2019 Silver Lake Release Evaluation and Assessment

NRDP Task Order No. 90024.3.1

Submitted by Morgan Case
Trout Unlimited Western Water and Habitat Program
January 14, 2019

Acknowledgements

Trout Unlimited would like to acknowledge that this project would not have been possible without the help of numerous partners. The Montana Natural Resource Damage Program provided funding, guidance, and monitoring support. The Government of Butte Silver Bow, particularly the staff of the Water Division, was instrumental in conducting the release and collecting data. The Clark Fork Coalition and Watercourse Engineering were valuable partners, assisting with project development and data collection. The US Geologic Survey and Montana Department of Fish, Wildlife and Parks shared flow and temperature data. Fred Lurie, Charles Stokke, and Dave McKernan volunteered to collect bi-weekly measurements at several Warm Springs diversions. And finally, the Stodden family granted access to their property to maintain 3 monitoring sites. They also reminded us of the importance of our work by telling fishing stories and encouraging their grandkids to observe and ask questions while we took measurements. Thank you.

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Abbreviations

BSB	City-County Government of Butte Silver Bow
CFC	Clark Fork Coalition
FWP	Montana Department of Fish, Wildlife and Park
NRDP	Montana Natural Resource Damage Program
TU	Trout Unlimited
UCFR	Upper Clark Fork River
UCFRB	Upper Clark Fork River Basin
USGS	US Geological Survey
WCE	Watercourse Engineering
WSC	Warm Springs Creek

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Executive Summary

Warm Springs Creek and the upper Clark Fork River between Warm Springs Creek and Deer Lodge have flows that are considered inadequate for supporting healthy fish populations. Water temperatures also regularly exceed thermal thresholds of 15°C for healthy bull trout habitat and 20°C for westslope cutthroat trout. In addition to flow and temperature, the UCFR has elevated metal and arsenic concentrations from historic mining and smelting as well as other limiting factors impacting aquatic life. Silver Lake provides a unique opportunity to utilize high quality, cold water stored in the reservoir to address the flow and temperature issues downstream. Increases to instream flows in WSC and the UCFR will improve fish habitat, moderate water temperatures, and dilute nutrient and metal loads.

The Montana Natural Resource Damage Program tasked Trout Unlimited with coordinating, monitoring, and evaluating a release of water from Silver Lake, in the headwaters of WSC, near Anaconda. The purpose of the release was to demonstrate the effects of the flow release during the typical period of low flows in WSC and the UCFR and build upon previous efforts to characterize the WSC and UCFR hydrologic systems.

Butte Silver Bow released 10.8-15.5 cfs by gravity flow from the surface of Silver Lake from July 29-August 5, 2019. Between 28.5-32.6 cfs was pumped from the lake from August 6-August 27, 2019. A total of 1,571 AF was released into WSC, dropping the surface elevation of Silver lake 5.4 ft. The water temperature of the water released from the surface of Silver Lake was significantly warmer (~10 °C) than the water pumped from the lake.

Increased stream flow was detected at gages in WSC down through the UCFR at Deer Lodge, with losses detected in WSC below Anaconda and in the UCFR between WSC and Galen Road. At the end of the release, flows throughout the UCFR dropped an average of 11 cfs, indicating approximately 37% of the 30 cfs released was augmenting flow at Deer Lodge. Additional downstream water delivery may be possible with active water administration.

Detecting the impact of the release on water temperatures throughout the system was complicated by the higher than average flows, relatively cold water, and several large precipitation events during the release. Watercourse Engineering, Inc. is developing a temperature model using data from the 2019 release, which will illustrate the temperature effects of flow augmentation in WSC.

TU recommends conducting additional test releases over several years to inform stakeholders how releases into WSC for fisheries benefit fit into overall management of Silver Lake, including the newly negotiated plan to transfer water from Silver Lake to Blacktail Creek.

I. Introduction

Warm Springs Creek and the upper Clark Fork River between Warm Springs Creek and Deer Lodge have flows that are considered inadequate for supporting healthy fish populations. They often fall below the targets of 40 cfs at Galen and Warm Springs and 90 cfs at Deer Lodge established by the Upper Clark Fork Steering Committee. Water temperatures also regularly exceed thermal thresholds of 15°C for healthy bull trout habitat (Fraley and Shepard 1998; Dunham et al. 2003) and 20°C for westslope cutthroat trout (Bear et al. 2007). In addition to flow and temperature, the UCFR has elevated metal and arsenic concentrations from historic mining and smelting as well as other limiting factors impacting aquatic life. Silver Lake provides a unique opportunity to use the high quality, large quantity, cold water in the reservoir to address the flow and temperature issues downstream. Benefits of increases to instream flows to WSC and the UCFR will improve fish habitat, moderate water temperatures, and dilute nutrient and metal loads.

The Montana Natural Resource Damage Program tasked Trout Unlimited with coordinating, monitoring, and evaluating a release of water from Silver Lake, in the headwaters of WSC, near Anaconda. The purpose of the release was to demonstrate the effects of the flow release during the typical period of low flows in WSC and the upper UCFR and build upon previous efforts to characterize the WSC and upper UCFR hydrologic systems. This knowledge can be used to support development and implementation of a long-term project to lease water stored in Silver Lake to address flow limitations in lower WSC and the UCFR. The project will partially implement Proposed Action 1, Flow Quantity, for the WSC watershed identified in section 3.2.2. 2019 Final Upper Clark Fork River Basin Aquatic and Terrestrial Resources Restoration Plans, (Restoration Plans) In addition the project will partially address the Restoration Plans goals for the mainstem fishery of: 1.) Restoring the mainstem UCFR trout fishery by improving recruitment of fish from tributaries, 2.) Replace lost trout angling in the mainstem by improving trout populations in the tributaries and 3.) maintain or improve native trout populations in the UUCFRB to preserve rare and diverse gene pools and improve the diversity and resiliency of the trout fishery.

II. Materials and Methods

TU, NRDP, the Clark Fork Coalition and Watercourse Engineering identified the major inflow and outflow locations between Silver Lake and the UCF near Deer Lodge, reviewed existing flow and temperature monitoring locations, and discussed available equipment and staffing before developing a monitoring plan and release schedule (Attachment 1).

The final monitoring locations are listed in Tables 1 and 2 and shown on the map in Figure 1. Stream discharge measurements were collected following USGS protocols using either a Marsh McBirney Flo-mate or Hach Portable Flow Meter. Solinst Leveloggers, Onset Hobo Water Level Loggers, and TruTrack Data Loggers were installed in PVC housings attached to metal posts sunk into the streambed. The loggers recorded water depth and temperature at regular intervals. A Solinst Barologger installed in the housing with the water level recorder on WSC above Meyers dam and a Barologger on Dry Creek Ranch were used to adjust records to compensate for ambient air pressure. Temperature loggers were attached to rebar or concrete form posts, which were sunk into the stream bed in areas with shade and moving water. All monitoring instrumentation was installed by July 18th, 2019.

Table 1. Flow monitoring locations during 2019 Silver Lake release.

Location Name	Device/Method	Equipment Owner	Latitude	Longitude
Ditch below Silver Lake dam	Parshall Flume	BSB	46.16589	-113.21239
Ditch below Silver Lake dam	Solinst Levelogger	WCE	46.16576	-113.21070
Unnamed trib of Cable Creek	Manual Flow Measurement	TU	46.17047	-113.18791
Cable Creek above WSC	Manual Flow Measurement	TU	46.16873	-113.15412
Twin Lakes Creek above WSC	Manual Flow Measurement	TU	46.16777	-113.15395
WSC below confluence with Cable Creek	Solinst Levelogger	TU	46.16862	-113.15312
WSC above Meyers Dam	Solinst Levelogger	TU	46.15390	-113.04011
WSC near Anaconda	USGS Gage 12323760	USGS	46.13367	-112.90315
Gardiner Ditch	Parshall Flume		46.13750	-112.89259
WSC below Gardiner Ditch	TruTrack Data Logger	CFC	46.13750	-112.89202
WSC above Mertzig Rd (airport)	Manual Flow Measurement	TU	46.14529	-112.86842
WSC above Johnson Property	Manual Flow Measurement	TU	46.16484	-112.82453
WMA diversion	Parshall Flume	FWP	46.17164	-112.80465
WSC below WMA	Manual Flow Measurement	TU	46.17189	-112.80418
WSC at Warm Springs	USGS Gage 12323770	USGS	46.18038	-112.78508
Lost Creek near Anaconda	USGS Gage 12323840	USGS	46.16133	-112.89380
Lost Creek below Gardiner Ditch	Manual Flow Measurement	TU	46.16248	-112.88963
Mill Creek at Opportunity	USGS Gage 12323700	USGS	46.11438	-112.81978
Willow Creek at Opportunity	USGS Gage 12323720	USGS	46.10716	-112.81061
SBC at Opportunity	USGS Gage 12323600	USGS	46.10776	-112.80528
SBC below WS Ponds	Onset Hobo Pendant	WCE	46.17828	-112.78182
SBC at Warm Springs	USGS Gage 12323750	USGS	46.17950	-112.78056
UCFR nr Galen (Perkins Lane)	USGS Gage 12323800	USGS	46.20824	-112.76735
Lost Creek nr Confluence	Onset HOBO Water Level Logger	CFC	46.22663	-112.75989
UCFR at Galen Road	Onset HOBO Water Level Logger	CFC	46.23745	-112.75315
Alvi-Beck Ditch	TruTrack Data Logger	CFC	46.24516	-112.75137
Modesty Creek	Manual Flow Measurement	CFC	46.25509	-112.75469
Westside/Whalen Ditch	Calculate	NA	46.26091	-112.75242
UCFR at Gemback Bridge	Onset HOBO Water Level Logger	CFC	46.26522	-112.74477
UCFR below Racetrack Creek	Onset HOBO Water Level Logger	CFC	46.28937	-112.72409
Valiton Ditch	TruTrack Data Logger	CFC	46.29423	-112.72344
UCFR at Sager Lane	Onset HOBO Water Level Logger	CFC	46.31741	-112.73612
UCFR at Deer Lodge	USGS Gage 12324200	USGS	46.39765	-112.74254

Table 2. Temperature monitoring locations during 2019 Silver Lake release.

Location Name	Device	Equipment Owner	Latitude	Longitude
Ditch below Silver Lake dam	Solinst Levelogger	WCE	46.16576	-113.21070
WSC below Sub	Onset Hobo Pro V2	FWP	46.22598	-113.18185
WSC above Cable Creek	Onset Hobo Pro V2	WCE	46.17302	-113.15688
Cable Creek above WSC	Onset Hobo Pro V2	TU	46.16873	-113.15412
Twin Lakes Creek above WSC	Onset Hobo Pro V2	TU	46.16777	-113.15395
WSC below confluence with Cable Creek	Solinst Levelogger	TU	46.16862	-113.15312
WSC above Foster Cr	Onset Hobo Pro V2	FWP	46.16195	-113.12893
WSC above Meyers Dam	Solinst Levelogger	TU	46.15390	-113.04011
WSC below Meyers Dam	Onset Hobo Pro V2	TU	46.15382	-113.03683
WSC near Anaconda	Onset Hobo Pro V2	FWP	46.14174	-112.98315
WSC below Gardiner Ditch	TruTrack Data Logger	CFC	46.13750	-112.89202
WSC near Mouth	Onset Hobo Pro V2	FWP	46.18042	-112.78529
Mill Creek at Opportunity	USGS Gage 12323700	USGS	46.11438	-112.81978
Willow Creek at Opportunity	USGS Gage 12323720	USGS	46.10716	-112.81061
SBC at Opportunity	USGS Gage 12323600	USGS	46.10776	-112.80528
SBC below WS Ponds	Onset Hobo Pendant	WCE	46.17828	-112.78182
Mill Willow Bypass	Onset Hobo Pro V2	TU	46.17815	-112.78333
SBC above WSC	Onset Hobo Pro V2	TU	46.18081	-112.77979
Silver Bow Creek near Opportunity	Onset Hobo Pro V2	FWP	46.10710	-112.80496
UCFR nr Galen (Perkins Lane)	Onset Hobo Pro V2	CFC	46.20853	-112.76748
Lost Creek nr Confluence	Onset HOBO Water Level Logger	CFC	46.22624	-112.76059
UCFR at Galen Road	Onset HOBO Water Level Logger	CFC	46.23745	-112.75315
UCFR at Gemback Bridge	Onset HOBO Water Level Logger	CFC	46.26522	-112.74477
UCFR below Racetrack Creek	Onset HOBO Water Level Logger	CFC	46.28937	-112.72409
UCFR at Sager Lane	Onset HOBO Water Level Logger	CFC	46.31741	-112.73612
UCFR at Deer Lodge	Onset Hobo Pro V2	CFC	46.39765	-112.74254

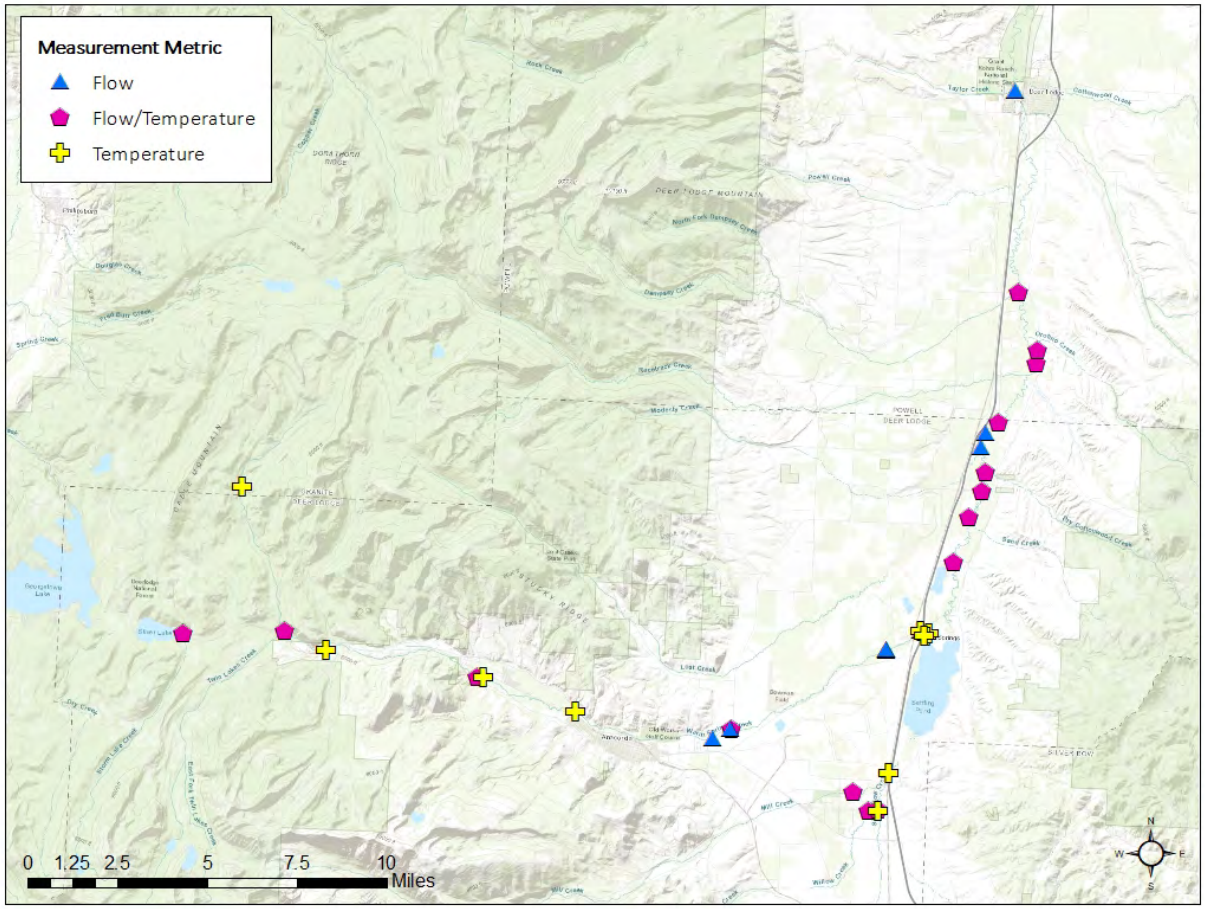


Figure 1. Flow and temperature monitoring locations for 2019 Silver Lake Release.

The monitoring plan called for three synoptic measurement events, which consist of a series of discharge measurements along the project reach within a short period of time. The results are intended to identify the location and magnitude of stream losses or gains due to interaction with groundwater or unmetered surface water. TU and project partners conducted pre-release synoptic measurements on July 18, 2019, and two mid-release synoptic measurement events on August 1 and August 16, 2019. Additional discharge measurements were taken mid-release to further characterize the hydrology and develop stage-discharge relationships for data loggers. Due to the inherent error in measurement (the USGS considers a +/- 5% error acceptable for the highest quality measurement), the discharge figures within this report are most informative when considered in terms of relative change over the period of the test release.

Major irrigation diversions were monitored during the release, but no attempts were made to shepherd the released water past diversions. Active administration of water rights in WSC and the upper UCFR during future releases could increase flow and temperature impacts downstream.

III. Results

Pre-release conditions

Prior to the Silver Lake release, flows at the four USGS stream gages between Silver Lake and Deer Lodge were higher than the median historic flow (see Appendix A). On July 28, 2019, the day before the release, the mean daily discharge at the USGS gage on WSC at Warm Springs was 55 cfs, 15 cfs greater than 40 cfs flow target set by FWP in the 1989 instream flow reservation application. On the day of the release, flows were trending towards hitting the 40 cfs target flow. Flows at the USGS gages on the UCFR near Galen and at Deer Lodge were significantly higher than the flow targets established in the NRDP 2011 Aquatic Prioritization Plan. The mean daily discharge was 121 cfs near Galen, more than triple the 40 cfs target; and 139 cfs at Deer Lodge, almost 50 cfs greater than the 90 cfs target. A rainfall event prior to the release resulted in increased flows in WSC and the upper UCFR, which were decreasing before the start of the release.

Release

BSB began a gravity release from Silver Lake on the morning of July 29, 2019 and continued releasing water (10.8-15.5 cfs, as measured in the Parshall flume in the outlet ditch) through August 5, 2019 (Figure 2). On the morning of August 6, 2019, BSB began pumping water from Silver Lake. They continued pumping (28.5-32.6 cfs) through August 27, 2019. Approximately 1,571 AF of water stored in Silver Lake was released. The surface elevation of the lake decreased 5.45 ft, which corresponds with a calculated storage loss of 1,631 AF. Evaporation and seepage losses likely account for the difference. The mean and maximum daily temperature of the water released via gravity were all over 20 °C and approximately 10 degrees warmer than the water released via pumping (Figure 2). See Appendix B.

