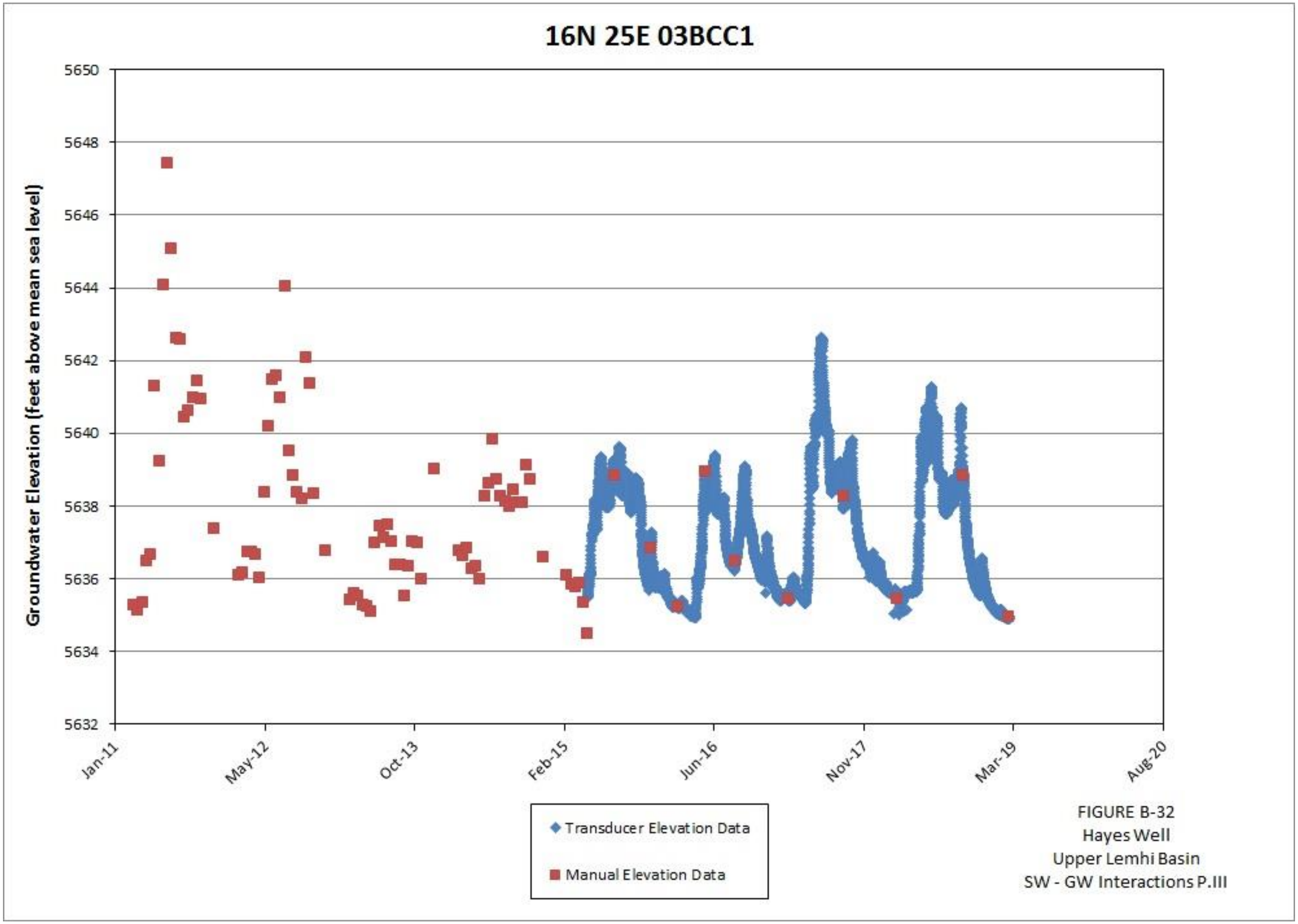


FIGURE B-32
Hayes Well
Upper Lemhi Basin
SW - GW Interactions P.III

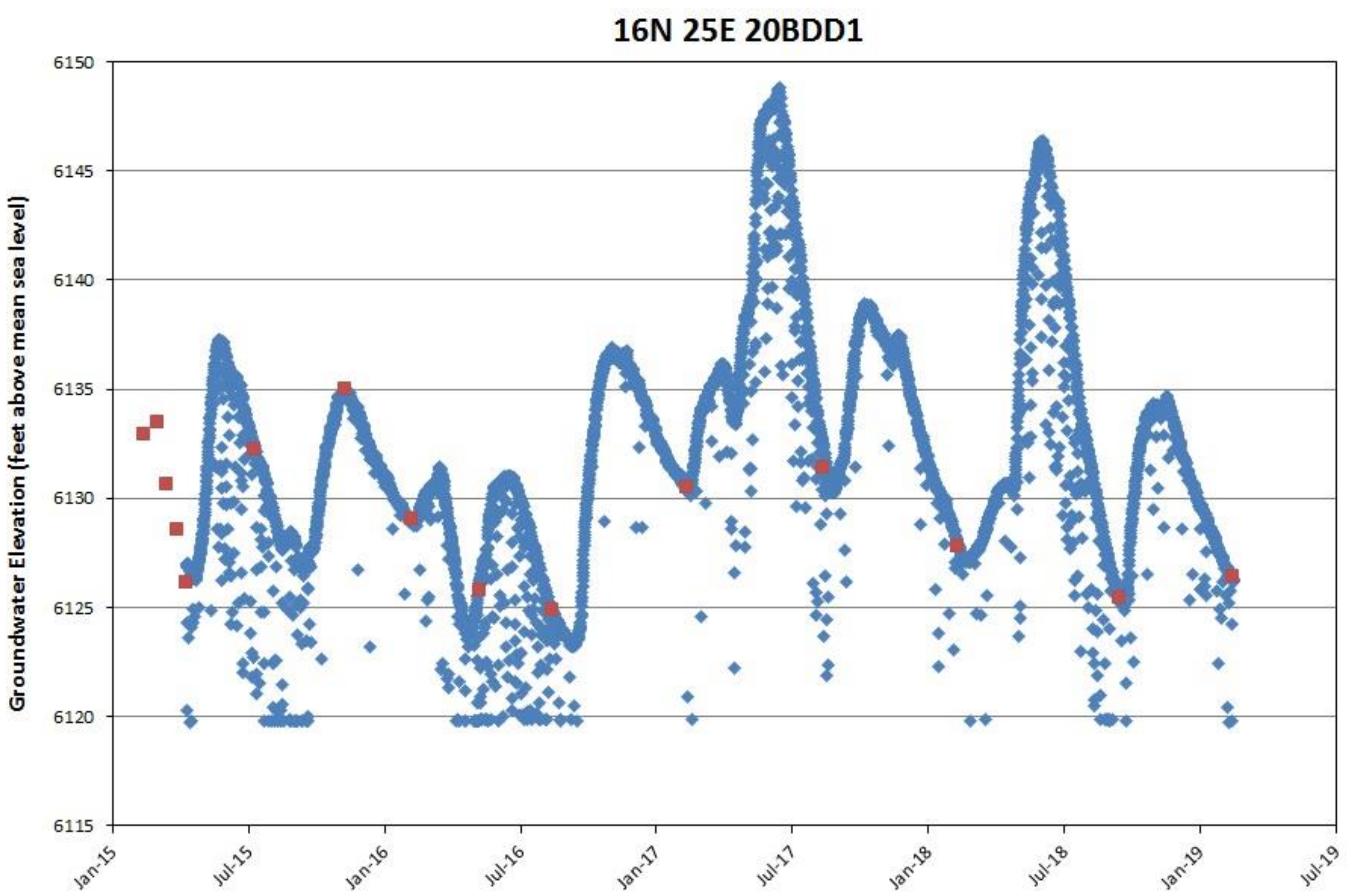


FIGURE B-33
England Well
Upper Lemhi Basin
SW - GW Interactions P.III

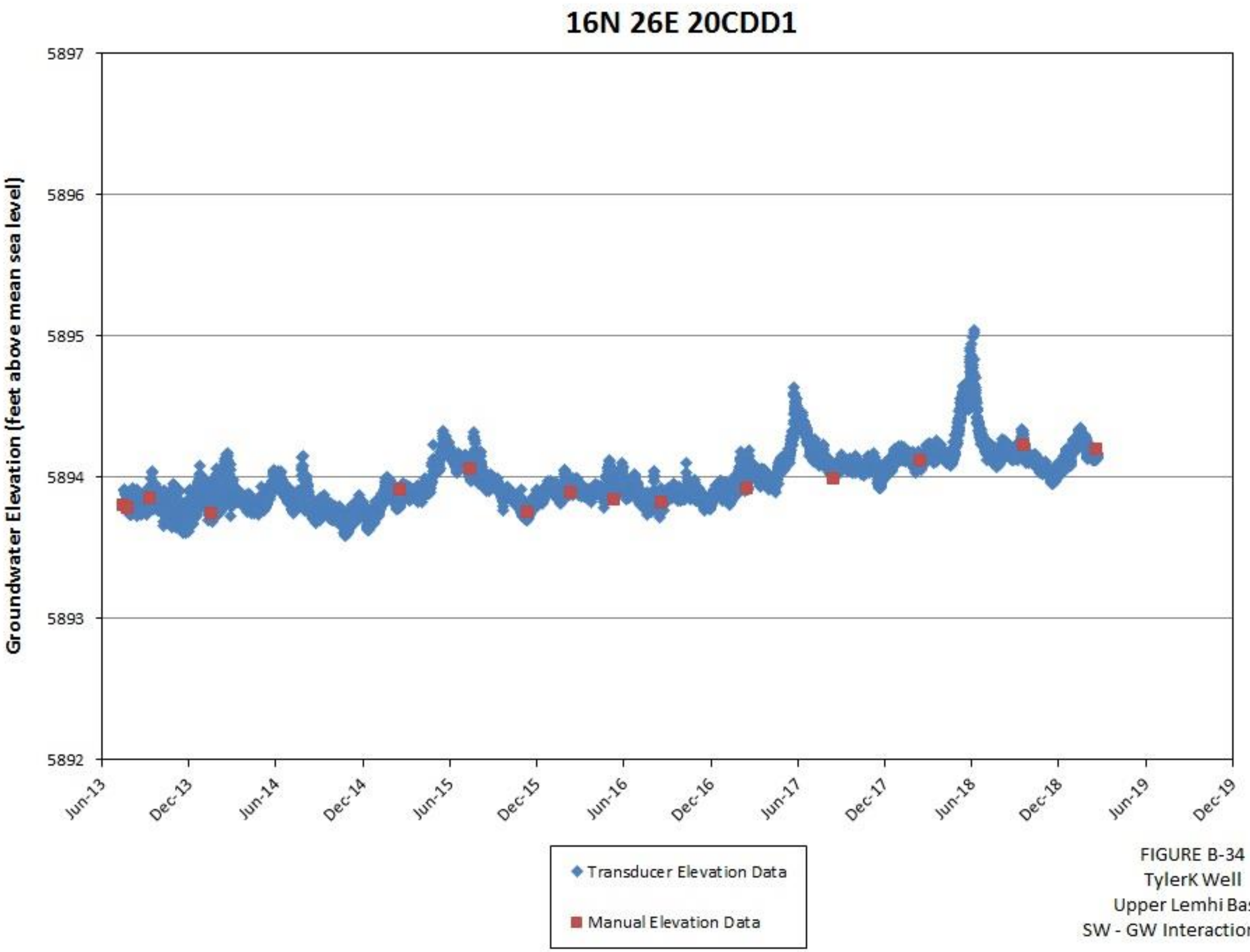


FIGURE B-34
TylerK Well
Upper Lemhi Basin
SW - GW Interactions P.III

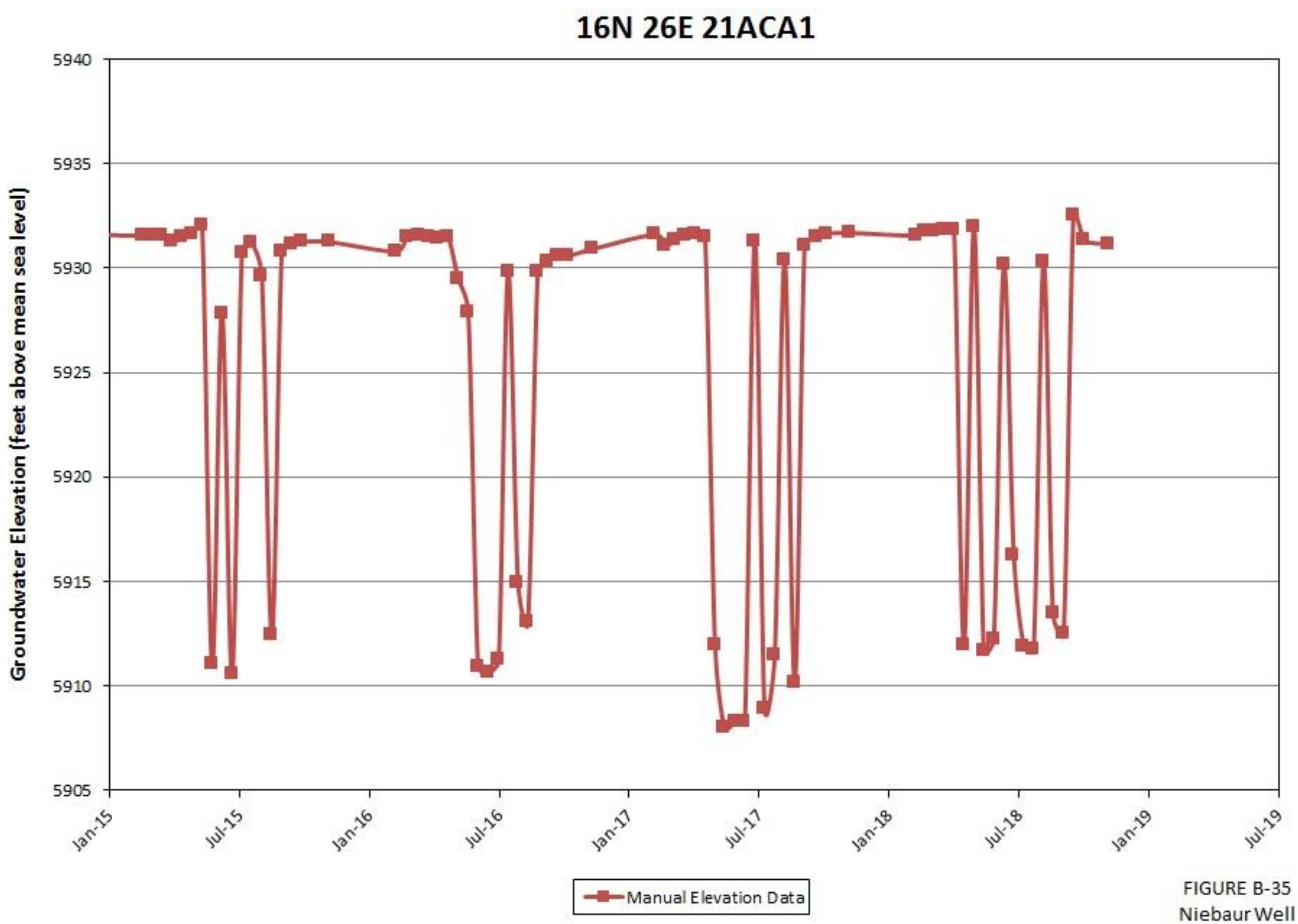


FIGURE B-35
Niebaur Well
Upper Lemhi Basin
SW - GW Interactions P.III

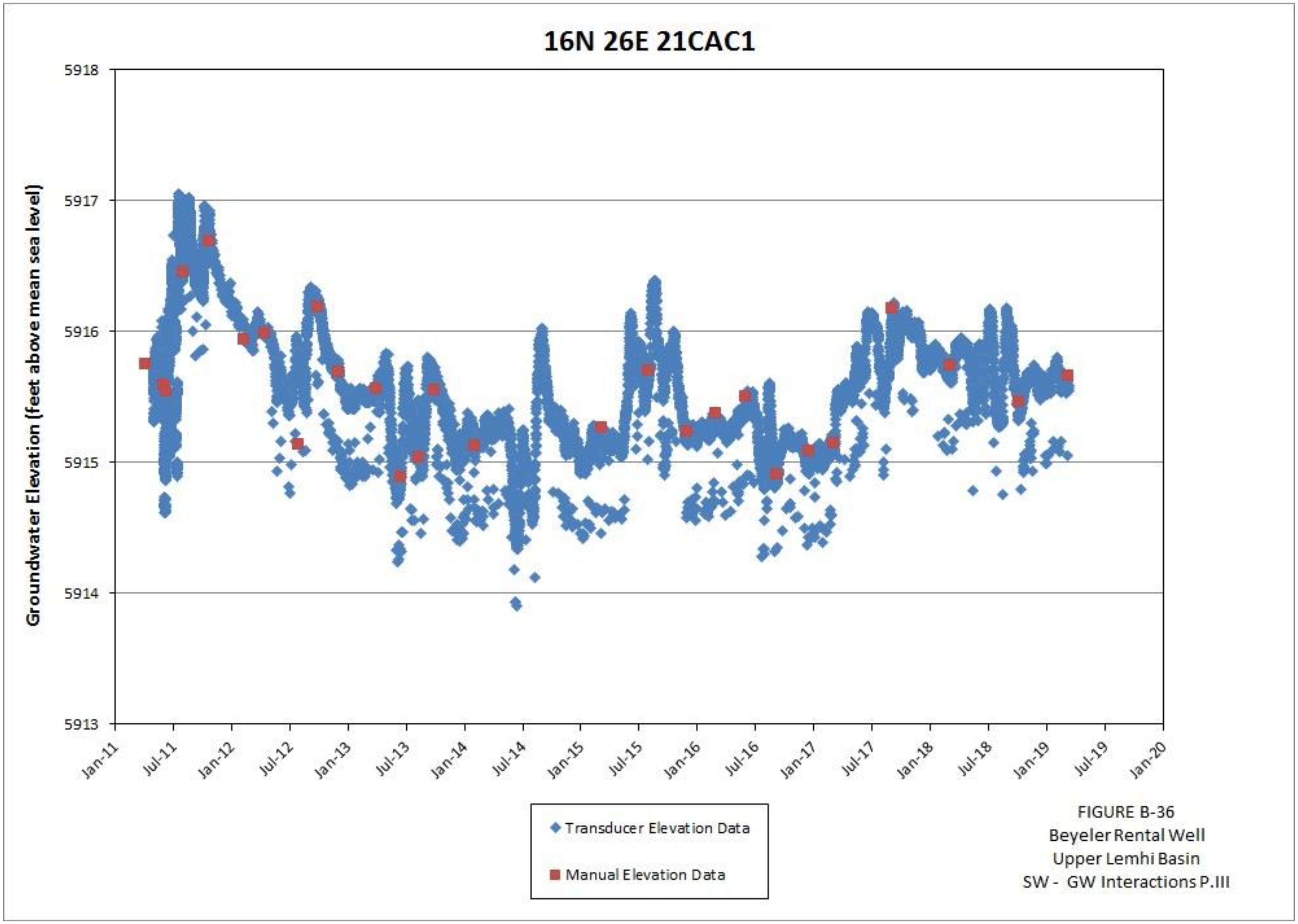


FIGURE B-36
Beyeler Rental Well
Upper Lemhi Basin
SW - GW Interactions P.III

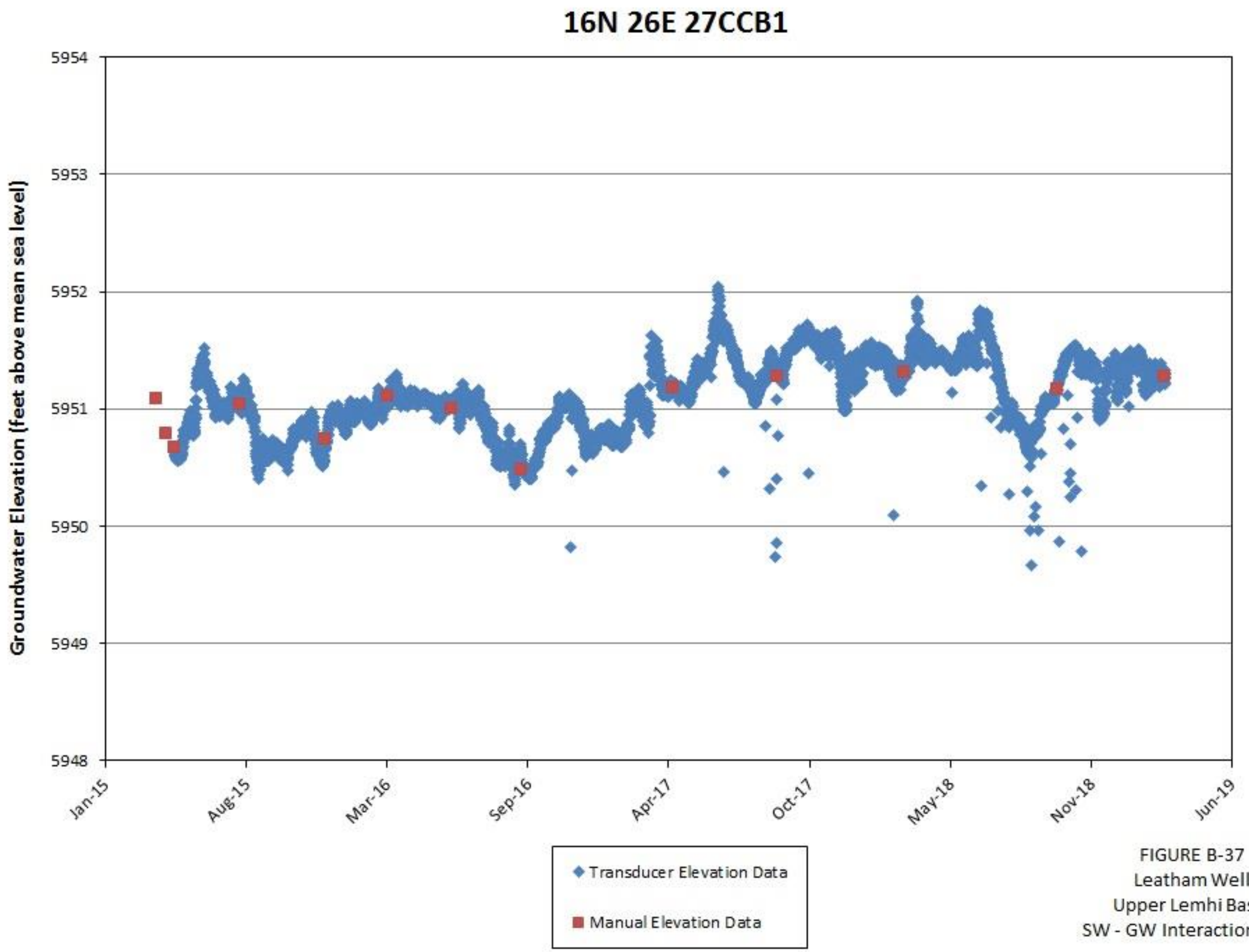


FIGURE B-37
Leatham Well
Upper Lemhi Basin
SW - GW Interactions P.III

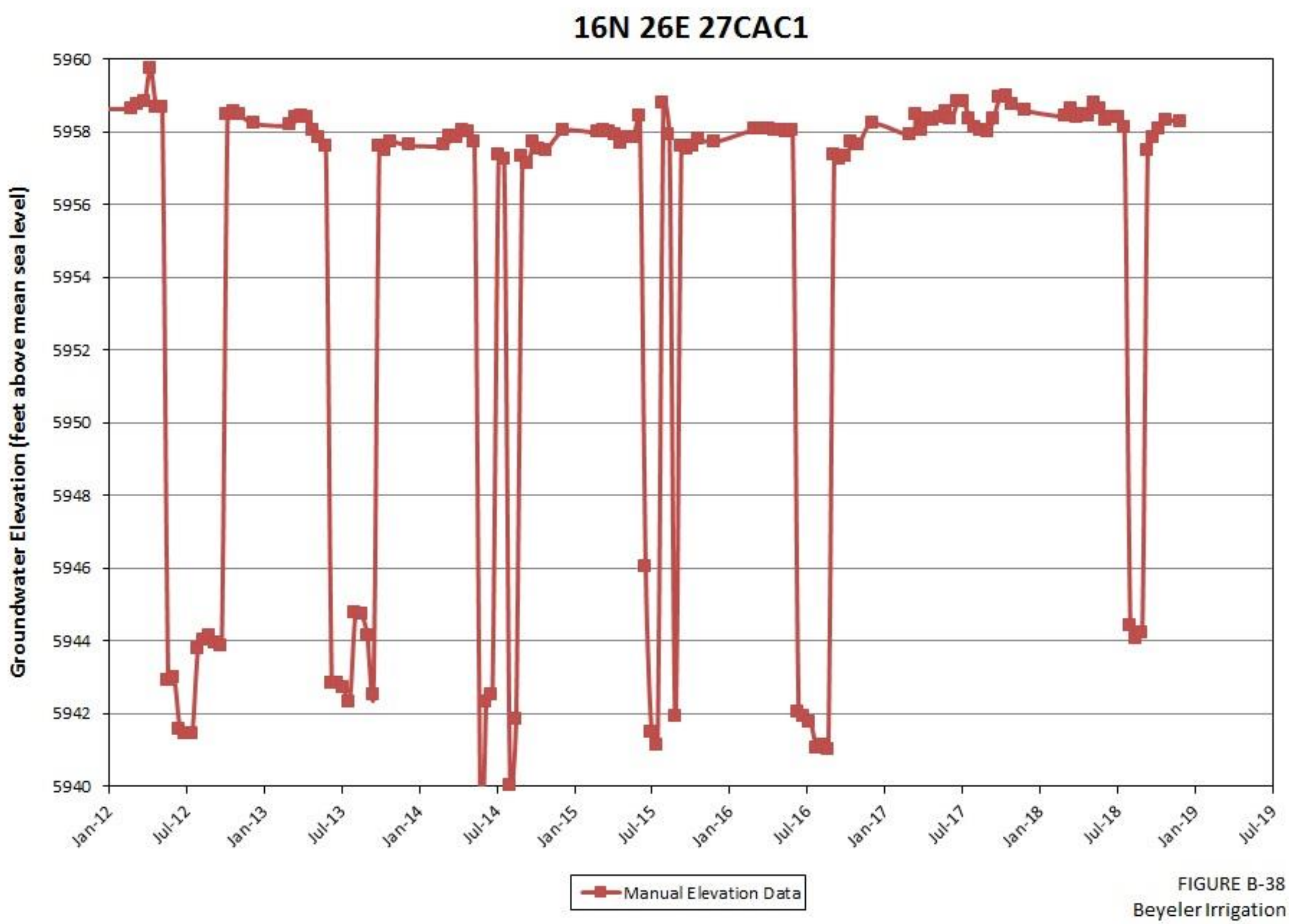


FIGURE B-38
Beyeler Irrigation Well
Upper Lemhi Basin
SW - GW Interactions P.III

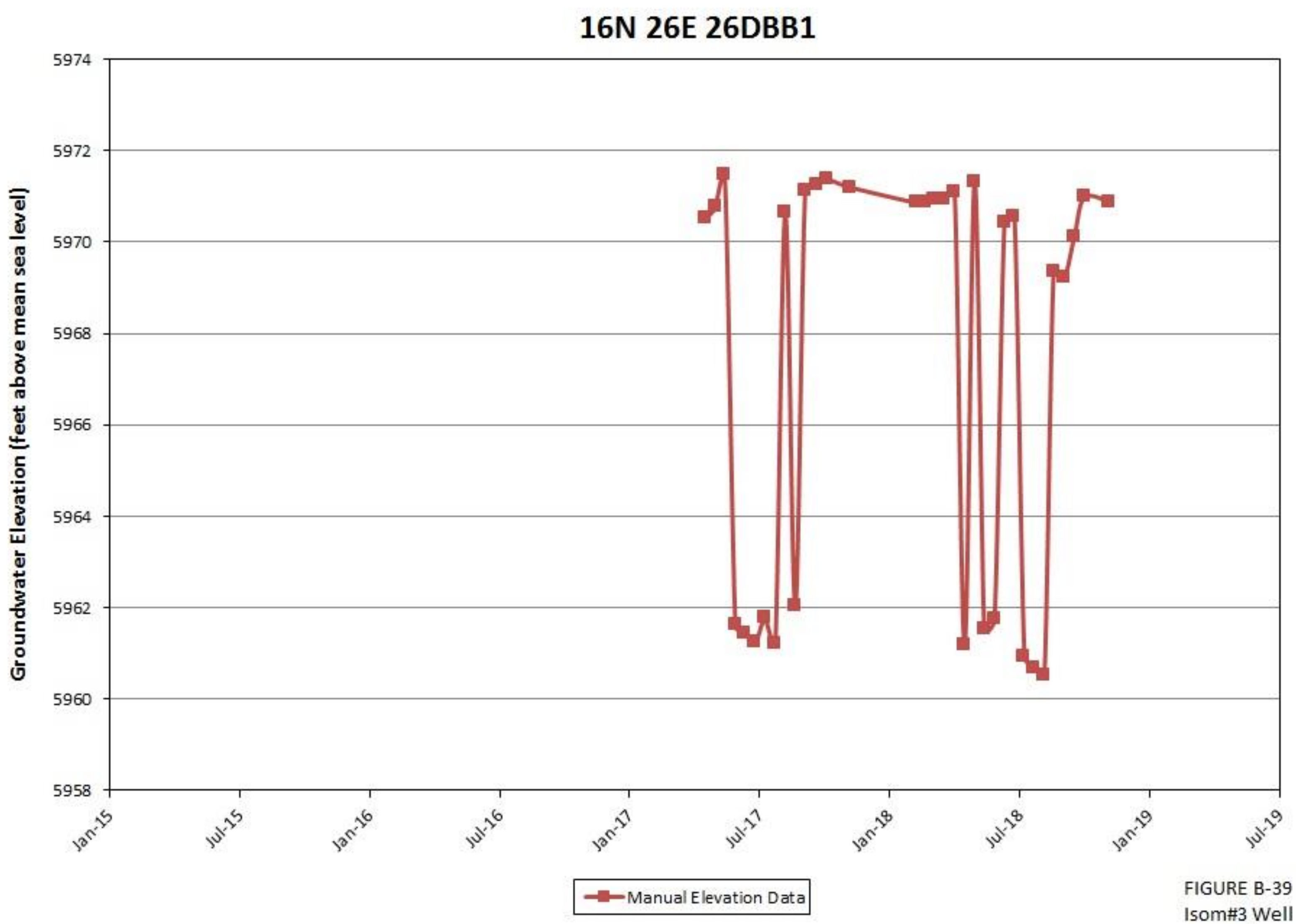
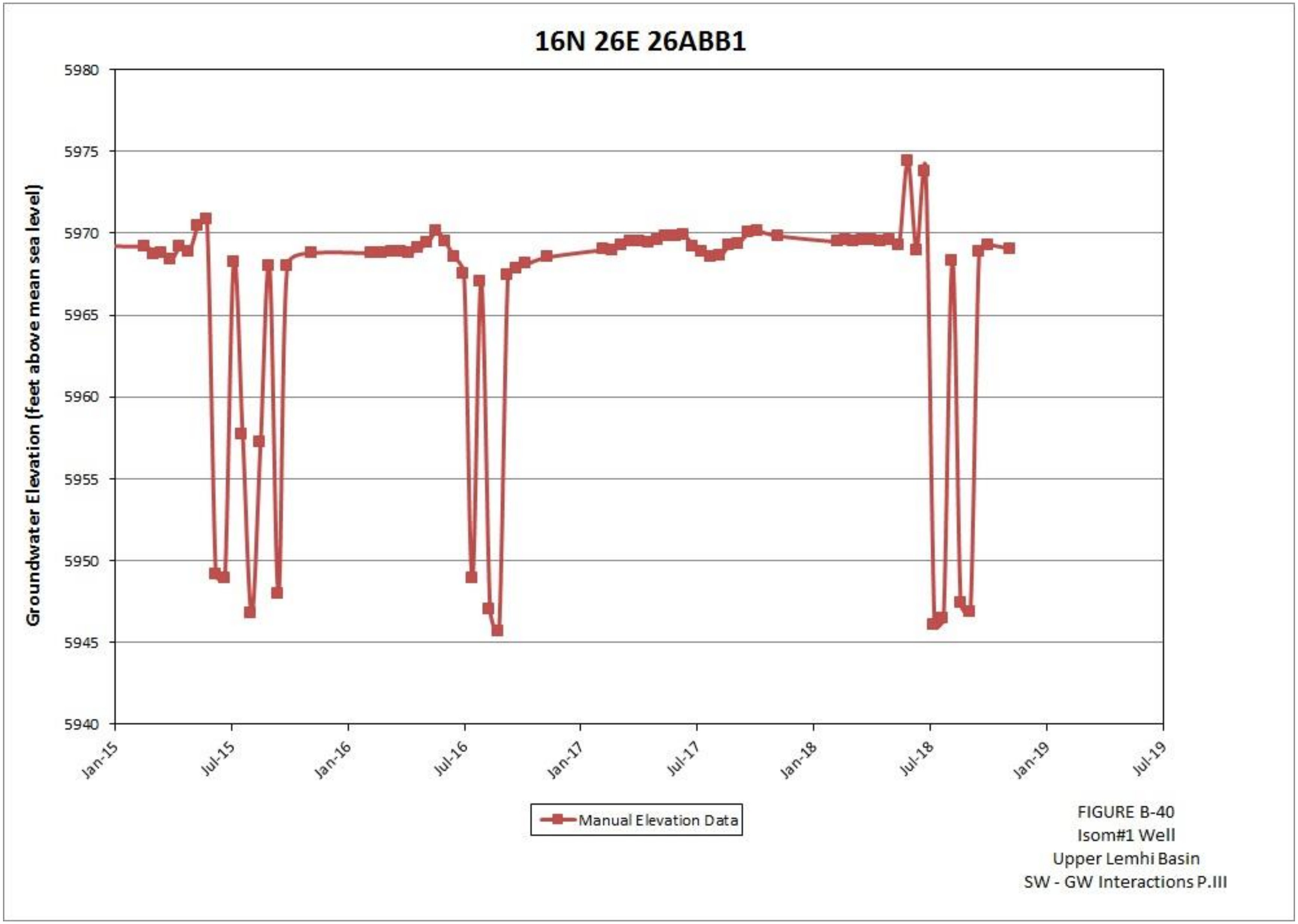


FIGURE B-39
Isom#3 Well
Upper Lemhi Basin
SW - GW Interactions P.III


16N 26E 26ABB1
Groundwater Elevation (feet above mean sea level)
5980
5975
5970
5965
5960
5955
5950
5945
5940
Jan-15
Jul-15
Jan-16
Jul-16
Jan-17
Jul-17
Jan-18
Jul-18
Jan-19
Jul-19
Manual Elevation Data
FIGURE B-40
Isom#1 Well
Upper Lemhi Basin
SW - GW Interactions P.III

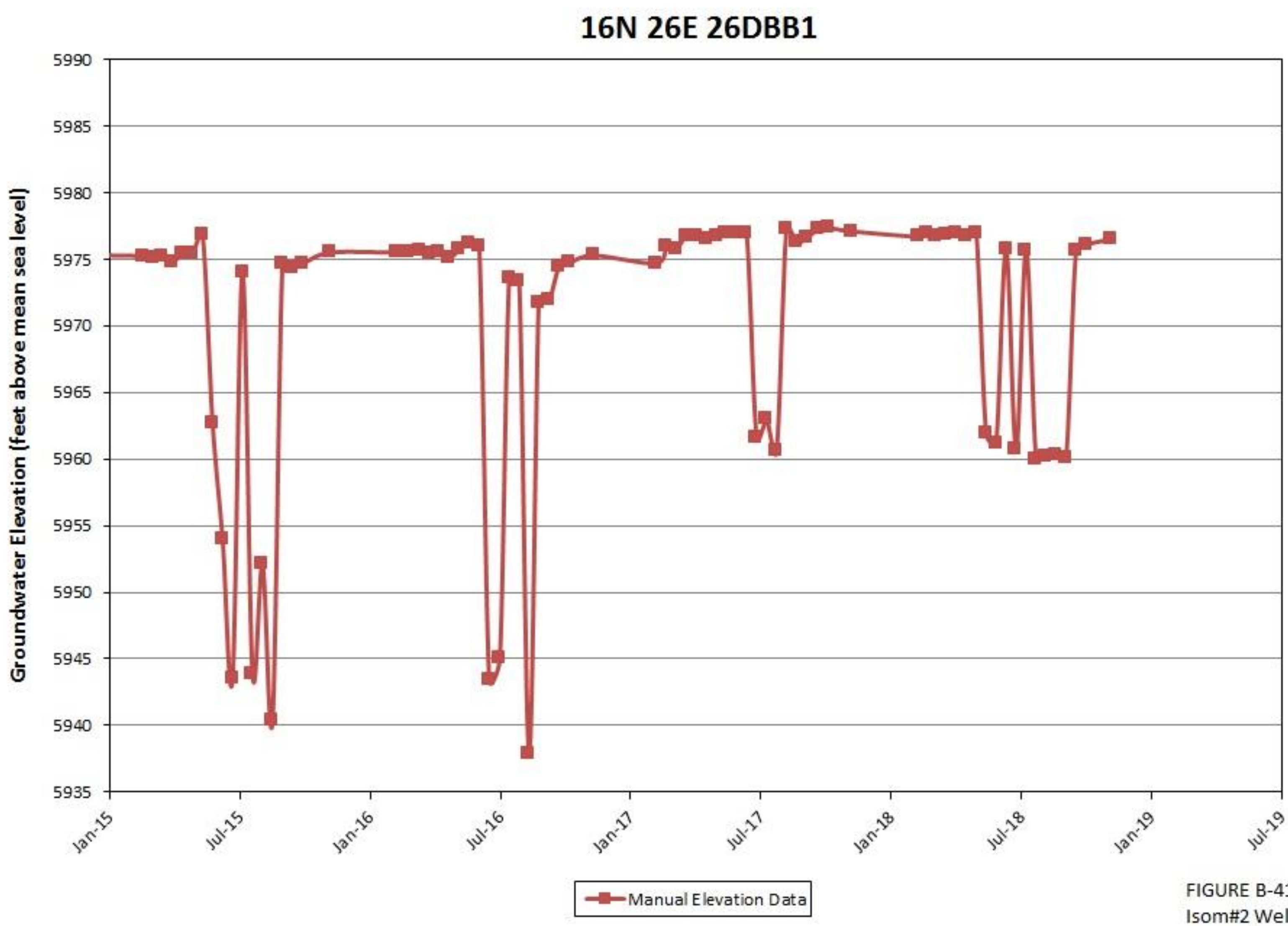


FIGURE B-41
Isom#2 Well
Upper Lemhi Basin
SW - GW Interactions P.III

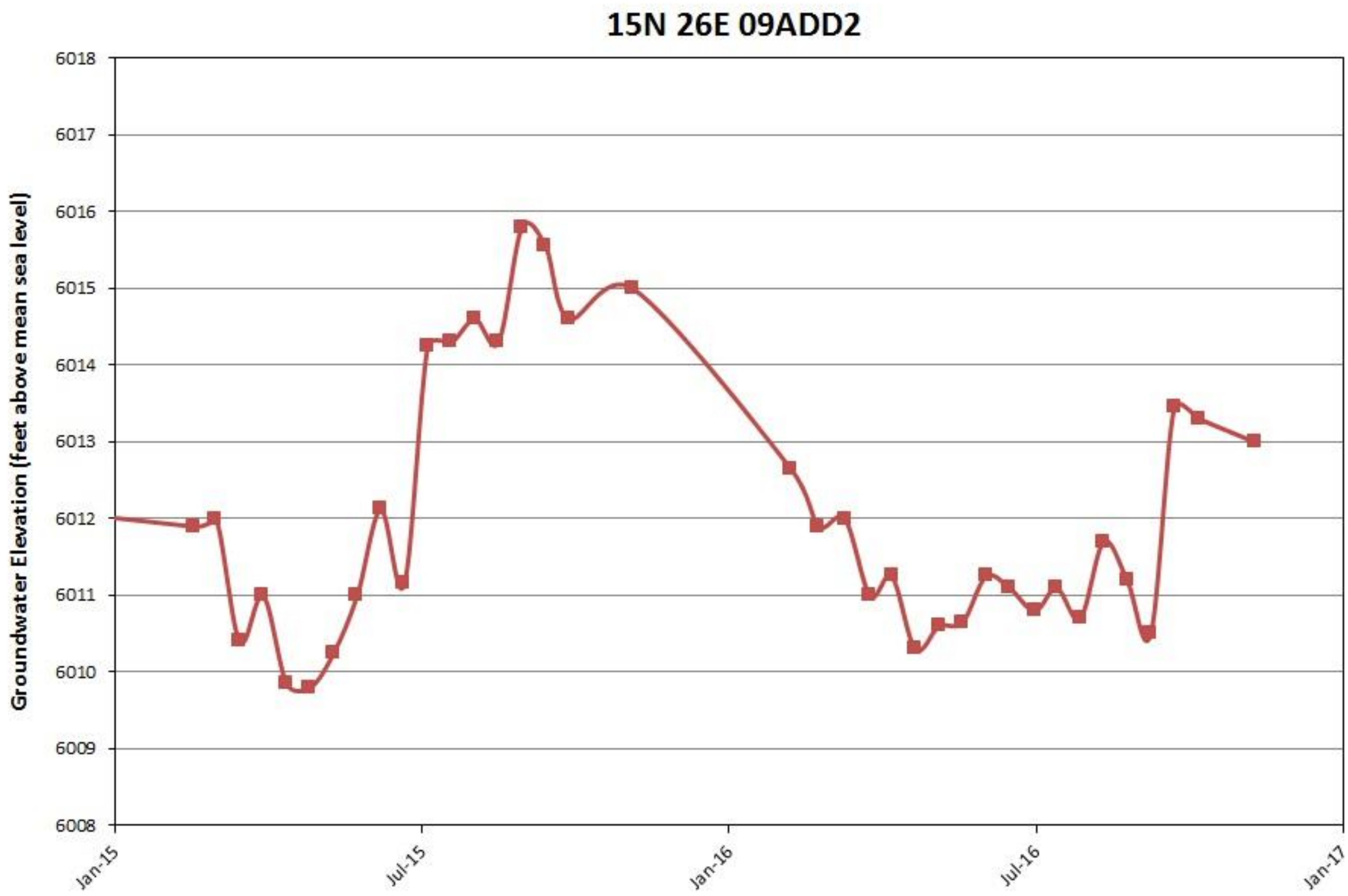


FIGURE B-42
Dart Well
Upper Lemhi Basin
SW - GW Interactions P.III

		Well Common Name	Manual or Instrument	97-98 Average	Current Average	97-98 NonIrrigation Average	Current NonIrrigation Average	97-98 Irrigation Average	Current Irrigation Average	Irrigation Impact	Trend
Lower Lemhi Basin	Salmon Area	Jackson	M	NA	1018	NA	4017	NA	4019	Yes	No
		Thomas	I	4034	4031	4028	4027	4038	4036	Yes	No
		Cheney	I	NA	4038	NA	4032	NA	4040	Yes	No
		Cockrell	M	4058	4058	4057	4057	4058	4059	Yes	No
		Fisher	M	4109	4110	4106	4108	4110	4111	Yes	No
		Richardson	M	4174	4174	4174	4174	4174	4175	Yes	No
		Stokes	M	NA	4240	NA	4238	NA	4241	Yes	No
		Daniels	I	4236	4235	4236	4234	4237	4236	Yes	No
	Baker Area	Jordan	I	4405	4403	4402	4404	3833	4403	Yes	No
		Sager	M	4407	4407	4406	4407	4407	4407	Yes	No
		Pratt Creek 1	I	NA	4584	NA	4583	NA	4586	Yes	No
		Pratt Creek 2	I	NA	4488	NA	4487	NA	4488	Yes	No
		Pratt Creek 3	I	NA	4474	NA	4473	NA	4474	Yes	No
		SnookE	I	4497	4499	4497	4498	4497	4501	Yes	No
		SnookQ	M	4551	4550	4551	4550	4551	4551	Yes	No
		Luftkin	M	NA	4599	NA	4595	NA	4601	Yes	no
		Probst	I	4666	4664	4665	4664	4666	4665	Yes	No
Lemhi Constriction area / Mid Basin	Tendoy to Lemhi	Sells	M	4751	4752	4751	4751	4752	4752	Yes	No
		Kesl	I	4850	4846	4847	4845	4851	4848	Yes	No
		Eastman	I	4875	4875	4873	4873	7877	7876	Yes	No
		Shuff	M	4981	4984	4981	4984	4982	4985	Yes	No
		Smith2	I	4929	4927	4924	4923	4933	4931	Yes	No
		Stout	M	5054	5054	5054	5054	554	5055	Yes	No
		Kibbee	I	NA	5101	NA	5092	NA	5109	Yes	No
		Whitson	I	5109	5110	5100	5101	5116	5117	Yes	No
		Plairfair	M	5174	5174	5170	5169	5178	5176	Yes	No
		Adams	I	5319	5318	5314	5312	5322	5322	Yes	No

Table B-1. Groundwater Level Trend Analysis.

		Well Common Name	Manual or Instrument	97-98 Average	Current Average	97-98 NonIrrigation Average	Current NonIrrigation Average	97-98 Irrigation Average	Current Irrigation Average	Irrigation Impact	Trend
Upper Lemhi Basin	Lemhi to Cottom Lane	ShinerS	I	5251	5244	5243	5240	5256	5247	Yes	No
		ShinerD	I	5274	5272	5271	5268	5276	5275	Yes	No
		SnyderR	I	5399	5398	5396	5395	5401	5401	Yes	No
		Hayes	I	5640	5637	5637	5636	5641	5638	Yes	No
		TylerS	I	6150	6145	6149	6145	6151	6145	Yes	No
		England	I	6144	6132	6143	6132	6145	6132	Yes	No
	Leadore Area	TylerK	I	NA	5894	NA	5894	NA	5894	Minimal	No
		BeyelerRental	I	5922	5916	5919	5915	5923	5916	Yes	No
		Niebaur	M	5932	5926	5934	5931	5930	5923	Pumping	No
		Leatham	I	5952	5951	5952	5951	5952	5951	Yes	No
		BeyelerIrrigation	M	5957	5954	5959	5958	5956	5952	Pumping	No
		Dart (Discontinued)	M	6027	6012	6025	6012	6029	6012	Yes	No
		Isom 3	M	NA	5967	NA	5971	NA	5966	Pumping	No
		Isom 2	M	5977	5971	5980	5976	5975	5968	Pumping	No
		Isom 1	M	5970	5966	5973	5969	5968	5965	Pumping	No

Continue Table B-1. Groundwater Level Trend Analysis.

Appendix C – Soil Moisture and Temperature

Soil moisture stations are composed of seven sensors. Six of the sensors are electrodes imbedded in gypsum blocks that measure the electrical resistance between two electrodes in the block;. The seventh sensor is a thermistor that measures temperature in the soil. The gypsum blocks are installed at depths of approximately 0.5, 1, 2, 3, 4, and 5 ft below land surface, and the thermistor is installed 1 ft below land surface. The sensors are programmed take readings every 8 hours. The resistance in the block is not an actual measure of moisture content but resistance is inversely proportional to soil moisture; therefore, it can be qualitatively related to moisture. Qualitative interpretation of the resistance values are:

- 0 – 10 centibars = Wet, may be saturated soil.
- 10 – 30 centibars = Soil is adequately wet (except coarse sands, which are beginning to lose water).
- 30 – 60 centibars = Usual range for irrigation (most soils).
- 60 – 100 centibars = Usual range for irrigation in heavy clay.
- 100 – 160 centibars = Soil is at or past wilting point.
- 160 – 200 centibars = Soil is dry.

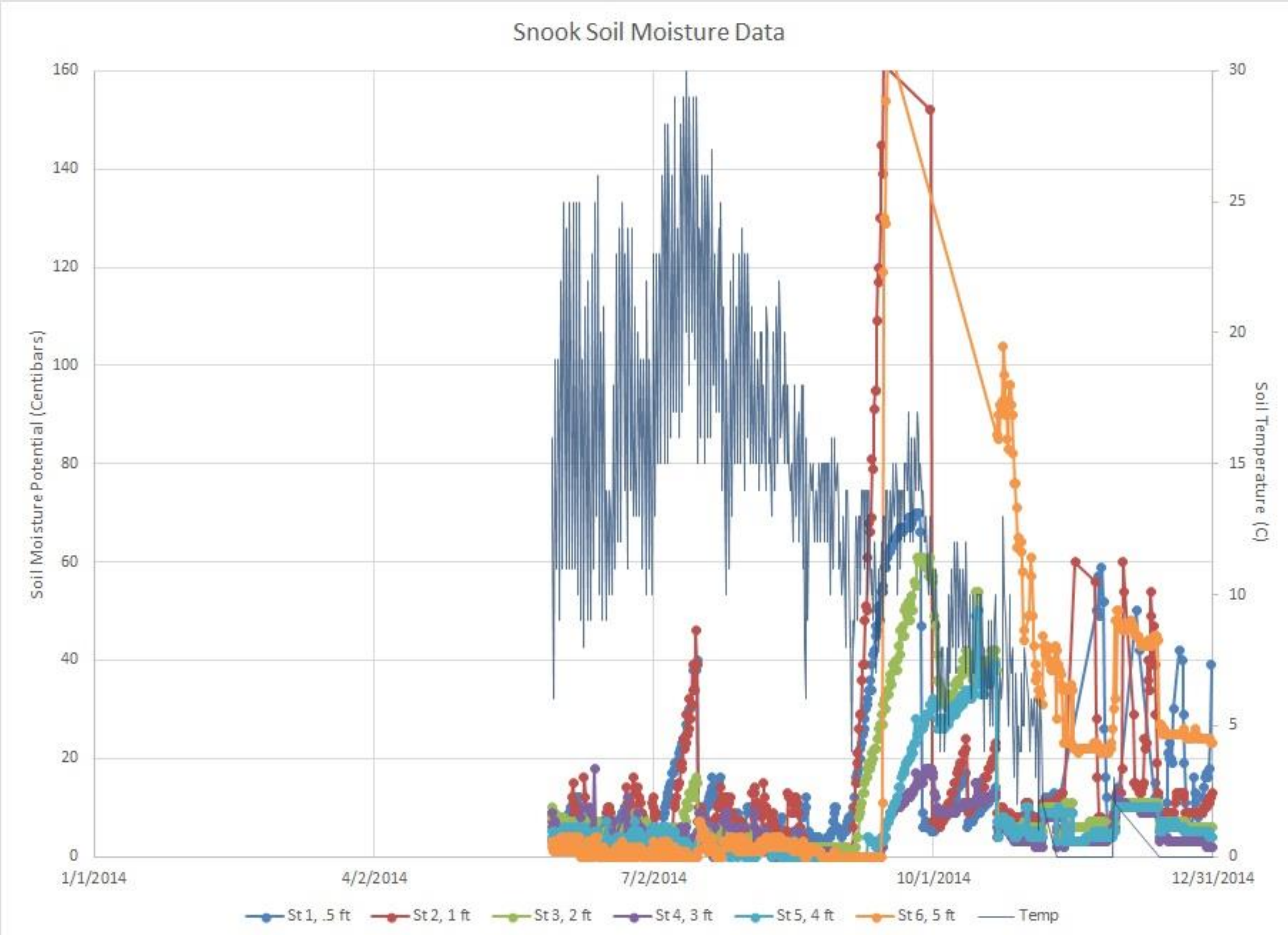

Snook Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
30
25
20
15
10
5
0
1/1/2014
4/2/2014
7/2/2014
10/1/2014
12/31/2014
St 1, .5 ft
St 2, 1 ft
St 3, 2 ft
St 4, 3 ft
St 5, 4 ft
St 6, 5 ft
Temp

Figure C-1

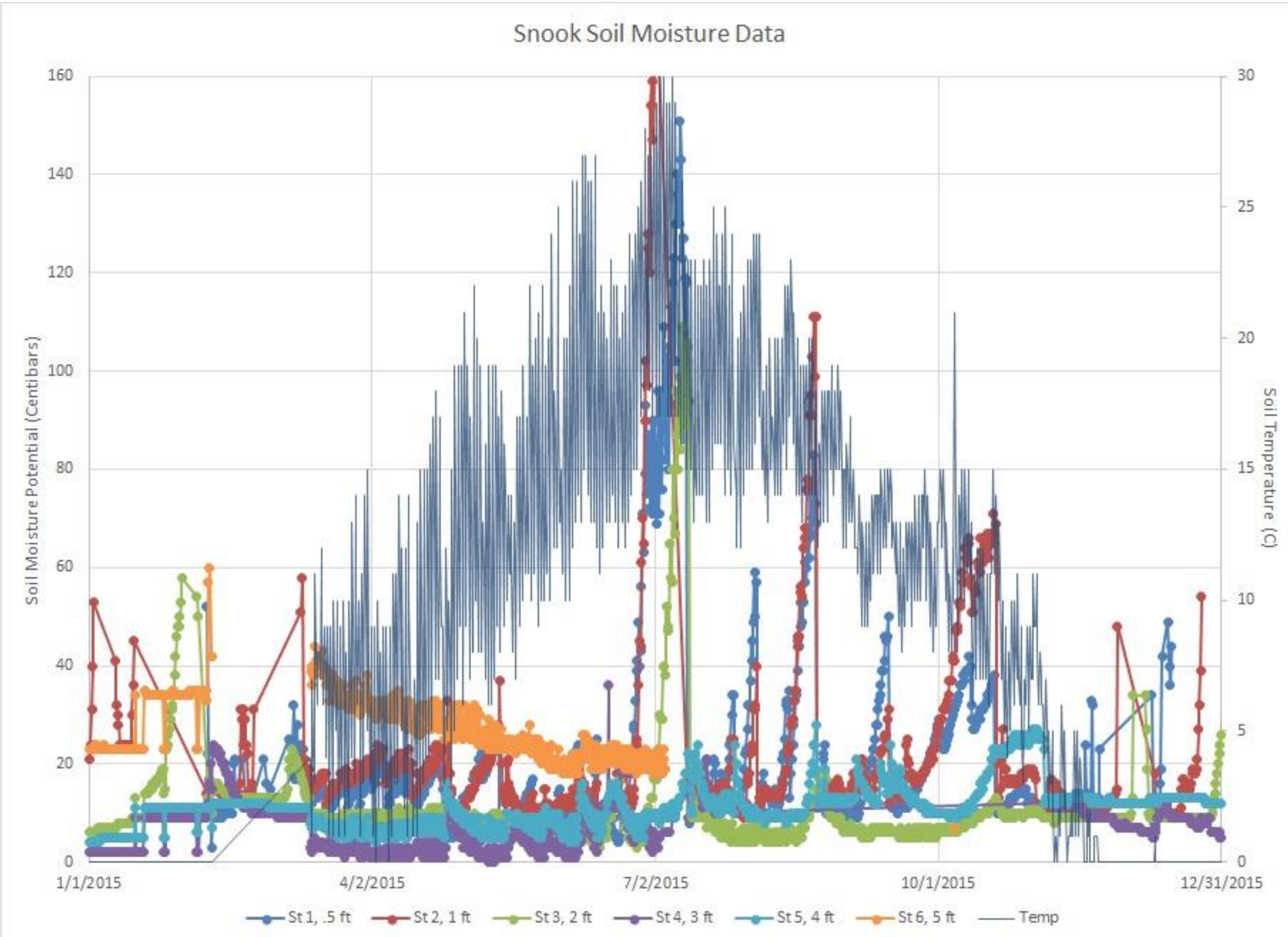
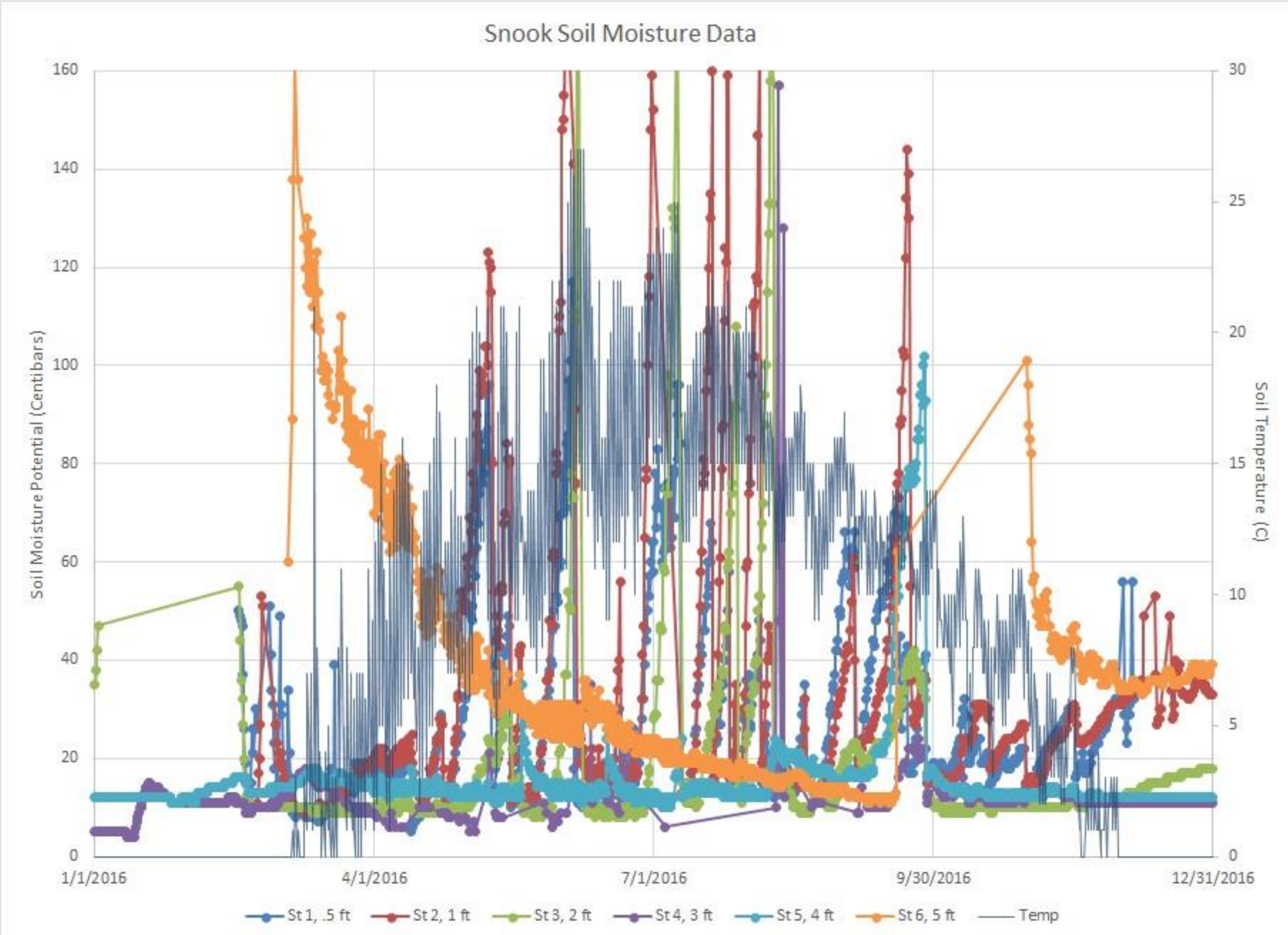

Snook Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
0
20
40
60
80
100
120
140
160
0
5
10
15
20
25
30
1/1/2015
4/2/2015
7/2/2015
10/1/2015
12/31/2015
St 1, .5 ft
St 2, 1 ft
St 3, 2 ft
St 4, 3 ft
St 5, 4 ft
St 6, 5 ft
Temp

Figure C-2



Snook Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
30
25
20
15
10
5
0
1/1/2016
4/1/2016
7/1/2016
9/30/2016
12/31/2016
St 1, .5 ft
St 2, 1 ft
St 3, 2 ft
St 4, 3 ft
St 5, 4 ft
St 6, 5 ft
Temp

Figure C-3

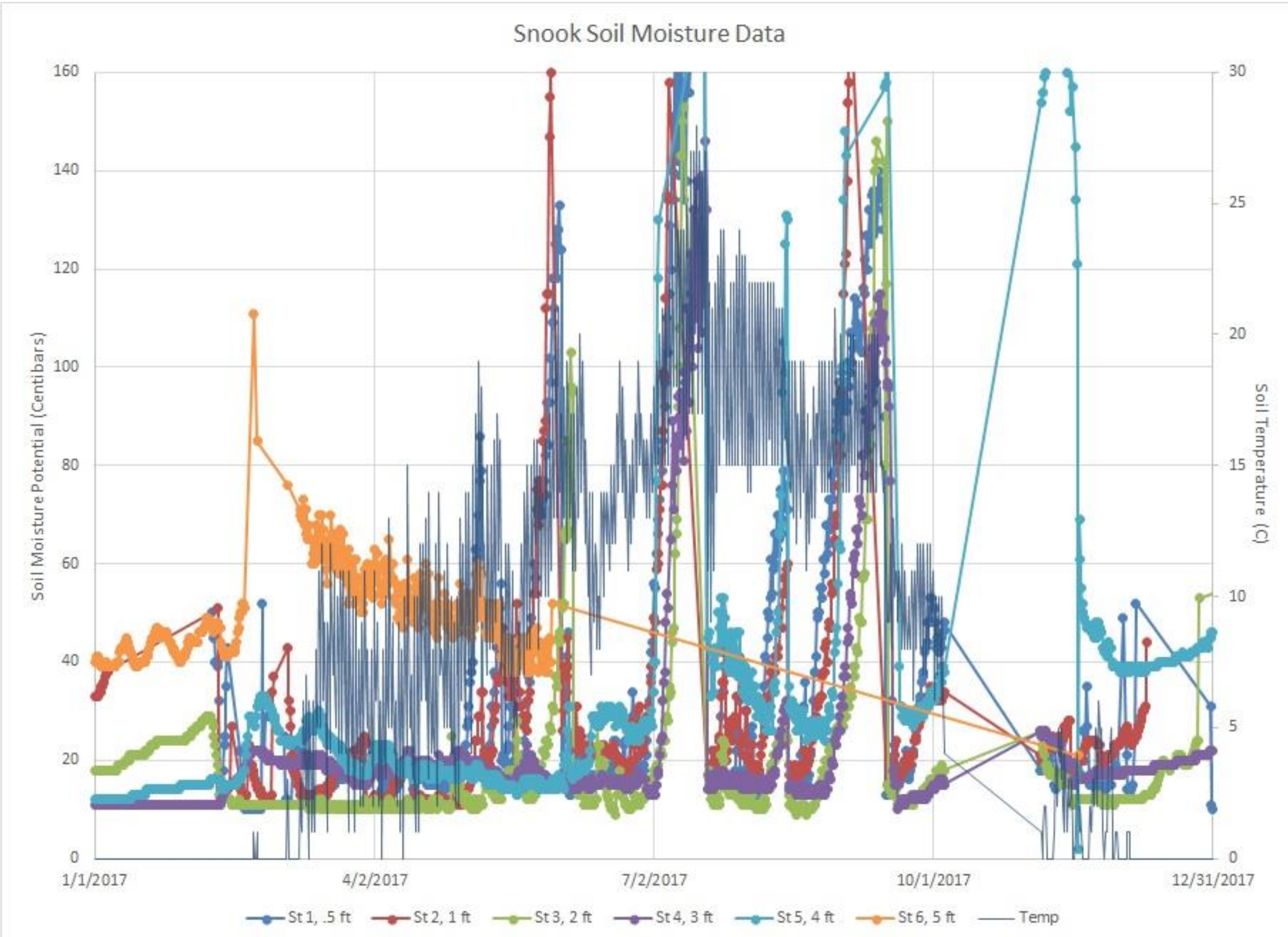

Snook Soil Moisture Data
Soil Moisture Potential (Centibars)
160
140
120
100
80
60
40
20
0
Soil Temperature (C)
30
25
20
15
10
5
0
1/1/2017
4/2/2017
7/2/2017
10/1/2017
12/31/2017
St 1, .5 ft
St 2, 1 ft
St 3, 2 ft
St 4, 3 ft
St 5, 4 ft
St 6, 5 ft
Temp

Figure C-4

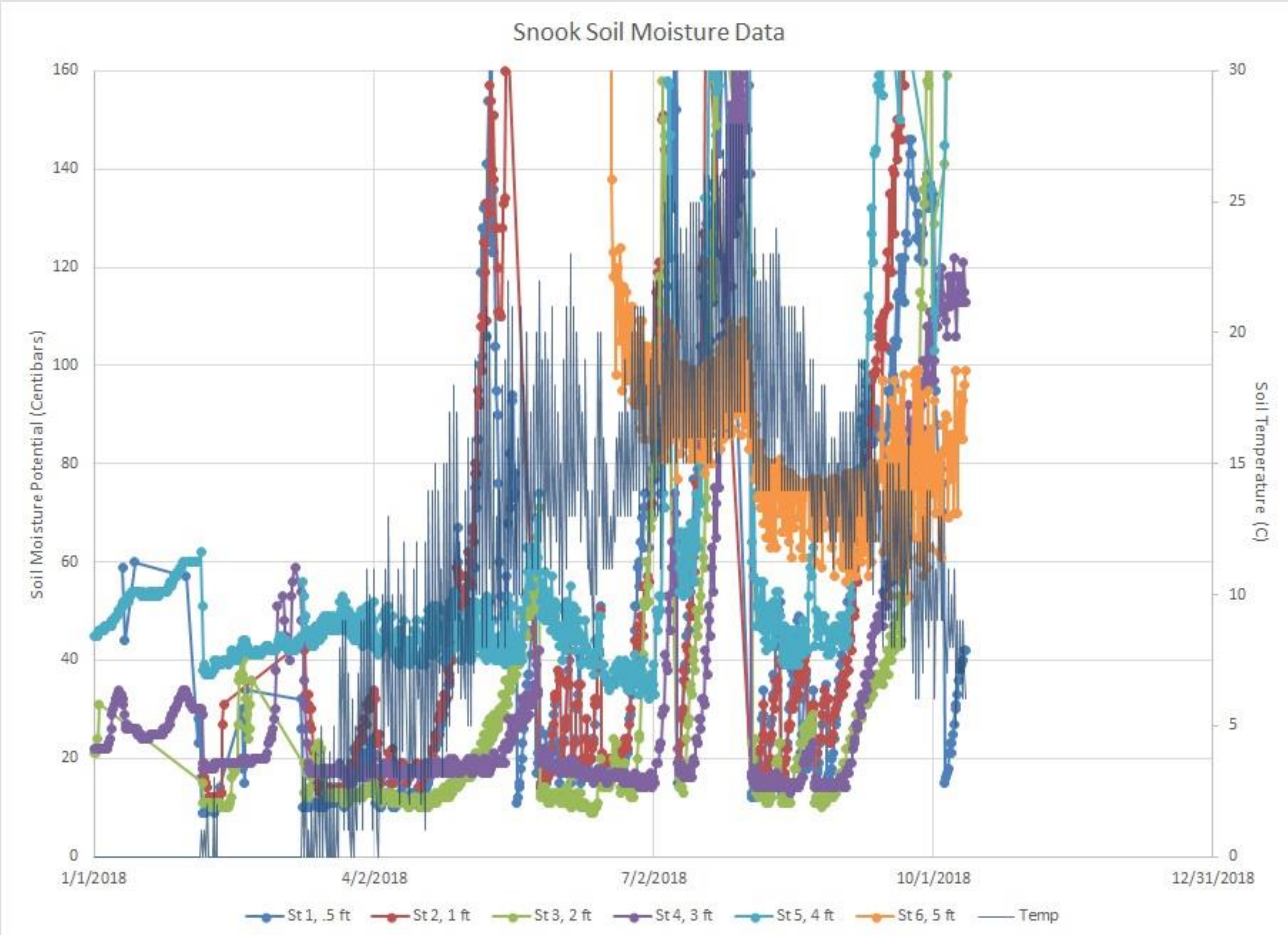

Snook Soil Moisture Data
160
140
120
100
80
60
40
20
0
Soil Moisture Potential (Centibars)
30
25
20
15
10
5
0
Soil Temperature (C)
1/1/2018
4/2/2018
7/2/2018
10/1/2018
12/31/2018
St 1, .5 ft
St 2, 1 ft
St 3, 2 ft
St 4, 3 ft
St 5, 4 ft
St 6, 5 ft
Temp

Figure C-5

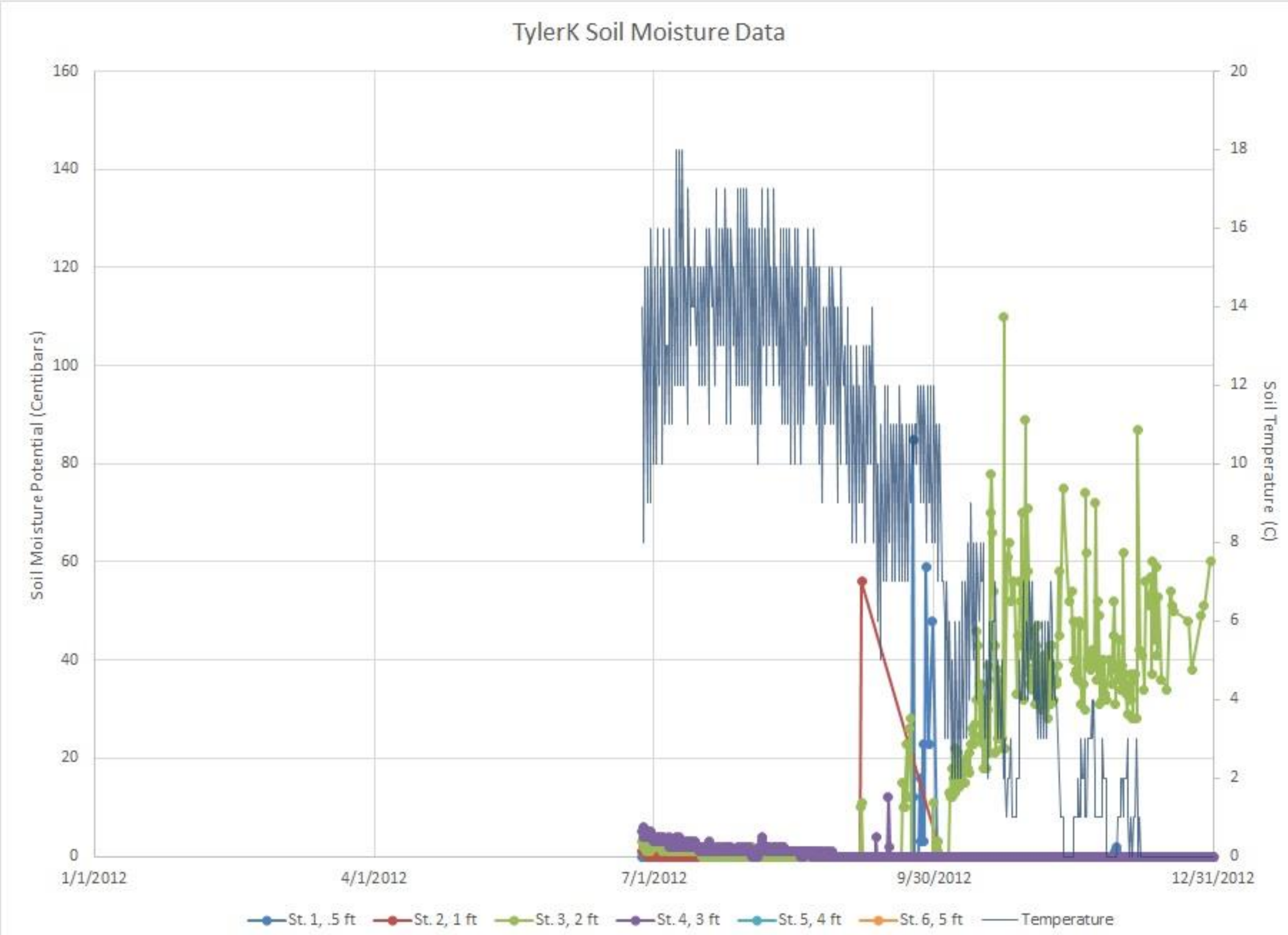

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
20
18
16
14
12
10
8
6
4
2
0
1/1/2012
4/1/2012
7/1/2012
9/30/2012
12/31/2012
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-6

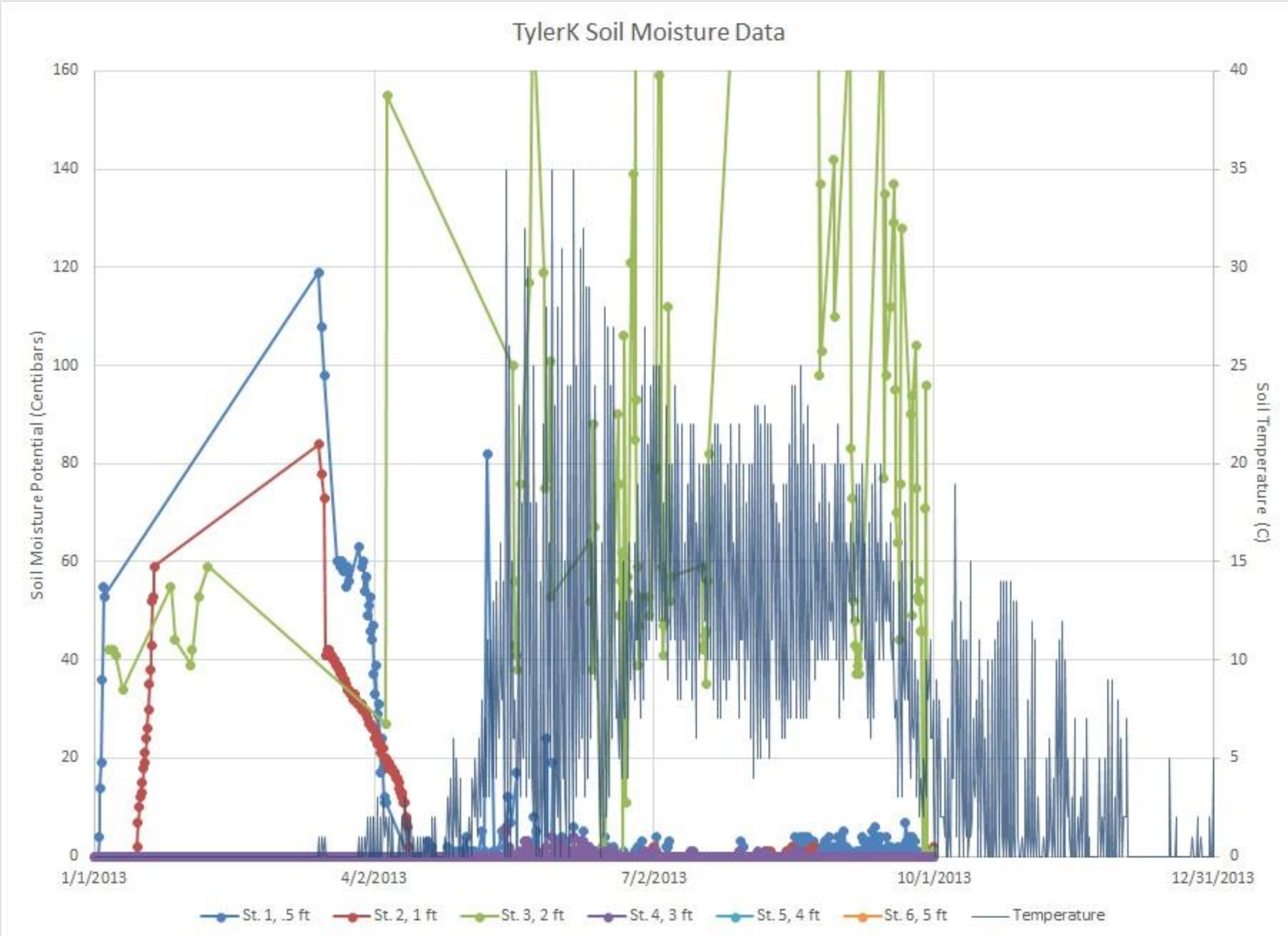

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
40
35
30
25
20
15
10
5
0
1/1/2013
4/2/2013
7/2/2013
10/1/2013
12/31/2013
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-7

