LOGAN RIVER
OBSERVATORY

State of the Logan River Watershed

2019-2020

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In partnership with:

UTAH DNR WATER RESOURCES

LOGAN CITY UNITED IN SERVICE

CACHE WATER DISTRICT

UtahStateUniversity

Preface

This report provides a summary of data collected within the Logan River Observatory as required by the Utah Legislative funds managed and overseen by the Utah Division of Water Resources. The primary objectives of the report are to highlight the data types and availability within the Logan River Observatory, provide a brief overview of the data from 2019-2020 within the context of historical data, and to summarize recent and ongoing research and outreach affiliated with the observatory.

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Background

Water is the lifeblood of our state. We depend on a safe and adequate water supply, not only for drinking water, but for other municipal, agricultural, industrial, and recreational uses. Much of Utah's water supply comes from reservoirs or streams that are fed by snowmelt. Utah's climate can be highly variable, with large changes in water availability from year to year. Furthermore, as Utah's climate shifts, historical data may not be predictive of future water supply, raising new questions. For example: *As weather patterns change to more rain and less snow, what will be the effect on springtime flows that fill our reservoirs and summer flows crucial for meeting agricultural and urban demands? How will Utah's rapidly growing population impact our already limited water supply? How will climate and population changes affect Utah's drought resiliency?* Reliable data are essential for answering questions like these, and monitoring Utah watersheds is necessary for making informed water management decisions. The Logan River Observatory (LRO) is a watershed monitoring network that is helping to meet these challenges by providing data to fill these important knowledge gaps.

Origins

In 2012, the three major Utah Universities (Utah State University, University of Utah, and Brigham Young University) proposed a new collaborative project for scientists and practitioners to collect, integrate and share physical, biological, and social water data to advance understanding and generate knowledge needed to solve urban and arid region water sustainability problems. The project included infrastructure (human, observational, and cyber) to lay a foundation for addressing water, population growth, and climate change issues that confront the State of Utah. The resulting EPSCoR (Established Program to Stimulate Competitive Research) program funding award from the National Science Foundation launched iUTAH (innovative Urban Transitions and Aridregion HydroSustainability): a 5-year, multi-institution, interdisciplinary project focused on water sustainability in Utah. A lasting legacy of the iUTAH project was its environmental observations via the GAMUT (Gradients Along Mountain to Urban Transitions) network. In the Logan River watershed, eight aquatic monitoring stations and four climate stations were established to measure, record, and publicly distribute a wide range of climate (e.g., precipitation, snow depth, air temperature, relative humidity), hydrology (e.g., water depth, flow rates), and water quality (e.g., water temperature, dissolved oxygen, pH, turbidity, nitrate) information. The sensor network was deployed to log and transmit the data, which is stored in databases and made publicly available via web-based tools and an online data repository. The monitoring sites and information streams established by iUTAH laid a solid foundation for data collection to support better water management in Cache Valley and provided an opportunity to study the long term impacts of rapidly growing rural counties on water use and quality across the state of Utah.

Logan River Observatory

In 2018, iUTAH's GAMUT network for the Logan River was organized into the Logan River Observatory (LRO). The overarching goal of the LRO is to provide long-term, comprehensive hydrologic data to inform local and statewide water management decisions based on Utah-specific hydrologic research. In support of this goal, the LRO is an outdoor laboratory and classroom for training the next generation of engineers and scientists who will be Utah's future water managers. Detailed watershed data (discharge, water quality, climate) combined with this increase in expertise provide opportunities to: (1) address existing water issues in the state, (2) support new research to advance understanding of Utah's watersheds, and (3) focus on future challenges associated with limited water supplies. The LRO team has established partnerships with local stakeholders to support and improve existing monitoring infrastructure, including the Utah Division of Water Resources, Utah State University, Logan City, and Cache Water District. The LRO Team also coordinates with the Logan River Task Force and supports their efforts via data collection.

Logan River Watershed Overview

The Logan River watershed is centrally located in the Bear River mountain range east of Logan, Utah. With headwaters near the Utah-Idaho border, the upper, or canyon, portion of the basin is steep and flows southwest through mostly natural land cover (forest and rangeland) with little development other than paved and dirt roads, a ski resort, and a small number of summer homes. Currently, the majority of precipitation falls as snow, resulting in a snowmelt-dominated hydrograph where peak flows occur in the late spring with an average annual flow at the mouth of the canyon of approximately 230 cfs (6.5 cms). The upper portion of the watershed has primarily limestone and dolomite geology (Dover, 1995) with topography characterized by sinkholes and fractures formed by dissolution of the rocks (also known as karst features) creating underground drainage systems. According to Spangler (2001; 2011), some Logan Canyon geologic layers (e.g., the Garden City Formation and Laketown Dolomite) have more karst development than other layers, but all units have the ability to transmit water via fractures, faults, and bedding planes created and enhanced by dissolution. The exception is the Swan Peak Formation, primarily composed of quartzite, which minimizes vertical groundwater movement between some of the karst layers and intersects the river in multiple places (Spangler, 2011). Groundwater movement is also influenced by the Logan Peak Syncline and the merger of the Naomi Peak Syncline and Cottonwood Canyon Anticline near Wood Camp Spring (Bahr, 2016).

Three major karst springs exist in Logan Canyon (Ricks, Wood Camp, and Dewitt Springs) that provide significant flow to the river throughout most of the year. Numerous smaller springs (both karst and non-karst) feed the Logan River or its tributaries and may or may not flow year round. Many tracer studies have been conducted in an effort to establish subsurface connectivity of the karst aquifer and these major springs (Spangler, 2001, 2011) as well as other short residence time intrabasin and interbasin subsurface connectivity. Dewitt Springs is a primary drinking water source for Logan City, and a large portion of its flow is diverted before entering the Logan River. Three additional perennial tributaries also join the Logan River (Beaver Creek, Temple Fork Creek, and Right Hand Fork Creek). Other tributaries are either limited in their contribution or are intermittent, with no flow reaching Logan River during parts of the year.

In lower Logan Canyon, a series of three small dams (First, Second, and Third Dam) divert flow for hydropower generation. An irrigation diversion between First and Second Dams supplies water to the Highline Canal. Once the river enters the valley portion of the watershed, it flows through residential areas, then more urbanized portions of Logan City, then residential areas again, and finally through agricultural areas west of Logan City. During the summer growing season, most, and sometimes all, of the river’s flow is diverted into three additional canals for residential and agricultural irrigation (Sumac, Crockett, and Young Ward Canals). Two major tributaries, Spring Creek and the Blacksmith Fork River, as well as many other smaller inflows also contribute to the river in the residential, urban, and agricultural areas. These inflows are primarily sourced from stormwater, groundwater drainage, and irrigation return flows. Various restoration efforts led by the Logan River Task Force (https://uwrl.usu.edu/lro/logan-river-task-force) have been implemented in the valley portion of the river to address human impacts throughout the watershed and along the river corridor.

LRO Data Types and Availability

As detailed by Jones et al. (2017), standard designs for both aquatic and climate stations were established for the original GAMUT network. In order to span a range of elevations and mountain to urban environments, aquatic monitoring stations were placed within the Logan River watershed: (1) in a high elevation first-order stream, (2) in a mid-elevation second- or third-order stream, (3) at a low elevation valley site, and (4) near the terminus of the stream below the Logan City urban area of interest. The climate and terrestrial monitoring stations were located at: (1) a high elevation mountain headwater area, (2) a mid-elevation area, and (3) a low elevation in the valley/urban areas. As the LRO has become more established, additional sites have been added, and adaptations to site specifications have been made to expand the original GAMUT network into what is now the LRO monitoring network. For example, several new aquatic stations that measure flow, temperature, and specific conductance have been added. These new stations capture the influence of tributaries on the Logan River and fill gaps in the initial infrastructure.

Currently, the LRO maintains climate and aquatic monitoring sites spanning from the headwaters of the Logan River (Franklin Basin) down to a location in the valley approximately 6 km (3.7 miles) upstream of the Logan River's mouth in the backwaters of Cutler Reservoir. The LRO website includes an interactive map of the station locations (https://uwrl.usu.edu/lro/locations; Figure 1) with classifications of sites maintained by the LRO and related research projects as well as complementary sites maintained by the United States Geological Survey (USGS) and the Utah Division of Water Rights. Data for each site can be accessed by clicking on the location markers in the web map. A simplistic schematic of primary LRO sites along the Logan River as well as major inflows and outflows monitored by the LRO (Figure 2) provides a brief overview of key data collection locations. A more comprehensive list of all LRO monitoring sites, frequency of data updates, status, and the data types or parameters available (Table 1) illustrates the extent of data gathered within the LRO. Given the variety of site types, the data types and frequency of updates can be important when using these data for different applications. A similar table is provided for the weather stations in the appendix (Table A1).

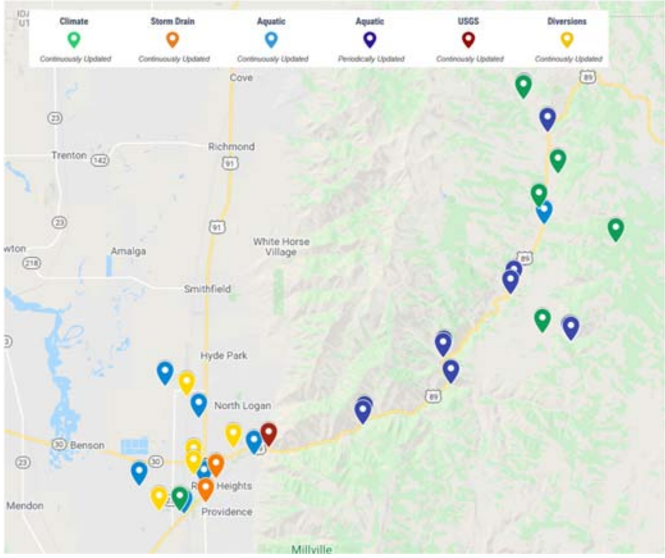


Figure 1. LRO and other relevant monitoring locations that provide complementary data (find this navigable map at https://uwrl.usu.edu/lro/locations).

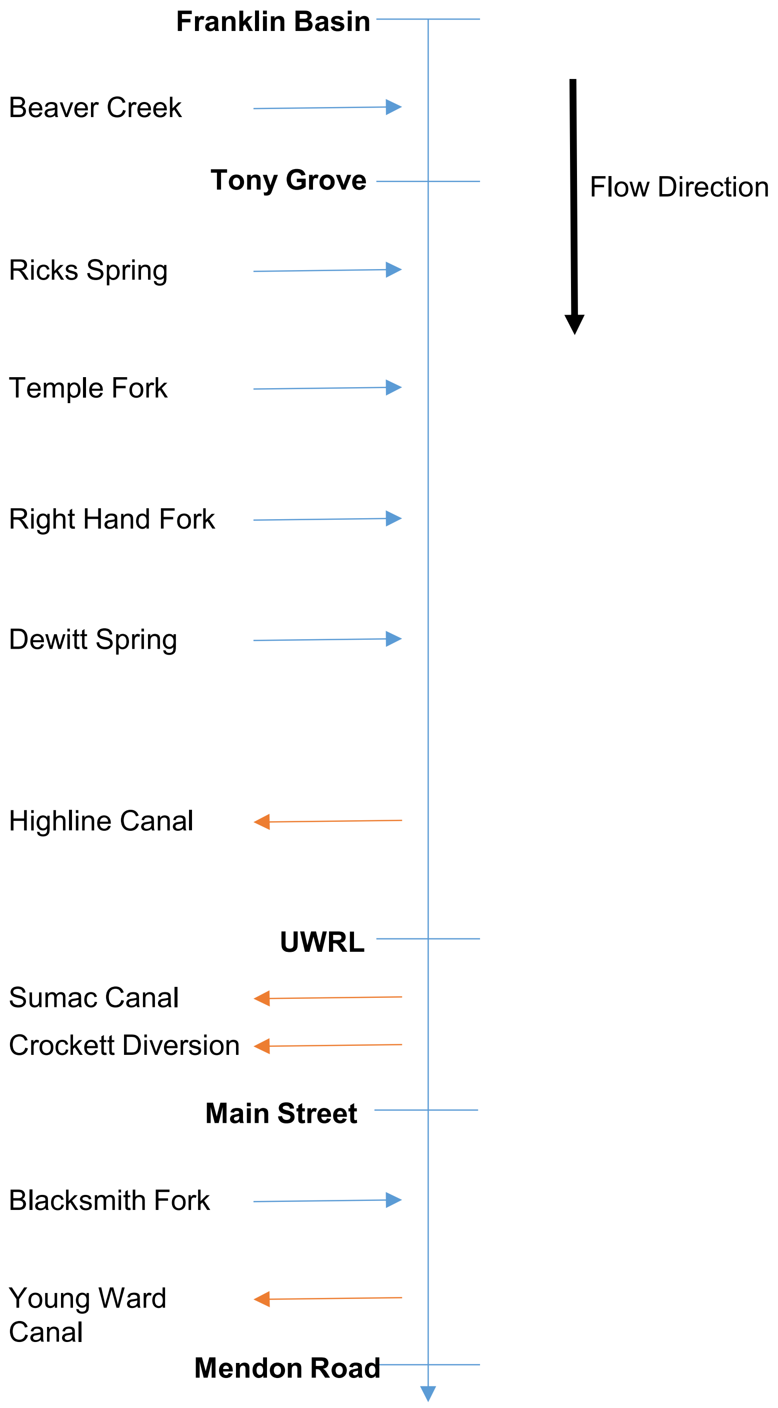


Figure 2. Simplified schematic of LRO mainstem and tributary site locations. The vertical line represents the Logan River, with flow from top to bottom. Arrows pointing toward the river (blue) indicate inflows, and arrows pointing away from the river (orange) indicate withdrawals. Lines that cross the river indicate the locations of continuous aquatic monitoring sites. Flow rates of all diversions are monitored by the Utah Division of Water Rights, but are included here to provide an overview of primary inflows and diversions that are monitored.