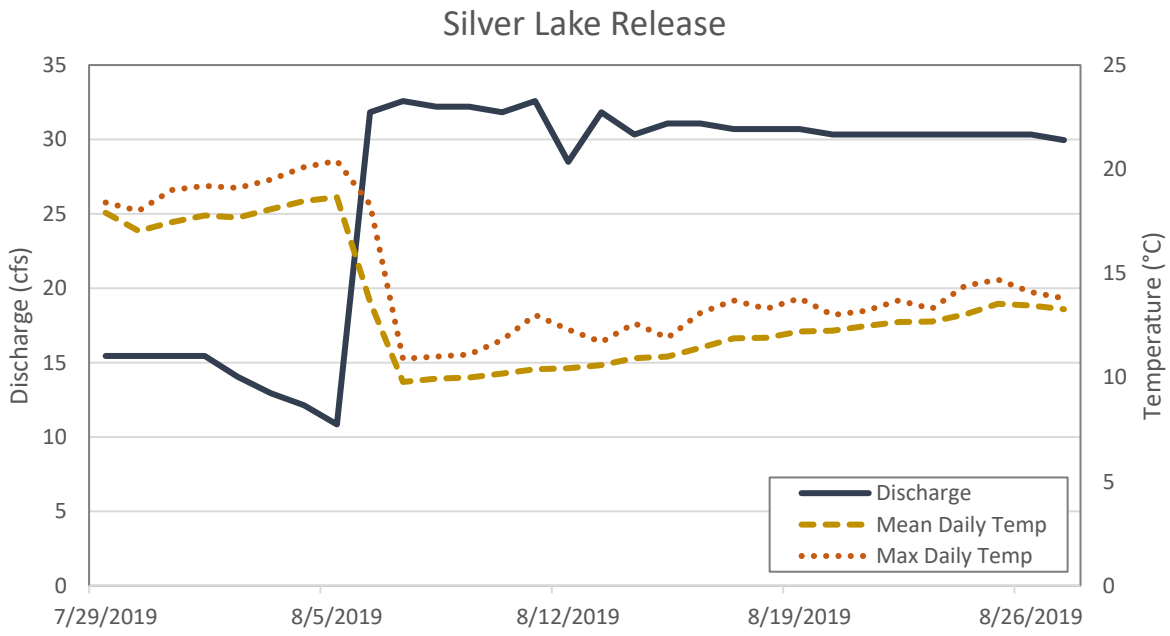


Figure 2. Silver Lake release discharge and water temperature, as measured by Parshall flume and Solinst Levelogger.

Discharge Response

The measured response of discharges in WSC and the UUCFR varied in timing and magnitude, with the more immediate, and therefore easier to correlate, increases in flow occurring closer to Silver Lake and attenuating with distance from the lake (see Appendixes A and C). All flow monitoring sites on WSC had changes in flow which followed the pattern of the release, with a 7.8-14.3 cfs increase between July 29 and July 31, 2019; additional increase of 7-24.2 cfs when pumping commenced on August 5, 2019; and a decrease of 16.2-34.2 cfs when pumping stopped on August 27, 2019 (Table 3 and Figure 3). Flows at Warm Springs dipped below the 40 cfs target towards the end of the gravity release, before increasing above the target during the pumped release.

The USGS gage at Warm Springs reflected the smallest increases 2 days after the gravity and pump releases began. The lower values could be attributed to longer travel times, reach losses, or measurement error. Rain events prior to and during the release make it difficult to isolate the effects of the Silver Lake release from the effects of precipitation (Figure 3), but the synoptic measurements (Table 4) showed that the reach from WSC below the WMA to the USGS gage at Warm Springs gained between 2 and 14 cfs, or an average of 10.5%. Another potential explanation for the loss is inaccurate estimation of the WMA diversion. During the release, TU staff determined that the Parshall flume on the ditch was operating in submerged conditions, making readings from the flume unreliable. TU measured 4.4 cfs in the ditch on both August 8 and August 16, 2019. Based on those measurements, TU assumed diversion in the ditch was relatively constant, and calculated the reach gain accordingly. See Appendix C.

Table 3. Warm Springs Creek mean daily discharge values before, during, and after Silver Lake Release.

Location	Gravity Release			Begin Pumping			Cease Pumping		
	7/29/2019 Mean Daily Discharge (cfs)	7/31/2019 Mean Daily Discharge (cfs)	Change (cfs)	8/5/2019 Mean Daily Discharge (cfs)	8/7/2019 Mean Daily Discharge (cfs)	Change (cfs)	8/26/2019 Mean Daily Discharge (cfs)	8/29/2019 Mean Daily Discharge (cfs)	Change (cfs)
Silver Lake Release	0	15.5		10.8	32.6		30.3	0	
WSC blw Cable Creek	33.4	47.7	14.3	40.5	60.9	20.4	53.9	23.2	-30.7
WSC abv Meyers Dam	80.2	88.4	7.8	79.7	104.9	24.2	94.7	67.1	-27.6
WSC near Anaconda	104.0	117.0	13.0	101.0	124.0	23.0	131.0	96.8	-34.2
WSC blw Gardiner Ditch	47.4	60.3	12.7	45.5	69.0	23.5	77.2	43.3	-33.9
WSC at Warm Springs (USGS 12323770)	46.7	55.3	8.6	42.3	49.3	7.0	58.5	42.3	-16.2

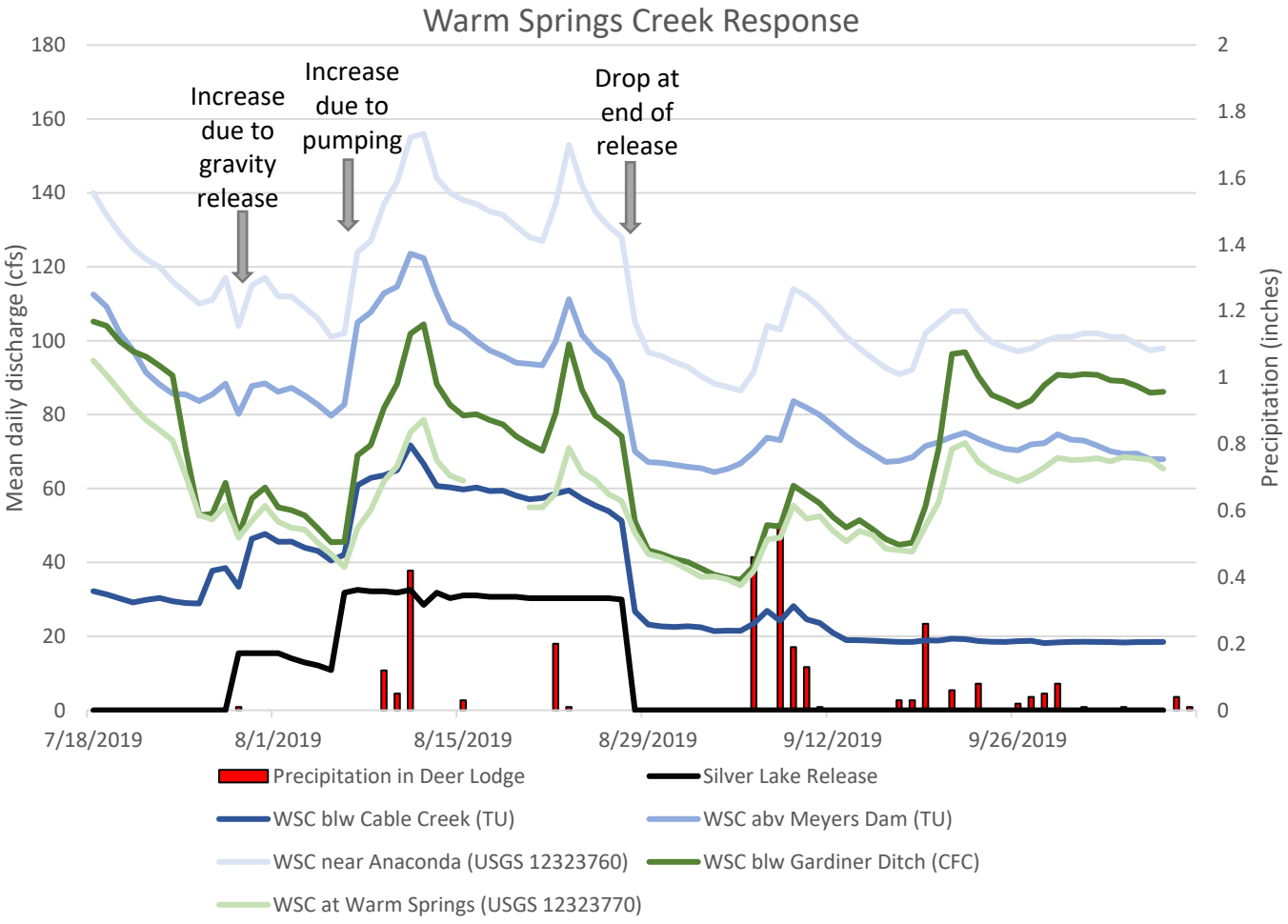


Figure 3. Mean daily discharge at Warm Springs Creek stream gages and daily precipitation at Deer Lodge, MT Agrimet Weather Station.

Irrigation and industrial diversions from WSC were measured or estimated during the release. While no adjustments were made to the Gardiner Ditch headgate, the diversion fluctuated passively in response to increased flows (Figure 4).

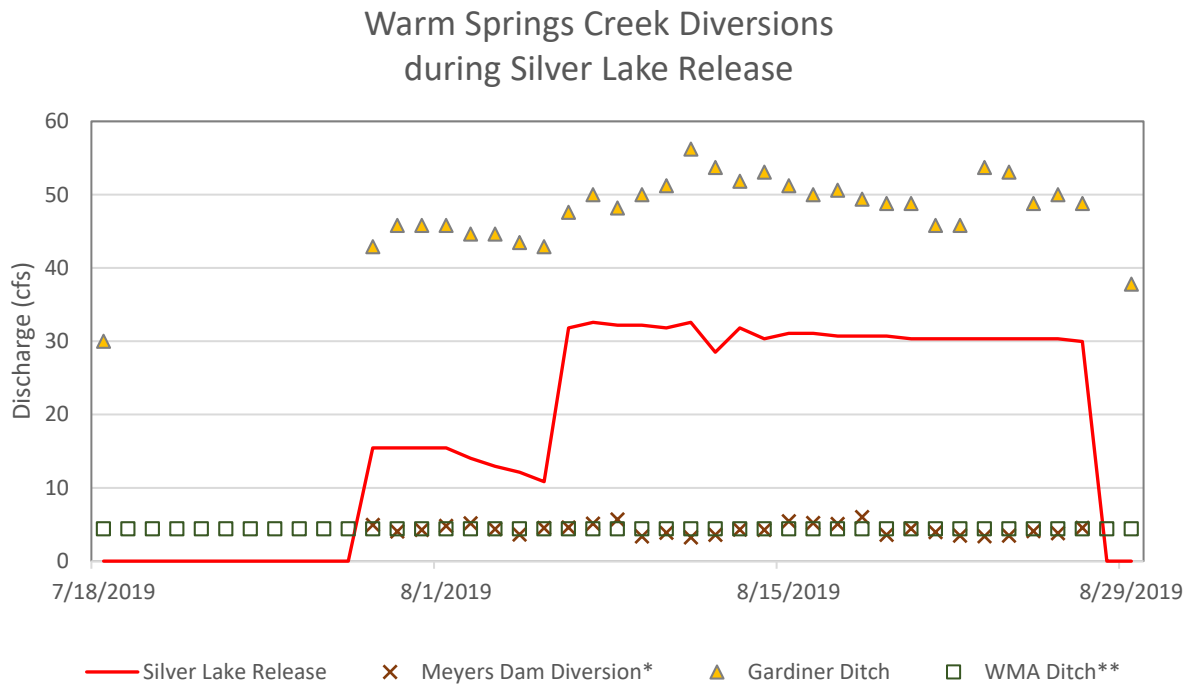


Figure 4. Warm Springs Creek diversions (cfs) during Silver Lake release. * Meyers dam diversion estimated using BSB TIFID influent measurements. ** WMA ditch estimated at a constant 4.4 cfs based on several discharge measurements.

The synoptic measurements also showed that WSC gains flow from the confluence with Cable Creek down to Anaconda. The reach below Cable Creek to Meyers dam gained 76 cfs (224%) on July 18, 2019 although that included Twin Lakes Creek, Foster Creek, and Barker Creek. The gains of 39 cfs (56%) and 28 cfs (35%) on August 1 and August 16, 2019, do not include the contribution of Twin Lakes Creek, 11 cfs and 17 cfs respectively. There is also an unmeasured irrigation diversion within that reach that suggests greater gains than calculated. The reach from Meyers dam to Anaconda gained 37.3 cfs (35%) prior to the release on July 18, 2019. Similar gains were recorded during the release, with a gain of 33.8 cfs (28%) on August 1, 2019 and 46.2 cfs (35%) on August 18, 2019. Diversion from Meyers dam was estimated using the TIFID influent values provided by BSB. See Table 6 and Appendix C.

WSC loses flow between the USGS gage near Anaconda and the WMA ditch. Prior to the release on July 18, WSC lost 6 cfs (5%) between Anaconda and below the Gardiner Ditch and 10 cfs (9%) between the gage below Gardiner to the measurement site below the WMA ditch. During the release, WSC lost 7 cfs (10%) and 23 cfs (14%) between Anaconda and below the Gardiner Ditch. An additional 10 cfs (17%) and 23 cfs (29%) was lost during the August 1 and August 16, 2019 synoptic measurements in the reach downstream to the WMA ditch. TU walked the reach between the Anaconda gage and the Gardiner ditch to see if there were any obvious pathways for the average 16.4% loss/mile. The stream appeared to have been straightened and confined to a narrow floodplain. There was no evidence of diversion or out of

channel flow. There were side channels without return paths to WSC that appeared to be active during high flow. There were also exposed unstable banks consisting of large gravel and cobble, like the stream bed materials. This material could facilitate loss to groundwater, especially at higher flows. See Table 4 and Appendix C.

Table 4: Synoptic Discharge measurements and reach characterization.

Location	7/18/2019 Discharge (cfs)	8/1/2019 Discharge (cfs)	8/16/2019 Discharge (cfs)	Average Change	Distance (mi)	Change/mi	River Mile	Comment
Silver Lake Release	0	14	31					
Cable Creek		23	39					
WSC blw Cable	34	43	62				25.6	Barker & Foster Creeks and small diversion in reach
+ Twin Lakes Creek		11	17					
= Calculated Flow at WSC abv Meyers		54	79					
Difference WSC Cable to abv Meyers		56%	35%	45%	6.2	7.3%		Insufficient data for 7/18 reach/gain analysis
WSC ab Meyers	110	84	107				19.4	
- TIFID influent (proxy for diversion at Meyers)	4.3	4.81	5.2					Average of record used for 7/18 and 7/25 values
= Calculated Flow at WSC nr Anaconda	105.7	79.2	101.8					
Difference WSC abv Meyers to Anaconda	35%	35%	28%	33%	8.0	4.1%		
USGS WSC nr Anaconda	143	113	137				11.4	Airport pump in reach
- Gardiner Ditch	30	46	50					
= Calculated Flow at WSC bl Gardiner	113	67	87					
Difference Anaconda to blw Gardiner	-5%	-10%	-14%	-10%	0.6	-16.4%		
WSC blw Gardiner Ditch	107.0	60.0	75.0				10.80	
- WMA Ditch	4.4	4.4	4.4					Assumed 4.4 cfs based on several measurements
= Calculated Flow WSC blw WMA Ditch	102.6	55.6	70.6					
Difference Above Gardiner to WSC blw WMA	-9%	-17%	-29%	-19%	6.6	-2.8%		
WSC below WMA Ditch	93	46	50				4.2	
Difference Between WSC blw WMA and Warm Springs	2%	11%	28%	14%	1.3	10.5%		
USGS WSC at Warm Springs	95	51	64				2.9	
Silver Bow Creek abv WS	104	63	63					
UCFR at Galen (Perkins Lane)	201	123	129				336.9	
+ Lost Creek nr Confluence	10	11.1	22					
= Calculated Flow at Galen Rd	211	134.1	151					
Difference between UCFR at Galen (Perkins Lane) and Galen Rd	-7%	-5%	6%	-2%	4.0	-0.5%		
UCFR at Galen Road	197	127	160				332.9	
+ Dry Cottonwood Creek	1.2	0	0					
- Alvi-Beck Ditch	4	4	4					
+ Modesty Creek	7.5	7.5	7.5					
= Calculated Westside/Whalen Ditch	44.7	35.5	33.5		4.1			Gain/loss not determined due to calculated diversion
UCFR at Gemback Bridge	157	95	130				328.8	
+ Racetrack Creek	5	5	5					
= Calculated Flow blw Racetrack	162	100	135					
Difference between UCFR at Gemback Bridge and below Racetrack	24%	8%	6%	12%	2.9	4.3%		Includes flow from Racetrack Creek
UCFR blw Racetrack Creek	212	109	143				325.9	
- Valiton Ditch	6.3	5.8	5.6					
= Calculated UCFR at Sager Lane	205.7	103.2	137.4					
Difference between UCFR blw Racetrack and at Sager Lane	1%	4%	0%	2%	3.1	0.6%		
UCFR at Sager Lane	208	107	138				322.8	
Difference between UCFR at Sager Lane and at Deer Lodge	32%	40%	33%	35%	8.6	4.1%		
UCFR at Deer Lodge	275	150	183				314.2	

* Color Legend: Measured Discharge, Estimated Discharge, Calculated Discharge, Reach Loss, Reach Gain

Despite the smaller gains in lower WSC, greater increases were recorded in the UCFR following the July 29, 2019 release, approximately 2 days later. The smallest increase (9 cfs) was recorded at USGS gage near Galen, with increases up to 21 cfs at the USGS gage at Deer Lodge (Table 5). The Agrimet weather station in Deer Lodge recorded 0.01 inches of rain on July 29, 2019, which may explain the anomalous larger scale increases further away from Silver Lake (Figure 5). The increases following the transition to pumping on August 6, 2019 follow the expected pattern of greater increases upstream and smaller increases towards Deer Lodge. A 17. 1 cfs increase at the USGS gage near Galen was detected one-day after the release. An increase of only 2 cfs was recorded at the USGS gage at Deer Lodge on the same day. Larger increases would be expected after several days, but unfortunately a large rainstorm caused flows to increase approximately 100 cfs starting on August 8, 2019 (Figure 5). This masked any delayed increases caused by the Silver Lake release. Two days following the end of the release, flows in the UCFR had dropped between 9.4 and 12.2 cfs, demonstrating approximately a third of the released Silver Lake water was contributing to flows in the upper Clark Fork near Deer Lodge.

Table 5. Clark Fork River mean daily discharge values before, during, and after Silver Lake Release.