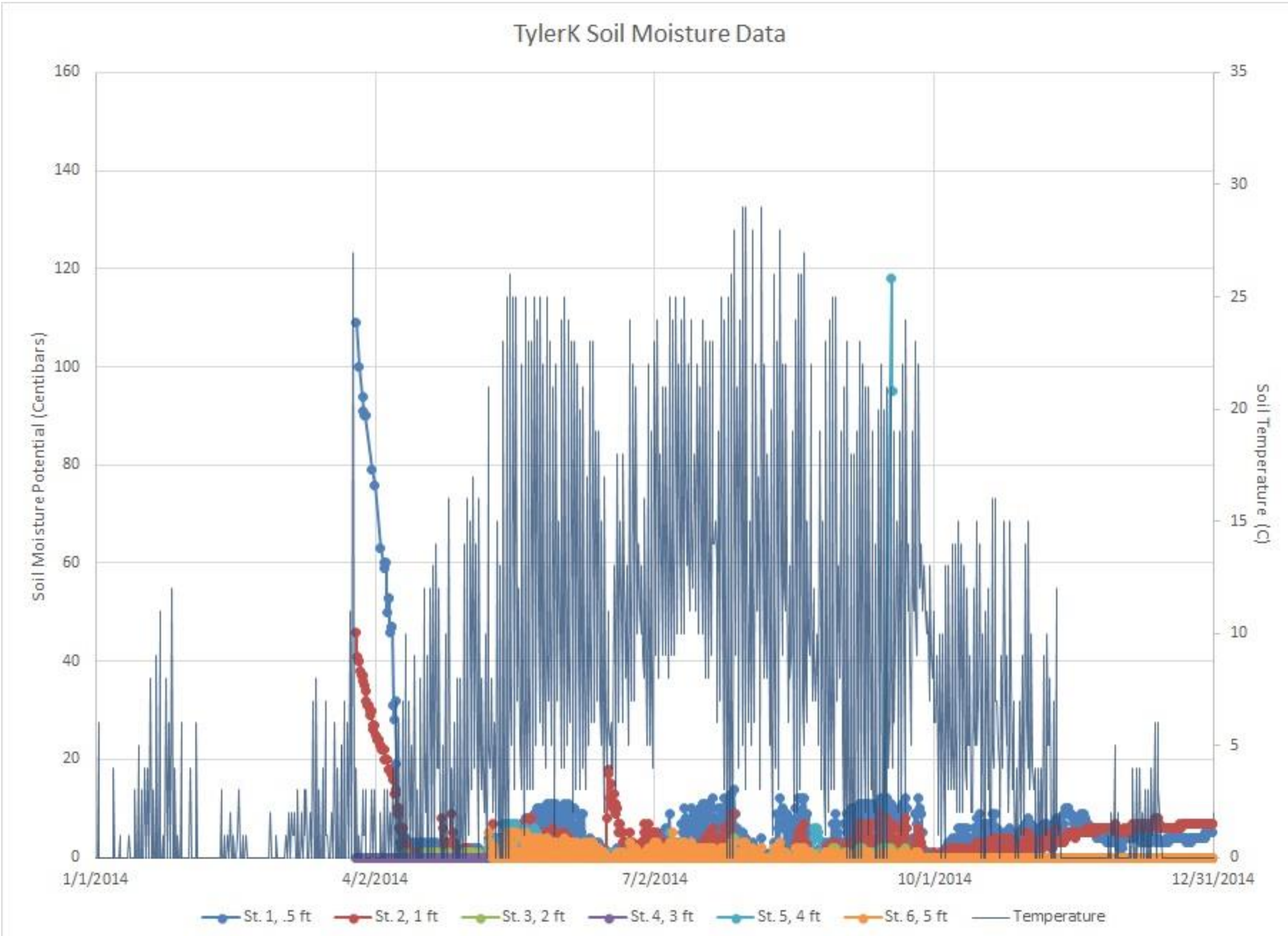

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
0
20
40
60
80
100
120
140
160
0
5
10
15
20
25
30
35
1/1/2014
4/2/2014
7/2/2014
10/1/2014
12/31/2014
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-8

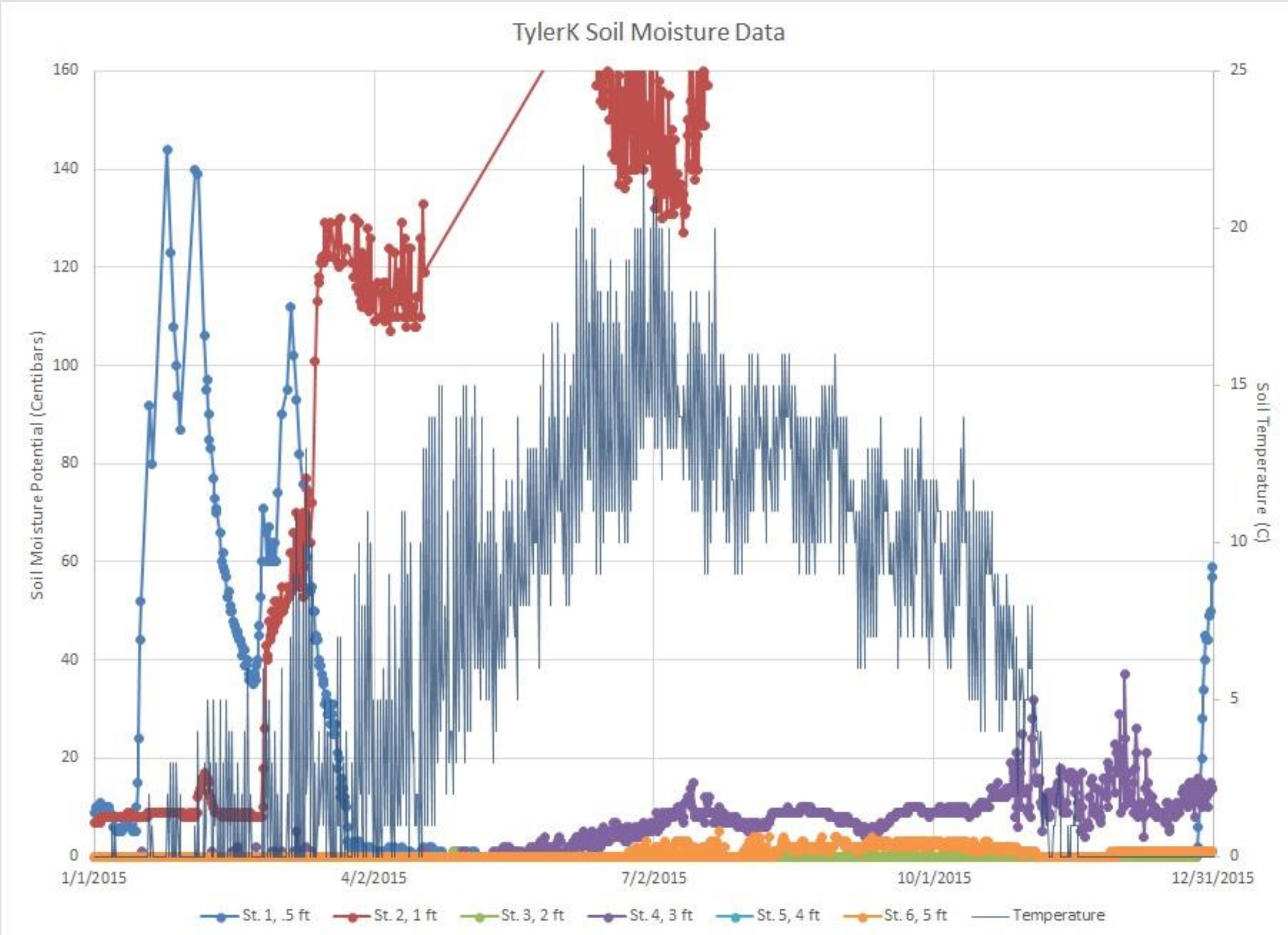

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
25
20
15
10
5
0
1/1/2015
4/2/2015
7/2/2015
10/1/2015
12/31/2015
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-9

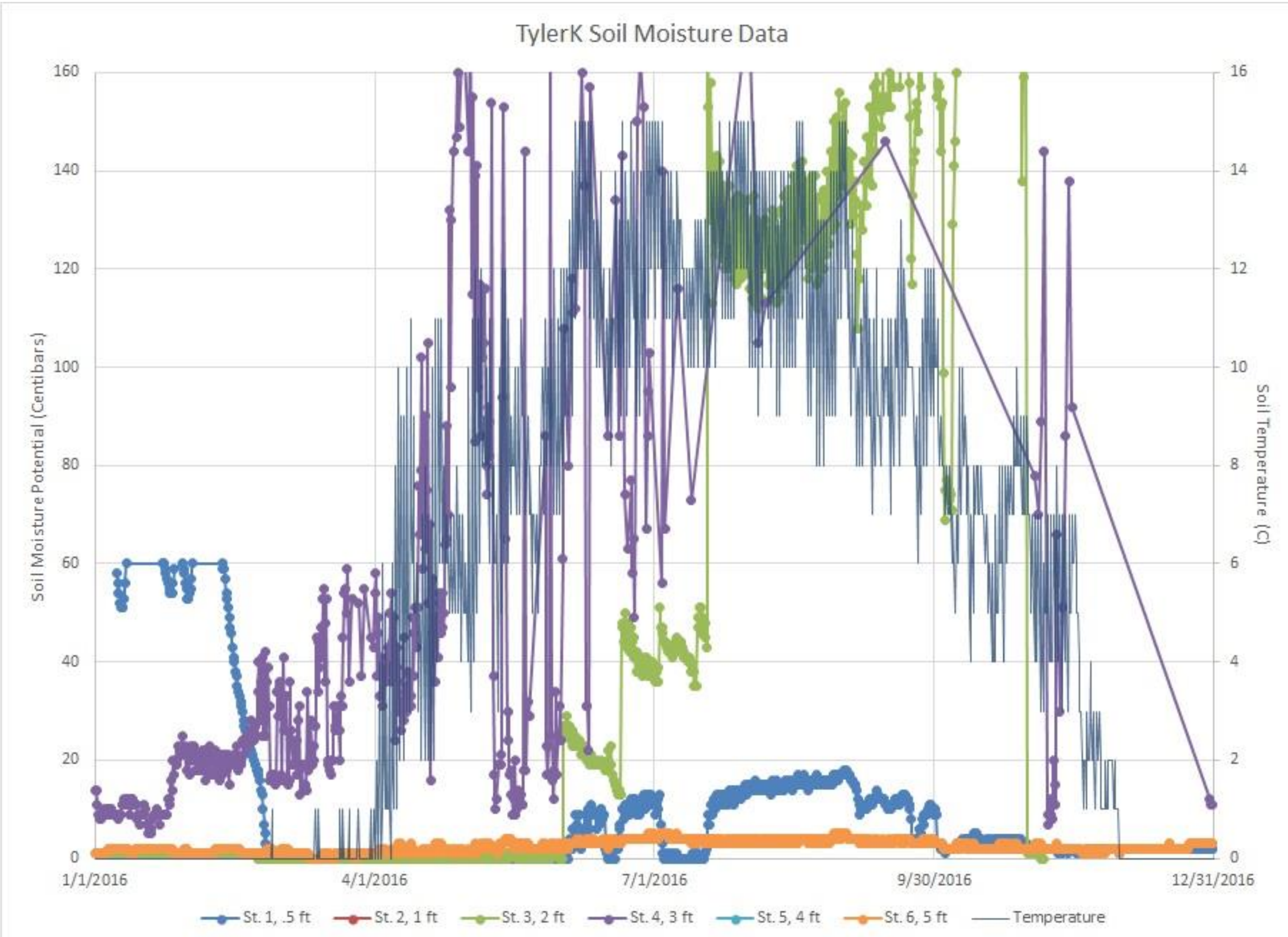

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
16
14
12
10
8
6
4
2
0
1/1/2016
4/1/2016
7/1/2016
9/30/2016
12/31/2016
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-10

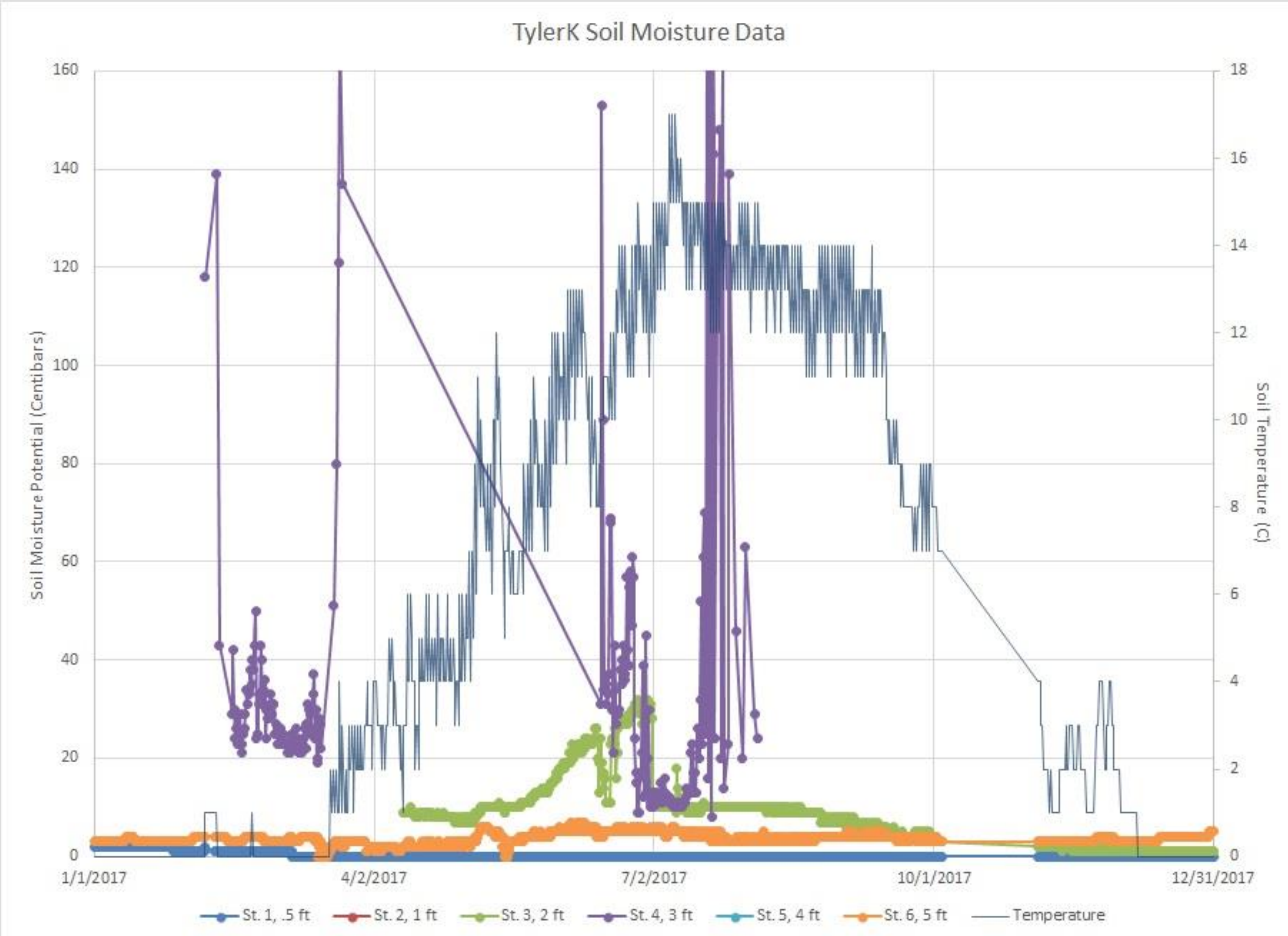

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
18
16
14
12
10
8
6
4
2
0
1/1/2017
4/2/2017
7/2/2017
10/1/2017
12/31/2017
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-11

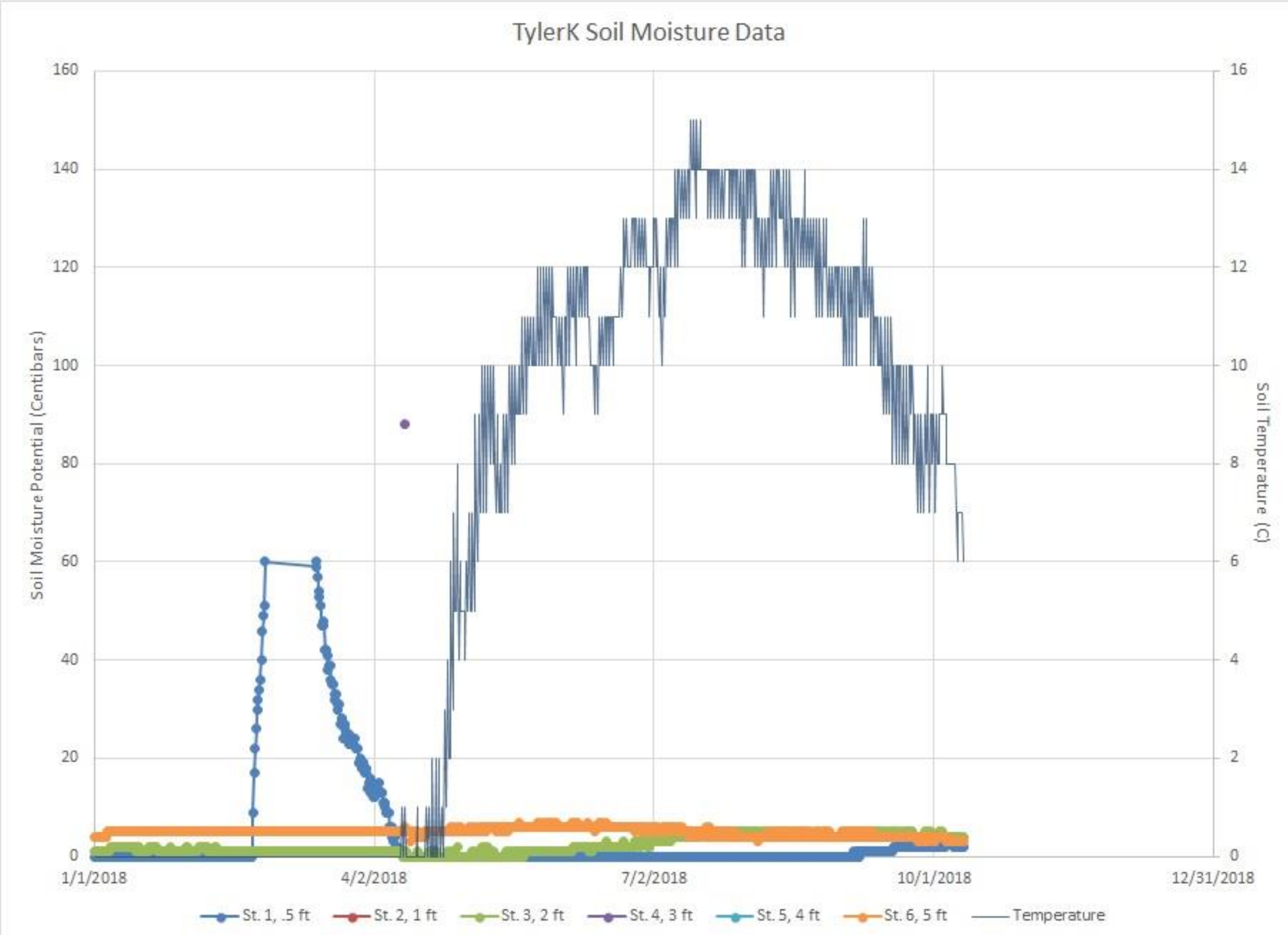

TylerK Soil Moisture Data
Soil Moisture Potential (Centibars)
Soil Temperature (C)
160
140
120
100
80
60
40
20
0
16
14
12
10
8
6
4
2
0
1/1/2018
4/2/2018
7/2/2018
10/1/2018
12/31/2018
St. 1, .5 ft
St. 2, 1 ft
St. 3, 2 ft
St. 4, 3 ft
St. 5, 4 ft
St. 6, 5 ft
Temperature

Figure C-12

Appendix D – Isotope Results

		Thomas		L7		Cheney		Lemhi		Jackson		Dup. Well Name	Dup		Diff. Betw. Dup & Sample	
Season	**Date**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**		**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**
Fall	10/7/2015	-128.36	-17.63	-128.96	-17.66	-132.36	-17.13	-136.02	-17.43	-135.14	-17.43	L7	-128.73	-17.40	0.23	0.26
Fall	9/7/2016	-131.92	-17.92	-137.11	-17.68	-136.35	-17.94	-133.46	-17.87	-136.90	-17.78	Cheney	-135.12	-17.79	1.23	0.15
Fall	9/8/2017	-129.09	-17.35	-133.74	-17.11	-135.61	-17.52	-130.40	-17.47	-127.18	-17.35	Cheney	-131.23	-17.65	4.38	0.13
Fall	9/6/2018	-134.21	-18.04	-134.86	-17.46	-132.92	-17.58	-135.02	-17.55	-134.49	-17.69	L-7	-133.04	-17.72	1.82	0.26
Winter	12/3/2015	-135.73	-17.34	N/A	N/A	-135.59	-17.48	-137.94	-18.00	-134.76	-17.48	Cheney	-132.90	-17.22	2.69	0.26
Winter	11/15/2017	-136.37	-17.87	-130.13	-17.98	-129.55	-18.08	-132.69	-18.43	-127.69	-18.01	Cheney	-136.20	-17.98	6.64	0.09
Spring	4/6/2016	-127.64	-17.68	-132.69	-17.25	-129.36	-17.65	-137.83	-17.90	-128.90	-17.73	Thomas	-132.27	-17.72	4.63	0.04
Spring	4/11/2017	-139.11	-17.32	-133.11	-17.81	-141.38	-17.77	-141.62	-17.24	-132.63	-17.20		N/A	N/A		
Spring	4/10/2018	-133.12	-17.44	-134.38	-17.49	-130.03	-17.64	-137.75	-17.95	-133.97	-17.55		N/A	N/A		
Summer	6/10/2015	-137.41	-18.08	-133.71	-17.50	-134.61	-17.67	-132.74	-17.75	-136.49	-17.67	Thomas	-136.77	-17.94	0.64	0.14
Summer	8/6/2015	-132.60	-17.76	-127.78	-17.76	-129.43	-17.64	-130.46	-17.58	-126.53	-17.80	Jackson	-128.77	-17.71	2.24	0.09
Summer	6/3/2016	-129.59	-17.50	-127.85	-17.52	-133.26	-17.73	-133.79	-17.59	-130.26	-17.51	Cheney	-125.43	-17.75	7.82	0.02
Summer	6/7/2017	-130.39	-17.62	-133.68	-18.18	-139.96	-17.61	-136.07	-18.50	-140.54	-17.59	Cheney	-129.41	-17.94	10.55	0.33
Summer	6/13/2018	-132.56	-17.90	-136.13	-17.98	-133.75	-17.95	-136.49	-18.09	-133.62	-17.80		N/A	N/A		
	MAX	-127.64	-17.32	-127.78	-17.11	-129.36	-17.13	-130.40	-17.24	-126.53	-17.20	**MAX**	-125.43	-17.22	10.55	0.33
	MIN	-139.11	-18.08	-137.11	-18.18	-141.38	-18.08	-141.62	-18.50	-140.54	-18.01	**MIN**	-136.77	-17.98	0.23	0.02
	AVERAGE	-132.72	-17.68	-132.62	-17.64	-133.87	-17.67	-135.16	-17.81	-132.79	-17.61	**AVERAGE**	-131.81	-17.71	3.90	0.16
	RANGE	-11.47	-0.76	-9.33	-1.07	-12.03	-0.95	-11.22	-1.26	-14.01	-0.81	**RANGE**	-11.34	-0.76		

Table D-1. Isotope results for the Town of Salmon Sites.

		Hawley		Texas		Lemhi @ L63		Big Eightmile		Lee		Little Springs		McFarland		Lemhi abv Hayden		Hayden		Lemhi @ L1			Dup		Diff. Betw. Dup & Sample	
Season	**Date**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**	**Dup Well Name**	**δD**	**$\delta^{18}O$**	**δD**	**$\delta^{18}O$**
Fall	9/8/2016	-140.00	-18.51	-135.53	-17.59	-135.68	-18.03	-133.88	-17.94	-136.81	-17.87	-145.48	-18.11	-138.21	-18.46	-139.20	-18.38	-135.06	-18.14	-134.25	-17.52	Lemhi abv Hayden	-140.46	-18.28	1.26	0.10
Fall	9/7/2017	-142.82	-18.69	-128.41	-17.56	-137.02	-17.87	-135.50	-17.76	-138.22	-17.26	-136.02	-18.61	-141.56	-17.50	-133.03	-18.35	-133.79	-18.32	-129.40	-17.80	Hawley	-143.15	-17.87	0.33	0.82
Fall	9/5/2018	-138.15	-18.60	-135.23	-17.92	-135.10	-18.06	-134.56	-18.11	-134.89	-18.54	-139.36	-17.84	-137.93	-18.83	-135.58	-18.04	-135.69	-17.92	-135.85	-17.45	Hawley	-137.57	-19.29	0.58	0.68
Winter	12/1/2015	-142.86	-18.83	-141.66	-18.76	-141.38	-18.11	-132.32	-18.57	-140.07	-18.11	-141.88	-18.23	-143.09	-18.58	-139.30	-18.45	-135.44	-18.40	-133.83	-18.15	Big Eightmile	-140.24	-18.46	7.92	0.12
Winter	12/20/2016	-139.36	-19.03	-139.71	-19.13	-136.17	-18.57	-135.23	-18.21	-135.17	-18.37	-137.85	-18.21	-135.67	-18.59	-135.10	-18.61	-133.24	-18.00	-133.52	-18.50	Hawley	-137.84	-19.06	1.52	0.03
Winter	11/14/2017	-141.42	-18.80	-139.99	-18.49	-137.97	-18.48	-135.35	-18.38	-129.63	-18.51	-138.64	-17.88	-130.25	-18.57	-133.84	-18.68	-129.74	-18.02	-135.14	-18.72	Hawley	-136.77	-18.97	4.65	0.17
Spring	4/5/2016	-141.68	-18.49	-131.10	-18.17	-136.46	-18.00	-132.45	-18.52	-129.14	-18.37	-132.00	-18.11	-138.80	-18.47	-135.37	-18.41	-134.31	-17.87	-131.39	-18.07	Hawley	-139.43	-18.89	2.25	0.40
Spring	4/11/2017	-146.89	-18.65	-134.74	-17.98	-136.65	-17.61	-134.69	-17.96	-135.45	-18.25	-137.88	-18.02	-143.00	-18.29	-142.03	-18.43	-137.98	-17.79	-142.41	-17.53	Lemhi @ L63	-137.23	-18.42	0.58	0.81
Spring	4/10/2018	-142.86	-18.39	-138.33	-17.93	-140.26	-17.96	-136.59	-18.12	-138.53	-17.98	-138.31	-17.88	-139.19	-18.26	-138.72	-17.88	-137.58	-18.23	-138.57	-17.87	Hawley	-142.47	-18.34	0.39	0.04
Summer	8/4/2015	-141.16	-18.34	-131.84	-17.87	-136.13	-18.17	-128.78	-17.68	-129.91	-17.93	N/A	N/A	-135.50	-18.36	-134.05	-18.22	-128.86	-17.42	N/A	N/A		N/A	N/A		
Summer	6/2/2016	-139.48	-18.02	-129.72	-17.51	-136.30	-18.15	-129.97	-17.90	-131.40	-17.58	-137.10	-18.02	-135.47	-18.14	-132.80	-18.48	-134.08	-17.66	-134.22	-17.98	Big Eightmile	-132.92	-17.85	2.94	0.05
Summer	6/6/2017	-140.73	-18.53	-140.17	-17.66	-141.55	-18.09	-133.37	-18.62	-138.27	-17.78	-132.71	-18.12	-130.62	-18.35	-135.01	-18.45	-141.79	-18.40	-140.02	-17.79	Hawley	-134.06	-18.78	6.67	0.25
Summer	6/13/2018	-141.47	-18.30	-134.27	-17.66	-137.83	-18.09	-136.68	-18.70	-138.71	-17.87	-136.91	-17.84	-140.27	-18.04	-137.35	-18.36	-137.27	-18.04	-136.23	-18.04	Hawley	-138.26	-18.34	3.21	0.04
	MAX	-138.15	-18.02	-128.41	-17.51	-135.10	-17.61	-128.78	-17.68	-129.14	-17.26	-132.00	-17.84	-130.25	-17.50	-132.80	-17.88	-128.86	-17.42	-129.40	-17.45	**Max**	-132.92	-17.85	7.92	0.82
	Min	-146.89	-19.03	-141.66	-19.13	-141.55	-18.57	-136.68	-18.70	-140.07	-18.54	-145.48	-18.61	-143.09	-18.83	-142.03	-18.68	-141.79	-18.40	-142.41	-18.72	**Min**	-143.15	-19.29	0.33	0.03
	Average	-141.45	-18.55	-135.44	-18.02	-137.58	-18.09	-133.80	-18.19	-135.09	-18.03	-137.84	-18.07	-137.66	-18.34	-136.26	-18.36	-134.99	-18.02	-135.40	-17.95	**Ave**	-138.37	-18.55	2.69	0.29
	Range	-8.74	-1.01	-13.25	-1.62	-6.45	-0.96	-7.90	-1.02	-10.93	-1.28	-13.49	-0.77	-12.83	-1.33	-9.22	-0.80	-12.93	-0.98	-13.01	-1.26	**Range**	-10.23	-1.43		

Table D-2. Isotope results for the Basin-wide sites.

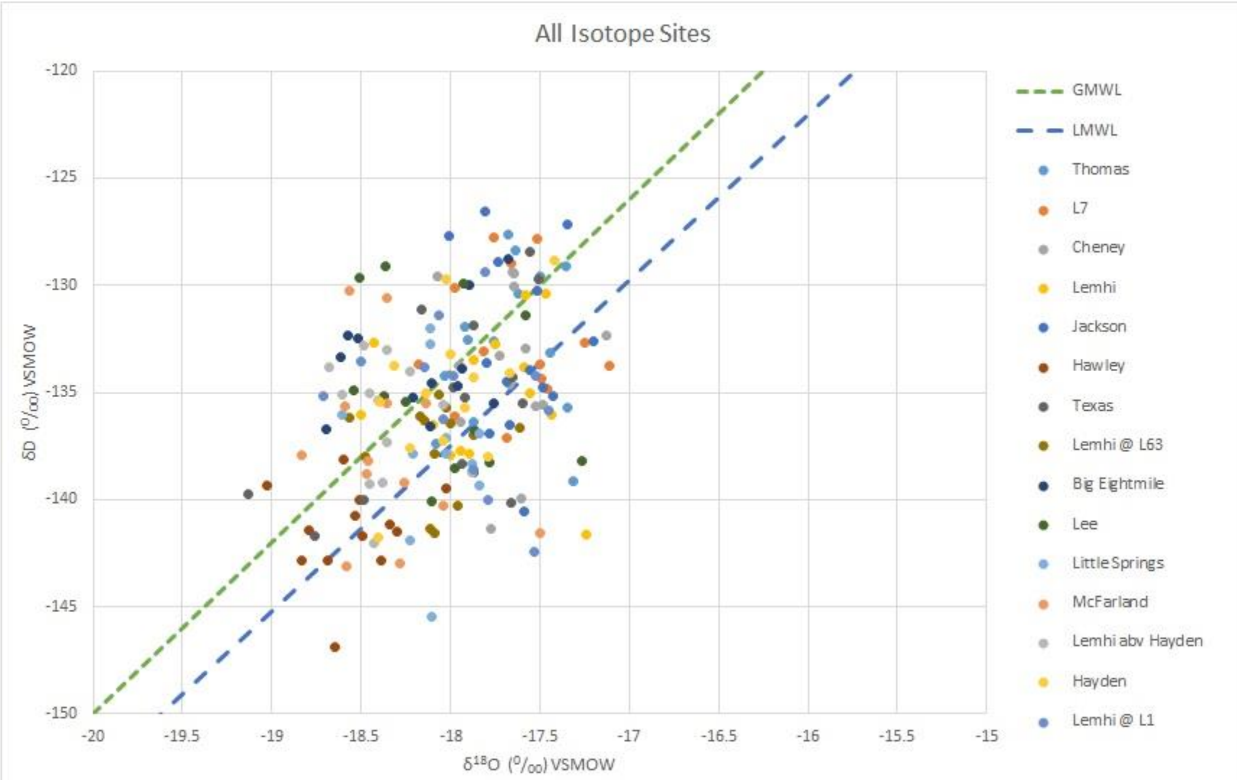


Figure D-1. All isotope data collected in the Lemhi, includes data from Town of Salmon sites and Basin-wide sites. GMWL- Global Meteoric Water Line, LMWL- Local Meteoric Water Line.

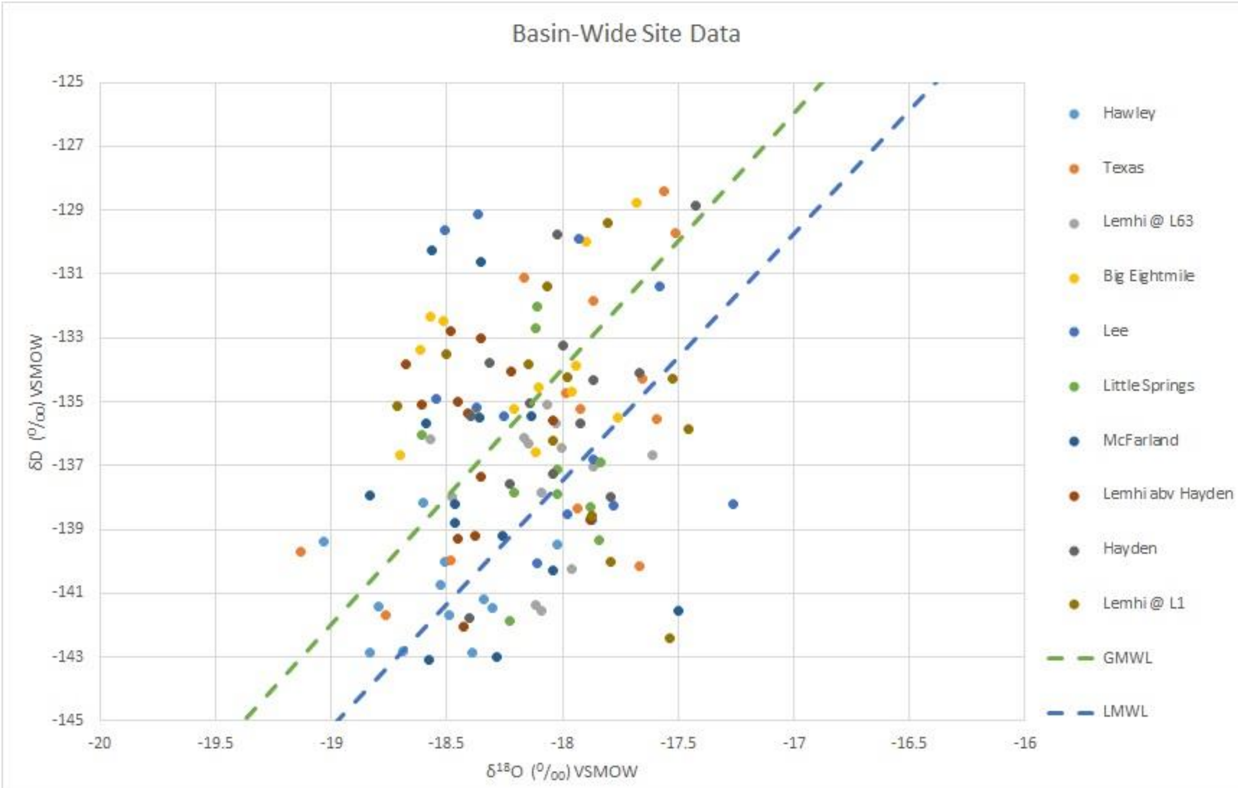


Figure D-2. Basin-wide isotope data collected in the Lemhi. GMWL- Global Meteoric Water Line, LMWL- Local Meteoric Water Line.

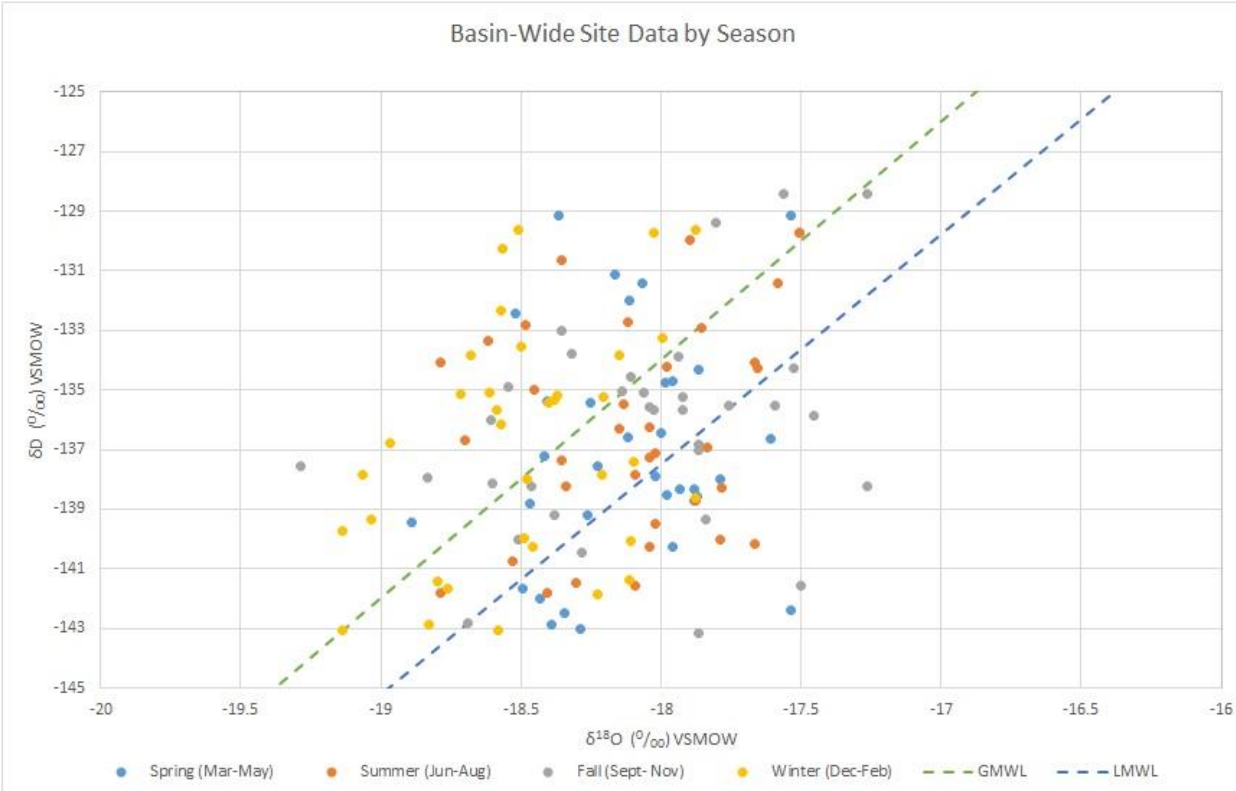


Figure D-3. Basin-wide isotope data collected in the Lemhi graphed by season sampled. GMWL- Global Meteoric Water Line, LMWL- Local Meteoric Water Line.

Figure D-4. Town of Salmon isotope data collected in the Lemhi. GMWL- Global Meteoric Water Line, LMWL- Local Meteoric Water Line.

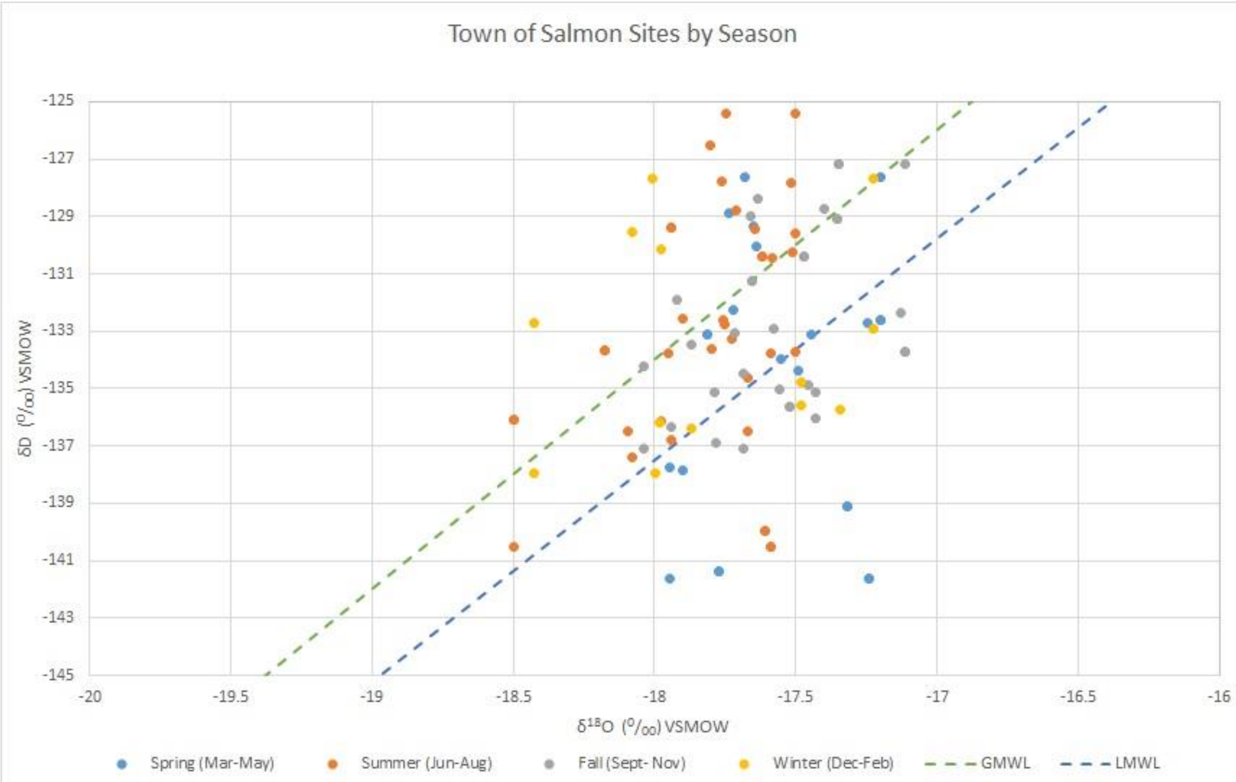
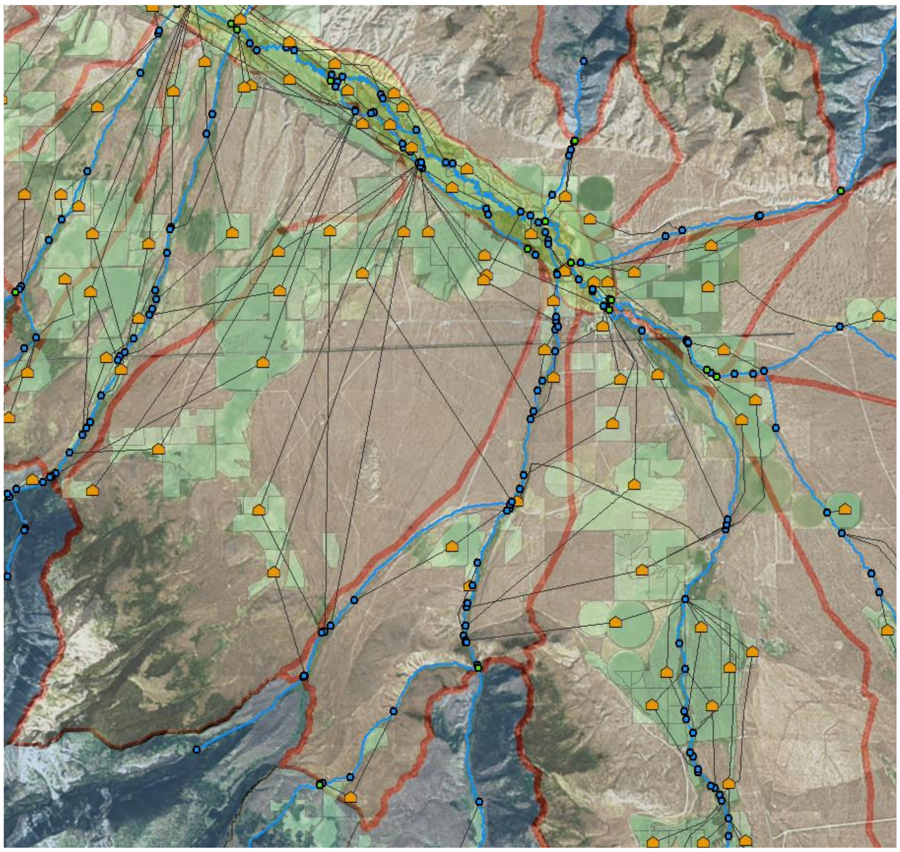


Figure D-5. Town of Salmon isotope data collected in the Lemhi graphed by season sampled. GMWL-Global Meteoric Water Line, LMWL- Local Meteoric Water Line.

Appendix E - LRBM



Lemhi River Basin Model

ANNUAL MAINTENANCE GUIDANCE DOCUMENT

Created for The Idaho Office of Species Conservation
by Carter Borden Centered Consulting International, LLC and
Ryan Warden – Idaho Department of Water Resources
March 2019

Table of Contents

1 INTRODUCTION

Water use in the Lemhi River Basin frequently changes and hydro-meteorological monitoring data is continually being collected. As the LRBM is a 'living' model, to remain relevant the base model, supporting MS EXCEL input files (EXCEL), and scenario graphical user interfaces (GUIs) of the LRBM need to be updated with recent monitoring data and changes in land use/irrigation practices observed during the previous year. IDWR is responsible for the maintenance including changes to the network system and alterations to the input/output interfaces as well as documenting and archiving these changes (Table 1). This maintenance plan provides guidance on how to update, recalibrate, and archive the LRBM and supporting files.

Table 1. Elements to maintain the LRBM and supporting files

Item	Description	Frequency
Update Hydro-meteorological/ Water User Demand Input Files	Time Series, Spatial Data: collect, process, and update input data to the base model	Annually
Model Network	Update the network configuration and operational rules in the LRBM to reflect changes in land use/irrigation practices, water management operations, and water related policies	Update to capture significant operational changes (e.g. change in POD location), systemwide review every 3 years
Supporting EXCEL Files	Update the input/output interfaces to reflect the input variables for baseline conditions and to formulate scenarios. This also includes the output metrics used to evaluate the scenarios	Annually for input files, as needed for addressing new issues
Scenario GUIs	Update Scenario GUIs input/output interfaces to reflect recent data, model network changes, and new scenarios	As needed, input data, model network, and scenarios
Documentation-Model Archive	Annual or upon significant changes to the model, the model, input data, interfaces, software, and supporting documentation is archived in a minimum of two separate servers or storage devices. A filing system will be implemented to expedite the retrieval of archived models with pertinent information	Annually at minimum, with significant changes to the model
Hardware	Update computers, servers supporting LRBM	Update every 2-3 years, should reflect IDWR's hardware policy
Software/Internet Services	Update software supporting the LRBM	Annual maintenance agreements

1.1 LRBM MAINTENANCE AND ARCHIVING PROTOCOL OVERVIEW

Maintenance tasks for the LRBM include:

1. *Time Series Update*. Acquire, process, and append the time series records for the meteorological, discharge, water level, and water quality monitoring information from the previous year. Processing may include resampling time series for the proper interval (e.g. averaging 15-minute data to daily values), gap filling, error checking, etc. Updates are performed annually.

2. *Computational Engine Network and Schematization Update*. These modifications represent physical changes to the water management system. Examples include the addition or removal of structures such as new or altered diversions, storage facilities, pipelines, etc. Updates to the stream network should be reviewed every 3 years and after the completion of restoration projects that change the network configuration.
3. *Recalibration*. Using the calibration locations in the Table 3, check the calibration of the LRBM after entering in the new data set and updating the network configuration. If calibration is deemed insufficient, recalibrate the LRBM according to the methodologies presented in Section 2.3.2.
4. *Support EXCEL Updates*. These changes represent existing or conceived modifications to the GUIs that would be beneficial to include in the standard. Also, modifications to the LRBM network and schematization may dictate a change in the GUIs to represent changes in the system. Note, this will likely be done concurrently when updating the LRBM.
5. *Document Updates*. In a brief word document, outline the updates to time series, spatial data, network, and schematizations for the LRBM and supporting EXCEL files.
6. *Specialized Models Update (optional)*. For models supporting special water management issues, follow steps 1-5. Note, if the issue-based model is currently being used for a study, it is likely unwise to update the LRBM with these changes as the update may slightly change the results.
7. *Archiving the LRBM*. Archive the LRBM and supporting EXCEL files, documentation, and the current version of MIKE BASIN. Optional is to archive issue-based models or fundamental studies that have been performed within the last year and believed to have future applications in function or science. The archived package is stored according to the protocol put forth by IDWR.

The steps and methods for updating and recalibrating the LRBM are outlined in Section 2 with a checklist and protocol for archiving the LRBM in Section 3.

1.2 Hardware, Software, Internet Upkeep

The technology supporting the LRBM involves a PC to run the MIKE BASIN software to simulate scenarios, player versions, and interfaces, as well as storage systems/servers to maintain current and past base versions, store important data sets, and model development documentations (Table 1). At least two storage systems should be maintained on independent storage devices on different networks. Hardware and software storage devices can fail losing a portion or all the information that was being stored. Redundancy on two storage devices in different location lessens the changes that if one device fails (e.g. virus, dropped hardware, fire), a backup copy can be accessed to retrieve the historic data. Hardware and storage will be updated in compliance to the protocol outlined by the IDWR technology polices.

2 UPDATING THE LRBM

Updating the LRBM requires acquiring and pre-processing data, loading input time series, updating calibrating parameters and time series, and checking results. Figure 1 depicts the data flow through the simulation process; depicting when NAM and MIKE BASIN models are employed as well as supporting EXCEL workbooks (see Section 2.4). Steps in the process are:

<u>Formatting and Importing Input Data</u>

1. *Discharge Formatting:* Stream gage and diversion records are collected and then formatted to construct a continuous daily record throughout the simulation period of record. As most stream gages and irrigation diversions are only operational May through October and can exist, missing records need to be filled. Using VBA macros, an EXCEL workbook assists in gap filling the records, constructing a daily flow time series for the simulation period, and transferring the constructed time series into the Water User Input File (Step 2). Formerly, water master reports and the IDWR database reported the water stage in irrigation ditches. The tool converted stage to discharge prior to gap filling. While currently unnecessary, this EXCEL file still contains this functionality.

2. *Water User Input Files:* For each water user node in the LRBM, an input time series file containing water demand, ground water fraction, and deficit carry over time series is required and, if return flow is predicted, a return flow fraction time series. Both time series files are stored in individual DFS0 files that are then "managed" through the MIKE BASIN interface (e.g. read, edit, display) or can be edited directly with DHI's TSObject, which is used when a DFS0 file is opened directly in Window Explorer.

   To coordinate the input time series and compute the return flow fraction time series, EXCEL files are developed for PODs in the upper and lower Lemhi River Basin. For each POD-POU system, the water demand time series from the Discharge Formatting file (Step 1) and the ground water fraction and deficit carry over time series are set to 0. For calculating the return flow fraction, macros use irrigated area, irrigation method, crops grown, and the basin's reference evapotranspiration (ET) to calculate consumption that is then applied to the water diverted for irrigation (DHI 2003, DHI 2006, Borden 2015). Macros are used to automatically load all the DFS0 files associated with each water user node. Files can be saved to document scenario conditions.

3. *Water User Deep Return Flow File:* based on the estimated length of time for the return flow to reconnect with the stream. For POD-POUs with equal to or less than 11 day return period, the return flow fraction is computed using the analytical response equation (CH2M 2014). For all water users employing the analytical response, a file creates the cumulative return flow for each tributary catchment. Macros retrieve the return flow fraction from the Water User Input Files and export them to the appropriate reach gain DFS0.

<u>Computing Catchment Inflow</u>

4. *NAM (MIKE 11 Rainfall-Runoff module):* NAM uses daily time series of precipitation, potential evapotranspiration, and temperature to estimate the expected runoff. Input files are MIKE 11

setup files (SIM editor, RR editor) and DFS0 time series files and output files are MIKE 11 results files (.res11).

5. *Catchment Inflow Input File:* Extracts time series from NAM results files and imports into the DFS0 files representing catchment inflow in LRBM. In addition, runoff time series can be compared to USGS Stream Stats results.

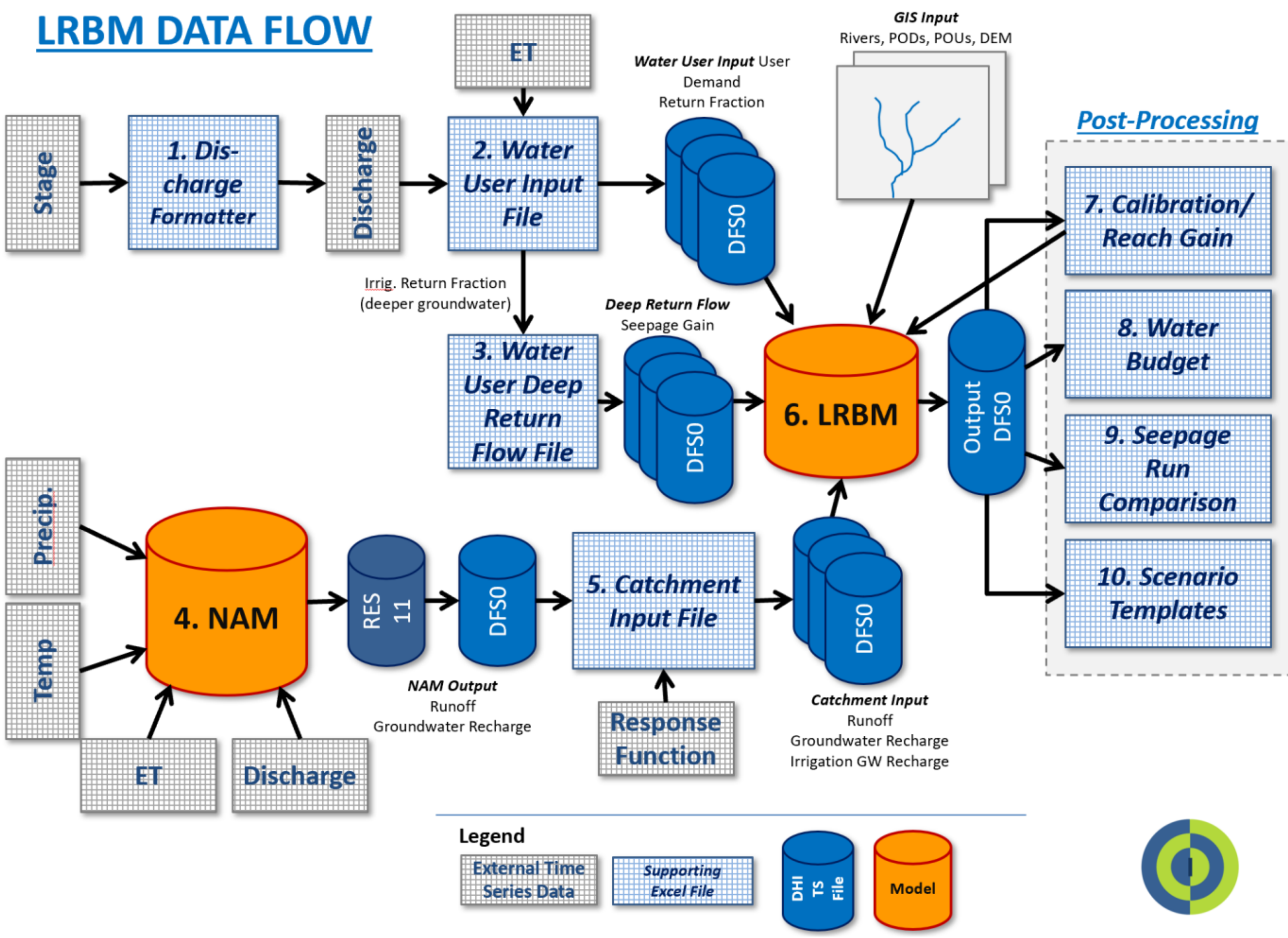


Figure 1. Data flow in for using the LRBM.

<u>Simulations and Post-Processing</u>

6. *LRBM*: MIKE BASIN GUI interface and computational engine organizes input, runs scenarios based on input variables and time series, and displays output. Note, after externally updating and saving input DFS0 files, the file references in the LRBM geodatabase must be updated. If only a few time series where modified, then the reference can be updated manually by opening the files in the time series tab in the LRBM GUI. If many files were updated, then the best means is to sss and sss the geodatabase. Warning, if you have multiple simulations in the model, this update can take a very long time. To avoid this issue, delete old scenarios. This will result in a loss of feature - time series connection in the MIKE BASIN GUI, but the results DFS0 is still

available and key connections can be manually reconnected for display and analysis at a future time.

7. *Calibration, Reach Gain Computations*: Import LRBM results for direct comparison with stream gage records. To support calibration, allows users to run the LRBM repeatedly with randomly changing the return flow lag factors to determine the best values. Once calibrated, the EXCEL file computes and loads the reach gain time series to LRBM's DFS0 input files. Table 1 lists the available gages in the
8. *Water Budget:* Water budget uses NAM and LRBM results to compute the water budget for the basin. The EXCEL workbook also contains hydrological norms by which to assess the simulation results. Macros load and process simulation results into the analysis.
9. *Seepage Run Comparison:* Compares LRBM results with historical seepage runs values in the Lemhi River for validating if baseline results correctly characterize the loss/gain of the stream network. *Seepage Run Excel Sheet Overview.docx* provides supporting documentation for use of the spreadsheet.
10. *Scenario Templates:* Post-processes LRBM results in a customized result template in EXCEL to evaluate scenarios. Macros are available from previous templates that transfer the results into the EXCEL file, reprocess to monthly values, and compute statistics.

This chapter provides background on how to acquire, preprocess, and load the data into the LRBM and supporting EXCEL files.

2.1 Data Required for Inputs

Before updating the LRBM, recent hydro-meteorological data and changes to the system need is obtained. This section discusses the data sources, the relevant data to obtain, and how to download the information.

2.1.1 Changes in the irrigation network.

The baseline LRBM was created from the USGS NHD GIS layer, IDWR POD and POU GIS layers, and consultation with water masters. As diversions PODs and POUs change, the model network configuration needs to be updated accordingly. Likely, this should be done after a water right transfer or restoration project has been completed. Note, routing water in MIKE BASIN is not based on channel configuration or geometry, so it is the relative placement of connecting arcs that is important (e.g. where in relation to diversions and return flow locations).

2.1.2 Weather station data

<u>Snotel Data</u> – Daily values of precipitation increment and accumulation as well as air temperature minimum, average, maximum, and average. How to obtain:

- Download data from the NRCS link: https://www.wcc.nrcs.usda.gov/snow/snow_map.html
- Station names: Lemhi Ridge (576), Bloody Dick (355), Dark Horse (436), Schwartz Lake (915), Beagle Springs (318), Meadow Lake (620), Moonshine (363)

- Click on ‘Precipitation’ under the Station Inventory. Use the interactive map to scroll to the Lemhi Valley. Hover over each station to identify them. Once the correct station is found, click on it and then click on ‘Site Page’.
- Under Site Reports: Click on the Daily (CSV Delimited) Link under the Historical column. This will generate all data for the station in comma delimited format in the browser.
- Copy and paste the data into an EXCEL Sheet. Name the tab by the site name and convert the text to columns under the Data tab menu.

RAWS Weather Data – Daily values of solar radiation, wind, air temperature, relative humidity, and precipitation. How to obtain:

- Download data from the RAWS USA Climate Archive link: http://www.raws.dri.edu/, Station names: Salmon Idaho and Leadore Idaho.
- On left side bar, click ‘Daily Summary Time Series’.
- Select the dates for the start and ending of the time series.
- Check the box for ‘Elements marked with *’.
- Check ‘Downloadable Ascii.
- Click ‘Submit Info’ (Leave everything else as default).
- Copy and Paste data into an EXCEL sheet and format data.

2.1.3 Climate Data

PRISM data – 30-year normal for precipitation and mean temperature: monthly and annual. How to obtain:

- Download datasets at the PRISM Climate Group: http://www.prism.oregonstate.edu/
- Use 30-year normal at 800 m resolution for precipitation and mean temperatures on monthly values and annual values.
- The 2017 LRBM is using the 1981-2010 dataset. The next dataset will be available after the next decade, 2020.
- PRISM data is in mm.

METRIC data – IDWR and University of Idaho computes and maps of actual ET using Landsat images. Each data set is for a given year and month. Data will be averaged between all data sets available to create an average. How to obtain:

- Data sets are accessed internally at IDWR State office. Current folder path is X:\Spatial\METRIC (IDWR internal server).
- Years used in the 2017 LRBM version are 1996, 2000, 2006, 2008, 2009, 2010, 2011, 2013, and 2016.
- METRIC data is in millimeters.

2.1.4 Stream Flow and Diversion Data

Streamflow data – USGS, IDWR staff, IDWR Contractors, Idaho Power collect streamflow data and post to the web.

- Daily mean flows are used in the LRBM and NAM for processing and calibration.
- Current gage stations in the Lemhi Basin for water year 2017 are:
  - IDWR monitored – Hawley Creek, Texas Creek, Big Eighteenmile Creek, Big Eightmile Creek, Lee Creek, Upper Bohannon Creek, Pratt Creek (installed April 2017)
  - IDWR Contracted – IWE: Agency Creek, Upper Big Timber Creek, Upper Big Eightmile Creek, Upper and Lower Big Springs Creek, Lemhi River above Big Springs, Lemhi River at Cottom Lane, Lower Bohannon Creek, Lemhi River at L-63, Lower Little Springs, and Hayden Creek.
  - Idaho Power: Lower Big Timber Creek, Canyon Creek, and Kenny Creek.

Table 1. Reach gain locations available in the model

Gage Name	Operator*	Start	End	Catchment Type	DHI Catchment	Reach Gain	DHI Arc	Use^
Agency Creek	IWE	2005	Present	Headwater	C299	N2394	E4969	RG
Big Eightmile Creek (Upper)	IWE	2005	Present	Headwater	C215	N1093	E2839	RG
Big Eightmile Creek (Lower)	IDWR	2008	Present	Pediment	n/a	N1423	E2693	RG
Big Springs Creek (Lower)	IWE	2005	Present	Valley	n/a	N1305	E2635	RG
Big Springs Creek (Upper)	IWE	2008	Present	Pediment	n/a	N1427	E2931	RG
Big Timber Creek - Lower	IPCO	2004	Present	Pediment	C250	N1463	E2828	RG
Big Timber Creek - Upper	IWE	2005	Present	Headwater	C222	n/a	n/a	RG
Bohannon Creek - Lower	IWE	2008	Present	Pediment	n/a	N2296	E4240	RG
Bohannon Creek - Upper	IDWR	2013	Present	Headwater	C303	n/a	n/a	RG
Canyon Creek	IPCO	2008	Present	Pediment	C252	N1420	E2687	RG
Eighteenmile Creek (Long-term)	IDWR	2006	Present	Pediment	C241	N1466	E2834	RG
Hawley Creek	IDWR	2008	Present	Upper	C208	n/a	n/a	RG
Hayden Creek	IWE	1997	Present	Pediment	n/a	N2165	E4726	RG
Kenney Creek (Upper)	IPCO	2004	Present	Headwater	C319	N2687	E5013	RG
Kenney Creek (Lower)			Present	Pediment	C320	N2688	E5014	RG
Lee Creek	IDWR	2009	Present	Pediment	C274	N1468	E3506	RG
Lemhi at L-5	USGS		Present	Valley	n/a	N2793	E5243	RG
Lemhi River abv Big Springs Ck	IWE	2005	Present	Valley	n/a	N1304	E2286	RG
Lemhi River abv L-63	IWE	2008	Present	Valley	n/a	N1464	E3486	RG
Lemhi River at Baker		2004	2009	Valley	n/a	N2074	E4642	RG
Lemhi River at Cottom Lane	IWE	2005	Present	Valley	n/a	N1303	E2284	RG
Lemhi River at Hayden		2004	2009	Valley	n/a	N1404	E2616	RG
Lemhi River at Lemhi	USGS		Present	Valley	n/a			RG
Lemhi River at McFarland				Valley	n/a			RG

Campground								
Little Springs Creek (Lower)	IWE	2008	Present	Valley	n/a	N1470	E2844	RG
Little Springs Creek (Upper)		2008	2016	Pediment	n/a	N1469	E2842	RG
Pratt Creek	IDWR	2017	Present	Pediment	n/a	N1469	E2842	RG
Texas Creek	IDWR	2008	Present	Pediment	C248	N1465	E2832	RG

* IWE is contracted by IDWR to maintain this gage

^ RR = rainfall-runoff, RG = reach gain

Diversion Data - IDWR databases hold contain diversion records for some of the PODs, but a request to the water master for an electronic file of the diversions can expedite compilation of the records. Appendix A lists the diversions with records is found in the IDWR database.

- Water District 74 diversion data is entered into IDWR Diversion database (DWR Central) and can be downloaded from the database once the data is inputted by the water master.
  - https://idwr.idaho.gov/apps/wm/DiversionDataApplication/Login.aspx
  - Districts data sources and processing requirements listed below (Table 2) found on the public website under Active Districts and searching for 74

Table 2. Sources of diversion records for Water Districts in the Lemhi River Basin.

Districts	Source
74, 74A, 74B, 74F, 74G, 74J, 74M, 74Q, 74U, 74Z	IDWR's public website* under "Active Districts", search for 74
74C	Electronic file format - Jerry Elsinga
74W	Electronic file format - Dan Smith

* https://idwr.idaho.gov/water-rights/water-districts/active.html

Considerations: water master diversion records are scanned pdfs of the water master's notes and will need to be converted into EXCEL. There are several factors that need to be considered when evaluating and formatting the input time series to the LRBM. They include:

- Not all the districts will report the daily diversion as some will report on a monthly basis and others will not be reported. For the latter, we use water right information to estimate the diverted waters. If monthly data is supplied, then the water right can be used to add up to the monthly amount.
  - High water diversions rates vary by water master. For those that report high water diversion rates, the values include diverted high water, so monthly diversion quantities will be over the diverted water right. For water masters that do not record high water diversions, they might only show the water right being diverted when in fact more water is being taken. Either high water would be ignored or would be guessed as to when and how much being taken on top of water right.

- Water master records can also be reported by the water rights, the water rights owner (several water right and/or diversions combined), by the diversion, or by whatever they thought made sense at the time.
  - It will require educated guessing on how to sort out the records, so they can be put into the LRBM.
  - Note that the LRBM tries following the ground truth of the diversions, but lumps together POUs more than it follows the exact PODs. One should allow a significant amount of time and effort into estimating how to put the water master's records into the LRBM framework.
  - An EXCEL workbook has been developed to automatically interpolate between records *Diversonflows_interpolator_yyyy.xlsm*. For gaps in the diversion records, the interpolation tool fills in daily diversion data to derive a daily time series. For gaps bounded by two positive values, the tool linearly fills in the time series. If the gap is bounded by a 0, then all days in the gap are treated as 0 as it is unknown when the diversion was off and on during that time period.

2.2 Processing of Raw Data

2.2.1 Climatic data supporting rainfall-runoff

PRISM Data – Each month (January through December) will need to be processed through ArcGIS. The steps for formatting PRISM data in ArcGIS are:

- Convert PRISM data from ASCII to Raster using: *Conversion Tools>To Raster>ASCII to Raster*
- Define the Projection to Nad1983 using: *Data Management>Projections and Transformations>Raster>Define Projection*
- Clip PRISM to Top= 45.5, Bottom, 44.3, Left= -114, Right-112.5, No Data Values=-9999 using: *Data Management >Raster>Raster Processing>Clip*
- Project Raster to WGS84, cell size = .008333333 using: *Data Management>Projections and Transformations>Raster>Projection*
- Convert Raster to ASCII using: *Conversion Tools>From Raster>Raster to ASCII*
  - Example File name for precipitation is "us_ppt_8110_30s.01.txt" for January, where the ppt, stands for precipitation, 8110 stands for the 1981 to 2010 prism dataset, 30s is the resolution, and 01 is the month. Name each accordingly for each month, all else should stay the same.
  - Example File name for Temperature is "us_tavg_8110_30s.01.txt"

METRIC Data – Each month (January through December) will need to be processed through ArcGIS as well as the select year's average together for each month. For winter months (November, December, January, February, and March) are simply a duplication of the October ET, which is probably an over estimate, but the closest estimate with the data available. The steps for formatting the monthly METRIC data in ArcGIS are:

- For each month of a given year:
  - Project METRIC data to WGS84 (Save in step on folder) using: *Data Management>Projections and Transformations>Raster>Projection*

- Clip to Top= 45.3, Bottom= 44.3, Left= -114, Right= -112.75, No Data values= -9999 (Save in Step two folder separated by month, ie. 04, 05, 06, etc.) using: *Data Management >Raster>Raster Processing>Clip*

- Then for each month folder
  - Use Cell Statistics to average (mean) the years together for each month using: *Spatial Analyst Tools>Local>Cell Statistics*
  - Convert Raster to asci (Save in folder 'Text files for Script') using: *Conversion Tools>From Raster>Raster to ASCII*
    - Note: the naming convention should be "et_avg_04.txt", where the number is the month of the year. (The Interpolation Tool Script will not recognize any other naming convention)

<u>Weather Station Data</u> - Weather data is processed through the PRISM Interpolation tool, REF-ET calculator, and in an EXCEL worksheet. The processed weather station data is used in NAM and the estimated outflow gets imported into MIKE BASIN as the catchment inflow boundary condition. The weather station data will be sorted and organized by precipitation (in inches) and by temperature (in Celsius).

- Column order should be Time (Date), Beagle Springs, Bloody Dick, Dark Horse, Lemhi Ridge, Meadow Lake, Moonshine, Schwartz Lake, Salmon, and Leadore.

- Start data at 10/1/1995 to present. Some stations were operational before that time, but the interpolation tool performs oddly when a station all sudden turns on.

- The Salmon and Leadore precipitation will not be included with the other stations. Those two stations have very low precipitation, so they lower the spatial interpolation of precipitation to under predict catchment values. Their temperature data is used in the interpolation tool and will be complied with the other stations.

- Once compiled, they need to be saved as a comma delimited text file to be run through the PRISM interpolation tool. File naming example is "LemhiRain.txt" "LemhiTemp.txt", or "LemhiET.txt". Save the files as an EXCEL ".csv" file and then renamed/change file extension in Window Explores, i.e. change the .csv to .txt, and a pop-up window will ask if you really want to change the file extension and that it can make the file unstable, but click yes.

- The temperature data needs to be reviewed. Data with a value of -9999 for no data will need to be averaged with the points around it for that station. If the no data (-9999) goes through the Interpolation tool, it uses that number and give an erroneous temperature. By linear interpolation the station data then the output data will be consistent.

- The Salmon and Leadore stations will also need to run through REF-ET. REF-ET uses the solar radiation and other data to compute the ET. The Salmon and Leadore Station data will need to be saved as their own csv file.
  - The file formatting can have two headers, first one for the data type and the second for the units.
  - The column should be (parenthesis second header) Month, Day, Year, Day of Year, Day of Run, Solar Radiation Total (ly.), Wind Speed Ave. (mph), Wind Dir Vector (deg.), Wind Speed Gust (mph), Air Temp Ave. (F), Air Temp Max (F), Air Temp Min (F), Relative Humidity

Ave.(percent), Relative Humidity Max. (percent), Relative Humidity Min.(percent), Precipitation Total (inches).

2.2.2 Diversion Data

Diversion Data – Depending on how the water master reports the daily records, this may require a lot of processing or sorting in EXCEL. Sometimes it is reported by the diversion (easiest sorting), by property/water rights owner, by water right number, or some combination of these.

- Diversion data is typically reported from a scanned pdf of the handwritten water master records. These need to be keyed into an EXCEL sheet. Use the worksheet "Diversionflows_interpolator.xlsm" to interpolate between gaps in the diversion records. The ReadMe tab explains how to use interpolation macro. Once all the diversion records are in an EXCEL spreadsheet, sort the records by diversions, using the MIKE BASIN assigned diversion. The Water Rights layer in hydrologic GIS layer can help match up diversions to the water user nodes in MIKE BASIN.
- Once the diversion data has been compiled and sorted to the MIKE BASIN diversion, it can then be copy pasted into the EXCEL workbooks named *UpperLemhi_LRBM_inputTS-v#.xlsm* and *LowerLemhi_LRBM_inputTS-v#.xlsm*. The "Reference" sheet in both files can be used to locate the sheet and column for the diversion.
- For the Water District 74, a macro can be used to load the data from the downloaded EXCEL file into *UpperLemhi_LRBM_inputTS-v#.xlsm* and *LowerLemhi_LRBM_inputTS-v#.xls*.
    - The Macro run button is located on the "Reference" tab under the heading "Load Historic Data". The data file must be placed in the same folder as the input sheets and be open. Hover over the input fields/cells to get instruction on how to fill out and run.
    - After the macro has ran, the Data Quality macro can then be run to evaluate the imported data.

2.2.3 Stream Gauge Data

Stream Flow Data -

- After being processed through Aquarius to get daily flows compiled the stream flows in the "*AllStreamData_…*" EXCEL sheet. This sheet will be used to load the (copy and paste) the data to steps that use it.
- Places that use the stream gage data are:
    - *ReachGainCalculator_Lemhi_v#.xlsm*. Used to calculate reach gains/losses in the LRBM by comparing the modeled streamflow to gages.
    - MIKE 11, copy-paste data into the gage files "IDWR Gages" and "ContractedGages".

2.2.4 Computing REF-ET

Refer to the REF-ET User's Manual for instruction on how to run the tool. Current user's manual file name is "Ref ET V3.1 Users Manual.pdf" can run search in window explorer to locate it.

- The calculations are run for the:
    - "full" ASCE Penman-Monteith with resistances by Allen et al, 1989 for ETo and ETr
    - "full" ASCE Penman-Monteith with user supplied surf. resistance for ETo and ETr

- Standardized form of the ASCE Penman-Monteith by ASCE 2005 for ETo and ETr
- 1982 Kimberly Penman (Wright, 1982; 1987; 1996) for ETo and ETr
- FAO 56 Penman-Monteith (1998)1 with resistance for 0.12 m grass for ETo and ETr
- 1972 Kimberly Penman (fixed wind func.) (Wright & Jensen 1972) for ETo and ETr

- The ETo assume the ET for alfalfa and the ETr assumes the ET for grass. The six calculation methods are then averaged each for Eto (alfalfa) and for Etr (grass) as well as averaging all the calculations for each day time step. The ET will also need to be converted to in/day from mm/day.
- The total average (all the calculations) for each day time step will be used in the PRISM interpolation tool. This data needs to be compiled into another spreadsheet, then saved as a comma delimited text file. The csv file will be in the PRISM Tool Folder under Input_ET.
- The averaged ETr, averaged ETo, and the total averaged ET will be complied and entered into the *UpperLemhi_LRBM_inputTS-v#.xlsm* and *LowerLemhi_LRBM_inputTS-v#.xlsm* spreadsheets in the tab "ETRate". Compile the data in columns S, T, U. The precipitation data will also be added in the ET tab in column W. The Salmon data goes into *LowerLemhi_LRBM_inputTS-v#.xlsm* and the Leadore data goes into *UpperLemhi_LRBM_inputTS-v#.xlsm*.

2.2.5 PRISM Interpolation Tool

2.2.5.1 Installation

You must have Python 2.4 installed separately. (This comes with ArcGIS 9.2, so if you have that installed, you probably have Python 2.4.). Python must be installed at "C:\Python24\". To install:

- Copy the "RainInterpolation" folder to your local hard-drive (it will not work from a network drive).
- Run the two installers in the "libs" directory:
  - *"numarray-1.5.2.win32-py2.4.exe"* installs a Python compatible library which is required by the tool to work with arrays.
  - *"wxPython2.8-win32-unicode-2.8.7.1-py24.exe"* installs the GUI components for Python so the input dialog can be displayed.