Table 1. Aquatic sites and variables measured at each site within the Logan River Observatory*.

Site Name	Site Code	Updates	Water Temperature (C)	Specific Conductance (uS/cm)	pH	Dissolved Oxygen (optical, local % saturation and mg/L)	Turbidity (NTU)	Gage Height (cm)	Water Surface Elevation (m, with respect to benchmark)	Discharge** (cms)	Blue Green Algae (RFU)	Chloro-phyll	CDOM (QSU)	Nitrate (mg/L)	Water Depth (m)	Velocity (m/s)
Logan River Sites																
Logan River near Franklin Basin	LR_FB_BA	Continuously	●	●	●	●	●	●	●	●						
Logan River near Tony Grove	LR_TG_BA	Continuously	●	●	●	●	●	●	●	●						
Logan River at Wood Camp Bridge	LR_WCB_A	Periodically	●	●				●	●							
Logan River at Guinavah Campground Bridge	LR_GCB_A	Periodically	●	●				●	●							
Logan River at the Utah Water Research Laboratory west bridge	LR_WaterLab_AA	Continuously	●	●	●	●	●	●	●	●	○	○	○	○		
Logan River at Main Street (Highway 89/91) Bridge	LR_MainStreet_BA	Continuously	●	●	●	●	●	●	●	●						
Logan River at Mendon Road (600 South)	LR_Mendon_AA	Continuously	●	●	●	●	●	●	●	●	○	○	○	○		
Tributary Sites																
Beaver Creek		Periodically	●	●				●	●	●						
Temple Fork Outlet		Periodically	●	●				●	●	●						
Ricks Spring		Periodically	●	●				●	●	●						
Right Hand Fork		Periodically	●	●				●	●	●						
Spring Creek above confluence with Logan River	SC_CONF_A	Continuously	●	●				●	●							
Blacksmith Fork above confluence with Logan River	BSF_CONF_BA	Continuously	●	●	●	●	●	●	●	●						
Canal Sites																
Northwest Field Canal at 1600 North	NWF_1600N_CNL	Continuously	●	●	●	●	●	●		●						
South Logan Benson Canal at Airport Rd Pumping Station	SLB_Pump_CNL	Continuously	●	●	●	●	●	●	●							
Storm Drain Sites																
River Heights Bridge Storm Drain	LR_RH_SD	Continuously	●							●					●	●
Spring Creek Storm Drain	LR_SC_SD	Decommissioned	○							○					○	○

*● indicates that data are presently being collected for this parameter; ○ indicates that data were historically collected for this parameter; Continuously = real-time updates of data online and available via time-series analyst; Periodically = periodic downloads of sensors with data posted on time-series analyst and/or Hydroshare (https://www.hydroshare.org/).

** For the continuously updated stations that have discharge, the underlying data and details of the rating curves can be found by clicking "Explore Rating Curve" button below the "Most Recent Instantaneous Measurements" on each site's details accessed from http://lrodata.usu.edu/. The data for these sites, as well as the periodically updated sites, can also be found directly by going to http://www.hydroshare.org and searching for "Logan River rating curves." The exception is the Northwest Field Canal site.

The following sections provide an overview of the historical context of Logan River hydrology by examining long term flow data from the USGS along with the past five years of data from the LRO. We then focus on the most recent state of the Logan River watershed by examining flow and water quality data from 2019–2020 within the context of the last 5 years of data for the Logan Canyon and Cache Valley portions of the watershed.

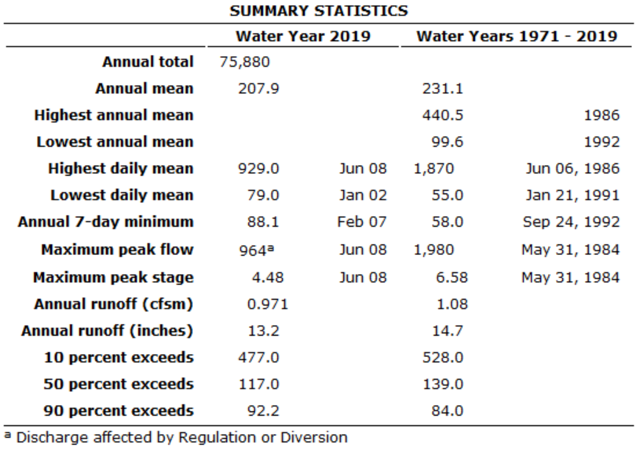
To illustrate the availability of data and tools provided by the LRO, where possible, plotting and summaries provided within this report were created using the LRO Time Series Analyst web application, which can be accessed at http://lrodata.usu.edu/tsa/.

Logan River Hydrology

Historical Context

Long Term USGS Discharge. The long term USGS gaging station (10109000 LOGAN RIVER ABOVE STATE DAM, NEAR LOGAN, UT) is located immediately upstream of First Dam just before the Logan River exits Logan Canyon. The long duration of the USGS data at this site offers historical hydrologic context that the limited duration of LRO discharge data (~2015–2020) cannot yet provide. Summary statistics provided by the USGS Water-year summary (Table 2) show that the 2019 Water Year (WY, Oct. 1, 2018 – Sept. 30, 2019) had below average annual mean flow and annual runoff relative to the overall period from 1971–2019. 2019 had a peak flow of 964 cfs (27.3 cms) compared to a maximum of 1980 cfs (56 cms) observed in 1984. In 2019, 10% of the flows exceeded 477 cfs (13.5 cms), while from 1971–2019, 10% of the flows exceeded 528 cfs (15 cms), suggesting that relatively low spring runoff occurred. However, 90% of the 2019 flows were higher than 92 cfs (2.6 cms), which is slightly higher than the 84 cfs (2.37 cms) from 1971–2019. This suggests that, while spring runoff was lower in 2019, the summer low flow values were similar to other prior years; therefore, the lower magnitude spring runoff lowered the mean annual flow value for 2019. In the following sections, we provide a more detailed summary of precipitation and discharge data for the years between 2014 and 2020. These historical data then provide context for a more specific analysis of the state of the Logan River with respect to precipitation and discharge for the most recent two water years (WY2019 and WY2020).

Table 2. USGS Water-year Summary (cfs) for Site 10109000 (Logan River Above State Dam, Near Logan, UT).

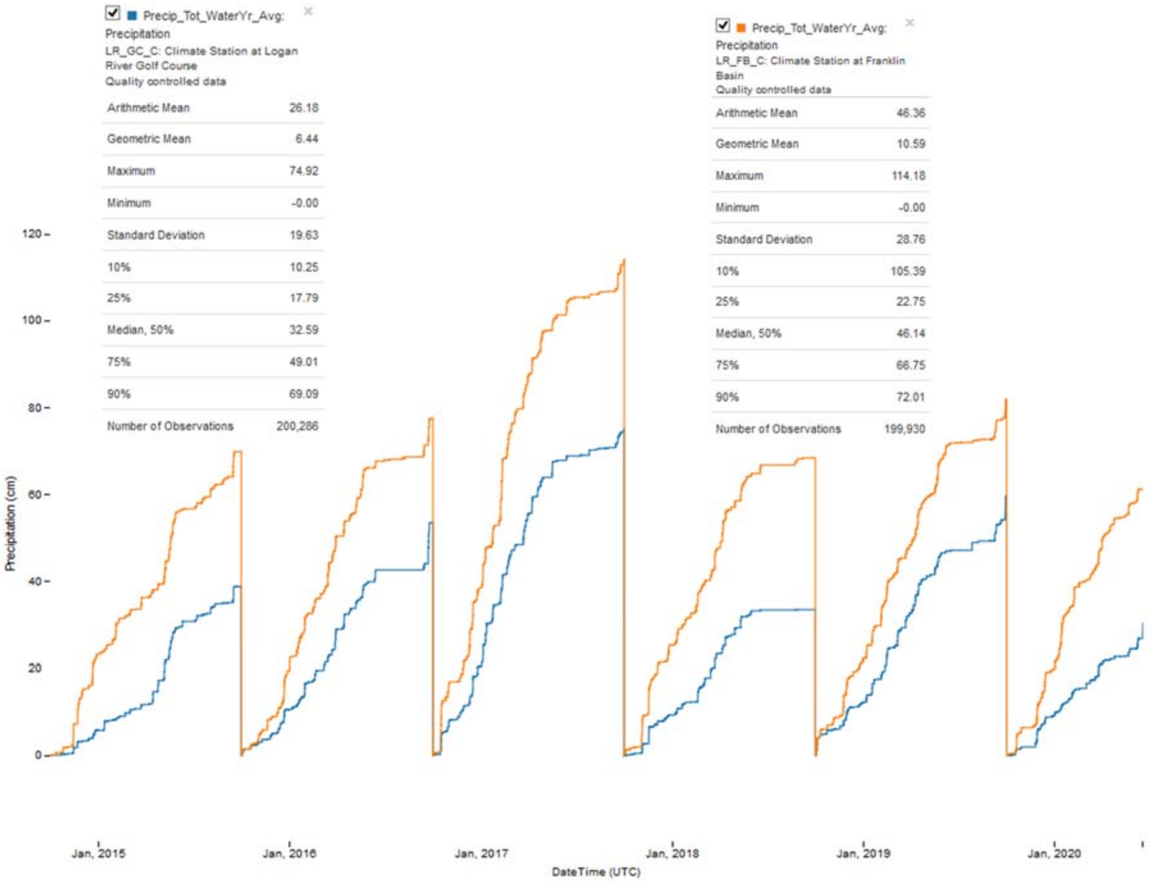


SUMMARY STATISTICS

	Water Year 2019		Water Years 1971 - 2019	
Annual total	75,880			
Annual mean	207.9		231.1	
Highest annual mean			440.5	1986
Lowest annual mean			99.6	1992
Highest daily mean	929.0	Jun 08	1,870	Jun 06, 1986
Lowest daily mean	79.0	Jan 02	55.0	Jan 21, 1991
Annual 7-day minimum	88.1	Feb 07	58.0	Sep 24, 1992
Maximum peak flow	964[a]	Jun 08	1,980	May 31, 1984
Maximum peak stage	4.48	Jun 08	6.58	May 31, 1984
Annual runoff (cfsm)	0.971		1.08	
Annual runoff (inches)	13.2		14.7	
10 percent exceeds	477.0		528.0	
50 percent exceeds	117.0		139.0	
90 percent exceeds	92.2		84.0	

[a] Discharge affected by Regulation or Diversion

2014–2020 Precipitation. The primary driver of river discharge is precipitation. Using the available LRO precipitation and snow accumulation data from 2014–2020 at different locations, insight can be gained regarding differences in flow patterns between years. In the Logan River, flow dynamics are mostly dictated by snow accumulation and melt rates that control the magnitude and duration of spring runoff and influence subsequent low flow periods. The upper mountainous portion of the watershed recieves significantly more precipitation than the valley (Figure 3), and the valley receives significantly less of its precipitation as snow compared to the mountainous areas (Figure 4). While several Natural Resources Conservation Service (NRCS) Snow Telemetry (SNOTEL) sites are located within the basin at high elevations, the LRO provides additional measures of precipitation and snow depth at lower elevations (which can provide important information related to earlier spring flows). In general, WY2015 and WY2018 exhibited low precipitation and snow accumulation, while WY2016 and WY2019 correspond to high precipitation and snow accumulation. Notably, the valley received greater precipitation earlier in WY2019 than WY2016. The beginning of WY2020 has been similar to WY2019, but the onset of snow melt occurred earlier and new snow did not accumulate to recover to early season levels.