	Gravity Release			Begin Pumping			Cease Pumping		
Location	7/29/2019 Mean Daily Discharge (cfs)	7/31/2019 Mean Daily Discharge (cfs)	Change (cfs)	8/6/2019 Mean Daily Discharge (cfs)	8/7/2019 Mean Daily Discharge (cfs)	Change (cfs)	8/28/2019 Mean Daily Discharge (cfs)	8/30/2019 Mean Daily Discharge (cfs)	Change (cfs)
Silver Lake Release	0	15.5		31.8	32.2		0	0	
UCFR near Galen	114.0	123.0	9.0	90.9	108.0	17.1	99.1	87.9	-11.2
UCFR at Galen Rd	117.7	131.2	13.5	105.6	111.1	5.5	130.1	118.3	-11.8
UCFR at Gemback Bridge (CFC)	86.1	103.5	17.4	68.5	74.4	5.9	105.9	95.7	-10.2
UCFR blw Racetrack Creek (CFC)	97.2	117.1	19.9	80.6	84.7	4.1	121.3	109.1	-12.2
UCFR at Sager Ln	93.2	110.2	17.0	82.7	85.1	2.4	116.5	107.1	-9.4
UCFR at Deer Lodge	135.0	156.0	21.0	119.0	121.0	2.0	173.0	161.0	-12.0

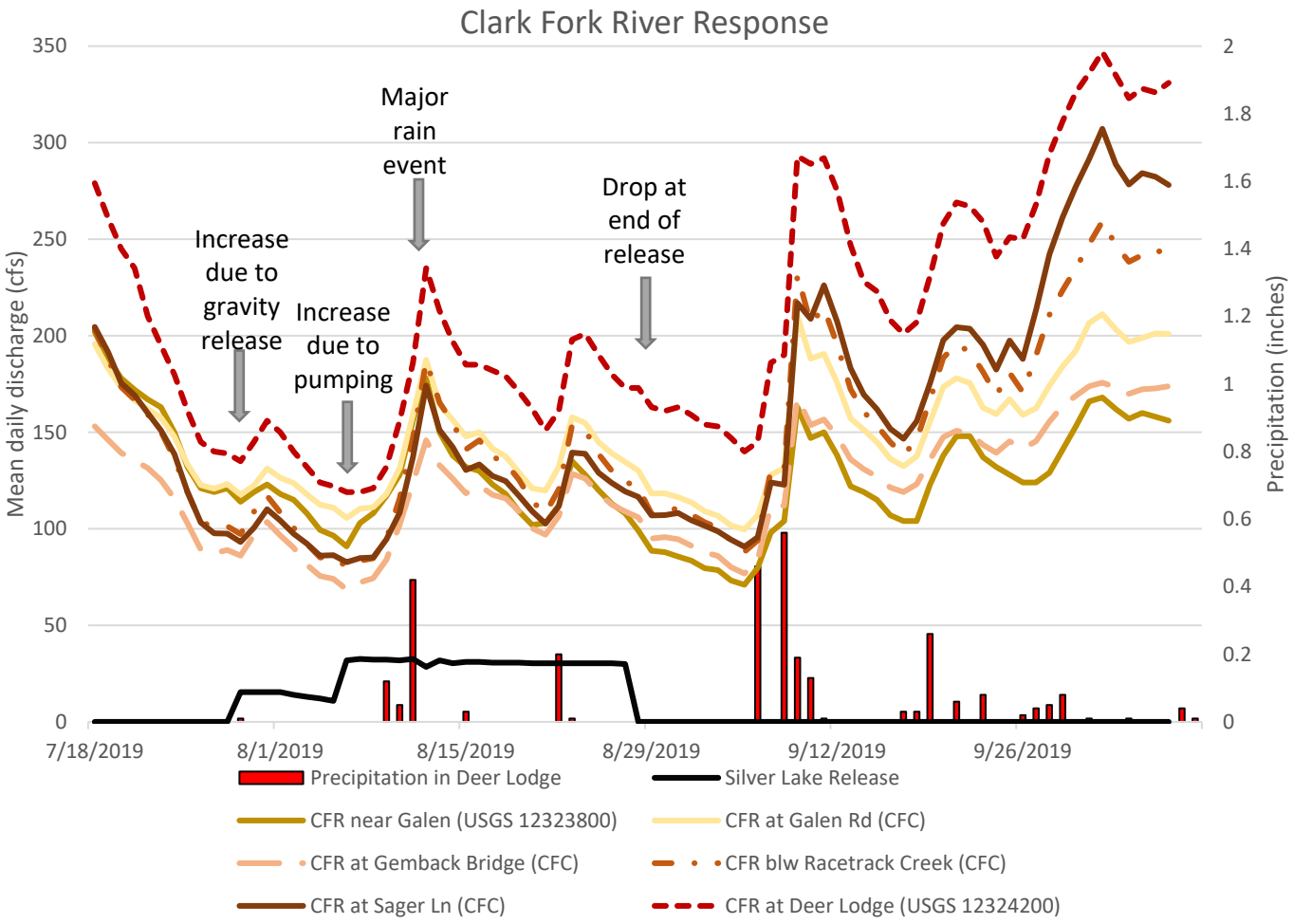


Figure 5. Mean daily discharge at Clark Fork River stream gages and daily precipitation at Deer Lodge, MT Agrimet Weather Station.

The pre-release synoptic measurements on the upper Clark Fork showed losses of 14 cfs (7%) and 7.1 cfs (5%) in the reach between the USGS gage near Galen and the CFC gage at Galen Road on July 18, 2019 and August 1, 2019, respectively. The measurements on August 16, 2019, following the large rain event, showed a 9 cfs (6%) gain. In the reach between Galen Road and the Gembeck bridge, Dry Cottonwood Creek added 1.2 cfs on July 18, 2019, but was dry during the other synoptic measurements. Modesty Creek was estimated to contribute a consistent 7.5 cfs, based on spot measurements by CFC; the Alvi-Beck ditch was estimated to divert 4 cfs, based on a CFC measurement on July 31, 2019; and all other losses were attributed to diversion into the Westside-Whalen Ditches. From Gemback to below Racetrack Creek, the UCFR consistently gained flow. Racetrack Creek was estimated to contribute a consistent 5 cfs based on past CFC measurements. The UCFR gained 50 cfs (24%) prior to the release, 9 cfs (8%) on August 1, 2019, and 15 cfs (6%) on August 18, 2019.

The reach below Racetrack Creek to Sager Lane showed small gains, with 2.3 cfs (1%) prior to the release on July 18, 2019, 3.8 cfs (4%) on August 1, 2019, and 0.6 cfs (<1%) on August 16, 2019 during the release.

The lowest reach, between Sager Lane and Deer Lodge showed the largest gains, aligning with previous studies which have shown significant ground and surface water returns. Prior to the release, the UCFR gained 67 cfs (32%). During the release it gained 33 cfs (40%) on August 1, 2019 and 27 cfs on August 16, 2019 (35%).

Assuming irrigation diversion was curtailed by early October and discharge values reflected the natural flow condition, TU applied the reach losses seen at that time to a range of flow releases to model the expected flow impact through the system (Table 6). Additional pre-release and post-release synoptic measurements could be used to refine a similar model accepted by not only the entities developing a long-term agreement, but also the water users and local public.

Table 6. Modeled discharge increase based on October 7, 2019 reach losses between Silver Lake and Deer Lodge. Diversion was assumed to be curtailed. Gaining reaches were assigned zero loss.

	Discharge on 10/7/2019	Reach Loss	Expected increase from release (cfs)		
			30 cfs release	20 cfs release	10 cfs release
WSC blw Cable Creek (TU)	18.5				
WSC abv Meyers Dam (TU)	68.3	0%	30	20	10
WSC near Anaconda (USGS 12323760)	97.9	0%	30	20	10
WSC blw Gardiner Ditch (CFC)	86.2	-12%	26.4	17.6	8.8
WSC at Warm Springs (USGS 12323770)	65.4	-24%	20.0	13.4	6.7
UCFR at Galen Rd (CFC)	200.9	0%	20.0	13.4	6.7
UCFR at Gemback Bridge (CFC)	173.8	-13%	17.3	11.6	5.8
UCFR blw Racetrack Creek (CFC)	241.9	0%	17.3	11.6	5.8
UCFR at Sager Ln (CFC)	278.1	0%	17.3	11.6	5.8
UCFR at Deer Lodge (USGS 12324200)	331.0	0%	17.3	11.6	5.8

Temperature

Teasing out the impact of the release on water temperatures throughout the system was complicated by the higher than average flows, relatively cold water, and several large precipitation events during the release. Releases during drought conditions would be expected to have a more significant impact on the system. Nevertheless, the monitoring documented several important temperature-related aspects of the Warm Springs and upper Clark Fork system.

WSC, above the confluence with Cable Creek, goes subsurface and returns to the surface at a consistently cold temperature. The maximum daily temperature of WSC below the subsurface reach stayed between 6°C and 7°C throughout release, which is significantly colder than the other headwater inputs from Cable Creek and Twin Lakes Creek, which had peak temperatures between 12°C and 17°C prior to the release. The Silver Lake water released from the surface via gravity had a mean daily maximum temperature of 19.1°C, over 5 degrees warmer than the pre-release temperature in Warms Springs Creek, 6 degrees warmer than the mean daily maximum of 12.9°C for the pumped water, close to the 20°C threshold for westslope cutthroat trout habitat, and over the 15°C threshold for bull trout habitat. This difference is

likely due to a thermocline in the Silver Lake Reservoir, which stratifies the lake into varying thermal zones. The warm temperatures at the surface could also be exacerbated by diversion of Twin Lakes Creek into the reservoir through an asphalt-lined canal and the location of the outlet in the shallow flats at the east side of the lake.

The surface release contributed water to the WSC system at temperatures higher than the natural streams. Water temperatures in Cable Creek and WSC below Cable Creek rose during the surface release. At the same time, water temperatures in Twin Lakes Creek, which was unaffected by the release, rose as well. The same held true when temperatures in Cable Creek and WSC below Cable Creek dropped several degrees when BSB switched to the pumped release; Twin Lakes water temperature dropped at the same time. See Figure 5 and Appendix E.

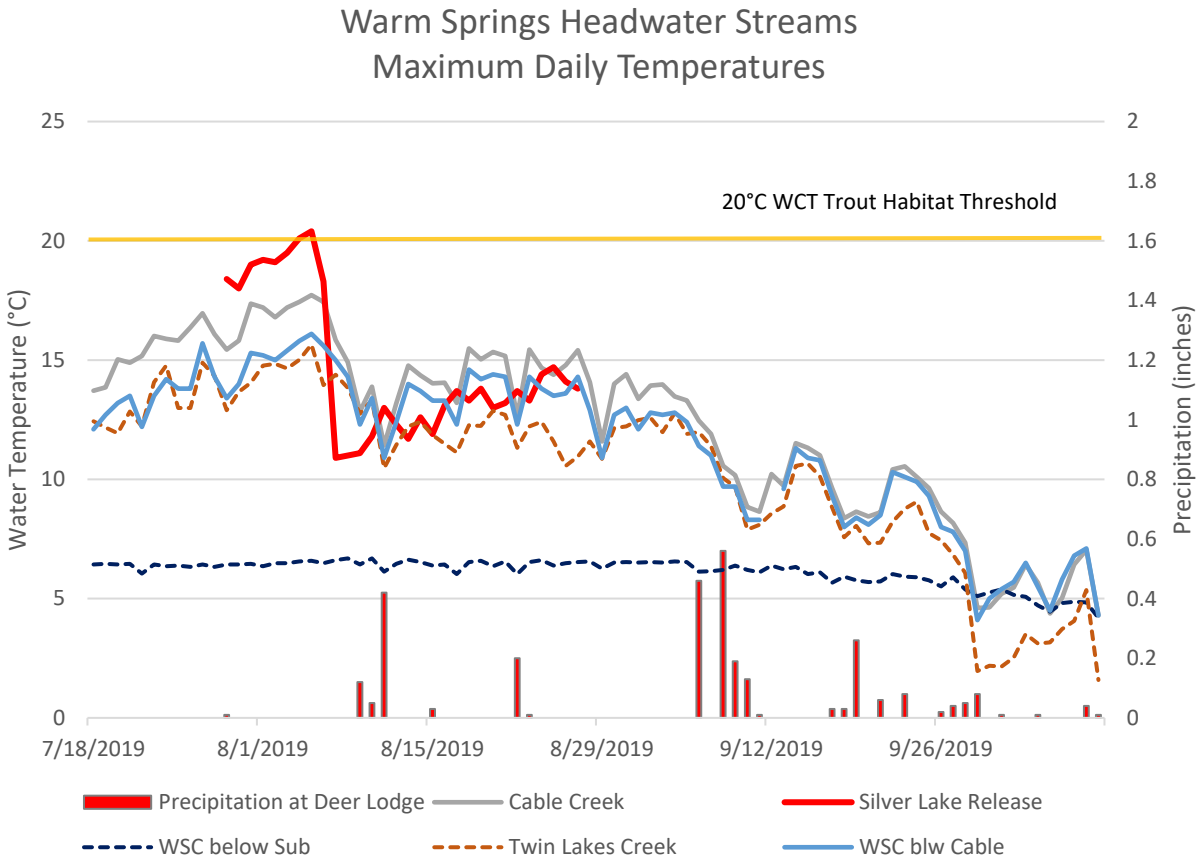


Figure 6. Maximum daily water temperatures (°C) of Silver Lake release and headwater streams in Warm Springs Creek. Dashed lines represent streams not affected by release.

Throughout the monitoring period, maximum daily water temperatures in WSC exceeded the 20°C threshold only one time, on August 5, 2019 at the USGS gage at Warm Springs. In contrast, Silver Bow Creek exceeded the threshold 35% of the days between July 18 and October 9, 2019 and Lost Creek exceeded the threshold 23% of the days. Combined, the three tributaries of the UCFR exceeded the threshold 25% of the days between July 18 and October 9, 2019 as measured at Galen Road (Figure 6).

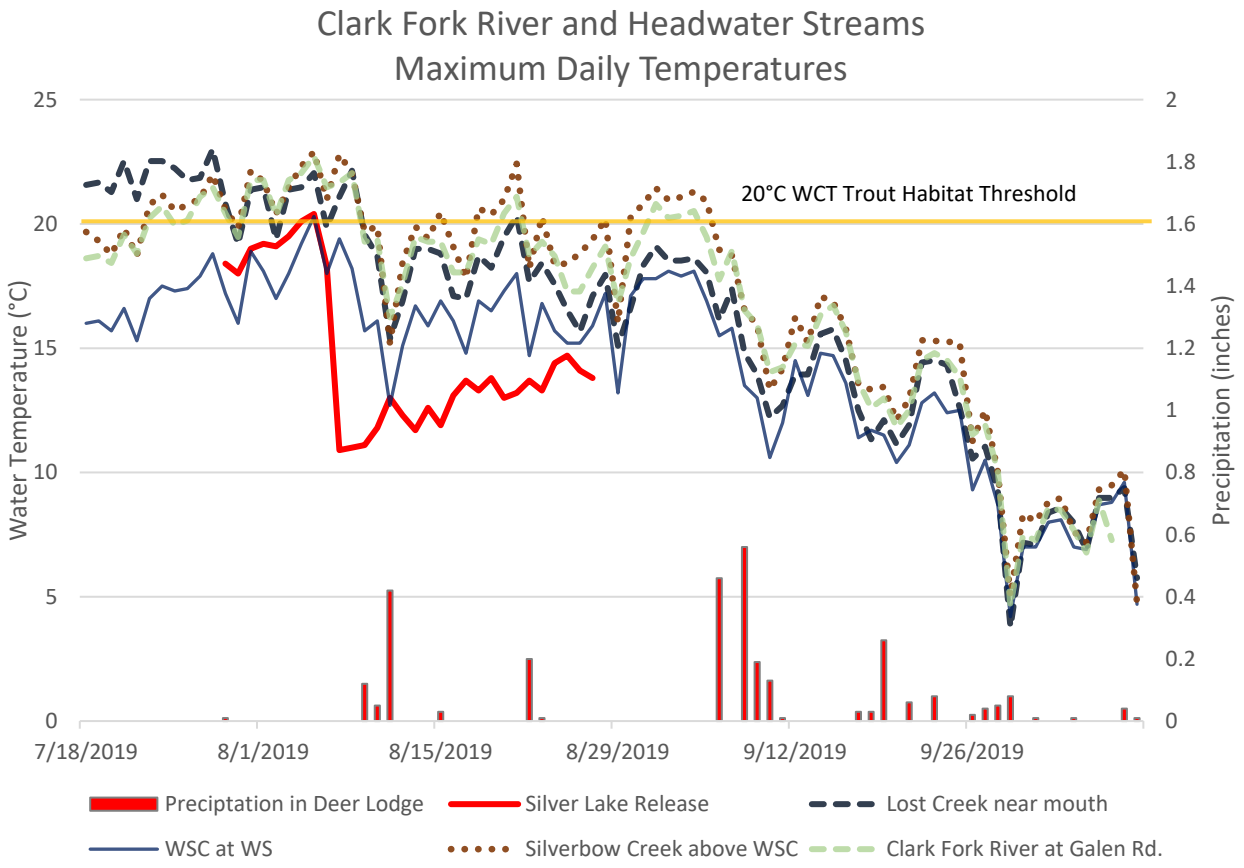


Figure 7. Daily precipitation in Deer Lodge, MT Agrimet Weather Station and maximum daily water temperatures (°C) in the Clark Fork River and contributing headwater streams.

The effect of the Silver Lake release on maximum daily temperatures in the UCFR between Galen and Deer Lodge was unclear. In general, the maximum daily temperatures increased from Galen down to Sager Lane, with the 20°C threshold exceeded 25% at the top of the reach near Galen, 40% at Sager Lane. Reach gains, likely irrigation returns, between Sager Lane and Deer Lodge cooled the river slightly with the threshold exceeded 37% (Figure 7). The W3T model in development should be a tool to assess and predict water temperature changes.

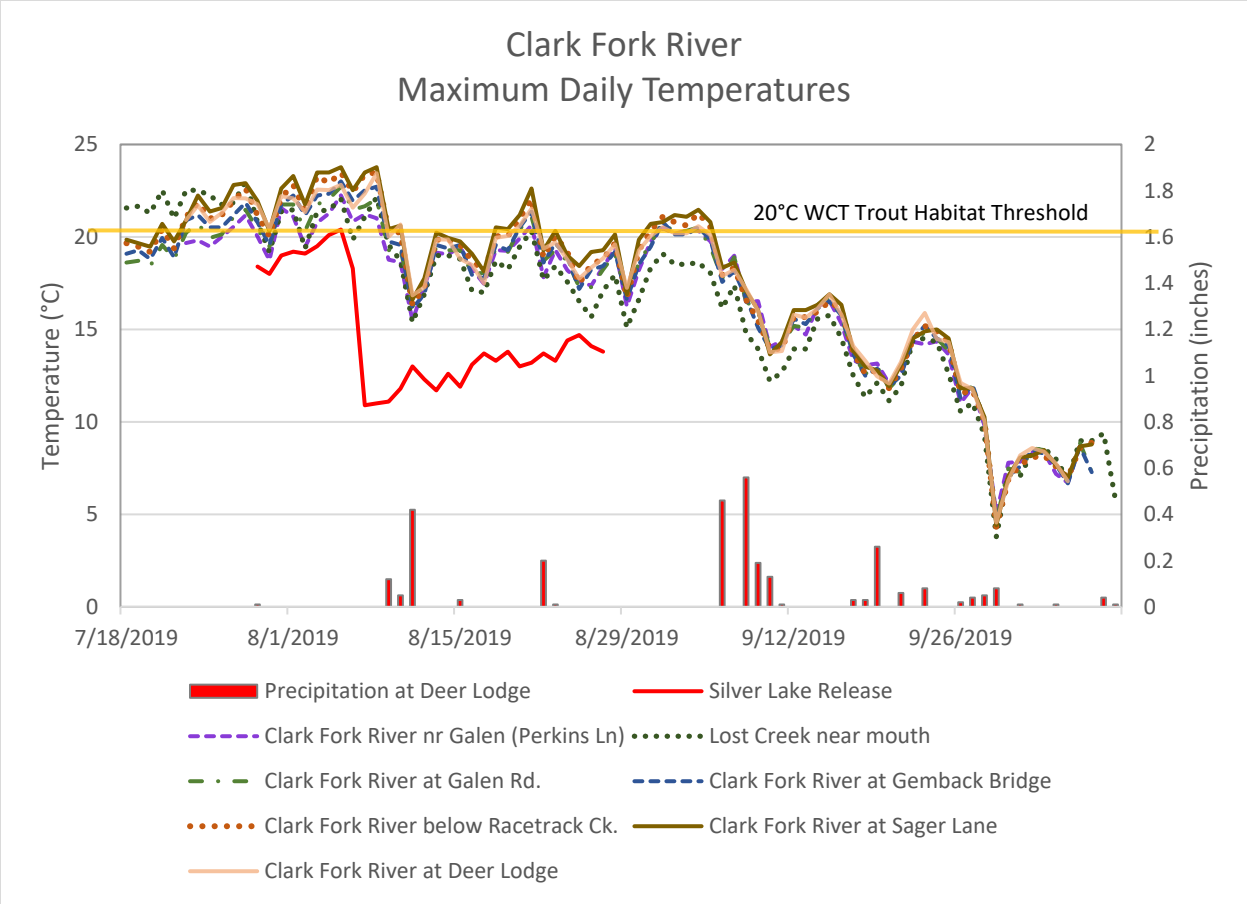


Figure 8. Daily precipitation in Deer Lodge, MT Agrimet Weather Station and maximum daily water temperatures (°C) in the Clark Fork River between Galen and Deer Lodge.