Test the installation by running the "RainSurf.bat" batch file. This will bring up a dialog with input parameters already set to use the sample data that comes with the program. You may want to shorten the run period to just a few days (e.g. 2006-01-01 to 2006-01-07) for testing. The output will be written to the "output" subdirectory (see "Output" section below). Some progress information will be displayed in the command window behind the dialog.

2.2.5.2 Methodology

This tool was written to work for rainfall data and makes certain assumptions about the input data:

- The tool is adapted from Luzio, et al. (2008) to construct retrospective gridded daily precipitation and temperature datasets for the conterminous United States.
- The spatial reference of the grid data should be in decimal degrees, using the WGS 1984 spheroid.
- The units for the data are *mm/month* for the input prism grids and *inches/day* for the rainfall time series. Output is in *inches/day*. The script does the conversions.

- The script only works with input time series that have daily time steps. Output is in daily time steps as well.
- The methodology uses relative (percent) differences between the station rainfall data and the monthly averages.
- The precipitation script follows the Luzio, et al. (2008) equations.
- The temperature script follows the Luzio, et al. (2008) equations but uses the Fahrenheit for the PRISM and the daily station data.
- The Evapotranspiration script follows the Luzio, et al. (2008) equation, but uses ET values from the METRIC data and ET values in inches derived from ET Idaho using daily station data. The Output is biased towards the METRIC database since it has a better spatial representation then the two weather stations.

Required Input Files. The following files should be in the "Input" sub-directory:

- Parameter file (parameters.txt): Contains input parameters which are set in the GUI dialog. Only needs to be edited if you are using the non-GUI interface.
- Stations file (StationData.txt): This file lists the rainfall gauge names and locations. The name of this file is entered in the parameter file (or GUI) and can be named anything.
- Station time series: This file contains the rainfall time series data for each station (see "LemhiRain.txt" for an example of the data format). The names of the stations in the header must match the names in the stations file. The name of this file is entered in the parameter file (or GUI) and can be anything.
- Basin grid. This is an optional file in ESRI ASCII grid format with the basin areas delineated. Each basin should be identified with a unique integer value. It is used to output summary data for each basin. The name of this file is entered in the parameter file (or GUI) and can be anything.

PRISM data representing mean monthly rainfall should be located in the "Prism" subdirectory. These are in ESRI ASCII grid format. The climatological data must have names in the format *us_ppt_7100_30s.01.txt* where "7100" represents the years (1971-2000) or "8110" represents the years (1981-2010), "30s" is the resolution in arc seconds, and "01" represents the month. A month of "14" is the annual mean rainfall.

2.2.5.3 Output

There are three output file types. The last two are optional:

- A grid-time series file (*rain_for_dfs2.txt*). This is an ASCII file that can be directly imported into a MIKE ZERO dfs2 file and contains the entire 2D time series for the area. To import, create a new dfs2 file in MIKE ZERO and select "From Ascii File".
- Individual daily output grids. These are in ESRI ASCII grid format and contain the rainfall distribution during each day of the requested time period. This is optional and can be toggled off in the parameters file (or GUI).
- Summary data by basin. If a basin grid was used in the input, the mean rainfall per day in each basin is output to a file specified in the parameters file (or GUI). To toggle this off, leave the basin grid file blank in the input, or use a name which does not exist in the input directory.

2.2.5.4 Running the Tool

SIR_GUI.py is the main python code to run. It will pop up a GUI window that will generate the *parameters.txt* for the script. *SIR_main.py* is the script that runs the whole tool. There are three version of the main (precipitation, temperature, and ET) each one has a change in the code so that it looks for the correct files and does the correct computations. There are three folders needed for the script;

- input - stores the input files including:
    - *LemhiRain.txt, LemhiTemp.txt*, and *LemhiET.txt* are station time series data for precipitation, average temperature, and ET, respectively.
    - *StationData.txt* includes the station coordinates with file name (absolutely must be in the same coordinate system as the grid).
    - *Basingrid.txt* is the grid file that defines the basins and area extent to analyze. This grid needs to be projected in WGS84 and cells aligned to the PRISM files. The grid needs to extend out to all the weather stations, a dummy catchment will encompass all the area outside of the Lemhi Basin.
- prism - stores the PRISM files for precipitation, temperature, and the averaged METRIC ET data.
- output - stores the interpolated data from the PRISM interpolation tool.

Put the correct input files into the input folder and make sure the PRISM files in the prism folder are named correctly. Folder structure is done in way to keep precipitation, temperature, and ET in their own corresponding folder and just copy and paste the folder contents into the input or prism folder. Open the corresponding SIR_main script (ie. *SIR_main_P.py, Sir_main_T.py,* or *SIR_main_ET*) with IDLE and re-save as *SIR-main.py*. This will put the correct code into the script for the right variable.

Double click on the GUI which will bring up a new window. Fill in the start and end dates and file names in the input folder. The analysis extent is:

- Left longitude = -144.0
- Right longitude = -112.5
- Lower latitude = 44.3
- Upper latitude = 45.5

Create a name for the output file that corresponds to the variable being interpolated. Check the box "Use basin grid as analysis extent of rainfall grid". Check the radio button "Climatological mean of monthly precipitation". Clicking on Run will start the tool.

This can be where the frustration of the tool may occur. In the DOS Command window, the tool will show the progress of the interpolation as well if the tool errors out. The window will show where it errored out and the user will have to problem solve what the error means. Usually the error is because of incorrect formatting in the input files. The files must be exactly formatted for the tool to run, so check the files closely.

2.2.5.5 Processing Output Data

All output data will need to be reviewed for errors. Open the output text files (precipitation, temperature, and ET) in its own EXCEL worksheet. The data is formatted by date and basin. The output data will need to be processed into calibration basins. The calibration basins are aggregated basins that encompass all the headlands above stream gages just below the headwater basins. Those calibrations basins are Big Eightmile Upper, Big Timber Agg (Big Timber Upper, Big Timber Lower Trib, Big Timber Lower), Agency Agg (Agency Upper Top, Agency Upper Cow Creek, Agency Upper), Hawley Agg (Hawley Upper, Hawley Lower), Bohannon Upper Top. The basins are aggregated by taking the percent of the basin area covered by the aggregate basin then multiplying the data for the basin together and then adding all the basins together for the aggregate basin.

2.3 Calibrations

2.3.1 MIKE 11 Rainfall-runoff (NAM) Calibrations

MIKE 11 Rainfall-runoff (RR) module using the NAM method is used to estimate runoff in each catchment. For each gaged catchment (Table 3), NAM is parameters are calibrated to best simulate the observed conditions given catchment averaged rainfall, potential ET, and temperature. The parameters defined in the calibrated catchments are then extrapolated to other catchments with similar physical and hydrological characteristics. NAM results will be loaded into the LRBM as inputs into the catchment inflow. Description of the input time series, parameters, and initial conditions for each catchment include:

Input Daily time series:

- Precipitation (Pavg) – area-weighted average, determined using PRISM Interpolation tool, a Python program with PRISM, SNOTEL data
- Temperature (Tavg) – area-weighted average, determined using PRISM Interpolation tool, a Python program with PRISM, SNOTEL, and RAWS data
- Evapotranspiration (Ea,avg) – area-weighted average, determined using PRISM Interpolation tool, a Python program with METRIC and RAWS data processed through Ref ET. The dataset will need to be increased from it processing from the PRISM interpolation tool. The data from the tool represents actual ET and the rainfall-runoff requires potential ET. Increase the ET by the percentage needed for the Canyon Aq catchment data (the catchment the weather gage falls in) to be similar to the Leadore Ref ET data set. 2017 update increased the ET dataset by 200%
- Snow melt coefficients (Csnow) – scaled from Tavg; accounts for melting rates that vary according to seasonal factors, such as albedo, relative humidity, and solar radiation. Csnow units are mm/day•°C and are calculated by Csnow = 0.0614 * x + 1.519 where x is the daily Tavg for the catchment. Also run an "if" statement in EXCEL so that if a Tavg is less than -8⁰ C then Csnow is = 1; example =IF(Sheet1!B3<-8,1,0.614*Sheet1!B3+1.519)
- Observed runoff – stream gauge data

Catchment characteristics:

- Total catchment area – calculated with ArcGIS Calculate Areas tool or Zonal Statistics
- Elevation zones:
    - Number of zones: 7 zones on whole Lemhi Basin using *Natural Breaks* (Jenks) on a DEM
        - Breaks were done at 1192-1609, 1609-1875, 1875-2097, 2097-2327, 2327-2558, 2558-2806, and 2806-3454.

- The natural breaks (Jenks) is then converted to polygon shapefile
- In ArcToolbox use *Analysis Tools=>Overlay=>Inters*ect to join the 7 elevation zone shapefile and the catchment shapefile from MIKE BASIN
- In the new Intersected shapefile, add a new field for text data and use the field calculator combine the catchment name and the grid code to produce a unique identifier for statistics. Use code str(Gridcode) to turn the integer grid code to a string, so that it will be added to the string catchment name.
- The DEM, and/or PRISM data may need to be resampled to a 30 x 30 m grid for it to calculate area within the 7 zones.

▪ Average elevation of each zone – determined from elevation zone raster table; In ArcToolbox use *Spatial Analyst Tools => Zonal=> Zonal Statistics* as Table

- Use the *Intersected Zone* and catchment shapefile with the DEM to find the spatially averaged elevation for each zone in a catchment.

▪ Area of each zone – calculated with ArcGIS *Calculate Areas* tool or sum up the raster cells from the *Zonal Statistics* and multiplying by 30 x 30 m grid size. (900 m^2 x number of cells = zone area)

▪ Precipitation – Using the intersected zone shapefile, the catchment shapefile, the PRISM dataset for annual precipitation, and the process precipitation from the interpolation tool. Use the *Zonal Statistics as Table* to get the average annual precipitation (PRISM) for each catchment and each zone. Compile and then calculate in EXCEL spreadsheet.

- Precipitation correction factor (Pc) – Using the *Zonal Statistics as Table* from the intersected zones and the annual mean PRISM data producing the spatially weighted annual mean precipitation and then the spatially weighted mean elevation for each zone in a catchment, find the linear regression between the mean annual precipitation and mean elevation for each zone in a catchment. The regression is then multiplied by 100 and then divided by the mean annual precipitation from the Interpolation Tool to produce the lapse rate Pc (percent/100meter).
- Reference elevation for precipitation (Epr) – Calculate the annual mean precipitation from the interpolated precipitation data for each catchment. First sum the precipitation for each year and then average the years together. This value will be used to find the reference elevation. Using the *Zonal Statistics* from the intersected zones and PRISM data, find the spatially weighted mean for each zone in each catchment using the Annual Mean PRISM data. Match the zone closest to the annual mean from the interpolated data. That zones average elevation will represent the reference elevation for precipitation.

▪ Temperature correction factor (lapse rate, Tc)
▪ Reference elevation for temperature (Etr)

<u>Initial conditions:</u>

- Relative water content in surface zone (U/Umax) – Set to 0
- Relative water content in root zone (L/Lmax) – Set to 0
- Overland flow (QOF) – Set to 0

- Interflow (QIF) – Set to 0
- Upper baseflow (BF) – Set to 0 cfs
- Lower baseflow (BFlow) – If known should match historic inflows. If unknown, can either set to 0 cfs or median USGS Stream Stats values for the catchment. Median values can be found in *StreamStats_MontlyAnnual_2015_v02a.xlsm*
- Snow storage – Set to 0 cfs

2.3.3.1 Calibration of Aggregate Basins

NAM calibration involves adjusting catchment parameters to achieve the best match between observed and simulated discharge given the modeling objective. For the NAM modeling, all other catchment parameters are iterative model calibrations, using various combinations of manual and auto-calibration techniques. Upper and lower limits of each parameter are converged upon successive iterations and based upon typical ranges (DHI 2006). When run autonomously, best-fit parameters are selected by the Overall Root Mean Square Error option with 30,000 evaluations. Note, to support the LRBM, the objective is to produce a simulation with an overall good fit to the observed data and with a strong emphasis on summer-time base flows to target flow regimes that are of highest concern to fish populations. A minimum of 3 years including periods of above-average precipitation is recommended for calibration, with longer periods resulting in a more reliable model. Disparity between simulated and observed discharge arise due to quality of time series data or other attributes. For ungaged streams, parameters developed for another catchment with similar topographic, climatic, geologic, vegetative, and land use characteristics are applied.

Table 3. NAM calibration gauged catchments in the Lemhi River Basin.

Catchment	Period of Record	Calibration Period	Operator
Headwaters			
Agency Creek Upper	WY 2008 - 2106	WY 2008 - 2106	
Big Eightmile Creek (Aggregate)	WY 2008 - 2106	WY 2008 - 2106	
Big Timber Creek (Aggregate)	WY 2008 - 2106	WY 2008 - 2106	
Bohannon Creek	WY 2008 - 2106	WY 2008 - 2106	
Hawley Creek (Aggregate)	WY 2008 - 2106	WY 2008 - 2106	
Kenney Creek Upper	WY 2004 - 2106	WY 2004 - 2106	
Pediment Catchments			
Big Timber Creek	WY 2008 - 2106	WY 2008 - 2106	
Canyon Creek	WY 2008 - 2106	WY 2008 - 2106	
Kenney Creek	WY 2008 - 2106	WY 2008 - 2106	

2.3.3.3 Processing data into MIKE BASIN

Catchment discharge results from NAM can be opened in MIKE VIEW. To transfer into from MIKE VIEW to the *LRBM Catchment_InputTS_v##.xlsm,* select and copy the data and paste into the EXCEL file. Use *LRBM Catchment_InputTS_v##.xlsm* to upload the catchment from the converted DFS0 into the worksheet. In the EXCEL file, use the "StreamStatsComp" tab to evaluate catchment runoff estimates for the ungaged basins. The "Load Runoff Time Series" button in the "StreamStatsComp" tab uses the NAM results to compute the average monthly flow per catchment, then loads the results for identifying months that deviate from StreamStat predicted flows by ±30%.

2.3.2 LRBM Calibration

Calibration occurs at locations of observed flow, progressing from upstream to downstream through determining the irrigated water loss to the intermediate groundwater system (IGW) and the lag time of return. The best configuration of these two parameters is determined by minimizing the difference between simulated and observed flow records and comparing the LRBM results with the seepage run inflow/outfow measurements (ideally ±15%). After determining the best configuration, reach gains for the gage are calculated and imported into the LRBM. The process proceeds to the next downstream gage. This methodology assumes that the LRBM network is complete and supporting time series files associated with nodes have been updated with and the reference updated.

2.3.2.1 Considerations on Calibration

The goal is to minimize the difference between the observed and simulated flow at each gage. Assuming that the computed rainfall-runoff is accurate, the simulated flow can be altered by changing the magnitude and timing:

- Magnitude is adjusted by the remaining unconsumed diverted water is seeping into the deeper groundwater system. This can be adjusted in several manners: i) adjust in the *UpperLemhi_LRBM_InputTS-v#.xlsm* and *LowerLemhi_LRBM_InputTS-v#.xlsm* workbooks by selecting the IGW factors when computing loss. Advantage is that this is easy to implement. The disadvantage is that this amount is lost to the system (until a solution is developed), ii) implement a seepage loss from a known seepage run. This will likely be a standard amount lost as a % as a flux would. Easy to implement, but requires knowledge of the seepage quantity, iii) for water users away from the stream network, implement a combination of shallow and IGW solutions. The shallow represents that portion returning via the link channel and the IGW will need to be a reach gain computed in the *LRBM Catchment_RG_InputTS.xlsm*. A time series stating what percentage of the return flow is lost to the IGW will need to be placed on the link channel.
- Timing is adjusted by changing the delay function. In the LRBM, the delay function is separated into the rapid delays (<11 days to 50% on the analytical solution) and long delays (>11 days to 50% on the analytical solution).
  - Rapid delay: These are simulated using a linear reservoir function with the K factor defining how rapidly water is returned. In the LRBM, this factor is set on the returning link channel from a water user node when the "linear reservoir routing" method has been selected. By default, entered suggested lag times provided by local landowners to provide baseline results for comparison. These will then by adjusted as the calibration progresses and by using the Run Calibration button in each sheet of the *ReachGainCalculator_Lemhi.xlsm*.
  - Long delay: For water user nodes beyond the 11 day return period, are computed using the *LRBM Catchment_RG_InputTS.xlsm*. This workbook combines multiple returns from water user nodes in the catchment that will likely return near the outlet of the catchment as the intermediate groundwater system recharges the stream system at a given location. The return fraction as computed for each water user in the *UpperLemhi_LRBM_InputTS-v#.xlsm* and *LowerLemhi_LRBM_InputTS-v#.xlsm* is applied to the response function calculated in the return flow function

2.3.2.2 Calibration Method

Following network construction; associating time series files with nodes, rivers/channels, and catchments; and populating the time series files with data, the steps for calibration are as follows:

1. *Import observed data* into a calibration sheet in the *ReachGainCalculator_Lemhi.xlsm*. Make sure to populate the result file path and name on the "Lemhi Gages" sheet as well as the reach gain DFS0 file path and name on the calibration sheet that you are working. In the sheet, determine all the water users have return flow link channels entering the stream between the upstream gage and the gage being evaluated. Enter in the salient information as well as the lag time (K factor) between 25 and 300 percent of the suggested lag times. Enter the LRBM node downstream of the reach gain arc in cell "C6" and the arc in "E6".
2. *Reach gain to 0.* Before calculating the reach gain, set the time series in the LRBM to 0. The *Test.DFS0* option is the dummy time series with 0 values that can be used until the full reach gain has been computed.
3. *Run the LRBM and upload the latest simulation results into the calibration sheet using the Download Sim Flow button.* Examine the graphs of the two hydrographs to determine the direction the calibration needs to proceed. The goal is to minimize the difference between the two curves. Assuming that the computed runoff is accurate, the simulated flow can be altered by changing the magnitude and timing.
4. *Adjust the magnitude* using the methods described above. Repeat 1-3 until the magnitude is as close as it can be given the data. Once sufficient, proceed to step 5.
5. *Adjust the return flow timing*. Run between 50 and 150 simulations to determine the optimal array of return flow lag factors. This process has been automated in a calibration sheet in the *ReachGainCalculator_Lemhi.xlsm* using the Run Calibration button. Based on the range of return flow values for each diversion specified in the Generate Variables table (Columns U-Z), the algorithm randomly varying the lag time between 25 and 300 percent of suggested lag times for each run, then generates performance statistics for each simulation. Using the performance statistics (Sum of squares & slope, b-intercept, r^2 of line plotting simultaneous observed and simulation discharge records), select the best configuration of return lag times. Though the return lag times are changed automatically using the "Run Calibration" button, changing them here is still done manually in the program.
6. *Seepage Run Comparison.* Checked the flow of water in the network by comparing the relative amount of water diverted and returned to the Lemhi River seepage studies. The results should be within ±15% change in locations without significant seepage gains. If reach gains are found, then they should be incorporated if possible. However, it is difficult from a spot measurement to know if the
7. *Acceptable:* Once deemed acceptable, the reach gain for the gage can be calculated and imported to the model. The Upload Reach Gains button loads the reach gain time series file in cell G6 on the calibration sheet. Be sure to switch from the Test.DFS0 to the reach gain time series file in the LRBM.
8. Repeat process for the next downstream gage.

2.4 EXCEL WORKBOOKS

To expedite input/output and calibration of the LRBM, a series of EXCEL files were developed that support the modeling effort. Though simulations can largely be run within MIKE BASIN, the EXCEL files provide a means of organizing and transferring data that increase workflow, reduce potential errors, and provide a means of documenting input. Table 4 provides a description of the EXCEL files in Figure 1.

Table 4. EXCEL Files supporting the LRBM. Numbers correspond to the numbers in Figure 1.

File Type	Description
Formatting and Importing Data	
1. Discharge Formatter	To gap fill the discharge/diversion records and convert them to a discharge time series for import to the Water User Input File. Macros assist in importing data gap filling and exporting the formatted and updated time series. EXCEL: *Diversonflows_interpolator_yyyy.xlsm* (version customized based on water year reported)
2. Water User Input File	For each water user node in the LRBM, lists the input water demand time series, return flow fractions time series, water rights, irrigated area, irrigation method, crops grown, and high-water capacity. Macros are used to compute the daily return flow fractions based on the area, crops, and irrigation method along with the reference ET. Macros are used to automatically load all the DFS0 files associated with each water user node. Files can be saved to document scenario conditions. EXCEL: *UpperLemhi_LRBM_InputTS-v09.xlsm, LowerLemhi_LRBM_InputTS-v09.xlsm*
3. Water User Deep Return Flow File	For all water users employing the deep return fraction, this file creates the return flow for each tributary catchment. Macros retrieve the return flow fraction from the Water User Input File and export them to the appropriate reach gain DFS0. EXCEL: *LRBM Catchment_RG_InputTS_v03.xlsm*
5. Catchment Input File	Extracts time series from NAM results files and imports into the DFS0 files supporting catchment inflow in LRBM. Macros are used for both processes. In addition, runoff time series can be compared to USGS Stream Stats results. EXCEL: *LRBM Catchment_InputTS_v04.xlsm* Comparing time series: *StreamStats_MontlyAnnual_2015_v02a.xlsm*
Post-Processing	
7. Calibration, Reach Gain Computations	Imports LRBM results for direct comparison with stream gage records. To support calibration, allows users to run the LRBM repeatedly with randomly changing the return flow lag factors to determine the best values. Once calibrated, computes and loads the reach gain time series to DFS0 files input files supporting the LRBM. EXCEL: *ReachGainCalculator_Lemhi_v06.xlsm*
8. Water Budget	Water budget uses NAM and LRBM results to compute the water budget for the basin. The EXCEL workbook also contains hydrological norms by which to assess the simulation results. Macros load and process simulation results into the analysis. EXCEL: *LRBM-WB-2019v01.xlsm*
9.Seepage Run Comparison	Compares LRBM results with historical seepage runs values in the Lemhi River for validating if baseline results correctly characterize the loss/gain of the stream network. Macros assist

File Type	Description
	the importing and formatting process. *Seepage Run Excel Sheet Overview.docx* provides supporting documentation for use of the spreadsheet. EXCEL: *LemhiBasinSeepage_Output TS _v01.xlsm*
10. Scenario Templates	Imports LRBM results for a customized result template. EXCEL: Varies based on scenario.

3 Archiving Files

Annually, or after major updates, the LRBM and supporting document need to be archived in accordance with IDWR protocols. The archived items include:

- Baseline LRBM, including the ArcView files, geodatabase, time series files, and GIS layers
- Latest Supporting MS EXCEL Files (see table 3)
- Original data files if updates are made. Note ma portion of this information will be stored in the supporting EXCEL files
- Software installation, version on which the Baseline LRBM operates
- Memo documenting the updates
- Recommended is to also include a readme file.
- Optional, any scenarios that need to be documented

These files can be gathered in a folder or zipped as one file.

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Appendix A. Large Tables

Table A-1. PODs/POUs in the LRBM and the corresponding variables. Description of each variable follows the table.

Appendix F – Seepage Run Memo

Memorandum

Date: June 20, 2019

To: Idaho Office of Species Conservation

From: Ryan Warden

Subject: Preliminary Seepage Analysis for restriction area, Mid Lemhi Basin.

IDWR proposed conducting a seepage study in the area of the Lemhi known as the “narrows” as part of USB GW-SW Interaction Phase 3 grant. The reach is shown in Figure 1, as reach 7 in the Donato seepage survey that was done in 1997 as well as the IDWR seepage survey done in 2014. This area is noted as a location where the Lemhi River should always be gaining due to the geological restraints forcing groundwater into the river. Although the seepage survey results show that the area becomes a losing reach in October and it’s due to this occurrence was the reason for further study and proposal of the seepage study.

The results of both seepage studies can be found in Table 1 for the 2014 and the 1997 runs. In both runs, there is a gain in reach 7 for August and then in October it becomes a losing reach. After reviewing further data (geology, aerial map, well depth, and groundwater levels) an explanation for this change was formed no longer needing a more in depth seepage study as proposed.

Aquifer and Alluvium Extent

This reach can be broken into two section, using Figure 4, an arbitrary boundary between the two sections was drawn. The arbitrary boundary coincides with the shallowest well depth, the Stout well, which has a maximum depth of 16 ft before hitting bedrock. It is noted by Donato (1998) that at the arbitrary boundary the majority of groundwater is force up into the river, thus making it a gaining reach. At the arbitrary boundary there is a spring seep which supports the up welling of groundwater at this location.

Using Figure 2 and 3, the lateral extent of the alluvium and valley bottom can be measured. The upper section of the reach (the southern section) is approximately 10,243 ft long while the lower section of the reach (the northern section) is approx. 15,716 ft long. The measurements on the Figures show that the lower section has a wider extent of the valley bottom alluvium as well as being a longer section. Using ArcMap, the lateral extent of the valley bottom alluvium was measured for the upper and lower sections. The upper section measured 16,706,103 ft^2 and the lower section measured 39,512,455 ft^2.

Figure 4 show the depths of wells within the reach. The bolded 45 ft depth at the mouth of Hayden Creek is the Whitson well. The italicized 16 near the arbitrary boundary is the Stout well, and the Italicized 80 ft well near Agency Creek is the Smith 2 well. The well depths show that from the Whitson well to the Stout well the alluvium aquifer is shallowing, becoming thinner by going from 45 ft deep to 16 ft deep. From the Stout well to the Smith 2 well the alluvium aquifer goes from 16 ft to 80 ft deep, becoming deeper and bigger.

An average depth of alluvium was created for the upper and lower section of the reach by averaging the depths with the Stout well at the arbitrary boundary and the well depths closest to the beginning or end of the section (Whitson and Smith 2 wells respectively). For the upper section, the Whitson well depth of 45 ft averaged with the Stout Well of 16 ft, is 30.5 ft. The lower section averaged the Smith 2 well depth of 80 ft with the Stout Well for an average depth of 48 ft. Using the average depths and the lateral extents, results in an approximant alluvium aquifer size for the upper and lower sections. The upper section has approx. 509,536,141 ft^3 and the lower section has 1,896,597,840 ft^3. In comparison the lower section has 372% more aquifer space available than the upper section.

Groundwater Level Analysis

Table 2 shows groundwater analysis of four wells that are within the reach. Hydrographs of the well data are in Appendix A. Hydrographs show varying water levels due to irrigation occurring between May and October. Water levels rise when irrigation is running and then fall to a baseline during the non-irrigation season. For example the Stout well near the arbitrary boundary has the least amount of variability of about 5 feet. Whereas, the Kibbee well has the most variability with 25 ft. An average water level was found for the irrigation and non-irrigation season for the years of data available. Comparing the Whitson well to the Kibbee which is near perpendicular to the river, shows a head gradient going from Whitson to Kibbee during irrigation and non-irrigation but a slight bigger gradient during the non-irrigation. This indicates a small flow loss away from the river during both seasons but slightly more during the non-irrigation.

Comparing the Whitson well to the Stout well, shows a head gradient change of 62 feet during the irrigation season and a 47 ft change during non-irrigation. Since the Stout well has the least of amount of change (about 1 foot between the average irrigation to non-irrigation) the change in the gradient occurs within the Whitson well. This indicates there less flow towards the Stout well during the non-irrigation season compared the irrigation season. In turn the gain at the arbitrary boundary would be less during the non-irrigation season.

Comparing the Stout well to the Smith 2 well, shows a head gradient change of 124 ft during the irrigation season and 131 ft during the non-irrigation season. Again, the Stout well changes the least, thus the majority of the change occurs within the Smith 2 well. This indicates there is more groundwater flow towards the Smith 2 well during the non-irrigation season but at a deeper depth. This most likely leads to a greater loss (infiltration) from this section of the reach during non-irrigation compared to irrigation season.

Conclusion

The two sections in this reach broken by the arbitrary boundary are very different. The alluvium in the upper section becomes thinner and narrower as it goes downstream forcing groundwater up into the river. Whereas, the alluvium in the lower section widens and deepens as it goes downstream, allowing infiltration and loss from the river. The upper section forces the river into a gaining portion while the lower section allows for loss from the river. During the irrigation season all groundwater levels rise, causing a higher amount of groundwater to be gained in the river in the upper section as well as less water being lost in the lower section. When irrigation shuts off the ground water levels drop, which reduces the amount of water gained in the upper section but increases the amount lost in the lower section. This explains the switch between a gaining reach during the irrigation season and then a losing reach during non-irrigation season. It is simply a balance of losing and gaining to the river that is influenced by the groundwater levels impacted by irrigation.

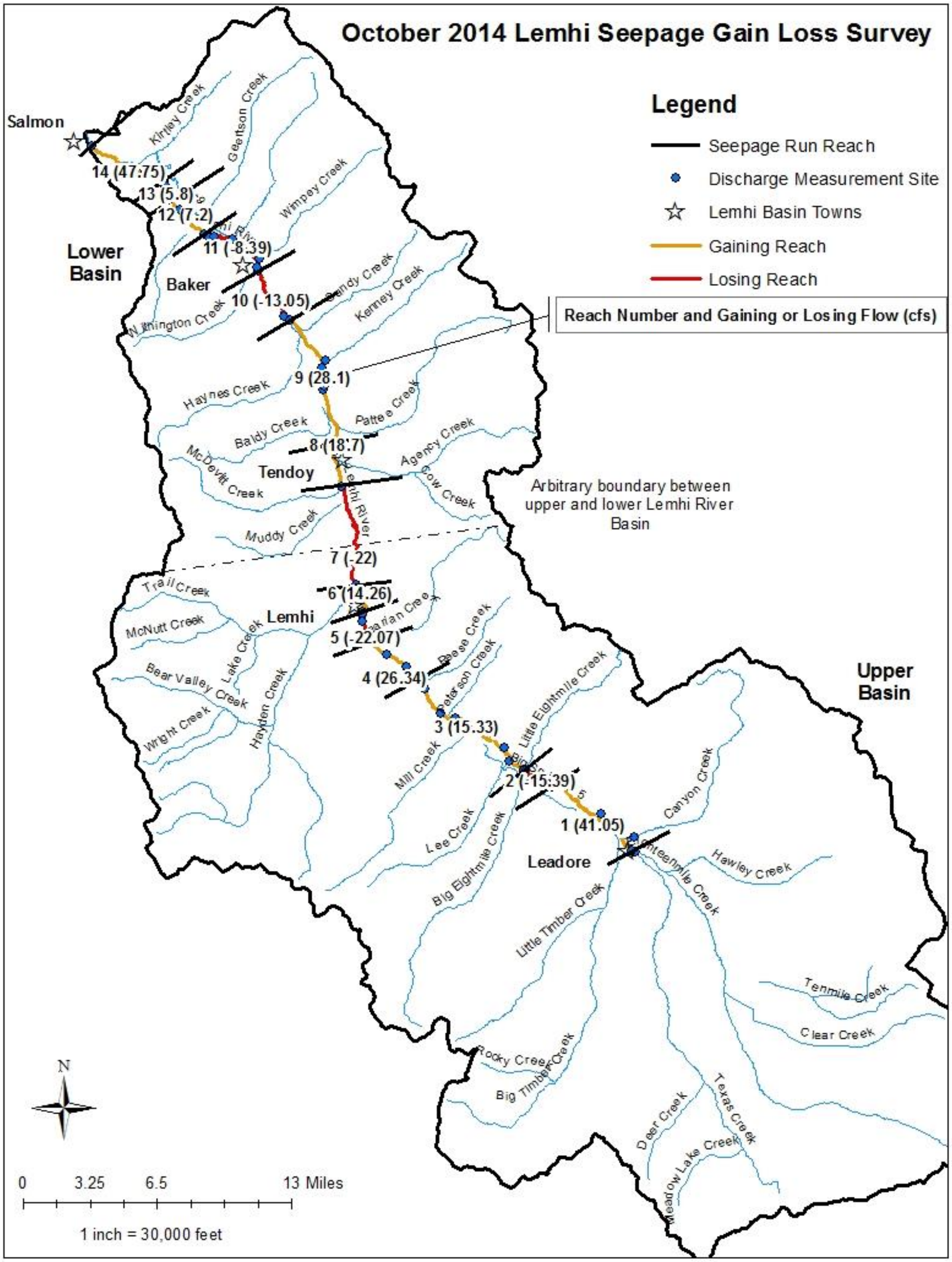


Figure 1. 2014 October Seepage Gain Loss Survey results.

Reach	Miles	Flow Rate (cfs)				Gain/Loss Percent of flow				Gain Loss (cfs)				Gain Loss (cfs/mi)			
		8/2014	10/2014	8/1997	10/1997	2014		1997		2014		1997		2014		1997	
						August	October	August	October	August	October	August	October	August	October	August	October
0	0	7.54	27.84	34	72.3												
1	7.6	41.586	99.09	88	140	595%	147%	225%	104%	44.83	41.05	76.50	74.90	5.87	5.37	10.10	9.90
2	2.1	77.179	138.11	151	216	39%	-16%	30%	6%	16.38	-15.39	26.20	8.80	7.76	-7.29	12.50	4.20
3	8.2	80.9	182	151	244	26%	11%	2%	-9%	19.85	15.33	3.43	-20.00	2.43	1.87	0.40	-2.40
4	3.8	88.8	212	184	259	16%	14%	1%	1%	12.60	26.34	1.42	2.80	3.28	6.85	0.40	0.70
5	1.8	106.1	220	213	263	5%	-10%	11%	-9%	4.33	-22.07	20.30	-22.80	2.42	-12.33	11.30	-12.70
6	1.6	101.9	238	220	318	4%	6%	8%	18%	4.70	14.26	16.10	47.00	2.86	8.68	10.10	29.40
7	5.6	130	272	358	361	14%	-9%	19%	-6%	14.50	-22.00	41.60	-18.90	2.58	-3.92	7.40	-3.40
8	2.2	124.3	299	408	425	16%	7%	24%	15%	21.11	18.70	84.20	54.30	9.48	8.39	38.30	24.70
9	7.2	130	331	410	428	40%	8%	16%	-1%	49.88	25.10	66.00	-5.20	6.90	3.47	9.20	-0.70
10	3.5	119.5	322	403	398	-1%	-4%	6%	-8%	-0.73	-13.05	26.20	-33.50	-0.21	-3.73	7.50	-9.60
11	4.1	85.44	335	321	454	17%	-3%	-1%	8%	20.25	-8.39	-5.51	32.20	4.99	-2.07	-1.30	7.80
12	1.8	33.1	313	252	409	7%	2%	2%	-7%	5.76	7.20	7.22	-29.50	3.20	4.00	4.00	-16.40
13	1.8	60.98	331	275	463	7%	2%	12%	13%	2.16	5.80	30.40	53.00	1.18	3.18	16.90	29.40
14	4.7	85.46	376	368	504	96%	14%	42%	5%	58.40	47.75	116.00	22.40	12.38	10.12	24.70	4.80

Table 1. Seepage Gain Loss results for the 2014 and 1997 runs. Broken up by reach sections. The highlighted section 7 is the reach under futher analysis.

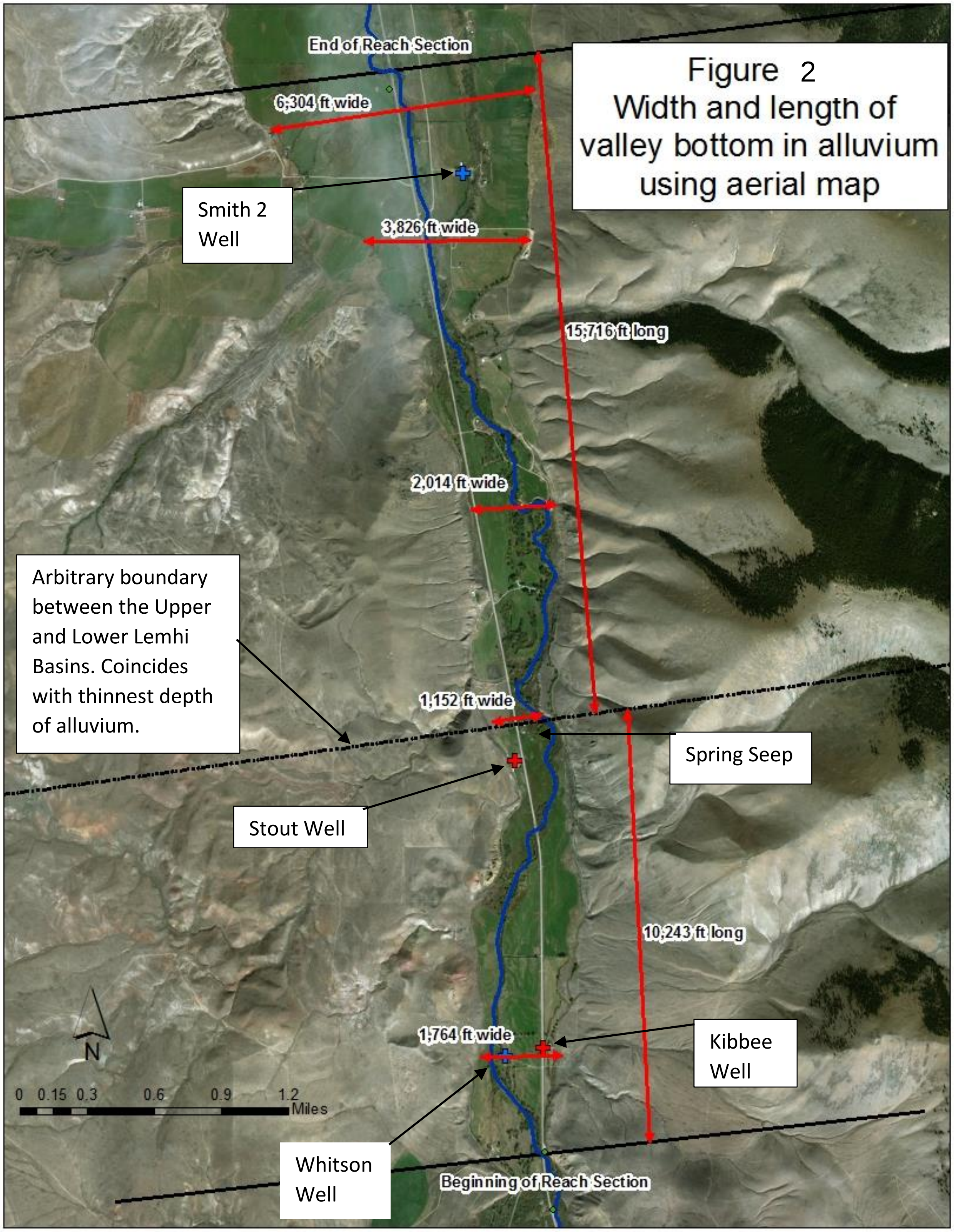


Figure 2
Width and length of valley bottom in alluvium using aerial map
End of Reach Section
6,304 ft wide
Smith 2 Well
3,826 ft wide
15,716 ft long
2,014 ft wide
Arbitrary boundary between the Upper and Lower Lemhi Basins. Coincides with thinnest depth of alluvium.
1,152 ft wide
Spring Seep
Stout Well
10,243 ft long
N
1,764 ft wide
Kibbee Well
0 0.15 0.3 0.6 0.9 1.2 Miles
Whitson Well
Beginning of Reach Section

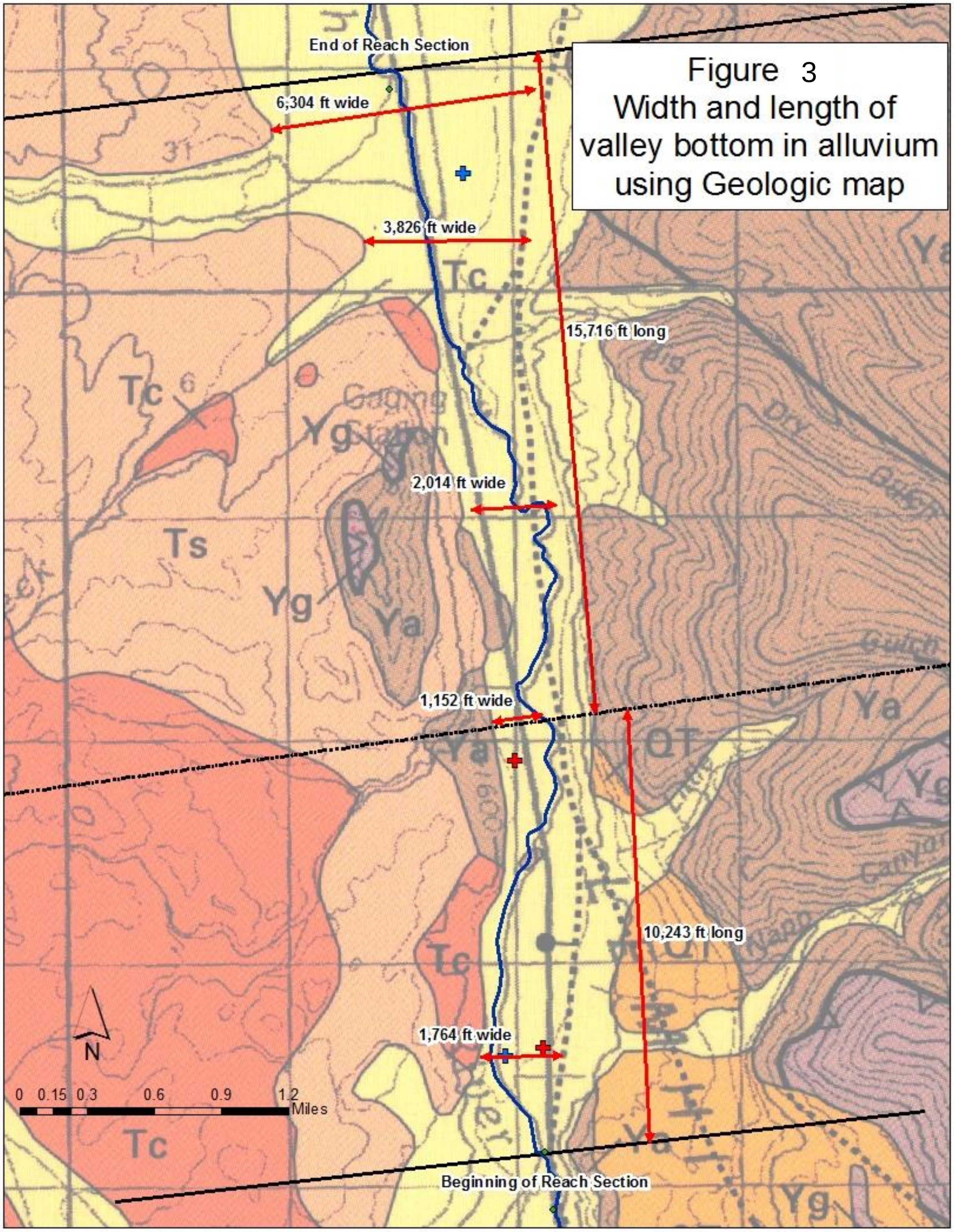


Figure 3
Width and length of valley bottom in alluvium using Geologic map
End of Reach Section
6,304 ft wide
3,826 ft wide
15,716 ft long
2,014 ft wide
1,152 ft wide
10,243 ft long
1,764 ft wide
Beginning of Reach Section
Tc
Ts
Yg
Ya
QT
N
0 0.15 0.3 0.6 0.9 1.2
Miles

Well Name	Irrigation Average Water Level Elevation (DTW)	Change in Water Level Elevation going downstream	Non-Irrigation Average Water Level Elevation (DTW)	Change in Water Level Elevation going downstream	Surface Elevation	Change in Surface Elevation going downstream
Whitson	5117 (7.5)	-	5101 (23.5)	-	5124.5	-
Kibbee	5109 (18.5)	8 ft *	5092 (35.5)	9 ft *	5127.5	+ 3 ft *
Stout	5055 (7)	62 ft	5054 (8)	47 ft	5062	62.5 ft
Smith	4931 (7)	124 ft	4923 (15)	131 ft	4938	124 ft

Table 2. Groundwater Level evalutions from wells within the narrows of the Lemhi Basin.

* These changes in elevations are relatively perpendicular to the river system, showing a lateral gradient.

Figure 4. Depths of wells in feet, within the narrows of the Lemhi Basin. Depths to bedrock are used for maximum depth of alluvium, whereas if no bedrock was encounterd, then a minimum depth is implied.

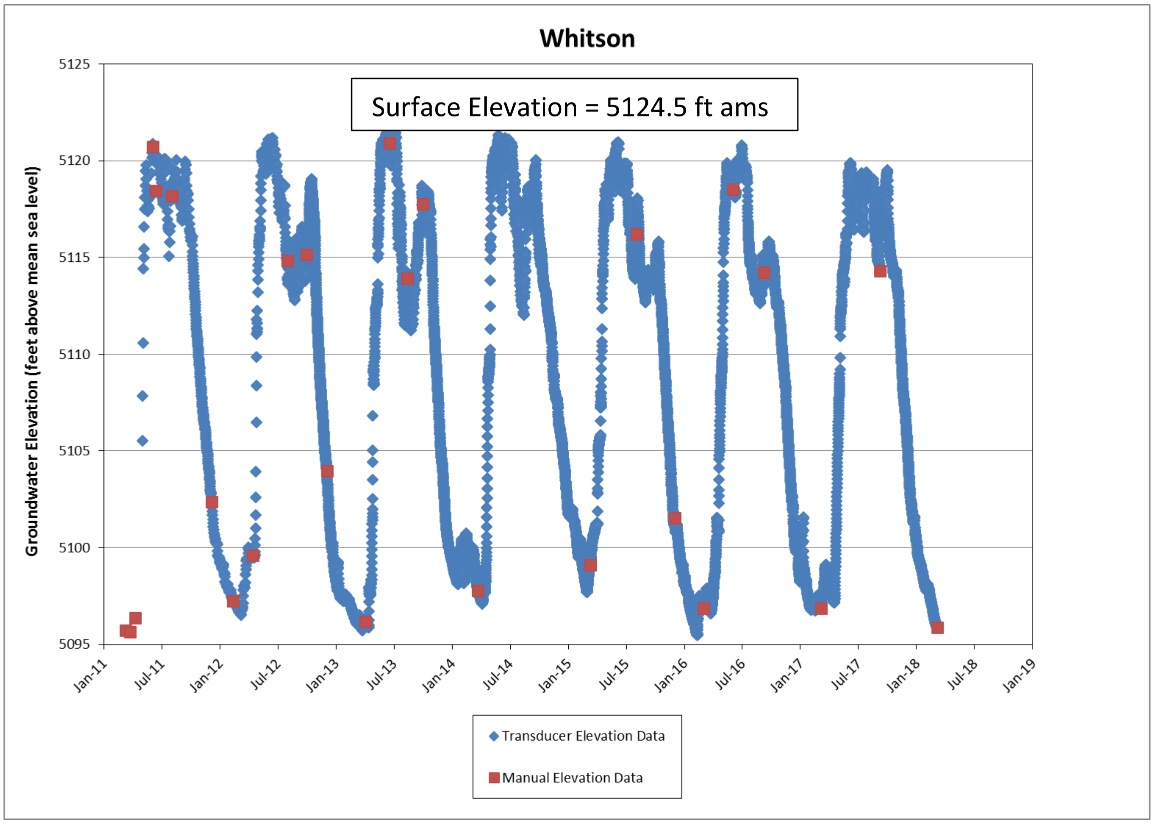


Figure 5.

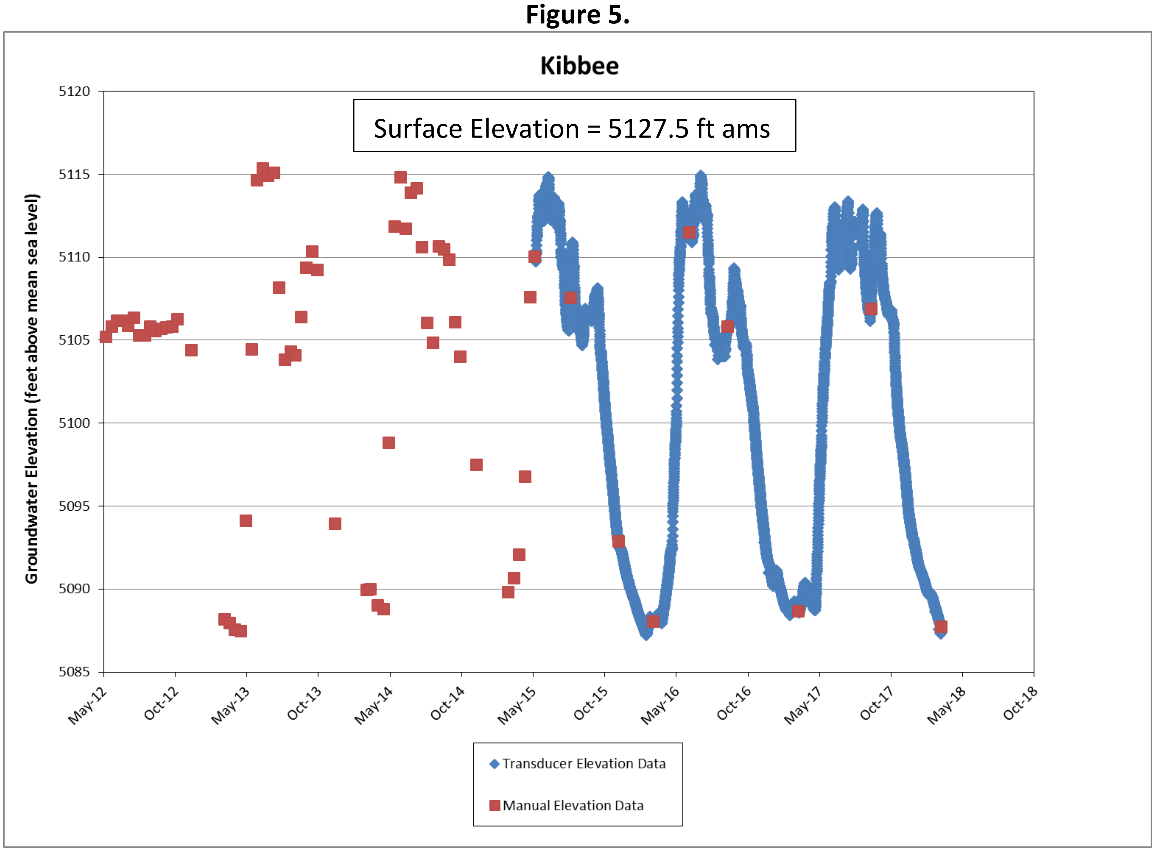


Figure 6.

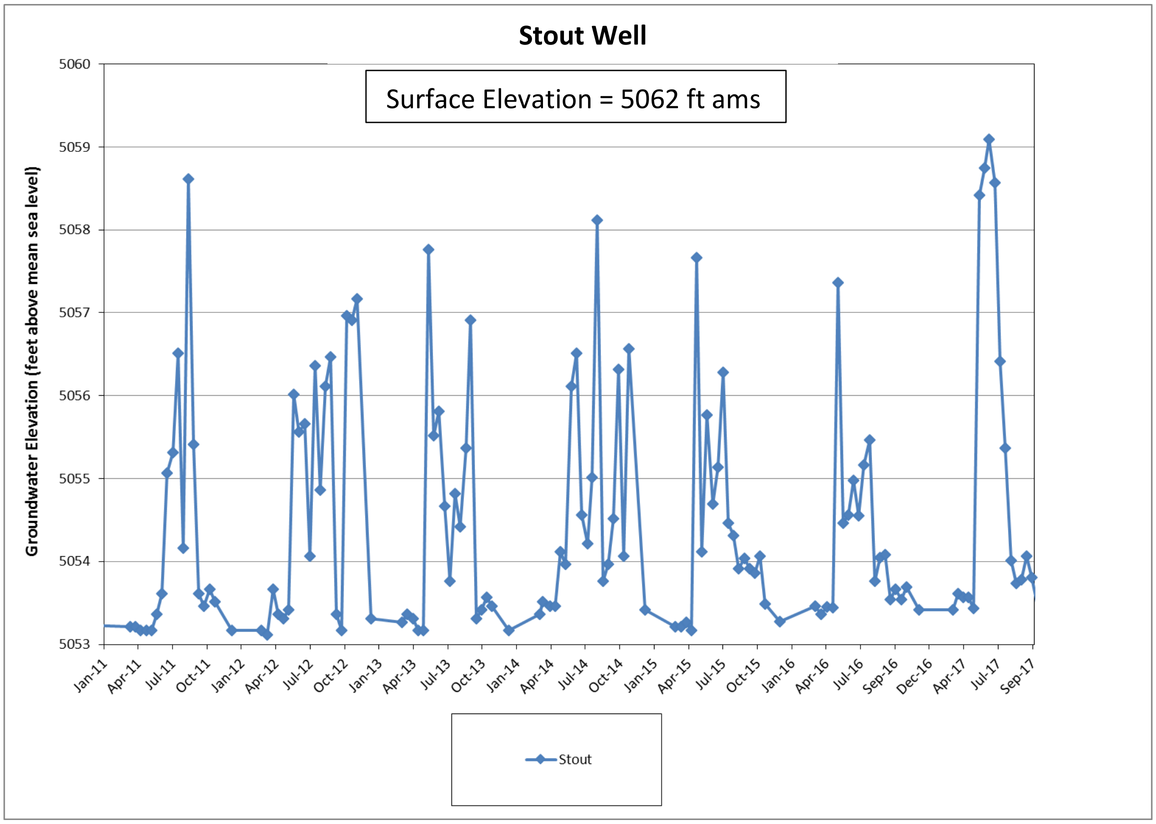


Figure 7.

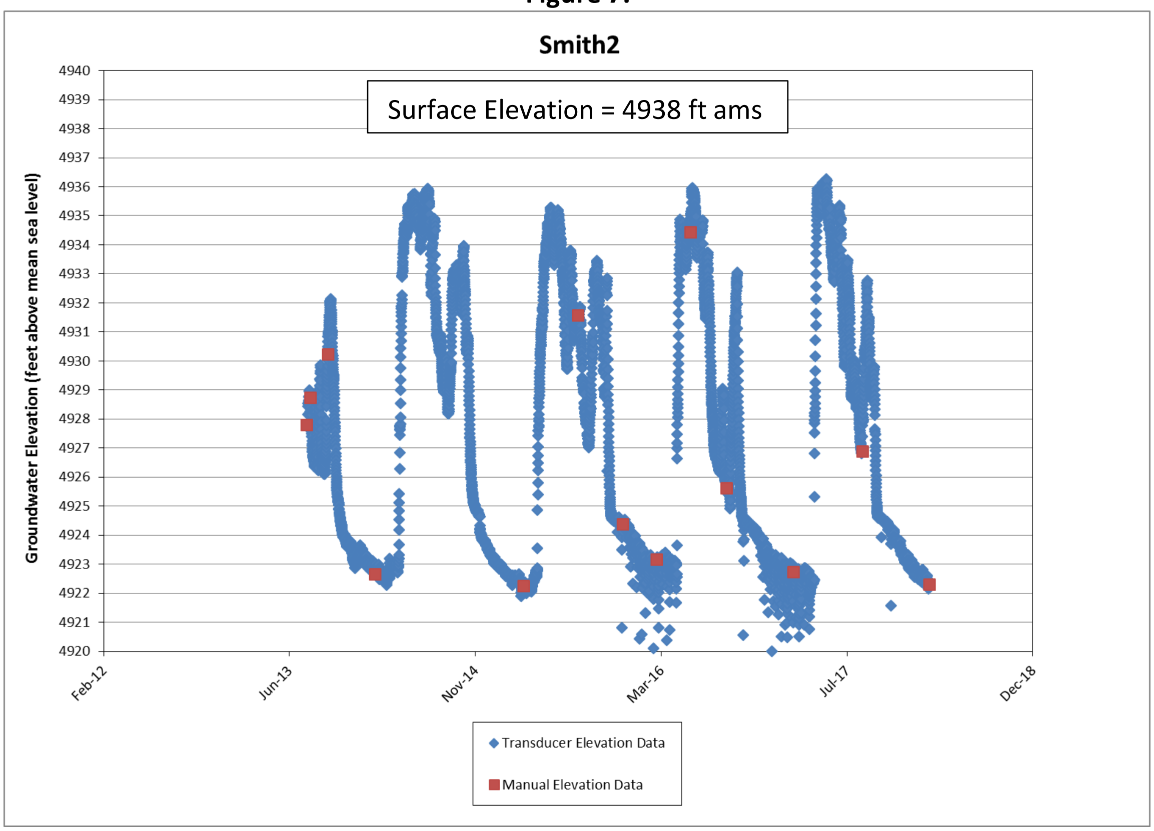


Figure 8.

References

Donato, M.M. 1998. Surface-Water/Ground-Water Relations in the Lemhi River Basin, East-Central Idaho. U.S. Geological Survey, Water Resources Investigations Report 98-4185. Boise, ID.

Appendix G – Pratt Creek Drainage

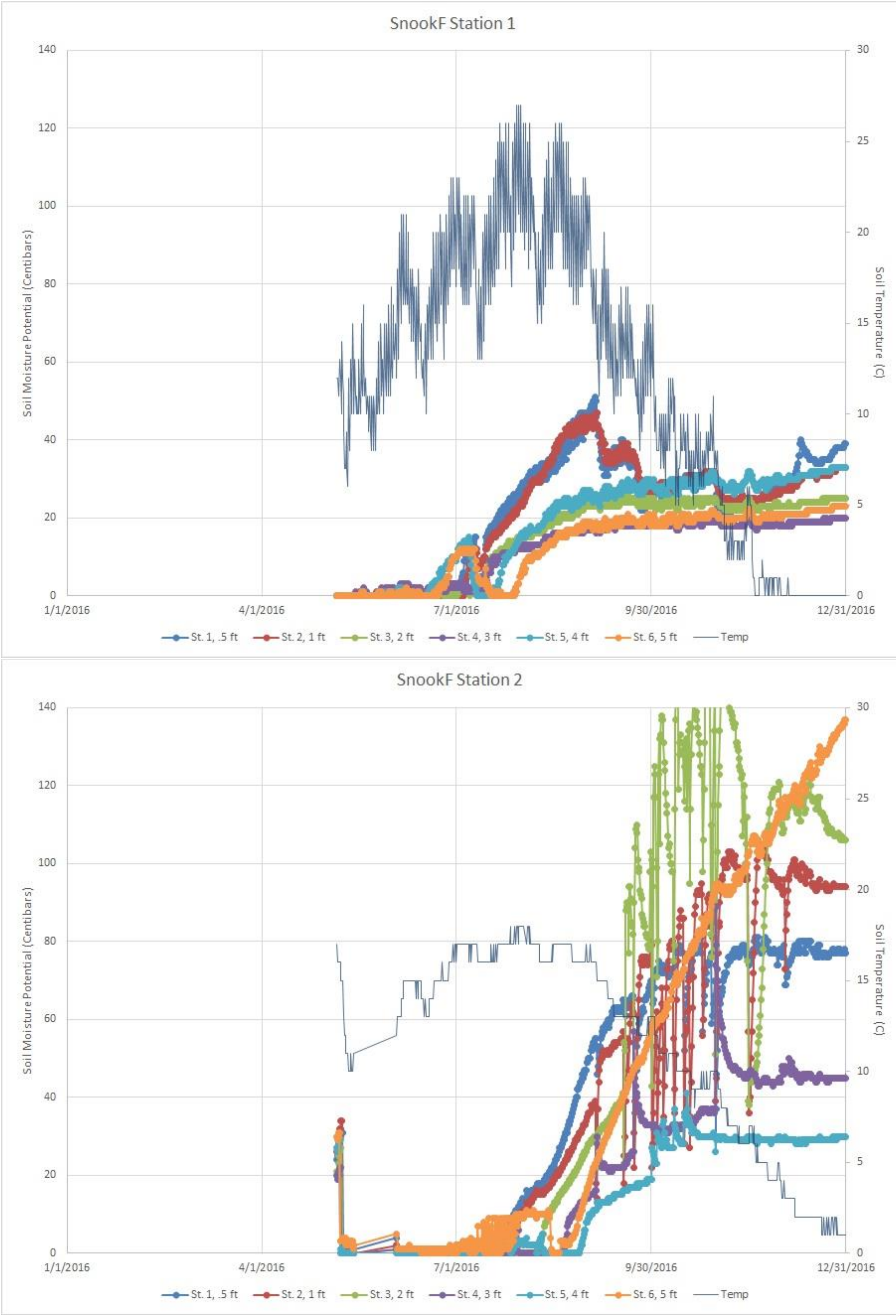


Figure G-1. Comparison of SnookF soil moisture stations for the year of 2016.

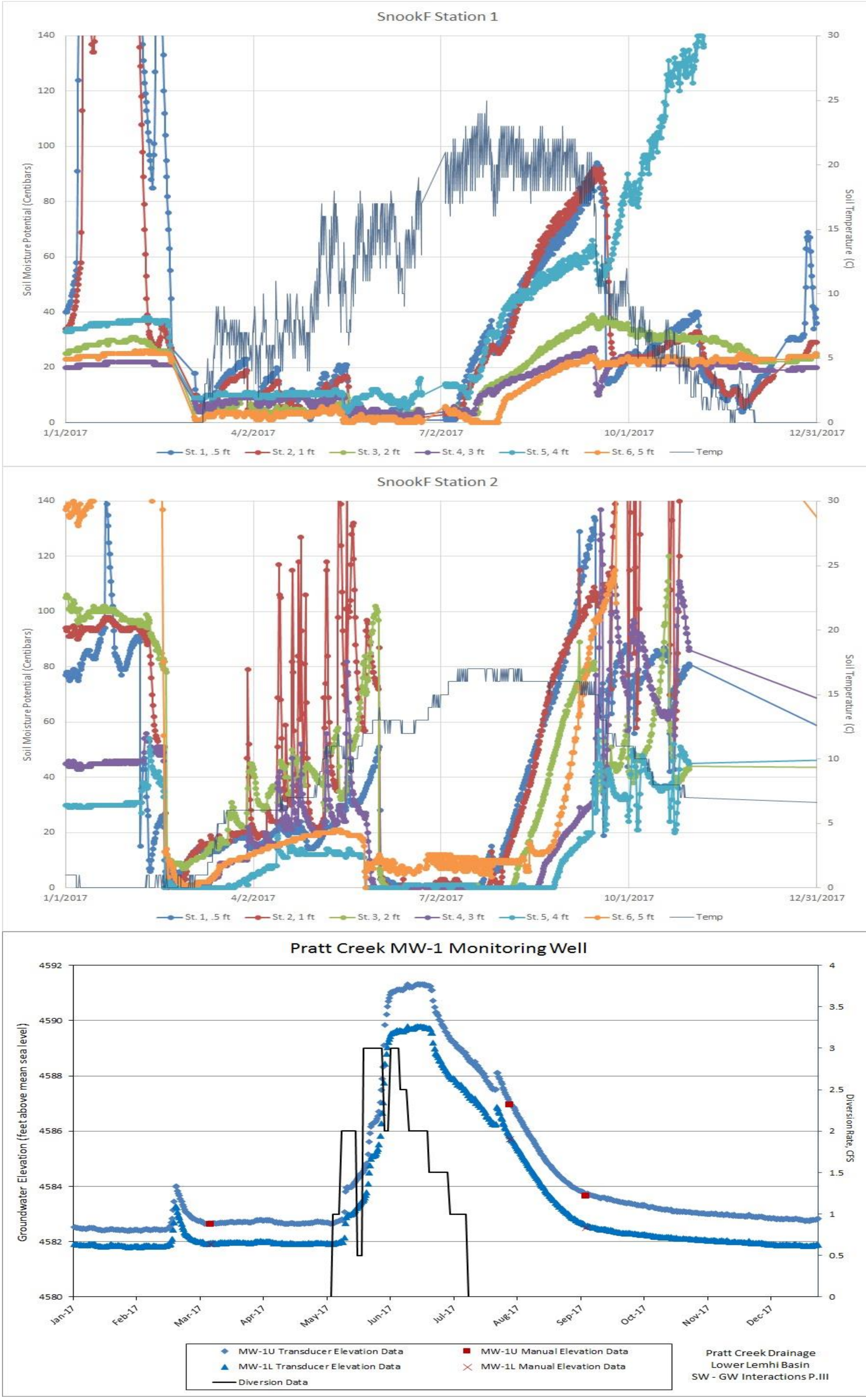
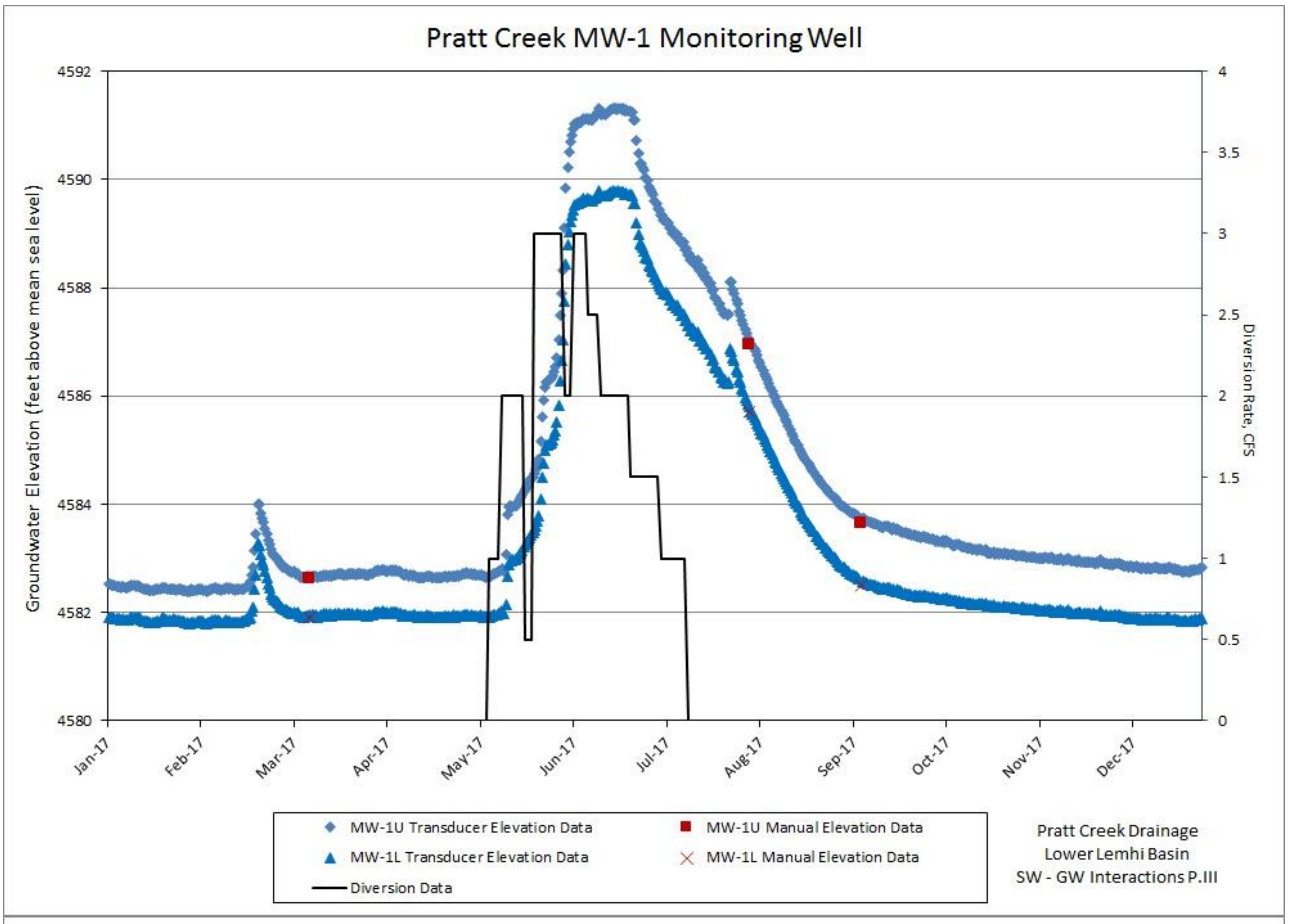


Figure G-2. Comparison of SnookF soil moisture stations and MW-1 for the year of 2017.



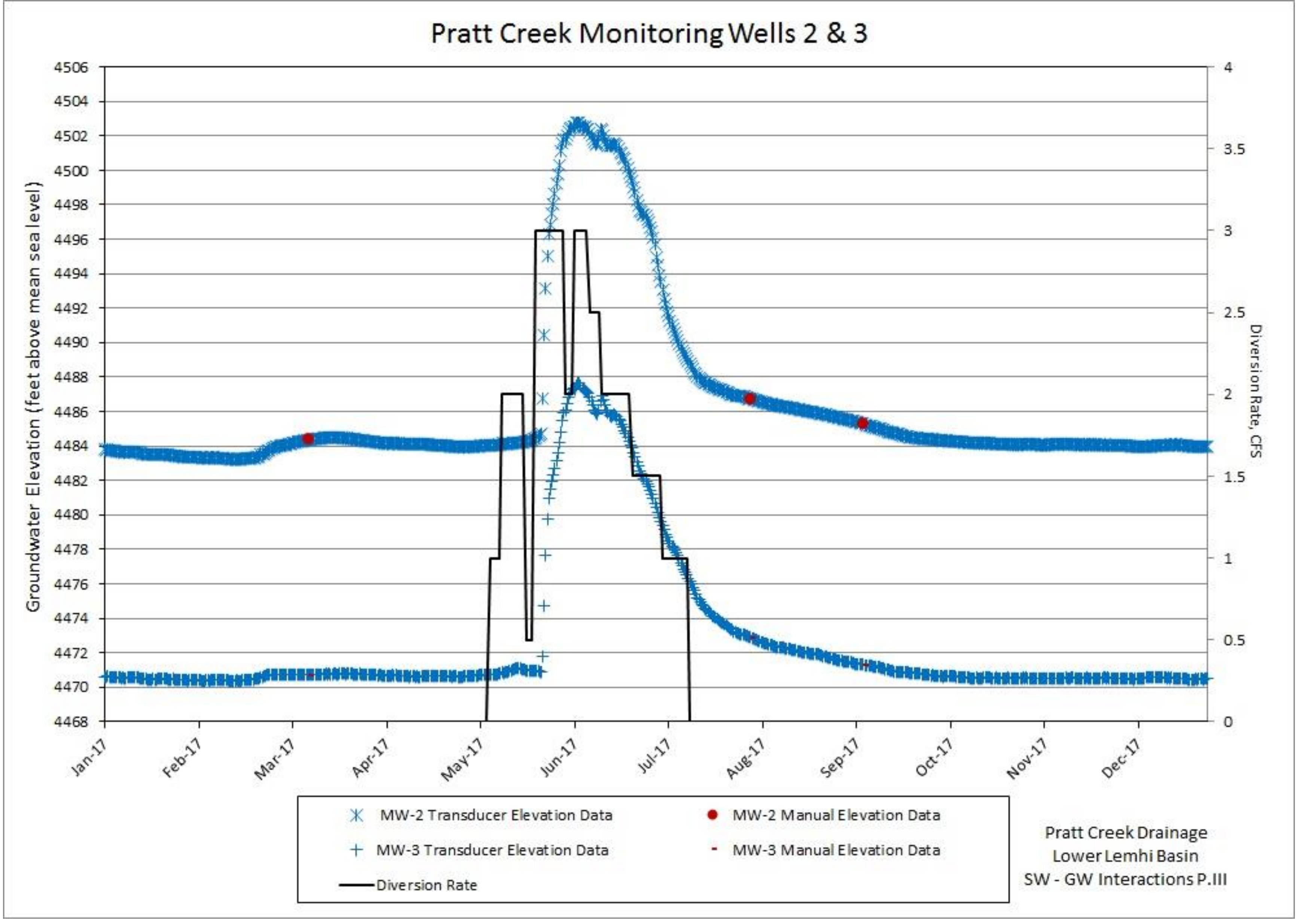


Figure G-3. Comparison of MW-1, MW-2, and MW-3 for the year of 2017.

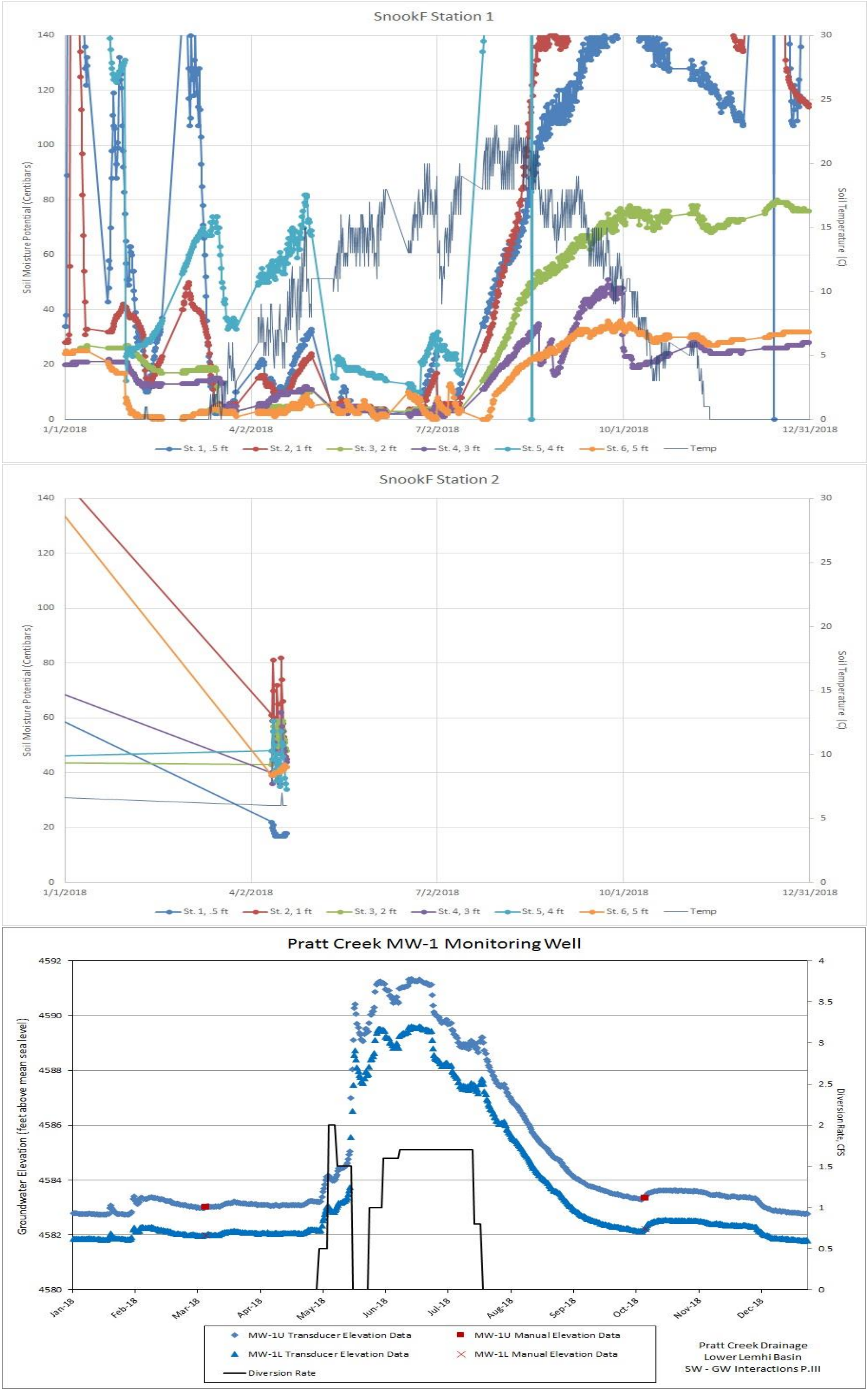
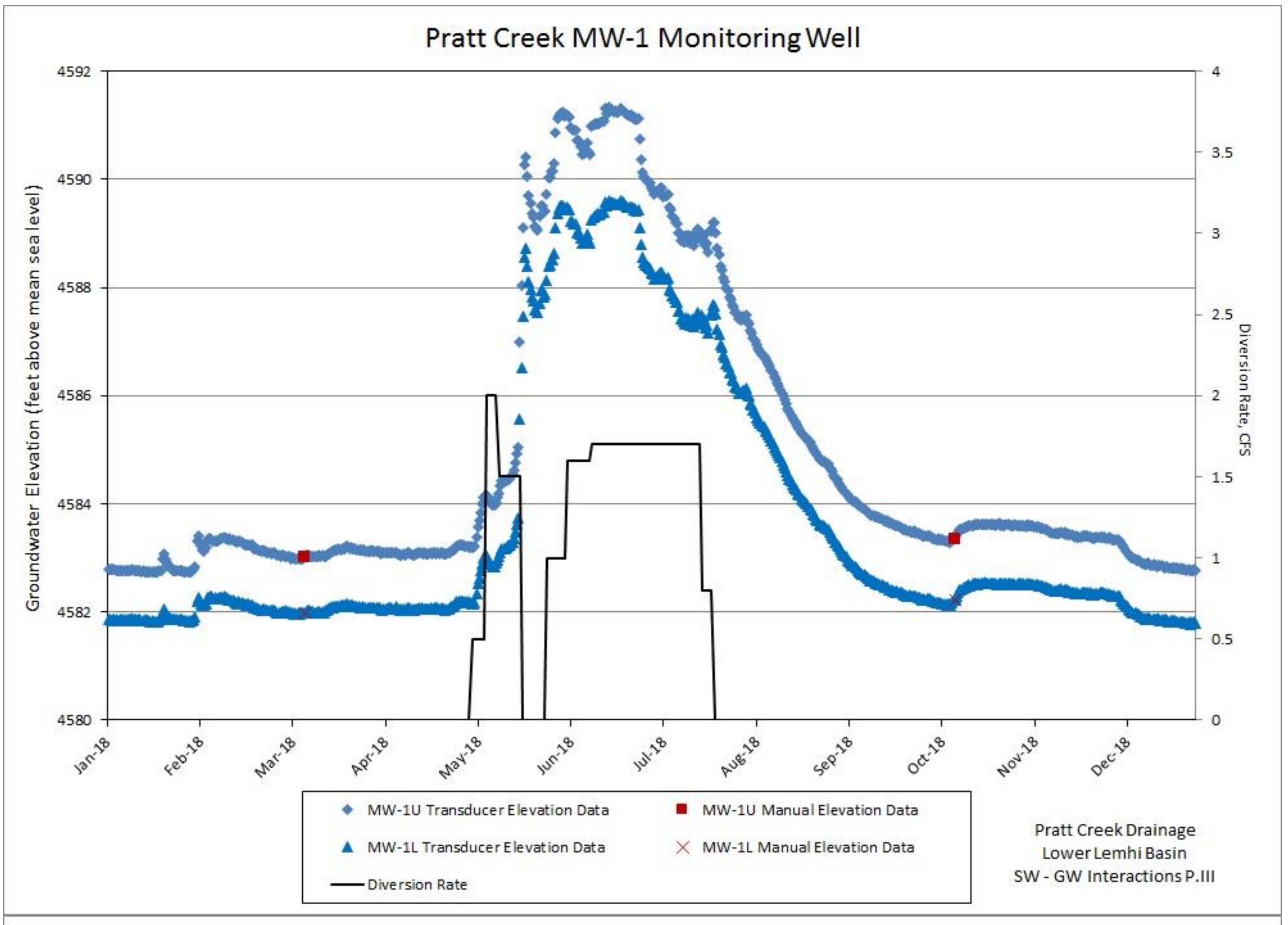


Figure G-4. Comparison of SnookF soil moisture stations and MW-1 for the year of 2018.