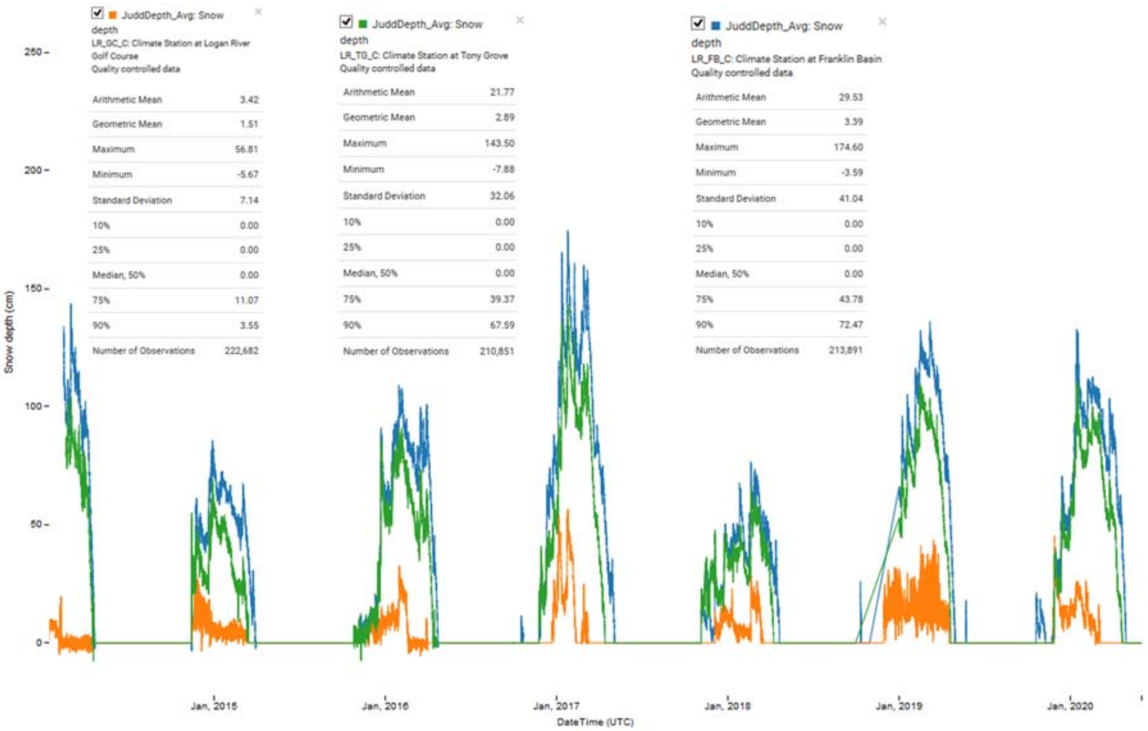
☑ ■ Precip_Tot_WaterYr_Avg:
Precipitation
LR_GC_C: Climate Station at Logan River Golf Course
Quality controlled data

Arithmetic Mean	26.18
Geometric Mean	6.44
Maximum	74.92
Minimum	-0.00
Standard Deviation	19.63
10%	10.25
25%	17.79
Median, 50%	32.59
75%	49.01
90%	69.09
Number of Observations	200,286

☑ ■ Precip_Tot_WaterYr_Avg:
Precipitation
LR_FB_C: Climate Station at Franklin Basin
Quality controlled data

Arithmetic Mean	46.36
Geometric Mean	10.59
Maximum	114.18
Minimum	-0.00
Standard Deviation	28.76
10%	105.39
25%	22.75
Median, 50%	46.14
75%	66.75
90%	72.01
Number of Observations	199,930

Figure 3. Water year total cumulative precipitation in Logan Canyon (Climate Station at Franklin Basin) and valley (Climate Station at Logan River Golf Course) from 2014 to 2020.



☑ 🟧 JuddDepth_Avg: Snow depth
LR_GC_C: Climate Station at Logan River Golf Course
Quality controlled data

Arithmetic Mean	3.42
Geometric Mean	1.51
Maximum	56.81
Minimum	-5.67
Standard Deviation	7.14
10%	0.00
25%	0.00
Median, 50%	0.00
75%	11.07
90%	3.55
Number of Observations	222,682

☑ 🟩 JuddDepth_Avg: Snow depth
LR_TG_C: Climate Station at Tony Grove
Quality controlled data

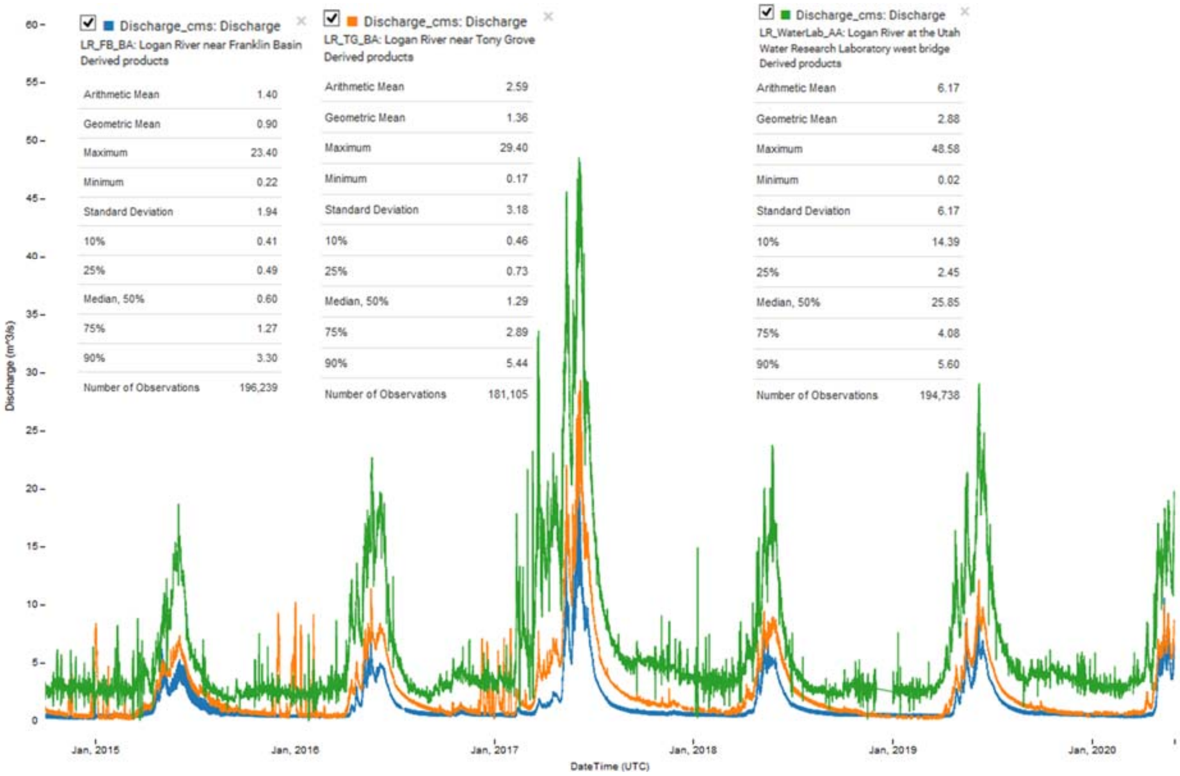
Arithmetic Mean	21.77
Geometric Mean	2.89
Maximum	143.50
Minimum	-7.88
Standard Deviation	32.06
10%	0.00
25%	0.00
Median, 50%	0.00
75%	39.37
90%	67.59
Number of Observations	210,851

☑ 🟦 JuddDepth_Avg: Snow depth
LR_FB_C: Climate Station at Franklin Basin
Quality controlled data

Arithmetic Mean	29.53
Geometric Mean	3.39
Maximum	174.60
Minimum	-3.59
Standard Deviation	41.04
10%	0.00
25%	0.00
Median, 50%	0.00
75%	43.78
90%	72.47
Number of Observations	213,891

Figure 4. Snow depth accumulation at LRO climate stations from 2014 to 2020.

2014-2020 Discharge. The flow information from the upper, Logan Canyon portion of the watershed provides insight regarding the amount of precipitation or snowmelt that becomes runoff each year. Because the watershed drainage area increases as it progresses downstream, the flow increases, as is apparent in the canyon (Figure 5). Years with low precipitation and snow accumulation (WY2015 and WY2018) would be expected to have lower peak flows in the canyon in the spring. However, in 2018, the peak flow was higher than that in 2015. In 2017, high precipitation and snow accumulation resulted in high peak flows in spring extending into the summer low flow period.


☑ 🟦 Discharge_cms: Discharge
LR_FB_BA: Logan River near Franklin Basin
Derived products

Arithmetic Mean	1.40
Geometric Mean	0.90
Maximum	23.40
Minimum	0.22
Standard Deviation	1.94
10%	0.41
25%	0.49
Median, 50%	0.60
75%	1.27
90%	3.30
Number of Observations	196,239

☑ 🟧 Discharge_cms: Discharge
LR_TG_BA: Logan River near Tony Grove
Derived products

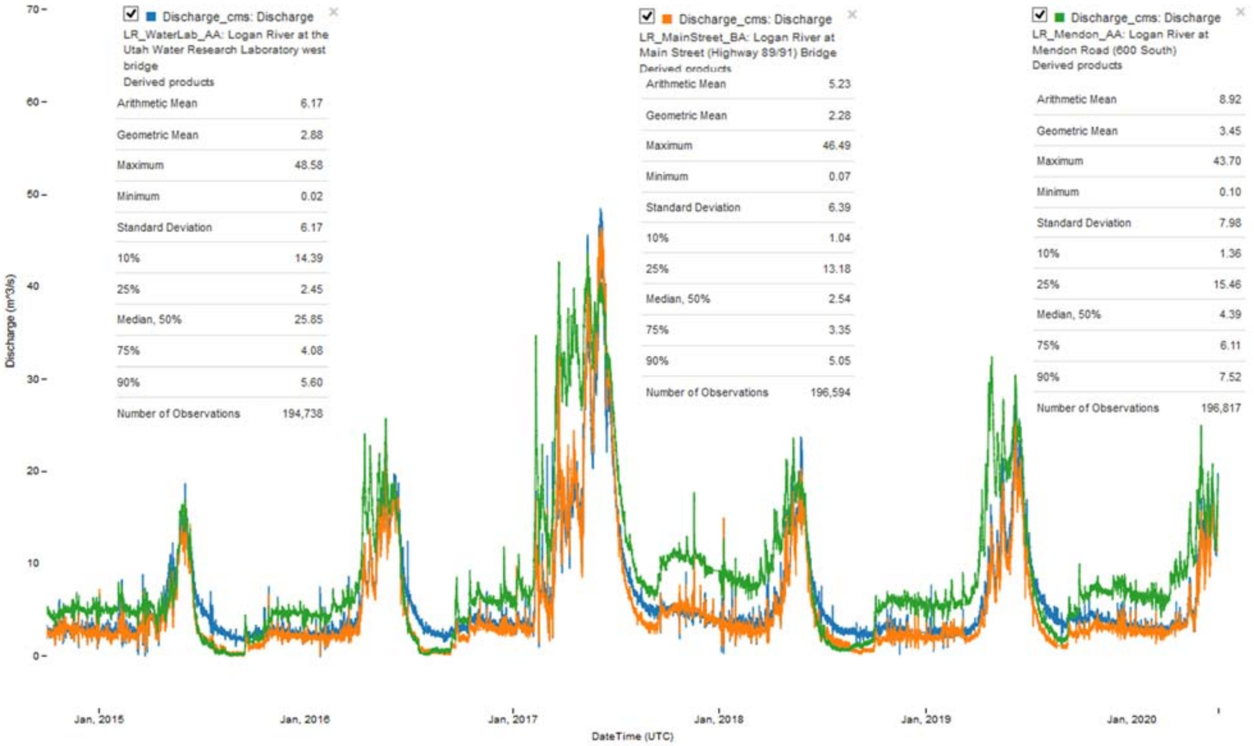
Arithmetic Mean	2.59
Geometric Mean	1.36
Maximum	29.40
Minimum	0.17
Standard Deviation	3.18
10%	0.46
25%	0.73
Median, 50%	1.29
75%	2.89
90%	5.44
Number of Observations	181,105

☑ 🟩 Discharge_cms: Discharge
LR_WaterLab_AA: Logan River at the Utah Water Research Laboratory west bridge
Derived products

Arithmetic Mean	6.17
Geometric Mean	2.88
Maximum	48.58
Minimum	0.02
Standard Deviation	6.17
10%	14.39
25%	2.45
Median, 50%	25.85
75%	4.08
90%	5.60
Number of Observations	194,738

Figure 5. Canyon site discharge and summary statistics for October 1, 2014 – May 31, 2020. It should be noted that the high-frequency variability in the LR_Waterlab_AA site are not instrument issues but are observable hourly and daily fluctuations due to dam, canal, hydropower and UWRL hydraulic testing operations.

During periods of runoff, the lower portion of the watershed, or valley sites, show similar spring runoff responses to those in the canyon (Figure 6). However, the additional drainage area, contribution of tributaries, and increased runoff due to urbanization results in less predictable flow patterns than in the canyon. In contrast, the summer low flow periods combined with significant human influences (e.g., irrigation diversions, hydropower generation, culinary water demands from springs, etc.) that remove a large portion of the inflow from the canyon result in a highly variable flow regime at all valley sites. The influences of diversions once again become apparent at the end of the irrigation season (ranging from September to October) when diversions are no longer occurring. At this point in the year, an increase in flow occurs at all stations, but this is most apparent at Mendon Road.