W3T model

As discussed above, the assessing the impacts of increased flow on water temperature through a reach is complex. Modeling the hydrologic system can be an easier way to predict changes. Watercourse Engineering, Inc. is developing a series of W3T reach models that will forecast the downstream impacts of a water release on flow and water temperature. The model will use channel morphology, discharge data, water temperature data, meteorological data, and riparian vegetation data to model flow characteristics, solar reduction, the heat budget, and ultimately the fate and transport of flow and temperature.

The model outputs will include the following:

- Hourly time series data – upstream and downstream longitudinal charts for minimum, mean, and maximum water temperature
- "Baseline versus scenario comparison
- Longitudinal profile (reach specific conditions)
- Solar shade reduction
- Tabulated data summary

WCE has received all discharge and temperature data collected during course of the Silver Lake Release project. They are currently evaluating the data and have begun model development. Anticipated completion is mid-January 2020. See Appendix E.

IV. Conclusions and Recommendations

The 2017 and 2019 Silver Lake releases demonstrated that water released from the reservoir will increase streamflow through WSC and the UCFR to Deer Lodge. Without active management of the released stored water past diversions, greater increases were observed in WSC and attenuated downstream to Deer Lodge. Intense local rainfall events during the 2019 release increased natural stream flow and made tracking of released water more difficult through the monitored reach. Despite this challenge, a rapid 12 cfs decrease in streamflow was observed in Deer Lodge at the end of the release after a week of dry conditions. That drop may be the best indication that a portion (37%) of the released water was contributing to flow in the Clark Fork at Deer Lodge.

While a portion of the Silver Lake water augmented flow in Deer Lodge, there is potential for larger impacts with active water right administration by a water commissioner, who could shepherd the stored water past diversions. Refining the conceptual model of reach gains and losses, absent influence of diversion, could provide a tool for negotiations, public education, and commissioner operations.

While understanding the fate of the released water is important for developing a successful long-term project, the quality of the water also needs consideration. Gravity-released water from Silver Lake was significantly warmer than the water released by the pumps. Long-term agreement negotiations should consider the thermal impacts that delivery infrastructure has on water released to the Warm Springs and upper Clark Fork system. It is also worth evaluating the temperature impacts of delivering Twin Lakes Creek water to the reservoir through the asphalt ditch during warm periods. Characterizing the temperature stratification of Silver Lake would also be valuable for informing the design for any infrastructure improvements that could take advantage of access to cooler water (i.e. pump placement, siphon structure, etc.).

TU recommends conducting additional test releases over several years to inform stakeholders how releases into WSC for fisheries benefit fit into overall management of Silver Lake, including the newly negotiated plan to transfer water from Silver Lake to Blacktail Creek.

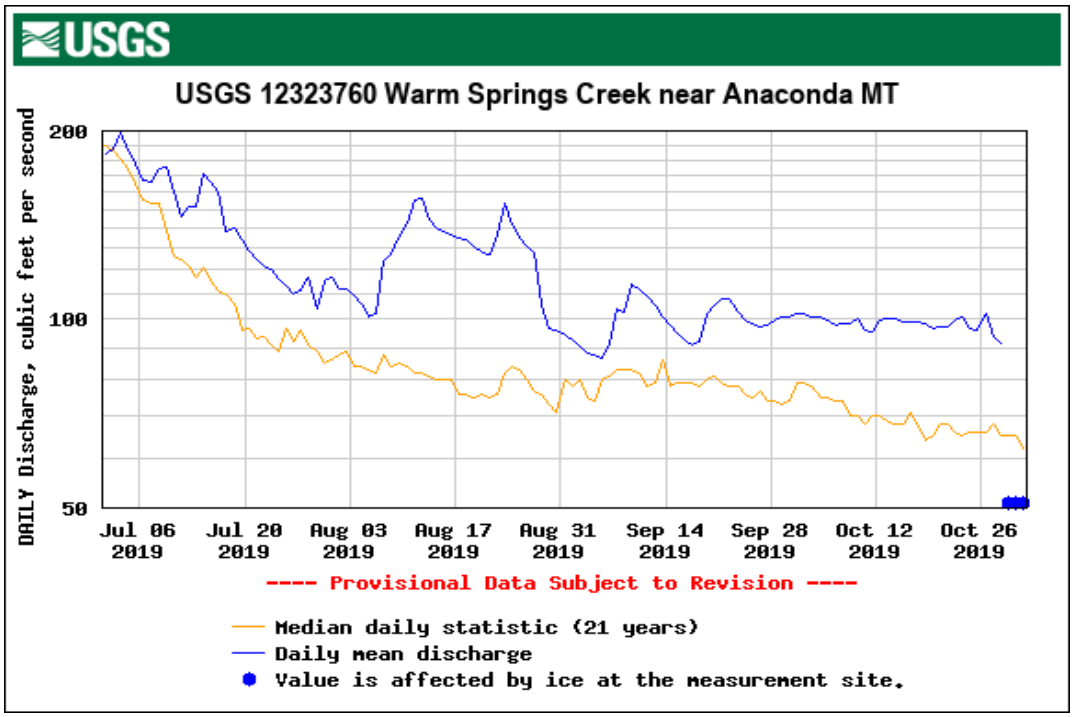
V. References

Bear, E.A., T.E. McMahon, and A.V. Zale. 2007. Comparative thermal requirements of westslope cutthroat trout and rainbow trout: Implications for species interactions and development of thermal protection standards. Transactions of the American Fisheries Society 136: 1113-1121.

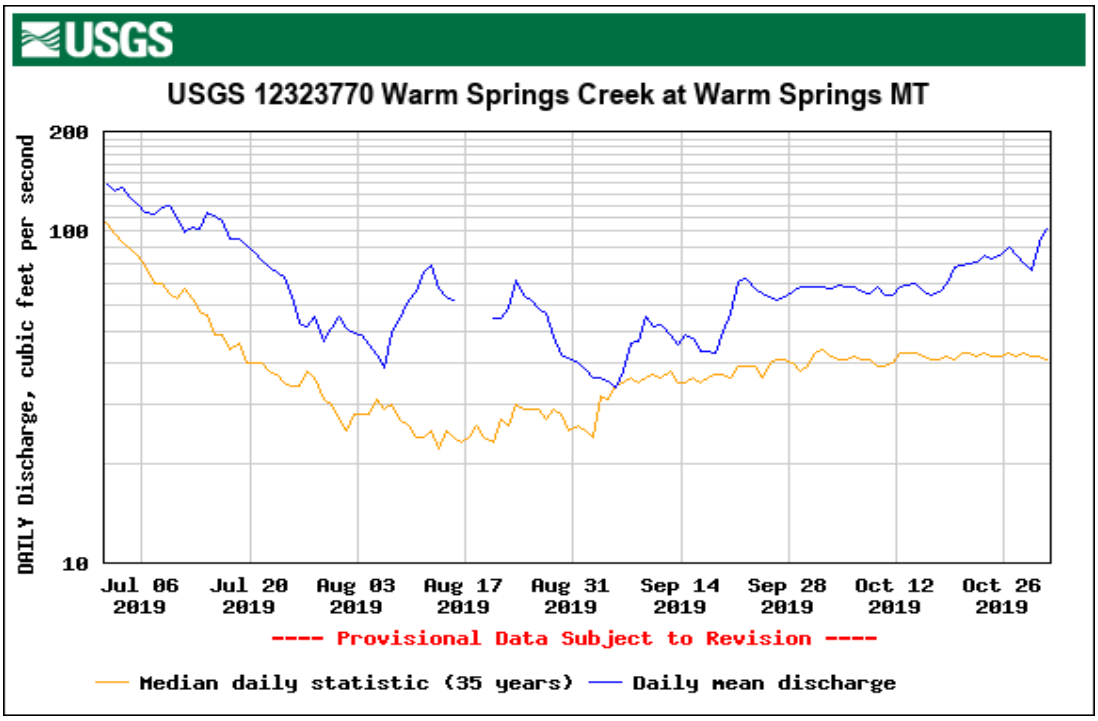
Dunham, J.B., B.E. Rieman, and G.L. Chandler. 2003. Influences of temperature and environmental variables on the distribution of bull trout within streams at the southern margin of its range. North American Journal of Fisheries Management 23:894-904.

Fraley, J.J., and B.B. Shepard. 1989. Life history, ecology, and population status of migratory bull trout (Salvelinus confluentus) in the Flathead Lake and River System, Montana. Northwest Science 63:133-143.

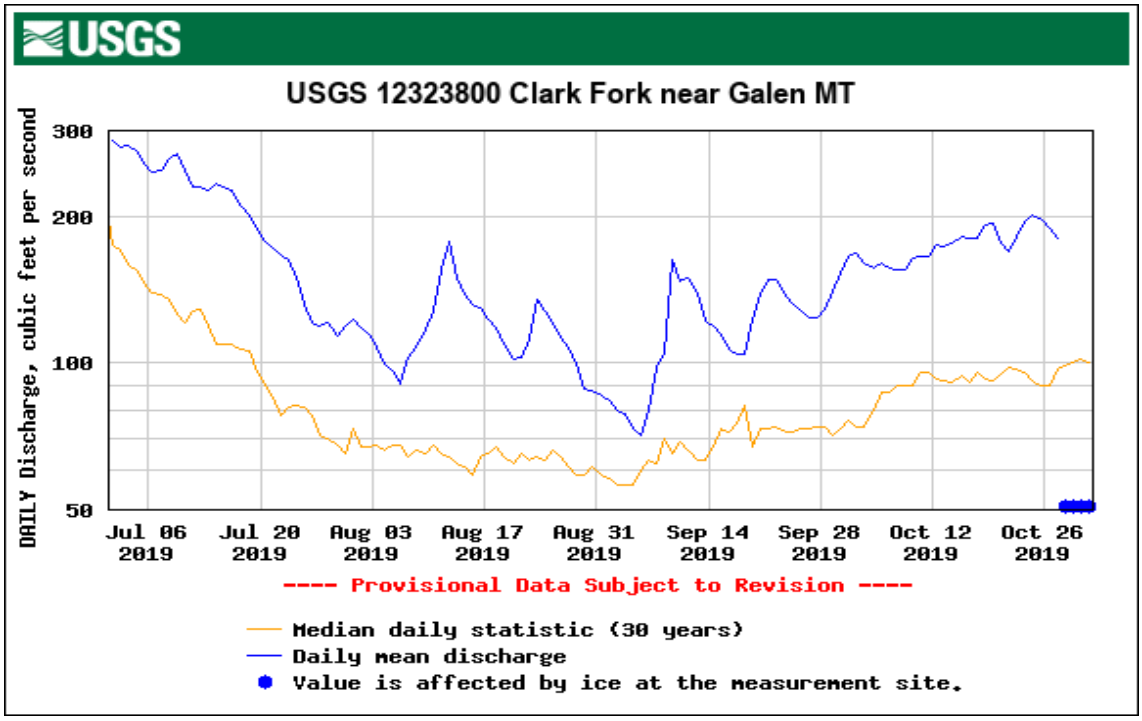
Appendix A: USGS Stream Gage Hydrographs



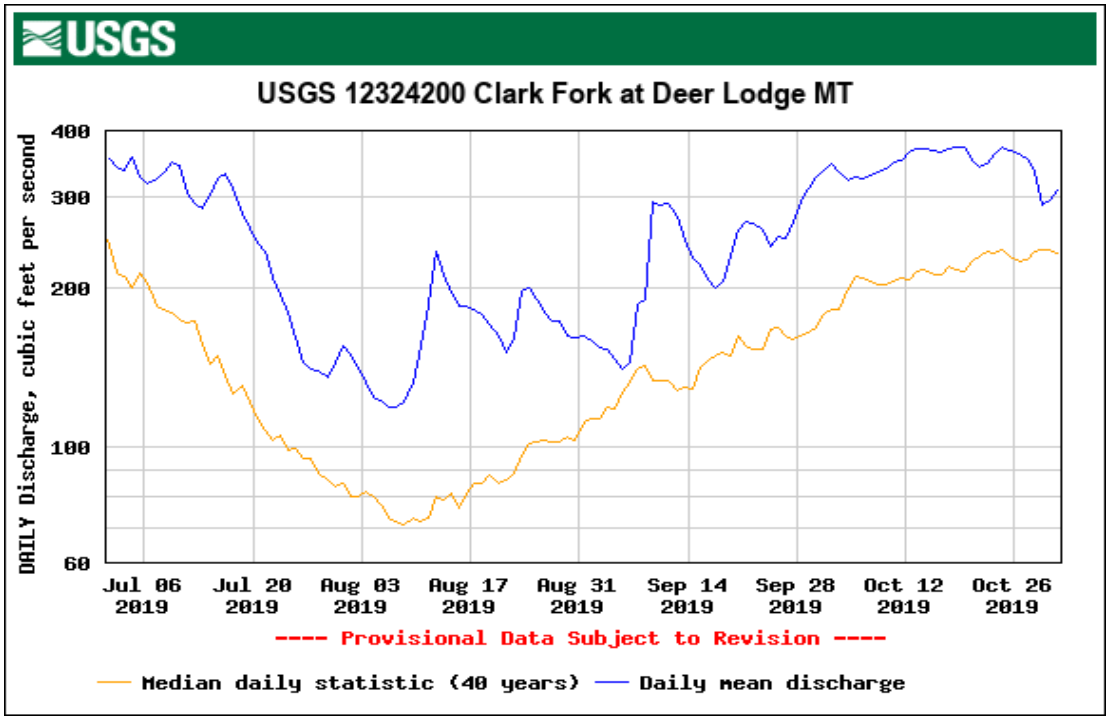
USGS Gage 12323760 Warm Springs Creek near Anaconda daily mean and 21-year median daily discharge, July 1 to October 31, 2019.



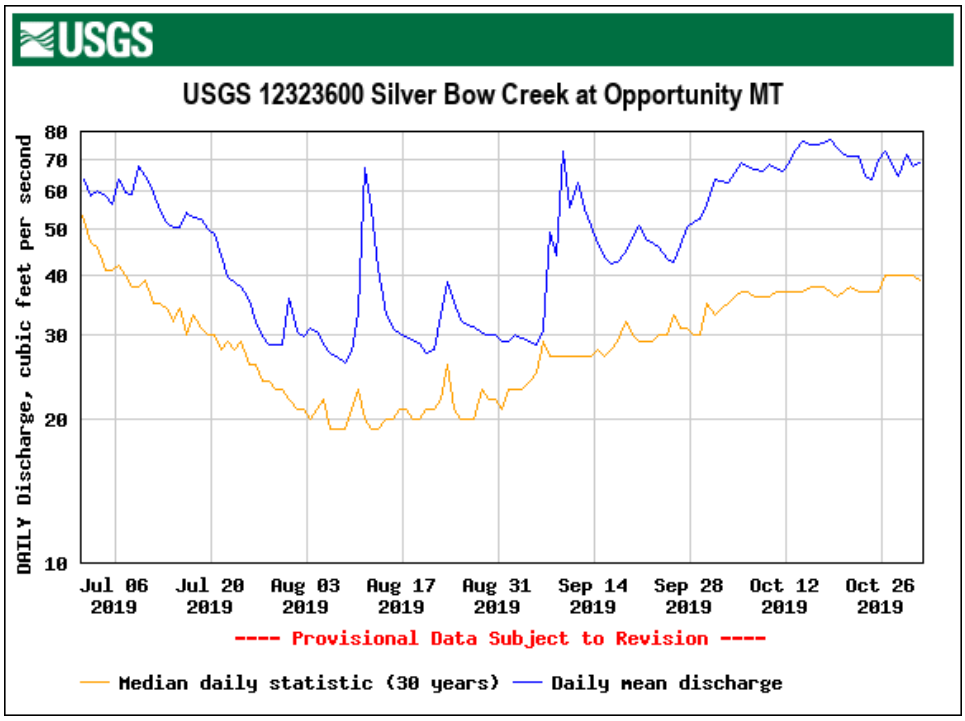
USGS Gage 12323770 Warm Springs Creek at Warm Springs daily mean and 21-year median daily discharge, July 1 to October 31, 2019.



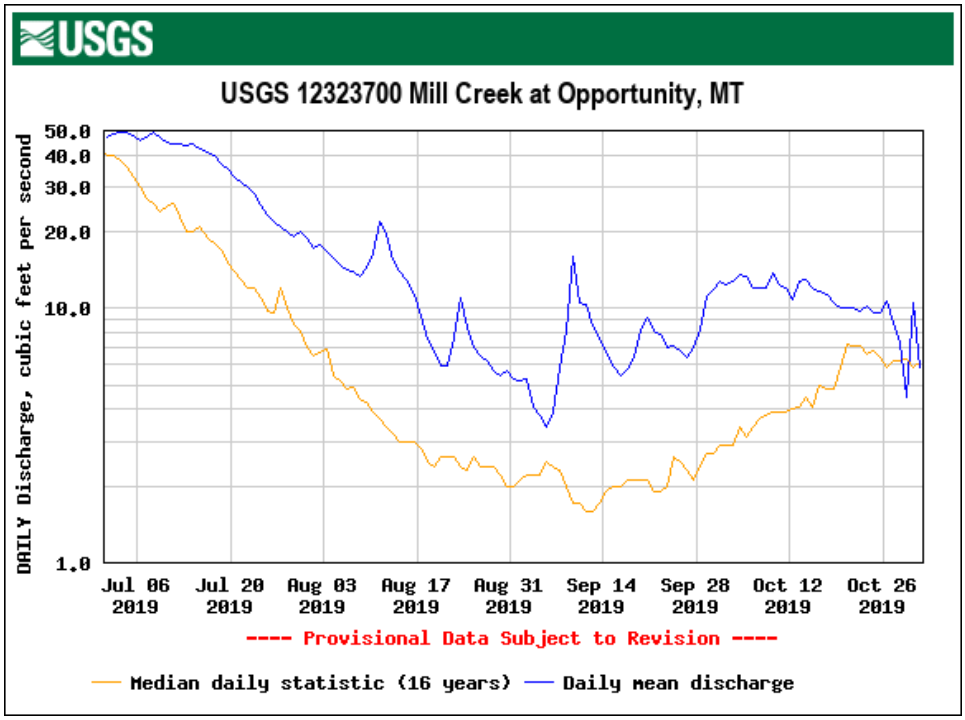
USGS Gage 12323800 Clark Fork River near Galen mean and 30-year median daily discharge, July 1 to October 31, 2019.



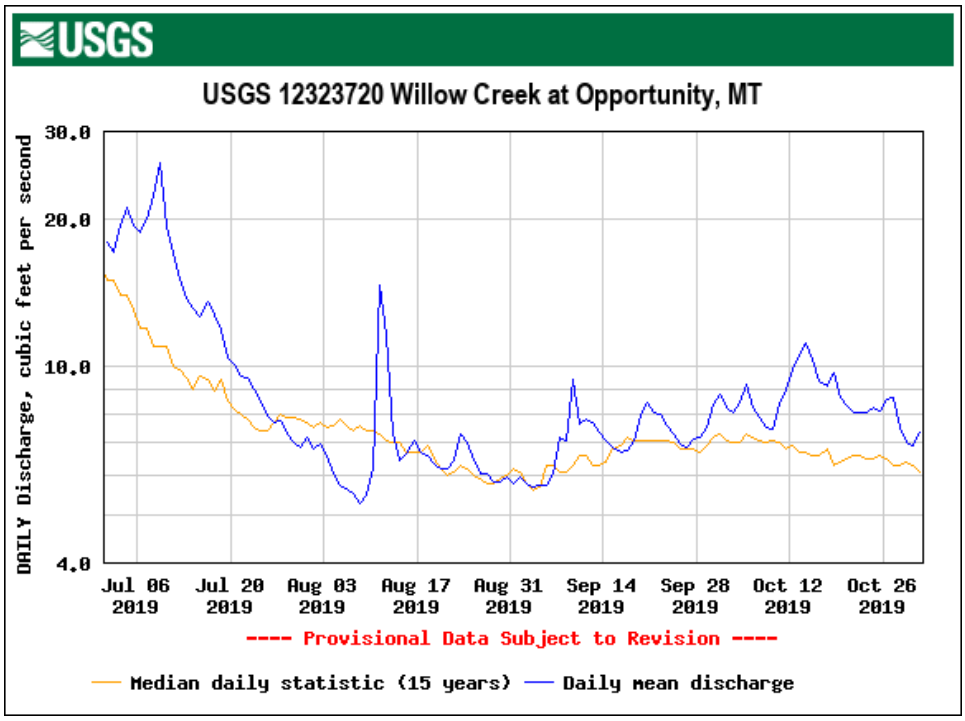
USGS Gage 12324200 Clark Fork River at Deer Lodge mean and 40-year median daily discharge, July 1 to October 31, 2019.