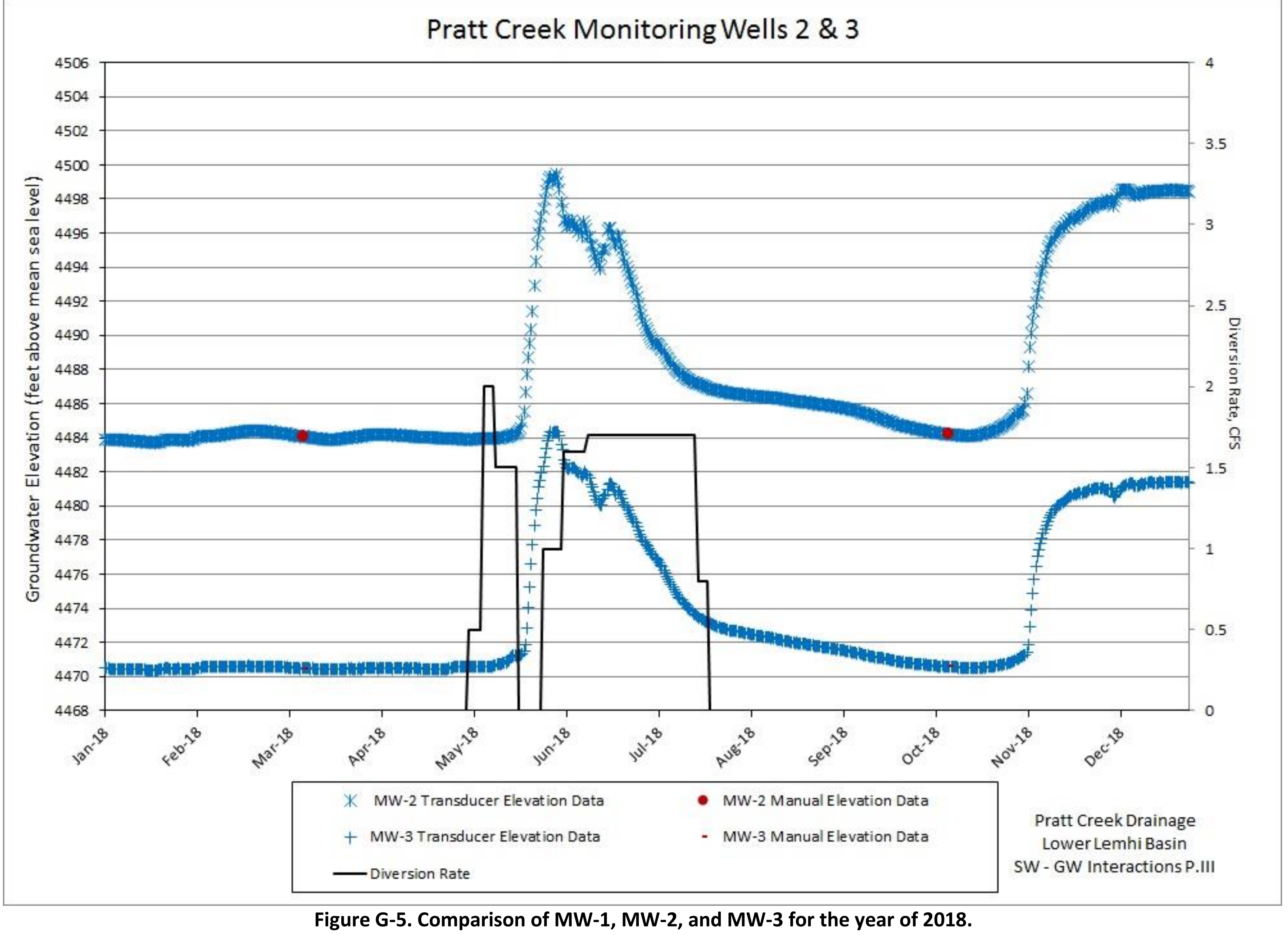


Figure G-5. Comparison of MW-1, MW-2, and MW-3 for the year of 2018.

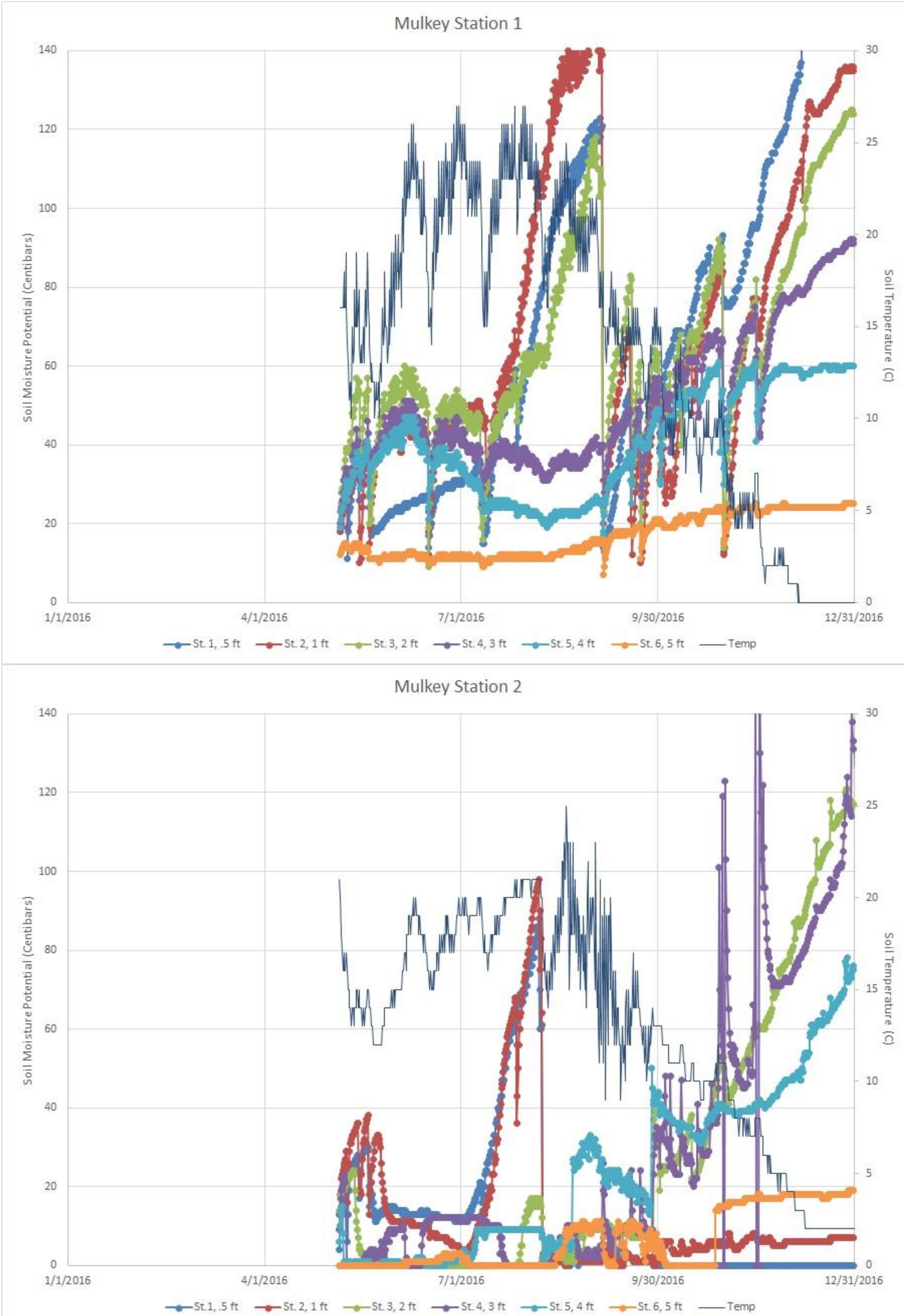


Figure G-6. Comparison of Mulkey soil moisture stations for the year of 2016.

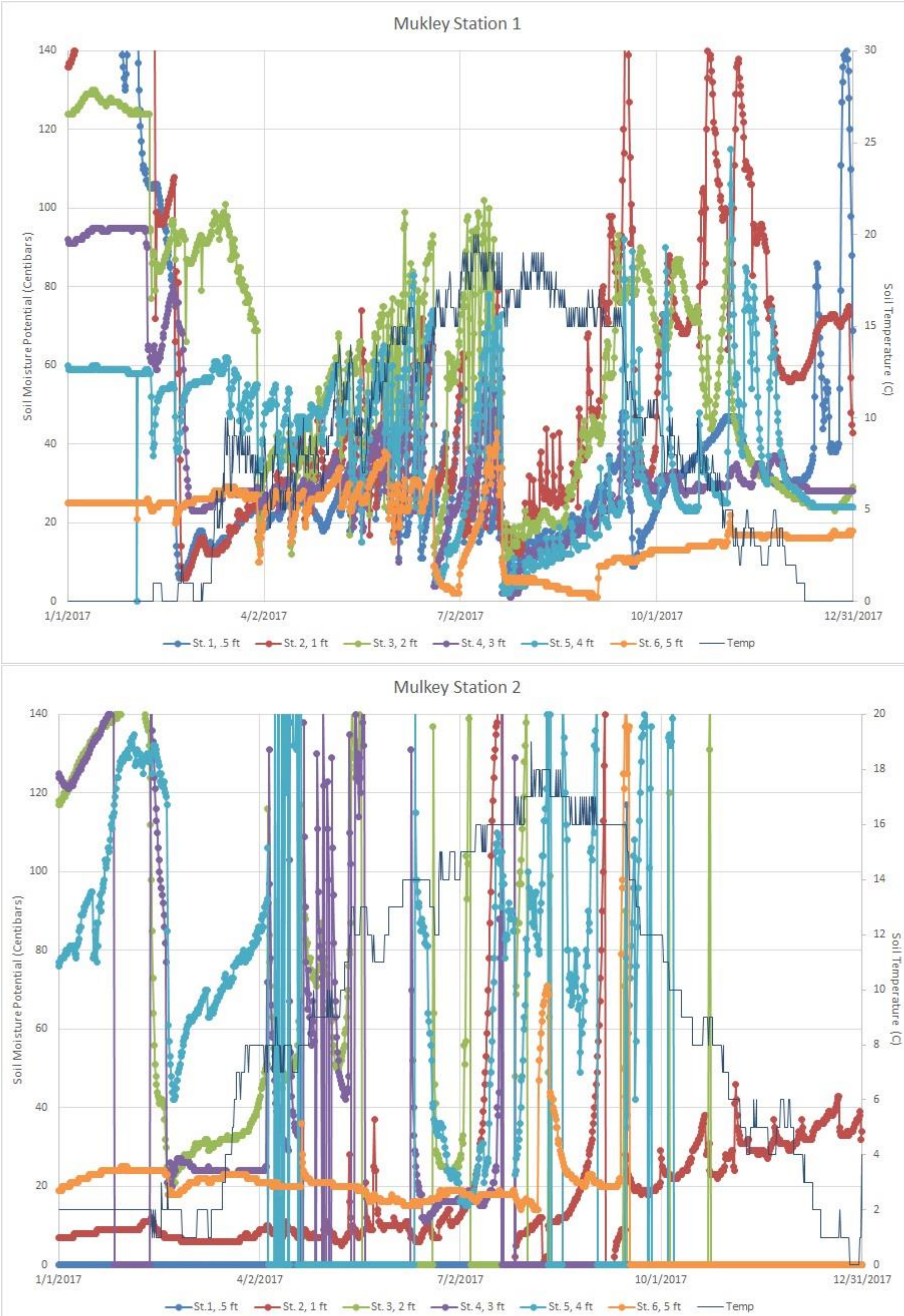
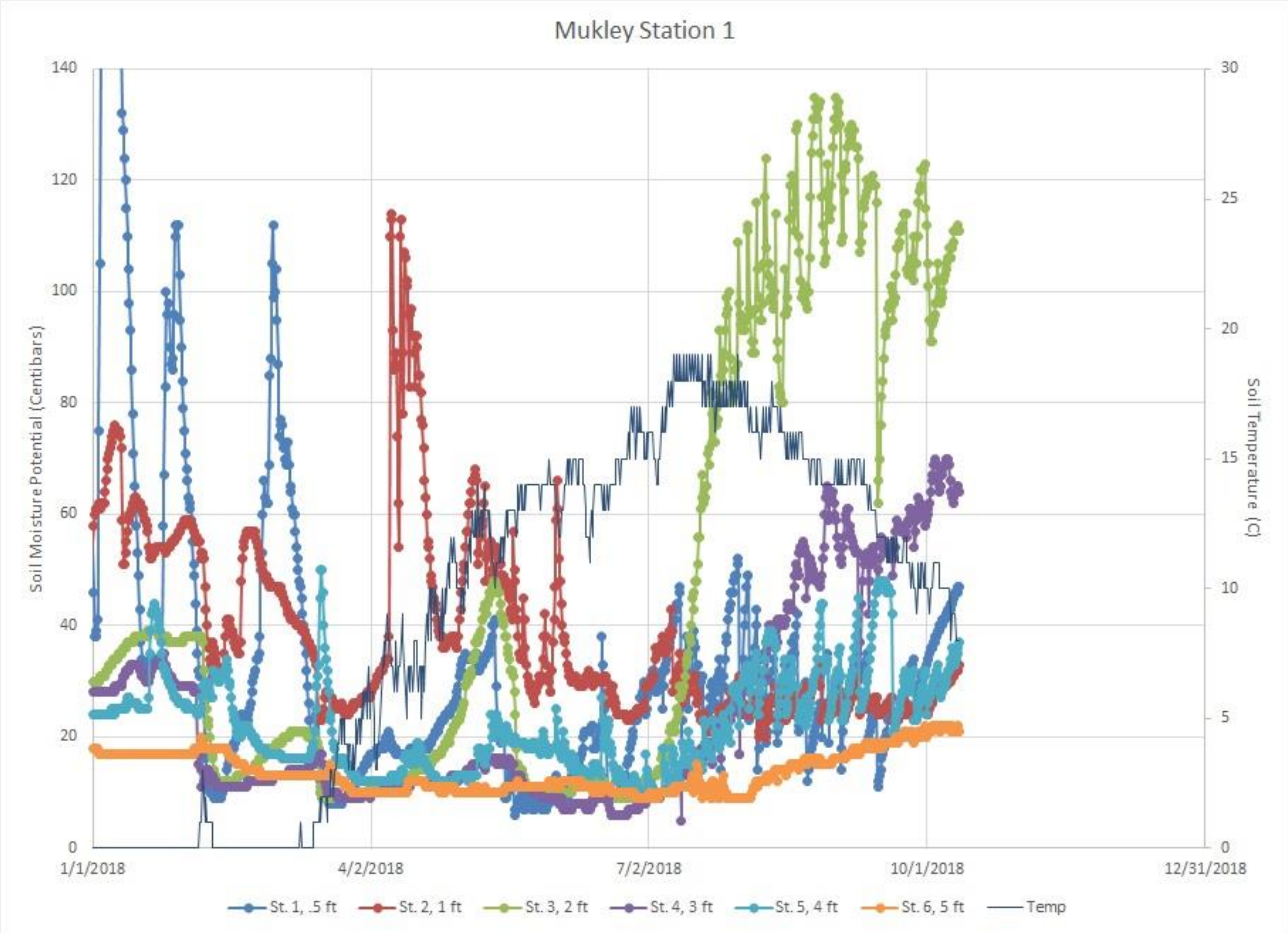


Figure G-6. Comparison of Mulkey soil moisture stations for the year of 2017.



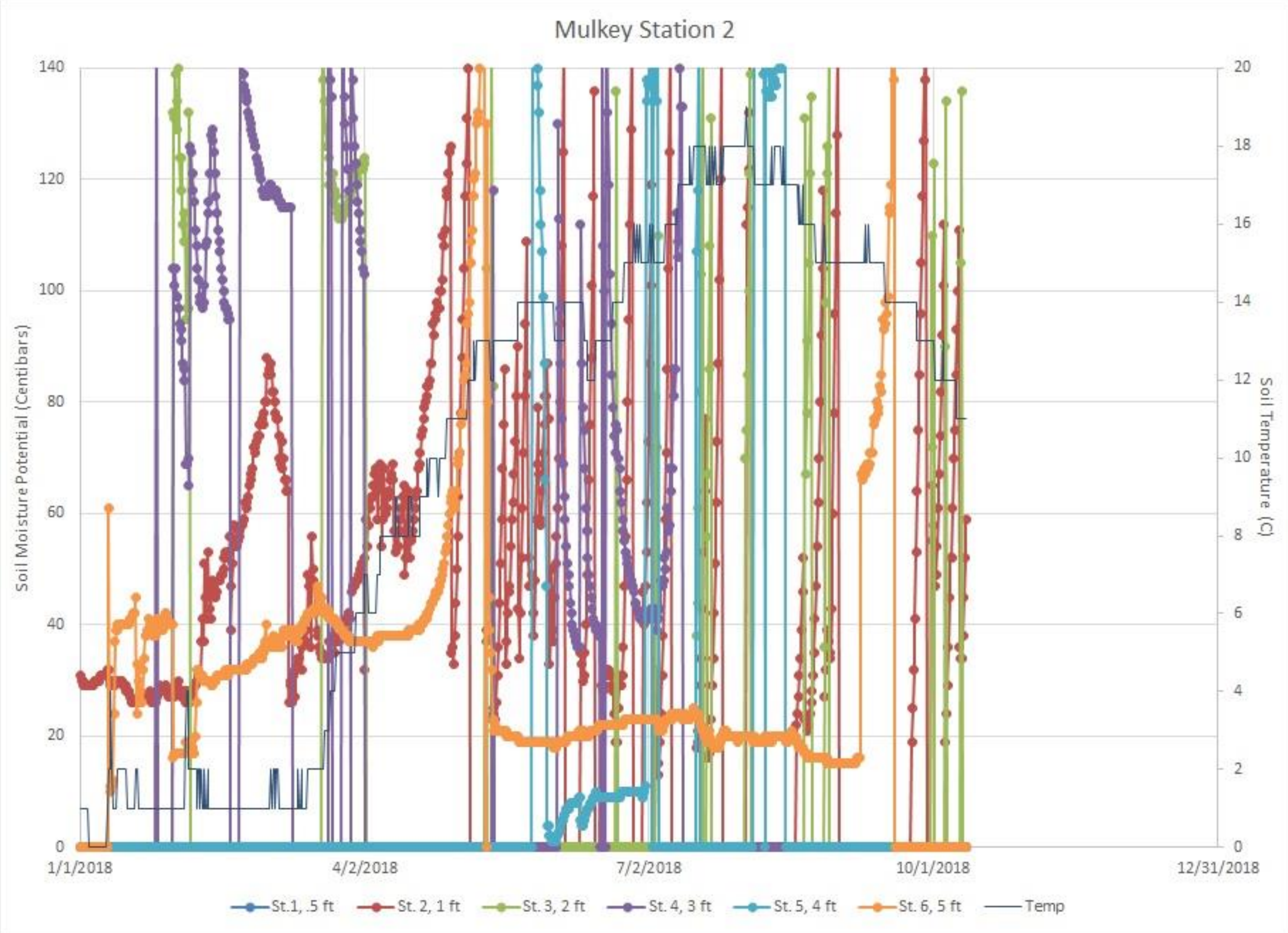
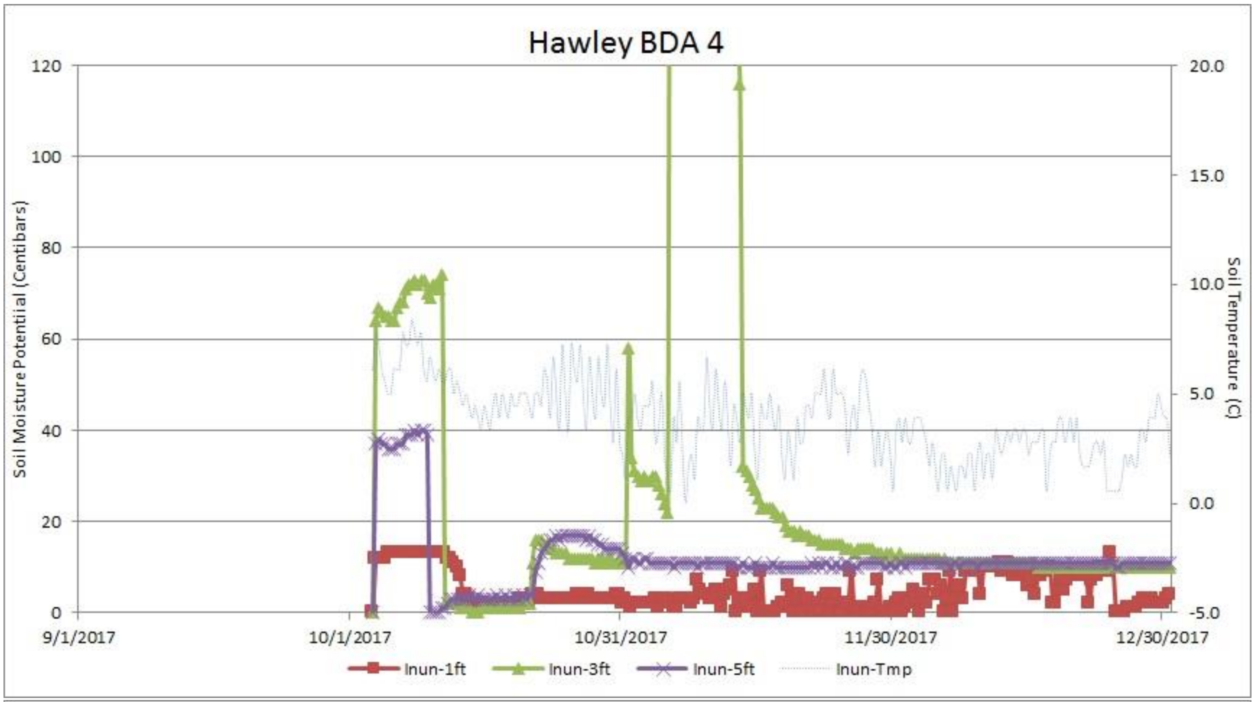


Figure G-6. Comparison of Mulkey soil moisture stations for the year of 2016.

Appendix H – Hawley Creek Beaver Dam Analog Monitoring



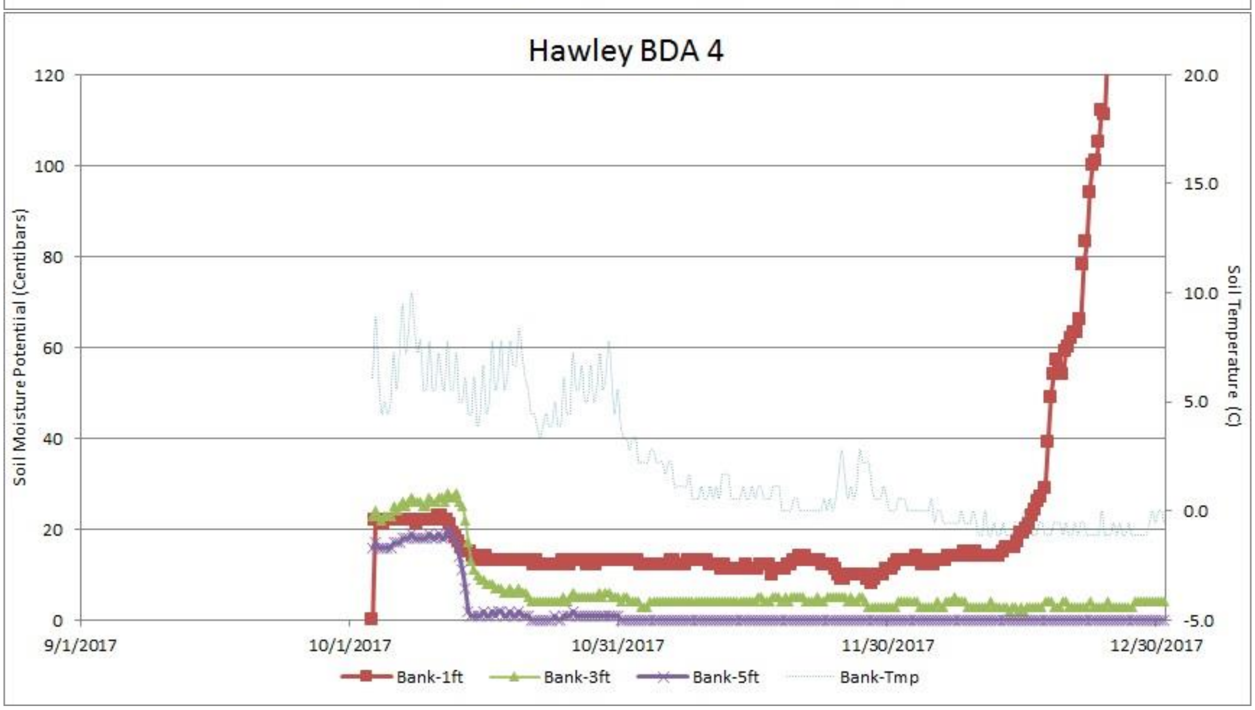


Figure H-1. Hawley BDA Station 4 soil moisture data for 2017.

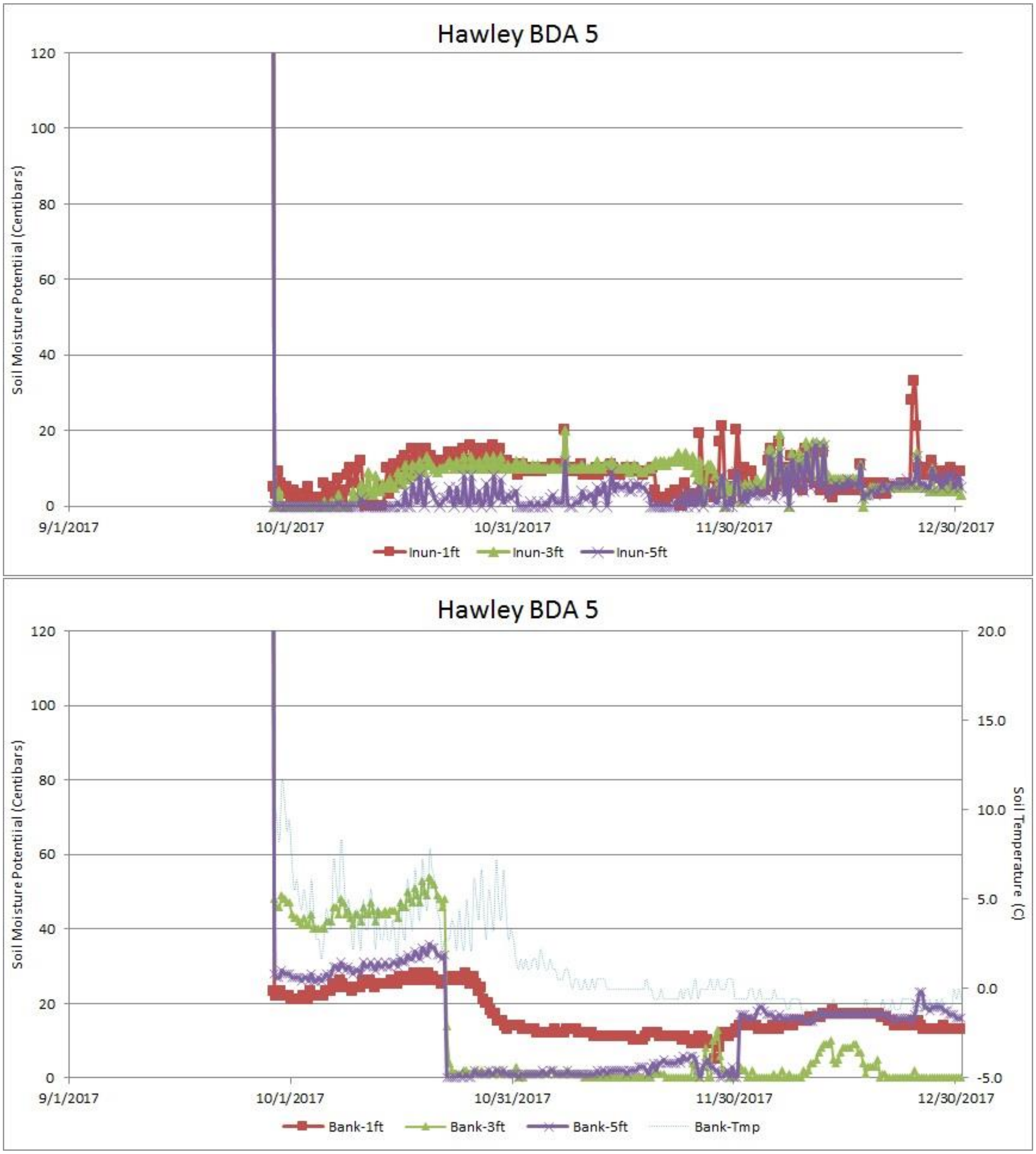
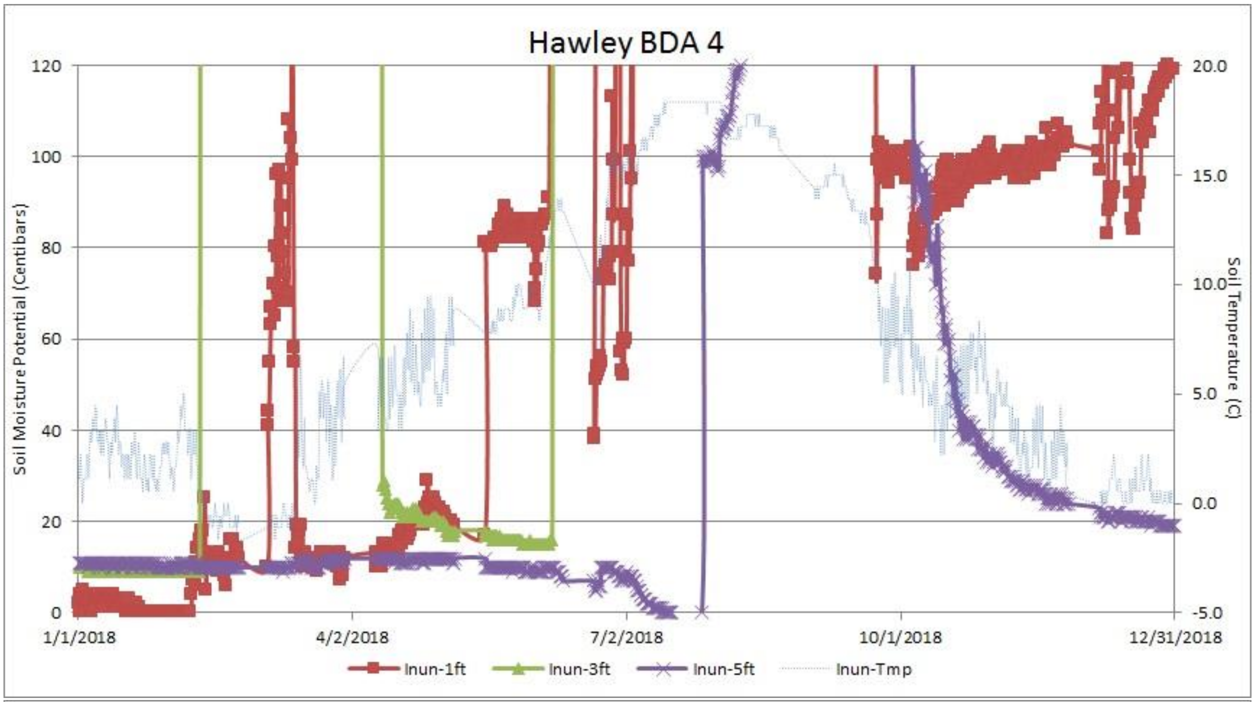


Figure H-2. Hawley BDA Station 5 soil moisture data for 2017.



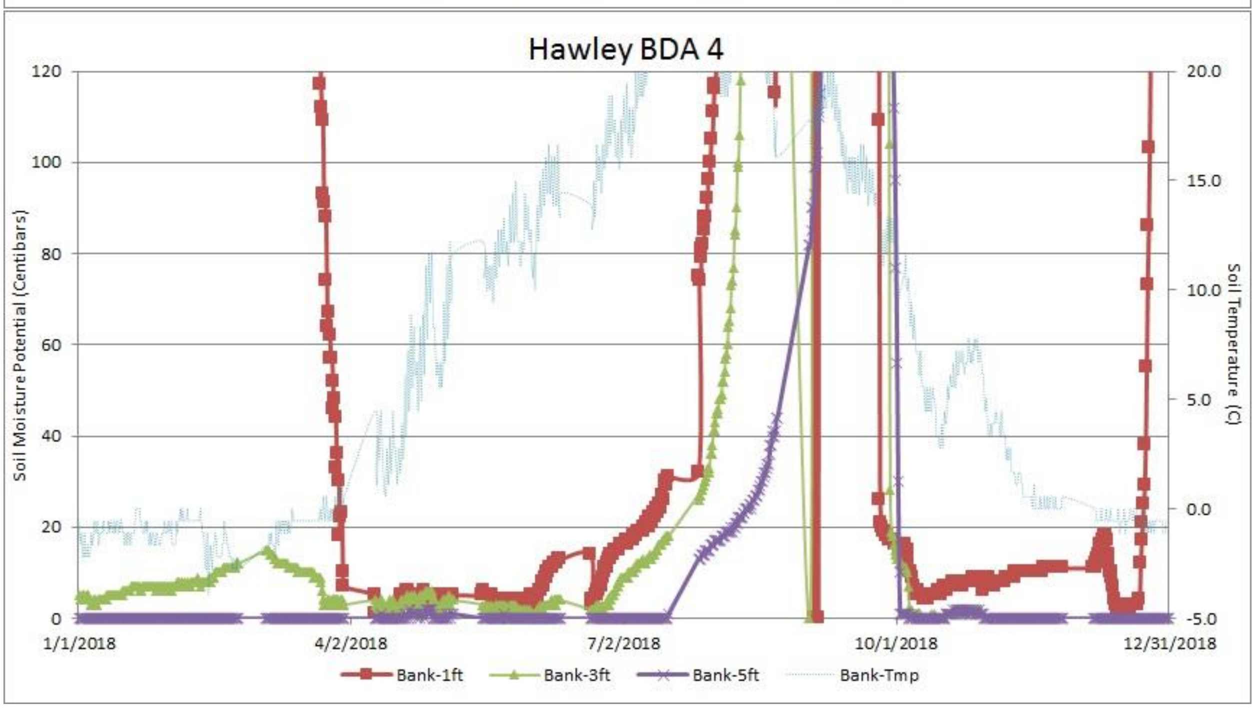
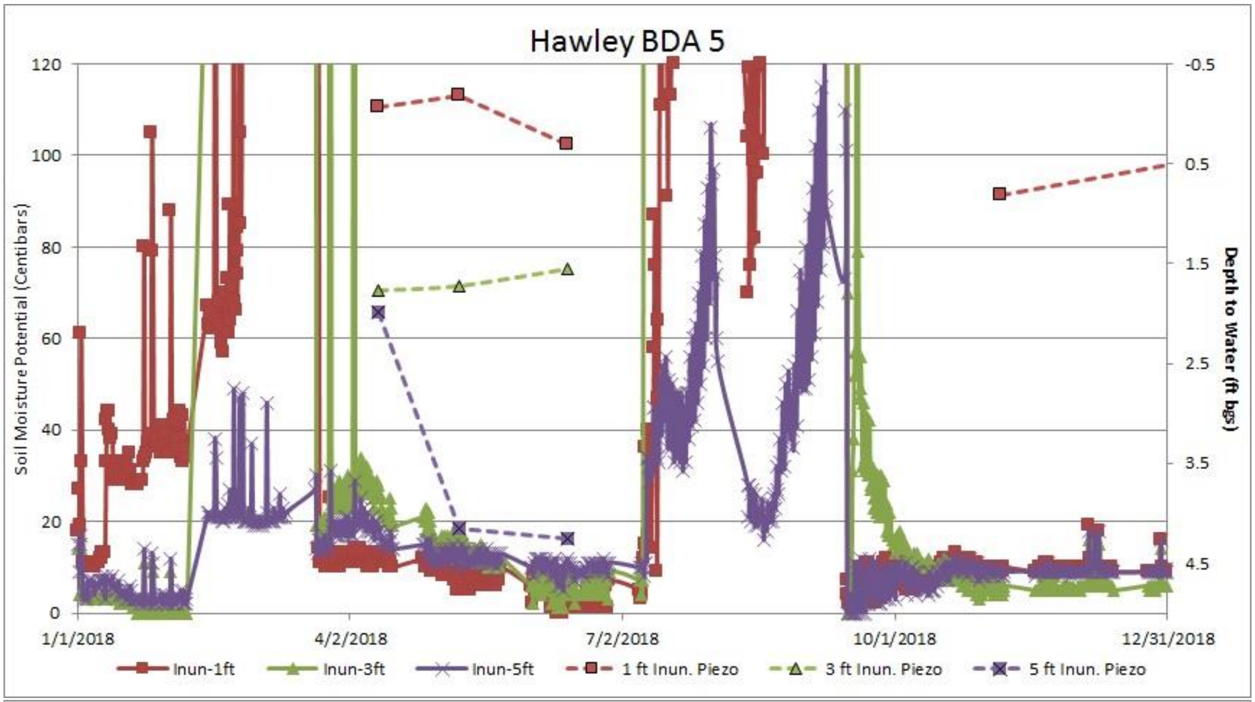


Figure H-3. Hawley BDA Station 4 soil moisture data for 2018.



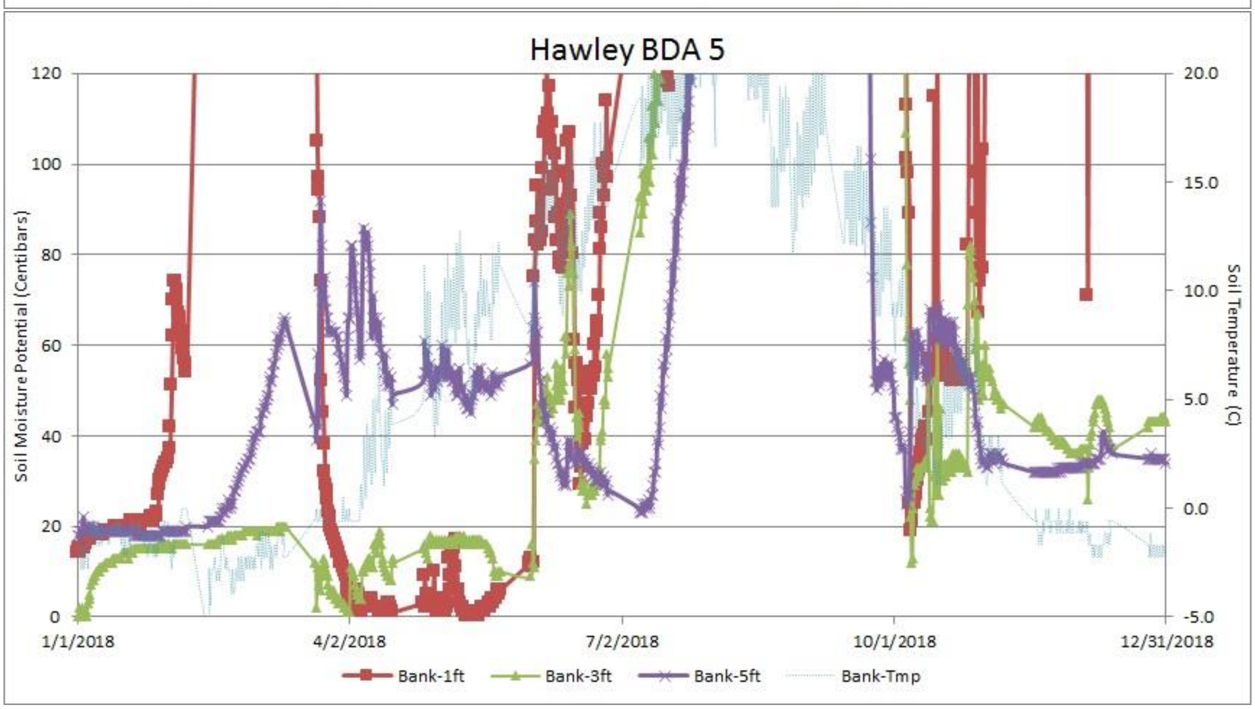


Figure H-4. Hawley BDA Station 5 soil moisture data with piezometer data for 2018.

Appendix I – Water Budget Memo

LRBM Water Budget

By Carter Borden

1 Overview

The Lemhi River Basin Model (LRBM) is a surface water budget model developed by Idaho Department of Water Resources (IDWR) to predict how diversion operations and climate conditions will influence stream flow throughout the Lemhi River Basin. The functionality, construction, and calibration of the LRBM are described in *Lemhi River Basin Model Supporting Documentation* (CCI 2015). The LRBM simulates daily stream flows and operations for water years 2008-2017 and has been calibrated to stream discharges in gages and seepage run along the Lemhi River. To ensure the model is correctly simulating the hydrologic cycle, water budgets were developed for i) the Lemhi River Basin (LRB) downstream to the confluence with the Salmon River, ii) the upstream portion of the Lemhi River Basin downstream to USGS Gauge Lemhi River at Lemhi (Upper LRB), and ii) the downstream portion of the Lemhi River Basin from the USGS Lemhi River at Lemhi to the Lemhi River confluence with the Salmon River (Lower LRB) (Tables 1-3). This document presents the results of the LRBM water budget.

2 LRBM Water Budgets

The equation used for computing the LRBM water budgets is:

$$Precip + Q_{in} + GW_{in} - (Q_{out} + ET + GW_{out}) = \Delta S \qquad \text{Eq. 1}$$

where *Precip* is precipitation, Q_{in} and Q_{out} are streamflow in and out, GW_{in} and GW_{out} are groundwater in and out, *ET* is evapotranspiration, and ΔS is change in storage (primarily groundwater). Sources for each term are described in Table 5.

Water budgets are reported on an annual basis over the simulation period (WY 2008 – WY 2017). For all water budgets, GW_{in} = 0 and ΔS = 0 is assumed since groundwater levels show minimal fluctuation between years and there is no measurement of soil moisture. GW_{out} was assumed to be 3.45% of the surface water outflow (Q_{out}) as per Donato (1998). Source of each element is presented in Table 5.

The average annual water budget balances for the LRB 37,204 ac-ft, 29,068 ac-ft, and 1,290 ac-ft, respectively, which is equivalent to 3.7%, 3.6%, and 0.5% of the total annual inflow (Table 1, Table 2, Table 3). For the LRB, the annual water budget balances vary between -10.0% and 12.8% of the inflow. The Upper LRB and Lower LRB are similar in range of percentage of annual water budget balances to inflow and each year is consistent with the others in trend (Figure 1). The exception is the Lower LRB in WY2009, WY2010, WY2011, and WY2015 when large contributions from the Lemhi River offset the precipitation contribution to the annual inflow. However, water budget balance is independent of water year type, as denoted by precipitation (Figure 2).

In the LRB and Upper LRB water budgets, the average annual inflow is the average annual precipitation which averages 950,919 ac-ft and 752,664 ac-ft, respectively (Table 1, Table 2). Average annual precipitation in the Upper LRB contributes 79% of the LRB inflow annual inflow. For average outflow conditions, ET is the dominate process with 675,704 ac-ft and 518,315 ac-ft for the LRB and Upper LRB, respectively. This translates to 74% and 72% of the total outflow. Annual average outflow (Q_{out}) from the Lemhi River is 230,075 ac-ft and 198,435 ac-ft for the LRB and Upper LRB water budgets, or 25% and 27% of the total average annual outflow. In all water budgets, GW_{out} is 1% of the total outflow.

As the Lemhi River is contributing to the Lower LRB inflow, the average annual inflow of 400,600 ac-ft splits 50% for precipitation and Q_{in} (Table 3). The Lower LRB differs from the other water budgets in that 40% is associated with ET and Q_{out} is 58%, thus river flow is more dominant in LRB. In the LRB and Upper LRB water budgets, GW_{out} is 1% of the total outflow and 2% for the Lower LRB.

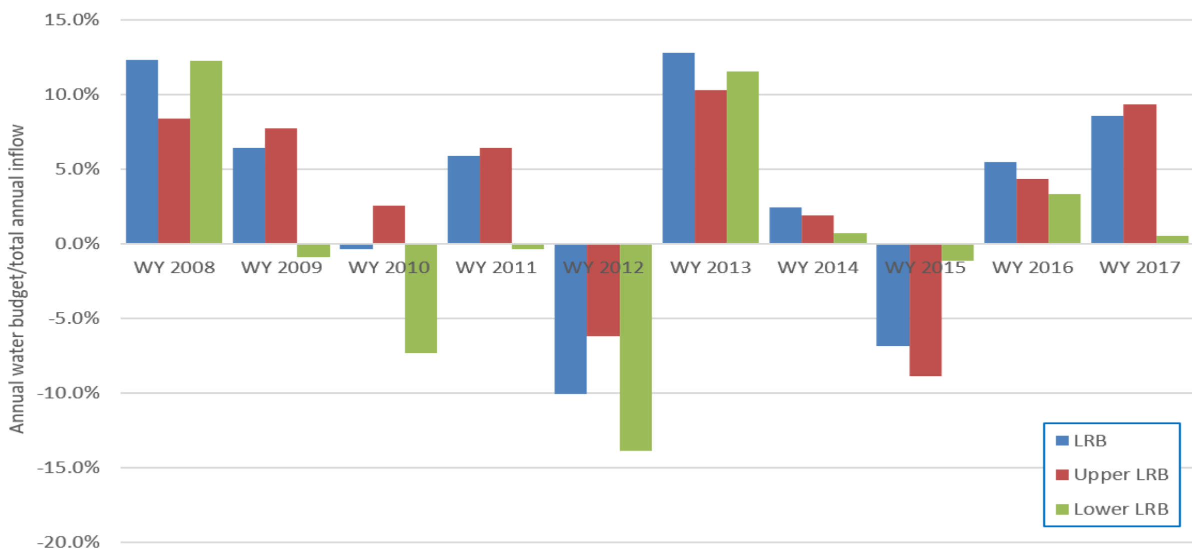


Figure 1. Percentage of annual water balance in relation to the annual inflow.

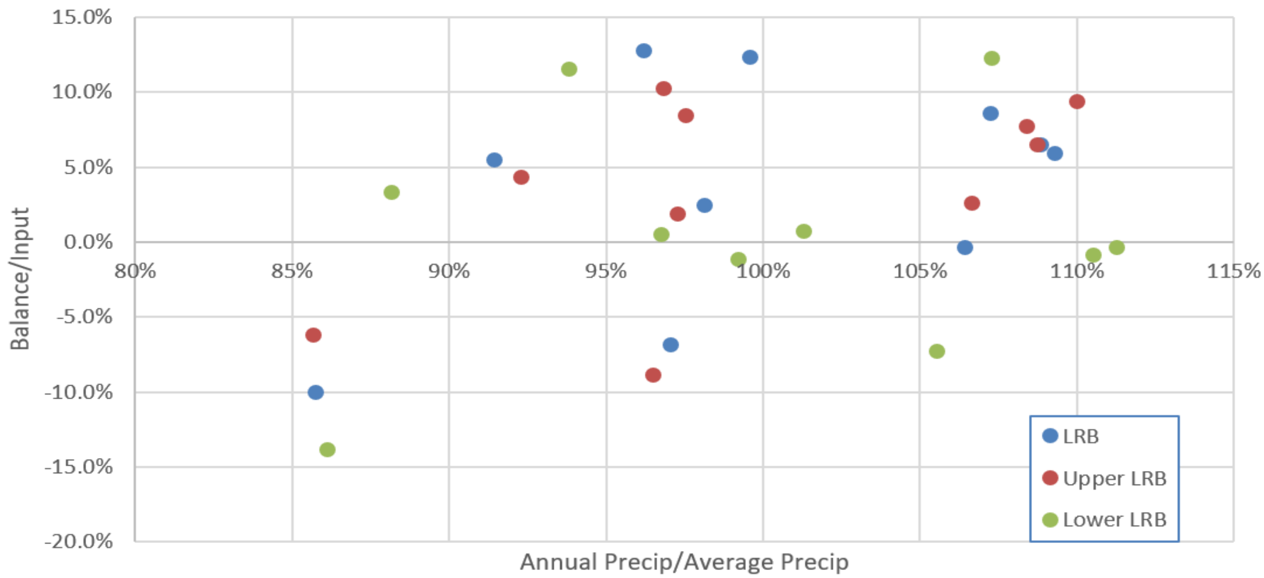


Figure 2. Normalized annual inflow to the water balance to total Inflow

Table 1. Lemhi River Basin water budget includes the Lemhi River Basin upstream of the confluence with the Salmon River. Terms are defined in Eq. 1.

Acre-Ft	Precip.	Q_{in}	GW_{in}	*Inflow*	ET	Q_{out}	GW_{out}	Outflow	Δ Storage	*Balance*	*% Difference*
Min	**815,543**	**0**	**0**	***815,543***	**599,530**	**133,142**	**4,593**	***797,672***	**0**	***17,871***	***-10.0%***
Ave	**950,919**	**0**	**0**	***950,919***	**675,704**	**230,075**	**7,938**	***913,716***	**0**	***37,204***	***3.7%***
Max	**1,039,197**	**0**	**0**	***1,039,197***	**805,432**	**365,489**	**12,609**	***1,015,408***	**0**	***23,789***	***12.8%***
WY 2008	946,891	0	0	*946,891*	637,842	185,938	6,415	*830,194*	0	*116,696*	*12.3%*
WY 2009	1,035,041	0	0	*1,035,041*	694,436	264,573	9,128	*968,136*	0	*66,905*	*6.5%*
WY 2010	1,012,029	0	0	*1,012,029*	722,444	283,194	9,770	*1,015,408*	0	*-3,379*	*-0.3%*
WY 2011	1,039,197	0	0	*1,039,197*	599,530	365,489	12,609	*977,628*	0	*61,569*	*5.9%*
WY 2012	815,543	0	0	*815,543*	645,620	243,291	8,394	*897,304*	0	*-81,761*	*-10.0%*
WY 2013	914,827	0	0	*914,827*	659,937	133,142	4,593	*797,672*	0	*117,155*	*12.8%*
WY 2014	933,116	0	0	*933,116*	705,158	198,396	6,845	*910,399*	0	*22,717*	*2.4%*
WY 2015	923,129	0	0	*923,129*	805,432	174,702	6,027	*986,161*	0	*-63,032*	*-6.8%*
WY 2016	869,572	0	0	*869,572*	628,228	187,348	6,464	*822,040*	0	*47,533*	*5.5%*
WY 2017	1,019,848	0	0	*1,019,848*	658,410	264,674	9,131	*932,215*	0	*87,633*	*8.6%*

Table 2. Upper Lemhi River Basin water budget includes the Lemhi River Basin downstream to USGS Gauge Lemhi River@Lemhi. Terms are defined in Eq. 1.

Acre-Ft	Precip	Q_{in}	GW_{in}	*Inflow*	ET	Q_{out}	GW_{out}	Outflow	Δ Storage	*Balance*	*% Difference*
Min	**644,826**	**0**	**0**	***644,826***	**452,406**	**137,854**	**4,756**	***653,958***	**0**	***-9,132***	***-8.9%***
Ave	**752,664**	**0**	**0**	***752,664***	**518,315**	**198,435**	**6,846**	***723,596***	**0**	***29,068***	***3.6%***
Max	**828,043**	**0**	**0**	***828,043***	**626,436**	**302,824**	**10,447**	***790,852***	**0**	***37,191***	***10.3%***
WY 2008	734,157	0	0	*734,157*	482,602	183,466	6,330	*672,398*	0	*61,759*	*8.4%*
WY 2009	815,910	0	0	*815,910*	525,448	219,734	7,581	*752,764*	0	*63,147*	*7.7%*
WY 2010	802,794	0	0	*802,794*	543,919	230,104	7,939	*781,961*	0	*20,834*	*2.6%*
WY 2011	818,589	0	0	*818,589*	452,406	302,824	10,447	*765,677*	0	*52,912*	*6.5%*
WY 2012	644,826	0	0	*644,826*	503,467	175,163	6,043	*684,673*	0	*-39,847*	*-6.2%*
WY 2013	728,854	0	0	*728,854*	511,348	137,854	4,756	*653,958*	0	*74,896*	*10.3%*
WY 2014	732,290	0	0	*732,290*	536,829	175,495	6,055	*718,379*	0	*13,912*	*1.9%*
WY 2015	726,398	0	0	*726,398*	626,436	158,933	5,483	*790,852*	0	*-64,454*	*-8.9%*
WY 2016	694,775	0	0	*694,775*	487,444	171,361	5,912	*664,716*	0	*30,059*	*4.3%*
WY 2017	828,043	0	0	*828,043*	513,248	229,421	7,915	*750,583*	0	*77,460*	*9.4%*

Table 3. Lower Upper Lemhi River Basin water budget includes the Lemhi River Basin from the USGS Gauge Lemhi River@Lemhi to the confluence with the Salmon River. Terms are defined in Eq. 1.

Acre-Ft	Precip.	Q_{in}	GW_{in}	*Inflow*	ET	Q_{out}	GW_{out}	Outflow	Δ Storage	*Balance*	*% Difference*
Min	**170,717**	**137,854**	**0**	***323,827***	**140,784**	**133,142**	**4,593**	***286,324***	**0**	***37,504***	***-13.9%***
Ave	**198,256**	**198,435**	**0**	***396,691***	**157,389**	**230,075**	**7,938**	***395,401***	**0**	***1,290***	***0.5%***
Max	**220,608**	**302,824**	**0**	***523,432***	**178,996**	**365,489**	**12,609**	***525,223***	**0**	***-1,791***	***12.3%***
WY 2008	212,734	183,466	0	*396,200*	155,239	185,938	6,415	*347,592*	0	*48,608*	*12.3%*
WY 2009	219,131	219,734	0	*438,865*	168,987	264,573	9,128	*442,688*	0	*-3,823*	*-0.9%*
WY 2010	209,235	230,104	0	*439,338*	178,526	283,194	9,770	*471,489*	0	*-32,151*	*-7.3%*
WY 2011	220,608	302,824	0	*523,432*	147,124	365,489	12,609	*525,223*	0	*-1,791*	*-0.3%*
WY 2012	170,717	175,163	0	*345,880*	142,153	243,291	8,394	*393,837*	0	*-47,957*	*-13.9%*
WY 2013	185,973	137,854	0	*323,827*	148,589	133,142	4,593	*286,324*	0	*37,504*	*11.6%*
WY 2014	200,826	175,495	0	*376,321*	168,330	198,396	6,845	*373,570*	0	*2,751*	*0.7%*
WY 2015	196,730	158,933	0	*355,663*	178,996	174,702	6,027	*359,725*	0	*-4,061*	*-1.1%*
WY 2016	174,797	171,361	0	*346,158*	140,784	187,348	6,464	*334,596*	0	*11,562*	*3.3%*
WY 2017	191,805	229,421	0	*421,226*	145,162	264,674	9,131	*418,968*	0	*2,258*	*0.5%*

Comparing the LRBM and USGS water budget for the Lower LRB (Donato 1998), the hydrologic components agree within 10% in the Q_{in}, Q_{out}, GW_{out}, and ΔStorage, but differs in the Precipitation and ET components (Table 4). The differences in Precipitation and ET are due to the methodology used to compute the values as USGS uses norms and the LRBM is based on measured values. In the USGS water budget, interpolated regional isohyetal maps based on 30 years of precipitation data are used to estimate precipitation over the Lower LRB, whereas the LRBM uses measured climate station data extrapolated across PRISM surfaces. The USGS estimated 51% more into the Lower LRB. For ET, the USGS used landuse/landcover GIS maps coupled with ET norms for forest, irrigated crops, and rangeland categories whereas the LRBM ET is based on measured ET from METRIC. The METRIC method estimates 77% less ET is produced than the USGS method. Despite these differences, both methods balance within 0.2% of the inflow to the basin.

Table 4. Comparison of the LRBM and Donato (1998) annual water balance for the Lower LRB. All units are in ac-ft.

Hydrologic Component	LRBM	Donato (1998)	% Difference
Precipitation	198,256	299,100	51%
Q_{in}	198,435	194,784	-2%
GW_{in}	0	0	-
ΣInput	***396,691***	***493,884***	***25%***
ET	157,389	279,225	77%
Q_{out}	230,075	207,244	-10%
GW_{Out}	7,938	7,415	-7%
ΣOutput	***392,065***	***493,884***	***26%***
Δ Storage	0	0	-
Balance	***1,290***	***0***	***-100%***
% Difference	***0%***	***0%***	***-100%***

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Appendix J – Evaluation of the Potential for a Groundwater Flow Model

Prepared by

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Upper Salmon Basin Groundwater-Surface Water Interactions Study, Phase 3

Task 5 – Evaluate the potential for a groundwater flow model

The objectives of Task 5 are to assess the utility of two groundwater models for the basin: MIKE SHE by the Danish Hydrologic Institute (DHI) and MODFLOW by the U.S. Geological Survey (USGS). The following assessment discusses available groundwater modeling options and existing data, provides future direction for a potential groundwater flow model, and highlights where data gaps exist that would hinder using a groundwater flow model.

5.1 Aquifer geometry

The principal water bearing units in the Lemhi basin consist of unconsolidated sediments including alluvial deposits associated with the Lemhi River and tributary streams, and older alluvial terrace, alluvial fan, and glacial deposits (Donato, 1998). The thickness and geometry of the aquifer are not well defined. Limited information on aquifer thickness can be obtained from well drillers' logs. Donato (1998) recommended seismic profiling to gather additional information on the geometry and uniformity of the alluvial sediments, particularly in the vicinity of Lemhi, to better understand the nature of groundwater flow between the upper and lower Lemhi basin. Surficial geologic mapping of the unconsolidated sediments provides an approximate areal extent of the Lemhi Valley aquifer (Figure 3 in main report).

Well logs reviewed by Donato (1998) indicate the unconsolidated sediments are over 200 feet thick in the vicinity of Leadore, but are less than 100 feet thick along much of the Lemhi River corridor (Figure 13 in main report). The aquifer is constricted both laterally and vertically between Lemhi and Tendoy, where the aquifer is estimated to be less than 0.5 mile wide and have a saturated thickness of less than 40 feet (Burnop, 2014). The aquifer is also constricted at the downgradient basin boundary, where alluvial sediments are estimated to be less than 50 feet thick and approximately one mile wide (Burnop, 2014).

Groundwater head elevation ranges from over 6,400 feet in tributary subbasins above Leadore to approximately 4,000 feet at the mouth of the Lemhi River near Salmon (Figure 14 in main report). The hydraulic gradient averages approximately 45 feet per mile.

5.2 Water budget

A Lemhi basin water budget has been calculated by Borden (Appendix I) for water years 2008 through 2017. Average precipitation was 951,000 AF/yr and average ET (including irrigated and non-irrigated land) was 676,000 AF/yr. Because the aquifer is relatively thin and narrow at the mouth of the basin, groundwater underflow from the Lemhi basin to the Salmon River is relatively small compared to surface discharge. Borden (Appendix I) calculated average surface water outflow of 230,000 AF/yr and groundwater outflow of 7,900 AF/yr.

Groundwater underflow was estimated by Donato (1998) to be 7,400 AF/yr (10 cfs) using a water budget method or 500 to 3,000 AF/yr (1 to 4 cfs) using a Darcy's Law method. Donato concluded the groundwater outflow from the Lemhi basin was small compared to the annual surface water outflow of approximately 207,000 AF/yr (286 cfs).

Construction of a groundwater flow model will require calculation of spatially distributed aquifer recharge associated with the infiltration of precipitation, canal seepage, and irrigation water and aquifer discharge associated with groundwater pumping. Data available to calculate an aquifer water budget is discussed in a subsequent section of this report.

5.3 Existing model representations of groundwater flow in the Lemhi basin

Spinazola (1998) developed a spreadsheet tool that calculates the impact of pumping at multiple well locations on surface water supply using an analytical method to calculate stream depletions (Jenkins, 1968). The analytical method requires inputs of aquifer hydraulic conductivity, saturated thickness, specific yield, and distance between the well and stream, the values of which are constants specified in the spreadsheet tool. The user enters the pumping location, rate, duration, and time after pumping stops for each well location of interest. Spinazola (1998) populated the hydraulic conductivity field by estimating hydraulic conductivity from specific capacity derived from drillers' logs for 44 domestic and irrigation wells within the Lemhi valley. Because Spinazola believed this method underestimated the hydraulic conductivity, he multiplied the results by a factor of twelve to make the average aquifer transmissivity similar to the average transmissivity estimated at five irrigation wells located in the nearby Pahsimeroi valley aquifer[1]. Hydraulic conductivity for locations between the 44 well locations was then populated by kriging. Spinazola assumed a constant specific yield of 0.12.

Estimating hydraulic conductivity from the specific yield of a well can result in a good approximation if the well screen penetrates a significant portion of the aquifer saturated thickness, the well is efficient, and the test pumping method is efficient. Unfortunately, these conditions are not often met because most wells are not constructed for the purpose of determining aquifer properties. Domestic and small irrigation wells, which do not require a high yield, often have short screen intervals (or open bottoms), and are often test pumped using compressed air. Test pumping using compressed air does not provide a useful measurement of water level drawdown. Large irrigation wells and municipal wells requiring a high yield are more likely to have long screen intervals, be more efficient, and be test pumped in a manner that allows for adequate measurement of water level drawdown. A better estimate of hydraulic conductivity might be derived from the specific capacity of these wells, but it is still only an estimate of the aquifer properties in the immediate vicinity of the well, and may not be a good estimate of the bulk properties of the aquifer on a larger scale.

The Lemhi River MIKE BASIN model was developed by DHI, Inc. to evaluate streamflow, diversion operations, and surface water-groundwater relationships (DHI, 2006; Borden 2015). The MIKE BASIN model is a network model, which is insufficient for addressing physically-based questions such as groundwater – surface water interactions distributed over the landscape (Borden, 2015). Thus, the MIKE BASIN model does not explicitly model groundwater flow in the aquifer, but represents groundwater contributions to streamflow as return flows. The return flows are calculated in a pre-processor and input into MIKE BASIN as reach gains (Borden, 2015). The MIKE BASIN model represents groundwater contributions derived from two sources, tributary underflow associated with mountain-front recharge

[1] Transmissivity estimates for the Pahsimeroi valley aquifer were based on specific capacity calculated from discharge and drawdown measurements made by the U.S. Geological Survey at five irrigation wells in 1971 (Young and Harenburg, 1973).

and incidental recharge associated with surface water irrigation (CH2MHill, 2014). The first version of the MIKE BASIN model used exponential decay curves to calculate the return flows associated with groundwater contributions to streamflow. CH2MHill (2014) calculated spatially-distributed response functions for each tributary underflow and irrigation place of use location, which were used to replace the return flow time series representing groundwater contributions to streamflow in the MIKE BASIN model. The CH2MHill (2014) response functions incorporated the Spinazola (1998) hydraulic conductivity estimates to calculate an average hydraulic conductivity for each catchment. CH2MHill (2014) assumed a constant specific yield of 0.12, and a constant saturated thickness of 100 feet throughout the Lemhi basin aquifer. In addition to the groundwater contributions to streamflow represented as return flows, reach gains from (or losses to) the regional groundwater system are assumed to account for discrepencies between predicted and observed streamflow. Additional adjustments to reach gains are made during calibration of the MIKE BASIN model to account for the assumed contribution from the regional groundwater system (Borden, 2015).

5.4 Data availability for groundwater flow model development

The Upper Salmon Basin Watershed Program (USBWP) has supported significant data collection efforts in the Lemhi Basin in recent years. Prior data collection efforts by the U.S. Bureau of Reclamation (BOR) and U.S. Geological Survey (USGS) also contribute to data available for developing a model of the Lemhi Valley aquifer.

Groundwater head

- Groundwater level is measured in 41 wells in the Lemhi basin, with locations distributed between the vicinity of Leadore and Salmon (Figure 4 in main report). Water level data are not available in the uppermost portion of the aquifer in the upper reaches of the Eighteenmile, Texas, and Big Timber drainage areas. Thirty of the wells were monitored from 1996 to 1997 by the Bureau of Reclamation and monitoring was reinstated between 2011 and 2015 for the USBWP study. Monitoring in ten of the wells began between 2011 and 2015. One well was monitored from 1991 through 2009 and reinstated in 2011.

- Water levels were monitored by the Bureau of Reclamation between 1996 and 1997 in 49 wells that are not included in the current USBWP monitoring network. Water level contour maps (Figure 15 in main report**Error! Reference source not found.**) for June 1996 and November 1996 were presented by Donato (1998).

- Seasonal water level fluctuation ranges from a few feet to over 25 feet (Figure J-1). Canal seepage and other incidental recharge associated with surface water irrigation is the primary cause of groundwater head fluctuation (Figure J-2). The highest seasonal fluctuation occurs in the Whitson and Kibbee wells located upgradient of the constriction between the upper and lower basin (Figure J-1 and Figure J-3). Seasonal fluctuation is notably less in the Stout well, which is located within the constriction (Figure J-1 and Figure J-3Figure). Long-term trends in groundwater levels are not evident in wells with data collected in 1996-1997 and 2011-2018 (Figure J-2). The lack of long-term water level trends suggests groundwater head in the absence of surface water irrigation is primarily controlled by topography and river level.

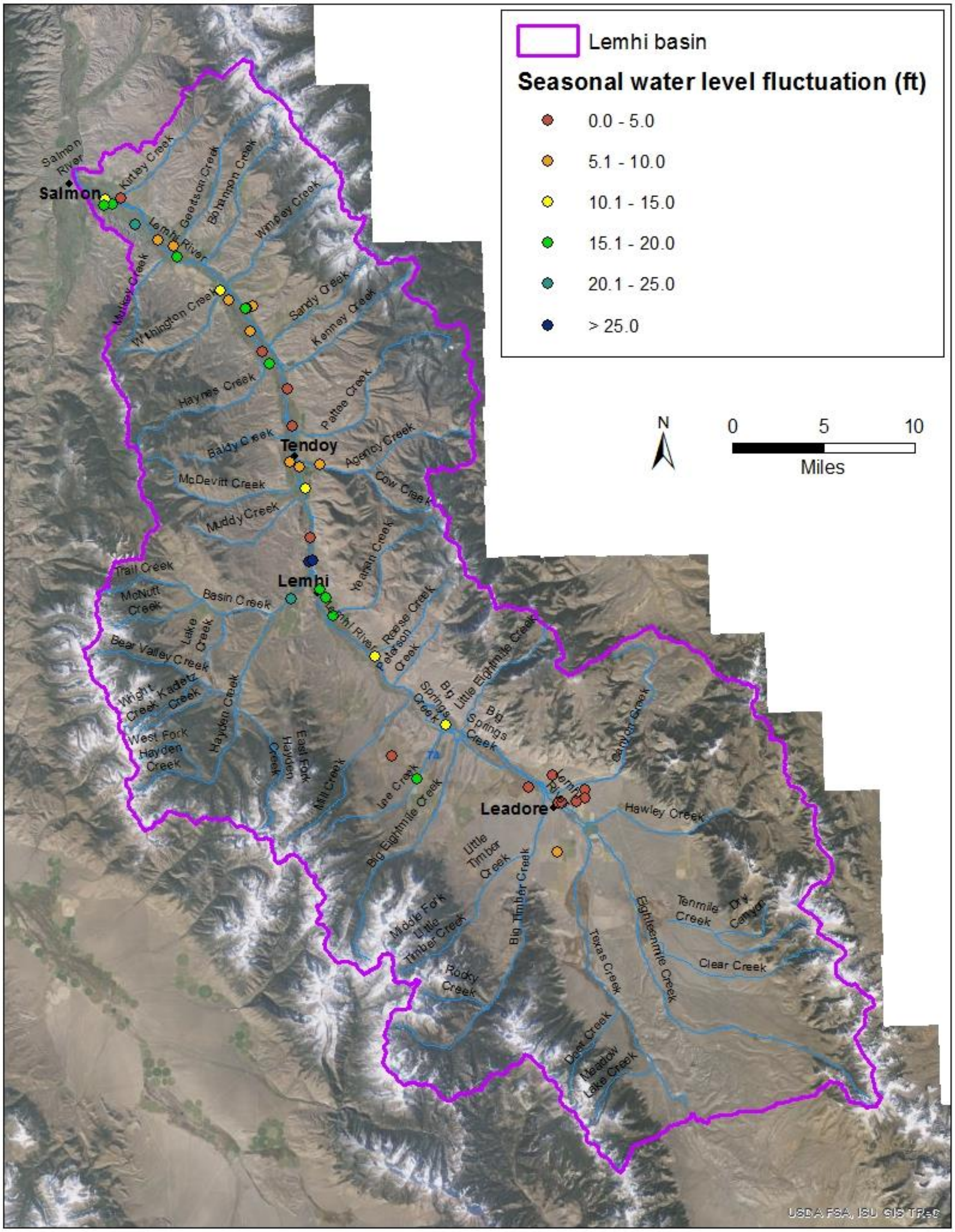
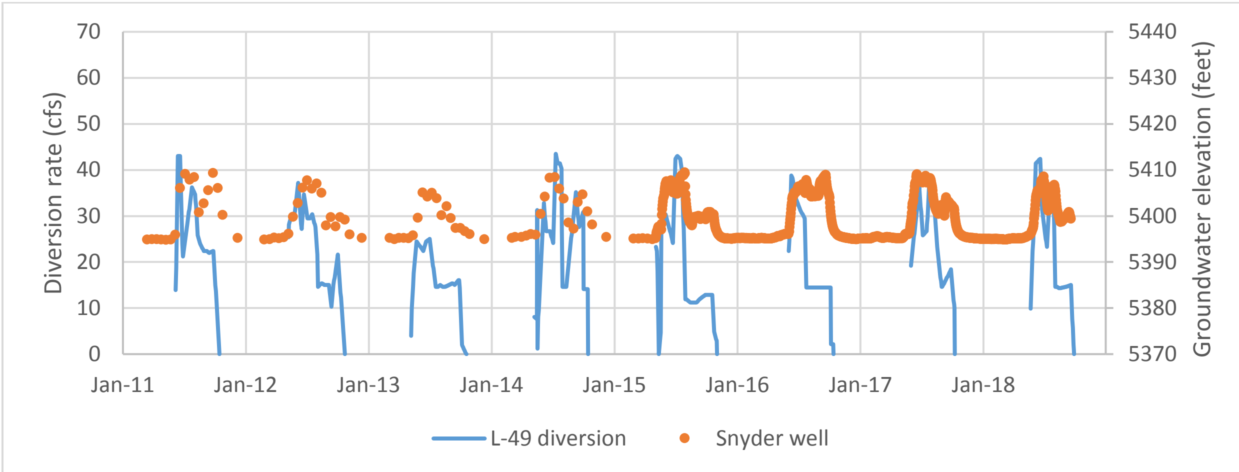
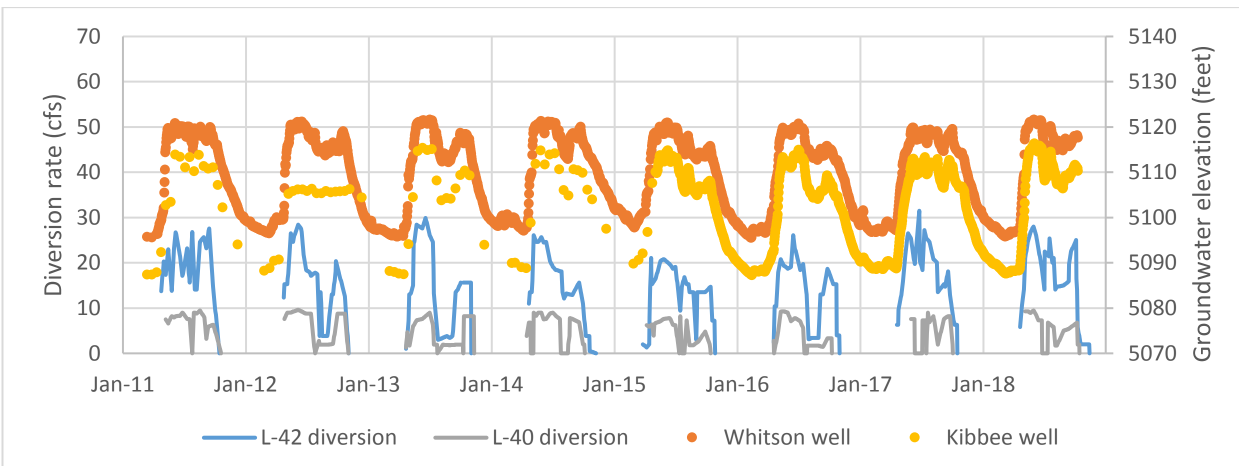


Figure J-1. Seasonal water level fluctuation in groundwater head observation wells.