☑ 🟦 Discharge_cms: Discharge
LR_WaterLab_AA: Logan River at the Utah Water Research Laboratory west bridge
Derived products

Arithmetic Mean	6.17
Geometric Mean	2.88
Maximum	48.58
Minimum	0.02
Standard Deviation	6.17
10%	14.39
25%	2.45
Median, 50%	25.85
75%	4.08
90%	5.60
Number of Observations	194,738

☑ 🟧 Discharge_cms: Discharge
LR_MainStreet_BA: Logan River at Main Street (Highway 89/91) Bridge
Derived products

Arithmetic Mean	5.23
Geometric Mean	2.28
Maximum	46.49
Minimum	0.07
Standard Deviation	6.39
10%	1.04
25%	13.18
Median, 50%	2.54
75%	3.35
90%	5.05
Number of Observations	196,594

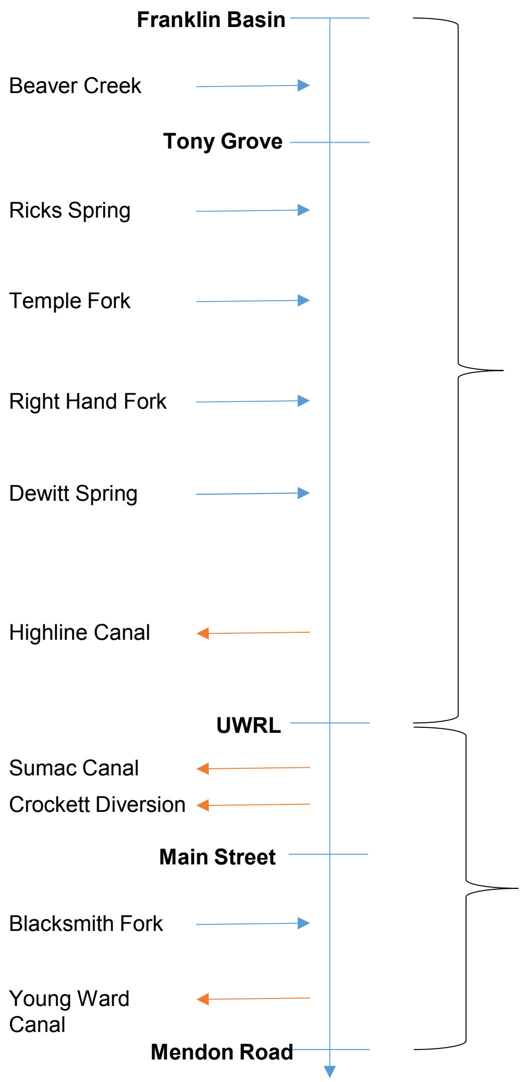
☑ 🟩 Discharge_cms: Discharge
LR_Mendon_AA: Logan River at Mendon Road (600 South)
Derived products

Arithmetic Mean	8.92
Geometric Mean	3.45
Maximum	43.70
Minimum	0.10
Standard Deviation	7.98
10%	1.36
25%	15.46
Median, 50%	4.39
75%	6.11
90%	7.52
Number of Observations	196,817

Figure 6. Valley site discharge and summary statistics for October 1, 2014 – May 31, 2020.

To understand the importance of different sources of water during different times of the year, we investigated the contributions of multiple flow sources for the different portions of the watershed. Figure 7 illustrates the percent contributions from tributaries, lateral inflows (which include ungaged tributaries, springs, and groundwater), and water coming from upstream for the 2014–2020 timeframe. This information is summarized for three important periods in the Logan River watershed each year (see Appendix A for details on flow balance methods for estimating contributions). The "Runoff" period spans March–June, the "Low Flow – Irrigation" period spans July–September, and the "Low Flow – No irrigation" period spans October–December.

For the canyon section, tributaries can represent 27–53% of the inflows with the highest percentage contributions occurring from July–September. Lateral inflows range from 44–60% and are consistently a large fraction of the flow during all seasons. As expected, the diversion influence is most important during July–September (removing 34%), even though diversions can occur from April–October. In the valley portion of the watershed, tributary contributions are less variable (22–25%), in part because the largest tributary (the Blacksmith Fork River) is also consistently dewatered by irrigation diversions. The three diversions in the valley (Figure 7) remove an additional 42% of the flow that passes the UWRL gage during the low flow irrigation period. Lateral inflow contributions in the valley section range from 12–37% with the 37% occurring during low flow periods. This suggests that lateral inflows are critical for maintaining summer low flows after major diversions remove a large fraction of the water from the river.



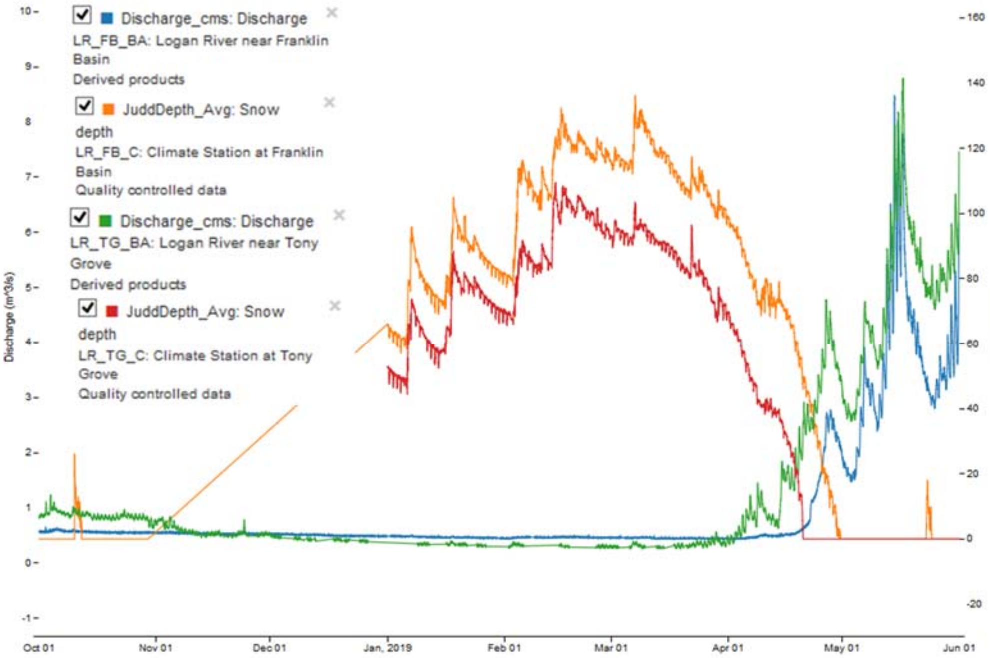
	Runoff (Mar-June)	Low Flow - Irrigation (July - Sept)	Low Flow - No Irrigation (Oct-Dec)
% Upstream	25%	20%	17%
% Tributary	27%	53%	46%
% Lateral Inflows	57%	60%	44%
% Diversion	-10%	-34%	-7%

	Runoff (Mar-June)	Low Flow - Irrigation (July - Sept)	Low Flow - No Irrigation (Oct-Dec)
% Upstream	75%	83%	49%
% Tributary	24%	22%	25%
% Lateral Inflows	12%	37%	27%
% Diversion	-11%	-42%	-1%

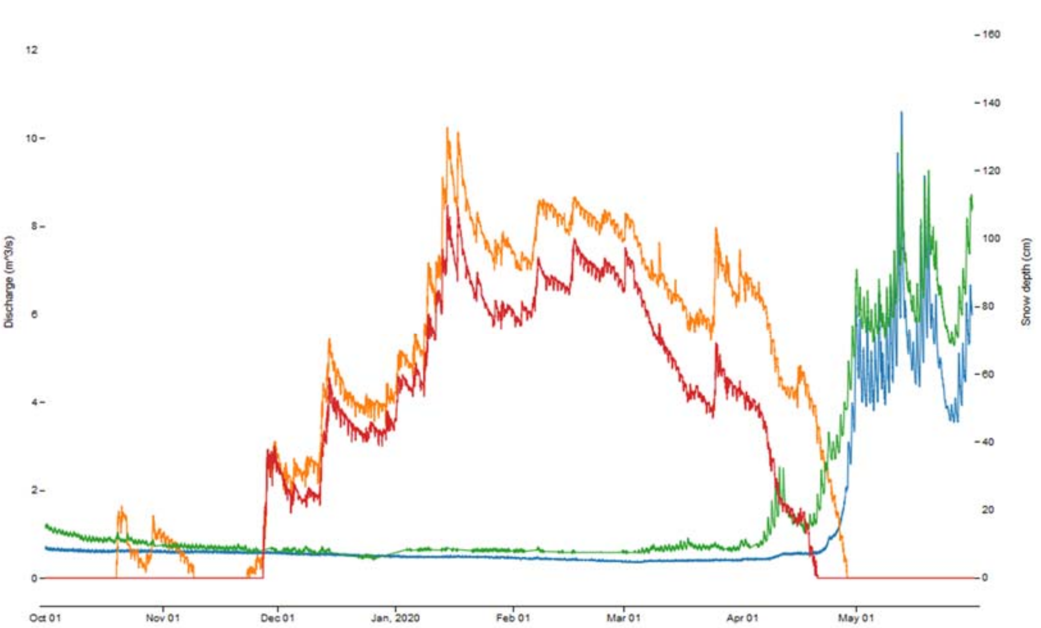
Figure 7. Percent contributions (positive percentages) or withdrawals (negative percentages) for the canyon and valley sections of the Logan River for the time period spanning August 8, 2015–May 1, 2020.

State of the Logan River in Logan Canyon for WY2019 and WY2020

In both WY2019 and WY2020, snowmelt and increased discharge began in early April at Tony Grove and in late April at Franklin Basin (Figure 8). However in WY2020, the Franklin Basin flow initially increased gradually followed by a rapid increase due to a rapid decrease in snowpack before May 1.



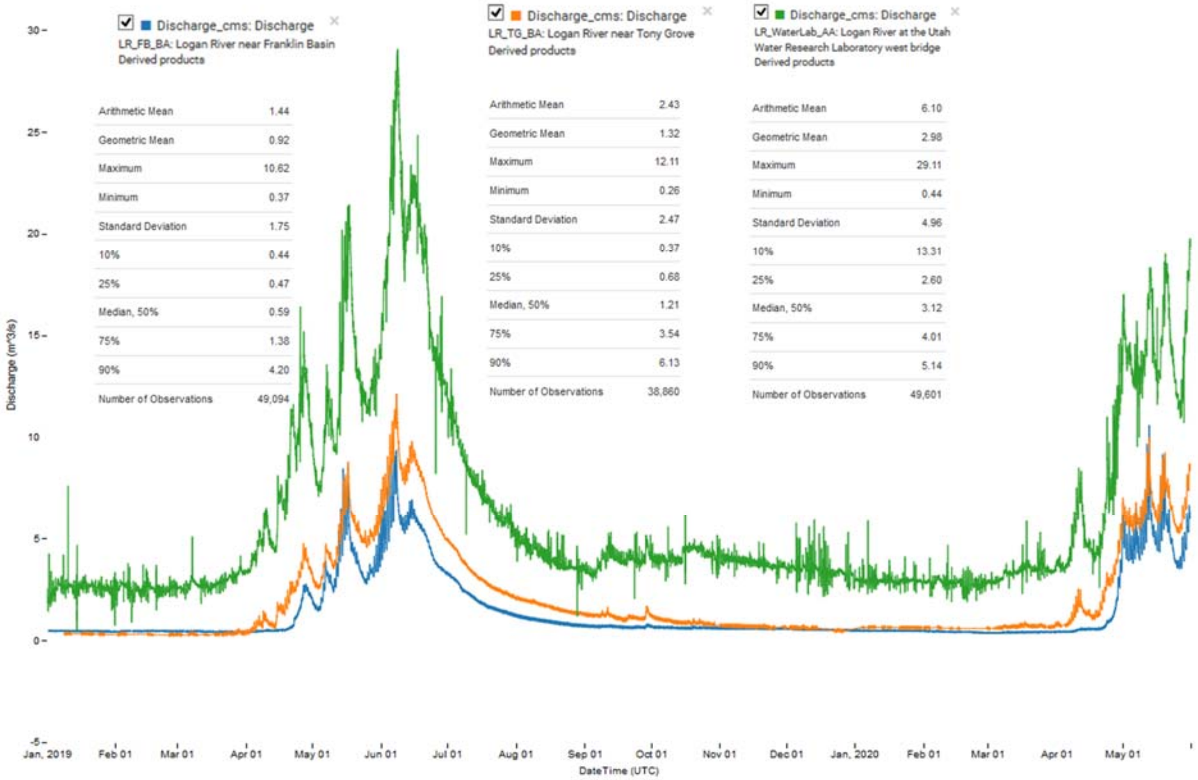
2018-2019



2019-2020

Figure 8. Example plot of relationships between snow accumulation and melt with increased stream flow at two locations in Logan Canyon for October 1, 2018 – May 31, 2019 and October 1, 2019 – May 31, 2020.

In looking at the time series of discharge data for the period spanning January 1, 2019 – May 31, 2020, a clear snowmelt signal is propagated down through the three small reservoirs and is amplified, at times, by tributary contributions between Tony Grove and the UWRL (Figure 9). As mentioned above, human influences between Tony Grove and the UWRL are also apparent during the low flow periods as shown by the discharge variability in summer and winter periods. Between these sites, hydropower diversions from Third and Second Dams and the Highline Canal irrigation diversion below Second Dam all occur. First Dam is then further influenced by hydropower and the UWRL hydraulic testing water intake. These human influences cause short time scale (hours to days) fluctuations at the UWRL site that are propagated through the other valley sites. During winter low flows, the discharge at Franklin Basin and Tony Grove are similar, but either location can have higher baseflows depending on the water year.