USGS Gage 12323600 Silver Bow Creek at Opportunity mean and 30-year median daily discharge, July 1 to October 31, 2019.



USGS Gage 12323700 Mill Creek at Opportunity mean and 16-year median daily discharge, July 1 to October 31, 2019.



USGS Gage 123237200 Willow Creek at Opportunity mean and 15-year median daily discharge, July 1 to October 31, 2019.

Butte Silver
Water Utility Division

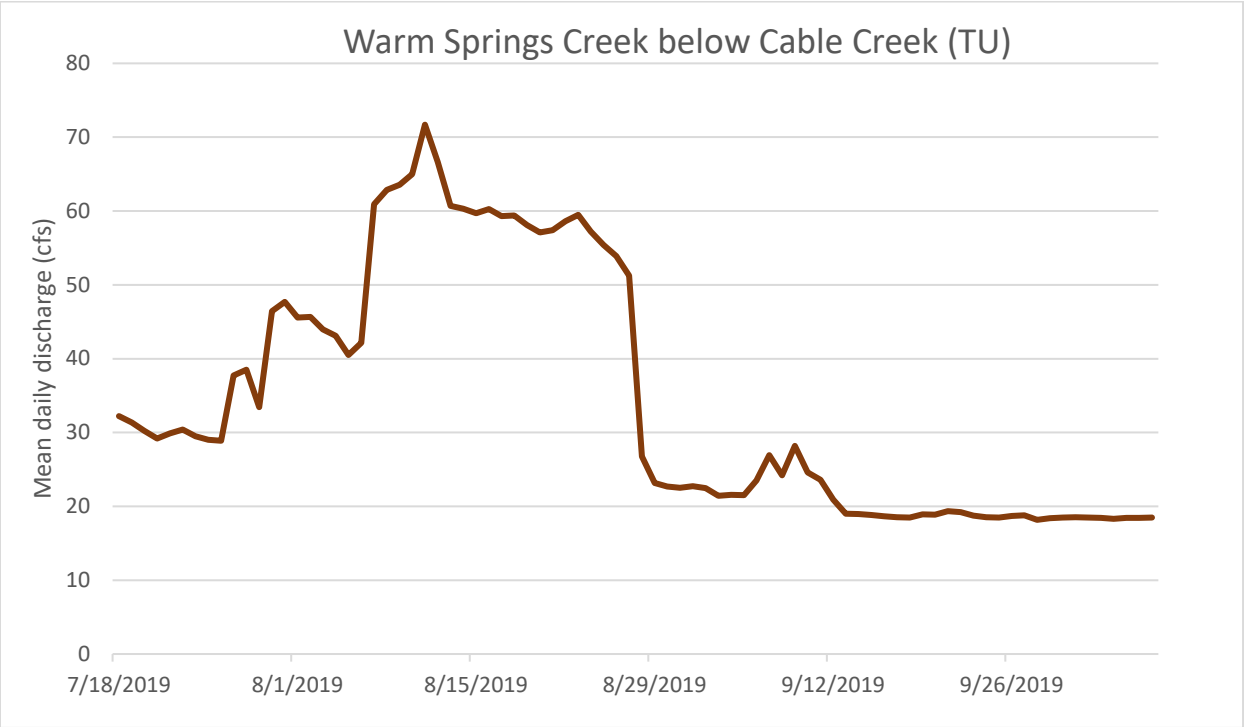
Date	Time	Lake Elevation	Volume		5' Parshall Flume				Gardner Ditch 8' Parshall Flume				TIFID Influent	
			Acre ft	MG	Reading	cfs	MGD	Water Temp. F	Reading	cfs	MGD	Water Temp. F	cfs	MGD
29-Jul-19	10:00 AM	6432.05	16,474	5,368.07	0.85	15.45	9.99		1.20	42.89	27.72		4.94	3.19
30-Jul-19	10:00 AM	6431.99	16,474	5,368.07	0.85	15.45	9.99	61.60	1.25	45.80	29.60	52.1	4.04	2.61
31-Jul-19	2:40 PM	6431.87	16,443	5,357.97	0.85	15.45	9.99	64.00	1.25	45.80	29.60	55.8	4.26	2.75
1-Aug-19	9:30 AM	6431.78	16,412	5,347.9	0.85	15.45	9.99	59.40	1.25	45.80	29.60	54.4	4.81	3.11
2-Aug-19	11:15 AM	6431.70	16,381	5,337.8	0.80	14.04	9.07	63.10	1.23	44.63	28.84	54.5	5.15	3.33
3-Aug-19	2:15 PM	6431.63	16,350	5,327.7	0.76	12.94	8.36	66.20	1.23	44.63	28.84	57.4	4.38	2.83
4-Aug-19	2:30 PM	6431.54	16,319	5,317.6	0.73	12.14	7.85	67.20	1.21	43.47	28.09	58.3	3.64	2.35
5-Aug-19	9:30 AM	6431.45	16,319	5,317.6	0.68	10.84	7.01	64.40	1.20	42.89	27.72	54.9	4.52	2.92
6-Aug-19	12:00 PM	6431.39	16,288	5,307.5	1.34	31.82	20.57	50.90	1.28	47.58	30.75	56.0	4.60	2.97
7-Aug-19	9:45 AM	6431.12	16,195	5,277.2	1.36	32.58	21.06	50.10	1.32	49.99	32.31	52.7	5.12	3.31
8-Aug-19	12:00 PM	6430.85	16,133	5.257.0	1.35	32.20	20.82	51.20	1.29	48.18	31.14	58.1	5.68	3.67
9-Aug-19	9:30 AM	6430.62	16,041	5,227.0	1.35	32.20	20.82	50.90	1.32	49.99	32.31	53.4	3.36	2.17
10-Aug-19	2:00 PM	6430.35	15,979	5,206.8	1.34	31.82	20.57	49.90	1.34	51.22	33.10	56.3	3.87	2.50
11-Aug-19	2:00 PM	6430.20	15,918	5,186.9	1.36	32.58	21.06	49.50	1.42	56.22	36.33	51.3	3.23	2.09
12-Aug-19	11:00 AM	6431.60	16,350	5,327.7	1.25	28.50	18.42	51.40	1.38	53.70	34.70	53.2	3.57	2.31
13-Aug-19	12:20 PM	6429.64	15,735	5,127.3	1.34	31.82	20.57	50.50	1.35	51.83	33.50	52.0	4.30	2.78
14-Aug-19	10:15 AM	6429.30	15,645	5,097.6	1.30	30.33	19.61	51.60	1.37	53.07	34.30	50.5	4.26	2.75
15-Aug-19	10:30 AM	6429.05	15,554	5,068.3	1.32	31.07	20.09	53.20	1.34	51.22	33.10	52.9	5.45	3.52
16-Aug-19	10:45 AM	6428.89	15,524	5,058.5	1.32	31.07	20.09	52.70	1.32	49.99	32.31	51.4	5.20	3.36
17-Aug-19	11:15 AM	6428.66	15,464	5,038.9	1.31	30.70	19.85	54.70	1.33	50.60	32.70	52.1	5.08	3.28
18-Aug-19	10:00 AM	6428.25	15,374	5,009.6	1.31	30.70	19.85	54.10	1.31	49.39	31.92	49.8	6.00	3.88
19-Aug-19	11:00 AM	6428.13	15,284	4,980.3	1.31	30.70	19.85	55.10	1.30	48.78	31.53	54.5	3.57	2.31
20-Aug-19	1:15 PM	6427.79	15,195	4,951.3	1.30	30.33	19.61	55.40	1.30	48.78	31.53	55.3	4.44	2.87
21-Aug-19	9:30 AM	6427.70	15,166	4,941.9	1.30	30.33	19.61	55.60	1.25	45.80	29.60	55.5	3.96	2.56
22-Aug-19	9:30 AM	6427.60	15,136	4,941.9	1.30	30.33	19.61	55.40	1.25	45.80	29.60	55.3	3.47	2.24
23-Aug-19	10:30 AM	6427.50	15,107	4,922.6	1.30	30.33	19.61	55.70	1.38	53.70	34.70	53.2	3.39	2.19
24-Aug-19	12:15 PM	6427.20	15,018	4,893.6	1.30	30.33	19.61	55.40	1.37	53.07	34.30	50.7	3.47	2.24
25-Aug-19	11:30 AM	6426.90	14,931	4,865.3	1.30	30.33	19.61	57.40	1.30	48.78	31.53	49.6	4.08	2.64
26-Aug-19	9:30 AM	6426.80	14,902	4,855.8	1.30	30.33	19.61	56.80	1.32	49.99	32.31	50.4	3.79	2.45
27-Aug-19	12:00 PM	6426.60	14,843	4,836.6	1.29	29.96	19.37	56.00	1.30	48.78	31.53	52.1	4.55	2.94
Total		5.450	1,631	512.3		792.14	512.12			1,462.39	945.07		130.16	84.12

4.34

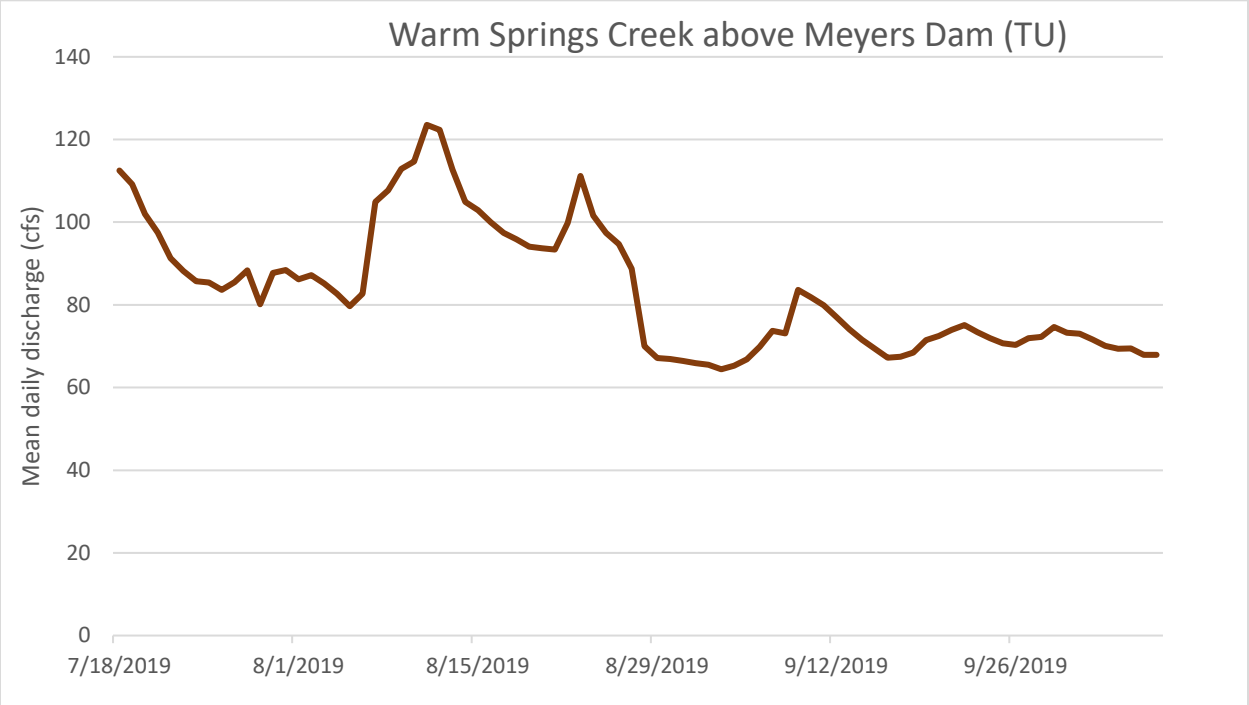
Start: July 29th @ 1000 hr. - Opened gate vavle on east side of dam, discharge by gravity only, "no pumping".
Started Silver Lake Pumps @ approximately 11:00 AM on Aug. 6th - 32 cfs.

Notes: Lake elevation reading on August 12 not correct.
August 27th - turned pumps off, no longer conveying water out of Silver Lake

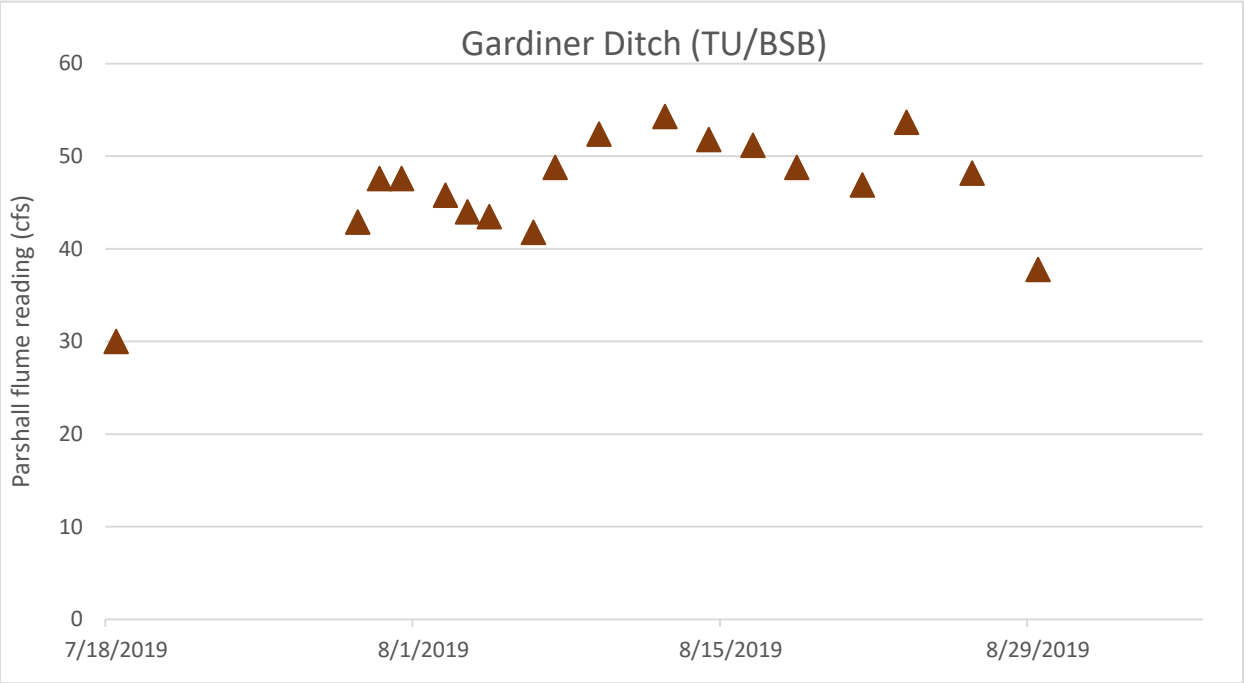
Appendix C: Trout Unlimited and Clark Fork Coalition Hydrographs



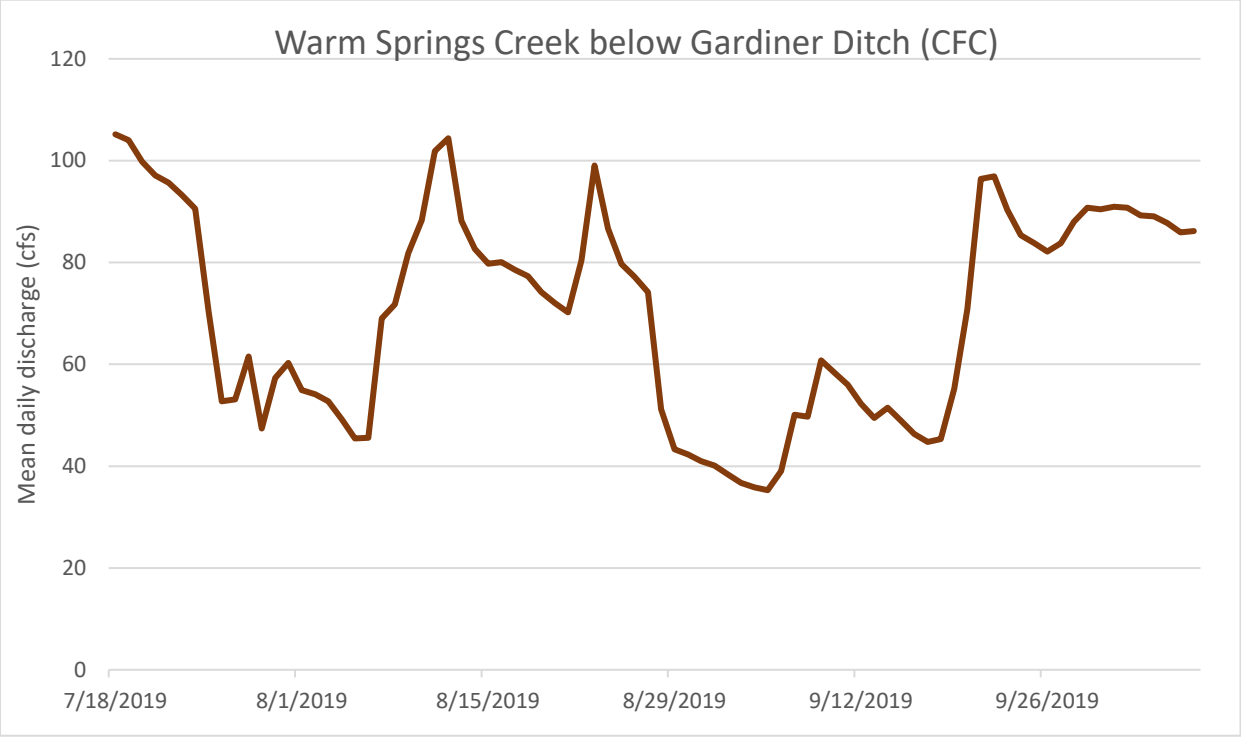
Mean daily discharge in Warm Springs Creek below Cable Creek (TU).