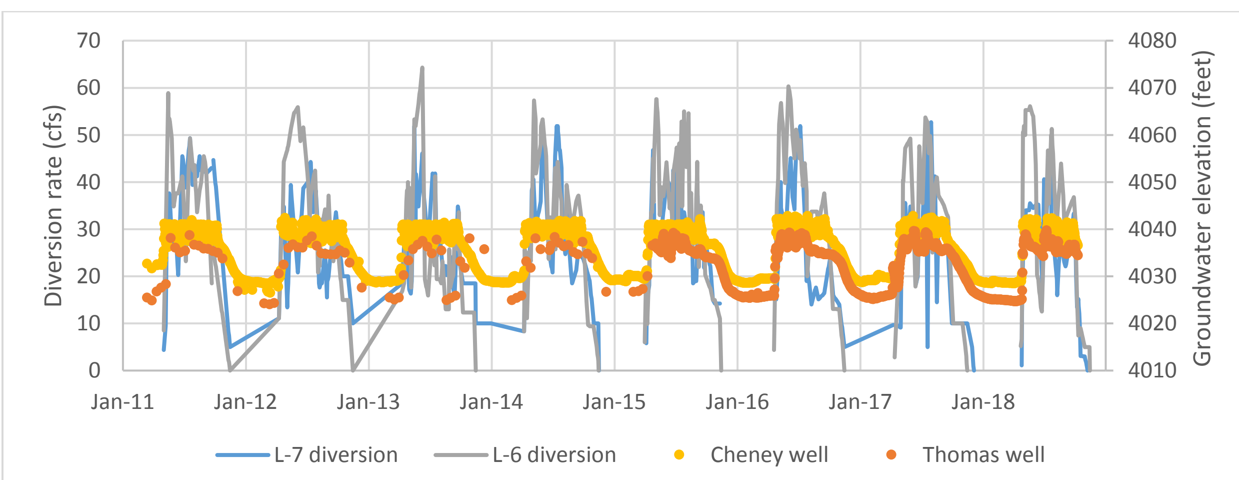


Figure J-2. Examples of the relationship between surface water diversions and groundwater head

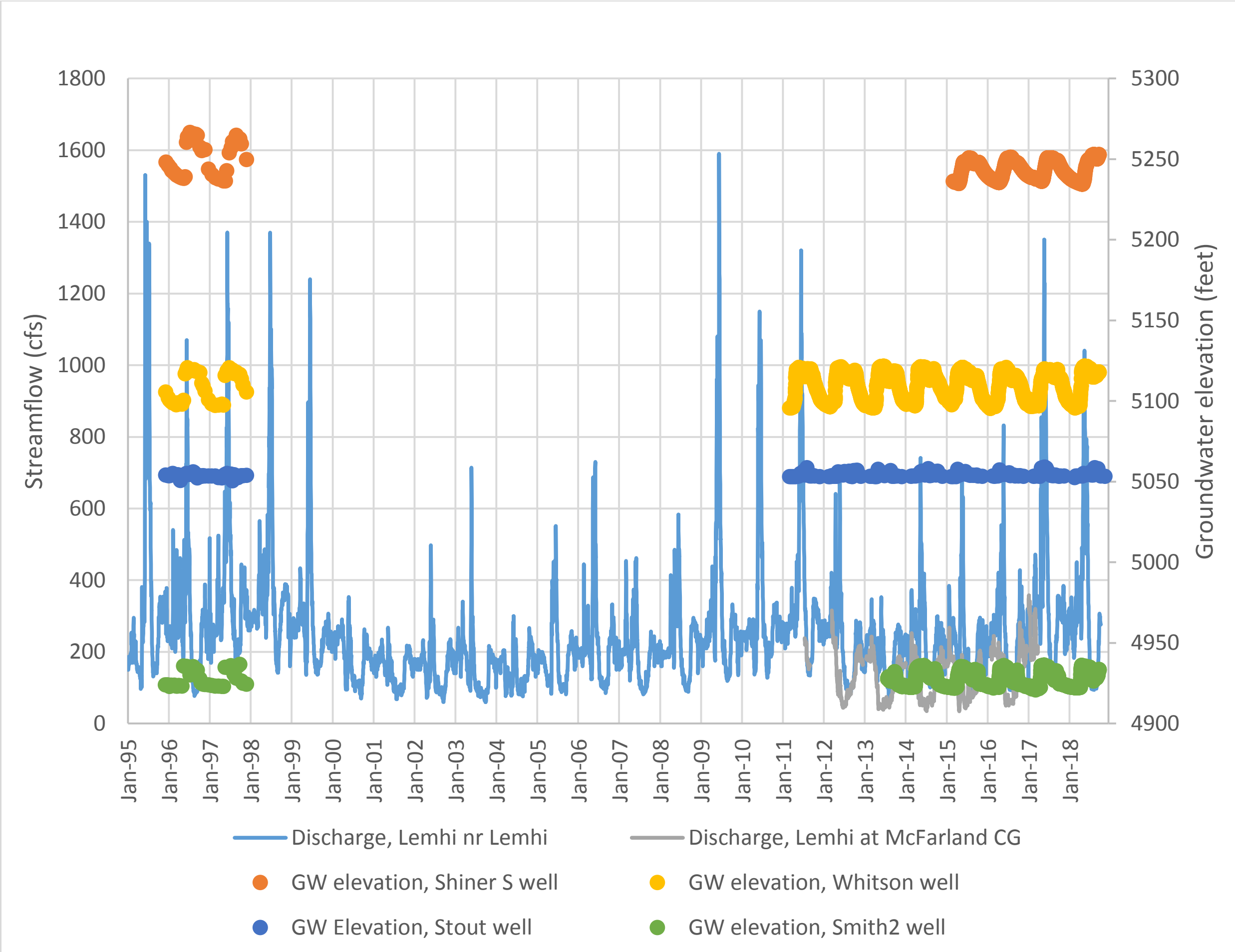


Figure J-3. Groundwater head in selected wells between the McFarland Campground and near Lemhi streamflow gages

Stream gaging

- The U.S. Geological Survey operates continuous gaging stations at two locations on the Lemhi River (Figure J-4). The gaging station near Lemhi has been in continuous operation since 1967. The gaging station below the L-5 diversion was installed in 1992. River stage and discharge data are available for these stations.
- Additional continuous stream gaging stations are operated at five locations on the Lemhi River and 19 locations on 14 tributary streams (Figure J-4). Most of the gaging stations were installed between 2004 and 2009. Three of the gaging stations have been operating since 1997. Two were installed between 2013 and 2017. River stage and discharge data are available for these stations. Some stations may need to be surveyed to determine datum elevations for the stage data.
- Calculation of reach gain time series for calibration of a groundwater flow model is expected to be possible for up to six reaches of the Lemhi River and for several of the tributary streams. Time series duration will vary with the period of record of the gaging stations and availability of other data such as diversions and surface return flows.

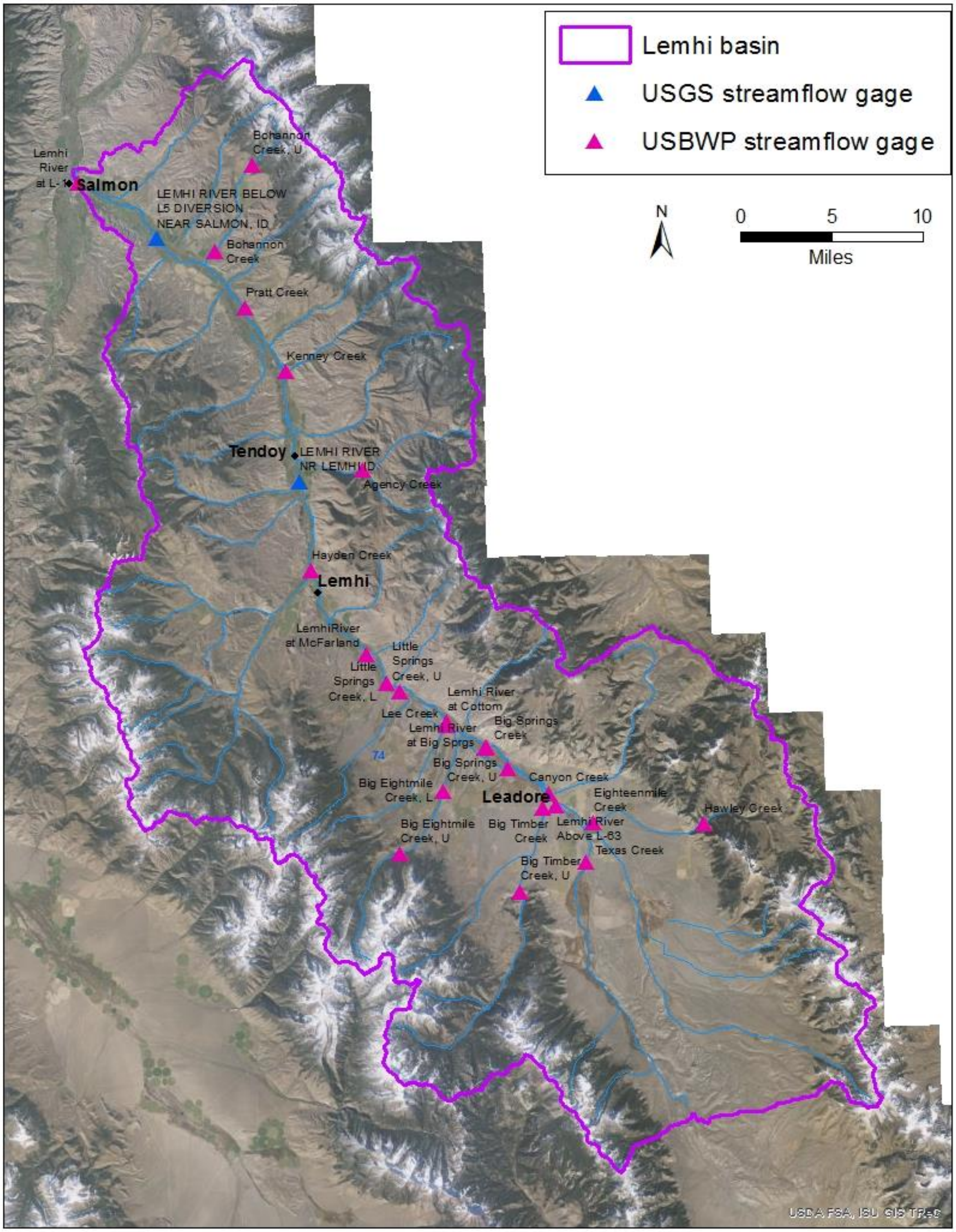


Figure J-4. Location of continuous streamflow gaging stations in the Lemhi basin

Discrete reach gain data are available from the following seepage studies

- Lemhi River, August 4-8, 1997, 60-mile reach of Lehmi River between Leadore and Salmon, with 14 subreaches (Donato, 1998)
- Lemhi River, October 27-31, 1997, 60-mile reach of Lehmi River between Leadore and Salmon, with 14 subreaches (Donato, 1998)
- Lemhi River, August 2014, 60-mile reach of Lehmi River between Leadore and Salmon, with 14 subreaches (IDWR, unpublished)
- Lemhi River, October 2014, 60-mile reach of Lehmi River between Leadore and Salmon, with 14 subreaches (IDWR, unpublished)
- Little Springs Creek, 8/22-24, 2012 (Burnop, 2014)
- Bohannon Creek, 8/7/2013 (Burnop, 2014)

Land Use

- Irrigation water right places of use include approximately 60,000 acres within the Lemhi basin (Figure J-5). The majority of the irrigation water is diverted from surface water sources. Approximately 1,000 acres are irrigated with groundwater as the primary water source and approximately 4,000 acres use groundwater as a supplemental water source.
- Alfalfa, grass hay, and pasture are the primary irrigated crops produced in the Lemhi basin (CH2MHill, 2014).
- The Lemhi basin is not within the area for which IDWR has performed detailed irrigated lands delineation.

Diversions

- Surface water diversions are recorded by several water districts in the Lemhi basin (Figure J-6). Daily surface water diversion records have been compiled for the MIKE BASIN model for the 2008 through 2017 irrigation seasons. Older diversion records may be available from watermaster reports.
- Groundwater diversions do not appear to be measured, but can be estimated from irrigation demand (evapotranspiration less precipitation).

Evapotranspiration (ET)

- The Lemhi basin is located within the area for which METRIC (Mapping Evapotranspiration at High Resolution with Internalized Calibration) ET is processed for the Eastern Snake Plain Aquifer. METRIC ET data are available for the 1996, 2000, 2006, 2008, 2009, 2010, 2011, 2013, 2015, 2016, 2017, 2018 irrigation seasons. METRIC ET data are compiled and readily available as monthly raster datasets. METRIC ET data may need to be partitioned into shorter time periods if the time-scale of desired predictions is shorter than one month.
- ET_{Idaho} reference ET and ET by vegetation type are available for weather stations at Leadore, Leadore Creek, and Salmon.

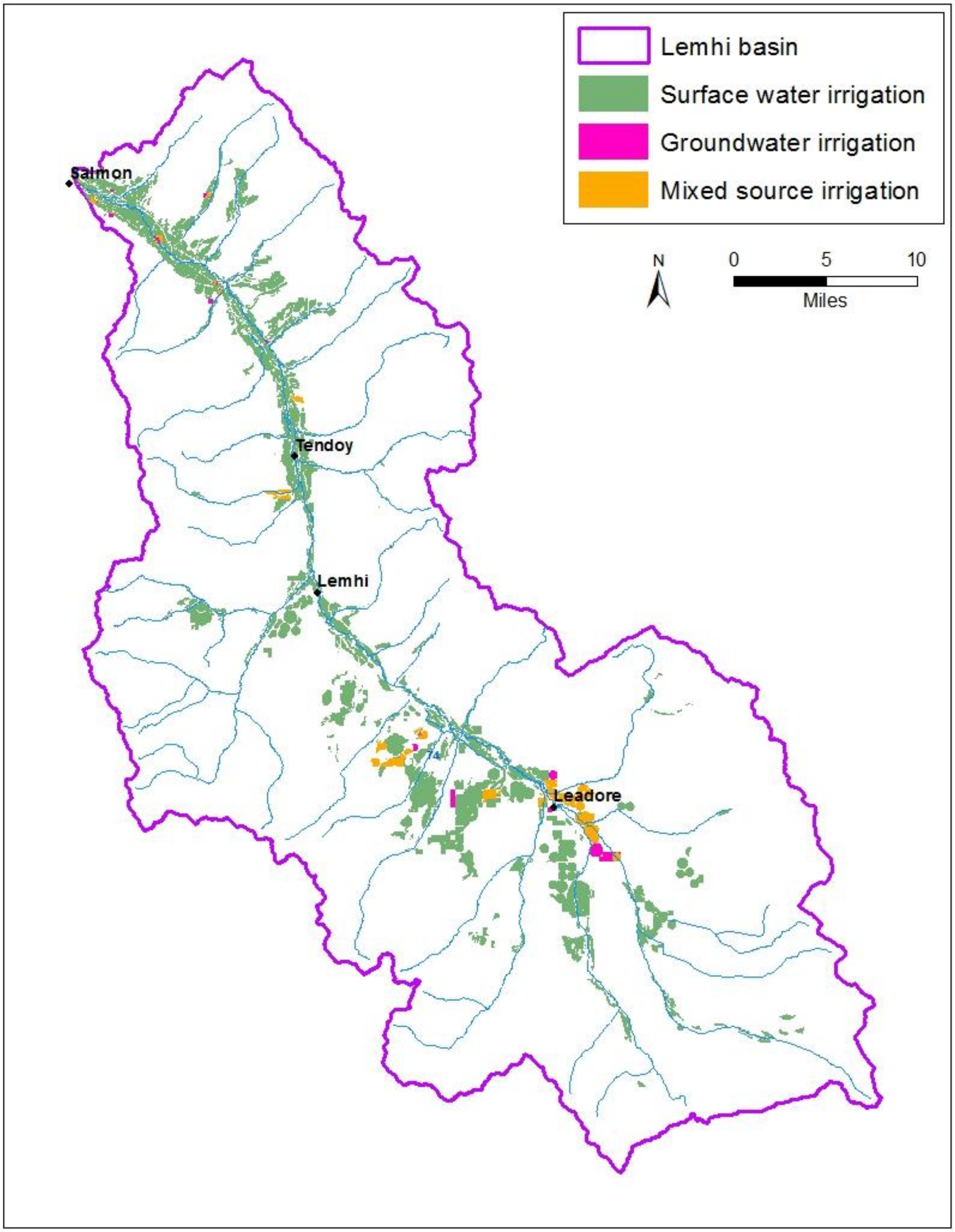


Figure J-5. Water sources for irrigation water right places of use in the Lemhi basin.

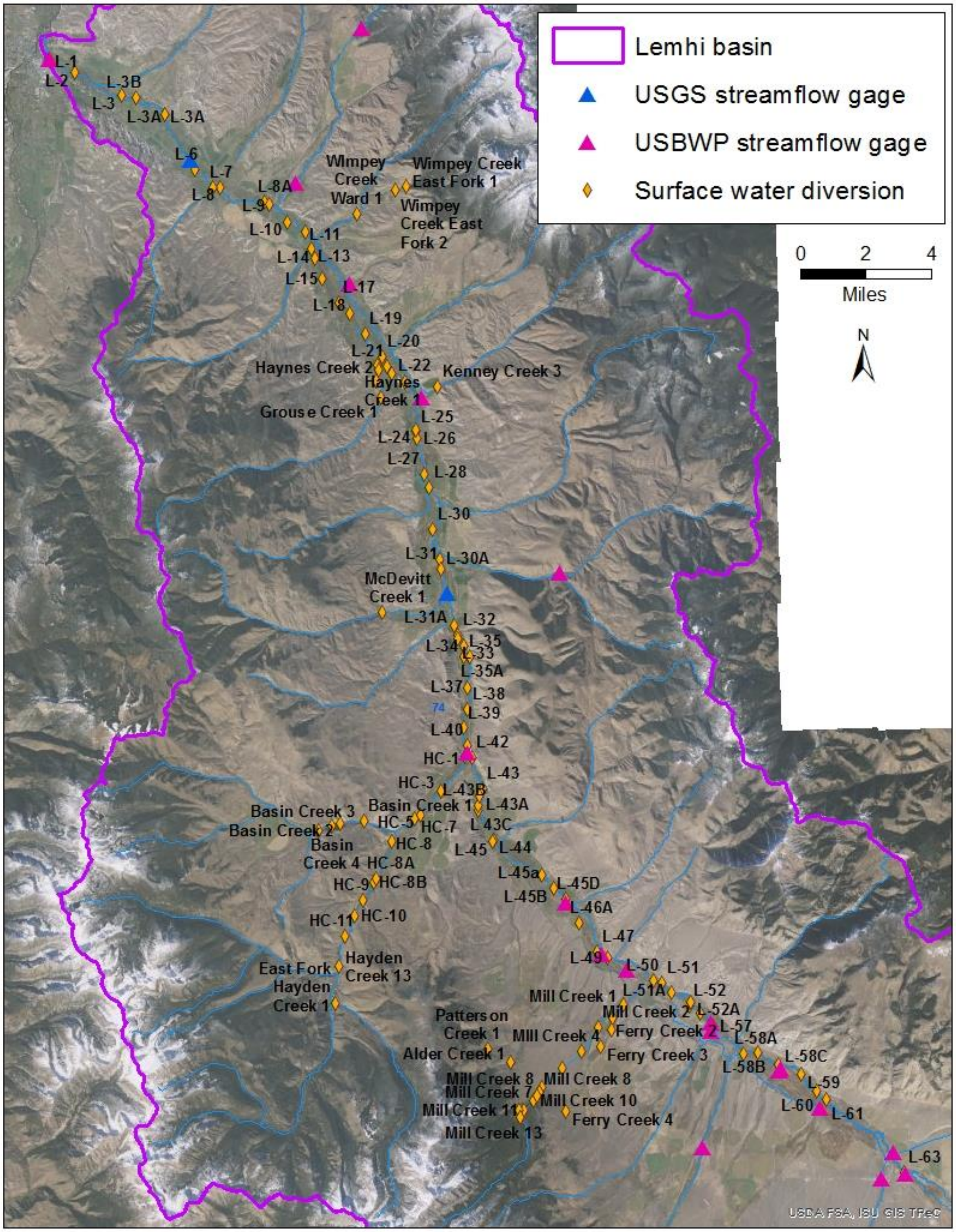


Figure J-6. Surface water diversion locations

Precipitation

- PRISM (Parameter-elevation Relationship on Independent Slopes Model) precipitation is available from Oregon State University, but may not be useful because the resolution (4 km x 4 km grid) will be too coarse to separate valley precipitation from mountain front precipitation
- Weather stations at the Lemhi County airport and Leadore are expected to provide a better estimate of precipitation within the valley.
- Weather station data from seven Snotel sites are interpolated to calculate mountain front precipitation for the MIKE BASIN model.

5.5 Discussion

Aquifer property values (hydraulic conductivity, specific yield, and saturated thickness) used to calculate response functions for the Spinazola (1998) spreadsheet tool and the current MIKE BASIN model (CH2MHill, 2014) are highly uncertain estimates based loosely on hydraulic conductivity calculated from well development data recorded on drillers' logs and assumed constant values for specific yield and saturated thickness. Developing a numerical groundwater flow model would allow calibration of the spatial distribution of aquifer properties with consideration of the spatial and temporal distribution of incidental recharge, available groundwater head data, and available stream reach gain data. A calibrated numerical groundwater flow model would be expected to provide improved estimates of aquifer properties and response functions.

Borden (2015) notes that the current method of incorporating groundwater return flows using response functions requires preprocessing the return flow time series and inputting them into the MIKE BASIN model as reach gains. Borden (2015) also comments that preprocessing the return flow time series is cumbersome when running scenarios. If a groundwater flow model is developed for the Lemhi valley aquifer, time series of groundwater contributions to streamflow calculated by the groundwater flow model can be input into the MIKE BASIN model as reach gains, replacing the current method of preprocessing the return flow time series using the CH2MHill (2014) response functions and Spinazola (1998) aquifer property estimates.

Software options for developing a numerical groundwater flow model include MIKE SHE and MODFLOW. MIKE SHE is an integrated hydrologic modeling tool developed by DHI. Hydrologic processes simulated by MIKE SHE include snowmelt, interception, overland flow, infiltration, evapotranspiration, and subsurface flow in the unsaturated and saturated zones (Loinaz, 2013). MIKE SHE uses a finite difference solution to the three-dimensional Darcy equation to model saturated zone flow (Akram, et al, 2012; Loinaz, 2013). The software is proprietary and the purchase of software licenses from DHI would be required for developers and users of a model developed with MIKE SHE.

MODFLOW is a saturated zone groundwater flow model, developed by the USGS. MODFLOW also uses a finite difference solution to the three-dimensional Darcy equation to model saturated zone flow (Langevin, et al, 2017). The software is open-source and can be freely downloaded from the USGS website by model developers and model users. MODFLOW is widely used in the United States and internationally for simulating and predicting groundwater conditions and groundwater – surface water interactions. Because the software is freely available and widely accepted in the scientific community, it has been used by IDWR to produce groundwater flow models of the Eastern Snake Plain, Spokane Valley-Rathdrum Prairie, Wood River Valley, and Treasure Valley aquifers. Free availability of MODFLOW software facilitates transparency and makes the models readily available to the public.

Akram, et al (2012) developed two groundwater flow models of the same aquifer, one with MIKE SHE and one with MODFLOW, and provided a comparison of the software. Akram, et al (2012) stated the main difference between the software packages was the ability to calculate recharge and model the unsaturated zone with MIKE SHE. For MODFLOW, aquifer recharge must be calculated separately and applied as a boundary condition. Other differences noted by Akram, et al (2012) included the following:

- Drain levels and riverbed hydraulic conductivity are constants in MIKE SHE. These parameters can be varied with time in MODFLOW.
- In MODFLOW, a time-constant transmissivity model can be developed without specifying top and bottom elevations of the aquifer. In MIKE SHE, a top and bottom elevation are required.
- The user interface for MODFLOW is "much easier, can be learned quickly from the users' manual." The user interface for MIKE SHE is "complicated and a training program is suggested."
- Operation speed for MODFLOW is "much faster" than for MIKE SHE.

Sufficient data are available to support development of a groundwater flow model of the Lemhi Valley aquifer. A calibration period of 2011 through 2018 might be considered based on the availability of aquifer head data. Extending the calibration period back to 1996 to incorporate head data collected by the BOR might also be considered, but the availability of streamflow and diversion data would need to be reviewed further.

The most significant data gap for development of a groundwater flow model is a lack of data defining the extent and saturated thickness of the aquifer. Because of uncertainty regarding the thickness of the aquifer, it is unclear to what extent the assumption of linearity is violated and whether a time-constant-transmissivity model will provide an adequate simulation of groundwater flow and groundwater-surface water interaction. While there is no absolute guidance on when a time-constant transmissivity model will provide an adequate representation, a 10 percent fluctuation in saturated thickness has been used as a general rule of thumb by some researchers (Reilly and Harbaugh, 2004; Barlow and Leake, 2012). However, a satisfactory calibration of the Wood River Valley groundwater flow model was achieved with a time-constant transmissivity model (Wylie, et al, 2019; Fisher, et al, 2016). Saturated thickness fluctuations are similar in the upper Wood River Valley and Lemhi Valley aquifers. Additional information on the geometry of the aquifer may not be needed if a time-constant-transmissivity model is capable of simulating the observed head changes and reach gains. If a time-constant-transmissivity calibration is unsatisfactory, more detailed delineation of the alluvial sediments may be needed, particularly in areas where the saturated thickness may be less than 50 feet.

There is a lack of groundwater head data south of Leadore, but that may not be a significant concern if model predictions are not of interest in this area. Datum elevations for stream gage stage readings will need to be surveyed at sites that have not previously been surveyed. If significant quantities of irrigation water are returned to the river via surface flow, quantification of surface return flows will be needed.

5.5 Recommendations

Development of a physically-based, head-dependent groundwater flow model is expected to result in improved estimates of aquifer properties and improved ability to model streamflow responses to changes in irrigation practices that affect groundwater recharge or discharge. Time series results from groundwater flow model simulations could be input into the MIKE BASIN model as reach gains, and could replace the response function time series and reach gain adjustments currently used to represent groundwater in the MIKE BASIN model. If a groundwater flow model is desired to provide better predictions of streamflow responses to changes in aquifer recharge or discharge, the nature, location, and time-scale of the desired predictions should be defined to guide the development of objectives for the groundwater flow model.

Use of MODFLOW, rather than MIKE SHE is recommended for development of a groundwater flow model for the following reasons.

1. MODFLOW is freely available to the public.
2. MODFLOW is easier to use and runs faster than MIKE SHE (Akram, et al, 2012).
3. The Lemhi River MIKE BASIN model is already available to model the surface water network. MODFLOW can account for the spatial distribution of groundwater – surface water interactions and generate time series for reach gains, which can be entered into the existing MIKE BASIN model.

Because of data collection efforts supported by the USBWP, BOR, and USGS, data availability for developing a groundwater flow model of the Lemhi Valley aquifer is very good. Some additional data collection needs, such as surveying datum elevations for stream stage at gaging stations and quantifying or estimating surface return flows, may be identified during model development.

5.6 References

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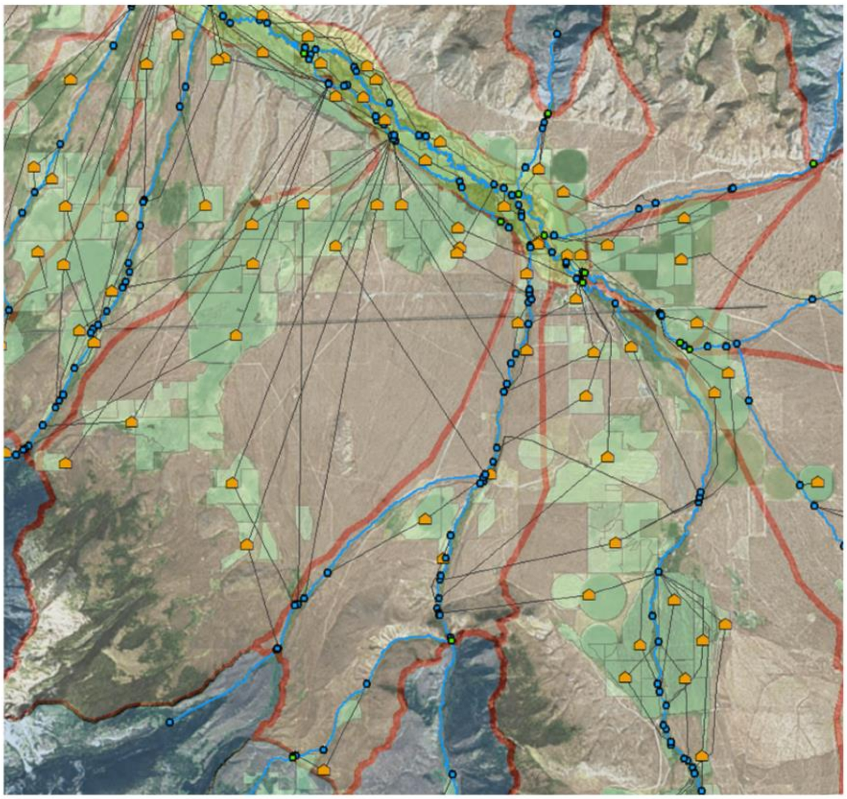
Appendix K – LRBM Documentation



Lemhi River Basin Model

SUPPORTING DOCUMENTATION

Created for The Idaho Office of Species Conservation by Carter Borden
Centered Consulting International, LLC
December 2015

TABLE OF CONTENTS

1 INTRODUCTION

This report describes further development by the Idaho Department of Water Resources (IDWR) and the State of Idaho Office of Species Conservation to develop a surface water budget model for the Lemhi River Basin (LRB), Idaho. The purpose for developing the Lemhi River Basin Model (LRBM) is to quantify and collectively represent sources and uses of streamflow throughout the entire mainstem of the Lemhi River system and 26 tributaries. The LRBM will be used to understating the hydrology and irrigation systems within the LRB as well as evaluate the impacts to stream flows associated with past and future projects.

Since 2006, the Lemhi River Basin Model (LRBM) has gone through a series of development cycles with the Idaho Department of Water Resources (IDWR) staff Nick Scheidt, Eric Rothwell, Taylor Dixon, and Alison Burnop providing contributions to the its development, enhancement, modification, and augmentation. These efforts yielded a model that has a networks of stream, points of diversion (PODs), and places of use (POUs); historical diversion records for each POD; PODs linked to POUs via water rights (some serving multiple water); crops grown and irrigation method for each POU; and estimates of catchment inflow from 82 catchments throughout the Lemhi River Basin (LRB). While the LRBM is well constructed and has the majority of the information needed to simulate conditions in the LRB, an effort to calibrate the current LRBM identified several limitations in the construction. Before proceeding with the calibration, the LRBM required updating the inflow catchments, including high flow water diversions rates, and improvement of return flow timing and quantities.

The model construction is the latest effort to update, improve, and calibration the LRBM. During this period, IDWR and Centered Consulting International, LLC (CCI) personnel refined and updated the river network, compiled and populated the model with recent data, improve return flow timing and quantities, update the rainfall-runoff model, and calibrated the model. The calibrated model can be used to evaluate operation scenarios for the impacts of flow augmentation projects throughout the Lemhi. However, the accuracy of the model varies with greater accuracy of input data and rainfall-runoff modeling. This report includes a description of the construction and calibration of the LRBM, rainfall-runoff modeling, and scenarios. Ryan Warden (IDWR) was instrumental in model construction and contributing to this report.

2 LEMHI RIVER BASIN MODEL (LRBM)

2.1 LRBM Construction

2.1.1 Software Overview

The LRBM includes rainfall-runoff model (NAM) to predict inflow to the system (described in Section 3) and a water allocation model to route water in the stream network and account for irrigation practices. The software providing the basis for the LRBM is DHI Water and Environment's (DHI) MIKE BASIN Software; a geographic information systems (GIS) based water allocation software. MIKE BASIN uses polygons to represent catchment inflow, arcs to represent the streams network and canal system to route water, and nodes to compute mass balance and off-stream nodes to represent water use. On-stream nodes represent computations such as gages, diversions, return flows, bifurcations, and off-stream nodes represent water use such as municipal, commercial, industrial, water treatment, irrigation, and hydropower. The software simulates the water distribution by calculating water mass balance at every node and routing water between nodes via branches. The water uses can simulate consumption and irrigation node will compute the demand and consumption based on the FAO 56 method. Hydropower nodes compute hydropower production given the difference in head, volume of water passing the turbines, and system efficiency. Nodes representing lakes and reservoirs are on-stream and include salient features (e.g. height-volume-area curves, crest-level) as well as gate, valve, and spillway operations.

Branches route water between nodes and represent the stream network as well as link channels connecting water user and irrigation nodes to the stream network. In addition to routing water, flow routing functions can be used to delay travel along an arc and seepage loss applied to account for reach gains and losses.

Results from the model can be viewed as a time series of any computational component (e.g. river flows, groundwater storage volumes, deficits for water users), a water distribution map of the model network with graduated color result presentations for many combinations of results, or statistical analysis that can also be plotted on the map. Though conceptually simple, river basin models allow water managers to investigate different management alternatives associated with different diversion operations, crop irrigation/rotation methods, and an understanding of how return flows influence stream flows in response to irrigation practices.

The LRBM simulates the performance of the overall system by accounting for catchment inflows; routing of water in the stream network; and computing the diversion, consumption, and return flows for irrigation. Simulations take into account the irrigation water use by individual extraction points of diversion (PODs) and places of use (POUs) throughout the system on a daily time step. Results from the LRBM are viewed as time series of any computational component (e.g. river flows, groundwater storage volumes, deficits for water users) and as water distribution maps of the model network with graduated color result presentations of results. Supporting the LRBM are several MS EXCEL workbooks that aid in inputting time series data for catchments and irrigation nodes as well as extracting output results for display and computing analytical results from a water distribution scenarios. The current LRBM represents the surface components of the hydrologic system with inferences to groundwater return flow responses given an irrigation event.

2.1.2 Model Network

In the LRBM, branches represent rivers and canals and water user nodes represent domestic and irrigation water use. Construction of the LRBM involved gathering GIS coverages of the stream network from the NHD hydrography layer (USGS 2012), PODs and associated POUs (IDWR 2010, IDWR 2012), and aerial photography and then consulting local water authorities and stakeholders to construct the model network (Figure 1). The stream network, developed from the NHD hydrography layer, represents the Lemhi River and 26 tributaries. Inflow to the model is represented by 82 catchments (Section 2.1.3). In the LRBM, 82 catchments representing inflows from precipitation were delineated to determine inflow. Creating the catchments involved selecting the catchment pour point (catchment node in the LRBM) and delineating the contribution area from the USGS 30m NED digital elevation model (DEM) (DHI 2006). The resulting catchments were compared to watershed GIS coverage provided by IDWR to ensure reasonable catchment delineation.

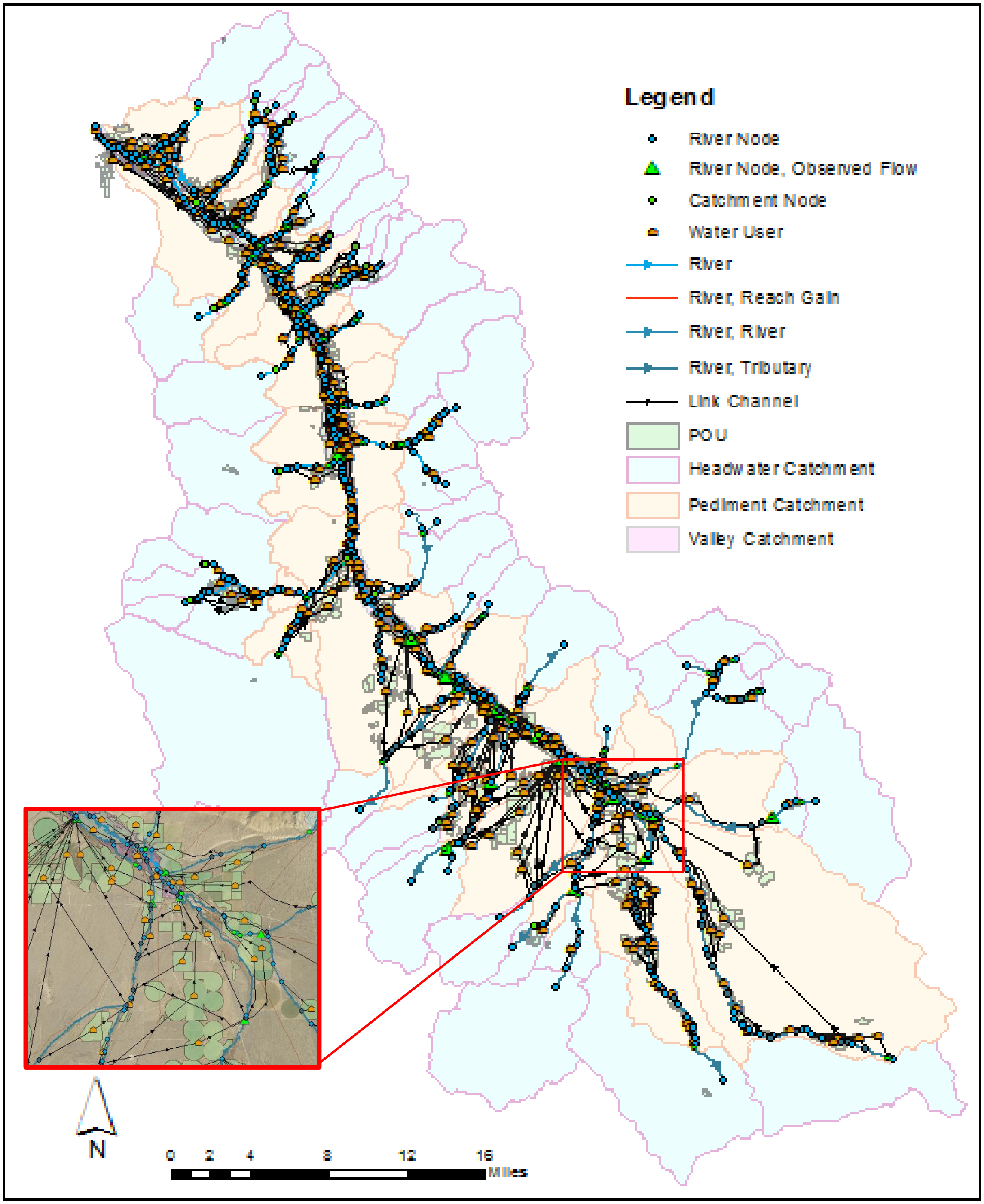


Figure 1. LRBM network. Green polygons represent the POUs that were symbolically represented as water user nodes in the LRBM.

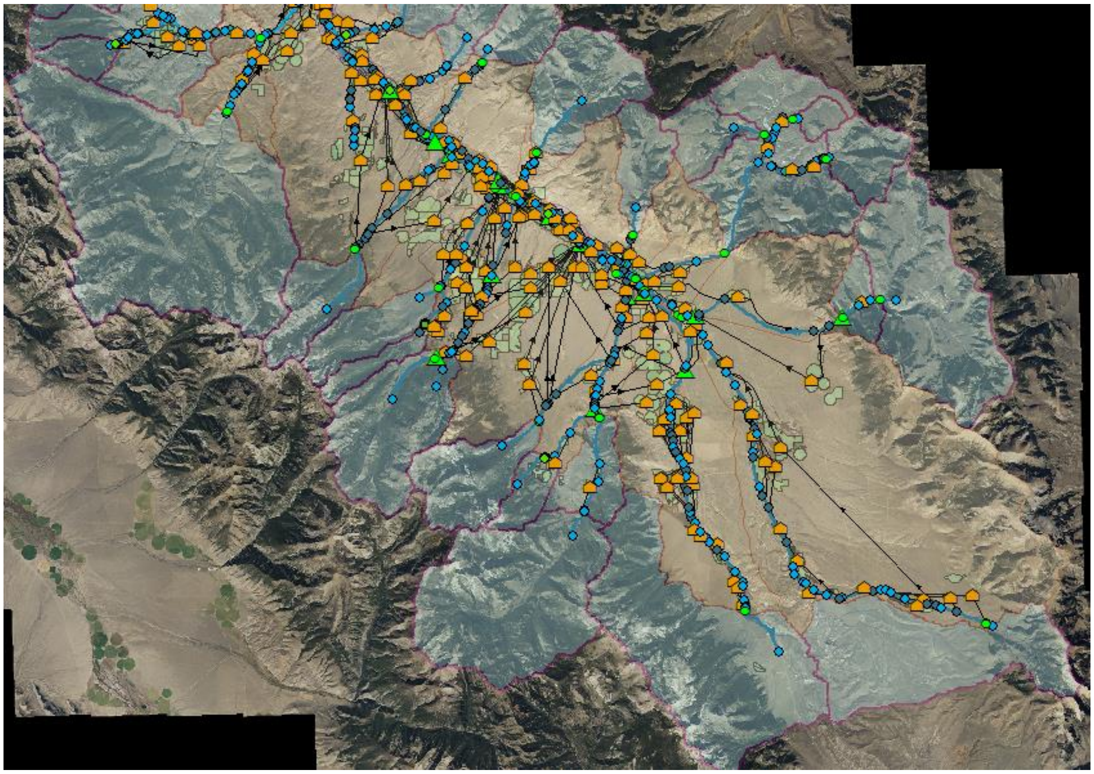


Figure 2. Upper LRBM network.

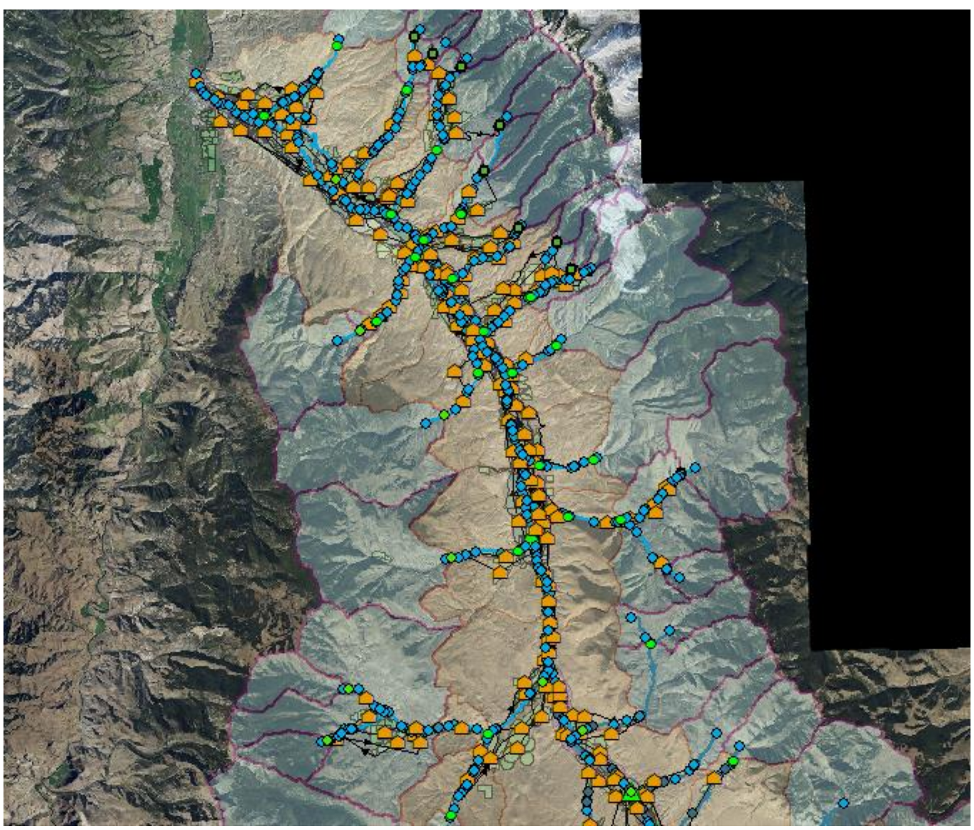


Figure 3. Lower LRBM network.

Catchment outlets are the location where water is introduced to the model network. Thus diversion upstream of a headwater catchment outlet will not receive water (Figure 4). As of 2015, 11 catchments held diversions above the pour point and thus the model will not deliver water to the user. To solve this limitation, the catchment was split to represent contributing areas upstream and downstream of the diversion (Figure 5). The headwater catchments corrected included Agency Creek, Basin Creek, Bohannon Creek, Big Eightmile Creek, Geertson Creek, Pratt Creek, Sandy Creek, Wimpey Creek, and Withington Creek (Table 1). To support the rainfall-runoff modeling, for each catchment the area and vertical zones were redefined and new precipitation, temperature, and evapotranspiration (ET) time series created (Section3).

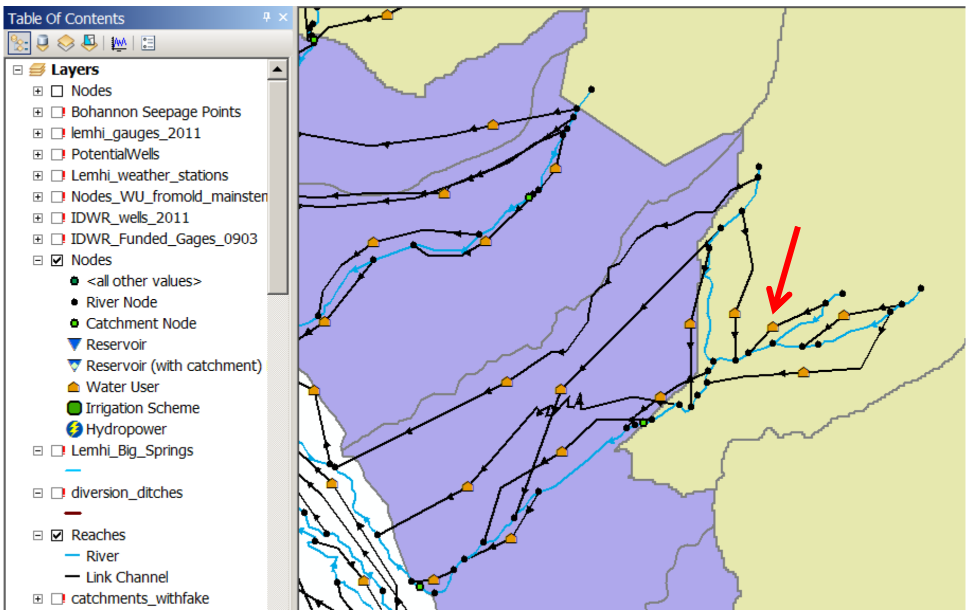


Figure 4. Example of diversions that are placed upstream of the catchment inflow along Sandy Creek in the current LRBM.

Three hundred twenty two water user nodes represent the center of the irrigated area and connecting link channels represent the connection between the POD and POU as well as the location where the majority of return flow occurs (Section 2.1.4). Connecting the PODs and POUs, determining the return location, and salient information for each POU was a significant effort in model development. Using water right information and consultation from local water masters, PODs were connected via a link channel to POUs to simulate irrigation use throughout the basin. Taylor Dixon constructed the upper LRBM (above the "narrows") using aerial photos, local stakeholders (primarily Rick Sager, Lemhi River District 74 Water Master), and field visits. Alison Burnop updated the upper LRBM and extended the model to the lower basin using aerial photos, local stakeholders (primarily Rick Sager), field visits, and an extensive review of the water rights records. As the location of irrigation application within the POU is unknown (IDWR only reports diversion rate at the POD), the exact location of return flow is unknown. Therefore, the return flow location was set to downstream point where the majority of overland and shallow return flows from the POU enters the river system. IDWR and CCI further updated network to reflect changes to the stream and irrigation network as of Fall 2015.

Table 1. Notes from catchment adjustments and corrective actions taken to the LRBM. Italicized text denotes actions to be taken.

Catchment Adjusted	Category	DHI Nodes	DHI Catchment	Actions Taken
Geertson_Upper	Catchment	N2667	C304	Resized
Geertson_Upper Top East	NEW	N2809	C343	Added
Geertson_Upper Top West	NEW	N2810	C344	Added
Bohannon_Upper	Catchment	N2666	C303	Resized
Bohannon_Upper Top	NEW	N2808	C342	Added
Wimpey Upper Top	NEW	N2806	C340	Added
Wimpey Upper Mid	NEW	N2807	C341	Added
Wimpey_Upper	Catchment	N2665	C302	Resized
Pratt_Upper	Catchment	N2664		*Remove, redraw river*
Pratt_Upper	New	N2665	C345	Added
Sandy_Upper	Catchment	N2663	C300	Resized
Sandy Upper 1	NEW	N2803	C337	Added
Sandy Upper 2	NEW	N2804	C338	Added
Sandy Upper - Mid	NEW	N2805	C339	Added
Agency_Upper	Catchment		C299	Resized
Agency_Upper	NEW		C335	Added
Agency_Upper	New	N2801	C336	Added
Withington_Upper	Catchment	N2664	C340	*Remove, redraw river. Check to confirm this is not a gage location*
Withington_Upper	New	N2812	C347	Added
Withington_Aq	Aquifer	N2681	C342	Resized
Basin_Upper	Catchment	N2754	C348	Resized
Basin_Upper Top South	NEW	N2813	C348	Added
Basin_Upper Top North	NEW	N2814	C349	Added
Mill Creek	Put river node in downstream of reservoir and removed reservoir			
Big Eightmile Upper	Moved DevilsCanyon-1 to come out of river downstream of Big Eightmile Upper inflow node			
Lee Upper 2	New	N2816	C350	Added, Determine Creek Name
Lee Upper aq	Aquifer		C274	Resized
	Moved Everson-3 to come out of river downstream of Lee Upper 2 inflow node			

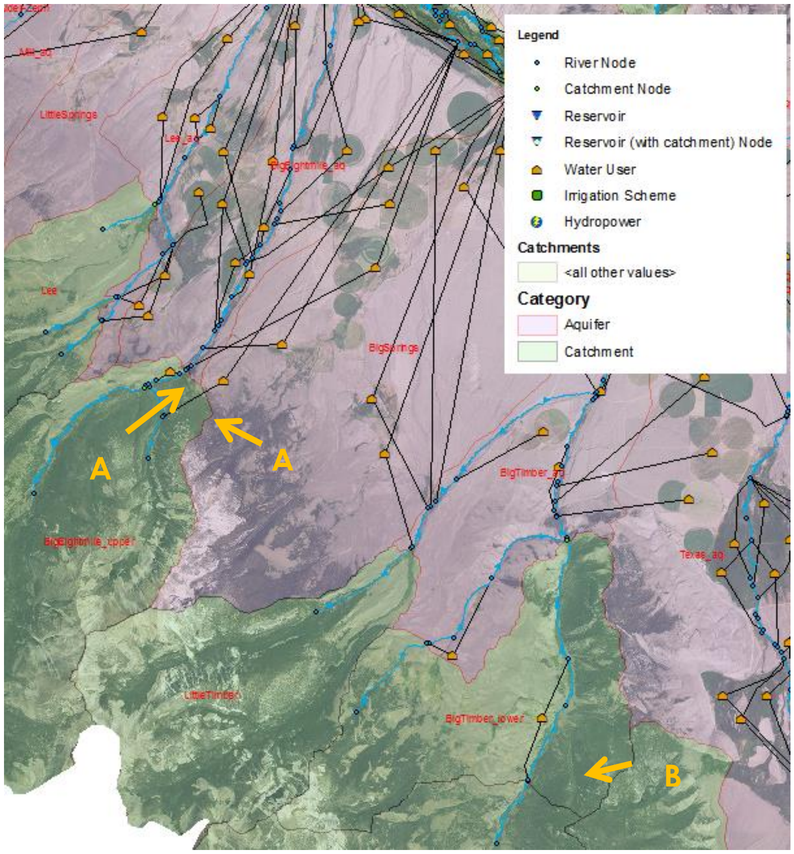


Figure 5. Big Timber Creek and Big Eightmile Creek representation in the LRBM. Notice the majority of the diversions are below the headwater catchments pour points, thus receiving inflow. Point A is above the Big Eightmile_Upper catchment pour point at point A' and will not receive any inflow. The upper Big Timber Creek catchment has been divided into two catchments and so the water user downstream of Point B diversion will receive water.

2.1.3 Catchments

Catchments require streamflow runoff time series and, if ground water is activated, a time series of specific recharge. A detailed description of the rainfall-runoff methods used to estimate runoff is found in Section 3. For implementation, the catchments are classified as headwater, pediment, and valley floor type catchments (Figure 1 - Figure 3). Headwaters catchments represent the mountainous sections of each tributary with the pour point typically located just above the first diversion. Pediment catchments represent the valley walls from the base of the mountains to the Lemhi River valley floor. Dixon and Burnop referred to these catchments as "aquifer" catchments in their reports and notes. Pediment catchment boundaries were defined by the USGS HUC boundaries and pour points defined where the LRBM stream network enters the Lemhi River valley floor. Unlike the headwater catchments, the pediment catchments represent areas where the alluvium has sufficient depth to have groundwater influence. Thus, they have a different set of calibration parameters in the rainfall-runoff model. Both headwater and pediment catchments use rainfall-runoff model results as the inflow time series.

Valley floor catchments represent the contributions to Lemhi River flows from precipitation, tributary inflow (surface and subsurface), groundwater exchange, and irrigation. Pour points for these catchments are placed at existing river gages currently operating along the Lemhi River Big Springs, and Little Springs. The pour points for the "valley floor" catchments introduced to the LRBM include Lemhi River gauges at Cottom Lane, above Big Springs inflow, McFarland campground, USGS Lemhi gage, L-5 diversion, and L-1 diversion. Unlike headwater and pediment catchments, inflow contributions to flow at these locations were determined by reach grains calculated at each gage location. These represent the contributions from precipitation, tributary inflow (surface and subsurface), and groundwater exchange. Changes in irrigation practices influencing return flows were taken into account in the reach gains.

In MIKE BASIN, groundwater is accounted for using linear reservoirs that simulate the availability of water underlying the catchment as well as baseflow. An extensive effort was conducted to attempt to use this functionality in determining how precipitation influences reach gains. NAM predicts the infiltration of precipitation to below the unsaturated zone as an output variable. However, two factors made this infeasible. First, the NAM results factor in the baseflow contribution so separating out that component of the inflow time series was difficult. Second, calibration of pediment catchment NAM results was very difficult due to uncertainty with upstream flows and accounting for the diversion activities. This made it very difficult to predict an accurate infiltration rate. What was possible was to compute the influence of irrigation response to the inflow that fulfills the goal of the LRBM.

2.1.4 Water user nodes

A key goal of the LRBM is to determine the influence of irrigation practices on stream flows in the Lemhi River and its tributaries. Irrigation practices have two effects: 1) dewatering streams due to irrigation withdrawal at diversions and 2) recharging streams at a later time with return flows from unconsumed diversion waters. To simulate these effects, water user nodes require time series data for water demand, fraction of the demand satisfied by ground water, fraction of the demand returning to the system (a.k.a. consumptive component of diverted water), and lag time for the return fraction to re-enter the stream. Water demand for each user is based on historic diversion records in IDWR's diversion database (Figure 6). If historical records were not available, demand was set to the water right from May 1 to September 30 of every year. No water user nodes were set to use groundwater as a supply source for satisfying irrigation demand. Table A-1 provides a summary of the source of the water demand rates for each water user node for water years 2008-2014.

Return flows are characterized by the quantity consumed and the location and timing of return flows (Figure 7). Consumptive rates were calculated by the method outline by DHI (2003), which uses crop coefficients and reference evapotranspiration records (ETo) reported by ETidaho (www.kimberly.uidaho.edu/ETIdaho/). Required input for the computing consumption for a water user node is irrigated acreage, irrigation method, and crops grown as well as the historic diversion rate (if known) or the legal diversion amount as stated in the water rights for the POUs. Efforts were taken to map water rights to all POD-POU connections throughout the basin in order to know the maximum diversion rate. Irrigated acreage, irrigation method, and crops grown for each water user are reported in Table A-1. Individual water right data are compiled in supporting MS EXCEL files.

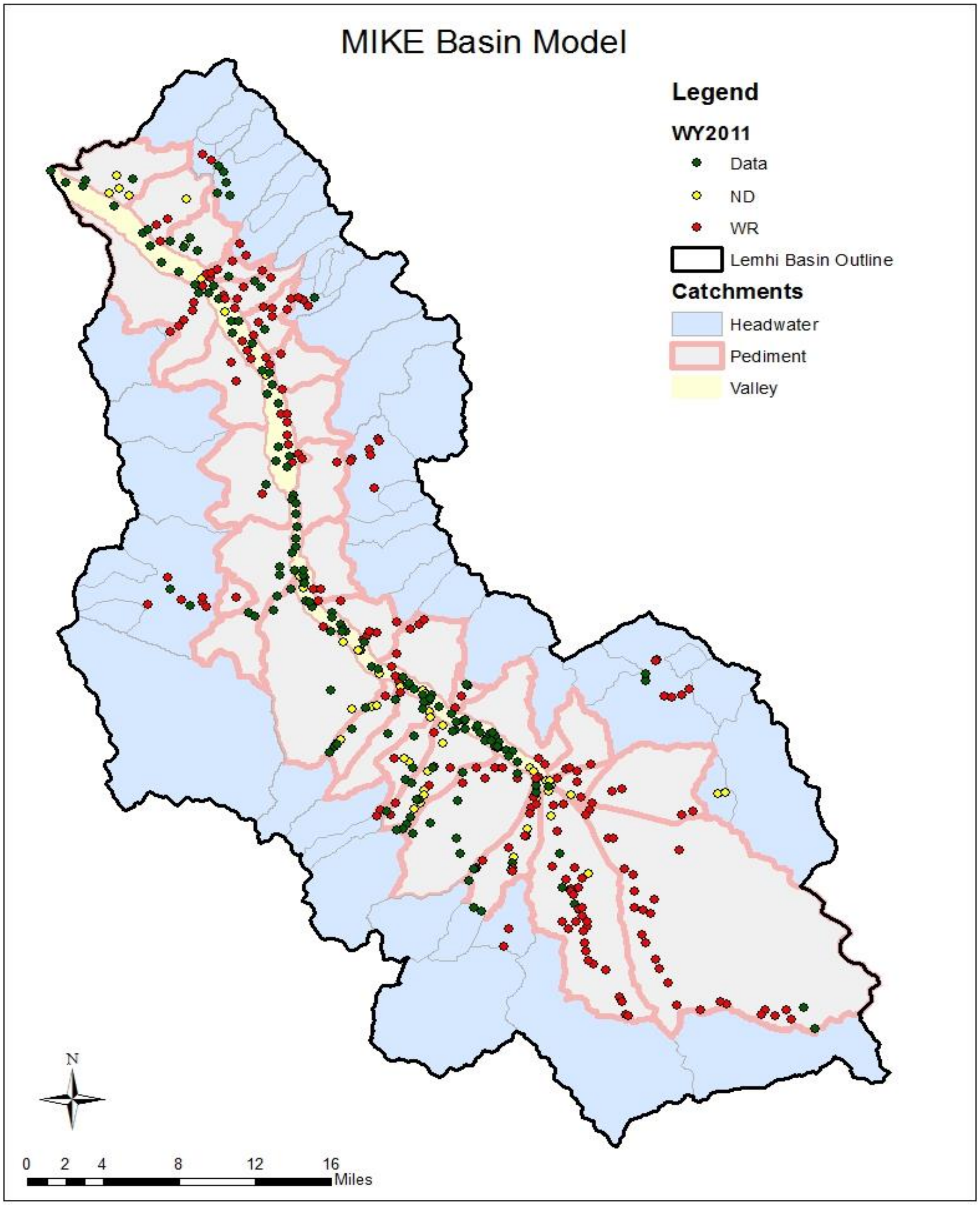


Figure 6. Status of water demand data sources for water users during the 2011water year.

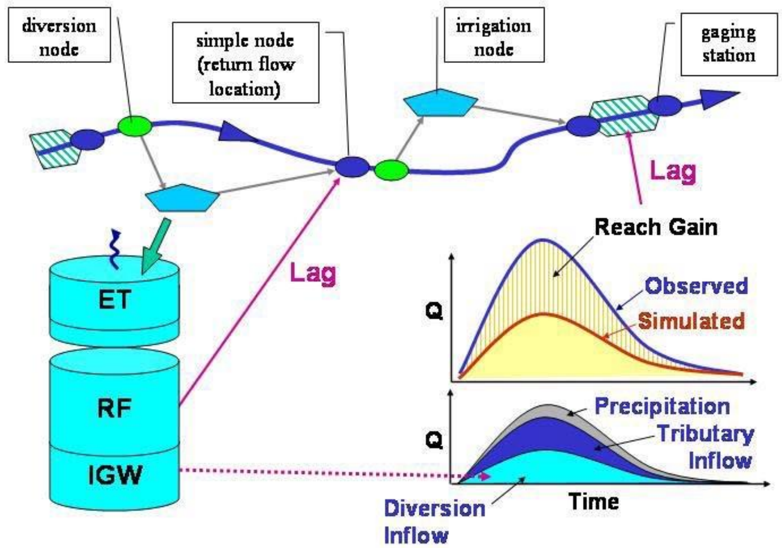


Figure 7. Schematic of the water flow through an irrigation node. The blue cylinder is the parcel of water diverted and has been divided into the consumptive rate (ET) and the fraction that returns (RF, IGW). Rapid, local return flow is defined by RF and the fraction that enters the regional groundwater system defined by IGW (DHI 2003).

Timing and quantity is important in determining when the unconsumed diverted water returns to the stream network. In the LRBM, return flow is organized into rapid, local returns and the portion that enters the regional groundwater system. The former return type is modeled using functionality in MIKE BASIN and the latter return type uses response functions to calculate reach gains. MIKE BASIN incorporates three methods for lagging return flows: 1) Muskingham routing, 2) linear reservoir, and 3) translational. Of the three, linear reservoir is most suited to simulate the response as it quickly returns and then decreases as time progresses (Figure 8). The equation for linear reservoir is (DHI 2012):

Equation 1

$$q_0 = \left(1 - \frac{x}{(dt/T)}\right) * q_i + x * S$$

and

$$x = 1 - \exp\left(-dt/T\right)$$

where:

q_i is the inflow from the irrigation node

q_0 is the outflow from the irrigation node

dt is the time step length T is the lag time

S is the subsurface storage (accordingly, $\Delta S = q_i - q_o$)

MIKE BASIN users can specify the lag time to control the timing of the return fraction. The longer the user defined time interval, the slower the response (Figure 8). During LRBM calibration, this parameter was adjusted to influence the time of peaks.

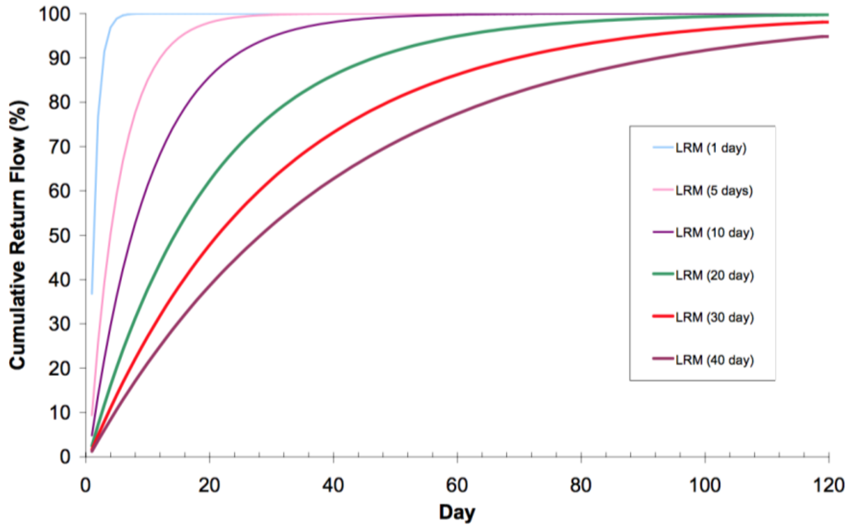


Figure 8. Cumulative return flow fraction by varying the lag time parameter. The value in parentheses is the user specified lag factor (DHI 2003).

While the linear reservoir method is appropriate for POUs near the stream network with rapid returns, it poorly represents return flows for POUs that do not have an immediate connection with the stream network. To represent these POUs, an analytical method was used by CH2M Hill to compute response function (CH2M 2014). These analytical response functions (ARF) are characterized by a delay in return flows reaching the stream followed by a rising limb that reaches a peak return flow after some time (Figure 9). The receding limb of the ARF gradually tapers until all the unconsumed, diverted water has returned to the stream. As observed in the Geertson Creek POUs (Figure 10), quicker ARFs are characterized by shorter time to peak and smaller recession limbs following the peak. The further away from the Lemhi River, the longer the delay to the peak, increased days until 50% of the return flow reaches the stream network, and the more muted the quantity returning. Required parameters to compute ARFs includes aquifer thickness, hydraulic conductivity, aquifer length, and distance of centroid of POU to stream (ibid). Data for the analysis was gleaned from hydrogeological parameters in Spinazola's groundwater analysis (Spinazola 1998), an assumed aquifer thickness, and distances derived from the stream network and POU GIS coverages from the LRBM. For all 322 POUs, an ARF was calculated.

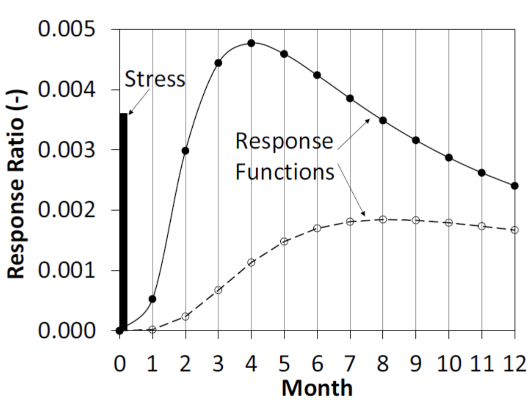


Figure 9. Hypothetical examples of impacts to a river reach from a local stress (solid line) and distant stress (dashed line)(CH2M 2014).

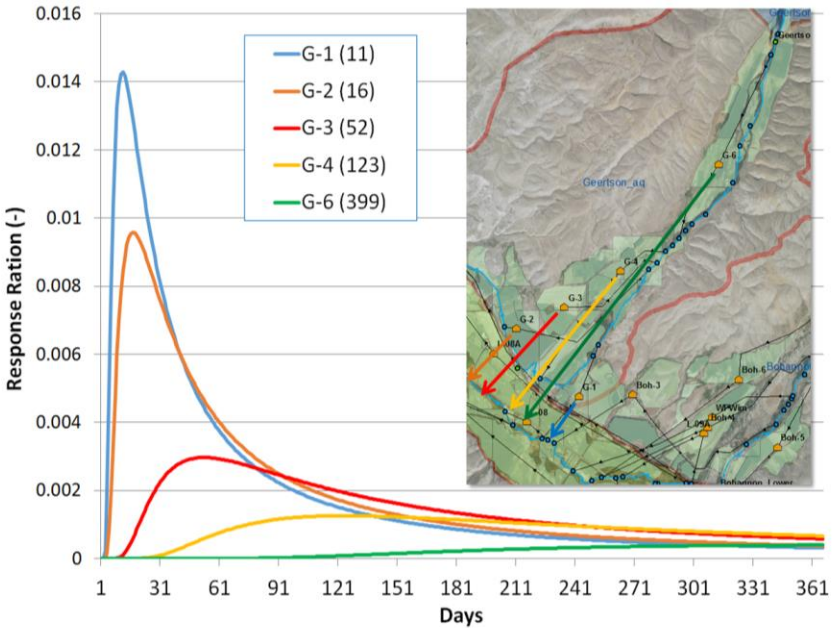


Figure 10. Analytical response functions for Geertson Creek diversion. The figure illustrates the influence of distance from the LRB. In the legend, the value in parentheses is the day when the peak return flow occurs.

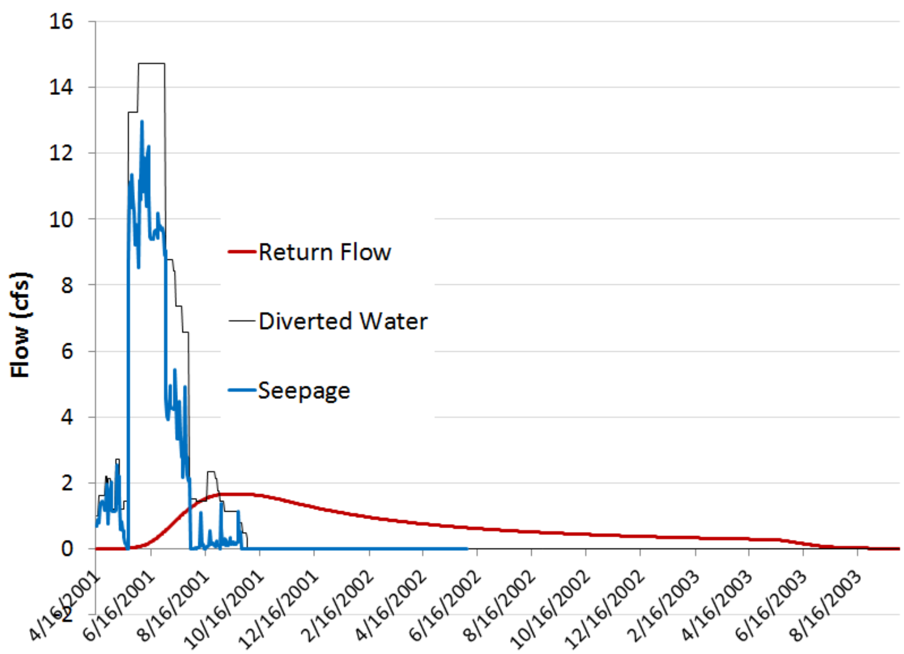


Figure 11. Example diverted water, unconsumed water (seepage), and return flow time series for diversion G-4. Note, return flow for a single irrigation season continues over a two-year period.

Incorporating return flows using ARF requires preprocessing the return flow time series and inputting it into the LRBM as a reach gain. Preprocessing the time series involves computing the daily consumptive of diverted water, then multiplying the unconsumed portion by the ARF over the return period (i.e. as long as the return period had positive values) (Figure 11.). This procedure is performed for each day irrigation water is applied with the results added to return flow quantities from previous days. In the LRBM, the total return flow is added as a reach gain at the location where the inflow is likely to occur. If multiple POUs return to a similar location, the return flows from all POUs are summed and added as the same reach gain (Figure 12, Figure 13). The return flow locations for POUs away from streams were determined by examining topography and aerial photographs as well as consulting with Rick Sager, Daniel Bertram, and Allen Bradbury. In the LRBM, these locations are denoted as a link channel from the POU to the location where the reach gain is realized in the stream network (Figure 12). No flow is given to the link channel as it is accounted for in the reach gain. For the LRBM, irrigation reach gain calculations were computed in a separate MS EXCEL file.

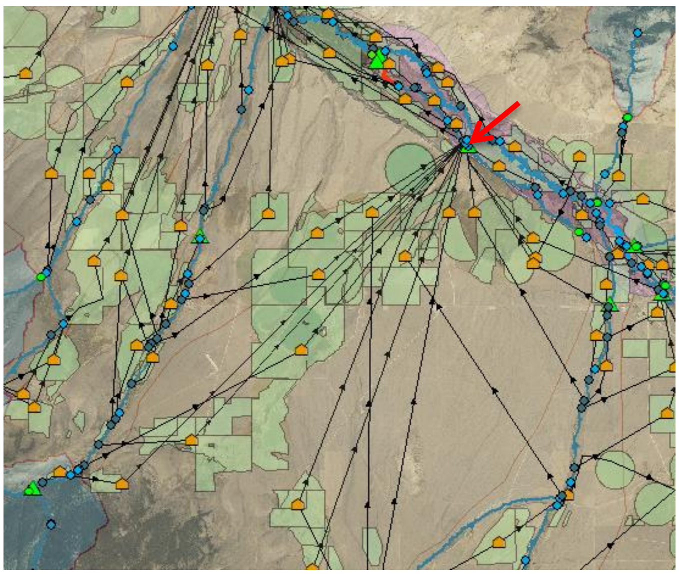


Figure 12. Red arrow marks the location of ARF return flow for POUs on the pediment influencing Big Springs.

As using ARFs is more cumbersome when formulating scenarios, the linear reservoir method in MIKE BASIN was used when appropriate and the ARF method used elsewhere. To determine the appropriate instances to apply each method, resulting return flow curves from each method were compared. Using an optimization algorithm that modified the linear reservoir delay to minimize the difference between the resulting curves, an analysis was performed on all POUs with ARFs where days to 50% cumulative return flow of less than 20 days (Figure 14 - Figure 17, Table 2). The results showed that for POUs with ARFs of less than 12 day to 50% cumulative return function, the MIKE BASIN linear reservoir method was sufficient.

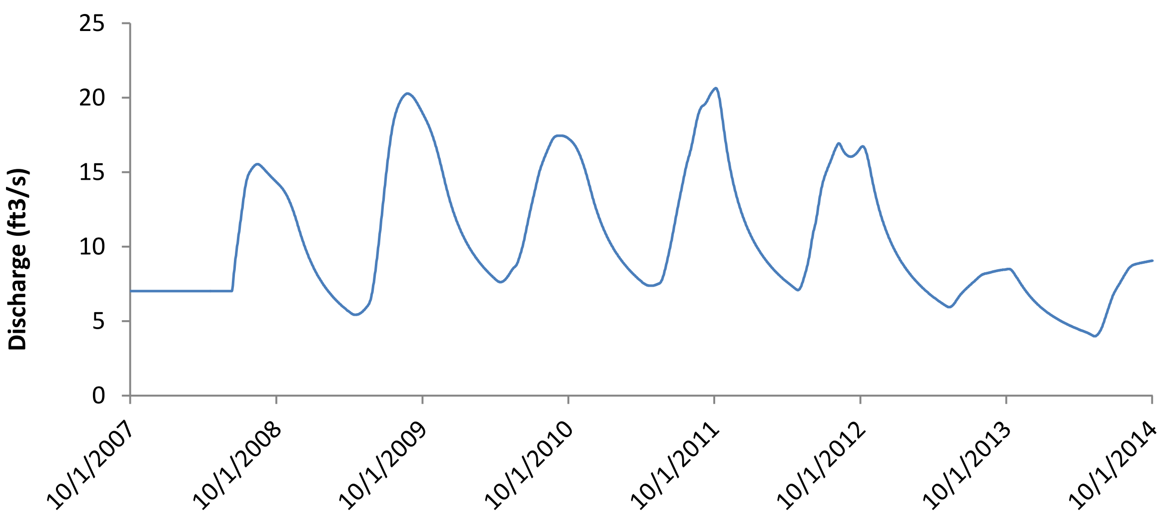


Figure 13. ARF return flow reach gains into Big Springs for the baseline conditions. 13 POUs contribute to the reach gain at this location. Location shown in Figure 12.

Table 2. Examples of comparisons between the linear reservoir and ARF methods.

POU# (Diversion)	MIKE BASIN Linear Reservoir Delay Value	Day 50% Cumulative Return Flow		Figure
		Linear Reservoir	ARF Method	
POU 7 (L-47)	64.2	44	60	Figure 14
POU 110 (A-8)	42.4	29	31	Figure 15
POU 152 (L-33)	18.1	12	13	Figure 16
POU 200 (L-57)	6.2	4	4	Figure 17

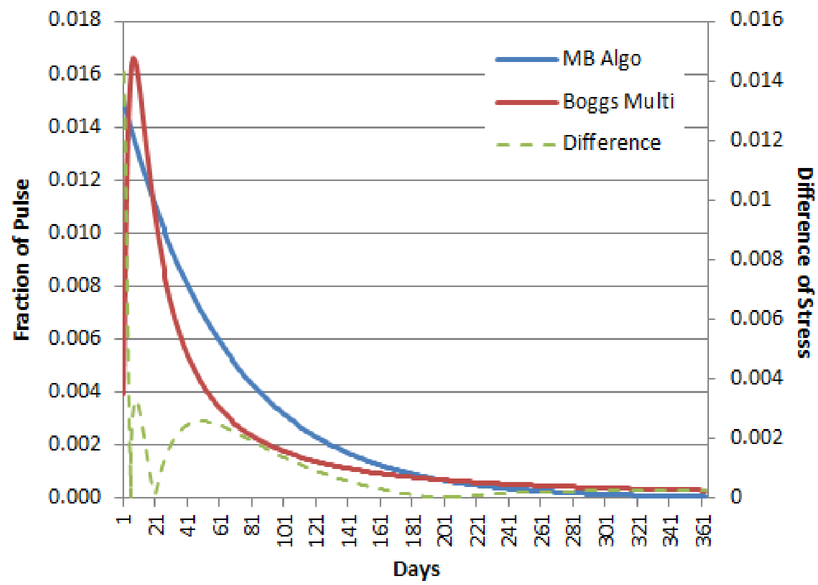


Figure 14. Comparison of linear reservoir method (MB Algo) and the ARF (Boggs Multi) for POU 7 (Diversion L-47).