☑ 🟦 Discharge_cms: Discharge
LR_FB_BA: Logan River near Franklin Basin
Derived products

Arithmetic Mean	1.44
Geometric Mean	0.92
Maximum	10.62
Minimum	0.37
Standard Deviation	1.75
10%	0.44
25%	0.47
Median, 50%	0.59
75%	1.38
90%	4.20
Number of Observations	49,094

☑ 🟧 Discharge_cms: Discharge
LR_TG_BA: Logan River near Tony Grove
Derived products

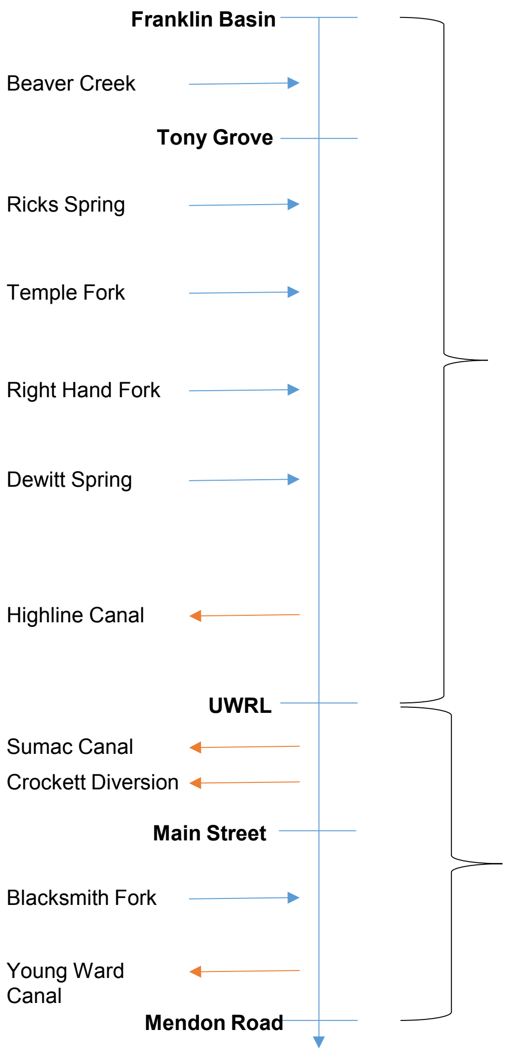
Arithmetic Mean	2.43
Geometric Mean	1.32
Maximum	12.11
Minimum	0.26
Standard Deviation	2.47
10%	0.37
25%	0.68
Median, 50%	1.21
75%	3.54
90%	6.13
Number of Observations	38,860

☑ 🟩 Discharge_cms: Discharge
LR_WaterLab_AA: Logan River at the Utah Water Research Laboratory west bridge
Derived products

Arithmetic Mean	6.10
Geometric Mean	2.98
Maximum	29.11
Minimum	0.44
Standard Deviation	4.96
10%	13.31
25%	2.60
Median, 50%	3.12
75%	4.01
90%	5.14
Number of Observations	49,601

Figure 9. Logan Canyon site discharge and summary statistics from January 1, 2019 to May 31, 2020.

To understand the importance of different sources of water from January 1, 2019 to May 31, 2020, we again investigated the contributions of sources for the different portions of the watershed (Figure 10). Though many of the key tributaries and springs are gaged, a large fraction of the contributions to the system (or lateral inflows, 54–76% of the flow) still are not directly measured. Based on the findings of Neilson et al. (2018), it is likely that a large fraction of this is due to ungaged springs (Wood Camp and Logan Cave) and other groundwater contributions. The gaged tributaries and springs (including Ricks Spring) are an important fraction of the total flow, but are relatively constant at 24–34%. It is also important to note that the Highline Canal diversion removed ~30% of the flow from the canyon during the primary irrigation season.



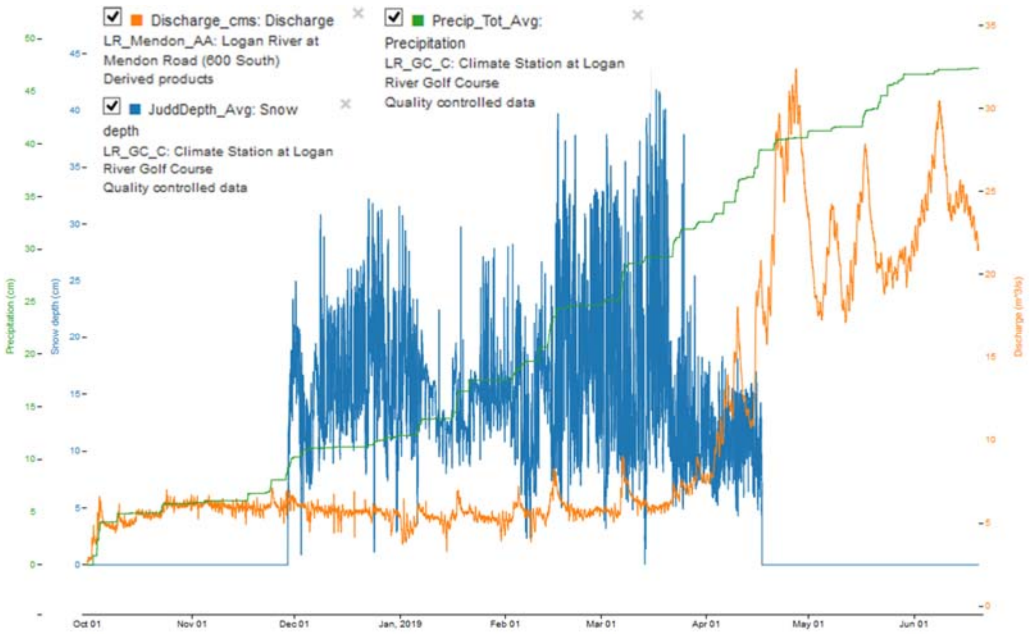
	Runoff (Mar-June)	Low Flow - Irrigation (July - Sept)	Low Flow - No Irrigation (Oct-Dec)
% Upstream	26%	19%	18%
% Tributary	24%	34%	28%
% Lateral Inflows	60%	76%	54%
% Diversion	-10%	-29%	0%

	Runoff (Mar-June)	Low Flow - Irrigation (July - Sept)	Low Flow - No Irrigation (Oct-Dec)
% Upstream	69%	80%	47%
% Tributary	20%	15%	19%
% Lateral Inflows	22%	34%	21%
% Diversion	-11%	-30%	0%

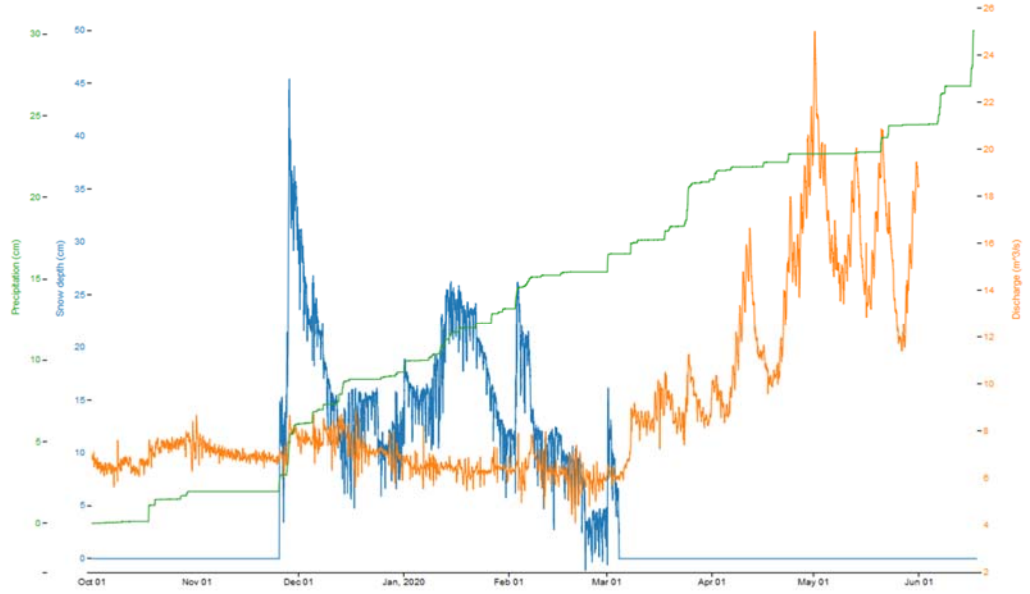
Figure 10. Percent contributions or withdrawals for the canyon and valley sections for time period of WY2019 (October 1, 2018 – September 30, 2019).

State of the Logan River in Cache Valley for WY2019 and WY2020

Snow accumulation in the valley is much lower than that in the canyon (Figure 11). In WY2019, significant precipitation occurred from January to June, with melt occurring in mid-April. This timing is similar to the canyon sites (Figure 8). A number of thaw events during the 2018–2019 winter (shown as big drops in the snow depth) influenced downstream discharge, shown by peaks in the discharge. Note that the high-frequency variability in 2018–2019 snow depth is due to vegetation interferences in these data, but the general trends are still relevant. In WY2020, snow melted in the valley by early March, and less precipitation occurred between January and June of 2020. The influence of valley snowmelt and contributions from lower elevation tributaries in spring 2020 results in a small step increase in downstream discharge in early March. The larger increase in flow between April and June at Mendon Road corresponded with snowmelt from the higher elevation portions of the watershed.



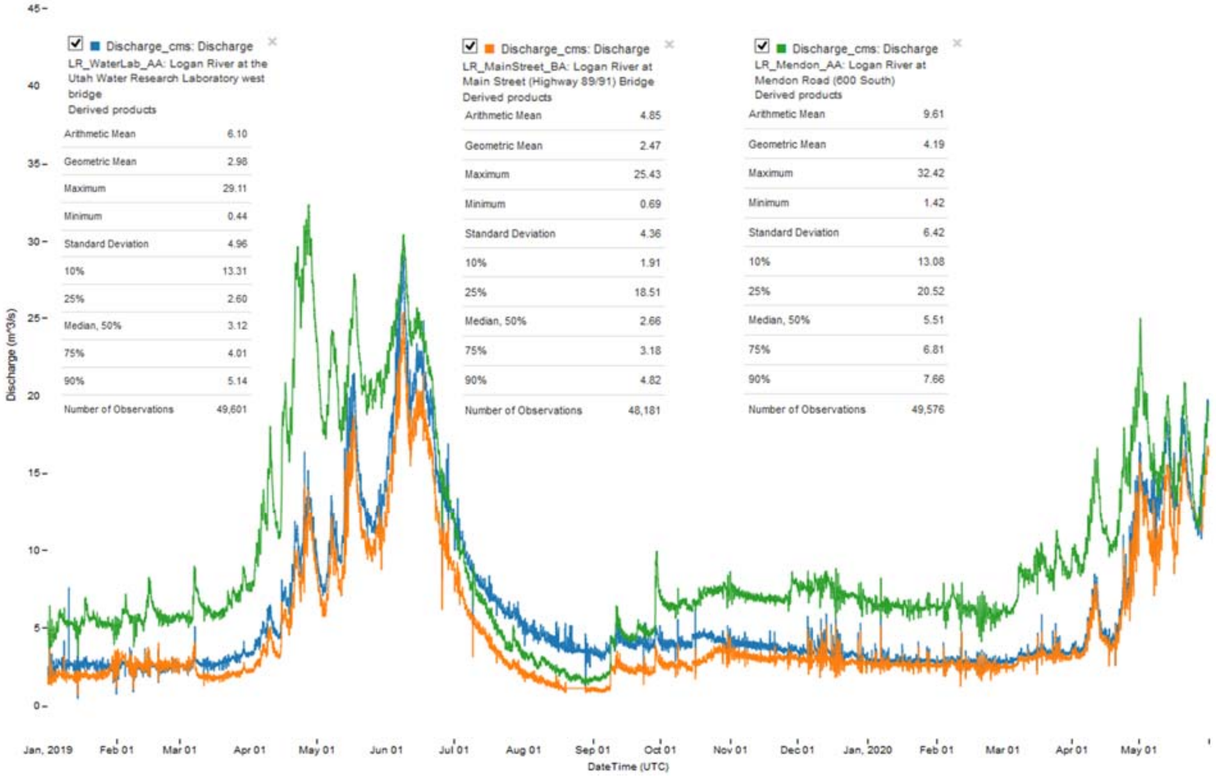
2018-2019



2019-2020

Figure 11. Example plot of relationships between snow accumulation and melt with increased discharge in the valley for October 1, 2018 – May 31, 2019 and October 1, 2019 – May 31, 2020.

Investigating the January 2019 – May 31, 2020 discharge time series (Figure 12) shows that runoff starts earlier at the lowest point in the valley (Mendon Road), likely due to valley snowmelt that is intercepted by a series of canals that then deliver that water to the river lower in the watershed than where the melt originated. The UWRL and Main Street flow gaging stations report similar flows for this period, but for most of the time from January to September, Main Street has the lowest flows of all the valley sites. Higher flows at the UWRL than the downstream Mendon Road from mid-June through mid-September illustrate the role of diversions in this portion of the watershed. Although the river at Mendon Road includes a much larger contributing area (with lateral inflows that make up 21–34% of flows) and two tributaries (that contribute 15–20% of flows), 30% of its flow is diverted from the river during irrigation season (Figure 10). Given the magnitude of diversions, as stated previously, these lateral inflows and tributary contributions are important for maintaining summer low flows.