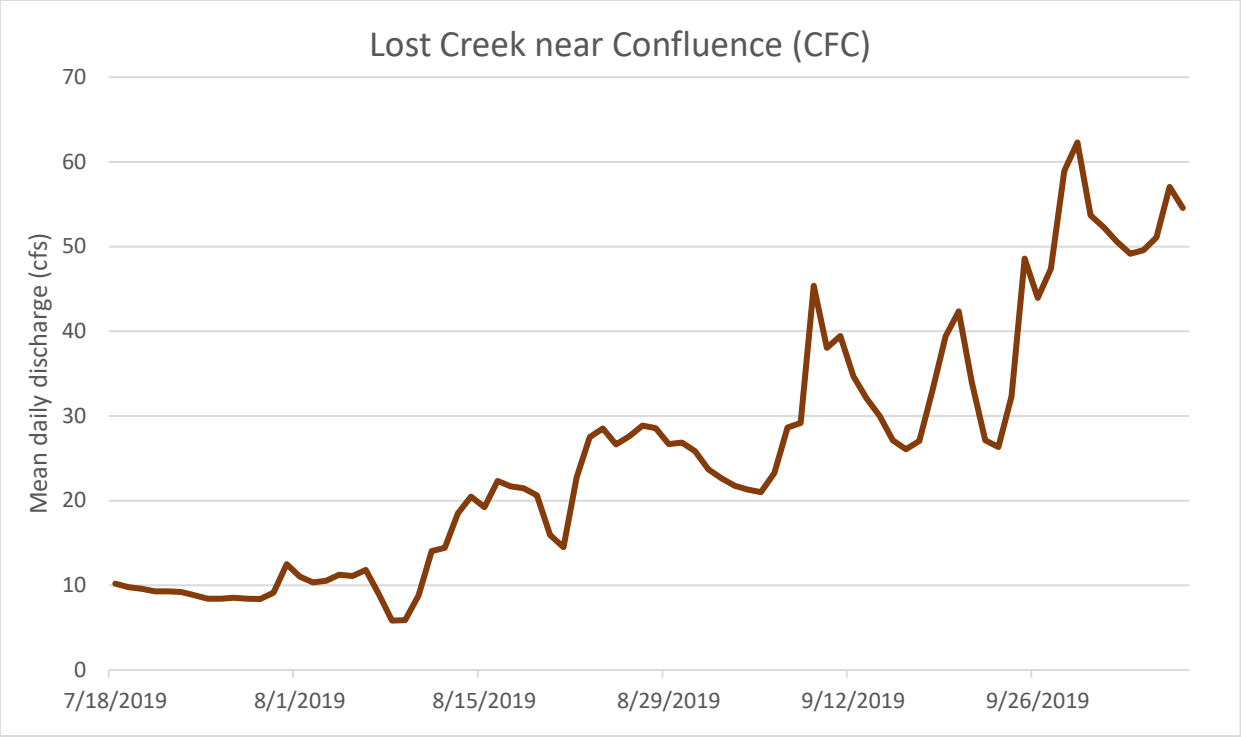
Mean daily discharge in Warm Springs Creek above Meyers Dam (TU).



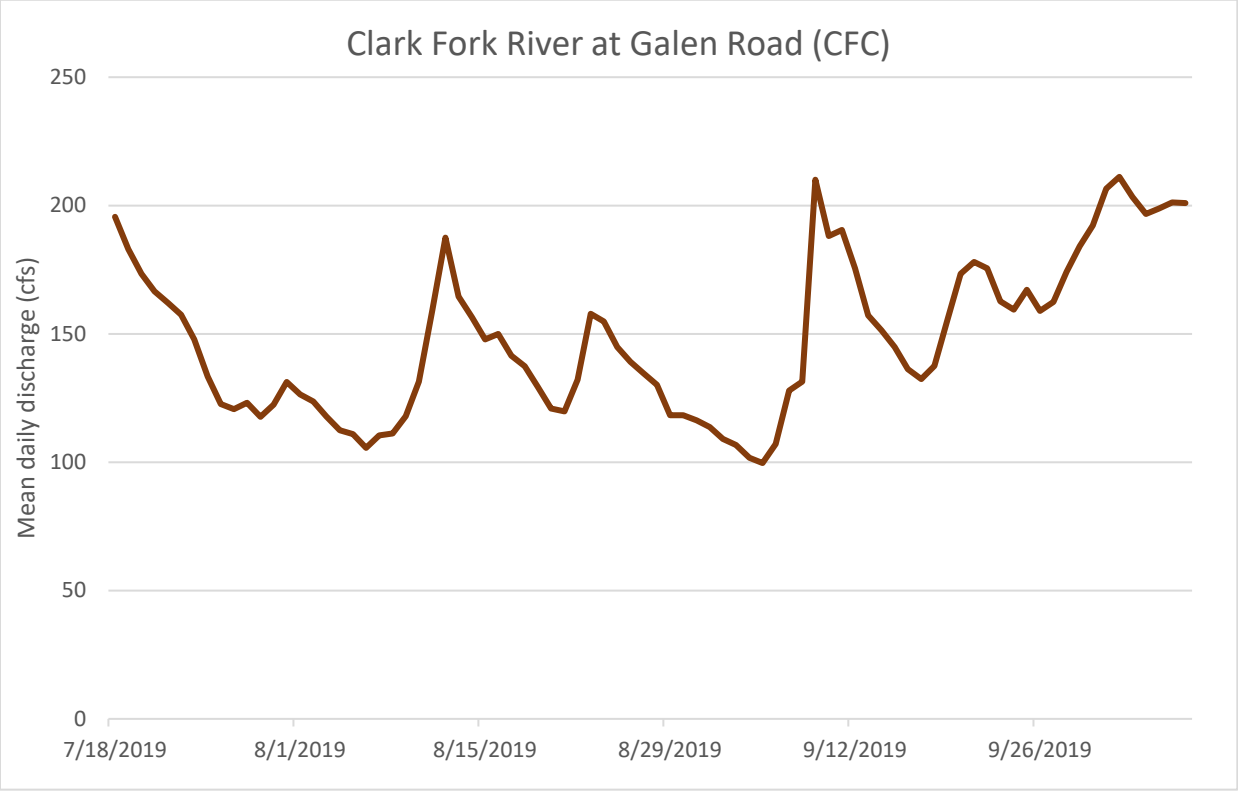
Discharge in Gardiner Ditch according to Parshall Flume.



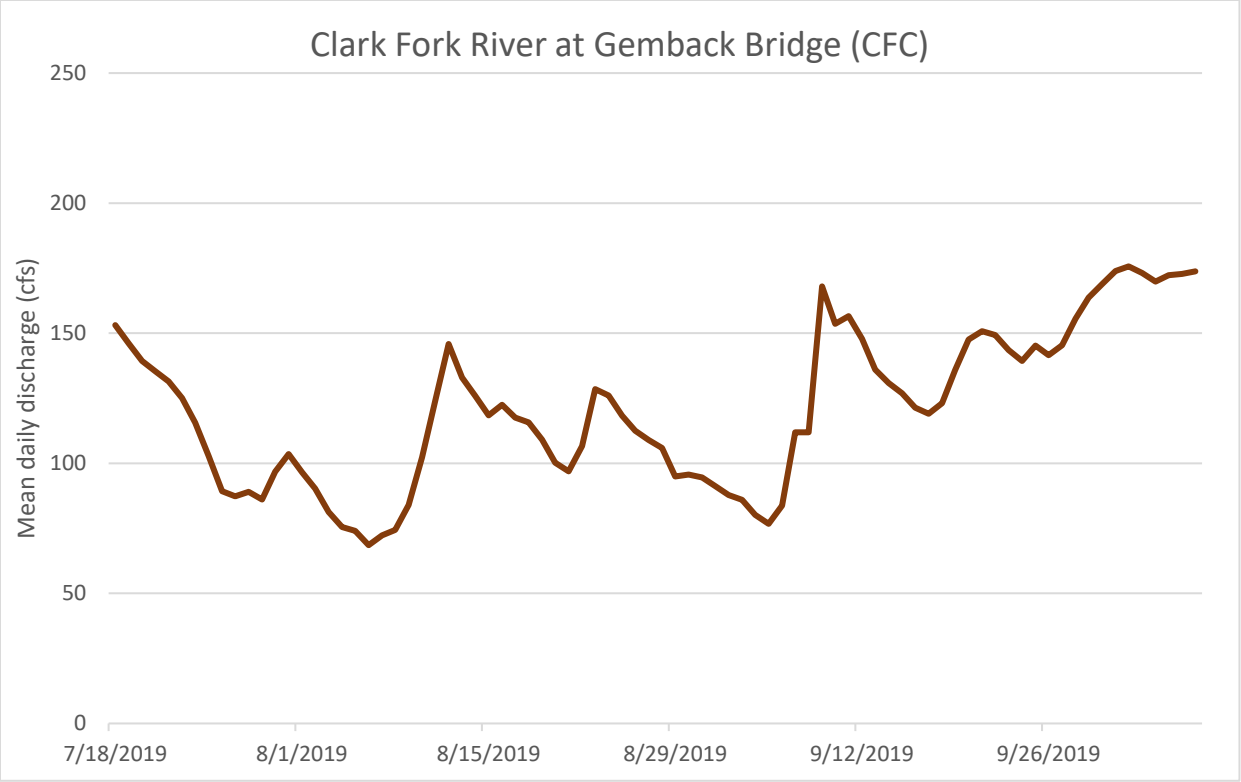
Mean daily discharge in Warm Springs Creek below Gardiner Ditch (CFC).



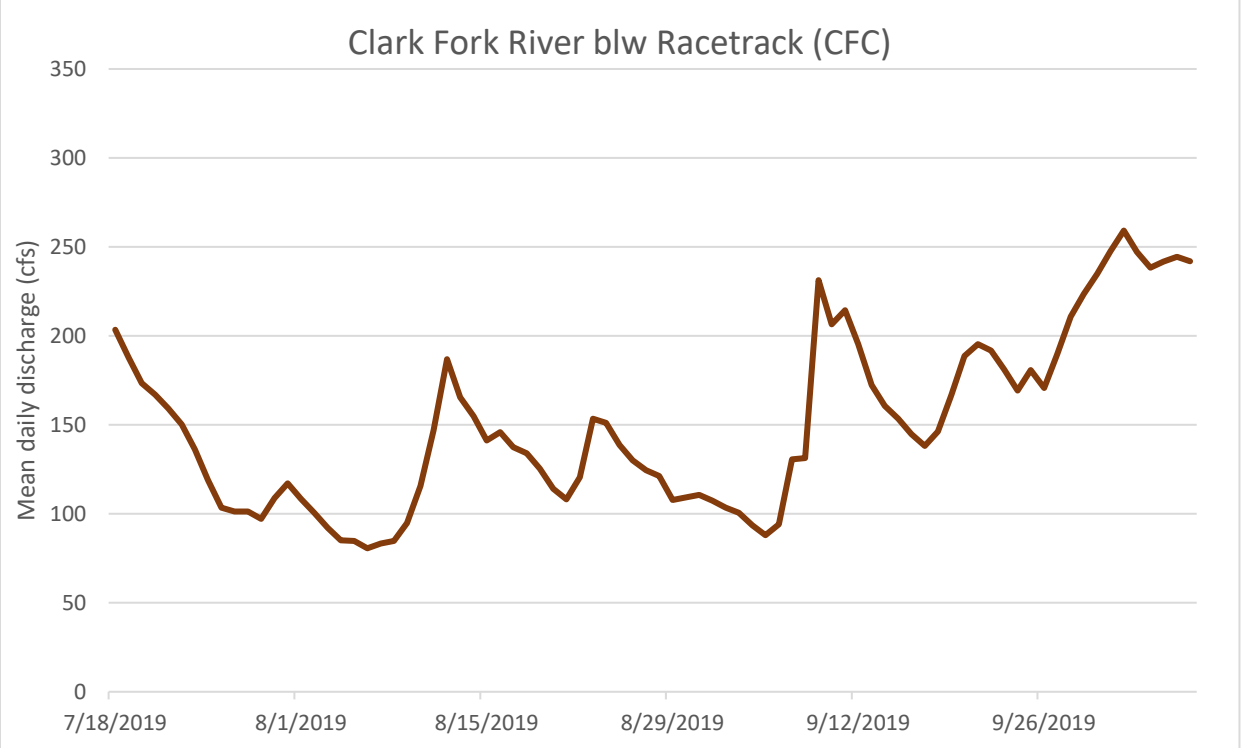
Mean daily discharge in Lost Creek near confluence (CFC).



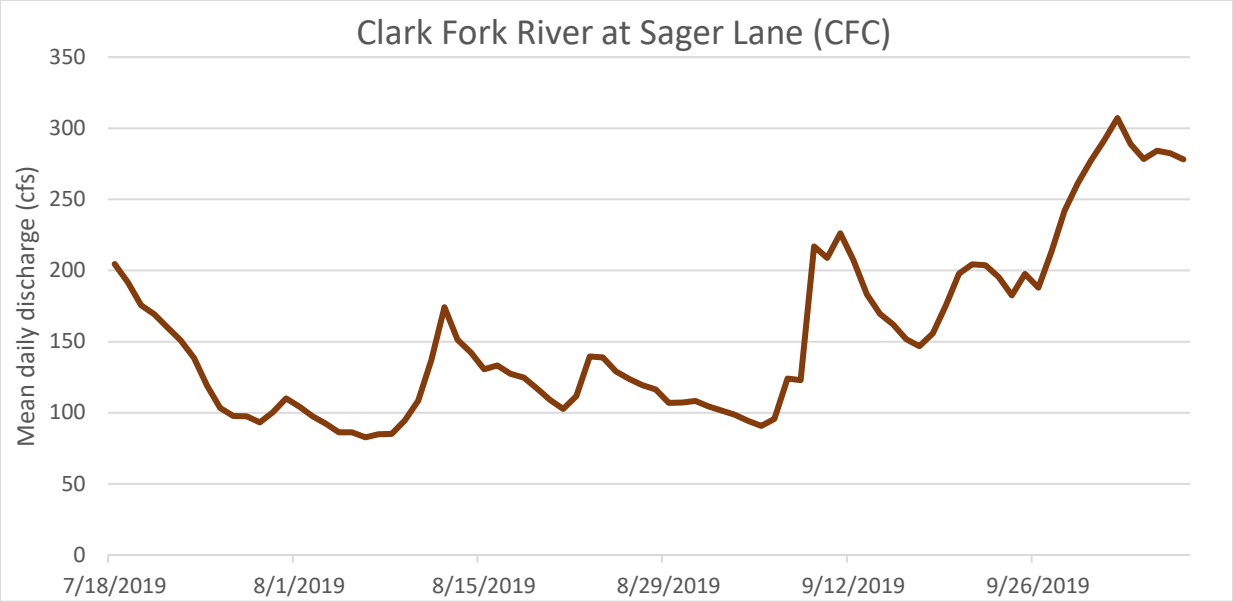
Mean daily discharge in Clark Fork River at Galen Road (CFC).



Mean daily discharge in Clark Fork River at Gemback Road (CFC).



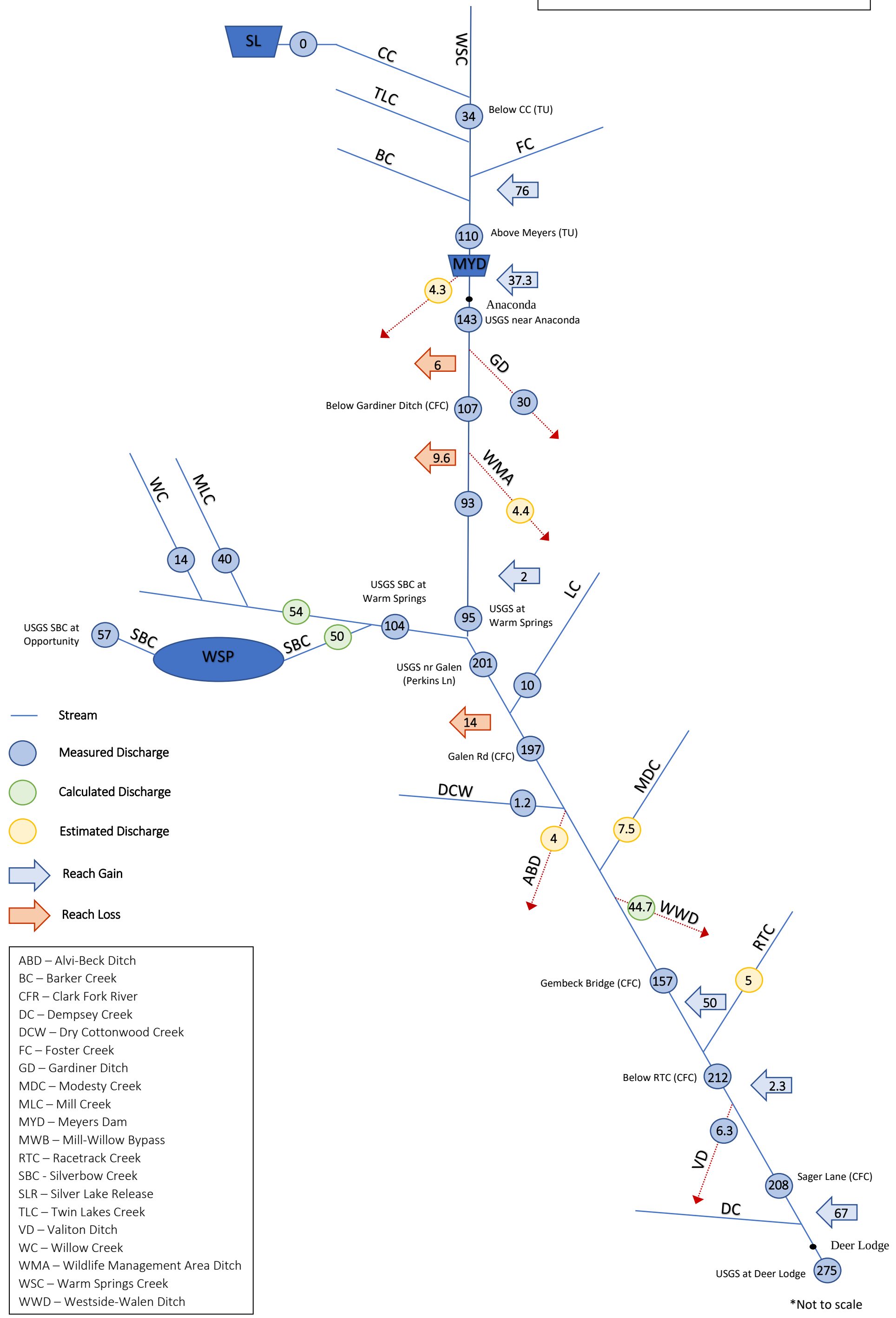
Mean daily discharge in Clark Fork River below Racetrack Creek (CFC).



Mean daily discharge in Clark Fork River at Sager Lane (CFC).