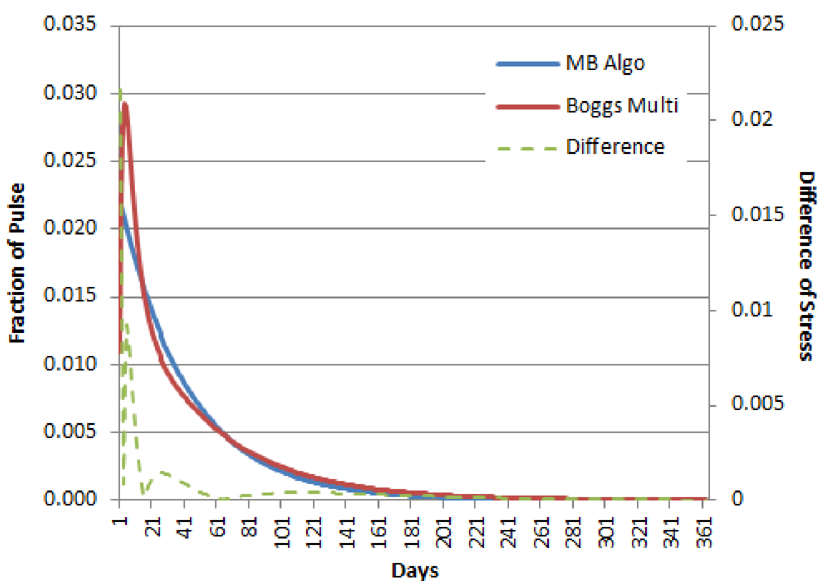


Figure 15. Comparison of linear reservoir method (MB Algo) and the ARF (Boggs Multi) for POU 110 (Diversion A-8).

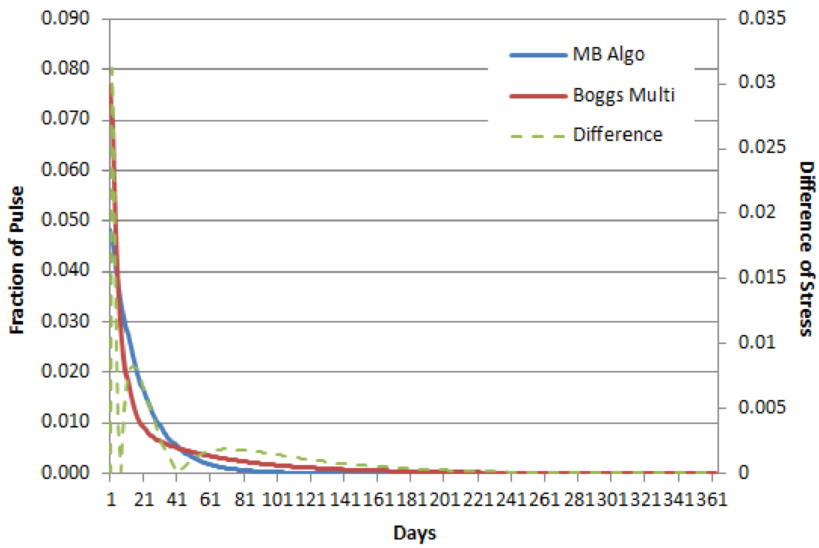


Figure 16. Comparison of linear reservoir method (MB Algo) and the ARF (Boggs Multi) for POU 153 (Diversion L-33).

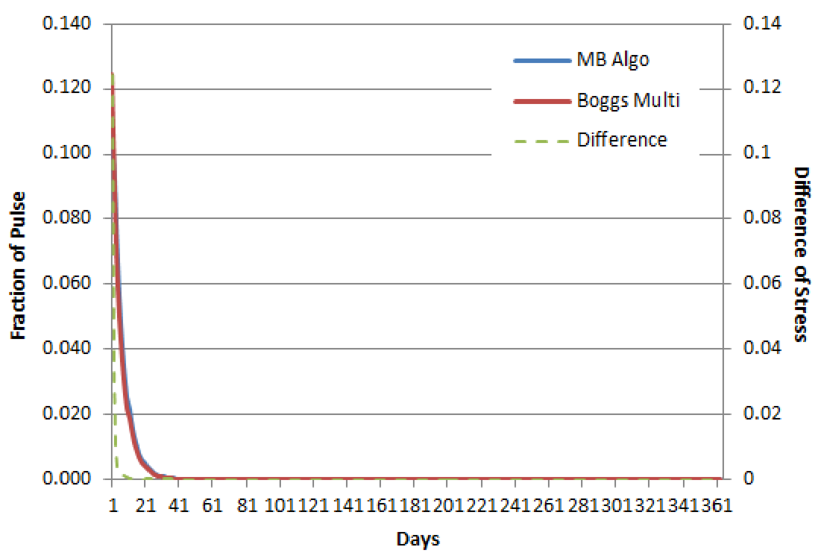


Figure 17. Comparison of linear reservoir method (MB Algo) and the ARF (Boggs Multi) for POU 200 (Diversion L-57).

To aid in selecting the appropriate method, a contour map was created by kriging the days to 50% cumulative return flow for all POUs (Figure 18 - Figure 21). This map indicates that for POUs along the Lemhi River valley bottom, return flows to the river are rapid and the linear reservoir method applies to most POUs. Return flow response times rapidly decrease around the edges of the valley bottom and moving up the pediment surfaces, therefore the ARF method was selected for these POUs. These guidelines were generally upheld with two exceptions: 1) when POUs are very near the river system in the upper reaches of tributaries, and 2) for POUs just upstream from and within the large spring complexes along Texas and Eighteenmile Creeks.

POUs using ARF to compute return flows were aggregated into15 locations, which for pediment catchments, was used to determine their contribution to regional reach gains (Table 3). Table A-1 has the return flow method used for all POUs.

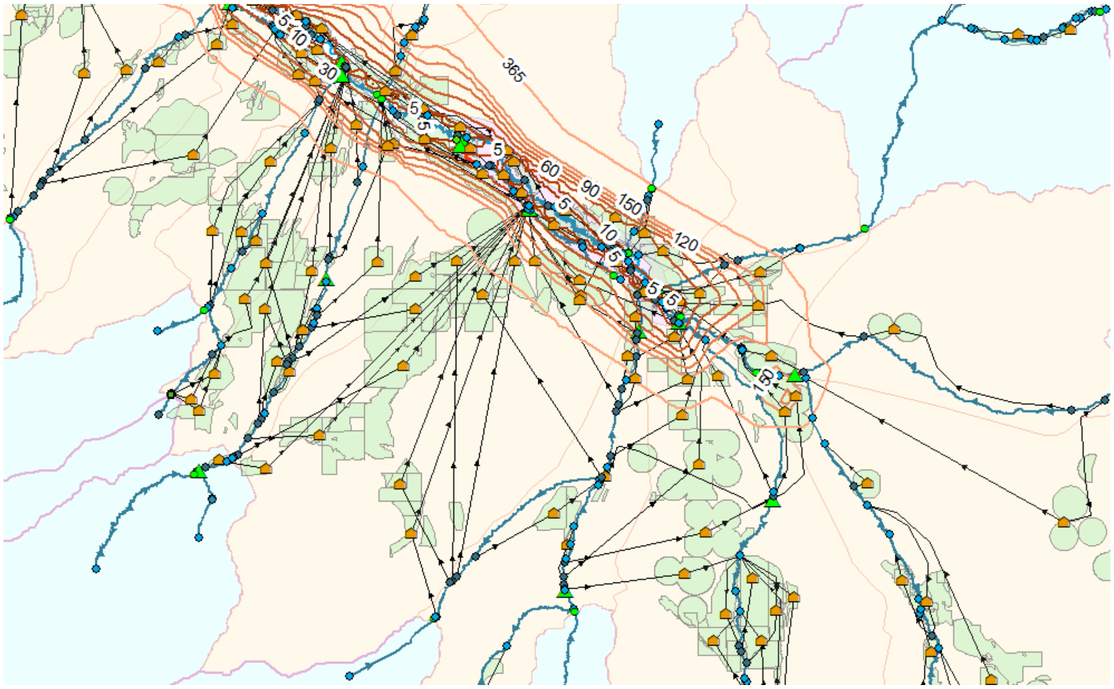


Figure 18. Contour map of time of return flow for based on the ARF for all POUs in the upper LRB. Contour values are days to 50% cumulative return flow.

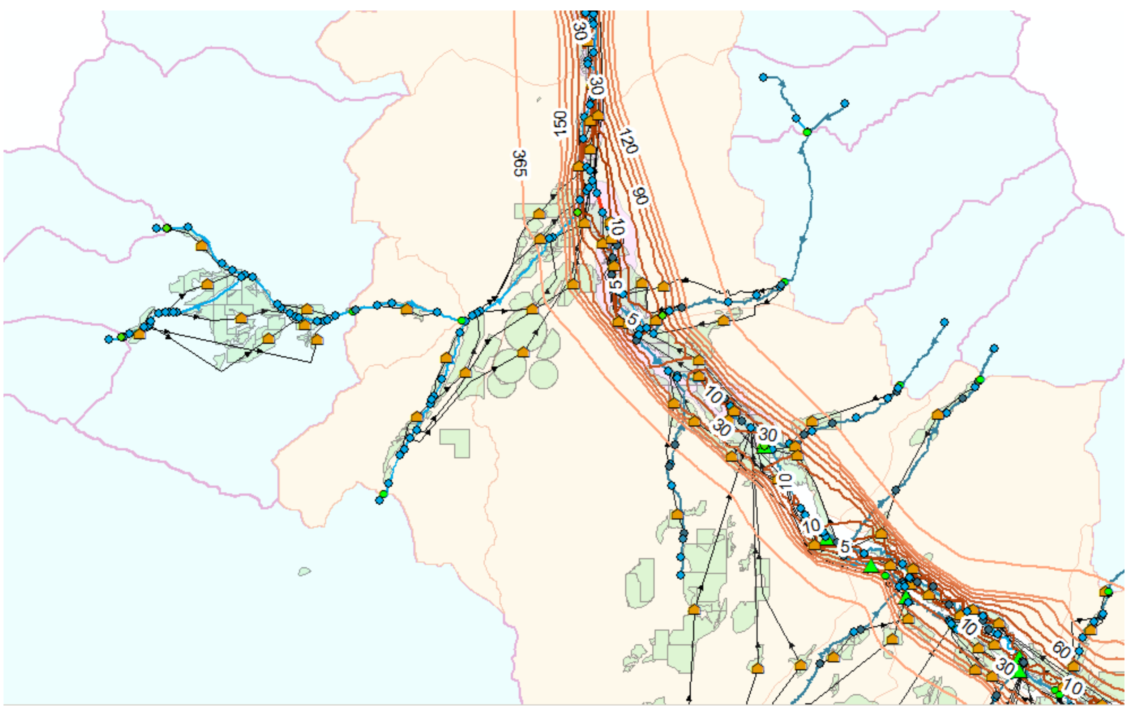


Figure 19. Contour map of time of return flow for based on the ARF for all POUs in the upper-mid LRB. Contour values are days to 50% cumulative return flow.

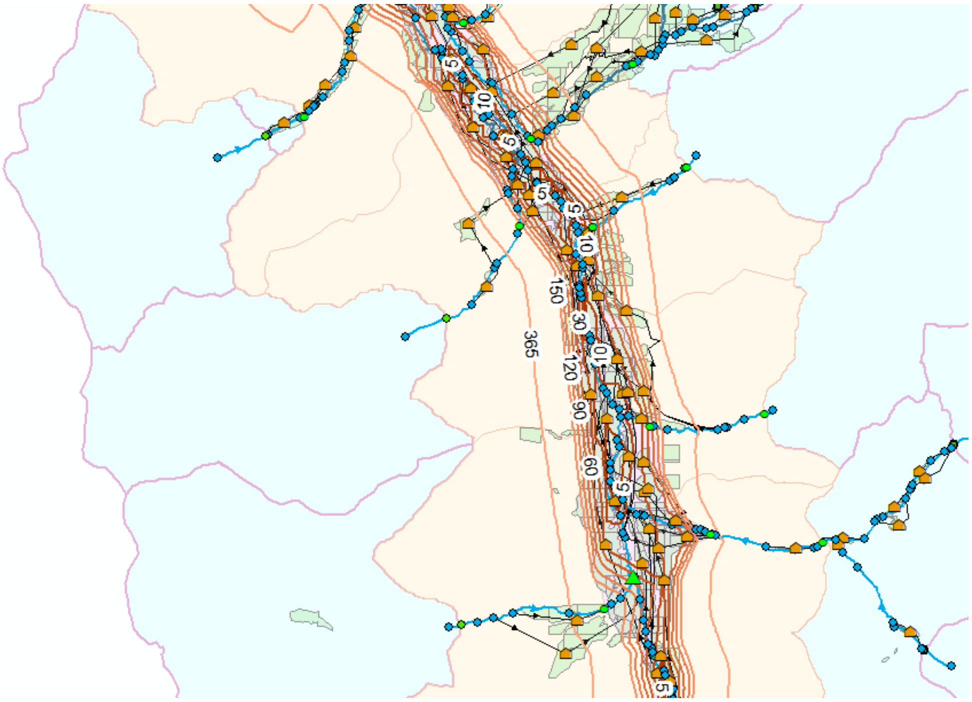


Figure 20. Contour map of time of return flow for based on the ARF for all POUs in the lower-mid LRB. Contour values are days to 50% cumulative return flow.

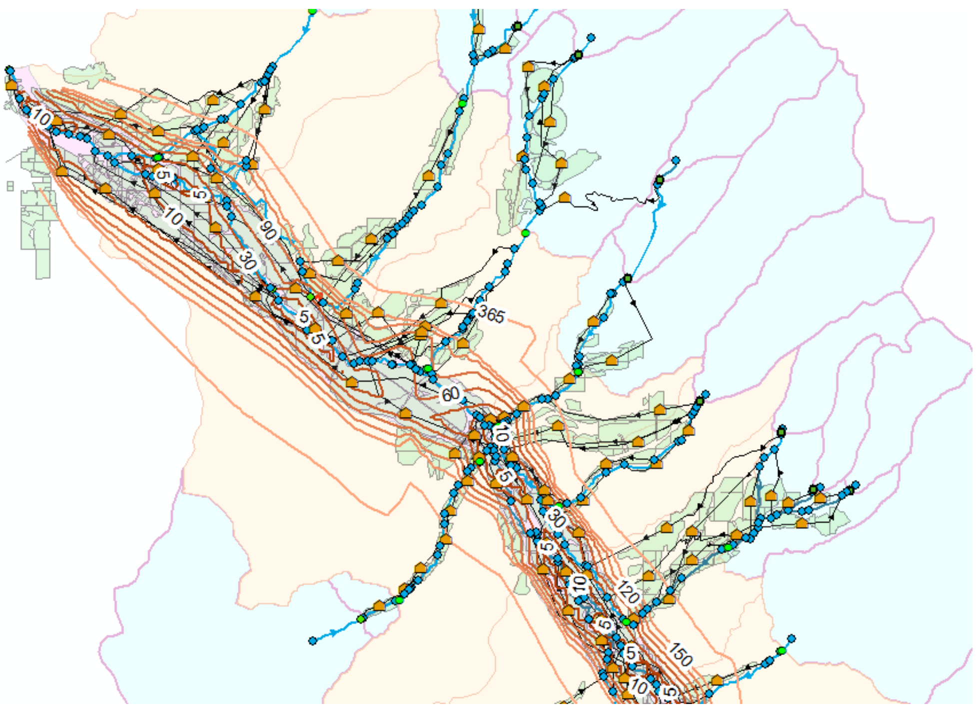


Figure 21. Contour map of time of return flow for based on the ARF for all POUs in the lower LRB. Contour values are days to 50% cumulative return flow.

Table 3. Irrigation reach gains calculated using ARF and their associated POUs.

Irrigation Reach Gain Locations	DHI Arc	Diversion Names
Big Eightmile AQ	E2683	BigEightmile-3, BigEightmile-4, BigSprings-1b
Big Springs AQ	E2370	BigEightmile-5, BigEightmile-8, BigEightmile-13, BigEightmile-14, LittleTimber-2, LittleTimber-3, LittleTimber-4, LittleTimber-5, L-62A_BigTimber-2, BigTimber-3, BigTimber-7, BigTimber-10, L-63
Big Timber AQ	E5396	LittleTimber-1, BigTimber-6
Lemhi L1	E4828	L-09a, L-09b, Kirt-1, Kirt-2, Kirt-3, Kirt-5
Bohannon AQ	E5021	Boh-5, Boh-6
Canyon AQ	E2687	Canyon-3, Hawley-1, Eighteenmile-3
Eighteenmile AQ/Hawley AQ	E5224	BigTimber-11a, Texas-2a, Eighteenmile-13, Hawley-2, Hawley-3
Geertson AQ	E5141	G-3, G-4, G-6
Kirtley AQ	E5023	Kirt-4, Kirt-6
Lee AQ	E3505	Lee-2a, Lee-2b, Lee-3a, Lee-3b, Everson-1, Everson-2, BigEightmile-7a, BigEightmile-7b
L.Springs_RG	E2366	L-54, L-58, L-58A, BigSprings-5, Lee-1, Mill-6
Mill Ck	E3435	Mill-1, Mill-5
Reese Ck	E3097	Reese-2
Sandy_ AQ	E4349	S-1, S-2, S-3, S-4, S-5
Texas AQ	E5402	Texas-2b, Texas-3, Texas-4, Texas-5, Texas-6, Texas-7, Texas-8, BigTimber-8a, BigTimber-9, BigTimber-12, BigTimber-13, BigTimber-15, Texas-9
Wimpey AQ	E5019	Wim-3, Wim-4, Wim-5, Pra-8

2.1.5 High Flows

In the LRB during the spring freshet, PODs divert water to their high water right until streamflows recede and the basin goes into regulation (Rick Sager, personal communication 2014). To account for this in the LRBM, the ditch capacity along the link channel connecting the POD to the POU was set to the high flow for all diversions. Ditch capacities were set according to known ditch capacities, historical maximum recorded flow, or water right. In cases where high flow rates are unknown, it is assumed that the max high flow rates are equal to the ditch capacity. If neither the ditch capacity nor historical flow record is known, then the ditch capacity is set to the water rights for the POD (Table A-1). Currently, the LRBM simulates diversion rates according to the water master records or the water rights if records are not available. The latter method underestimates the actual diverted quantity in the basin and as such the LRBM demands need to be changed to simulate actual operations. To implement in the LRBM, ditch capacities for all the diversions have been included as a capacity restriction on each link channel connecting the POD to the water user node representing a POU. Ditch capacity is important in future scenarios where the water demand computed for new crops, increased acreages, or changes in irrigation methods may exceed existing infrastructure.

2.2 CALIBRATION

While the LRBM accounts for major tributary inflow as well as diversion and return flow activities, there remains a difference between observed and simulated flows. This difference is caused by flow measurement inaccuracies as well as factors not directly accounted for in the LRBM including localized rainfall events, unmodeled tributary inflows, inaccuracies in rainfall-runoff predictions, variations in irrigation activities, losses to ET along the stream, and ground and surface water exchange through the stream bed. To incorporate these unaccounted factors, the LRBM is calibrated at gaged locations throughout the system using a reach gain to add or subtract flow to adjust to observed conditions.

Calibration is performed by adjusting the return flow lag times and quantity of water contributing to reach gains at IDWR, USGS, and USBR stream gages and not accounted for in return flows directly associated with the water user. The latter is adjusted to shift the simulated flow time series vertically by adding or subtracting flow in the river. The return flow lag time shifts the timing of the peaks. To achieve the best match between observed and simulated discharges at a gage, the LRBM was run up to 100 iterations where lag times were randomly altered for all diversions with return flows downstream of the last gage and upstream of the gage currently being evaluated. The best iteration was determined by selecting the configuration of lag times that resulted in the lowest root mean square difference between observed and simulated flows as well as the slope and R2 values nearest to 1 from the linear regression of the observed and simulated daily flow values. Macros in supporting MS EXCEL files assist in this effort. Once the best configuration of lag time and return flow quantity were achieved, reach gains were calculated based on the difference between observed and simulated flows. The procedure is conducted at each gage in the systems starting at the top of the system and working downstream. For this effort, the simulation period for calibration of the LRBM is October 1, 2007 to September 31, 2014.

Following reach gain computations, the LRBM was compared to the 2014 IDWR seepage run along the mainstem Lemhi River to determine if the diversions, tributaries inflows, and return flows were simulating the system. MS EXCEL files supporting the reach gain calibration and seepage run comparison were used in this analysis. The following text provides the results of these efforts.

2.2.1 Comparison with Stream Gages

To discern accuracy of flows in the LRBM, gages have been classified as upstream and downstream gages (Table 4). Upstream gages do not have an upstream gage with an associated reach gain. All other gages were considered downstream gages. Upstream gages varied in accuracy as a function of rainfall-runoff predictions and the accuracy of the water demand time series for upstream water user nodes (Figure 22-Figure 25). Big Eightmile Creek (Upper), Big Springs (Upper), Big Timber Creek (Upper), Hawley Creek, Hayden Creek, Agency Creek, and Kenney Creek reasonably matched simulated and observed flows. Aside from Hayden Creek, all are the upstream gages with calibrated rainfall-runoff models and minimal upstream diversions. For these upstream gages, it is assumed that rainfall-runoff predictions and diversion activities upstream of the gages are well simulated. Similarly, Bohannon Creek matched the baseflow and timing of the rising and falling limbs of the hydropographs, but simulation results during high flow consistently dropped below the observed gage records

(Figure 25). As the rainfall-runoff results for Bohannon Creek upstream accurately simulated the inflow (Figure 35), the differences in flows at the gage are likely due to the fact that water diverted for each water user was equal to the water right throughout the irrigation season and does not account for high flows taken during the spring freshet. This is likely not an accurate depiction of the historical diversion and therefore the stream flows upstream of this gage should be evaluated based on relative change in flow.

Table 4. Gages used in the calibration and calculation of reach gains.

Gage Name	Operator	Start	End	River Node	Reach Gain	Type
Agency Creek	IPCO	2005	present	N2394	E4969	Upstream
Big Eightmile Creek (Lower)	IDWR	2008	present	N1423	E2693	Downstream
Big Eightmile Creek (Upper)	IPCO	2005	present	N1093	E2839	Upstream
Big Springs Creek (Lower)	IPCO	2005	present	N1305	E2635	Downstream
Big Springs Creek (Upper)	IPCO	2008	present	N1427	E2931	Upstream
Big Timber Creek (Lower)	IPCO	2004	present	N1463	E2828	Downstream
Big Timber Creek (Upper)	IPCO	2005	present	N1412	E2826	Upstream
Bohannon Creek (Lower)	IPCO	2008	present	N2296	E4240	Upstream
Canyon Creek	IPCO	2008	present	N1420	E2687	Upstream
Eighteenmile Creek	IPCO	2006	present	N1466	E2834	Upstream
Hawley Creek	IDWR	2008	present	N1419	E3145	Upstream
Hayden Creek	IPCO	1997	present	N2165	E4726	Upstream
Kenney Creek (Lower)	IPCO	2004	present	N2688	E5014	Upstream
Lemhi at L-5	USGS	2000	present	N2793	E5243	Downstream
Lemhi River above Big Springs	IPCO	2005	present	N1304	E2286	Downstream
Lemhi River above L-63	IPCO	2008	present	N1464	E3486	Downstream
Lemhi River at Cottom Lane	IPCO	2005	present	N1303	E2284	Downstream
Lemhi River at Hayden	IPCO	2004	2009	N1404	E2616	Downstream
Lemhi River at Lemhi	USGS	1967	present	N2138	E5242	Downstream
Lemhi River at Macfarland Campground	WD74	1997	present	N2817	E2574	Downstream
Little Springs Creek (Lower)	IPCO	2008	present	N1470	E2844	Downstream
Little Springs Creek (Upper)	IDWR	2008	present	N1469	E2842	Upstream
Texas Creek	IDWR	2008	present	N1465	E2832	Upstream

Simulated flows at the other upstream gages were less accurate when compared to the observed flow (Figure 22-Figure 25). These gages include Canyon Creek, Eighteenmile Creek, Little Springs (Upper), and Texas Creek. All have unsatisfactory pediment catchments rainfall-runoff results. In addition, aside from Little Springs, historic diversion rates were unavailable for use in water demand time series so full water rights were used. Care should be taken when simulating activities upstream of these gages and future efforts in data collection and model refinement should be given to these gages.

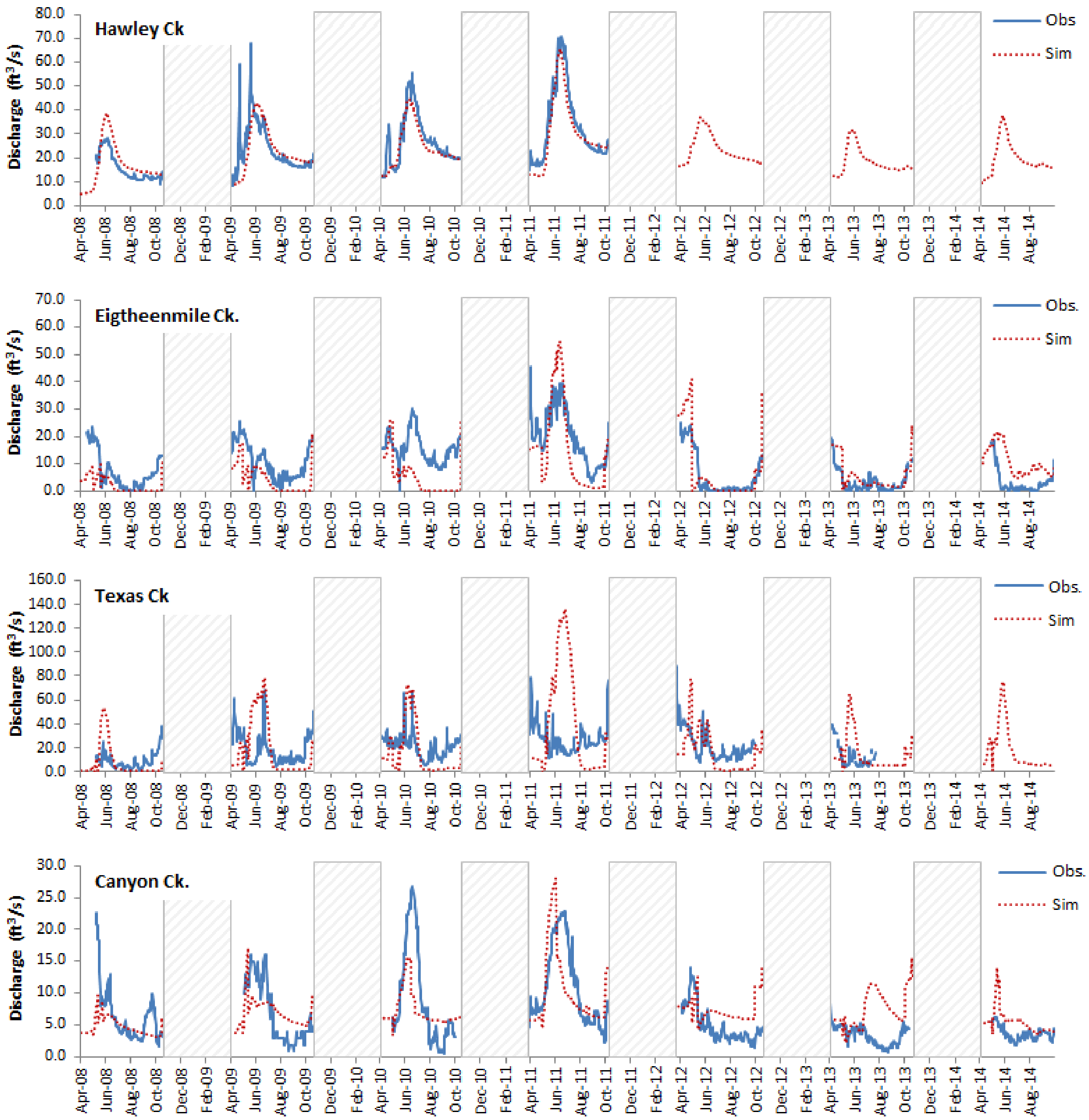


Figure 22. Comparison of observed versus simulated discharge values at the Hawley Creek, Eighteenmile Creek, Texas Creek, and Canyon Creek gages. Areas denoted in grey represent winter months when many gages are winterized and do not collect data.

As the LRBM is "updated" at each gage, the stream network downstream of gage with reach gain more closely matches stream historic flows and therefore can be used to examine the magnitude of change. That said, intervening tributary inflows, stream-groundwater interactions, and diversion activities can influence stream flows so the further downstream from a reach gain, the more the relative change in flow should be used to evaluate projects. Of the downstream gages on tributaries (Big Timber (Lower), Big Eightmile (Lower), Big Springs (Lower), and Little Springs (Lower), only Big Eightmile (Lower) has good agreement between observed and simulated discharge time series (Figure 23, Figure 24). Big Timber (Lower) simulates water discharge over the observed discharge values. This is likely due to seepage loss as well as not accurately accounting for high flow. Diversion records do not go above water rights and thus any water diverted above the water right during high flows is not accounted for in the model. Big Springs (Lower) and Little Springs (Lower) both over predict flows during the irrigation season.

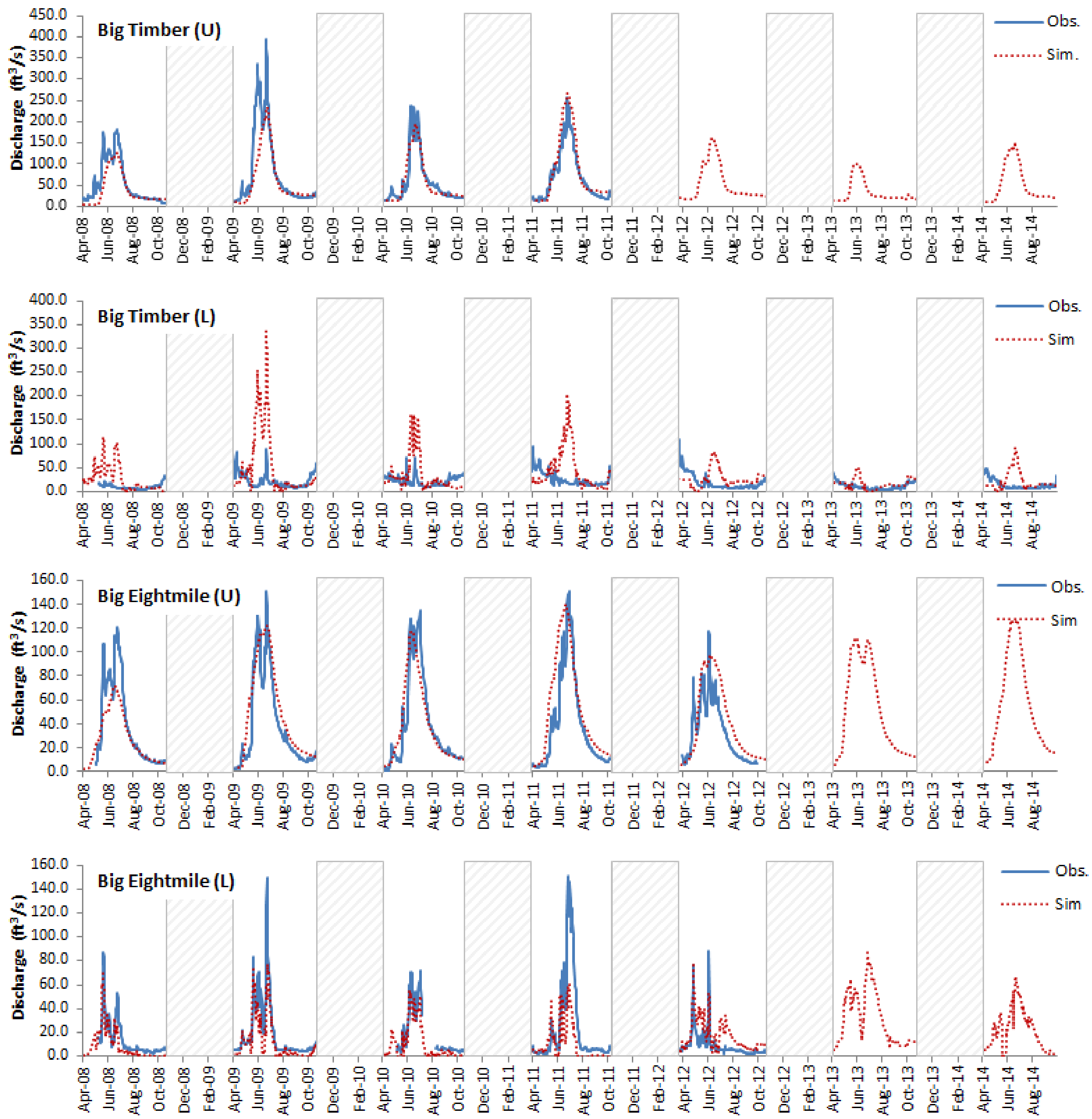


Figure 23. Comparison of observed versus simulated discharge values at Big Timber Upper and Lower gages and Big Eightmile Upper and Lower gages. Areas denoted in grey represent winter months when many gages are winterized and do not collect data.

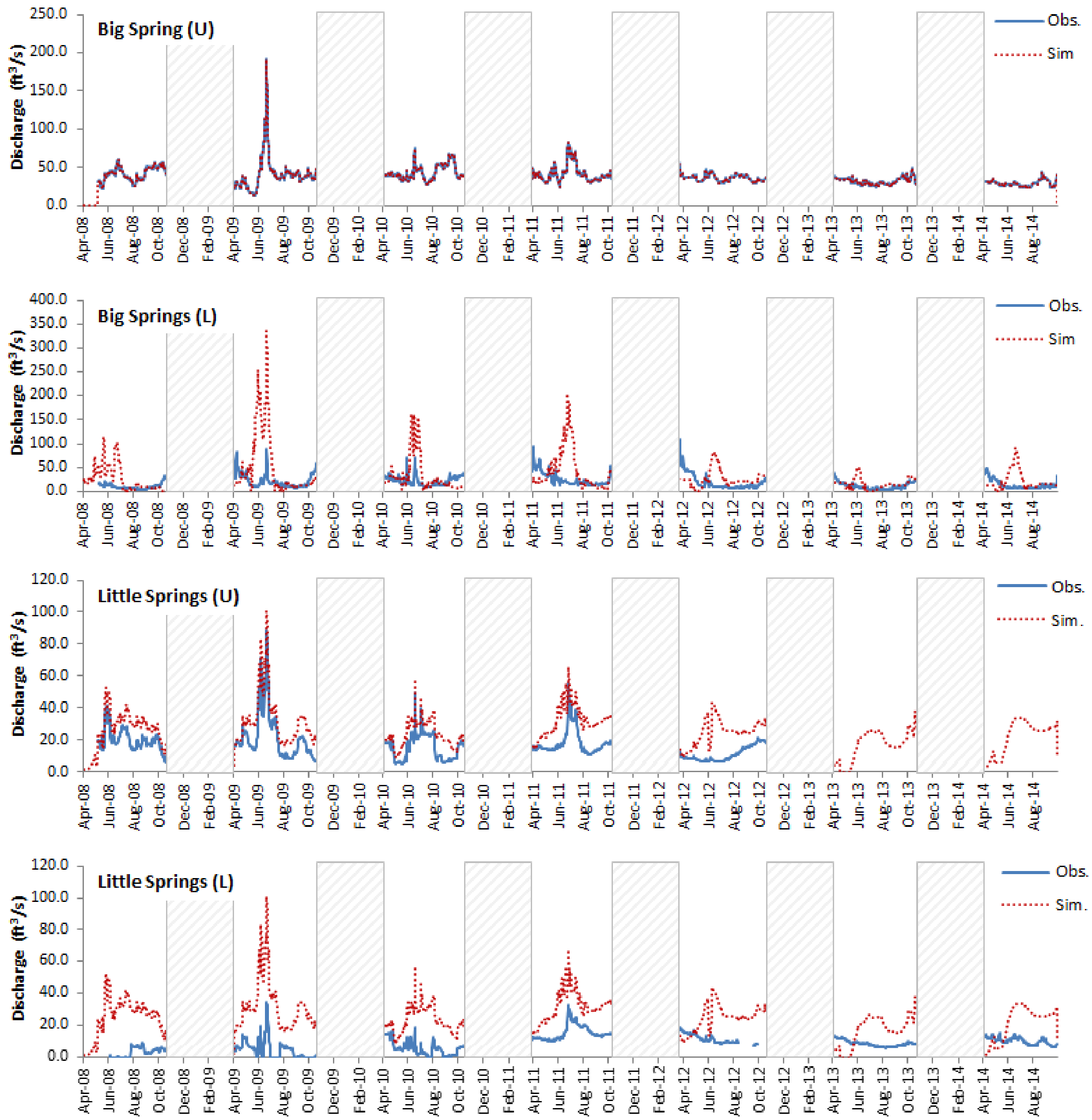


Figure 24. Comparison of observed versus simulated discharge values at Big Springs Upper and Lower gages and Little Springs Upper and Lower gages. Areas denoted in grey represent winter months when many gages are winterized and do not collect data.

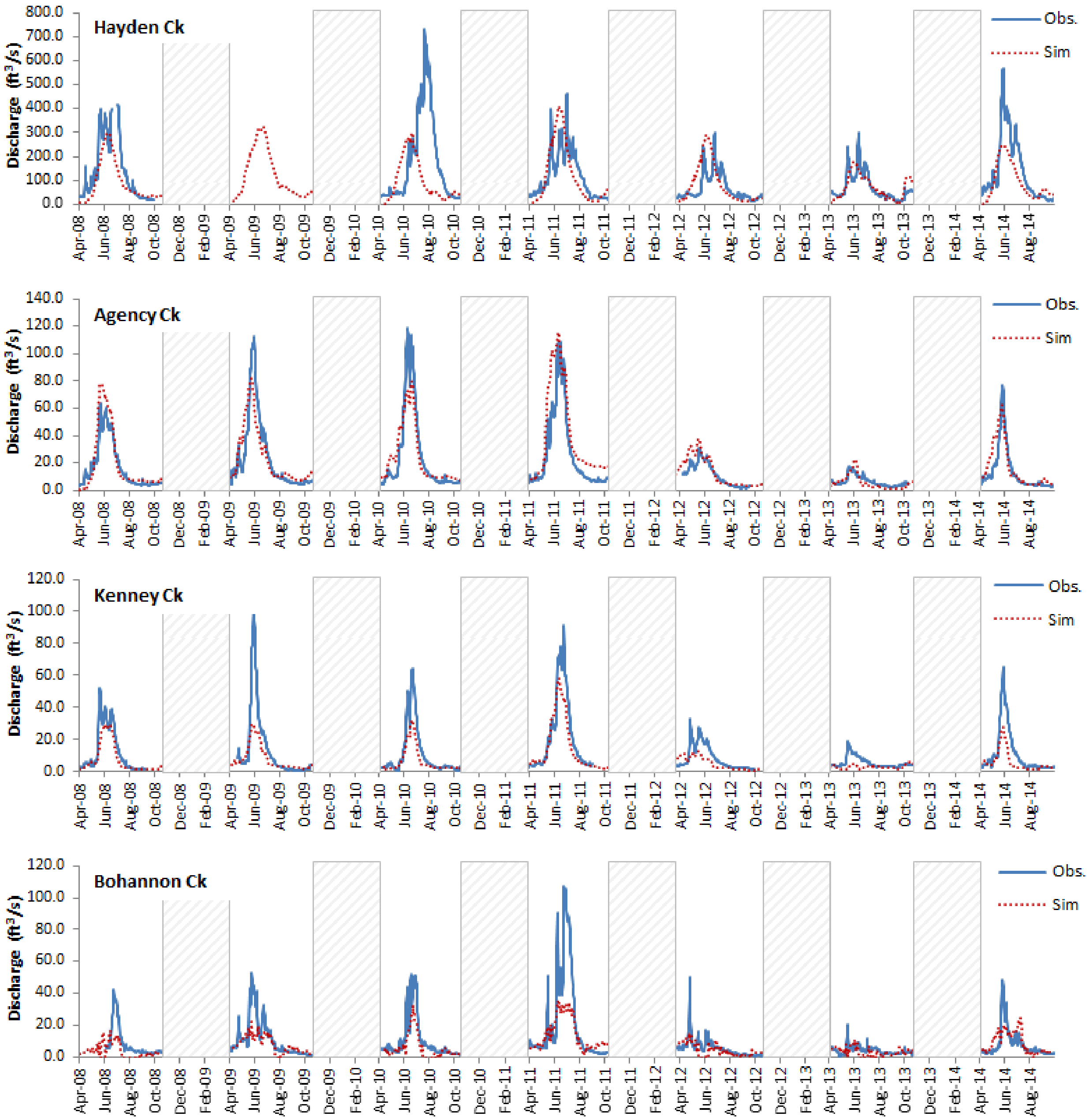


Figure 25. Comparison of observed versus simulated discharge values at Hayden Creek, Agency Creek, Kenney Creek, and Bohannon Creek gages. Areas denoted in grey represent winter months when many gages are winterized and do not collect data.

With the exception of the Lemhi River above Big Springs gage, gages along the Lemhi River show good agreement between simulated and observed discharges (Figure 26, Figure 27). At the Lemhi River above Big Springs gage, simulated discharges are below observed discharges. As the diversion records along this reach are well documented, the disparity between simulated and observed are likely a function of reach gains from the regional groundwater system and inaccuracies of the rainfall-runoff models predicting inflow from Jakes and Little Eightmile Creeks.

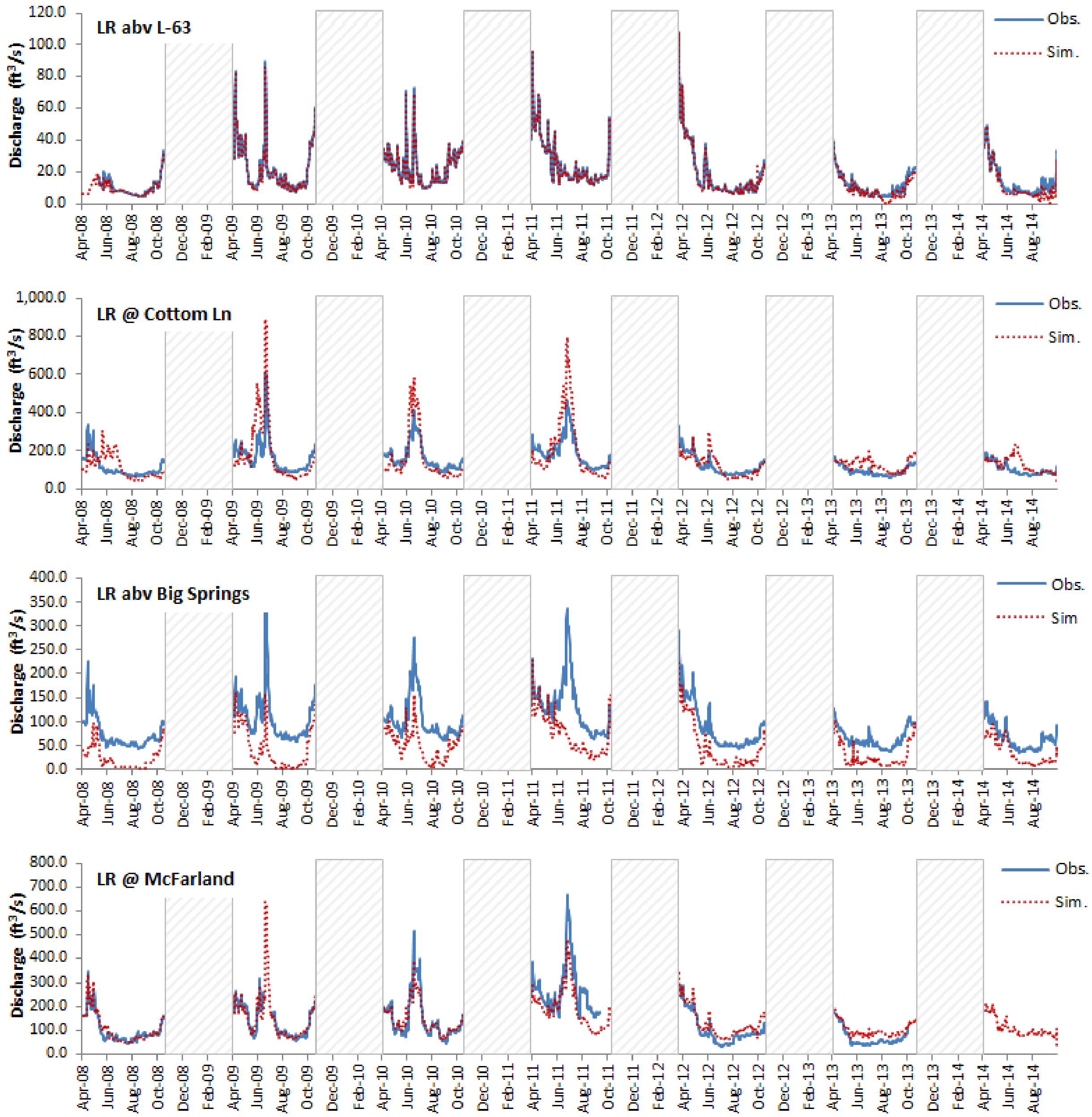


Figure 26. Comparison of observed versus simulated discharge values at Lemhi River gages at above L-63, at Cotton Lane, above Big Springs, and at McFarland Campground. Areas denoted in grey represent winter months when many gages are winterized and do not collect data.

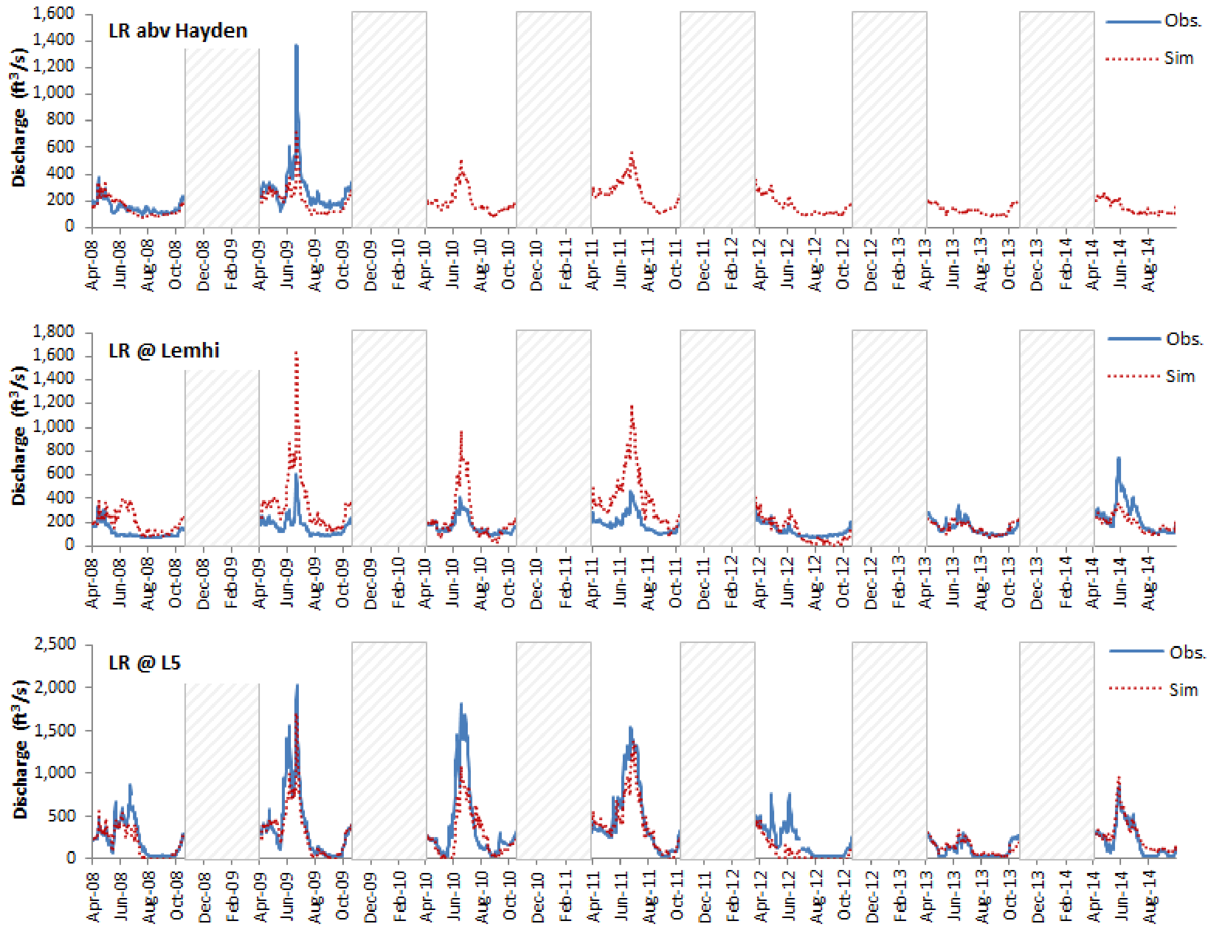


Figure 27. Comparison of observed versus simulated discharge values at Lemhi River gages at above Hayden Creek, at Lemhi, and at the L-5 diversion. Areas denoted in grey represent winter months when many gages are winterized and do not collect data.

2.2.2 Seepage Runs Comparison

LRBM results were compared to the mainstem Lemhi River seepage run conducted by IDWR on August 2014 to confirm if the diversion/return flow estimates in the model were accurate. The comparison involved mapping the LRBM network to seepage run measurement locations and obtains the simulation records for the same period. Results from the comparison indicate that the majority of the observed and simulated Lemhi River flows are within ±15% (

Table 5). The primary factor leading to discrepancy between simulated and observed discharges arises from tributary inflows predicted from the NAM modeling. This is apparent in reaches 7, 10, and 12. Diversions are very similar and mapped return flow drains are generally within 25%. The latter reflects effective characterization of return flows to the Lemhi. This comparison verified that the model is correctly simulating the diversion and inflows to the model along the Lemhi River.

Table 5. Comparison between IDWR Lemhi River seepage run measurements and average simulated flows for July 31, 2014-August 2, 2014. Black values in the difference column are with ±15%.

Reach No.	Description	Measured Flow [ft3/s]	Simulated Flow [ft3/s]	%Difference [ ]
1	BOR gaging station at Leadore to Big Springs inflow	7.6	5.02	0.34
2	Big Spring inflow to Little Eightmile Creek	41.6	35.53	0.15
3	Little Eightmile Creek to BOR Gaging Station at BLM McFarland Campground	77.2	87.32	-0.13
4	BOR gaging station at BLM McFarland Campground to highway bridge upstream from L-44 diversion	80.9	78.44	0.03
5	Highway Bridge upstream from L-44 to Lemhi	88.8	86.96	0.02
6	Lemhi to 0.1 mile downstream from Hayden Creek Road	106.1	106.64	-0.01
7	0.1 Mile downstream from Hayden Creek Road to USGS gaging station 13305000	101.9	75.91	0.26
8	USGS Gaging Station 13305000 to highway crossing downstream from L-30 diversion	130.0	111.70	0.14
9	Downstream from L-30 diversion to highway bridge 0.15 mi upstream from L-19 diversion	124.3	112.42	0.10
10	0.15 mi upstream from L-19 diversion to highway bridge 0.7 mi upstream from Baker intersection	130.0	95.86	0.26
11	0.7 mi A175 upstream from Baker intersection to BOR gaging station at Barracks Lane	119.5	132.00	-0.10
12	BOR gaging station at Barracks Lane to USGS gaging station 13305310	85.4	130.93	-0.53
13	USGS gaging station 13305310 to BOR gaging station at L-3A diversion	33.1	28.36	0.14
14	BOR gaging station at L-3A diversion to BOR gaging station at L-1 diversion	61.0	70.77	-0.16

2.2.3 Zones of Accuracy and Reporting Interval

Because the rainfall-runoff predictions for the pediment surfaces vary in accuracy, simulation accuracy are different above and below stream gages where reach gains are calculated. For the LRBM, two accuracy zones have been identified to consider when characterizing model results. Above stream gages, errors in predicting runoff and use of water right for the water user demand time series are less likely to predict the overall magnitude and timing of flows in the stream network. Higher accuracy zones occur between gages where reach gains have been calculated for the upstream gage and inflows and outflows are explicitly defined. With well-known reach gains and losses, the calculated in-stream flow should be quantitatively accurate. The exceptions are any gages that have ungauged tributary inflows predicted by uncalibrated rainfall-runoff modeling. Flow indicated by model results in low accuracy zones may be much less or greater than what the actual flow might be given a simulation. Improved rainfall-runoff modeling on the pediment catchments will improve the accuracy of simulated flows.

Though the model simulates on a daily time step, when running future scenarios results should be reported on a minimum of weekly time step. The reasons for lengthening the reporting time step are 1) to account for spikes and peaks in the rainfall-runoff results or reach gains that may be due to local events and not observed in the input data, and 2) once the water is diverted, where the water is applied within the POU is not monitored so the timing and location of return flows is not known. Lengthening the time step mitigates the influence of these factors while still depicting the influence of changed irrigation practices and projects within the stream network.

2.3 Assumptions, Limitations, and Future Improvements

All numeric models are approximations of the actual conditions. As such, there are assumptions and limitations in the basic algorithms, the available data supporting the LRBM, model construction, and calibration that limit the LRBM. Key assumptions and limitations include:

1. *Network Models:* Network models are insufficient for addressing physically-based questions such as flood propagation and attenuation, flood extent, ground water-surface water interactions distributed over the landscape, and stage within the river. These must be addressed using physically-based hydraulic models and/or distributed hydrologic models.
2. *Changing hydrologic system and irrigation practices:* The network and irrigation practices (e.g. crops, irrigation method, irrigated area) reflect 2014 conditions. As conditions and practices in the basin have changed since 2007, using a network and irrigation practice that represents 2014 conditions does not accurately reflect historic conditions and can lead to inaccuracies in estimating stream flow conditions for earlier years.
3. *Data Availability and Accuracy*: The accuracy of model results depends on the quantity and quality of the input data. Data limitations for the LRBM include:
    - Missing daily diversion records for diversions. This influences the predicted diversion and return flows making rainfall-runoff calibration, return flow calculations, high flow representation, and reach gains less accurate.
    - Availability and accuracy of diversion and gage data. This includes missing data, inaccurate reporting (just report that the diversion is on up to the water right regardless of the flow), and missing high flow diversion rates. In many tributaries, high flow rates are not reported. For example, when comparing observed and simulated flows at the upper and lower gages along Big Timber Creek, the LRBM showed good agreement at the upper gage but significantly over predicted flows at the lower gage. The difference could be due to not reporting high flows taken by intervening diversions.
    - Inaccuracy of rainfall-runoff inflow estimations. Catchment inflows drive the hydrologic system, so inaccuracies in these estimations propagate through the system. Limitations associate with rainfall-runoff inflow estimations are presented in

Section 3.7.
  - Missing records for winter months. Because tributaries ice over in the winter, many of the tributaries and upper Lemhi River gages are removed from November to March. During this period, flows occur in these water bodies that are not accounted for in the discharge records.
4. *Multiple POUs for a POD:* For PODs serving disparate POUs, multiple water user nodes are used and each requires a water demand time series. As it is unknown how diverted water is allocated between these POUs, the water demand time series for each is determined by splitting the historic diversion record proportional to irrigated area of each POU.
5. *Reuse of diverted water:* The LRBM does not account for increases the complexity of computing return fractions and lag times associated with the reuse of water for irrigation. Four systems that have significant reuse of diverted water or tributary inflow include:
   - Agency Creek: L-42 ⇒ L-32 ⇒ L-31A ⇒ L-31 ⇒ Agency Creek ⇒ Lemhi River
   - Withington Creek: L-30 ⇒ L-22 ⇒ L-21 ⇒ L-15 ⇒ Withington Creek ⇒ Lemhi River (some water may be diverted to L-14 and L-13 from Withington Creek)
   - Sandy Slough: L-23 ⇒ L-22 ⇒ Sandy Creek ⇒ L-21 ⇒ L-15 ⇒ Sandy Slough ⇒ Lemhi River
   - Bohannon Creek: L-23 ⇒ L-22 ⇒ L-21 ⇒ L-15 ⇒ Lemhi River.

   Currently, the lag times for these systems are determined for the individual diversion. For the upstream diversions, this results in long lag times that implicitly reflect the capture and reuse of the water. Greater monitoring will be required to simulate the capture and reuse of should it be required.
6. *Return flow locations:* Rapid return flow locations for POUs are located at a downstream point along the tributary system where the majority of the return flow is considered to return. While placing the return location at the downstream-most point is adequate for the majority of the system, this simplification could become problematic if model simulations indicate that the stream becomes sufficiently depleted downstream of an intermediate diversion that occurs between the original point of diversion and its return location.

   For POUs implementing ARF return flows, inaccuracy lies in predicting where the majority of the return flow will occur. As flow paths for the groundwater system are unknown, the current locations are determined from topography, aerial photos, consulting local water managers, and professional judgment. Thus, the location of return may not match the actual location where return flows enter the stream network.
7. *Return flow timing and quantity (Linear reservoir method)*: Return fractions and lag times for each irrigation node have been individually computed to approximate how long the water may take to re-enter the Lemhi River from that irrigation node.
8. *Return flow timing and quantity (ARF method)*: Several factors influence the accuracy of ARFs:
   - Preprocessed return flows assume water users get full water diversion and thus if the water user is short during a simuation, then the model over predicts return flows.
   - The analytical solution used for computing the response functions assumes a flat groundwater surface. As the groundwater surface underlying pediment surfaces is sloped, this over predicts the travel time taken for infiltrated water to reach the Lemhi River.

- All response functions are calculated using a perpendicular path to the Lemhi River. In reality, these paths may be oblique and thus require longer travel times.

9. *Groundwater system:* Regional groundwater in the LRBM is simulated as irrigation return flows and reach gains. A significant effort was given to developing a relationship between climate and reach gains that could be incorporated into MIKE BASIN functionality for use in simulating different climatic conditions. Given the uncertainty with the rainfall-runoff modeling of pediment catchments, this relationship requires reexamination once rainfall-runoff modeling of pediment catchments has improved. Furthermore, actual flow groundwater flow paths are unknown in the basin and thus have been inferred.
10. *Springs along Texas Creek, Eighteenmile Creek, Big Springs headwaters:* These springs provide significant inflow to the LRB and locally influence stream flows. As these features are not measured, they have not been explicitly included in the LRBM. To support their inclusion, downstream flow measurement and seepage runs should be conducted to supply the necessary information for their inclusion.

2.3.1 Future Improvements

The primary updates to support the future use of the LRBM include model updates, use and maintenance, and expansion to address other questions. The model updates include:

1. *Update network for Eighteenmile Creek, Texas Creek:* The catchments for Eighteenmile do not represent the headwater inflows and the major spring systems entering along Eighteenmile and Texas Creeks as well as the headwater of Big Springs. Refine the network to simulate inflow of rainfall as well as spring contributions to the systems.
2. *Improve rainfall-runoff modeling of pediment catchments:* As further data is collected with regard to diversion operations and measured inflow, calibration of the pediment surfaces should be redressed.
3. *Revisit the reach gain-climate relationship:* Following improvement of the pediment catchments calibrations, reexamine developing a relationship between climate and reach gains.
4. *Compare to other seepage runs:* For this calibration, LRBM were compared to IDWR's mainstem Lemhi seepage run in August 2014. Other seepage runs have been conducted on tributaries within the basin. Calibration, insight, and performance may improve with other seepage run comparisons.
5. *Incorporation of QCI discharge data:* To support biological studies, QCI has deployed a series of pit arrays with accompanying water level recorders. Given a stage-discharge rating curve at these locations, these water level records can be converted into flow records for use in calibration and computing reach gains.

Use and maintenance updates:

6. *Develop annual maintenance and software archiving protocol:* Though historic models exist, no formal mechanism has been put in place to update the baseline model, document changes, and archive model version and supporting software. Creating a maintenance plan that formalizes the update process is an effective means to consistently update and maintain the LRBM for future use. Furthermore, annually archiving models proved a record of the hydrologic and operational changes in the basin.

7. *Output interface*: Output for analysis can be performed in MIKE BASIN or using external tools in MS EXCEL. The former is time consuming and requires a MIKE BASIN license. The latter has been developed to support calibration and address specific project analysis, but not standardized to apply to many scenario evaluations. To support the rapid evaluation of LRBM results by OSC, USMWP, and interested stakeholders, a common results viewer can be developed to evaluate projects.
8. *Improving supporting MS EXCEL tools*: The current MS EXCEL tools supporting the LRBM are effective in their applications, but have been developed as tools and not for general use. For wider use, these MS EXCEL tools should be updated, tested by general users, and documented.
9. *Extend simulation period*: Longer simulation periods provide a wider variety of hydrologic conditions to test how the system responds. To extend the simulation time of the LRBM, two input time series need to be extended: 1) rainfall-runoff and 2) reach gains. Historical precipitation, temperature, and evaporation time series from 1995 to the present can be used in the rainfall-runoff models to generate inflow time series. Reach gain are more difficult as they are a result of flow measurements and incorporate measurement inaccuracies as well as factors not accounted for such as localized rainfall events, unmodeled tributary inflows, inaccuracies in rainfall-runoff estimates, variations in irrigation activities, losses to ET along the stream, and ground and surface water exchange through the stream bed. An examination of the reach gains with consideration of climatic conditions and diversion operations should be conducted to develop reach gains that can extend beyond the calibration period. If successful, the LRBM can simulate scenarios over a longer period and with future climatic conditions.

Extending the use of the LRBM:

10. *Extend the analysis to include ecological and economic evaluation:* LRBM output includes water distribution throughout the network on a daily to weekly time step as well as the water delivery to the water user nodes. The former is input data to support fish habitat analyses and the latter can be coupled with crop growth and economic output to compute the economic production associated with agricultural production in the LRB (Borden 2014).

3 LRBM RAINFALL-RUNOFF CALCULATIONS

The LRBM requires inflow boundary conditions for all simulated tributary streams. As the majority of the tributary streams in the model are ungauged, a method was needed for developing stream flow time series for the inflow boundaries of the ungauged tributaries. Several methods exist for developing stream flow time series in the ungauged tributary streams including installation of new stream gages, transfer of flow records from nearby catchments with similar characteristics, utilization of regional hydrologic curves or equations to predict statistical flows, and the development of rainfall-runoff models to simulate a catchments processing of precipitation into stream flow. The latter method was chosen for this study because rainfall-runoff models predict runoff given catchment attributes and can look at scenarios of different precipitation, temperature, and ET conditions. DHI's Nedbør-Afstrømnings-Model (NAM) was used in to estimate inflow to the LRBM.

NAM is a lumped conceptual rainfall-runoff model for simulating stream flow based on precipitation and evapotranspiration at a catchment scale. NAM operates by continuously accounting for the moisture content in three different and mutually interrelated storages that represent overland flow, interflow, and baseflow (Figure 28) (DHI 2012). As NAM is a lumped model, it treats each subcatchment as one unit thus parameters are considered to represent average values for the entire subcatchments. Precipitation in the form of snow is modelled as a fourth storage unit. For catchments with snow falling over a wide elevation range, the storage unit representing snow can be divided in up to ten subunits to represent different elevation zones. Water use associated with irrigation or ground water pumping can also be accounted for in NAM. The result is a continuous time series of the runoff from the catchment throughout the modelling period. Thus, the NAM model provides both peak and low flow conditions that account for soil moisture and baseflow conditions over the simulation period.

Basic data requirements for the NAM model include catchment area, initial conditions, and concurrent time series of precipitation and potential evapotranspiration (ET). When snowmelt is included in the model, temperature is required and radiation is optional. If the catchment is divided into elevation zones for the snowmelt calculation, also required are elevation of the precipitation gage, wet and dry adiabatic lapse rates (the rate of decrease of temperature with increasing altitude in the atmosphere), precipitation accumulation per zone, and maximum accumulation per zone.

For gaged basins, calibration of the NAM model involves adjusting the coefficients for the exchange of water between storage units and the storage unit depth so that simulated and observed discharges match as best as possible. A minimum of 3 years including periods of above-average precipitation is recommended for calibration, with longer periods resulting in a more reliable model. Disparity between simulated and observed discharge arise largely due to quality of time series data or heterogeneity of topographic, climatic, geologic, vegetative, and land use conditions within the catchment. For ungauged streams, NAM parameters developed for a gauged catchment having similar topographic, climatic, geologic, vegetative, and land use characteristics are used with local precipitation, temperature, and potential evaporation time series to predict runoff.

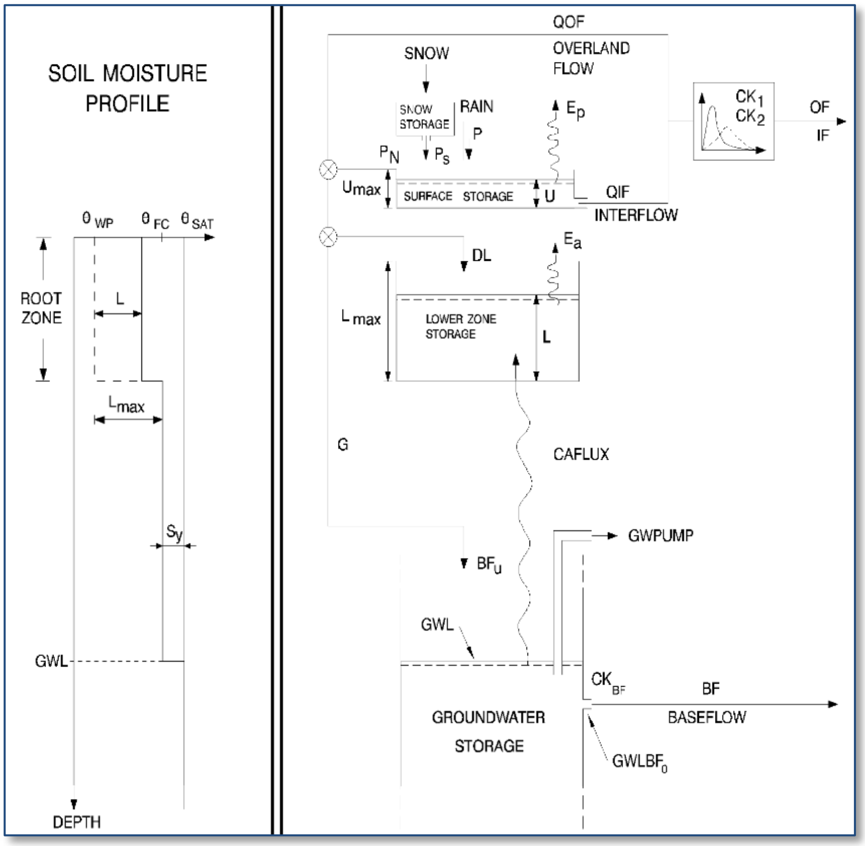


Figure 28. Structure of the NAM model (DHI 2012).

3.1 NAM Model Construction

The NAM catchments followed those defined in the LRBM (Figure 29). Snow distribution in the LRB is not evenly distributed vertically or horizontally across the landscape. To account for the vertical bias in distribution, the headwater and pediment catchments have been partitioned into 2 to 7 elevation zones with the pediment catchments with 1 or 2 zones and the headwater catchments with 5 to 7 zones. The elevation zone classification was completed using the ArcGIS Spatial Analyst Reclassify tool on the whole Lemhi basin using the USGS 30 m NED digital elevation model (USGS 2006), with the Natural Breaks (Jenks) classification method set to have 7 natural breaks. The average elevation of each elevation zone, the area within each elevation zone, and the total area for the catchment, were then calculated and entered into MIKE 11 NAM, where the precipitation-runoff model corrects the average precipitation and temperature data for the average elevations of the five elevation zones. The elevation representing the meteorological station, as required input for NAM, was set at the median elevation of the catchment.

3.2 Time Series Data

Time series data required for the NAM models includes concurrent daily precipitation, temperature, and potential evapotranspiration. Stream discharge is used in the calibrating model parameters in gauged catchments.

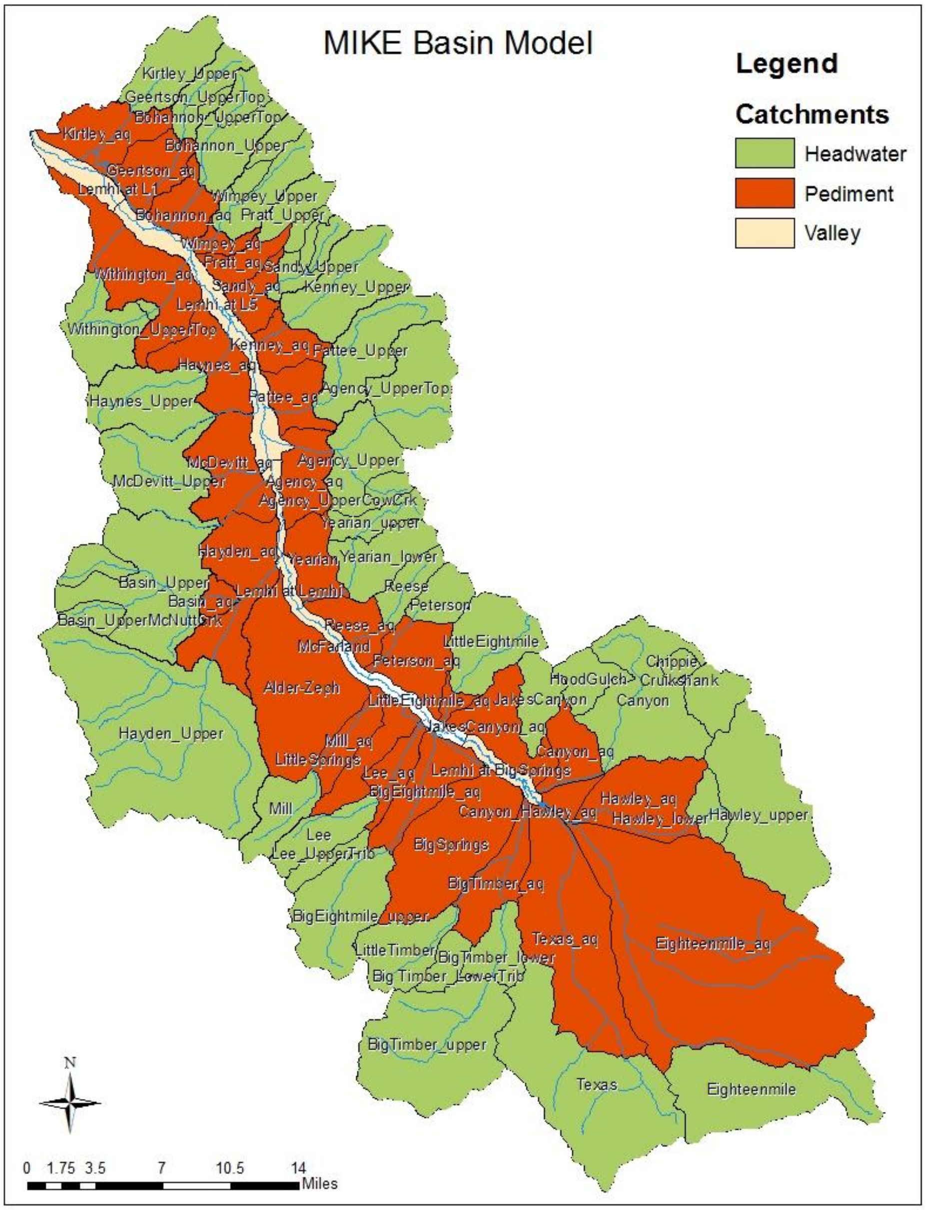


Figure 29. Catchments in the LRBM. Green and red polygons represent headwater and pediment catchments, respectively. Valley floor catchments have yet to be defined.

3.2.1 Precipitation and Temperature Input Time Series

Most of the precipitation falls as snow during winter, with local convective storms occurring periodically during the summer months. Due to the mountainous conditions in the LRB, precipitation and temperature vary greatly around the basin depending on aspect and elevation of the meteorological gages. An examination of the PRISM data indicates that precipitation varies widely within the Lemhi River Basin from approximately 9 to 53 inches/year largely as a function of elevation. Rain shadow effects are also an important factor in controlling the variation of precipitation within the basin. The SNOTEL sites are located at elevations ranging from 7,440 to 9,150 feet above mean sea level (asl) and are more representative of the middle and upper elevation portions of the NAM catchments. The

Corvallis AgriMet site is located at an elevation of 3,600 feet asl and is more representative of the lower elevation portions of the NAM catchments. The difficulty arises when trying to extrapolate the precipitation and evapotranspiration from the monitoring stations over the landscape given the orogenic effects on weather.

In 2008, DHI created a Python computer program for IDWR to spatially interpolate daily weather station precipitation and temperature data across catchments using monthly grid data as a statistical basis for the interpolation based on methods developed by Diluzio et al. (2008). The algorithm uses aggregating monthly PRISM (Parameter-elevation Regressions on Independent Slopes Model) grids precipitation distribution maps (PRISM 2012) coupled with local meteorological stations historic time series of precipitation to develop a gridded daily average precipitation surface. For temperature, the PRISM monthly minimum and maximum temperature (PRISM 2012) is coupled with meteorological stations historic time series of temperature to generate a gridded 12-hour minimum and maximum temperature surface (Rupp 2008). For input into NAM, the gridded surfaces are aggregated into a single daily time series of precipitation and temperature for each catchment.

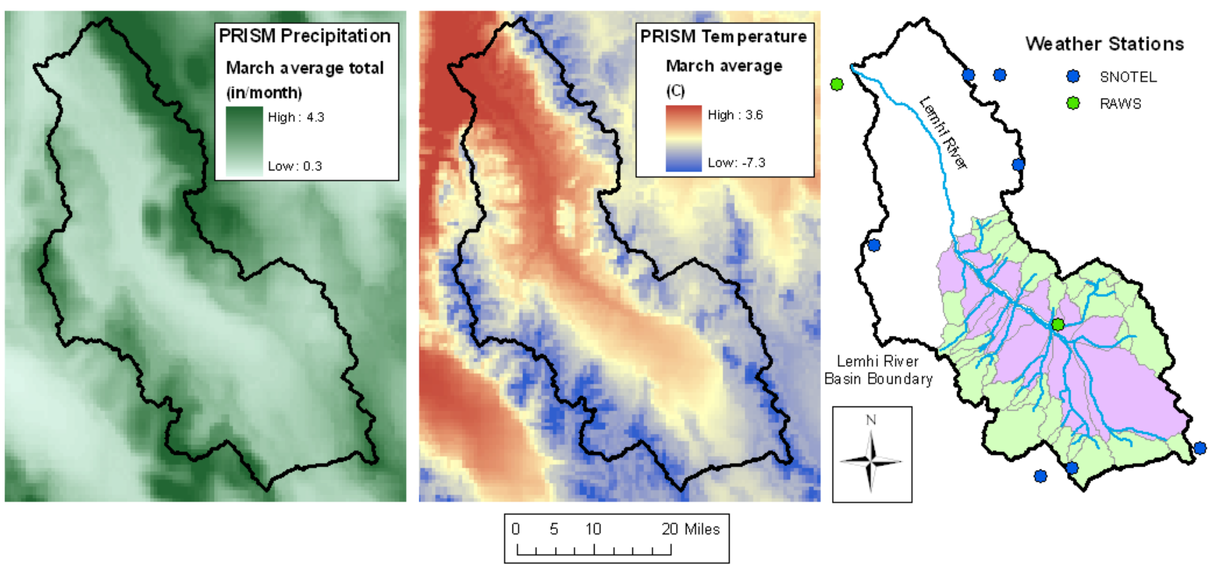


Figure 30. PRISM monthly precipitation and temperature data for the Lemhi, and locations of weather stations used for daily precipitation and temperature data in rebuilding the Upper LRBM (Dixon 2012).