☑ 🟦 Discharge_cms: Discharge
LR_WaterLab_AA: Logan River at the Utah Water Research Laboratory west bridge
Derived products

Arithmetic Mean	6.10
Geometric Mean	2.98
Maximum	29.11
Minimum	0.44
Standard Deviation	4.96
10%	13.31
25%	2.60
Median, 50%	3.12
75%	4.01
90%	5.14
Number of Observations	49,601

☑ 🟧 Discharge_cms: Discharge
LR_MainStreet_BA: Logan River at Main Street (Highway 89/91) Bridge
Derived products

Arithmetic Mean	4.85
Geometric Mean	2.47
Maximum	25.43
Minimum	0.69
Standard Deviation	4.36
10%	1.91
25%	18.51
Median, 50%	2.66
75%	3.18
90%	4.82
Number of Observations	48,181

☑ 🟩 Discharge_cms: Discharge
LR_Mendon_AA: Logan River at Mendon Road (600 South)
Derived products

Arithmetic Mean	9.61
Geometric Mean	4.19
Maximum	32.42
Minimum	1.42
Standard Deviation	6.42
10%	13.08
25%	20.52
Median, 50%	5.51
75%	6.81
90%	7.66
Number of Observations	49,576

Figure 12. Valley site discharge and summary statistics from January 1, 2019 to May 31, 2020.

Logan River Water Quality

While the Logan River was included within the Cutler Reservoir Total Maximum Daily Load (TMDL) study (Gaddis, 2010), it is not currently listed by the State of Utah as having impaired water quality. According to the Logan River Restoration Conservation Action Plan (Logan River Task Force, 2016), water quality within the Logan River generally ranges from "very good" to "good;" however, summer baseflow is classified as "poor" due to low flow levels. In watersheds that have very distinct high and low flow periods, like the Logan River, the most critical water quality period occurs during the summer low flow season. During this period when water volumes are lower, the corresponding shallow water depths and long water residence times result in higher water temperatures. Low velocities, decreased reaeration, and higher water temperatures decrease dissolved oxygen concentrations. Diversions along the Logan River intensify summer low flow periods, which can further degrade water quality. However, other considerations include the unique attributes of the canyon geology, groundwater interactions, and other human influences in the valley portion of the watershed. Accordingly, this analysis of LRO water quality data focuses on July–August, corresponding to the warmest period of summer low flows when irrigation demands are highest.

Evaluation of water temperature data collected within the canyon portion of the watershed highlights the spatial variability of inflows (Figure 13). Franklin Basin shows daily variability of temperature; however, the temperature range is relatively low (~2.5 °C) and consistent with deeper groundwater temperatures of the headwater spring upstream of this site. In contrast, Tony Grove temperatures are significantly warmer, with large daily fluctuations (~8 °C). It is surprising that peak instream temperatures approach 17 °C at this site, but this may be due to the wide, shallow channel and significant beaver dam ponds that increase residence time and potential for warming from solar radiation. Increased warming of water as it progresses downstream is often anticipated. In this case, while the average temperatures at the UWRL are higher than the Tony Grove temperatures, the maximum temperatures at Tony Grove are over 2 °C warmer. This is likely in part due to topographic shading downstream of Tony Grove as well as significant additions of cooler water from springs, tributaries, and direct groundwater contributions in the lower canyon. However, an additional cooling mechanism could be that two of the power plant diversions route water in buried pipes to the downstream hydropower facility and eventually return cooler water to the river. None of the canyon temperatures exceeded the maximum temperature standard (20 °C) set for the Logan River's Aquatic Wildlife 3A cold water fishery designation (Rule R317-2, 2020) in the summer of 2019. However, investigation of temperature data from prior years illustrate that Tony Grove is consistently warmer than the other stations and reaches summer temperatures of 19 °C during the lowest flow years.

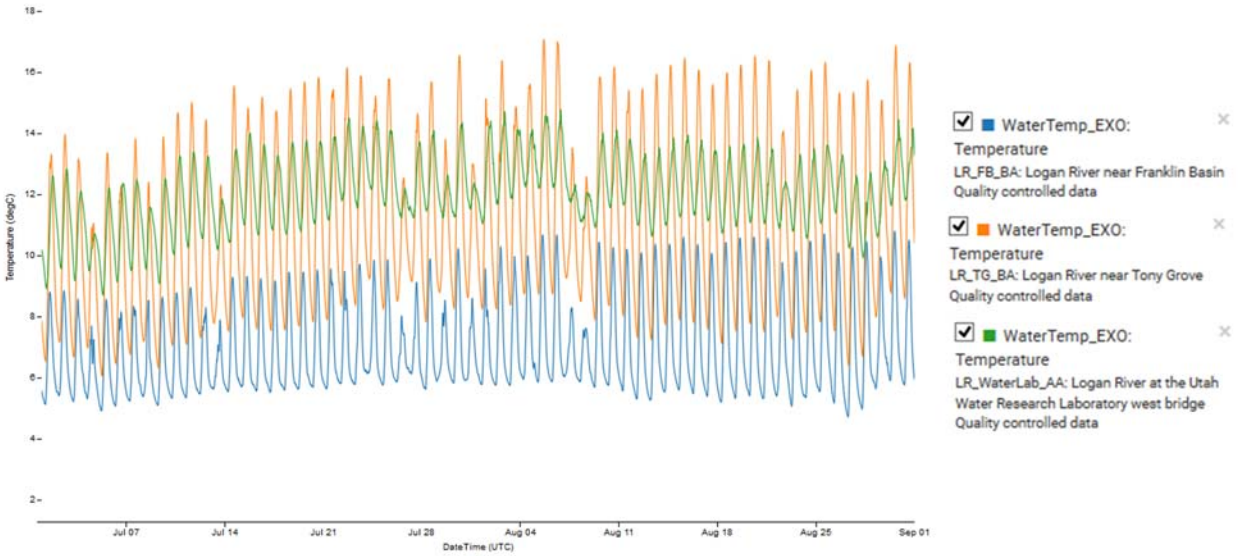


Figure 13. Logan River canyon site water temperature (°C) observations from July 1, 2019 to August 31, 2019.

In natural river systems without significant anthropogenic, chemical, or biological influences, dissolved oxygen concentrations generally have an inverse relationship with water temperature. Given the limited influence of nutrients in headwater areas and low variability in water temperature, dissolved oxygen concentrations at Franklin Basin vary less than 1 mg/L on most days (Figure 14). This variability increases at Tony Grove to approximately 1–2 mg/L each day, which is likely due in part to the larger daily temperature variation. However, at the UWRL, dissolved oxygen concentrations vary 2–3 mg/L each day. Given the low daily temperature range at this site, the relatively larger dissolved oxygen range is likely related to algae and macrophyte growth within First Dam that have occurred as flow through the reservoir has decreased due to changes in upstream diversion.

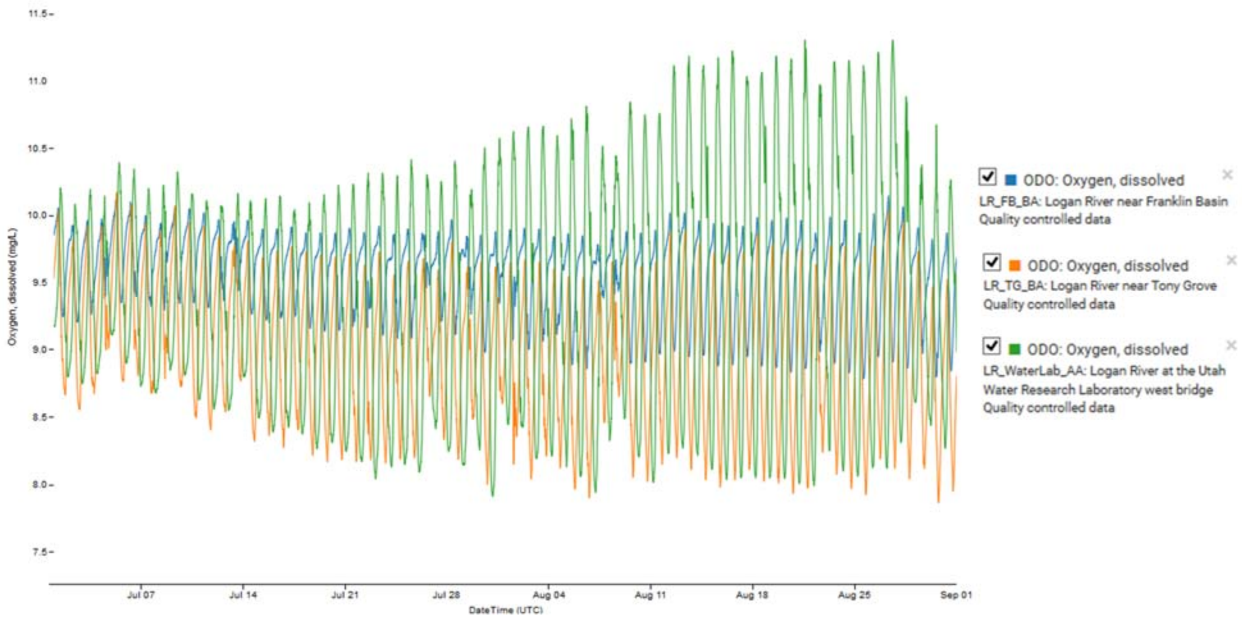


Figure 14. Dissolved oxygen (mg/L) observations at Logan River sites in Logan Canyon from July 1, 2019 to August 31, 2019.

In the valley portion of the watershed, as expected with decreased flow and increased human influences, the water temperature increases with distance downstream (Figure 15). During July, peak temperatures were similar between the UWRL and Main Street. However, near the end of July, peak Main Street temperatures were 1 to 1.5 °C warmer than those observed at the UWRL. This is likely due to larger diversion influences combined with a construction/river restoration project that removed a city block of riparian trees immediately above the Main Street monitoring site. Temperatures at Mendon Road were 3 °C higher on average than those at the UWRL and approached the 20 °C maximum temperature criteria for a cold water fishery. However, prior low flow years (2015, 2016, 2018) show regular exceedance of the 20 °C criteria at Mendon Road during the summer (Figure 16).

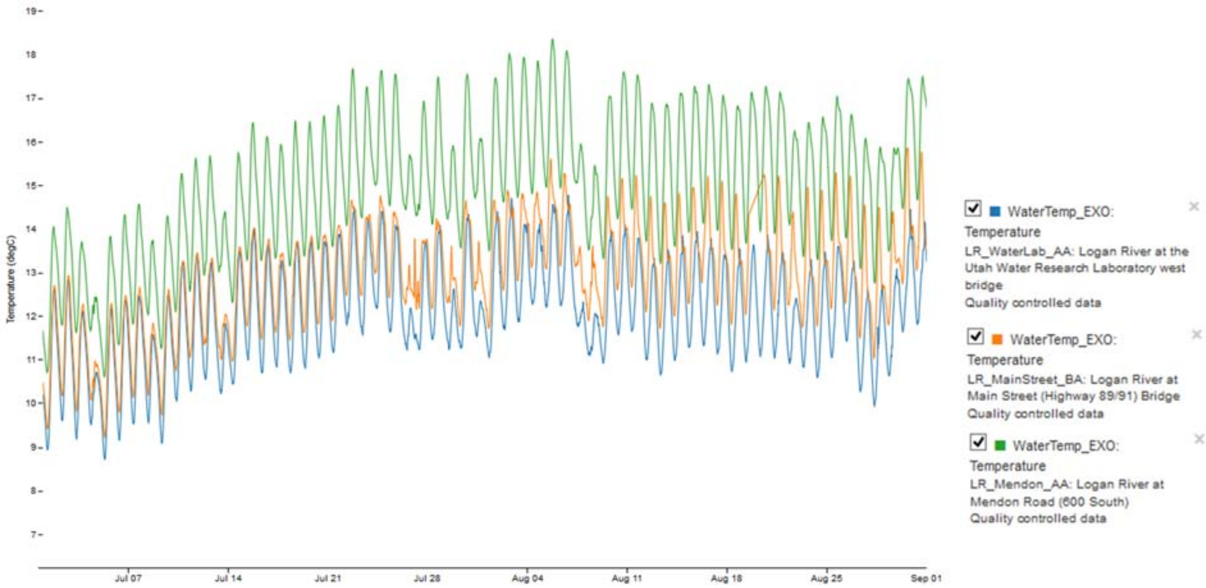


Figure 15. Logan River valley site water temperature (°C) observations from July 1, 2019 to August 31, 2019.