Appendix D: Synoptic Measurement Diagrams

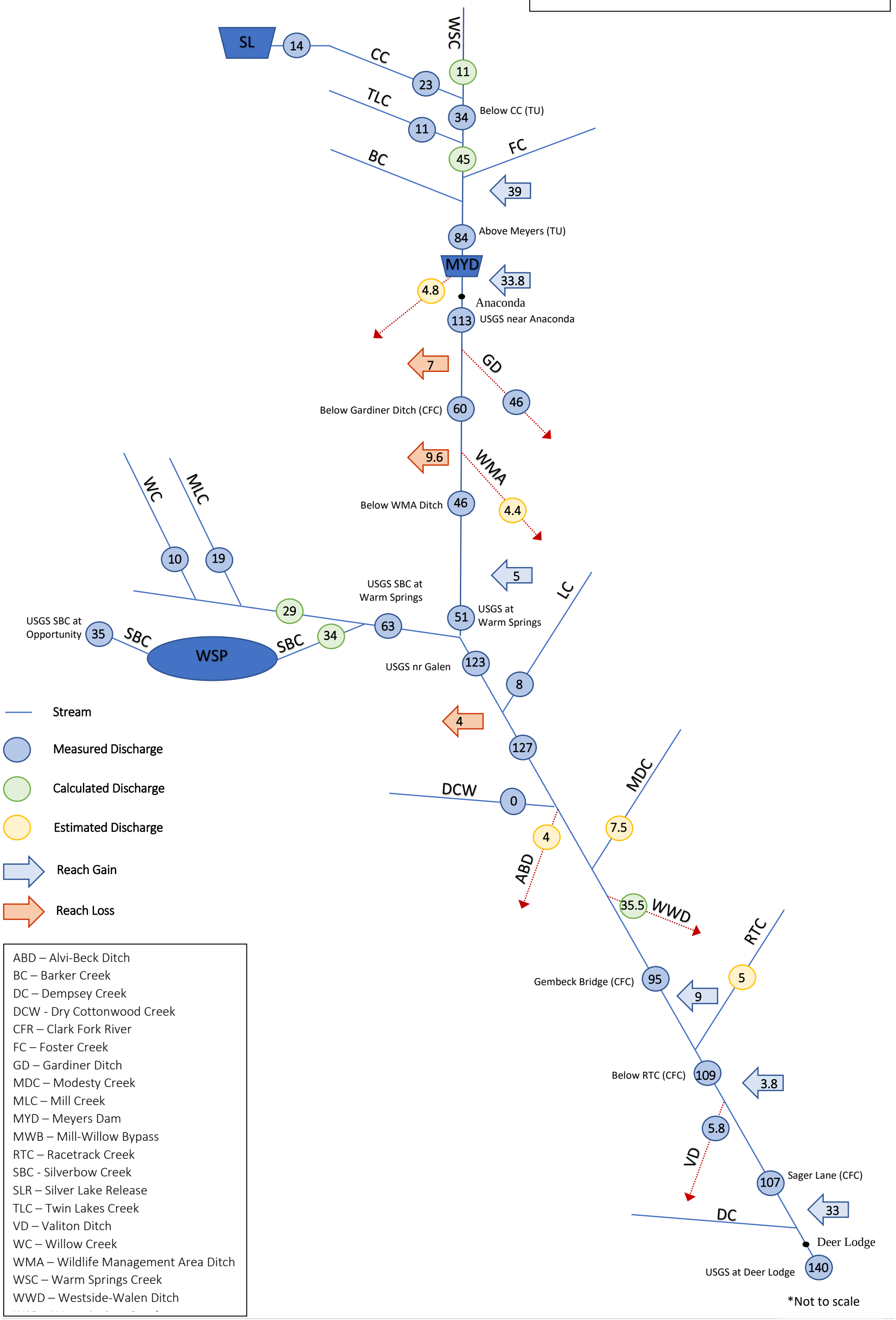
July 18, 2019 Synoptic Measurements



*Not to scale

ABD – Alvi-Beck Ditch
BC – Barker Creek
CFR – Clark Fork River
DC – Dempsey Creek
DCW – Dry Cottonwood Creek
FC – Foster Creek
GD – Gardiner Ditch
MDC – Modesty Creek
MLC – Mill Creek
MYD – Meyers Dam
MWB – Mill-Willow Bypass
RTC – Racetrack Creek
SBC - Silverbow Creek
SLR – Silver Lake Release
TLC – Twin Lakes Creek
VD – Valiton Ditch
WC – Willow Creek
WMA – Wildlife Management Area Ditch
WSC – Warm Springs Creek
WWD – Westside-Walen Ditch

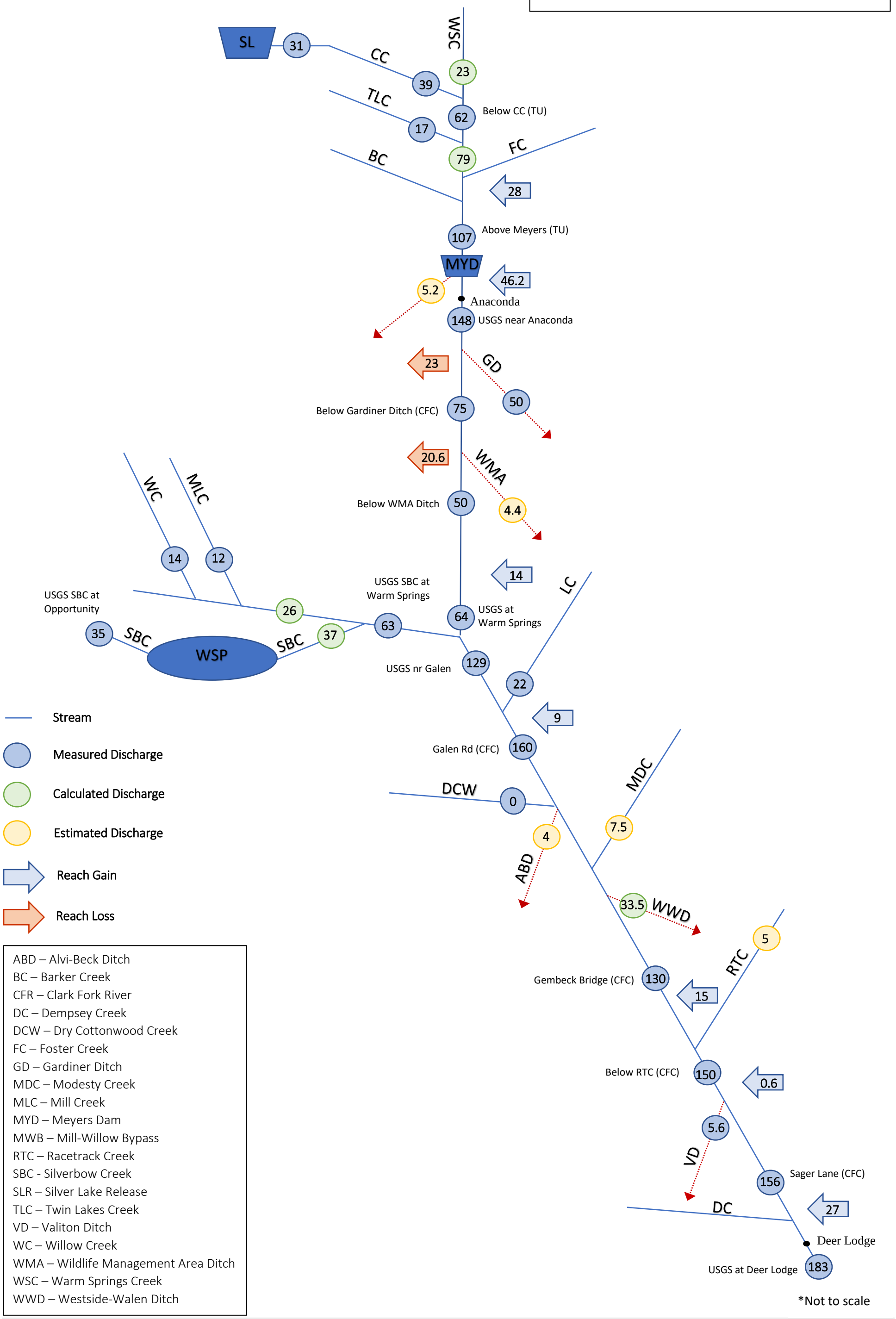
August 1, 2019 Synoptic Measurements



*Not to scale

ABD – Alvi-Beck Ditch
BC – Barker Creek
DC – Dempsey Creek
DCW - Dry Cottonwood Creek
CFR – Clark Fork River
FC – Foster Creek
GD – Gardiner Ditch
MDC – Modesty Creek
MLC – Mill Creek
MYD – Meyers Dam
MWB – Mill-Willow Bypass
RTC – Racetrack Creek
SBC - Silverbow Creek
SLR – Silver Lake Release
TLC – Twin Lakes Creek
VD – Valiton Ditch
WC – Willow Creek
WMA – Wildlife Management Area Ditch
WSC – Warm Springs Creek
WWD – Westside-Walen Ditch

August 16, 2019 Synoptic Measurements



ABD – Alvi-Beck Ditch
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MYD – Meyers Dam
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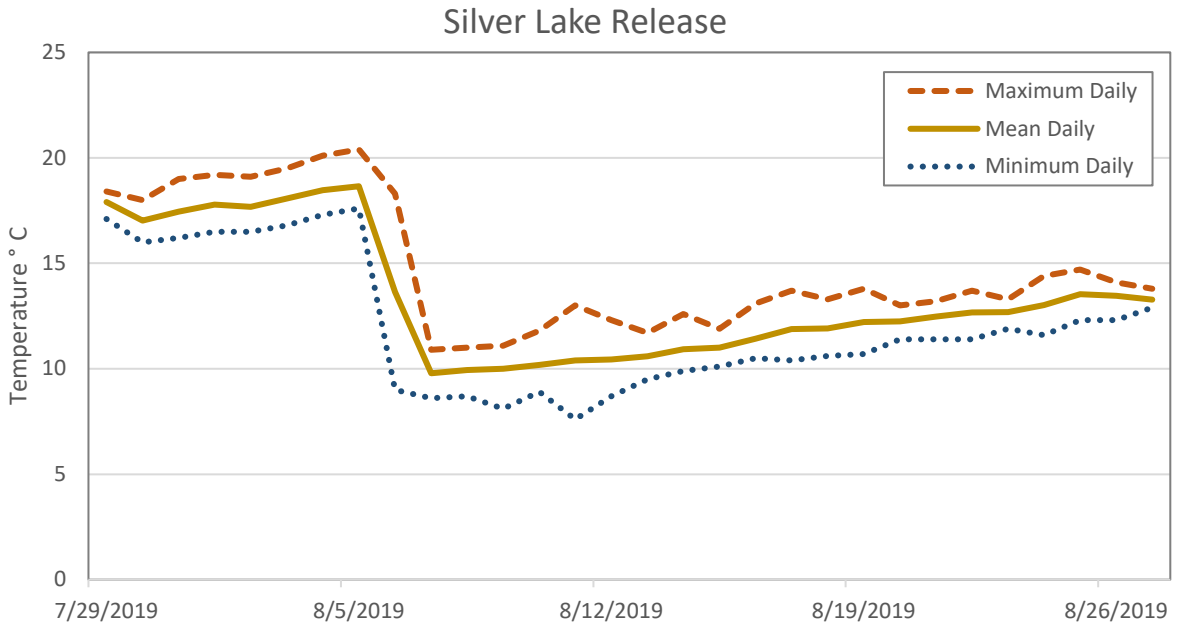
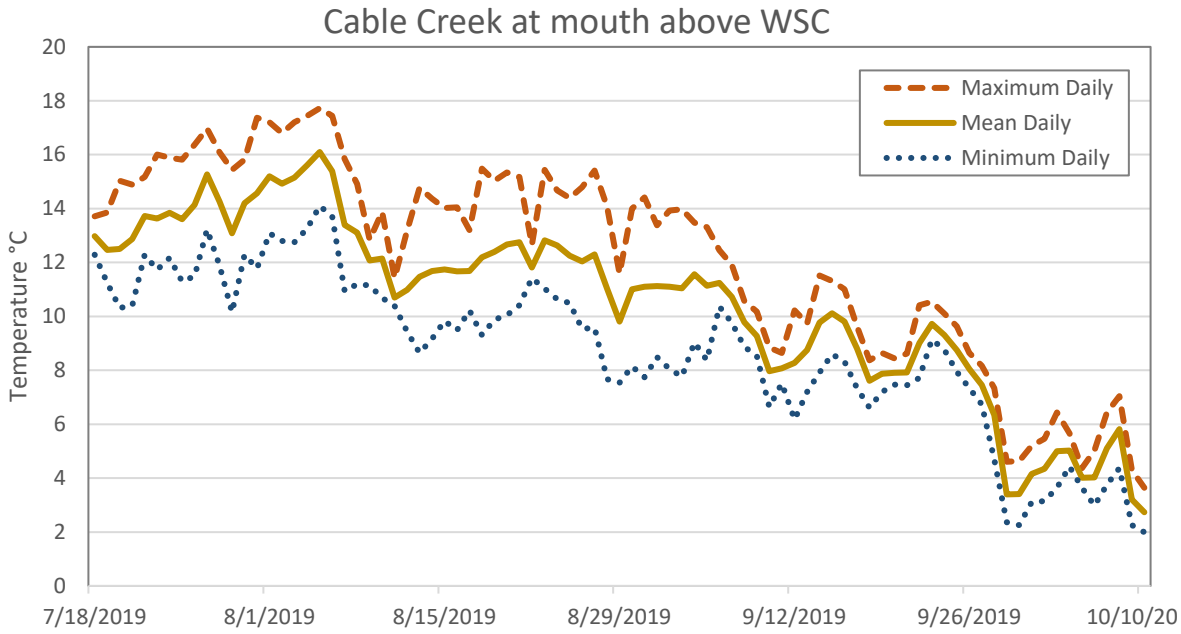
WMA – Wildlife Management Area Ditch
WSC – Warm Springs Creek
WWD – Westside-Walen Ditch

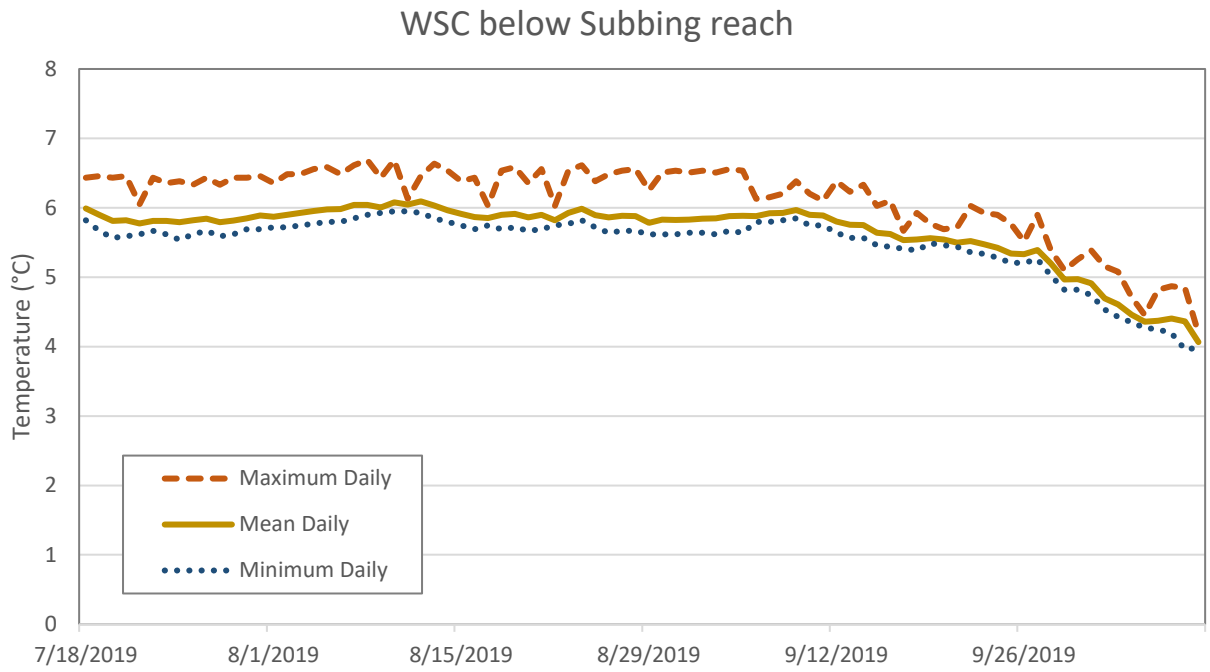
Appendix E: Temperature Monitoring Results



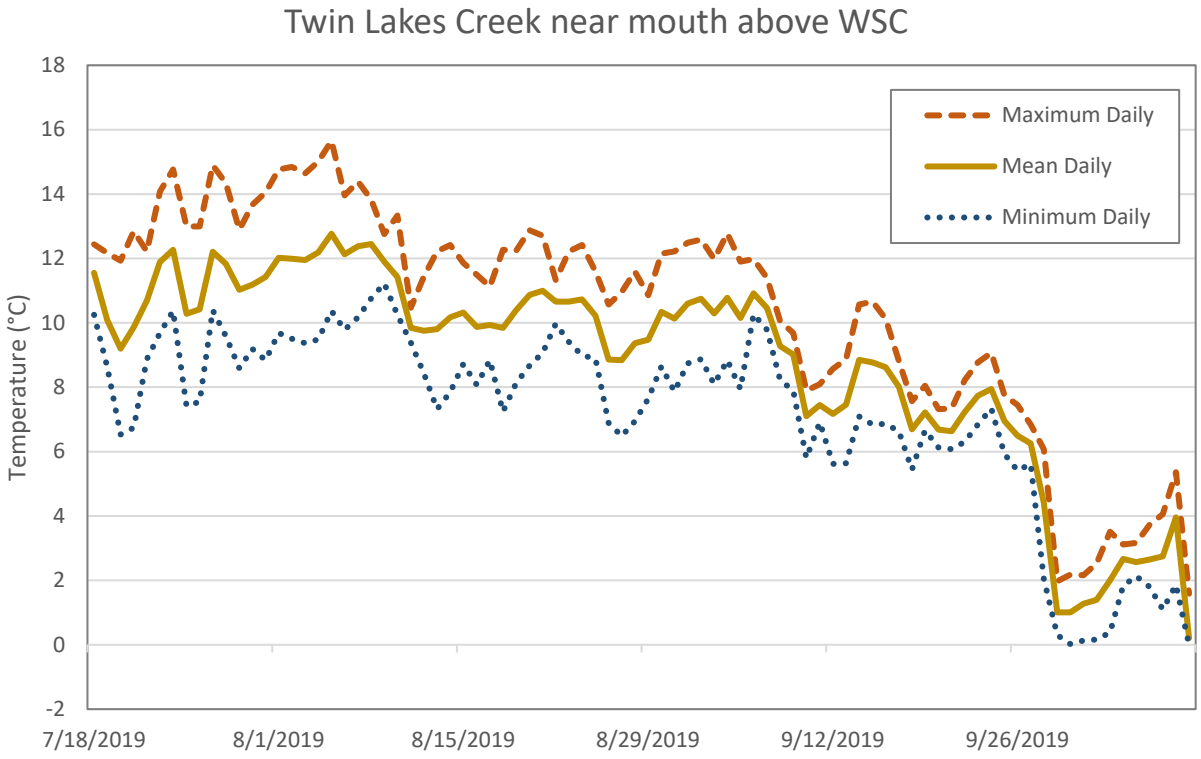
Temperature (°C) of Silver Lake release water, as measured by Solinst stage logger downstream of Parshall Flume.



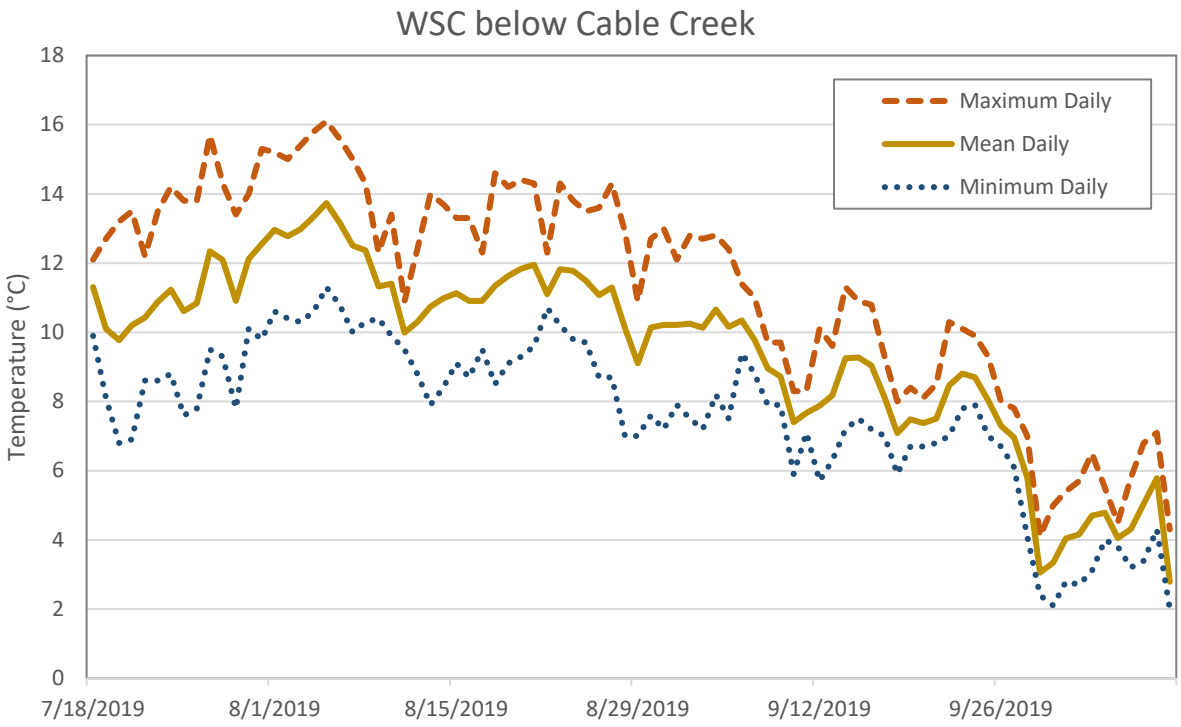
Cable Creek temperature (°C) near the confluence with Warm Springs Creek, as measured by Onset Hobo ProV2 temperature probe.