As stated, input data required for the algorithm (PRISM Tool) includes precipitation and temperature time series require meteorological station data, PRISM surfaces, spatial locations of the meteorological stations, and spatial extent of the NAM catchments in a raster format gridded with the same resolution as the PRISM data. The precipitation and temperature data were available from seven NRCS SNOTEL sites located in or near the basin (NRCS 2006). These sites include Schwartz Lake, Meadow Lake, and Moonshine in Idaho and Darkhorse Lake, Bloody Dick, Lemhi Ridge, and Beagle Springs in Montana (Table 6) and the Desert Research Institute RAWS (Remote Automated Weather Stations) network at Leadore and Salmon. For the PRISM surfaces, gridded monthly average (1971-2000) precipitation and temperature data were obtained from the Oregon State University PRISM Climate Group (OSU 2012) (Figure 30).

Meteorological station locations were obtained from the station metadata. The raster grid of NAM catchments was generated by intersecting the NAM vector shapefile with the PRISM grid in ArcGIS.

Table 6. List of meteorological stations used developing precipitation and temperature time series to support the rain-fall runoff modeling. Latitude and longitude are in NAD83.

Station Name	Station Id	Latitude	Longitude	Elevation (ft.)
Beagle Springs	SNOTEL	44.467	-112.983	8850
Bloody Dick	SNOTEL	45.167	-113.500	7600
Darkhorse Lake	SNOTEL	45.167	-113.583	8600
Leadore	RAWS	44.700	-113.350	6000
Lemhi Ridge	SNOTEL	45.000	-113.450	8100
Meadow Lake	SNOTEL	44.433	-113.317	9150
Moonshine	SNOTEL	44.417	-113.400	7440
Salmon	RAWS	44.700	-113.350	6000

3.2.2 Evapotranspiration Input Time Series

IDWR adapted the PRISM Tool used for computing precipitation and temperature to spatially interpolate daily evapotranspiration (ET) a across catchments using daily weather station ET and METRIC monthly grid data. ET time series were created by aggregating monthly METRIC (Mapping EvapTranspiration at high Resolution with Internalized Calibration) grids (source IDWR 2010) with daily time series of ET calculated using Ref-ET software and weather station data from the Leadore and Salmon RAWS stations (Figure 30). METRIC data, processed by IDWR and the University of Idaho, is based on satellite data and energy balance calculations that calculates actual ET and was available for the 1996, 2000, 2006, 2008, and 2010 irrigation seasons. Much like PRISM data, METRIC surfaces provide gridded data across a spatial domain (i.e. point data from weather stations) accounting for water limitations and various land covers. No METRIC surfaces were computed for winter months so the October surface was used as the default ET surface for November through April. The PRISM Tool outputs daily area-weighted average ET (ETa,avg) values that were imported into MIKE 11 NAM for runoff calculations.

Typical ET input for MIKE 11 NAM is the potential evaporation (ETr). Dixon (2012) explored using both ETr and Eta and found that "the *ETa,avg correlated strongly to the METRIC data, which is physically appropriate because ETr values are strictly for a given crop with no water limitations. Although, according to METRIC documentation (IDWR 2010), METRIC data is not specifically designed for use in non-irrigated areas (i.e. forested areas common in the Upper Lemhi LRBM catchments), IDWR assumed that using the METRIC data to scale ETr values across catchments was reasonable in a conservative sense – that is, applying ETr values across catchments would be an overestimation of ETa, given the relative lack of irrigated areas in the catchments*". Because ETr overestimated the calculated Eta, the ETa computed using the METRIC output was used in the MIKE 11 NAM calculations.

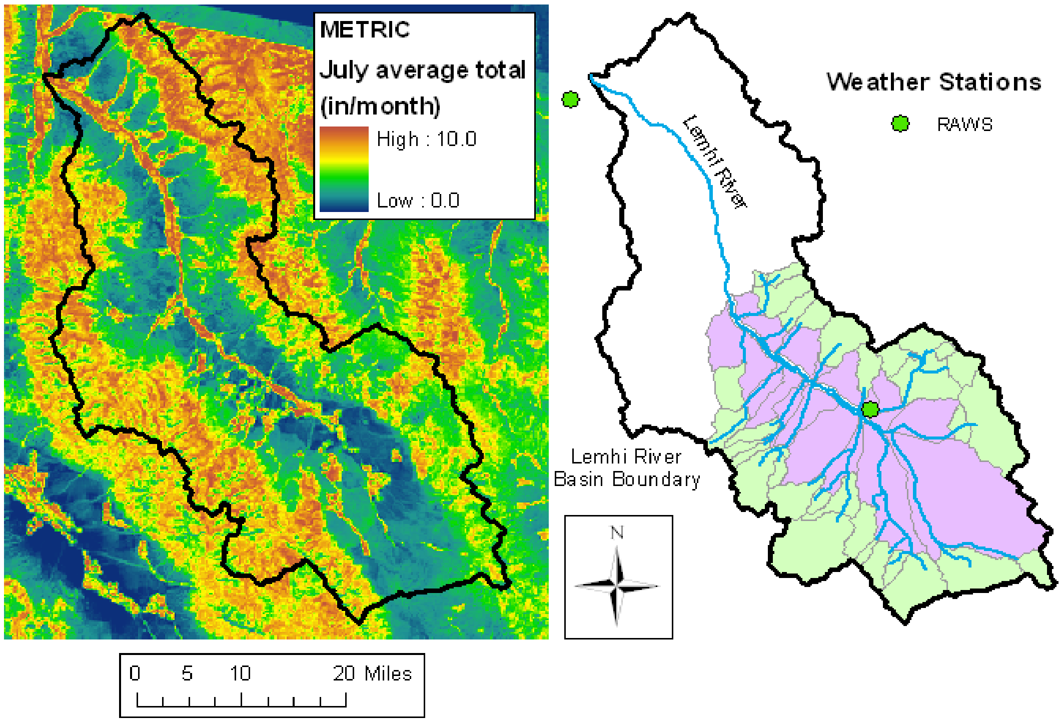


Figure 31. METRIC surface of average July ET for the Lemhi and the RAWS stations used in the ET computations (Dixon 2012).

3.2.3 Stream Discharge Calibration Time Series

Stream gage data along tributaries within the Lemhi Basin consists of sites on the Kenney Creek, Bohannon Creek, Agency Creek, Hayden Creek, Big Springs Creek, Little Springs Creek, Big Timber Creek, Big Eightmile Creek, Eighteen Mile Creek, Lee Creek, and Texas Creek. Headwater catchments with gauged records were used without correction as these observed flows were above diversions. The calibration period corresponded to the period of record that extended from October 1, 2007 to September 31, 2014 (Table 8).

In the LRBM NAM calibrations, the headwaters and pediment catchments use similar methods, but the preparation of the observed discharge time series is different. As with the headwater catchments, the objective of calibrating pediment catchments is to determine the contribution of water input from the catchment into the stream network at the catchment pour point. Complicating the quantification of this contribution is the adjustment of the observed hydrograph to account for headwater catchment inflows, diverted water, and high water practices. The high water practices, where irrigators divert the full ditch capacity during high spring flow, are not well documented in regards to the amount and timing of the diverted flow (Dixon 2012). The equation for the observed discharge for a pediment catchment is:

$$Qobs = Qrin + Qcin - Qdiv \qquad \text{Equation 2}$$

where *Qobs* is observed flow, *Qrin* is the upstream catchment flow, *Qcin* is the pediment catchment inflow contribution, and *Qdiv* is the diverted water (includes both water rights and high flows).

The NAM pediment catchment is calibrated against the *Qcin* term. Limiting factors in the calibration are due to:

1) Poor estimations of the Qrin. As an input to the pediment surface calibration is the inflow from the upstream catchment, the order that NAM models must be calibrated is progressively downstream. Thus, inaccuracies in upstream flows predicted by NAM are carried through in the calibration of downstream NAM catchments with gages.
2) Incorrect Qdiv time series. The accuracy of the adjusted flow varied depending on the quality of the diversion records. For Big Timber Creek and Canyon Creek, the diversion rates are recorded by the water master and reflect diversion rate. For Kenney Creek, diversion rates are not recorded so a constant diversion rate equal to the water right throughout the irrigation season was used. The uncertainty associated with using the water right for the diversion rate makes calibration difficult when comparing simulated and observed discharges as they are often different.
3) Missing periods of observed flow. Often, streams freeze over during the winter months and thus gages are removed to prevent damage. No measurements are recorded from mid-November through mid to late March. NAM requires discharge records to be complete throughout the simulation period, thus the flow record is interpolated during this period adding uncertainty to the gage record.
4) Inaccurate precipitation and/or evaporation input time series.

3.3 Snowmelt Parameterization

When including snow in NAM, several additional parameters are used including melting temperature, degree-day coefficient, minimum snow storage, maximum wet snow fraction, and initial snow storage (Table 4). The exception is the degree-day coefficients and snowmelt temperature, which were varied during the calibration of gaged catchments.

Table 7. Parameters used in the snowmelt computations

Parameter	Value	Unit
Melting temperature	2-3	^{o}C
Degree-day coefficient	0.5 – 4.5	mm/^{o}C/day
Minimum snow storage	20	mm
Maximum wet snow fraction	0.02	()
Initial total snow storage	0	Mm
Initial wet snow fraction	0	()

3.3.1 Precipitation Correction Factors

In MIKE 11 NAM, a precipitation correction factor (Pc) can be applied to the catchment elevations zones to simulate the vertical variability of precipitation rates. The Pc is a percentage multiplier change in precipitation from the elevation zone elevation to a reference elevation (Dixon 2012). Thus, the precipitation occurring at the reference elevation is multiplied by the Pc to determine the precipitation falling in elevation zone. The catchment reference elevation was determined using the annual average catchment precipitation (Pavg) determined from the

PRISM tool and comparing it to the corresponding elevation in the annual average precipitation from the PRISM precipitation grid. Following, the Pc for each elevation zone was calculated by comparing the average elevation and annual average PRISM precipitation for each elevation zone to the catchment reference elevation and its corresponding annual average PRISM precipitation. This process was carried out for all catchments in the LRBM.

3.3.2 Temperature Correction Factors

Similar to precipitation, the MIKE 11 NAM also incorporates a temperature correction factor (Tc) to account for the change in temperature with elevation. The Tc for each catchment was determined in an analogous fashion to that mentioned above for Pc, but using the average elevations and annual average PRISM temperatures of the elevation zones within a catchment and the annual average temperature (Tavg) for the whole catchment (Dixon 2012). This process was applied to the catchments in the LRBM.

3.3.3 Snow Melt Coefficients

MIKE 11 NAM incorporates snowmelt coefficients (Csnow) to account for melting rates. The software permits this parameter to vary according to seasonal factors, such as albedo, relative humidity, and solar radiation (DHI 2009a). Mr. Dixon (2012) investigated how to effectively describe Csnow values for each catchment by comparing weather station recorded values of daily average snow water equivalent (SWE), temperature, and solar radiation. Using the SWE and temperature data obtained from Beagle Springs SNOTEL station and the solar radiation data from Leadore RAWS station, Mr. Dixon found that SWE and solar radiation had a stronger relationship than SWE and average temperature, but the relationship was inversely proportional (ibid). From these findings, IDWR scaled Csnow by the daily area-weighted average temperatures (Tavg) for each catchment. This technique was used in developing the Csnow inputs in the upper and lower LRBM NAM catchments.

3.4 Initial Conditions

Initial conditions specified in NAM include U/Umax (surface storage) and L/Lmax (soil moisture), BF (baseflow), and snow storage. To correspond with start of the water years, NAM simulations start on October 1, which has antecedent dry and warm conditions. To simulate these conditions, U/Umax and L/Lmax were set to 0.0 and 0.3, respectively. BF was assumed to dominate the observed stream flow so initial QOF and QIF were set to 0 and initial BF was set to equal the observed flow at the simulation start date. For ungauged basins, the initial BFlow was set to 0. Lastly, snow storage was set at 0.

3.5 Calibration of Gauged Catchments

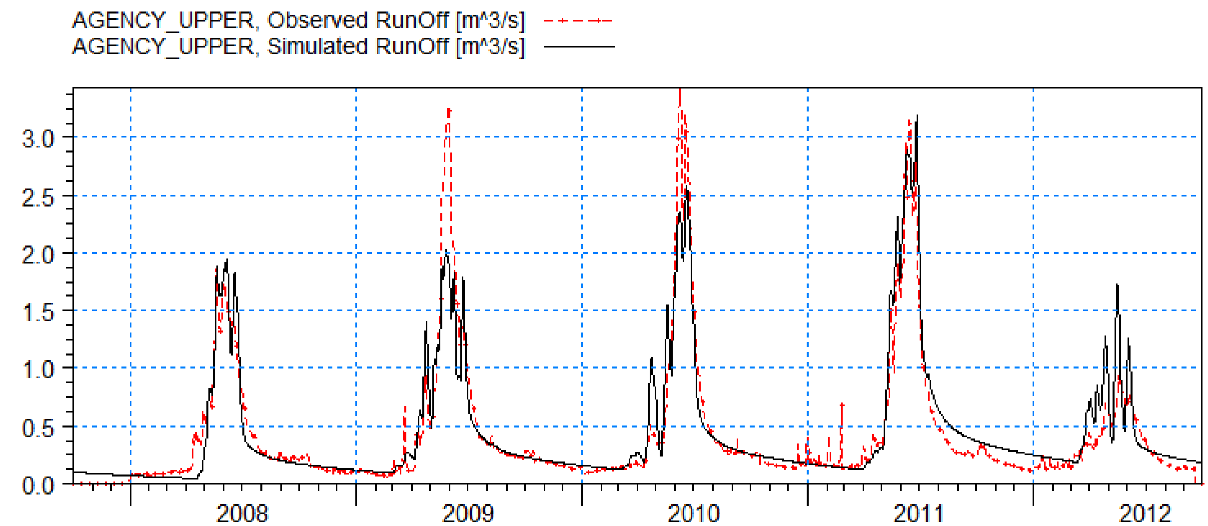
NAM calibration involves adjusting catchment parameters to achieve the best match between observed and simulated discharge given the modeling objective. For the LRBM NAM modeling, all other catchment parameters were effectively determined through iterative model calibrations, using various combinations of manual and auto-calibration techniques. Upper and lower limits of each parameter were converged upon through successive calibrations, and based upon typical ranges reported by DHI (DHI 2006). Best-fit parameters were converged upon by selecting the Overall Root Mean Square Error option with 30,000 evaluations. The calibration period used was water year 2008 to 2014 (Table 8). To support the LRBM, the objective was to produce a simulation with an overall good fit to the observed data and with a strong emphasis on summer-time base flows to target flow regimes that are of highest concern to fish populations.

The calibrated NAMs for Agency Creek, Big Eightmile Creek, Big Timber Creek, Bohannon Creek, Hawley Creek, and Kenney Creek produce good visual fits to the observed discharges (Figure 32 - Figure 37), with simulated discharges providing a reasonable match to observed discharges including the timing of the spring and summer snowmelt recession, the magnitude of base flows, and the water balance. The regression of concurrent observed and simulated flows resulted in R2 values ranging from 0.745 to 0.907 with an average of 0.844 indicating a strong relationship between the two time series (Table 8). Similarly, the cumulative water balance ranged between -5.6% and 1.1% with an average of -1.4%. Deviations between the cumulative observed and simulated flows for were primarily the result of not matching peak flow events. In addition, the shorter duration runoff events occurring throughout the fall and winter are not captured in the simulated discharges because these storm events are presumably local events and are not reflected in the precipitation gage records used in the model. These calibrations are sufficient to estimate inflow into the LRBM.

Table 8. NAM calibration results for gauged catchments in the Lemhi River Basin.

Catchment	Calibration Period	R^2	WBL [%]	Figure No.
Headwaters				
Agency Creek Upper	WY 2008 - 2014	0.876	-5.6%	Figure 32
Big Eightmile Creek (Aggregate)	WY 2008 - 2014	0.895	1.1%	Figure 33
Big Timber Creek (Aggregate)	WY 2008 - 2014	0.907	-1.2%	Figure 34
Bohannon Creek	WY 2008 - 2014	0.745	-0.2%	Figure 35
Hawley Creek (Aggregate)	WY 2008 - 2014	0.860	-3.0%	Figure 36
Kenney Creek Upper	WY 2004 - 2014	0.811	0.4%	Figure 37
Pediment Catchments				
Big Timber Creek	WY 2008 - 2014	-0.324	66.2%	Figure 38
Canyon Creek	WY 2008 - 2014	0.353	18.7%	Figure 39
Kenney Creek	WY 2008 - 2014	0.104	53.3%	Figure 40

The pediment catchments (Big Timber Creek, Kenney Creek, and Canyon Creek) calibrations are poor (Figure 38 - Figure 40, Table 8). Of the group, Canyon Creek is the best calibrated with a large portion of the error arising from periods when the observation gage is not operational. Kenney Creek is gauged for both the headwaters and pediment catchments, thus estimating Qdiv, the precipitation time series, and/or evaporation time series are is a limiting factor Kenney Creek seems to under represent the catchment contributions. Big Timber seems to missing the timing of peak runoff so the precipitation and/or evaporation input time series are primary suspects. Irrigated area accounts for only 9.0%, 1.4 %, and 9.2% of the Big Timber Creek, Kenney Creek, and Canyon Creek pediment catchment, so return flow is unlikely a major contributing source in the pediment catchment hydrographs.



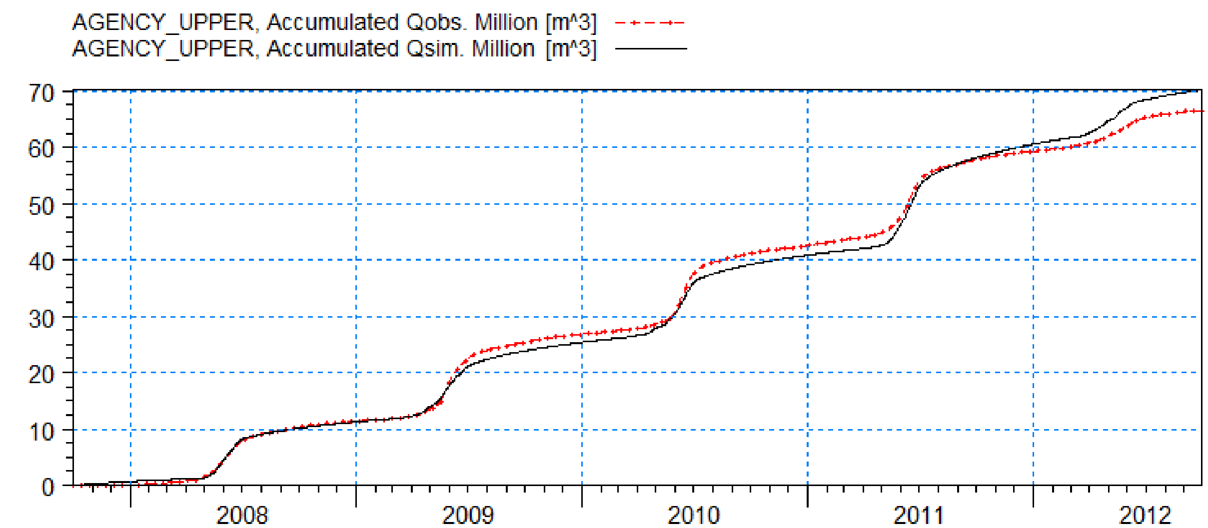
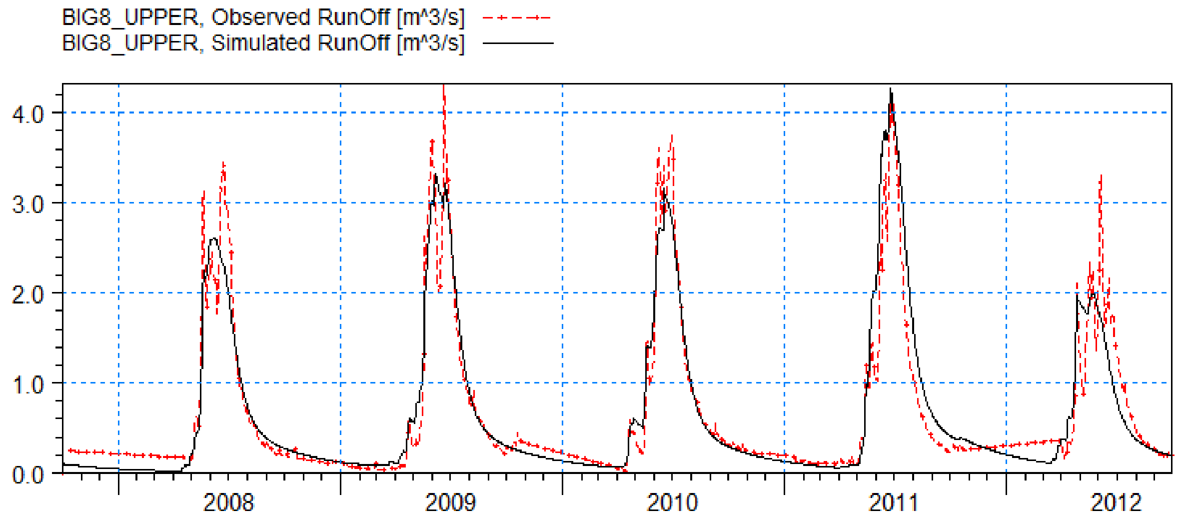


Figure 32. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Agency Creek Upper catchment (a headwater catchment). Note, discharge and accumulated flow are in SI units.



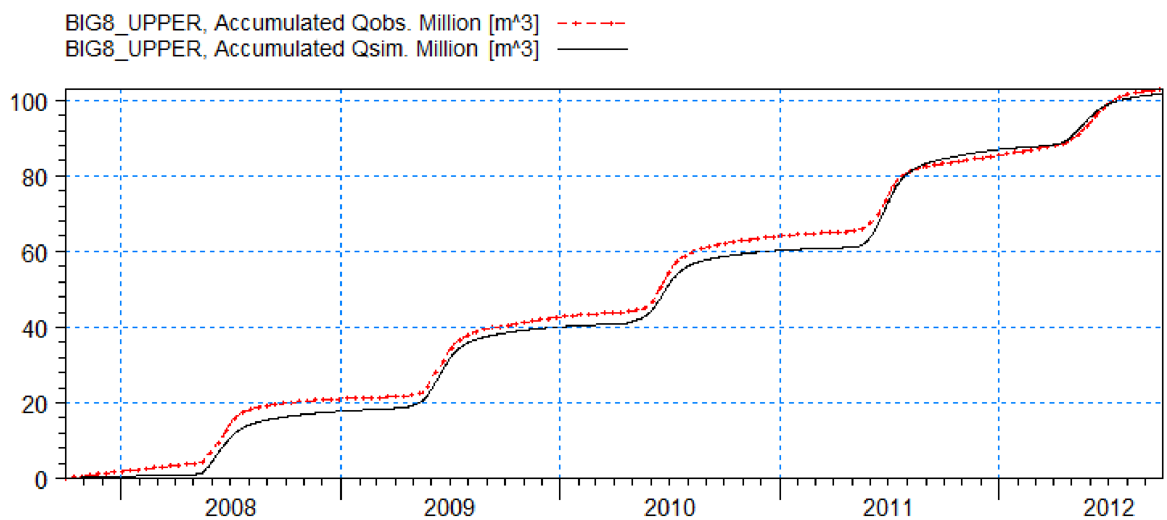


Figure 33. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Big Eightmile Creek Upper catchment (a headwater catchment). Note, discharge and accumulated flow are in SI units.

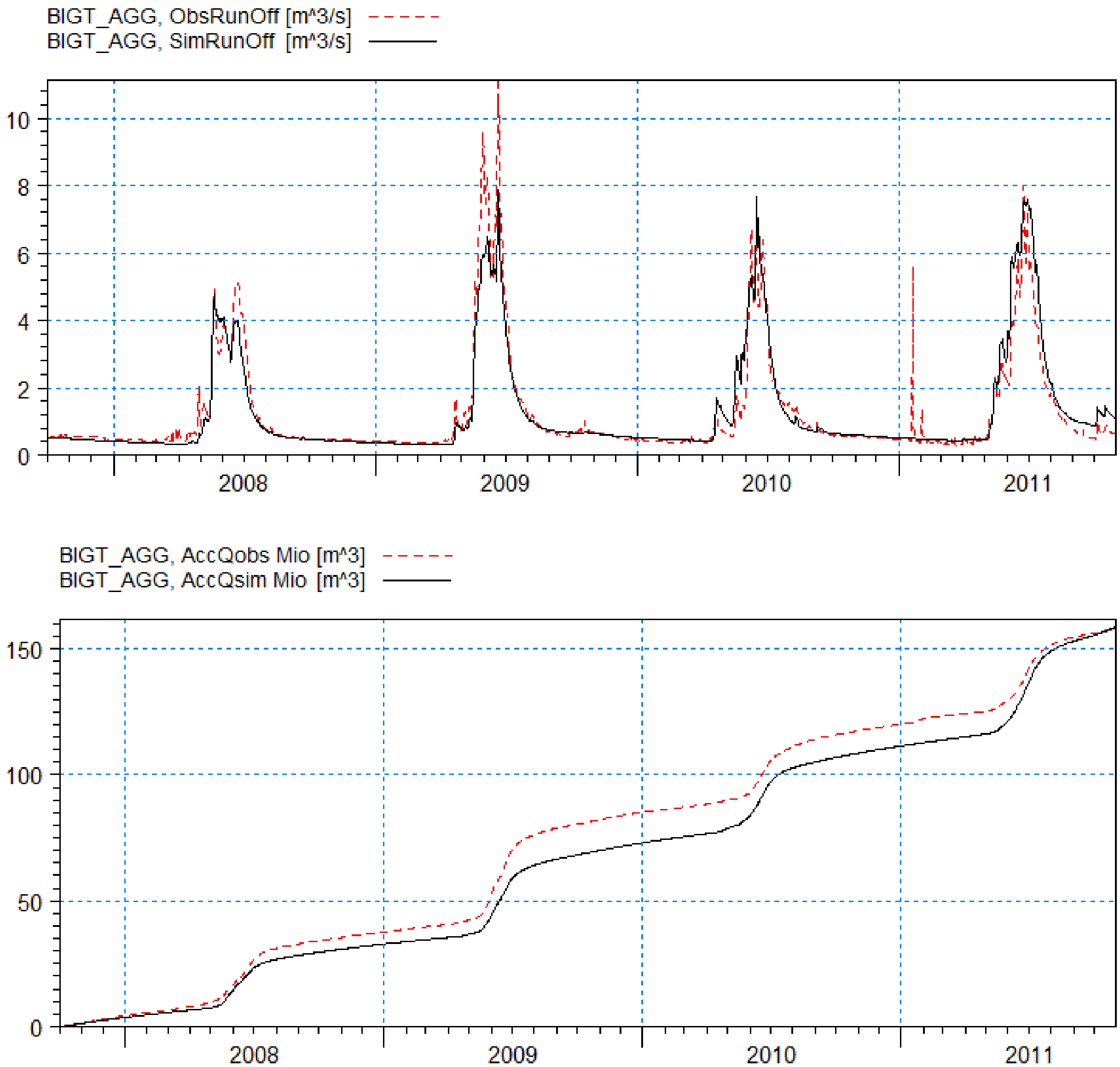
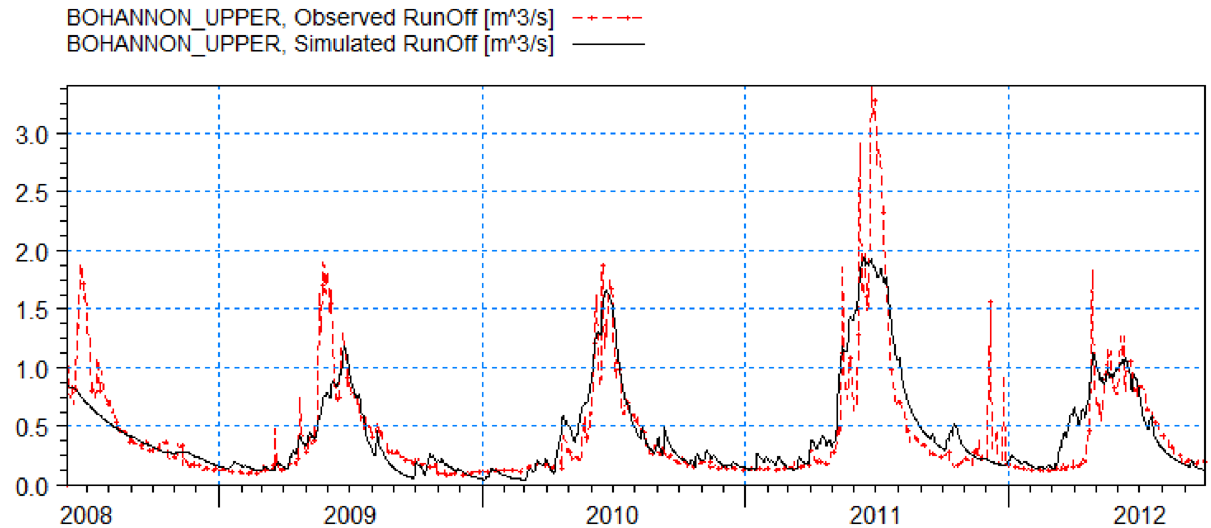


Figure 34. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Big Timber Creek Upper catchment (a headwater catchment). Note, discharge and accumulated flow are in SI units.



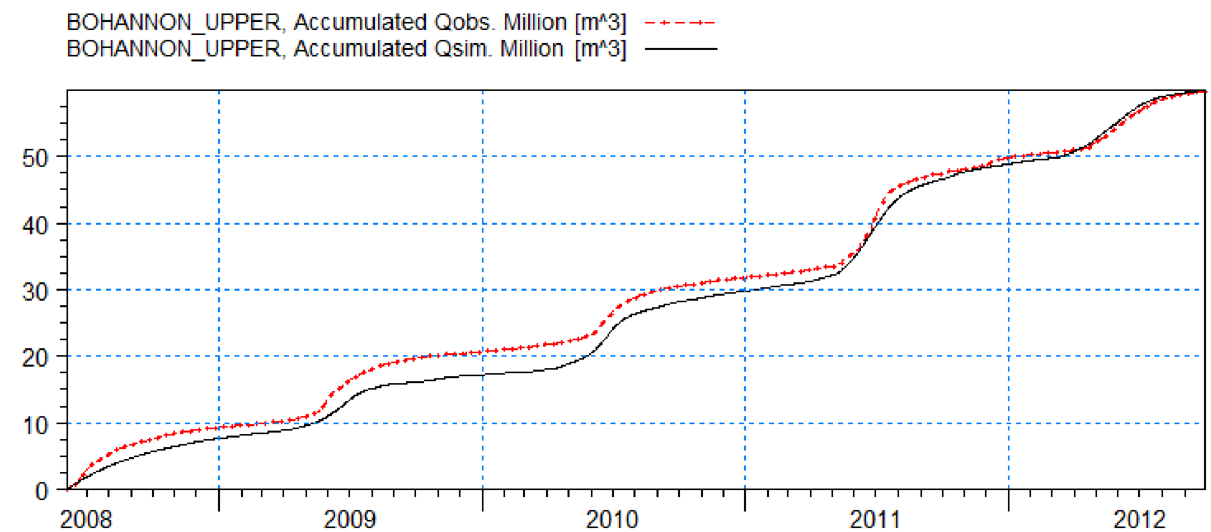
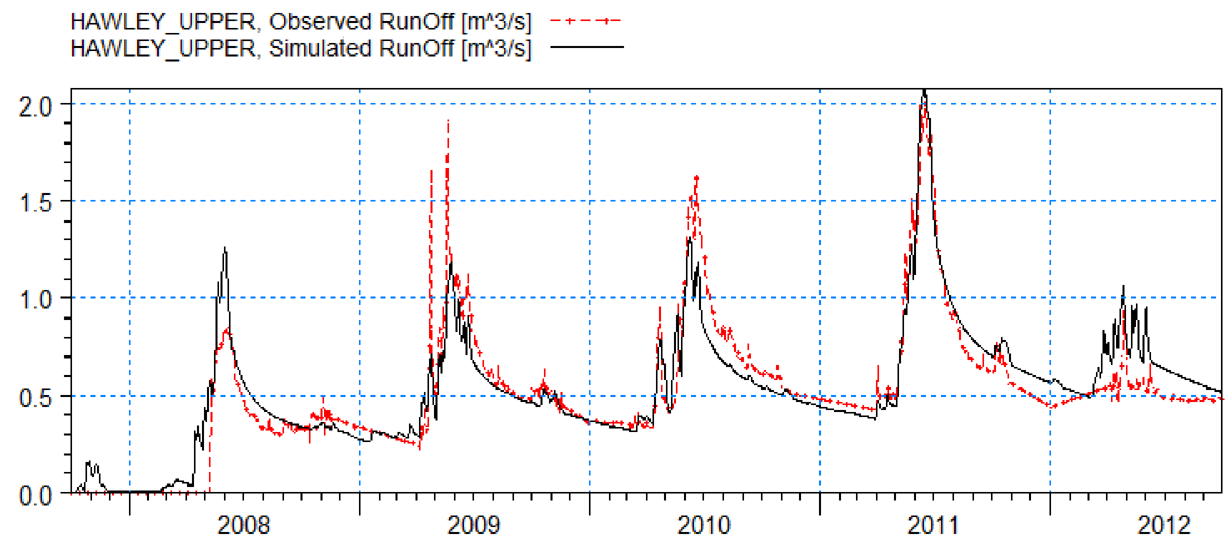


Figure 35. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Bohannon Creek Upper catchment (a headwater catchment). Note, discharge and accumulated flow are in SI units.



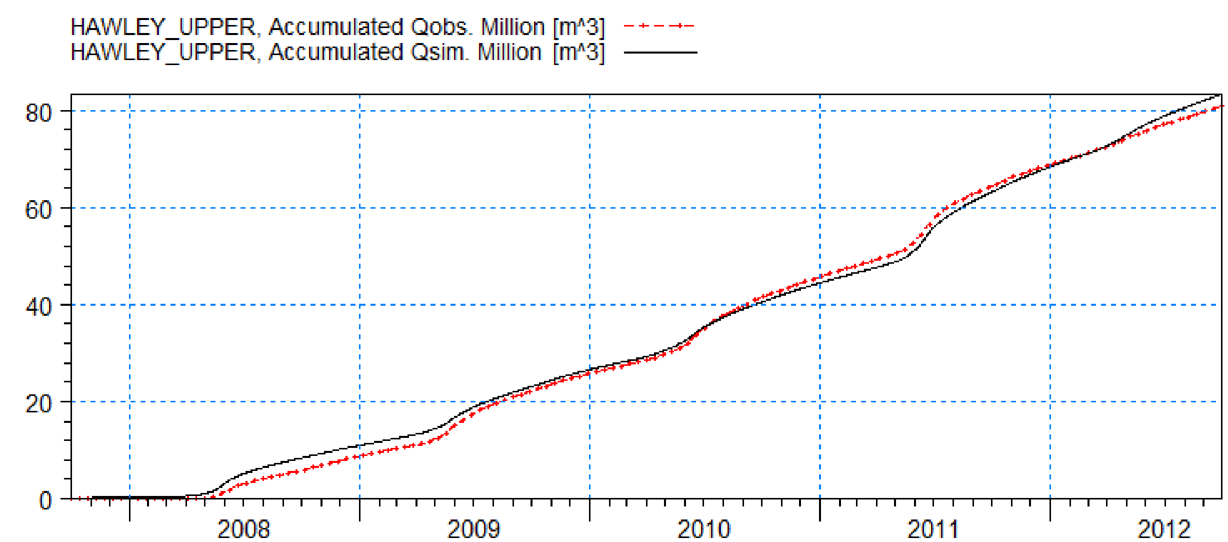
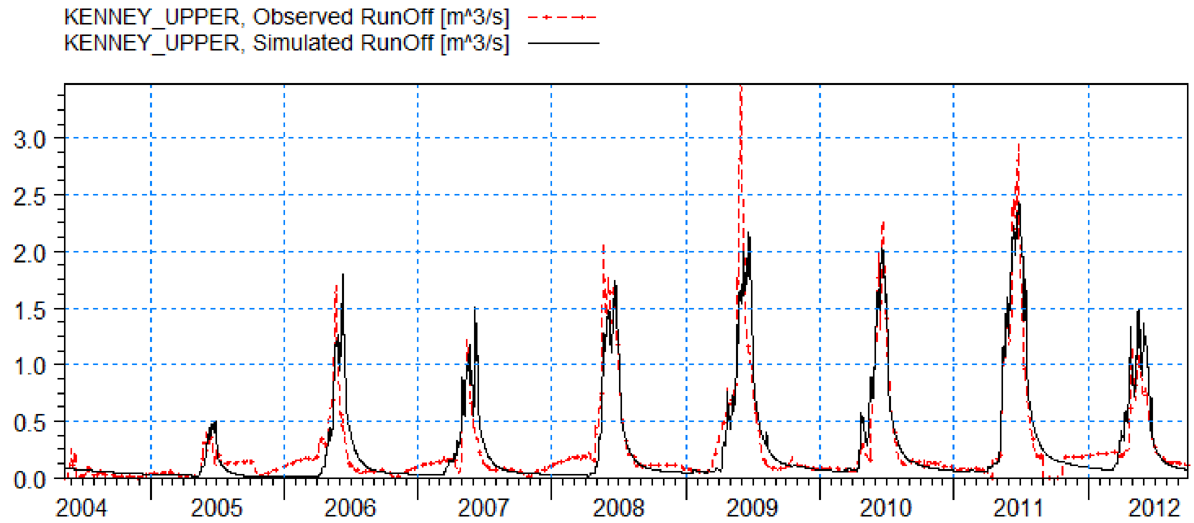


Figure 36. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Hawley Creek Upper catchment (a headwater catchment). Note, discharge and accumulated flow are in SI units.



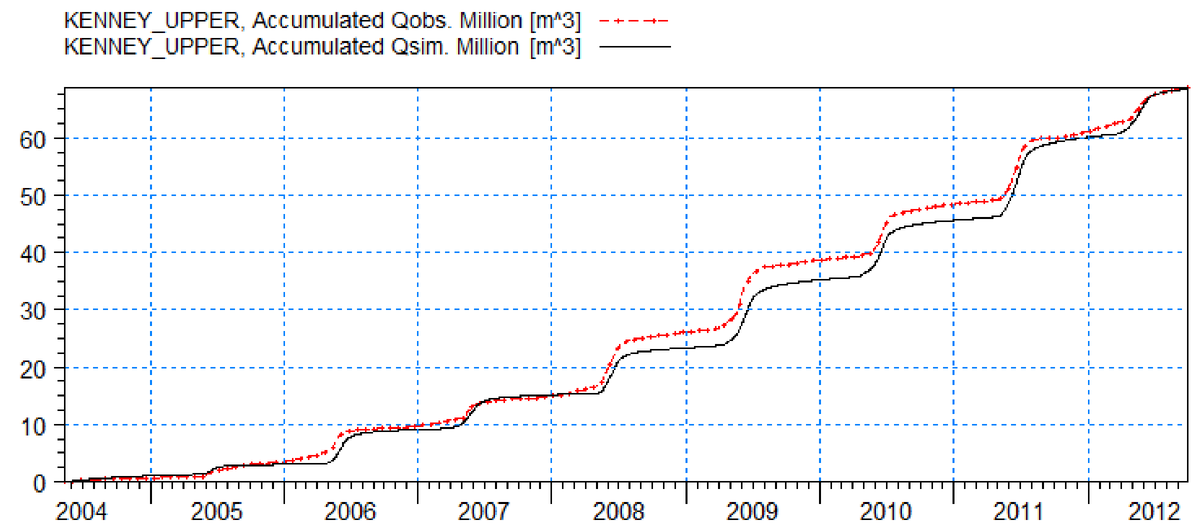
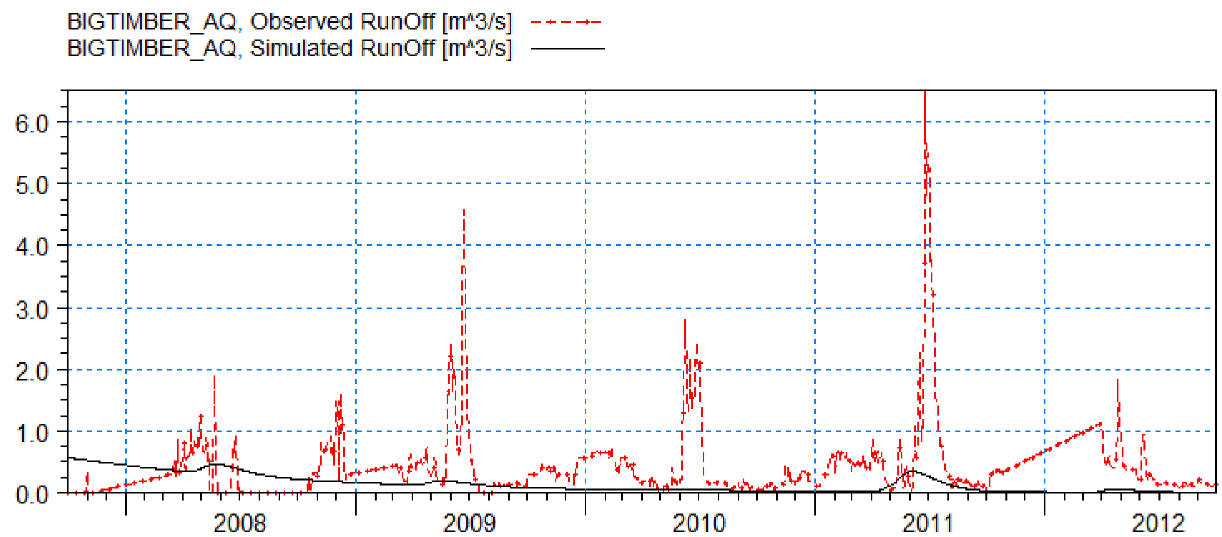


Figure 37. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Kenney Creek Upper catchment. Note, discharge and accumulated flow are in SI units.



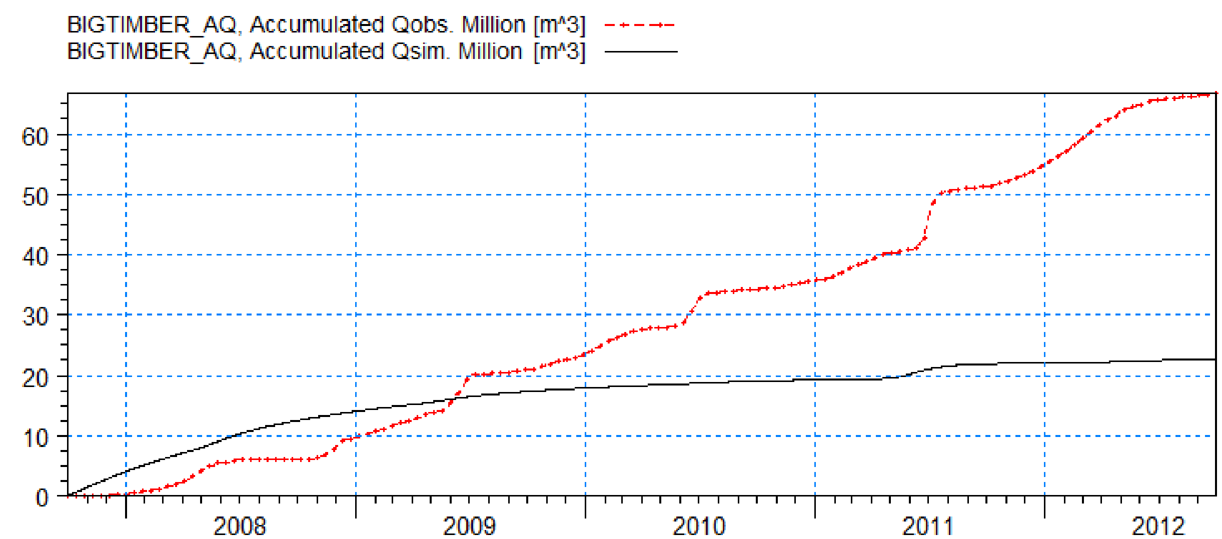
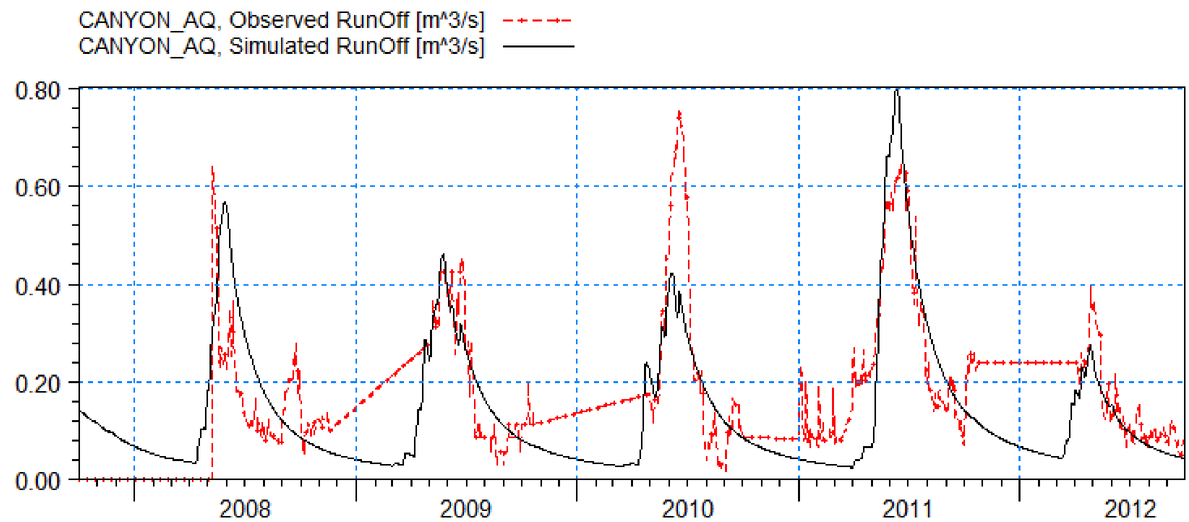


Figure 38. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Big Timber Creek Pediment catchment. Note, discharge and accumulated flow are in SI units.



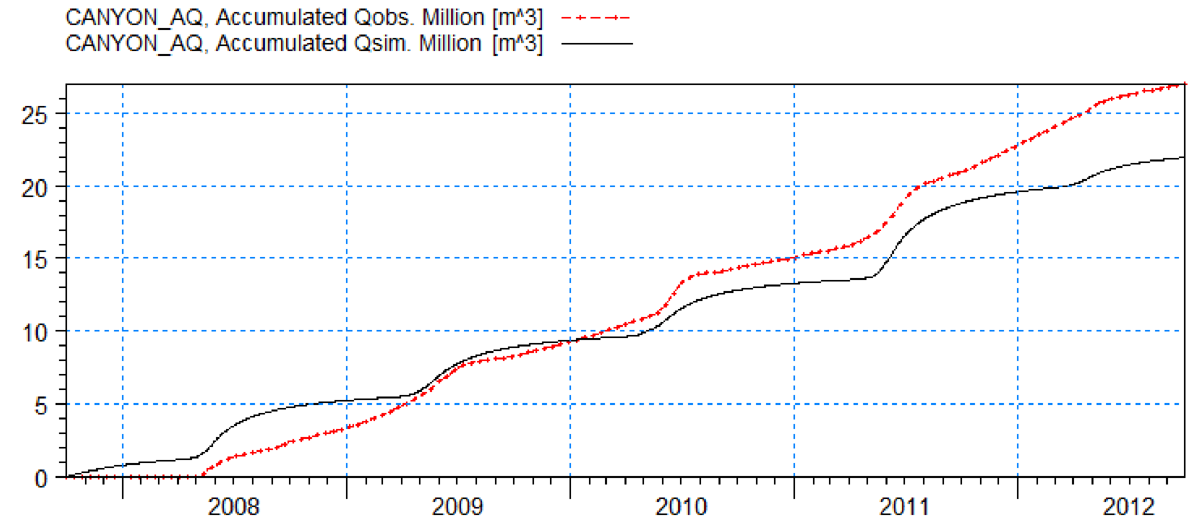


Figure 39. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Canyon Creek Pediment catchment. Note, discharge and accumulated flow are in SI units.

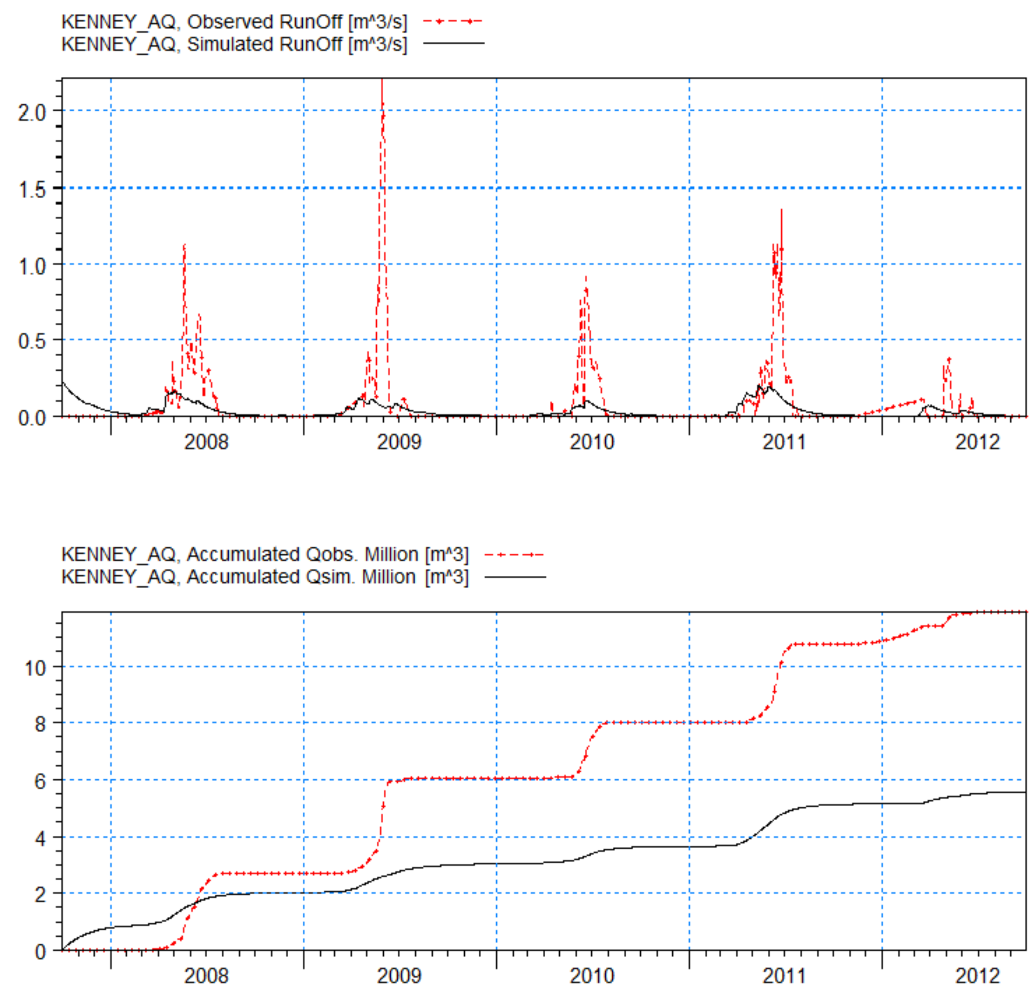


Figure 40. NAM calibration time series (top) and accumulated runoff (bottom) plot for the Kenney Creek Pediment catchment. Note, discharge and accumulated flow are in SI units.

3.6 Ungauged Basins

After satisfactory calibration of the gauged headwater catchments, the set of calibration parameters were then extrapolated to the other headwater catchments across the basin. Each ungauged headwater catchments was assigned parameters from one of the calibrated headwater catchments, based on similarities between physiological, geologic, topographic, land use, and hydrologic conditions in both catchments (Table A-2). Following parameterization, precipitation, temperature, potential ET, and Csnow time series to each headwater and pediment catchment were input and the MIKE 11 NAM simulated to produce runoff time series. The resulting runoff time series were used as catchment inflow in the LRBM.

3.7 LRBM NAM Limitations and Next Steps

Though the majority of the inflow has been adequately estimated with the current NAM models, improvements can be made to both improve and confirm the calibrations and estimations. Current limitation and the next steps include:

1. *Climate data:* Although there are several weather stations in and around the LRB, most are located at similar elevations in the upper elevation portions of the basin. There are relatively few weather stations available that represent conditions in the middle and lower elevation portions of the basin, and the Corvallis station used to represent the low-lying areas is located approximately 80 miles away and thus may not be representative of the area for which it was applied. Additionally, the use of only two meteorological stations to represent ET in the entire basin does not capture the expected degree of variation in ET within the LRB. Distributing precipitation, temperature, and ET using PRISM and METRIC data sets alleviates some of the inaccuracies associated with this spatially distributing climate, but does not account for local events such as thunderstorms in during the summer months. Furthermore, the METRIC data sets cover April through October and thus no winter data is available. Limitations in spatially interpolating climate data contribute to inaccuracies in estimating stream flow contributions from catchments throughout the LRB.
2. *Stream gage data:* Previous calibration for pediment had limited stream gage data. Use of longer periods of stream flow records should improve the inflow estimation from these catchments.
3. *Variable catchment characteristics:* Each catchment in the LRB has differing characteristics of elevation, geology, vegetation, soils, snow accumulation and melt, runoff, etc.. Extrapolation of NAM parameters from gauged to ungauged catchment requires comparison of the physiological, geologic, topographic, landuse, and hydrologic conditions in both catchments. Although effort was taken to distribute precipitation and temperature in as much detail as possible, the NAM parameters developed for the gauged catchments may not be representative of the parameters in the ungauged catchments to which they are being used. Next step: compare estimated stream time series generated by MIKE 11 NAM to regional characteristics to determine if the runoff values are realistic.
4. *Antecedent conditions:* Initial conditions of the ungagged catchments are unknown. While snow accumulation and U/Umax are likely 0, L/Lmax and BF (baseflow) are likely not equal to 0. These values can be checked by extracting the value on October 1st for subsequent years of the simulation.
5. *Absence of valley catchments:* Attempts were made to develop NAM models for the valley catchments. However, given the complexity of the diversion operations, groundwater/surface water interaction, and inflow from smaller tributaries not accounted for in the model, developing a representative hydrograph for calibration was deemed unrealistic. Thus, reach gains were used at these locations that account for the contributions from precipitation.

4 SCENARIOS

To demonstrate how the LRBM can be used to simulate projects and operational changes, two scenarios were modeled. The first involved the changes to Hawley Creek currently under construction and the second compared 2009 and 2014 conditions. The following text describes the modifications and accompanying results.

4.1 Scenario 1 – Hawley Creek

According to Daniel Bertram (USMWP), diversions along Hawley Creek are being converted to pipelines which will reduce diversion rates by H-3 (15.7 => 10.4 cfs), H-2 (5.5 => 4 cfs), and H-1 (5.7 => 3 cfs). The baseline LRBM was modified to simulate the installation of pipelines. Figure 41 illustrates the reduction in flows for each diversion and Figure 42 shows the simulation results. The results indicate that with the modification the Hawley Creek reach below H-3 gains 5.7 cfs. The Hawley Creek reach below Hawley-2 gains 4 cfs with an increase in the base flow to 5 cfs during the middle of the summer. Finally, Hawley Creek below H-1, having contributions from upstream runoff as well as H-2 return flows, is increased by up to 5.7 cfs. In the pre-project conditions, this reach nearly dries up in water year 2009 and fully dries up in water year 2010. With the project in place, it is projected that at least 3.6 cfs remains in the creek during the dry summer months.

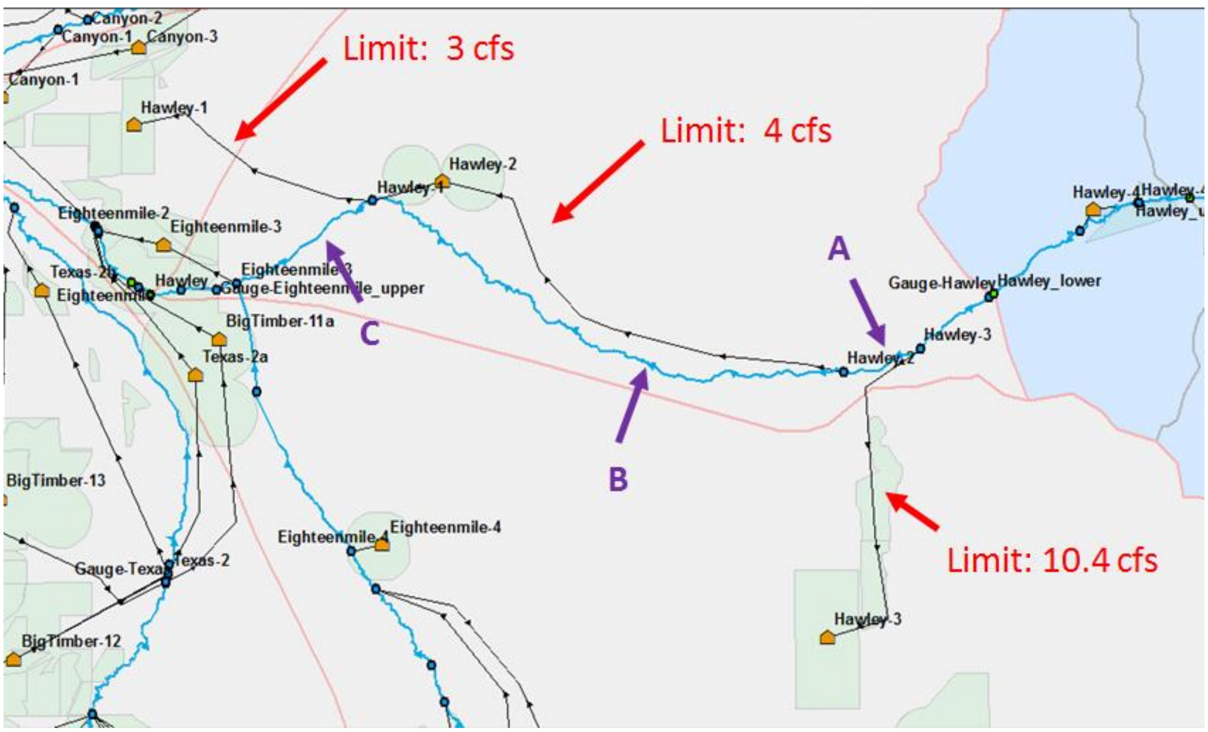


Figure 41. Modifications to Hawley Creek LRBM. Red arrows illustrate the proposed flow and purple arrows identify the location of the graphs in Figure 42.

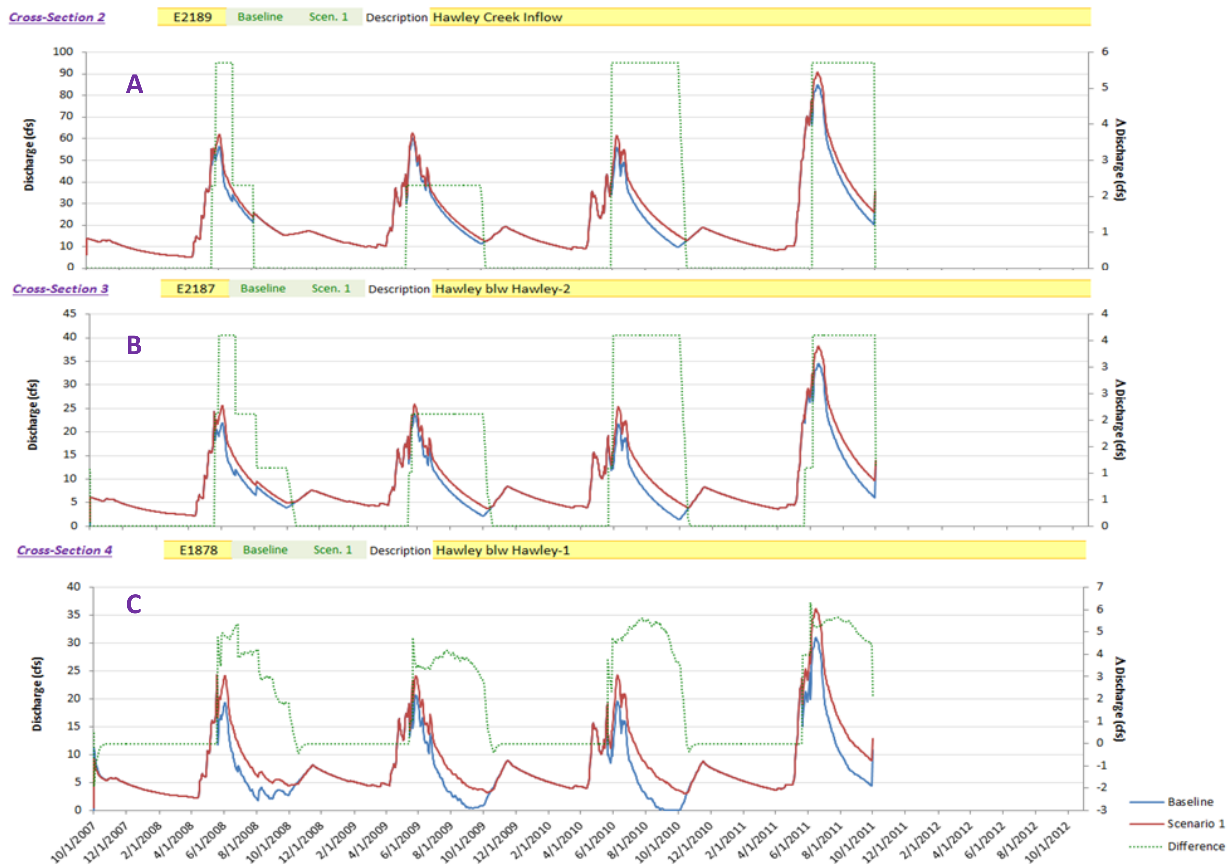


Figure 42. Comparison of stream discharge long Hawley Creek. Blue lines represents creek discharges for baseline conditions, red lines represents creek discharges following project implementation, and green line represents the change in creek discharge following the project. The locations of each time series are shown on Figure 41.

4.2 Scenario 2 – 2009 and 2014 Conditions

From 2009 to 2014, several large restoration and flow augmentation projects were implemented in the upper Lemhi River and its tributaries. This scenario involved altering the baseline LRBM in accordance with the document "Summary of Flow Restoration Projects on the Lemhi River 2007-2012" by Aurele LaMontagne (2012) and with the assistance of Daniel Bertram and Allen Bradbury (USMWP). The modifications included changes to Hawley Creek Canyon Creek, Big Timber Creek, Big Springs, Little Springs, and diversions from the Lemhi River. Modifications to the baseline LRBM are presented in Appendix B, Table B-1. Results from the simulations are presented as monthly average discharges for June through September (Appendix B, Figure B-1). The results indicate that the flow augmentation in Hawley Creek persist through the confluence with Eighteenmile Creek and down the Lemhi River for all months. Furthermore, Lemhi River discharges are further augmented with project work on Canyon and Big Timber Creeks as observed by the increasing gap between the 2009 and 2014 conditions.

5 SUPPORTING MS EXCEL FILES AND WORK FLOW

5.1 MODELING SCENARIOS WORK FLOW

The objective of the modeling is to determine the effects of water management in various hydrologic conditions given a specific set of operational and water use conditions. Once the model is established to the level of satisfaction where it can address the question being posed given the data quality, then scenarios can be simulated to predict impacts of different water management strategies. For the NAM and LRBM, the general workflow of a scenario is changing climate or water supply and/or changing water use or operation, running a simulation, then reporting the results (Figure 43). To represent a change in climate in (A in Figure 43), using the rainfall-runoff model generate runoff using either historic or synthetic long-term precipitation, potential evapotranspiration, and temperature (if snow is of concern). Next import the long-term inflow time series into the LRBM (B in Figure 43). To represent changes in water use or irrigation practices, input an annual time series representing the water demand and return flow fraction for the POU (C in Figure 43). Once input time series have been updated, simulate the hydrologic model over the period of generated inflows (D in Figure 43) and extract the time series results for each relevant node, branch, and catchment from the simulation (E in Figure 43). Finally, convert the result time series into graphical and statistical results relevant for evaluating a scenario (F in Figure 43). To aid in this process, a series of MS EXCEL files have been developed that are described in Section 5.2.

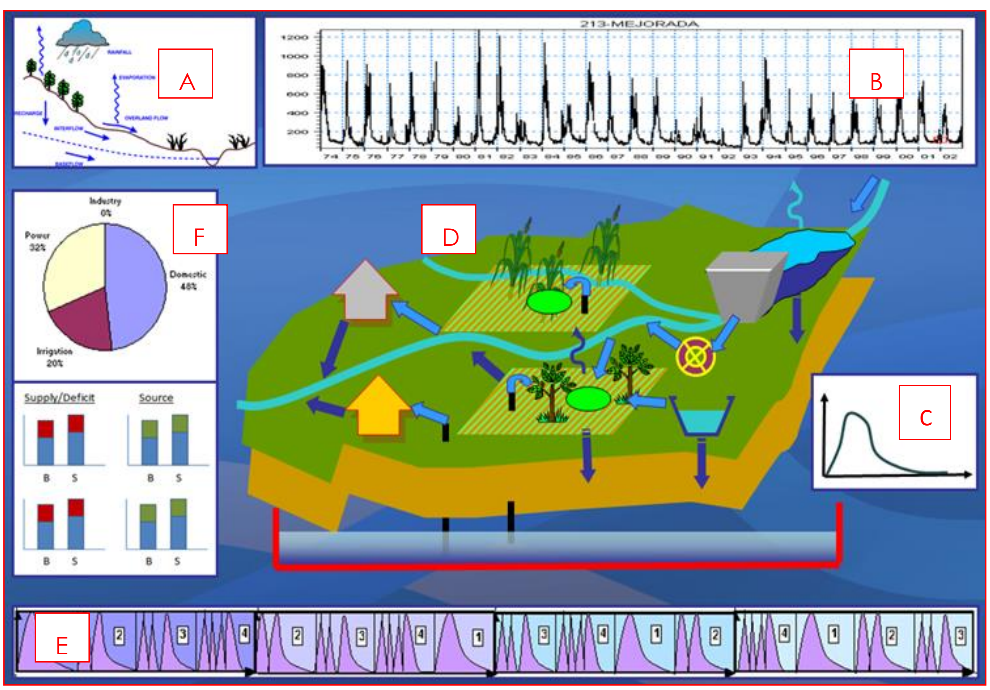


Figure 43. General computational flow of modeling using a river basin model. Clockwise starting in the upper left corner: A. develop a rainfall-runoff model to predict inflow, B. use long-term precipitation record to generate historic inflow from the rainfall-runoff model, C. input an annual time series for water user demands and reservoir rules, D. simulate the hydrologic model for the historic inflow, E. time series for each node and branch are generated, and F. convert the long-term result time series into statistics.

5.2 SUPPORTING MS EXCEL FILES

To expedite input/output and calibration of the LRBM, a series of MS EXCEL files were developed that support the modeling effort. Though simulations can largely be run within MIKE BASIN, the MS EXCEL files provide a means of organizing and transferring data that increase workflow, reduce potential errors, and provide a means of documenting input. Table 9 provides a description of the MS EXCEL files in Appendix C, Figure C-1.

Table 9. MS EXCEL Files supporting the LRBM. Numbers correspond to the numbers in Appendix C, Figure C-1.

File Type	Description
1. Stage-Discharge Conversion	Formerly, the IDWR database contained the water stage in the ditch throughout the irrigation season. To gap fill the results and convert them to a discharge time series for import to the Water User Input File. Macros assist in importing data gap filling, and exporting the formatted and updated time series. This tool is now unnecessary as IDWR reports the diversion rates as discharge.
2. Water User Input File	For each water user node in the LRBM, this file lists the input water demand time series, return flow fractions time series, water rights, irrigated area, irrigation method, crops grown, and high water capacity. Macros are used to compute the daily return flow fractions based on the area, crops, and irrigation method along with the reference ET. Macros are used to automatically load all the DFS0 files associated with each water user node. Files can be saved to document scenario conditions.
3. Water User Deep Return Flow File	For all water users employing the deep return fraction, this file creates the return flow for each tributary catchment. Macros retrieve the return flow fraction from the Water User Input File and export them to the appropriate reach gain DFS0.
4. NAM Files	See description in Section 3
5. Catchment Input File	Extracts time series from NAM results files and imports into the DFS0 files supporting catchment. Macros are used for both processes. In addition, runoff time series can be compared to USGS Stream Stats results.
6. LRBM	See description in Section 2
7. Calibration, Reach Gain Computations	Imports LRBM results for direct comparison with stream gage records. To support calibration, has the ability to run the LRBM repeatedly with randomly changing the return flow lag factors to determine the best values. Once calibrated, computes and loads the reach gain time series to DFS0 files input files supporting the LRBM.
8. Seepage Run Comparison	Imports LRBM results for direct comparison with historical seepage runs in the LRB for use in model calibration. Simulations results can be viewed to determine if the LRBM is correctly characterizing the loss/gain of the stream network (Section 2.2.2). *Seepage Run Excel Sheet Overview.docx* provides supporting documentation for use of the spreadsheet.
9. Scenario Templates	Imports LRBM results for a customized result template. Default is comparison of stream flow from two simulations at four different locations.

6 CONCLUSIONS

Over the past 15 years, stream restoration and reconnection projects to improve salmonid habitat have been constructed throughout the LRB. Needed is a tool to help the USMWP, federal and state agencies, and local stakeholders to understand the impacts of these and future projects. Since 2003, IDWR has been developing the LRBM to simulate flows and irrigation activities throughout the LRB. The document summarizes the recent efforts by CCI and IDWR to accelerate the LRBM development so that it can be used to evaluate the restoration projects.

The LRBM represents stream flow in the Lemhi River and 26 tributaries. To represent irrigation use in the basin, 322 water user nodes are used to representing PODs and POUs. Much work has been put into to accurately representing the water diversions and water rights in the basin. For each irrigation scheme, water rights, crop type, irrigation method, and irrigated area have been assessed and used to compute the consumption of irrigation water. Location as well as the time and quantity of return flows have been determined for all water user nodes. The linear reservoir method in MIKE BASIN as well as the ARF method computed by CH2M Hill (2014) was used to simulate return flows. Results from this effort depict the return flows from irrigation practices throughout the basin.

Eighty-two catchments represent inflow to the LRBM. DHI's rainfall-runoff model, NAM, was implemented to estimate runoff for 82 catchments represented in the LRBM. Precipitation and temperature, inputs to the NAM model, were extrapolated across the basin from weather station data and PRISM data using the PRISM tool. A similar exercise using the PRISM tool was performed for ET using weather stations data and the METRIC surfaces. The results were individual precipitation, temperature, and ET time series for each of the 82 catchments. Calibration was performed on 6 headwater catchments and 3 pediment catchments. The calibration resulted in a good visual fit and a quantitatively good fit between the simulated and observed discharges for the 6 headwater catchments and unacceptable on the pediment surface catchments. For acceptable calibrations in the headwater catchments, NAM parameters were applied to ungauged headwater catchments of similar characteristics. For the pediment catchments, further work is required to improve the calibration before applying parameters to ungauged pediment catchments.

Calibration of the LRBM was performed at 22 gages around the LRB. The result is a calibrated model with variable zones of accuracy. In general, upstream of the headwater gages, model accuracy is largely a function of the accuracy of rainfall-runoff estimates and diversion demand time series. Downstream of gages, the model is more accurate as reach gains have been applied to account for elements not explicitly modeled. The accuracy decreases with downstream distance from the gage. Comparison with the August 2014 Lemhi River seepage run showed good agreement between measured and simulated flows with the exceptions of reaches where uncalibrated rainfall-runoff estimates contribute to inflows. To demonstrate its applicability, the calibrated baseline model was altered to simulate 2009 and 2014 conditions in the basin.

The result of this effort is a LRBM that can be used to simulation the effects of current and proposed projects. With upkeep, the model will continue to be a valuable tool for understanding the hydrologic conditions throughout the LRB.

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APPENDIX A. LARGE TABLES

Table A-1. Catchment in the LRBM and the corresponding variables. Description of each variable follows the table.