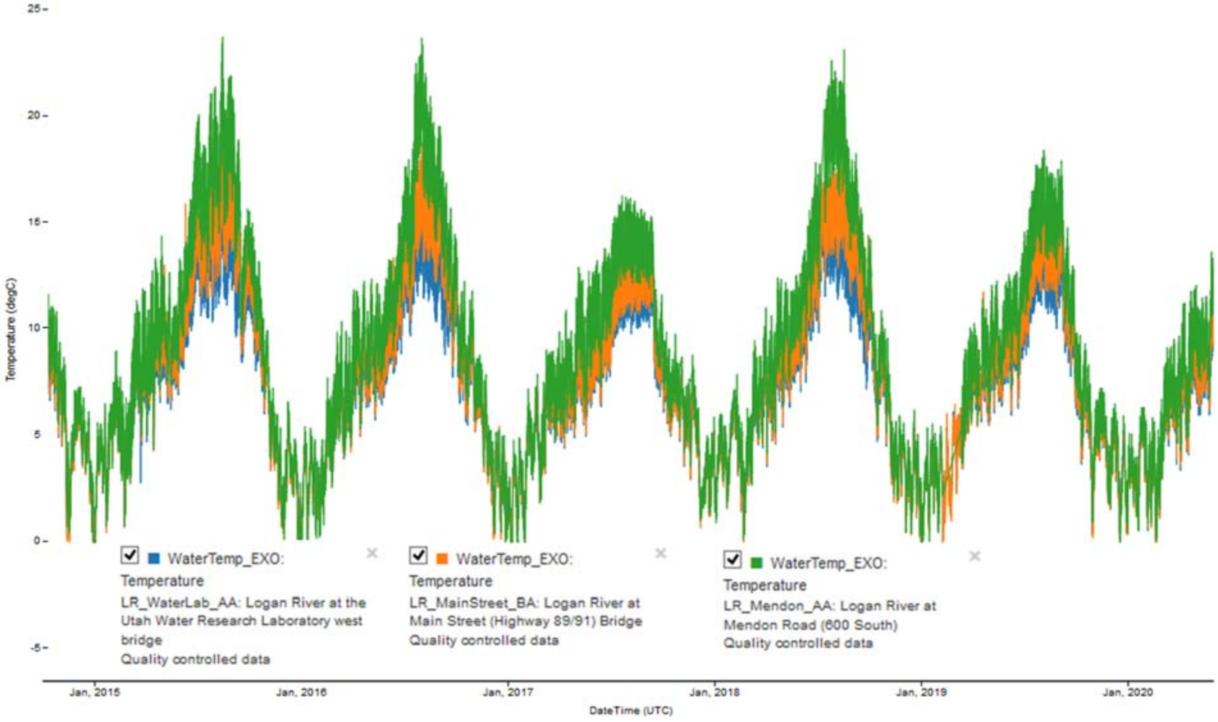


Figure 16. Logan River valley site water temperature (°C) observations from October 1, 2014 to May 31, 2020.

Dissolved oxygen concentrations at Main Street were similar to those at the UWRL in early July (Figure 17), but the daily variability at the UWRL was higher than at Main Street with lower minimum values. After late July, Main Street dissolved oxygen was reduced, in part due to temperature increases. Some data are missing at Main Street due to the construction in the area fouling the sensor. Dissolved oxygen is consistently lower at Mendon Road due primarily to elevated temperatures, but these values are not in violation of the Aquatic Wildlife 3A dissolved oxygen 30-day average standard of 6.5 mg/L for a cold water fishery (Rule R317-2, 2020). However, similar to temperature, in prior low flow years (2015, 2016, 2018) dissolved oxygen became very low and exceedances of the Aquatic Wildlife 3A minimum dissolved oxygen criteria of 4 mg/L occurred at Mendon Road in 2016 (Figure 18).

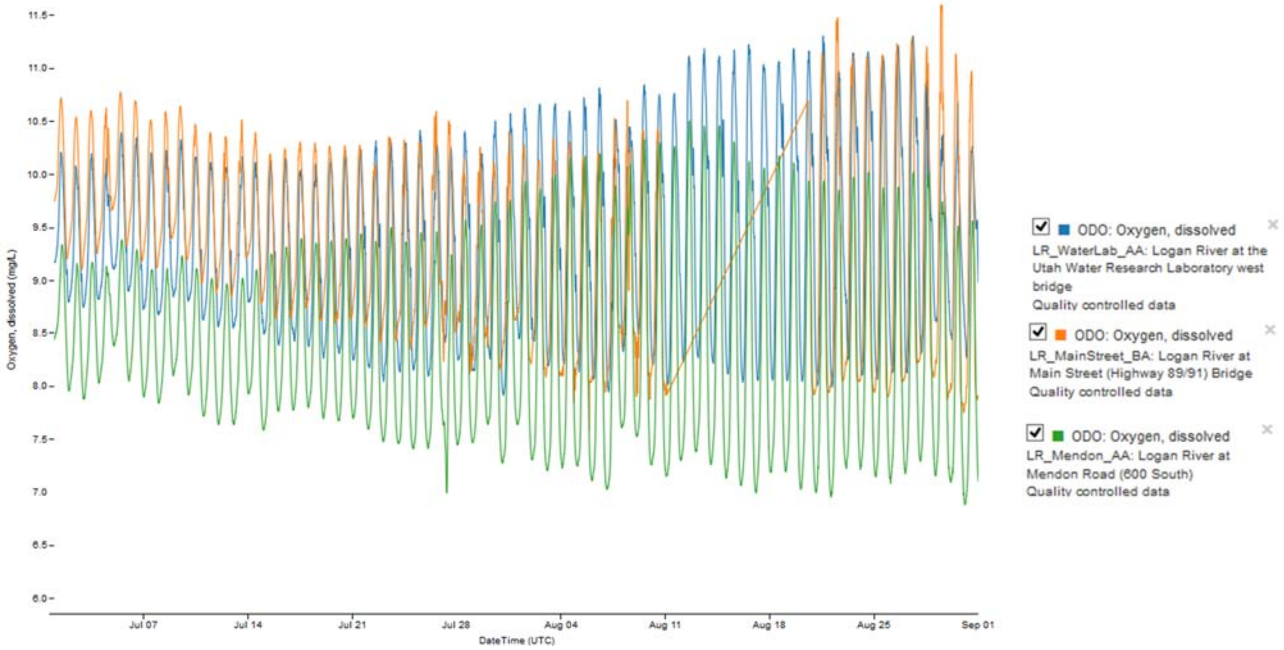


Figure 17. Logan River valley site dissolved oxygen (mg/L) observations from July 1, 2019 to August 31, 2019. Additional information regarding specific conductivity, turbidity, and pH are also available at these LRO locations.

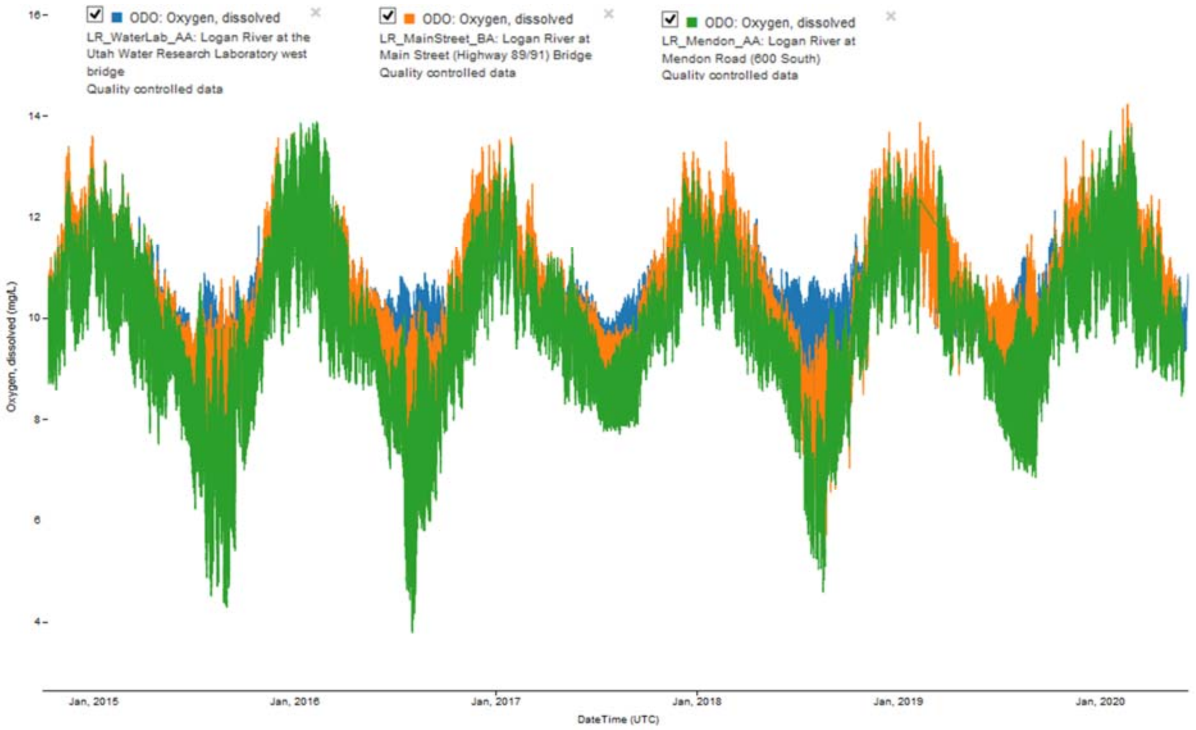


Figure 18. Logan River valley site dissolved oxygen (mg/L) observations from October 1, 2014 to May 31, 2020.

Summary of Key Findings

Logan Canyon portion of Logan River watershed:

- Lateral inflows in the canyon are important. A better understanding of the source of these contributions is clearly needed to ensure the reliability of water supply. Even with intense monitoring, understanding is limited regarding the sources of a large fraction (45–75% depending on season and year) of our water supply.

Cache Valley portion of the Logan River watershed:

- Diversions and reduced instream flows are impacting water temperature and dissolved oxygen concentrations lower in the valley. While summer 2019 had no water quality standard violations, summer low flow temperatures and dissolved oxygen concentrations at the Mendon Road site violated cold water fishery (3A) water quality standards during prior low flow years, and the Main Street location is nearing temperature thresholds.
- Similar to Logan Canyon, a relatively large fraction (~35%) of the summer flows in the valley are from unknown and unmeasured sources (e.g., stormwater, groundwater, agricultural returns). The hydrologic connectivity of different sources to the river needs to be better established in order to inform appropriate management activities. In other words, some conservation activities (e.g., lining of leaking canals or changes in irrigation practices) may potentially result in further reductions in summer low flow and water quality violations.

Summary of Research, Proposals, and Outreach Activities

The LRO data provides critical information to guide northern Utah's water resources planning and management decisions, but it also offers foundational information to support water-related research, which is a primary focus for scientists and engineers at the Utah Water Research Laboratory, other USU departments, and collaborators.

Completed and Ongoing LRO Research Projects

- **A hydraulic routing and river temperature model of the valley portion of the Logan River.** This model of a large section of the lower Logan River developed by Buahin et al. (2019) accounts for all gaged river inflows and outflows to determine other gains and losses to the system. This analysis resulted in an improved understanding of the dynamic inflows and outflows to the river system that was only possible with the high-resolution data collection and modeling employed.

- **Lateral inflow sources in the valley portion of the Logan River.** In Buahin et al. (2019), a calibrated temperature model allowed for determination of lateral inflow temperatures, which were used to indicate whether lateral inflows originated from colder groundwater or warmer urban/agricultural runoff.

- **Precipitation changes in snowmelt dominated watersheds with karst geology.** In Neilson et al. (2018), researchers found that significant amounts of river water were repeatedly exchanged between the river and the local aquifer and that the majority of the groundwater entering the river moves quickly through the system via karst aquifer conduits. These findings suggest that river flow each summer is highly dependent on very recent aquifer recharge from snow accumulation during the prior winter. Future research will focus on quantifying how changes to snowpack will influence summer streamflow.

- **Logan River LiDAR.** Light Detection and Ranging (LiDAR) topography data (0.5-m resolution) will be collected over the entire canyon portion of the Logan River watershed in late summer 2020. This data collection is a collaborative effort between Logan City, the LRO, and USGS 104(b). This new LiDAR data will augment data already available LiDAR for the valley section of the Logan River and will provide coverage of the full watershed to facilitate ongoing and future hydrologic studies.

- **Snow LiDAR.** LiDAR data will also be collected during winter 2020 in the Franklin Basin portion of the watershed. The resulting snow-on LiDAR will be combined with LRO snow-off LiDAR data and citizen science observations of snow depth conditions to further our understanding of snow distributions and water availability.

Student Projects

- **Inflow sources and losses in the valley portion of the Logan River.** Hyrum Tennant is an MS student in Civil and Environmental Engineering focusing on the valley portion of the Logan River. He is using flow, ion, and isotope data to establish detailed spatial estimates of flow losses, flow gains from ungaged lateral inflows, and flow source information.

- **Snow accumulation and melt modeling throughout the canyon portion of the Logan watershed to understand the connection to Logan River discharge.** Conor Tyson is an MS student in Civil and Environmental Engineering that is modeling snow accumulation and melt over the entire canyon portion of the Logan River watershed. These model results are being combined with machine learning approaches to link the spatial and temporal snowmelt patterns with streamflow.

- **Machine learning to better interpret LRO data.** Amber Jones is a PhD student in Civil and Environmental Engineering that will use different machine learning techniques to investigate surrogate measures, to develop automated methods of quality assurance/quality control of time series data, and to better understand lateral inflow variability throughout the Logan River watershed.

- **Didymo in Logan River.** Lindsey Capito is an MS student in Watershed Sciences investigating controls on *Didymosphenia geminate* (or didymo) growth in controlled and natural systems. Didymo is a stalk forming benthic diatom species that can diminish the recreational and aesthetic value of a stream, can cause infrastructure problems such as the fouling of water intakes, and can have significant ecosystem and ecological impacts. Didymo samples are being collected downstream of the UWRL site to monitor time variable responses where blooms have repeatedly occurred. LRO data at the UWRL site will be key in interpreting didymo trends.

Pending Proposals

- Neilson, B.T., J.S. Horsburgh. 2019. “Collaborative Research: Network Cluster: Water partitioning from mountains to lowlands: How critical zone structure modulates water supplies under a changing climate. National Science Foundation.
- Lane, B.A., B.T. Neilson, D. Isaak. 2020. “Quantifying summer stream temperature patterns and controls in irrigated western river basins.” National Science Foundation.
- Xu, T., B.T. Neilson, D.L. Newell, J.P. McNamara. 2020. “Collaborative Research: Quantifying Groundwater Sustainability Under Climate Change in Snow Dominated Mountainous Karst Areas Using Physically-based and Data-driven Hybrid Models.” National Science Foundation.

Education and Outreach

In addition to its value as a data source for research, the LRO also supports education by:

- Serving as an outdoor laboratory and classroom for training the next generation of engineers and scientists to address water issues in the state.
- Serving as a data source for real-world exercises in the classroom for several different USU classes.
- Supporting the research for many graduate and undergraduate students that will generate a better understanding of the limitations of and potential challenges related to our water supplies.
- In 2019, LRO provided opportunities to advance STEM education in local schools through K–12 outreach via the GearUP program.
- We are continuing to work to increase public awareness of the connection between the landscape, humans, and water.

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Spangler, L. E. (2001). Delineation of recharge in areas for karst springs in Logan Canyon, Bear River range, northern Utah, paper presented at U.S. Geological Survey karst interest group, U.S. Geological Survey Water Resources Investigations Report.

Spangler, L. E. (2011). Karst hydrogeology of the Bear River Range in the vicinity of the Logan River, Northern Utah, Paper Presented at Geological Society of America Rocky Mountain - Cordilleran Section Meeting, U.S. Geological Survey.

Rule R317-2, Standards of Quality for Waters of the State, Utah Administrative Code, Division of Administrative Rules, State of Utah, Salt Lake City, UT, January 1, 2020. Available at: https://rules.utah.gov/publicat/code/r317/r317-002.htm

Appendix A

Supplemental Materials

Table A-1. Climate site and parameters measured at each site within the Logan River Observatory.

Site Name	Site Code	Updates	Vapor Pressure (kPa)	Barometric Pressure (kPa)	Cumulative Precipitation (cm)	Snow Depth (cm)	Wind Speed (m/s)	Wind Direction	Air Temperature (C)	Relative Humidity (%)	Incoming Shortwave Radiation (W/m^2)	Outgoing Shortwave Radiation (W/m^2)	Incoming Longwave Radiation (W/m^2)	Outgoing Longwave Radiation (W/m^2)	Net Radiation (W/m^2)	Incoming PAR (umol/m^2 s)	Outgoing PAR (umol/m^2 s)	Soil Temperature @ 5,10,20,50,100 cm (C)	Soil Permittivity @ 5,10,20,50,100 cm	Soil Volumetric Water Content @ 5,10,20,50,100 cm (%)
Climate Station at Logan River Golf Course	LR_GC_C	Continuously Updated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Climate Station at Franklin Basin	LR_FB_C	Continuously Updated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Wilkins Repeater	LR_Wilkins_R	Continuously Updated					•	•	•	•										
Climate Station at TW Daniels Experimental Forest	LR_TWDEF_C	Continuously Updated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Climate Station at Tony Grove	LR_TG_C	Continuously Updated	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
Climate Station at Temple Fork		Periodically Updated		•	•		•	•	•	•										

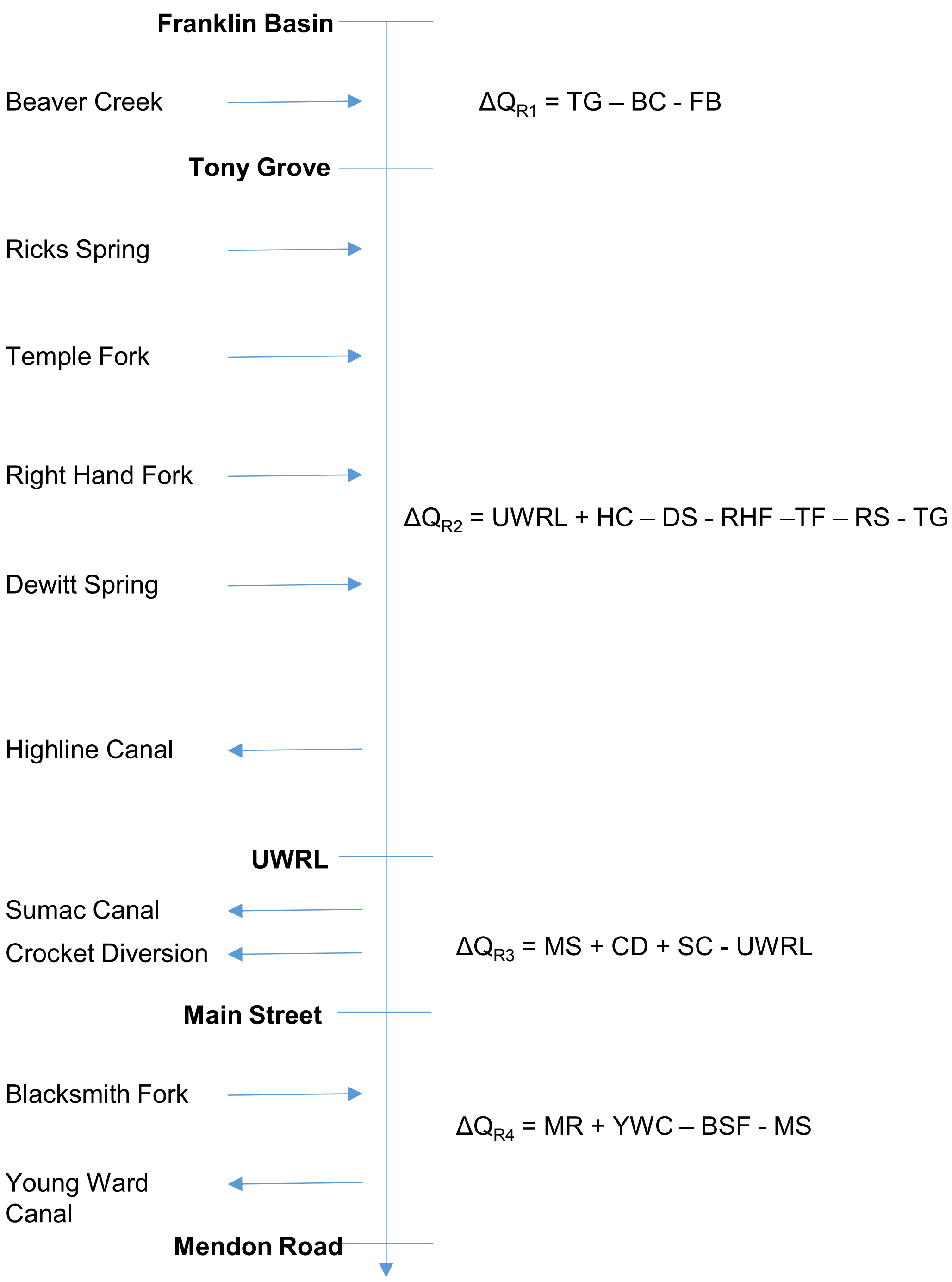

Figure A-1. Flow balance equations that were applied to daily average discharge values to get ΔQ values. ΔQ values represent amount of discharge that is not accounted for and is attributed to lateral inflows in Figure A-2 below and in Figures 7 and 10.

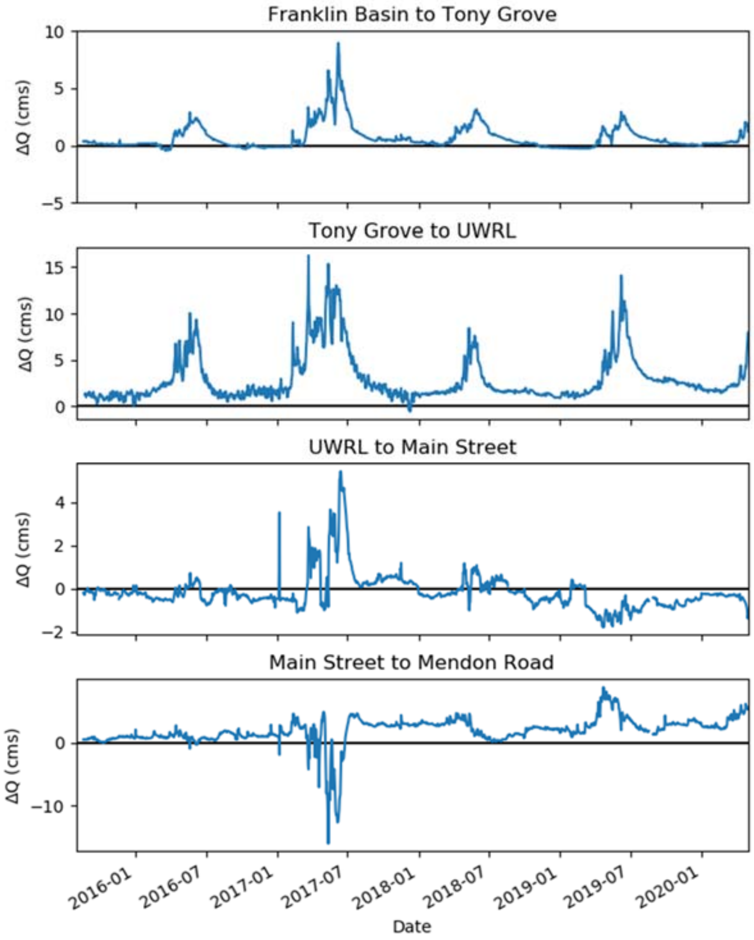

Figure A-2. Lateral inflow values over time for the different reaches in Figure A-1.

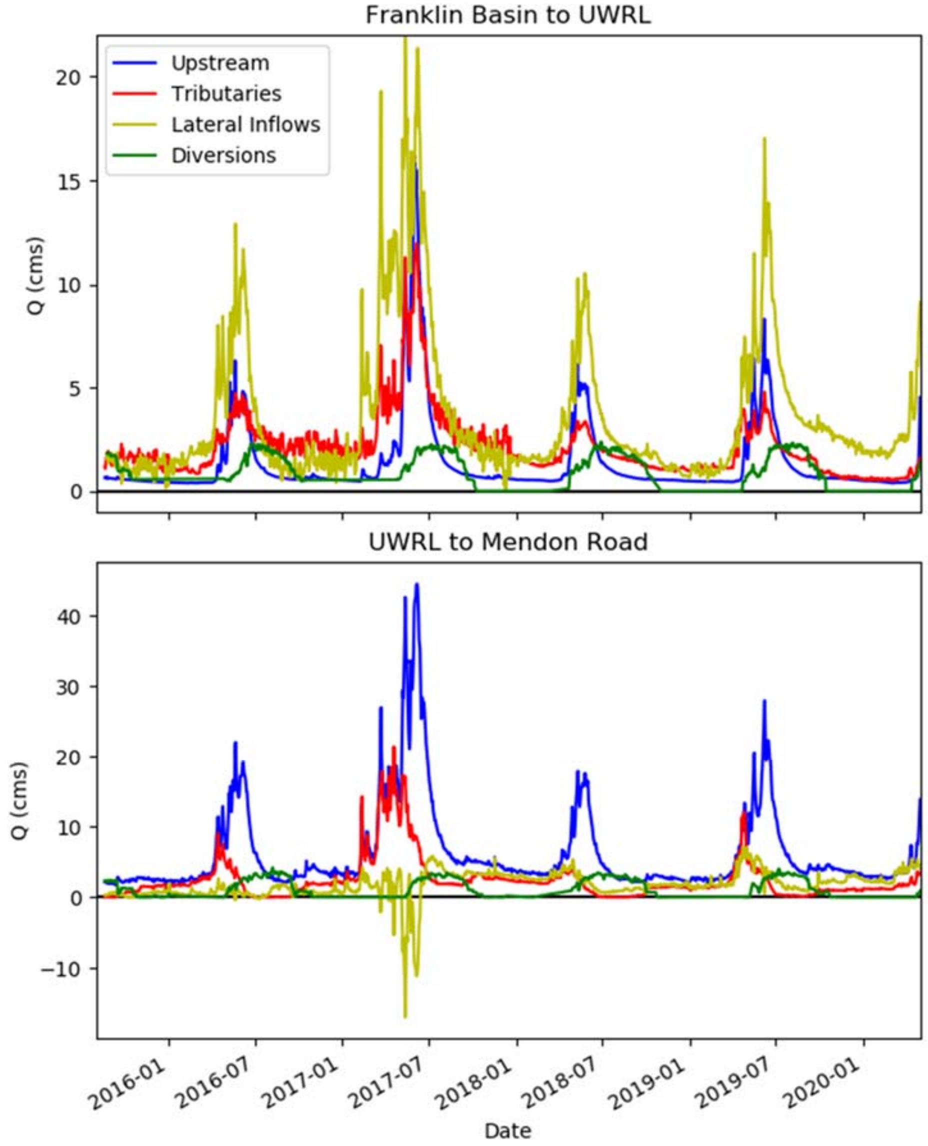

Figure A-3. Daily values of different inflow/outflow fractions used to estimate seasonal % contributions presented in Figures 7 and 10. These results combined equations in Figure A-1 to obtain the flow balance for the large sections of the Logan River watershed.