		Demand Time Series Data Source[DTS]							*Consumption Rate Factors*[CRF]					*Ditch Capacity*[DC]		*Lag Time*[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
A-10	ND	WR	WR	WR	WR	WR	Data	Data	0.3	100%	13.3	100%	0%	WR	0.27	Linear Res.	2
A-11	ND	WR	WR	WR	WR	WR	Data	Data	1.4	100%	24.0	100%	0%	WR	1.4	Linear Res.	3
A-12	ND	WR	WR	WR	WR	WR	Data	Data	0.4	100%	18.4	100%	0%	WR	0.37	Linear Res.	3
A-2	ND	WR	WR	WR	WR	WR	Data	Data	4.5	15%	240.1	100%	100%	WR	4.49	Linear Res.	7
A-3	ND	WR	WR	WR	WR	WR	Data	Data	2.0	0%	64.6	0%	100%	WR	2	Linear Res.	10
A-4	ND	WR	WR	WR	WR	WR	Data	Data	4.3	100%	76.0	100%	0%	WR	4.27	Analytic	
A-7	ND	WR	WR	WR	WR	WR	Data	Data	0.5	100%	22.5	100%	0%	WR	0.49	Analytic	
A-8	ND	WR	WR	WR	WR	WR	Data	Data	1.9	0%	72.9	0%	80%	WR	1.9	Analytic	
A-9	ND	WR	WR	WR	WR	WR	Data	Data	0.6	100%	19.0	100%	0%	WR	0.55	Linear Res.	3
AC-1	ND	WR	WR	WR	WR	WR	WR	WR	0.1	100%	4.6	100%	0%	WR	0.1	Linear Res.	2
AC-2	ND	WR	WR	WR	WR	WR	WR	WR	0.3	100%	13.0	100%	0%	WR	0.25	Linear Res.	2
AS-1	ND	WR	WR	WR	WR	WR	WR	WR	0.5	100%	21.0	100%	0%	WR	0.54	Linear Res.	5
AW-1	ND	WR	WR	WR	WR	WR	WR	WR	0.2	0%	10.0	0%	100%	WR	0.2	Linear Res.	4
B-1	ND	WR	WR	WR	WR	WR	WR	WR	1.4	15%	55.1	100%	85%	WR	1.35	Linear Res.	2
B-2	ND	WR	WR	WR	WR	WR	WR	WR	0.7	100%	36.5	100%	0%	WR	0.74	Linear Res.	2
B-3	ND	WR	WR	WR	WR	WR	WR	WR	2.3	100%	90.0	100%	0%	WR	2.33	Linear Res.	2
B-4	ND	WR	WR	WR	WR	WR	WR	WR	3.2	100%	82.5	100%	0%	WR	3.22	Linear Res.	6
B-5	ND	WR	WR	WR	WR	WR	WR	WR	22.2	100%	741.7	100%	0%	WR	22.2	Linear Res.	4
Basin-1	ND	WR	WR	WR	WR	WR	WR	WR	7.2	100%	338.0	100%		WR	7.2	Linear Res.	5
Be-1	ND	WR	WR	WR	WR	WR	WR	WR	2.9	20%	120.3	100%	100%	WR	2.94	Linear Res.	5
Be-2	ND	WR	WR	WR	WR	WR	WR	WR	1.0	25%	21.0	100%	100%	WR	1	Linear Res.	2
BigEightmile-1	ND	WR	WR	WR	WR	WR	WR	WR	1.0	100%	47.6	100%		DR	1	Analytic	
BigEightmile-10	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	#N/A	100%		WR	0	Linear Res.	5
BigEightmile-11	ND	Data	Data	Data	Data	Data	Data	Data	11.7	0%	201.0	0%	0%	DR	11.73	Linear Res.	10

		Demand Time Series Data Source[DTS]							*Consumption Rate Factors*[CRF]					*Ditch Capacity*[DC]		*Lag Time*[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
BigEightmile-13	ND	Data	Data	Data	Data	ND	Data	Data	17.7	100%	529.0	100%		DR	17.7	Analytic	
BigEightmile-14	ND	Data	Data	Data	Data	Data	Data	WR	18.4	0%	716.3	0%	0%	DR	18.44	Analytic	
BigEightmile-15	ND	Data	Data	Data	Data	ND	Data	Data	5.9	100%	18.0	100%		DR	5.85	Linear Res.	3
BigEightmile-2	ND	Data	Data	Data	Data	Data	Data	Data	25.0	100%	263.5	100%		DR	25	Analytic	
BigEightmile-3	ND	Data	Data	Data	Data	Data	WR	Data	138.0	0%	59.0	0%	0%	DR	138	Analytic	
BigEightmile-4	ND	Data	Data	Data	Data	Data	Data	Data	3.3	0%	153.2	0%	0%	DR	3.3	Analytic	
BigEightmile-5	ND	Data	Data	Data	Data	Data	Data	Data	15.3	0%	673.7	0%	0%	DR	15.34	Analytic	
BigEightmile-6	ND	Data	Data	Data	Data	Data	Data	Data	10.9	100%	72.0	100%		DR	10.86	Linear Res.	5
BigEightmile-7a	ND	Data	Data	Data	Data	Data	Data	Data	22.1	0%	762.6	0%	0%	DR	22.06	Analytic	
BigEightmile-7b	ND	ND	ND	ND	ND	ND	WR	Data	8.3	100%	149.4	100%		DR	8.28	Analytic	
BigEightmile-8	ND	Data	Data	Data	Data	Data	Data	Data	33.0	0%	219.0	0%	0%	DR	32.99	Analytic	
BigEightmile-9&12	ND	Data	Data	Data	Data	Data	Data	Data	18.1	0%	#N/A	0%	0%	DR	18.08	Analytic	
BigSprings-1a	13304275	Data	WR	Data	Data	Data	Data	Data	6.7	100%	416.0	100%		DR	6.74	Linear Res.	4
BigSprings-1b	13304275	Data	WR	Data	Data	Data	Data	Data	1.7	0%	59.0	0%	0%	WR	1.7	Linear Res.	10
BigSprings-2	13304270	Data	WR	Data	Data	Data	Data	Data	7.4	100%	40.0	0%		DR	7.4	Linear Res.	1.5
BigSprings-3	13304245	Data	WR	Data	Data	Data	Data	Data	9.7	100%	46.0	100%		DR	9.7	Linear Res.	5
BigSprings-4a	13304235	Data	WR	Data	Data	Data	Data	Data	4.0	100%	22.0	75%		DR	4.01	Linear Res.	3
BigSprings-4b	13304235	ND	WR	Data	Data	Data	Data	Data	4.0	100%	27.0	100%		DR	4	Linear Res.	3
BigSprings-5	13304220	Data	WR	Data	Data	Data	Data	Data	10.5	25%	152.2	100%	100%	DR	10.5	Linear Res.	15
BigSprings-6	13304195	Data	WR	Data	Data	Data	Data	Data	8.5	100%	185.0	100%		DR	8.5	Linear Res.	3
BigTimber-1	ND	WR	WR	WR	WR	WR	WR	WR	1.0	100%	40.0	100%		DR	1	Linear Res.	3
BigTimber-10	ND	Data	Data	Data	Data	Data	Data	Data	13.1	100%	316.0	0%		DR	13.1	Analytic	
BigTimber-11a	ND	Data	WR	Data	WR	WR	WR	WR	6.2	0%	209.0	0%	0%	DR	6.24	Analytic	
BigTimber-11b	ND	Data	Data	Data	Data	Data	Data	Data	0.2	100%	8.0	100%		WR	0.16	Linear Res.	2
BigTimber-12	ND	Data	Data	Data	Data	Data	Data	Data	18.6	0%	766.1	0%	0%	WR	18.57	Analytic	
BigTimber-13	ND	Data	Data	Data	Data	Data	Data	Data	38.0	0%	924.5	0%	0%	DR	38	Analytic	
BigTimber-14	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	25.0	100%		DR	0	Linear Res.	2
BigTimber-15	ND	Data	Data	Data	Data	Data	Data	Data	13.4	0%	667.1	0%	0%	DR	13.36	Analytic	
BigTimber-16	ND	Data	Data	Data	Data	Data	Data	Data	2.5	100%	143.7	100%		DR	2.48	Linear Res.	5

		Demand Time Series Data Source[DTS]							*Consumption Rate Factors*[CRF]					*Ditch Capacity*[DC]		*Lag Time*[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
BigTimber-2	ND	Data	Data	WR	WR	ND	ND	ND	21.0	100%	124.1	100%		DR	21	Linear Res.	3
BigTimber-4	ND	ND	Data	Data	Data	Data	ND	ND	0.5	100%	25.0	100%		WR	0.5	Linear Res.	8
BigTimber-5	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	3.6	100%		DR	0	Linear Res.	5
BigTimber-6	ND	Data	Data	Data	Data	Data	Data	Data	2.0	100%	69.0	100%		WR	2	Linear Res.	4
BigTimber-7	ND	Data	Data	Data	Data	Data	Data	Data	3.7	100%	239.0	100%		WR	3.72	Analytic	
BigTimber-8a	ND	Data	Data	Data	Data	Data	Data	Data	7.3	100%	216.4	0%		DR	7.28	Analytic	
BigTimber-8b	ND	Data	Data	Data	Data	Data	ND	Data	0.3	100%	7.0	100%		WR	0.28	Linear Res.	4
BigTimber-9	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	160.0	100%		DR	0	Analytic	
Boh-10	ND	Data	WR	Data	Data	Data	WR	WR	1.6	0%	53.6	100%	0%	WR	1.6	Linear Res.	20
Boh-12	ND	Data	Data	Data	Data	Data	Data	Data	1.4	100%	51.7	100%	0%	WR	1.4	Linear Res.	20
Boh-13	ND	Data	WR	WR	Data	Data	WR	WR	1.9	0%	116.8	0%	0%	WR	1.9	Linear Res.	8
Boh-3	ND	Data	Data	Data	Data	Data	Data	Data	14.1	35%	475.0	100%	25%	Screen	12.94	Analytic	
Boh-4	ND	Data	Data	Data	Data	Data	Data	Data	5.8	80%	129.0	100%	10%	Screen	9.18	Analytic	
Boh-5	ND	Data	Data	Data	Data	Data	Data	Data	4.0	15%	174.0	100%	80%	Screen	6.12	Analytic	
Boh-6	ND	Data	Data	Data	Data	Data	Data	Data	6.7	67%	258.6	100%	0%	Screen	9.24	Analytic	
Boh-7	ND	Data	Data	Data	Data	Data	Data	Data	0.9	100%	28.1	100%	0%	WR	0.9	Linear Res.	5
Boh-9	ND	Data	Data	Data	Data	Data	Data	Data	12.7	25%	693.5	100%	100%	Screen	8	Linear Res.	20
Canyon-1	ND	WR	WR	Data	Data	WR	WR	Data	0.5	0%	51.1	0%	0%	DR	0.5	Linear Res.	5
Canyon-2	ND	WR	WR	Data	Data	WR	WR	Data	5.5	0%	228.2	0%	0%	WR	5.5	Linear Res.	7
Canyon-3	ND	Data	Data	Data	Data	WR	Data	Data	6.8	0%	250.3	0%	0%	WR	6.78	Analytic	
Chippie-1	ND	WR	WR	WR	WR	WR	WR	WR	0.6	100%	30.8	100%		WR	0.62	Linear Res.	2
Cruikshank-1	13305016	WR	WR	WR	WR	WR	WR	WR	1.9	100%	90.0	100%		WR	1.9	Linear Res.	2
Cruikshank-2	ND	Data	Data	Data	Data	Data	Data	Data	1.0	100%	22.0	100%		WR	0.96	Linear Res.	2
Deer-1	ND	WR	WR	WR	WR	WR	WR	WR	4.6	100%	155.2	100%		WR	4.59	Linear Res.	5
DevilsCanyon-1	ND	Data	Data	Data	Data	Data	Data	Data	4.7	100%	73.0	100%		DR	4.69	Linear Res.	3
Divide-1	ND	WR	WR	WR	WR	WR	WR	WR	0.7	100%	22.0	100%		WR	0.7	Linear Res.	10
EFHC-1	ND	Data	Data	Data	Data	Data	Data	Data	10.5	100%	250.8	90%	0%	DR	10.5	Linear Res.	3
EFW-1	ND	WR	WR	WR	WR	WR	WR	WR	5.5	50%	232.0	100%	65%	WR	5.52	Linear Res.	20
Eighteenmile-1	ND	ND	ND	ND	ND	ND	ND	ND	0.0	0%	1.0	0%	100%	WR	0	Linear Res.	5

		Demand Time Series Data Source[DTS]							*Consumption Rate Factors*[CRF]					*Ditch Capacity*[DC]		*Lag Time*[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
Eighteenmile-10	ND	WR	WR	WR	WR	WR	WR	Data	8.7	100%	539.9	100%		WR	8.73	Linear Res.	5
Eighteenmile-11	13305102	WR	WR	WR	WR	WR	WR	Data	1.2	100%	55.0	100%		WR	1.2	Linear Res.	10
Eighteenmile-12a	13305103	WR	WR	WR	WR	WR	WR	Data	4.9	100%	246.0	100%		WR	4.91	Linear Res.	3
Eighteenmile-12b	ND	WR	WR	WR	WR	WR	WR	Data	0.8	100%	41.0	100%		WR	0.82	Linear Res.	10
Eighteenmile-13	ND	WR	WR	WR	WR	WR	WR	Data	4.5	100%	316.0	100%		WR	4.5	Linear Res.	30
Eighteenmile-14	ND	WR	WR	WR	WR	WR	WR	Data	1.2	100%	55.0	100%		WR	1.2	Linear Res.	10
Eighteenmile-15	ND	WR	WR	WR	WR	WR	WR	Data	1.8	100%	71.0	100%		WR	1.76	Linear Res.	10
Eighteenmile-2	ND	WR	WR	WR	WR	WR	WR	WR	3.2	0%	573.3	0%	100%	DR	3.16	Linear Res.	5
Eighteenmile-3	ND	WR	WR	WR	WR	WR	WR	Data	2.3	0%	115.0	0%	100%	WR	2.3	Linear Res.	15
Eighteenmile-4	ND	WR	WR	WR	WR	WR	WR	Data	3.6	0%	153.0	0%	100%	WR	3.6	Linear Res.	15
Eighteenmile-5a	ND	WR	WR	WR	WR	WR	WR	Data	2.8	0%	135.6	0%	100%	WR	2.76	Linear Res.	8
Eighteenmile-5b	ND	WR	WR	WR	WR	WR	WR	Data	3.9	0%	100.3	0%	100%	WR	3.9	Linear Res.	20
Eighteenmile-6	ND	WR	WR	WR	WR	WR	WR	Data	5.0	100%	58.0	100%		DR	5	Linear Res.	10
Eighteenmile-7	ND	WR	WR	WR	WR	WR	WR	Data	6.5	100%	530.0	100%		WR	6.47	Linear Res.	10
Eighteenmile-8	ND	WR	WR	WR	WR	WR	WR	Data	4.0	0%	236.0	0%	100%	DR	4	Linear Res.	15
Eighteenmile-9	ND	WR	WR	WR	WR	WR	WR	Data	1.3	100%	64.0	100%		WR	1.28	Linear Res.	5
Everson-1	ND	Data	Data	Data	Data	ND	WR	Data	15.4	0%	756.0	0%	0%	DR	15.38	Analytic	
Everson-2	ND	WR	Data	Data	Data	WR	WR	Data	6.0	0%	93.0	0%	0%	DR	6	Analytic	
Everson-3	ND	Data	Data	Data	Data	Data	WR	Data	3.0	100%	88.0	100%		DR	3	Analytic	
G-1	ND	Data	Data	Data	Data	Data	Data	Data	6.0	100%	52.0	100%	0%	DR	6	Analytic	
G-2	ND	Data	Data	Data	Data	Data	Data	Data	15.6	0%	188.1	0%	100%	DR	15.6	Analytic	
G-3	ND	Data	Data	Data	Data	Data	Data	Data	9.5	0%	219.1	0%	50%	DR	9.52993	Analytic	
G-4	ND	Data	Data	Data	Data	Data	Data	Data	8.0	85%	191.9	40%	100%	DR	8	Analytic	
G-6	ND	Data	Data	Data	Data	Data	Data	Data	12.6	80%	244.4	80%	100%	DR	12.62	Linear Res.	10
G-9	ND	Data	Data	Data	Data	Data	Data	Data	6.5	0%	67.2	0%	100%	DR	6.47007	Linear Res.	10
Ga-1	ND	WR	WR	WR	WR	WR	WR	WR	1.6	80%	50.0	100%	100%	WR	1.6	Linear Res.	10
H-1	ND	WR	WR	WR	WR	WR	WR	WR	2.0	100%	31.5	100%	0%	WR	2	Linear Res.	3
H-2	ND	WR	WR	WR	WR	WR	WR	WR	2.1	100%	177.0	100%	0%	WR	2.1	Linear Res.	4
H-3	ND	WR	WR	WR	WR	WR	WR	WR	5.1	20%	178.5	100%	100%	WR	5.1	Linear Res.	7

		Demand Time Series Data Source[DTS]								Consumption Rate Factors[CRF]				Ditch Capacity[DC]		Lag Time[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
H-4	ND	WR	WR	WR	WR	WR	WR	WR	2.2	50%	90.0	100%	100%	WR	2.2	Analytic	
H-5	ND	WR	WR	WR	WR	WR	WR	WR	0.4	100%	16.9	100%	0%	WR	0.365	Linear Res.	2
Hawley-1	ND	WR	WR	WR	Data	WR	Data	Data	3.0	0%	305.3	0%	0%	DR	3	Analytic	
Hawley-2	ND	WR	WR	WR	Data	WR	WR	WR	4.0	0%	225.2	0%	0%	DR	4	Linear Res.	5
Hawley-3	ND	Data	WR	WR	Data	WR	WR	WR	15.7	0%	521.7	0%	0%	WR	15.7	Analytic	
Hawley-4	ND	Data	Data	WR	Data	Data	Data	Data	2.0	100%	61.7	100%		DR	2	Linear Res.	5
HC-1	ND	Data	Data	Data	Data	Data	Data	WR	7.0	100%	91.0	85%	0%	DR	7	Linear Res.	5
HC-10	ND	Data	Data	Data	Data	Data	Data	WR	14.9	100%	214.5	100%	0%	DR	14.9	Analytic	
HC-11	ND	Data	Data	Data	Data	Data	Data	WR	15.1	0%	894.7	0%	100%	DR	15.1	Analytic	
HC-13	ND	WR	WR	WR	WR	WR	WR	WR	25.9	10%	93.5	100%	100%	DR	25.9	Linear Res.	3
HC-3	ND	Data	Data	Data	Data	Data	Data	WR	13.4	100%	142.0	100%	0%	DR	13.4	Linear Res.	5
HC-5	ND	Data	Data	Data	Data	Data	Data	WR	7.0	100%	80.5	100%	0%	DR	7	Analytic	
HC-7	ND	Data	Data	Data	Data	Data	Data	WR	14.4	0%	141.4	0%	10%	DR	14.4	Analytic	
HC-8	ND	Data	Data	Data	Data	Data	Data	WR	8.4	50%	131.6	100%	50%	DR	8.4	Analytic	
HC-8B	ND	Data	Data	Data	Data	Data	Data	WR	3.6	0%	54.5	0%	100%	DR	3.6	Linear Res.	3
HC-9	ND	Data	Data	Data	Data	WR	Data	WR	15.1	100%	317.1	100%	0%	DR	15.1	Linear Res.	5
HoodGulch-1	ND	WR	WR	WR	WR	WR	WR	WR	1.8	100%	91.0	100%		WR	1.8	Linear Res.	5
JakesCanyon-1&2	ND	WR	WR	WR	WR	WR	WR	WR	6.0	100%	179.6	100%		DR	6	Analytic	
K-1	ND	WR	WR	WR	WR	WR	WR	WR	0.3	100%	14.8	100%	0%	WR	0.31	Linear Res.	4
K-2	13305102	WR	WR	WR	WR	WR	WR	WR	2.6	100%	112.0	100%	0%	Screen	11.09	Linear Res.	4
K-3	13305103	WR	WR	WR	WR	WR	WR	WR	3.0	30%	121.6	100%	80%	Screen	3	Analytic	
Kirt-1	ND	Data	ND	ND	ND	Data	Data	Data	4.0	100%	123.2	100%	0%	DR	4	Linear Res.	10
Kirt-2	ND	Data	Data	Data	Data	Data	Data	Data	7.2	0%	295.2	0%	50%	DR	7.2	Analytic	
Kirt-3	ND	ND	ND	ND	ND	Data	Data	Data	3.6	100%	98.6	100%	0%	DR	3.6	Analytic	
Kirt-4	ND	Data	Data	ND	ND	Data	Data	Data	13.0	100%	341.0	60%	0%	DR	13	Analytic	
Kirt-5	ND	Data	ND	ND	ND	Data	ND	ND	0.8	0%	30.5	0%	0%	DR	0.8	Analytic	
Kirt-6	ND	Data	Data	Data	Data	Data	ND	ND	27.0	100%	96.2	100%	0%	DR	27	Analytic	
L-01	ND	Data	Data	Data	Data	Data	Data	Data	6.0	100%	44.9	75%	0%	Screen	4.59	Linear Res.	5
L-02	ND	ND	Data	Data	Data	Data	Data	Data	5.0	100%	17.0	100%	0%	Screen	6.17	Linear Res.	3
L-03	ND	Data	Data	Data	Data	Data	Data	Data	33.5	35%	551.0	100%	70%	Screen	33.28	Linear Res.	4
L-03A	ND	Data	Data	Data	Data	Data	Data	Data	21.1	100%	124.0	90%	0%	Screen	22.19	Linear Res.	3

Diversion Name	IDWR Ref No.	Demand Time Series Data Source[DTS] WY 2008	WY 2009	WY 2010	WY 2011	WY 2012	WY 2013	WY 2014	Max Div. Rate	Consumption Rate Factors[CRF] %Flood	Acres	% Flood Grass	% Spr. Grass	Ditch Capacity[DC] Method	Value	Lag Time[LT] RF Delay Method	Lag Time
L-03B	13305345	Data	Data	Data	Data	Data	Data	Data	8.0	100%	68.0	100%	0%	Screen	15.3	Linear Res.	3
L-06	ND	Data	Data	Data	Data	Data	Data	Data	64.3	60%	1488.7	100%	30%	Screen	51.77	Linear Res.	3
L-07	ND	Data	Data	Data	Data	Data	Data	Data	56.8	90%	888.6	80%	50%	Screen	42.84	Linear Res.	5
L-08	ND	ND	Data	Data	Data	Data	Data	Data	5.0	100%	24.8	100%	0%	Screen	7.65	Linear Res.	2
L-08A	ND	Data	Data	Data	Data	Data	Data	Data	42.5	100%	1255.1	100%	0%	Screen	33.28	Linear Res.	5
L-09	ND	Data	Data	Data	WR	Data	Data	Data	24.7	100%	708.8	75%	0%	Screen	27.54	Analytic	
L-10	ND	Data	Data	Data	Data	Data	Data	Data	29.6	50%	874.3	75%	75%	Screen	33.28	Linear Res.	5
L-13	ND	Data	ND	Data	Data	Data	Data	Data	26.1	100%	923.4	100%	0%	Screen	27.73	Analytic	
L-14	ND	Data	Data	Data	ND	Data	ND	ND	9.0	5%	56.1	100%	90%	Screen	15.3	Linear Res.	3
L-15	ND	Data	Data	Data	Data	Data	Data	Data	12.7	100%	125.0	50%	0%	Screen	18.36	Linear Res.	3
L-17	ND	Data	Data	Data	Data	Data	Data	Data	20.0	100%	395.1	100%	0%	Screen	18.36	Linear Res.	2
L-18	ND	ND	ND	ND	ND	ND	ND	ND	0.0	100%	19.0	100%	0%	Screen	4.59	Linear Res.	2
L-19	ND	Data	Data	Data	Data	Data	Data	Data	8.9	100%	25.0	100%	0%	Screen	9.24	Linear Res.	2
L-20	ND	Data	Data	Data	Data	Data	Data	Data	28.8	100%	352.9	100%	0%	Screen	24.48	Linear Res.	4
L-21	ND	Data	Data	Data	Data	Data	Data	Data	14.7	100%	246.9	100%	0%	Screen	15.3	Linear Res.	2
L-22	ND	Data	Data	Data	Data	Data	Data	Data	27.8	100%	628.6	100%	0%	Screen	27.54	Linear Res.	4
L-23	ND	Data	Data	Data	Data	Data	Data	Data	29.8	85%	328.2	100%	70%	Screen	27.73	Linear Res.	4
L-24	ND	ND	Data	Data	ND	Data	Data	Data	6.0	75%	36.8	100%	90%	Screen	6.12	Linear Res.	4
L-25	ND	Data	Data	Data	Data	Data	Data	Data	12.5	100%	118.2	100%	0%	Screen	15.3	Linear Res.	4
L-26	ND	Data	Data	Data	Data	Data	Data	Data	6.9	85%	69.0	100%	100%	Screen	4.59	Linear Res.	3
L-27	ND	Data	Data	Data	Data	Data	Data	Data	6.3	100%	76.5	100%	0%	Screen	7.65	Linear Res.	5
L-28	ND	Data	Data	Data	Data	Data	Data	Data	12.8	100%	522.5	100%	0%	Screen	12.24	Linear Res.	6
L-29	ND	Data	Data	Data	Data	Data	Data	Data	25.8	100%	305.0	100%	0%	Screen	27.54	Linear Res.	4
L-30	ND	Data	Data	Data	Data	Data	Data	Data	41.8	100%	911.3	100%	0%	Screen	44.37	Linear Res.	4
L-30A	ND	Data	Data	Data	Data	Data	Data	Data	6.0	50%	29.1	100%	80%	Screen	7.4	Linear Res.	2
L-31	ND	Data	Data	Data	Data	Data	Data	Data	19.6	100%	267.6	100%	0%	Screen	18.36	Linear Res.	4
L-31A	ND	Data	Data	Data	Data	Data	Data	Data	25.7	50%	209.8	100%	65%	Screen	22.95	Linear Res.	4
L-31B	ND	Data	ND	ND	ND	ND	ND	ND	2.9	70%	22.4	100%	100%	DR	2.9	Linear Res.	5
L-32	ND	Data	Data	Data	Data	Data	Data	Data	18.7	100%	617.0	100%	0%	Screen	18.36	Linear Res.	4
L-33	ND	Data	Data	Data	Data	Data	Data	Data	35.1	20%	1033.9	100%	100%	Screen	27.73	Linear Res.	5
L-34	ND	Data	Data	Data	Data	Data	Data	Data	2.8	100%	36.6	100%	0%	Screen	2.3	Linear Res.	3

		Demand Time Series Data Source[DTS]								Consumption Rate Factors[CRF]				Ditch Capacity[DC]		Lag Time[LT]	
Diversion Name	IDWR Ref No.	WY 2008	WY 2009	WY 2010	WY 2011	WY 2012	WY 2013	WY 2014	Max Div. Rate	%Flood	Acres	% Flood Grass	% Spr. Grass	Method	Value	RF Delay Method	Lag Time
L-35	ND	Data	Data	Data	Data	Data	Data	Data	4.0	0%	59.1	0%	85%	Screen	3.57	Linear Res.	4
L-35A	ND	Data	Data	ND	Data	Data	Data	Data	6.0	100%	20.4	100%	0%	Screen	4.3	Linear Res.	8
L-37	ND	Data	Data	Data	Data	Data	Data	Data	9.1	100%	145.0	80%	0%	Screen	7.4	Linear Res.	10
L-38	ND	Data	Data	Data	Data	Data	Data	Data	4.0	100%	35.0	85%	0%	Screen	3.57	Linear Res.	8
L-39	ND	Data	Data	Data	Data	Data	Data	Data	5.8	100%	31.0	100%	0%	Screen	4.46	Linear Res.	3
L-40	ND	Data	Data	Data	Data	Data	Data	Data	12.8	100%	56.0	100%	0%	Screen	12.24	Linear Res.	4
L-42	ND	Data	Data	Data	Data	Data	Data	Data	29.9	100%	410.5	100%	0%	Screen	33.28	Analytic	
L-43	13304750	Data	Data	Data	Data	Data	Data	Data	4.8	100%	22.5	100%		Screen	7.4	Linear Res.	5
L-43A	13304745	Data	Data	Data	Data	Data	ND	Data	7.4	100%	29.5	100%		Screen	7.4	Linear Res.	5
L-43B	13304740	ND	Data	Data	Data	Data	Data	Data	6.5	100%	14.0	100%		Screen	7.4	Linear Res.	2
L-43C	13304735	ND	ND	ND	ND	ND	ND	ND	0.0	100%	60.8	100%		Screen	0	Linear Res.	5
L-44	13304730	Data	Data	Data	Data	Data	Data	Data	14.4	100%	38.0	100%		Screen	6.12	Linear Res.	6
L-45	13304725	Data	Data	Data	Data	Data	Data	Data	10.3	100%	42.9	100%		Screen	7.65	Linear Res.	6
L-45A	13304726	Data	Data	Data	Data	Data	Data	Data	7.8	100%	61.0	100%		Screen	7.65	Linear Res.	8
L-45B	13304720	Data	Data	Data	Data	Data	Data	Data	6.0	100%	39.0	100%		Screen	6.12	Linear Res.	3
L-45D	13304715	Data	Data	Data	Data	Data	Data	Data	39.0	100%	222.0	100%		Screen	33.28	Linear Res.	6
L-46A	13304710	Data	Data	Data	Data	Data	Data	Data	25.8	100%	452.4	100%		Screen	27.73	Linear Res.	5
L-47	13304705	Data	Data	Data	Data	Data	Data	Data	33.5	100%	169.0	50%		Screen	33.28	Linear Res.	5
L-49	13304700	Data	Data	Data	Data	Data	Data	Data	43.5	100%	292.0	50%		Screen	38.82	Linear Res.	6
L-50_LittleSprings-1	13304645	ND	ND	ND	ND	ND	ND	ND	0.0	0%	49.0	0%	0%	Screen	4.46	Linear Res.	4
L-51	13304640	Data	Data	ND	Data	Data	Data	Data	6.0	100%	39.0	100%		Screen	6.12	Linear Res.	6.2
L-51A	13304625	Data	Data	Data	Data	Data	Data	Data	4.8	100%	78.0	100%		Screen	6.12	Linear Res.	1.9
L-52_LittleSprings-3	ND	Data	Data	Data	ND	ND	ND	ND	13.2	0%	18.0	0%	100%	Screen	7.65	Linear Res.	13
L-52A	13304615	ND	ND	ND	ND	ND	ND	ND	0.0	100%	12.0	100%		Screen	2.68	Linear Res.	5.4
L-54	13304600	Data	Data	Data	Data	Data	ND	ND	4.3	100%	56.0	100%		Screen	4.59	Linear Res.	2
L-57	13304604	Data	Data	Data	Data	Data	Data	Data	6.1	100%	66.5	100%		Screen	4.59	Linear Res.	4.6
L-58	13304605	Data	Data	Data	Data	Data	Data	Data	11.0	100%	48.0	100%		Screen	9.18	Linear Res.	2
L-58A	13304320	Data	Data	Data	Data	Data	ND	ND	10.8	100%	123.8	50%		Screen	14.79	Linear Res.	4
L-58B	13304310	Data	Data	Data	Data	Data	Data	Data	15.3	100%	172.0	50%		Screen	15.3	Linear Res.	6.7
L-58C	ND	Data	Data	Data	Data	Data	Data	Data	9.2	100%	54.0	0%		Screen	12.24	Linear Res.	4.9
L-59	13304265	Data	Data	Data	Data	Data	Data	Data	8.5	100%	44.0	0%		Screen	7.65	Linear Res.	2.4

Diversion Name	IDWR Ref No.	*Demand Time Series Data Source*[DTS]							Max Div. Rate	*Consumption Rate Factors*[CRF]				*Ditch Capacity*[DC]		*Lag Time*[LT]	
		WY 2008	WY 2009	WY 2010	WY 2011	WY 2012	WY 2013	WY 2014		%Flood	Acres	% Flood Grass	% Spr. Grass	Method	Value	RF Delay Method	Lag Time
L-60	13304260	Data	Data	Data	Data	Data	Data	Data	7.9	100%	39.2	100%		Screen	7.4	Linear Res.	5.8
L-61	13304240	Data	Data	Data	Data	Data	Data	Data	13.7	100%	108.2	100%		Screen	11.09	Linear Res.	10
L-62	13304180	Data	Data	Data	Data	Data	Data	Data	8.6	100%	354.8	100%		Screen	14.79	Linear Res.	2.5
L-62A_BigTimber-2	ND	Data	Data	WR	WR	Data	WR	WR	15.5	100%	248.1	100%		Screen	2.94	Analytic	25
L-63	13303050	Data	Data	Data	Data	Data	ND	ND	16.9	40%	126.6	40%	40%	Screen	27.54	Linear Res.	4
La-1	ND	WR	WR	WR	WR	WR	WR	WR	0.3	0%	16.7	0%	100%	WR	0.34	Linear Res.	5
Lee-1	ND	ND	ND	ND	ND	ND	ND	ND	2.1	0%	0.0	0%	0%	DR	2.14	Linear Res.	10
Lee-2a	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	25.0	100%		DR	0	Linear Res.	5
Lee-2b	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	18.0	100%		DR	0	Linear Res.	5
Lee-3a	ND	Data	Data	Data	Data	Data	Data	Data	37.6	100%	278.0	100%		DR	37.6	Analytic	
Lee-3b	ND	Data	Data	Data	Data	ND	Data	Data	1.7	100%	268.0	100%		DR	1.7	Analytic	
LittleEightmile-1a	ND	WR	WR	WR	WR	WR	WR	WR	2.7	0%	124.0	0%	0%	WR	2.72	Linear Res.	5
LittleEightmile-1b	ND	WR	WR	WR	WR	WR	WR	WR	1.0	100%	38.0	0%		WR	1.01	Linear Res.	5
LittleEightmile-2	ND	WR	WR	WR	WR	WR	WR	WR	0.9	100%	19.0	0%		WR	0.85	Linear Res.	5
LittleSprings-2	ND	WR	WR	WR	WR	WR	WR	WR	0.8	100%	28.0	100%		WR	0.84	Linear Res.	3
LittleTimber-1	ND	Data	Data	Data	Data	Data	Data	Data	9.6	0%	273.0	0%	0%	DR	9.6	Linear Res.	8
LittleTimber-2	ND	Data	Data	Data	Data	WR	Data	Data	17.0	100%	513.0	0%		DR	17.04	Analytic	
LittleTimber-3	ND	Data	Data	Data	Data	Data	Data	Data	7.1	100%	182.0	0%		DR	7.11	Analytic	
LittleTimber-4	ND	Data	Data	Data	Data	Data	Data	Data	14.1	100%	617.0	100%		WR	14.1	Analytic	
LittleTimber-5	ND	Data	Data	Data	Data	Data	Data	Data	6.2	100%	161.2	100%		DR	6.2	Analytic	
Mc-1	13305016	Data	Data	Data	Data	Data	Data	Data	6.2	0%	306.0	0%	60%	WR	6.2	Analytic	
Mc-2	ND	WR	WR	WR	WR	WR	WR	WR	4.1	0%	207.0	0%	15%	WR	4.14	Analytic	
McN-1	ND	WR	WR	WR	WR	WR	WR	WR	1.29	100%	65.0	100%	0%	WR	1.29	Linear Res.	2
MFS-1	ND	WR	WR	WR	WR	WR	WR	WR	1.2	100%	65.0	30%	0%	WR	1.16	Linear Res.	5
Mill-1	ND	WR	WR	WR	WR	WR	WR	WR	3.2	0%	89.9	0%	0%	WR	3.22	Linear Res.	5
Mill-2	ND	WR	WR	WR	WR	WR	WR	WR	0.4	100%	20.0	0%		WR	0.4	Linear Res.	5
Mill-3	ND	Data	Data	Data	Data	ND	ND	Data	2.0	100%	45.0	0%		DR	2	Analytic	
Mill-4	ND	Data	Data	Data	Data	Data	Data	Data	1.2	100%	46.0	0%		WR	1.2	Analytic	
Mill-5	ND	Data	Data	Data	Data	Data	Data	Data	8.6	100%	72.0	0%		DR	8.63	Analytic	
Mill-6	ND	Data	Data	Data	Data	Data	Data	Data	48.8	100%	1582.1	100%		DR	48.83	Analytic	
NegroGreen-1	ND	WR	WR	WR	WR	WR	WR	WR	4.5	100%	122.0	100%		WR	4.51	Linear Res.	5

		Demand Time Series Data Source[DTS]								*Consumption Rate Factors*[CRF]				*Ditch Capacity*[DC]		*Lag Time*[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
Pat-1	ND	WR	WR	WR	WR	WR	WR	WR	0.7	100%	33.0	100%	0%	WR	0.65	Linear Res.	4
Pat-2	ND	Data	Data	Data	Data	Data	Data	Data	0.5	100%	15.2	90%	0%	WR	0.46	Linear Res.	5
Pat-3	ND	WR	WR	WR	WR	WR	WR	WR	5.8	15%	432.0	80%	90%	WR	5.84	Analytic	
Pat-4	ND	WR	WR	WR	WR	WR	WR	WR	1.8	40%	90.1	80%	80%	WR	1.75	Analytic	
Peterson-1	ND	WR	WR	WR	WR	WR	WR	WR	2.3	100%	90.0	100%		WR	2.3	Linear Res.	5
Peterson-2	ND	WR	WR	WR	WR	WR	WR	WR	2.8	100%	100.8	100%		DR	2.8	Analytic	
Peterson-3	ND	Data	Data	Data	Data	Data	Data	Data	0.8	100%	#N/A	100%		DR	0.81		
Pra-1	ND	WR	WR	WR	WR	WR	Data	WR	3.4	100%	60.5	100%	0%	DR	3.4	Linear Res.	8
Pra-2	ND	WR	WR	WR	WR	WR	Data	WR	3.5	100%	158.0	50%	0%	DR	3.5	Analytic	
Pra-3	ND	WR	WR	WR	WR	WR	Data	WR	1.3	50%	40.0	100%	100%	DR	1.256	Linear Res.	8
Pra-4	ND	WR	WR	WR	WR	WR	Data	WR	4.0	100%	24.0	50%	0%	DR	4	Linear Res.	5
Pra-5	ND	WR	WR	WR	WR	WR	WR	WR	1.7	100%	17.0	50%	0%	DR	1.676	Linear Res.	3
Pra-6	ND	WR	WR	WR	WR	WR	Data	WR	7.3	30%	348.0	80%	100%	WR	7.3	Analytic	
Pra-7	ND	WR	WR	WR	WR	WR	Data	WR	10.7	30%	377.0	100%	80%	DR	10.738	Analytic	
Pra-8	ND	WR	WR	WR	WR	WR	Data	WR	5.5	75%	276.0	100%	100%	WR	5.5	Analytic	
Purcell-1	ND	Data	Data	Data	Data	Data	Data	Data	3.3	100%	141.0	100%		WR	3.34	Linear Res.	15
Purcell-2	ND	WR	WR	WR	WR	WR	WR	WR	6.9	100%	353.7	100%		WR	6.91	Linear Res.	15
Reese-1	ND	WR	WR	WR	WR	WR	WR	WR	0.1	100%	3.0	100%		WR	0.1	Linear Res.	8
Reese-2	ND	WR	WR	WR	WR	WR	WR	WR	0.2	100%	103.0	100%		DR	0.16	Analytic	
Reese-3	ND	WR	WR	WR	WR	WR	WR	WR	1.9	100%	#N/A	100%		DR	1.9		
S-1	ND	WR	WR	WR	WR	WR	WR	WR	0.3	100%	16.2	100%	0%	WR	0.28	Linear Res.	8
S-2	ND	Data	Data	Data	Data	Data	Data	Data	1.5	50%	104.1	50%	90%	WR	1.49	Linear Res.	8
S-3	ND	WR	WR	WR	WR	WR	WR	WR	4.4	75%	212.0	100%	100%	WR	4.35	Analytic	
S-4	ND	WR	WR	WR	WR	WR	WR	WR	4.7	75%	233.5	90%	100%	WR	4.68	Linear Res.	8
S-5	ND	WR	WR	WR	WR	WR	WR	WR	2.9	100%	144.0	75%	0%	WR	2.91	Linear Res.	5
S-6	ND	Data	Data	Data	Data	Data	Data	Data	3.9	100%	202.7	100%	0%	WR	3.87	Linear Res.	10
S-9	ND	WR	WR	WR	WR	WR	WR	WR	0.4	100%	27.6	50%	0%	WR	0.44	Linear Res.	5
SourdoughGulch-1	ND	WR	WR	WR	WR	WR	WR	WR	1.4	100%	27.2	100%		WR	1.42	Linear Res.	5
SS-0	ND	WR	WR	WR	WR	WR	WR	WR	1.6	0%	49.8	0%	80%	WR	1.6	Linear Res.	9
SS-1	ND	WR	WR	WR	WR	WR	WR	WR	1.3	100%	67.0	90%	0%	WR	1.34	Linear Res.	7
SS-2	ND	WR	WR	WR	WR	WR	WR	WR	1.8	100%	88.0	50%	0%	WR	1.76	Linear Res.	3

Diversion Name	IDWR Ref No.	*Demand Time Series Data Source*[DTS]							Max Div. Rate	*Consumption Rate Factors*[CRF]				*Ditch Capacity*[DC]		*Lag Time*[LT]	
		WY 2008	WY 2009	WY 2010	WY 2011	WY 2012	WY 2013	WY 2014		%Flood	Acres	% Flood Grass	% Spr. Grass	Method	Value	RF Delay Method	Lag Time
Stroud-1	ND	Data	ND	ND	Data	ND	ND	ND	2.0	100%	93.0	100%		DR	2	Analytic	
T-1	ND	WR	WR	WR	WR	WR	WR	WR	1.3	20%	65.0	100%	100%	WR	1.33	Linear Res.	2
Texas-1_BigTimber-2	ND	WR	WR	WR	WR	WR	WR	WR	1.4	100%	88.2	100%		WR	1.4	Linear Res.	3
Texas-10	ND	WR	WR	WR	WR	WR	WR	WR	0.8	100%	74.0	100%		DR	0.84	Linear Res.	10
Texas-11	ND	Data	Data	Data	Data	Data	Data	Data	0.9	100%	192.0	100%		DR	0.94	Linear Res.	10
Texas-12	ND	Data	Data	Data	Data	Data	Data	Data	1.6	100%	196.0	100%		DR	1.62	Linear Res.	10
Texas-13a	ND	WR	WR	WR	WR	WR	WR	WR	1.0	100%	74.0	100%		DR	1	Linear Res.	5
Texas-13b	ND	WR	WR	WR	WR	WR	WR	WR	0.1	100%	30.0	100%		DR	0.13	Linear Res.	5
Texas-14	ND	WR	WR	WR	WR	WR	WR	WR	2.3	100%	165.7	100%		DR	2.28	Linear Res.	5
Texas-2a	ND	WR	WR	WR	WR	WR	WR	WR	4.2	0%	609.3	0%	0%	DR	4.23	Analytic	
Texas-2b	ND	WR	WR	WR	WR	WR	WR	WR	2.1	100%	82.0	100%		DR	2.1	Linear Res.	8
Texas-3	ND	WR	WR	WR	WR	WR	WR	WR	3.8	100%	298.0	100%		WR	3.83	Linear Res.	5
Texas-4	ND	WR	WR	WR	WR	WR	WR	WR	4.0	100%	389.1	100%		DR	4	Linear Res.	5
Texas-5	ND	WR	WR	WR	WR	WR	WR	WR	2.2	100%	197.0	100%		DR	2.2	Linear Res.	10
Texas-6	ND	Data	Data	Data	Data	Data	Data	Data	3.9	100%	220.7	100%		DR	3.94	Linear Res.	8
Texas-7	ND	Data	WR	WR	WR	WR	Data	Data	2.8	100%	293.0	100%		DR	2.8	Linear Res.	5
Texas-8	ND	Data	Data	Data	Data	Data	Data	Data	0.0	100%	63.0	100%		DR	0	Linear Res.	15
Texas-9	ND	WR	WR	WR	WR	WR	WR	WR	1.1	100%	59.9	100%		DR	1.09	Linear Res.	20
W-1	ND	WR	WR	WR	WR	WR	WR	Data	3.5	100%	7.3	100%	0%	DR	3.46	Linear Res.	3
W-2	ND	WR	WR	WR	WR	WR	Data	Data	3.2	100%	87.5	100%	0%	DR	3.18	Analytic	
W-3	ND	Data	Data	Data	Data	Data	Data	Data	4.0	100%	63.2	100%	0%	DR	4	Analytic	
W-4	ND	WR	WR	WR	WR	WR	Data	data	3.0	100%	69.0	100%	0%	DR	3	Linear Res.	4
W-5	ND	WR	WR	WR	WR	WR	Data	Data	5.8	100%	52.0	100%	0%	DR	5.75	Linear Res.	5
W-6	ND	WR	WR	WR	WR	WR	Data	Data	3.8	100%	58.0	100%	0%	DR	3.75	Linear Res.	4
W-7	ND	WR	WR	WR	WR	WR	Data	Data	1.9	100%	13.3	100%	0%	DR	1.9	Linear Res.	4
W-8	ND	WR	WR	WR	WR	WR	Data	Data	3.1	100%	40.0	100%	0%	DR	3.09	Linear Res.	3
WFS-1	ND	Data	Data	Data	Data	Data	Data	Data	2.0	100%	101.0	0%	0%	WR	1.98	Linear Res.	10
WFS-2	ND	WR	WR	WR	WR	WR	WR	WR	0.7	100%	34.0	70%	0%	WR	0.66	Analytic	
WFS-3	ND	WR	WR	WR	WR	WR	WR	WR	2.0	100%	80.0	25%	0%	WR	2	Linear Res.	10
WFS-4	ND	WR	WR	WR	WR	WR	WR	WR	12.4	85%	533.0	90%	0%	WR	12.44	Analytic	
WFWim	ND	Data	Data	Data	ND	Data	Data	Data	8.8	95%	326.0	100%	10%	WR	8.8	Linear Res.	20

		Demand Time Series Data Source[DTS]								*Consumption Rate Factors*[CRF]				*Ditch Capacity*[DC]		*Lag Time*[LT]	
Diversion Name	**IDWR Ref No.**	**WY 2008**	**WY 2009**	**WY 2010**	**WY 2011**	**WY 2012**	**WY 2013**	**WY 2014**	**Max Div. Rate**	**%Flood**	**Acres**	**% Flood Grass**	**% Spr. Grass**	**Method**	**Value**	**RF Delay Method**	**Lag Time**
WFWimTransfer	ND	Data	Data	Data	ND	Data	Data	Data	8.8	95%	326.0	100%	10%	WR	8.8	Linear Res.	15
Wim-1	ND	WR	WR	WR	WR	WR	WR	WR	0.2	100%	8.1	100%	0%	Screen	4	Linear Res.	2
Wim-2	ND	WR	WR	WR	WR	WR	WR	WR	0.7	100%	21.8	80%	0%	Screen	3.57	Linear Res.	2
Wim-3	ND	WR	WR	WR	WR	WR	WR	WR	0.4	100%	17.6	80%	0%	Screen	2.3	Linear Res.	5
Wim-4	ND	WR	WR	WR	WR	WR	WR	WR	1.5	100%	44.4	100%	0%	Screen	4.85	Linear Res.	10
Wim-5	ND	WR	WR	WR	WR	WR	WR	WR	0.8	100%	41.0	0%	0%	Screen	4.85	Linear Res.	10
Wim-6	ND	WR	WR	WR	WR	WR	WR	WR	0.6	0%	73.4	0%	100%	WR	0.568	Linear Res.	10
Wim-7	ND	WR	WR	WR	WR	WR	ND	ND	6.1	100%		100%	0%	DR	6.06	Linear Res.	3
Yearian-1a	ND	WR	WR	WR	WR	WR	WR	WR	2.5	100%	99.0	100%		WR	2.5	Linear Res.	4
Yearian-1b	ND	WR	WR	WR	WR	WR	WR	WR	2.9	0%	35.0	0%	0%	WR	2.93	Linear Res.	4
Yearian-2a	ND	WR	WR	WR	WR	WR	WR	WR	7.8	50%	155.7	0%	0%	WR	7.78	Analytic	
Yearian-2b	ND	WR	WR	WR	WR	WR	WR	WR	2.7	0%	269.0	0%	0%	WR	2.67	Analytic	
Zeph-1	ND	WR	WR	WR	WR	WR	WR	WR	0.5	100%	40.6	100%		DR	0.54	Linear Res.	10
Zeph-2	ND	WR	WR	WR	WR	WR	WR	WR	0.8	100%	#N/A	100%		DR	0.8	Linear Res.	11
Zeph-3	ND	WR	WR	WR	WR	WR	WR	WR	4.4	100%	66.6	100%		WR	4.4	Linear Res.	5

Abbreviations in the text

DTS: "Data" is diversion records, "WR" is water rights, and "ND" indicates no data

CRF: "Max Div Rate" is the maximum diversion rate and "% Spr. Grass" is the fraction of the sprinkler irrigation that is grass

DC: "DR" is diversion records, "WR" is water rights, and "Screen" is from the design records in the IDFG Screen Shop

LT: "RF Delay Method" is Return Fraction Delay Method, "Linear Res." is the linear reservoir method, and "analytic" is the CH2M Hill response function

Table A-2. Catchment in the LRBM and the corresponding variables. Description of each variable follows the table.

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF	TG	CKBF	Calibration Catchment
MILL	6.01	379	0.541	213.5	274	0.00361	0.0205	0.196	3857	Big Eightmile Agg
BIGEIGHTMILE_UPPER	6.01	379	0.541	213.5	274	0.00361	0.0205	0.196	3857	Big Eightmile Agg
LITTLESPRINGS	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
BIGSPRINGS	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
LITTLETIMBER	49.50	233	0.287	258.7	118	0.0125	0.883	0.393	7755	Big Eightmile Agg
GEERTSON_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
BASIN_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
BIGTIMBER_LOWER	49.50	233	0.287	258.7	118	0.0125	0.883	0.393	7755	Big Eightmile Agg
YEARIAN_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
YEARIAN_LOWER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
REESE	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
PETERSON	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
LITTLEEIGHTMILE	6.01	379	0.541	213.5	274	0.00361	0.0205	0.196	3857	Big Eightmile Agg
JAKESCANYON	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
HOODGULCH	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
CHIPPIE	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
CRUIKSHANK	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
CANYON	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
BIGTIMBER_UPPER	49.50	233	0.287	258.7	118	0.0125	0.883	0.393	7755	Big Eightmile Agg
HAWLEY_UPPER	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
HAWLEY_LOWER	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
TEXAS	49.50	233	0.287	258.7	118	0.0125	0.883	0.393	7755	Big Eightmile Agg
EIGHTEENMILE	2.52	125	0.126	487.6	205	0.00487	0.887	0.00445	10460	Hawley Agg
EIGHTEENMILE_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
HAWLEY_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
CANYON_HAWLEY_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
TEXAS_AQ	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
BIGTIMBER_AQ	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
CANYON_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
JAKESCANYON_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF	TG	CKBF	Calibration Catchment
LITTLEEIGHTMILE_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
PETERSON_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
BIGEIGHTMILE_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
MILL_AQ	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
HAYNES_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
ALDER-ZEPH	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
REESE_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
LEE_AQ	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
AGENCY_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
SANDY_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
WIMPEY_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
BOHANNON_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
WITHINGTON_UPPERTOP	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
BASIN_UPPERTRAILCRK	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
GEERTSON_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
WITHINGTON_UPPER	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
HAYNES_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
WITHINGTON_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
MCDEVITT_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.196	3857	Agency Agg
HAYDEN_UPPER	6.01	379	0.541	213.5	274	0.00361	0.0205	0.196	3857	Big Eightmile Agg
KIRTLEY_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
KENNEY_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
PATTEE_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
PATTEE_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
KENNEY_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
MCDEVITT_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
HAYDEN_AQ	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
AGENCY_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
YEARIAN	6.79	1	0.107	100	524	0.0613	0.0667	0.811	5188	Canyon Aq
SANDY_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
PRATT_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
WIMPEY_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq

Name	Umax	Lmax	CQOF	CKIF	CK1,2	TOF	TIF	TG	CKBF	Calibration Catchment
BOHANNON_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
KIRTLEY_AQ	0.17	1.21	0.64	605.8	475	0.147	0.565	0.459	2417	Kenny Aq
BASIN_AQ	30.30	125	0.235	268.5	110	0.241	0.00866	0.116	5535	Big Timber Aq
AGENCY_UPPERTOP	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
BIG TIMBER_LOWERTRIB	49.50	233	0.287	258.7	118	0.0125	0.883	0.393	7755	Big Eightmile Agg
AGENCY_UPPERCOWCRK	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
SANDY_UPPERSOUTH	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
SANDY_UPPERNORTH	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
SANDY_UPPERMIDDLE	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
WIMPEY_TRIBUPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
WIMPEY_TRIBLOWER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
BOHANNON_UPPERTOP	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
GEERTSON_UPPERTRIB	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
GEERTSON_UPPERTOP	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
PRATT_UPPER	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
BASIN_UPPERMCNUTTCRK	27.30	199	0.28	967	118	0.627	0.138	0.869	5816	Agency Agg
LEE_UPPERTRIB	6.01	379	0.541	213.5	274	0.00361	0.0205	0.196	3857	Big Eightmile Agg
LEE	6.01	379	0.541	213.5	274	0.00361	0.0205	0.196	3857	Big Eightmile Agg

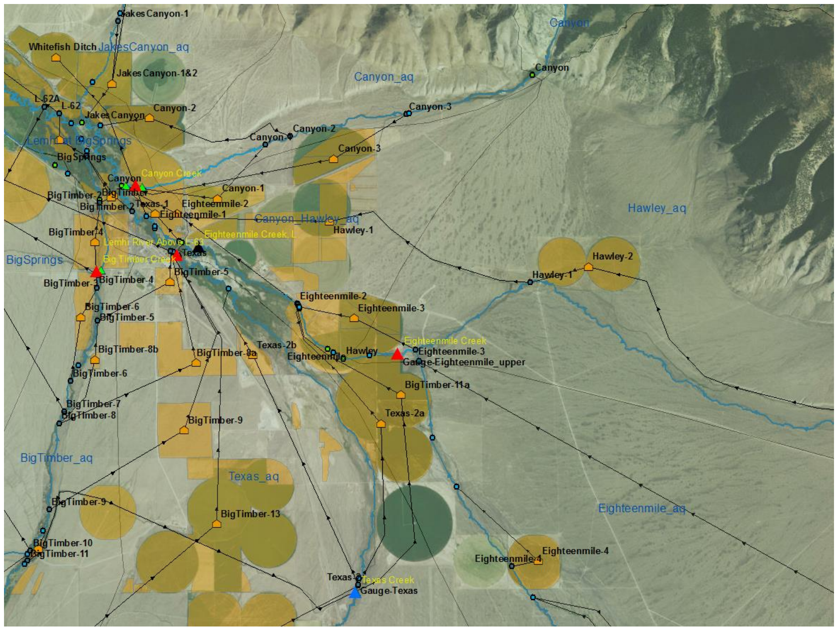
Parameter description:

- Umax: Maximum water content in surface storage
- Lmax: Maximum water content in root zone storage
- CGOF: Overland flow runoff coefficient
- CKIF: Time constant for routing interflow
- CK1,2: Time constant for routing overland flow
- TOF: Root zone threshold value for overland flow
- TIF: Root zone threshold value for interflow
- TG: Root zone threshold value for GW recharge
- CKBF: Time constant for routing baseflow
- Carea: Ratio of GW-area to catchment area
- Csnow: Constant degree-day coefficient
- Sy: Specific yield in the baseflow zone

APPENDIX B. SCENARIO FIGURES

Pre-Projects

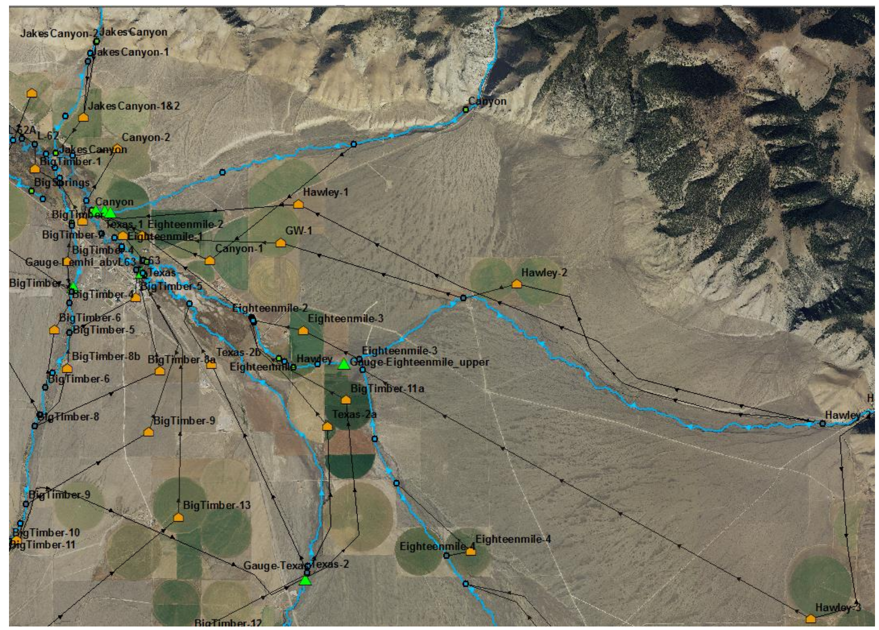
Canyon/Hawley Cr



Post-Projects

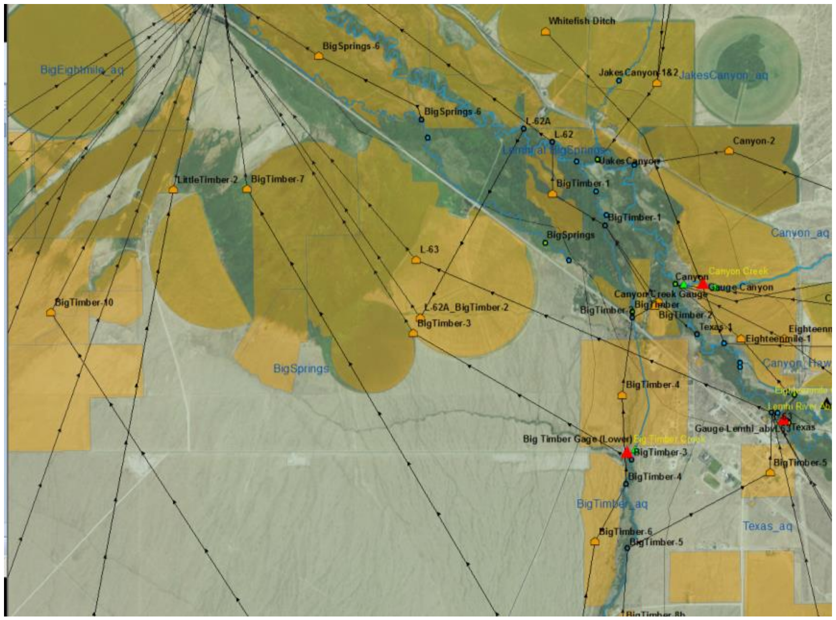
Canyon/Hawley Cr Changes

- Flow capacity to Hawley-3 limited to 10.4 cfs. Changed the demand time series to reflect this. No change in acreage
- Hawley-2 now in pipeline capacity of 3.27 cfs. Changed FC and Time Series. Area unchanged.
- Hawley-1. Switched POD to Hawley-2. Separate pipes, but will use same trench. Irrigate new fields. Pipe capacity 3.64 cfs. Changed FC and Time Series. System 100% efficient. Will turn off diversion once the pivot is turned off.
- Introduce GW-1
- Canyon-1 shifted to Canyon-3 POD.
- Canyon-2 moved to pump from Lemhi River. Beyeler property
- Whitefish ditch removed. Pumped up from Lemhi



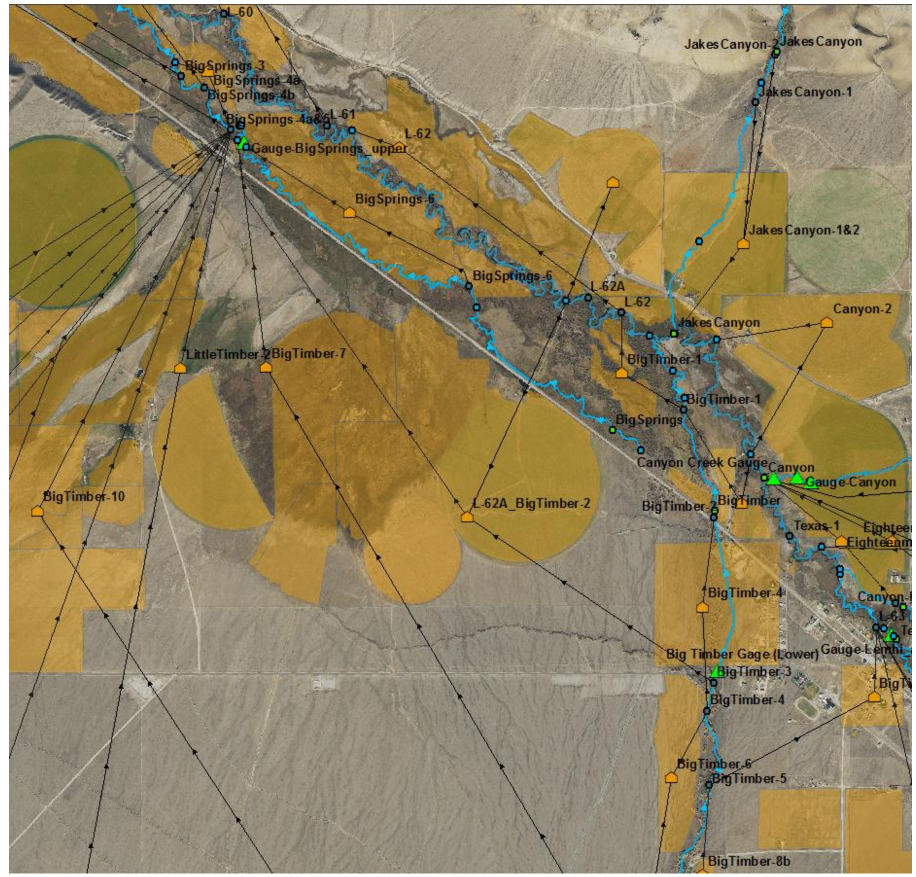
Pre-Projects	Post-Projects
Big Timber Creek	**Big Timber Creek**

Pre-Projects — Big Timber Creek



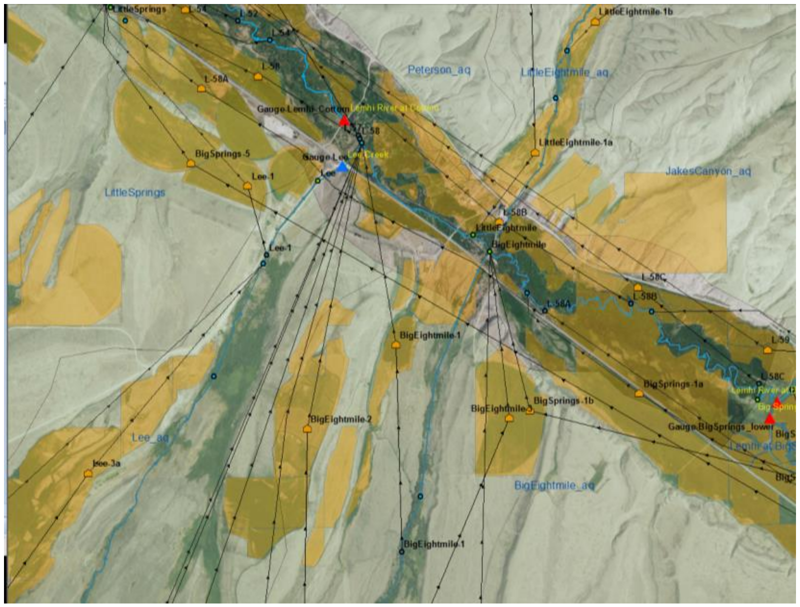
Post-Projects — Big Timber Creek

- Flow capacity to Hawley-3 limited to 10.4 cfs. Changed the demand time series to reflect this. No change in acreage



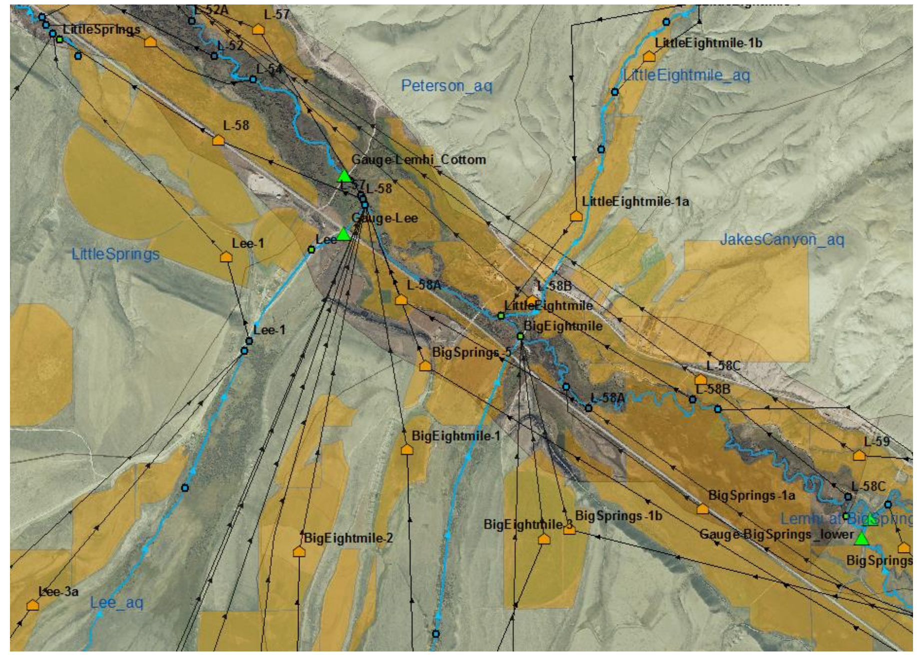
Pre-Projects	Post-Projects
Big Springs 5,L-58A,L-58	**Big Springs 5,L-58A,L-58**

Pre-Projects: Big Springs 5,L-58A,L-58



Post-Projects: Big Springs 5,L-58A,L-58

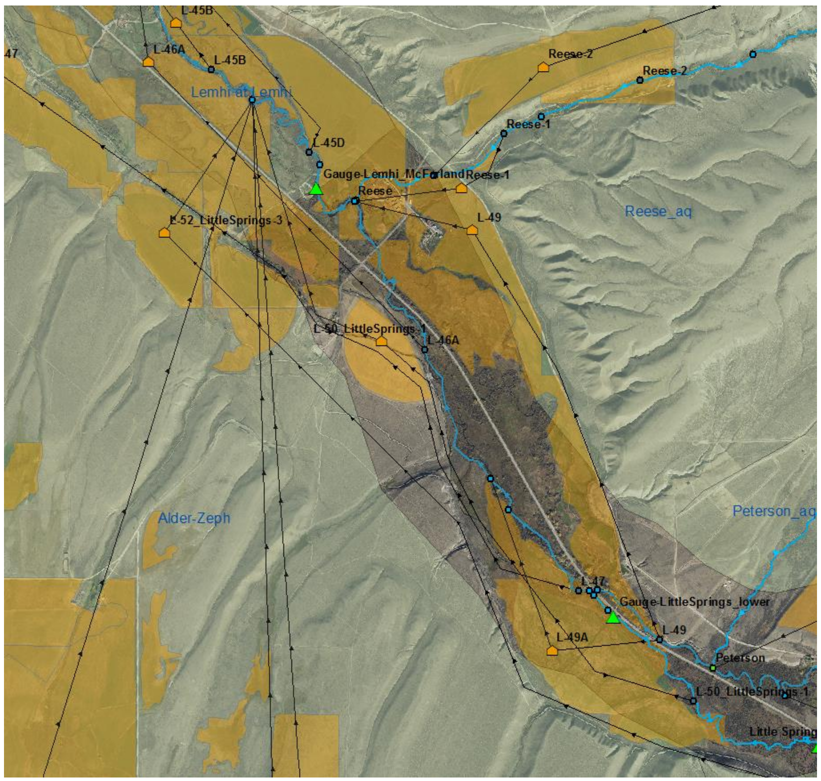
- Big Springs 5 no longer goes downstream to the Lee-1 area
- L-58A no longer goes downstream to the Lee-1 area
- Former L-58A area now pumped up from L-58



Pre-Projects

Little Springs

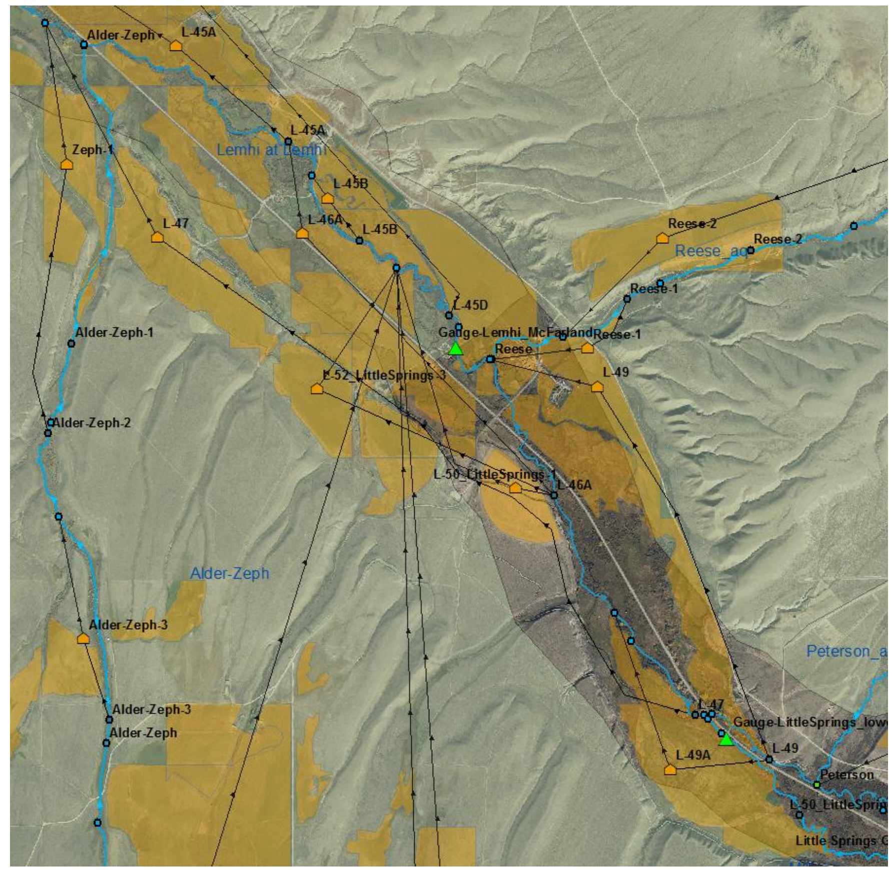
- Originally plumbing with diversions out of Little Springs



Post-Projects

Little Springs

- Big Springs 5 no longer goes downstream to the Lee-1 area
- L-58A no longer goes downstream to the Lee-1 area
- Former L-58A area now pumped up from L-58



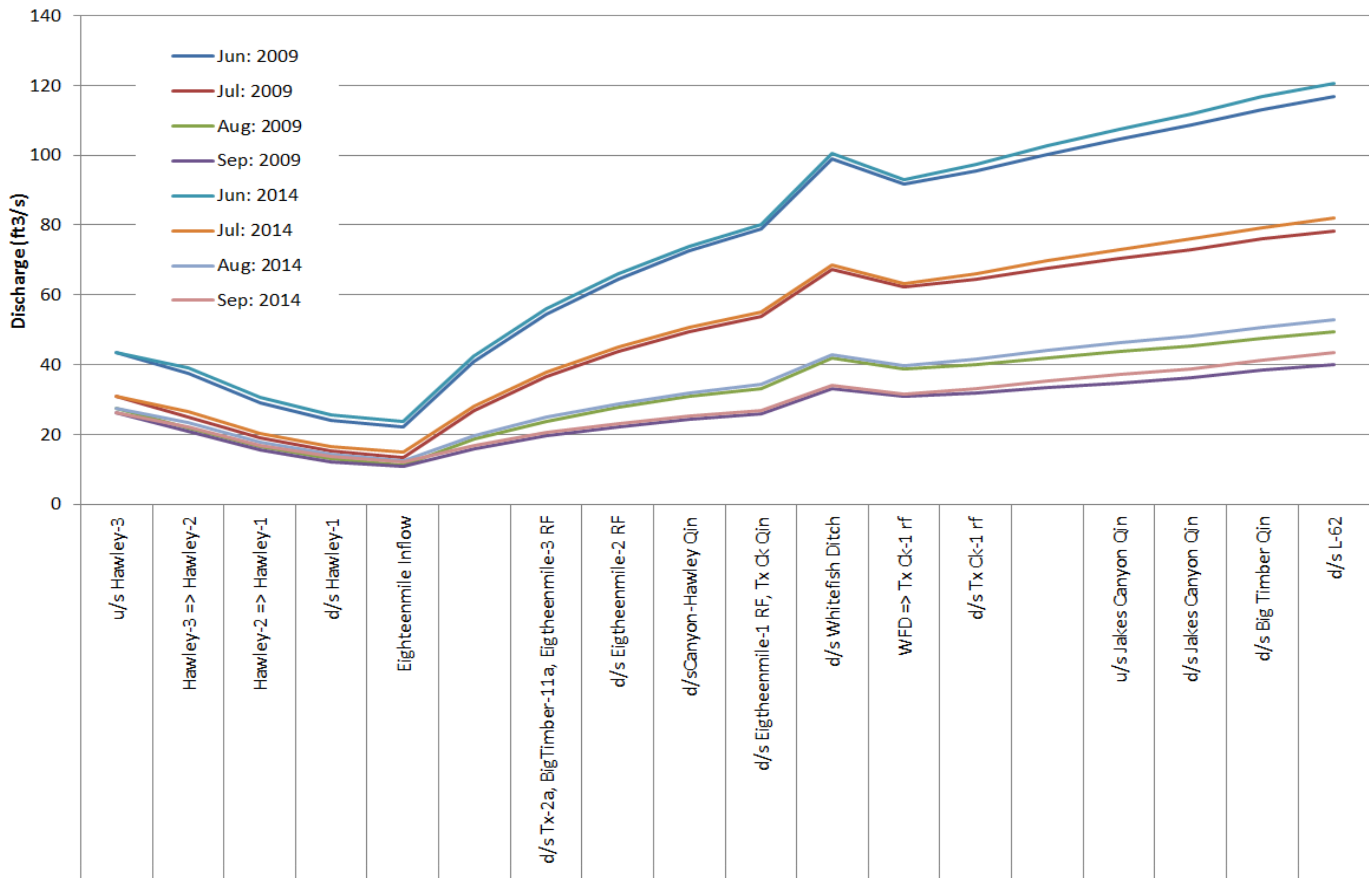


Figure B-1. Longitudinal profile of the average monthly discharges for the 2009 and 2014 conditons. The longitudinal profile progresses from Hawley Creek above H-3 into Eighteenmile then follows the Lemhi River to the reach downstream of the L-62 diversion. Reaches are labeled along the bottom axis.

APPENDIX C. AUXILIARY FIGURES

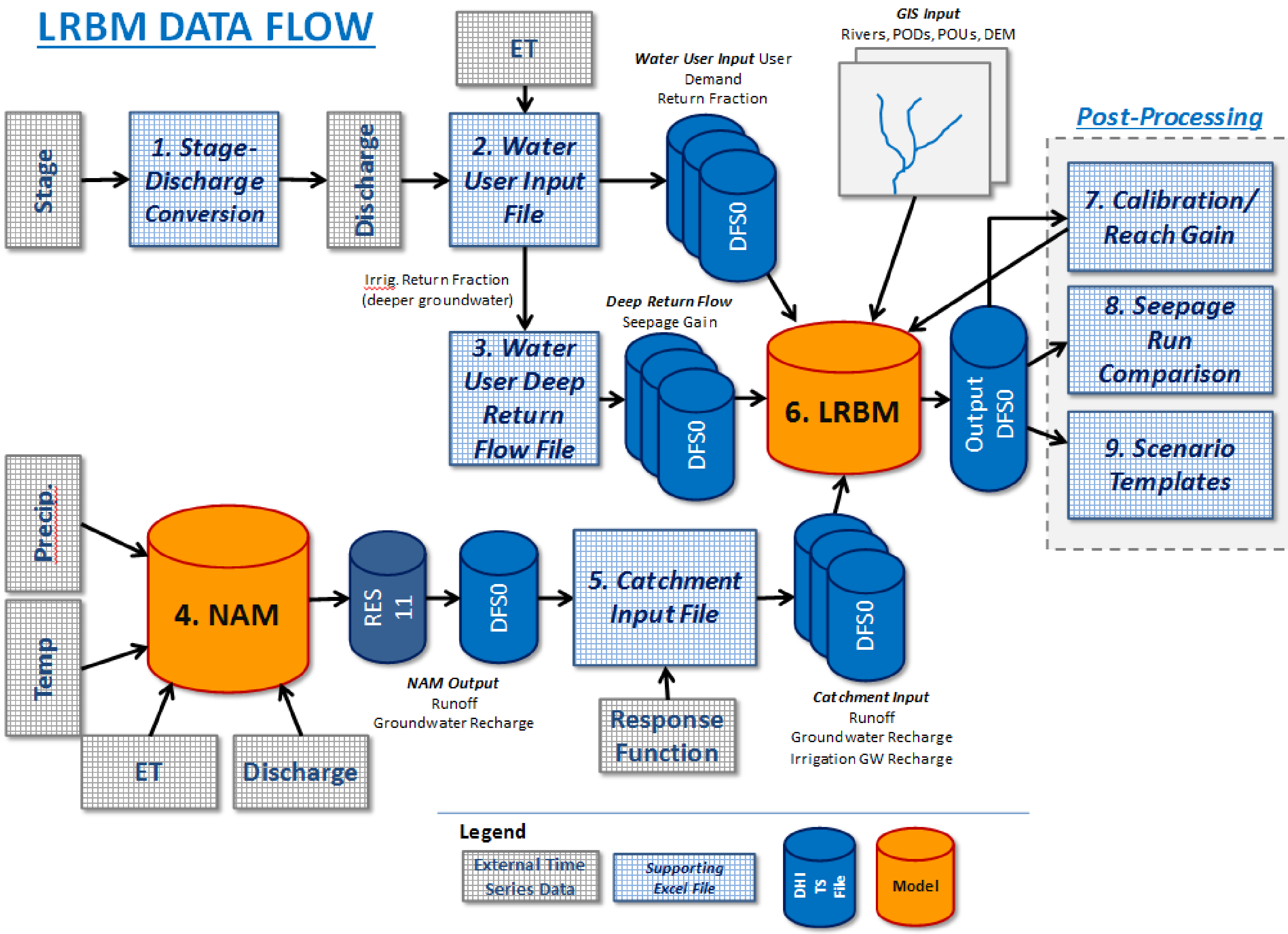


Figure C-1. LRBM Data Flow Schematic