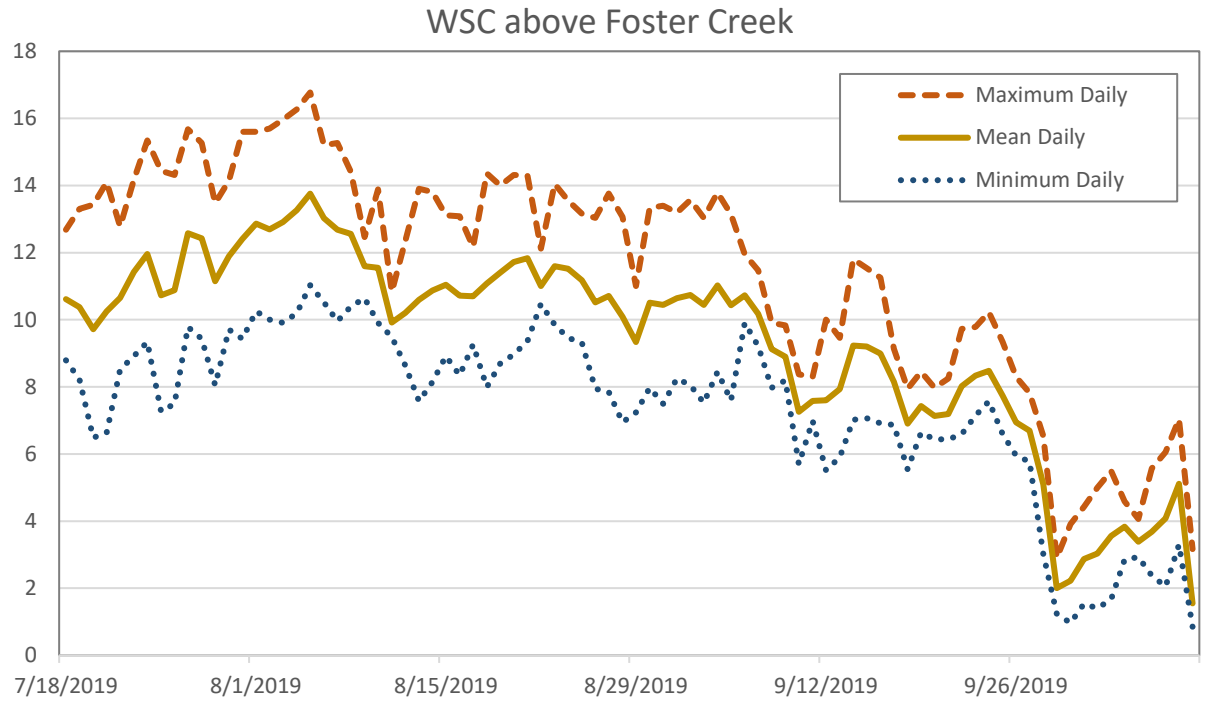
Warm Springs Creek temperature (°C) below a reach where flows go subsurface, as measured by MT Fish, Wildlife and Parks Onset Hobo ProV2 temperature probe.



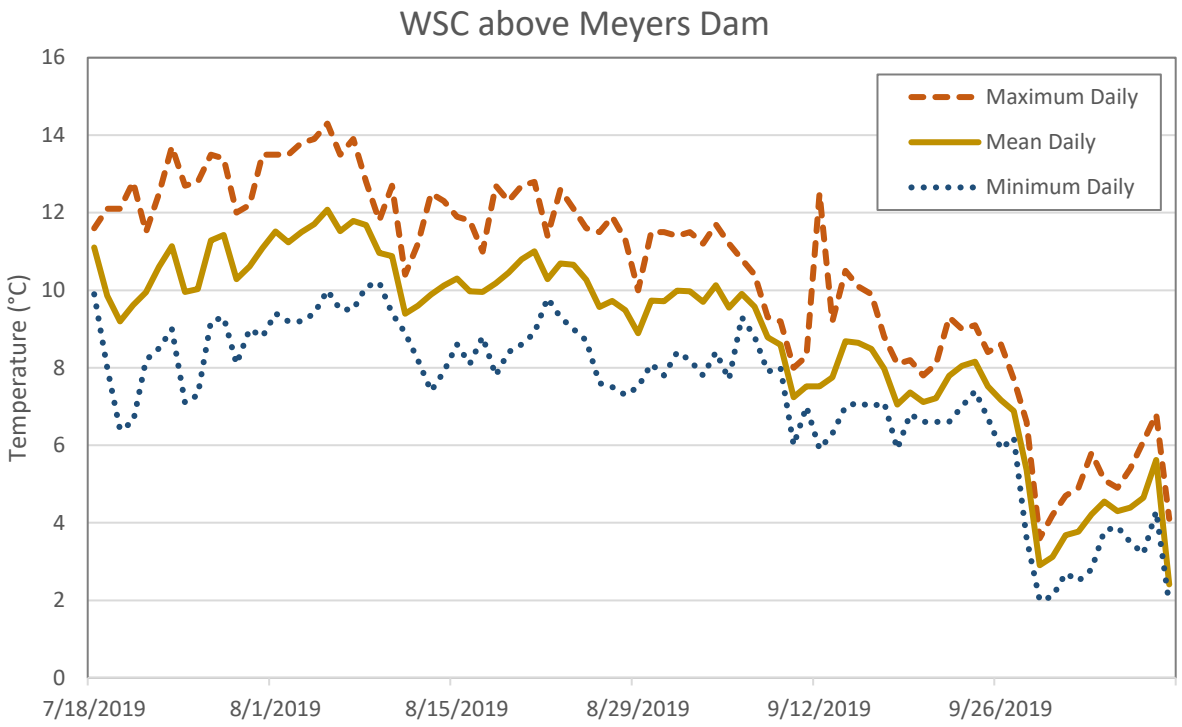
Twin Lakes Creek temperature (°C) near the confluence with Warm Springs Creek, as measured by Onset Hobo ProV2 temperature probe.



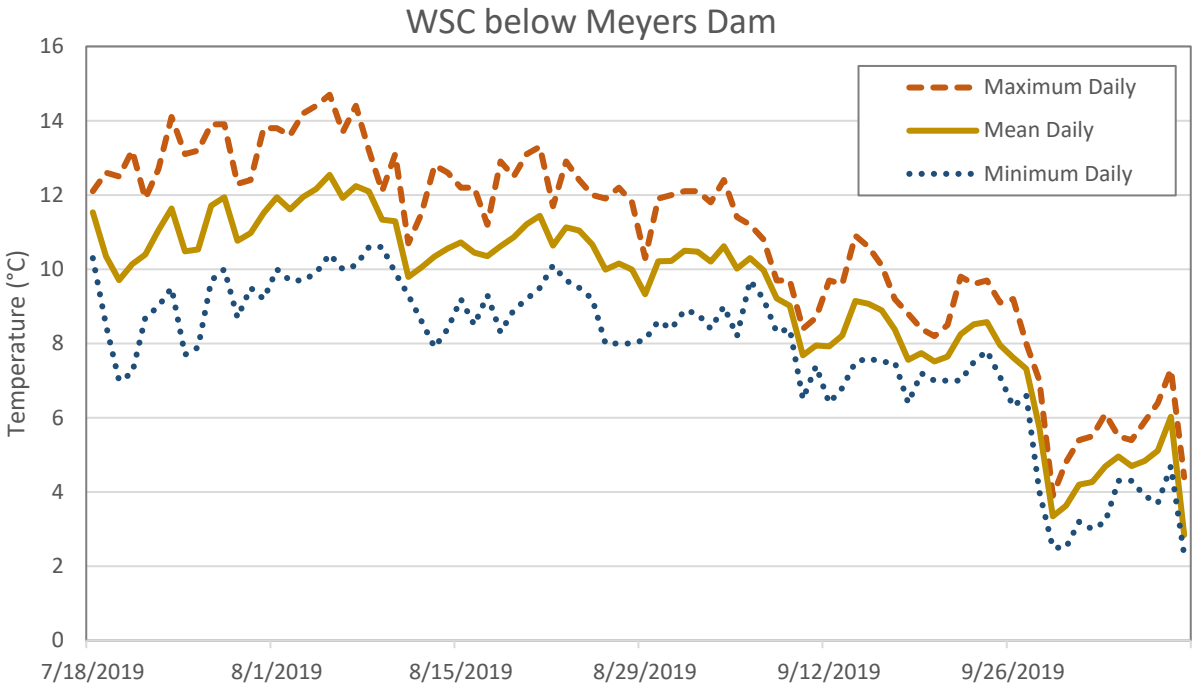
Warm Springs Creek temperature (°C) below confluence with Cable Creek, as measured by Solinst stage logger.



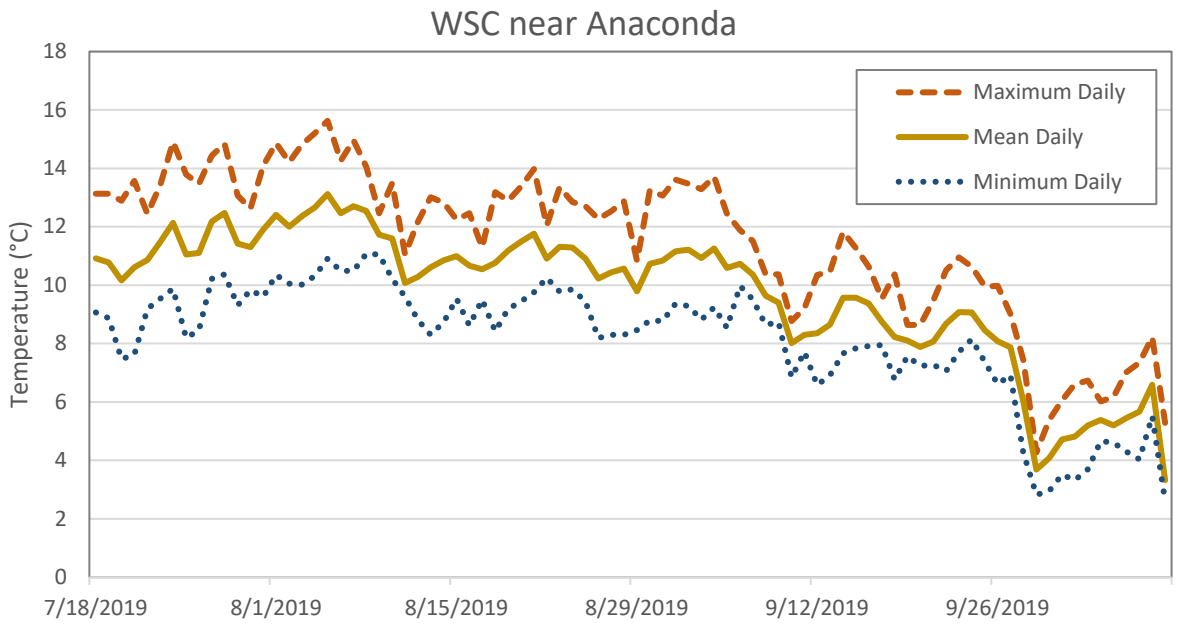
Warm Springs Creek temperature (°C) below Foster Creek, as measured by FWP Onset Hobo ProV2 temperature probe.



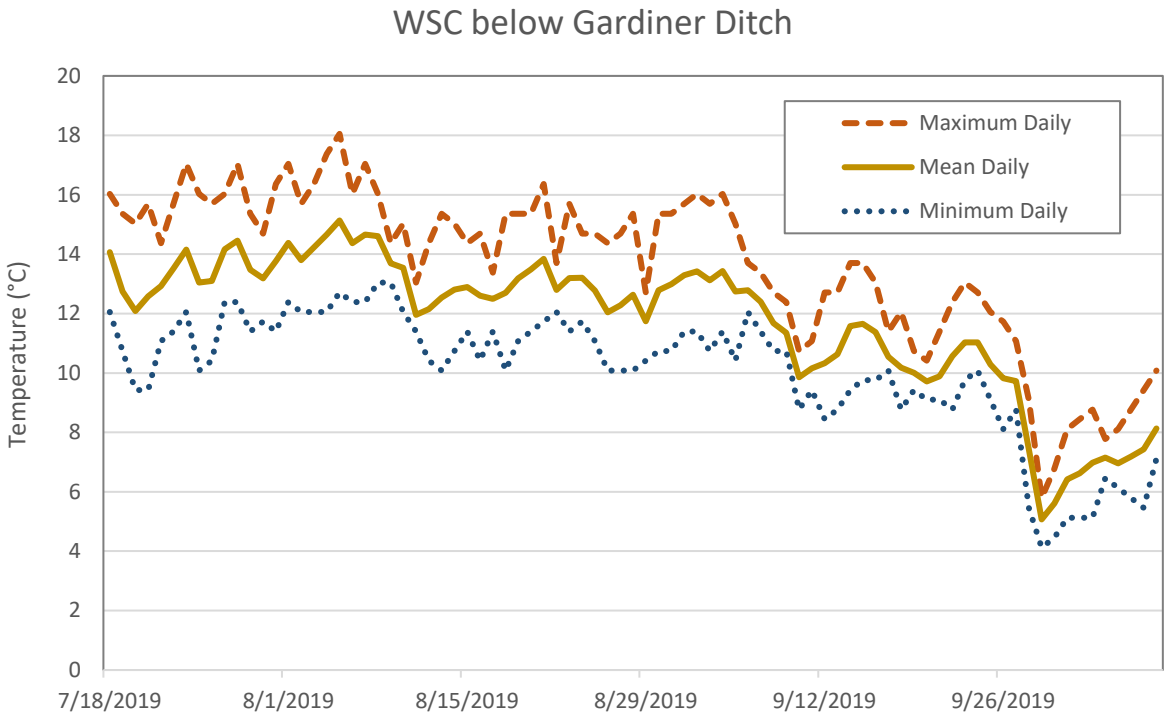
Warm Springs Creek temperature (°C) above Meyers Dam, as measured by Solinst stage logger.



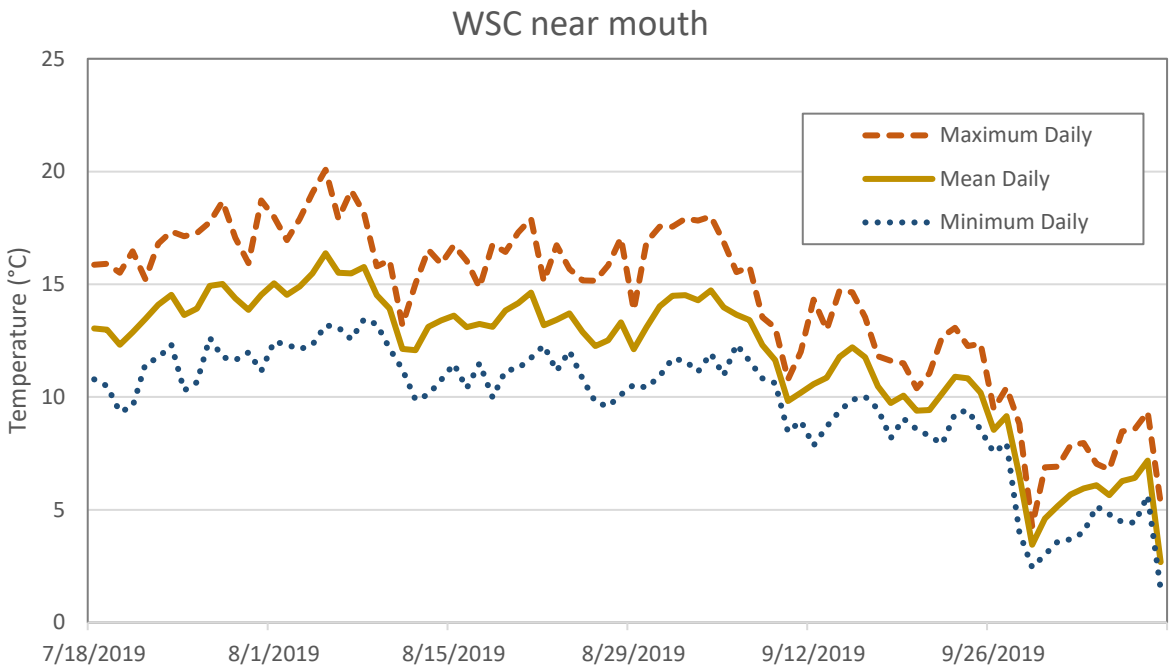
Warm Springs Creek temperature (°C) below Meyers Dam, as measured by Hobo ProV2 temperature probe.



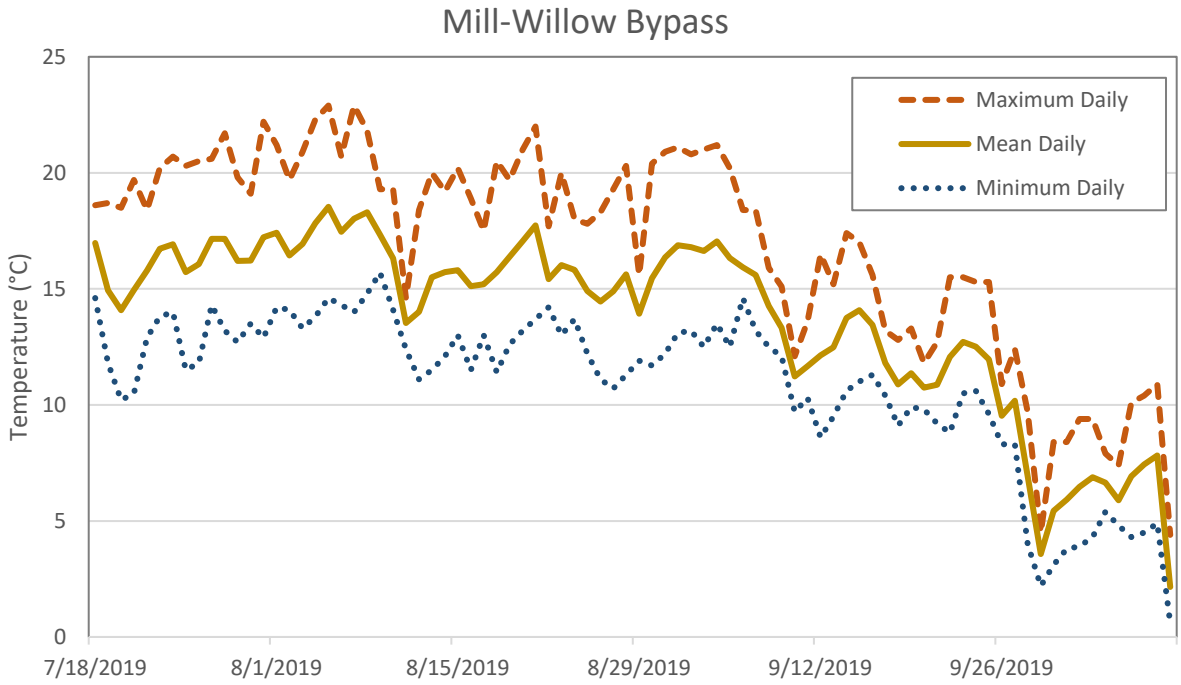
Warm Springs Creek temperature (°C) near Anaconda, as measured by MT Fish, Wildlife and Parks Hobo ProV2 temperature probe.



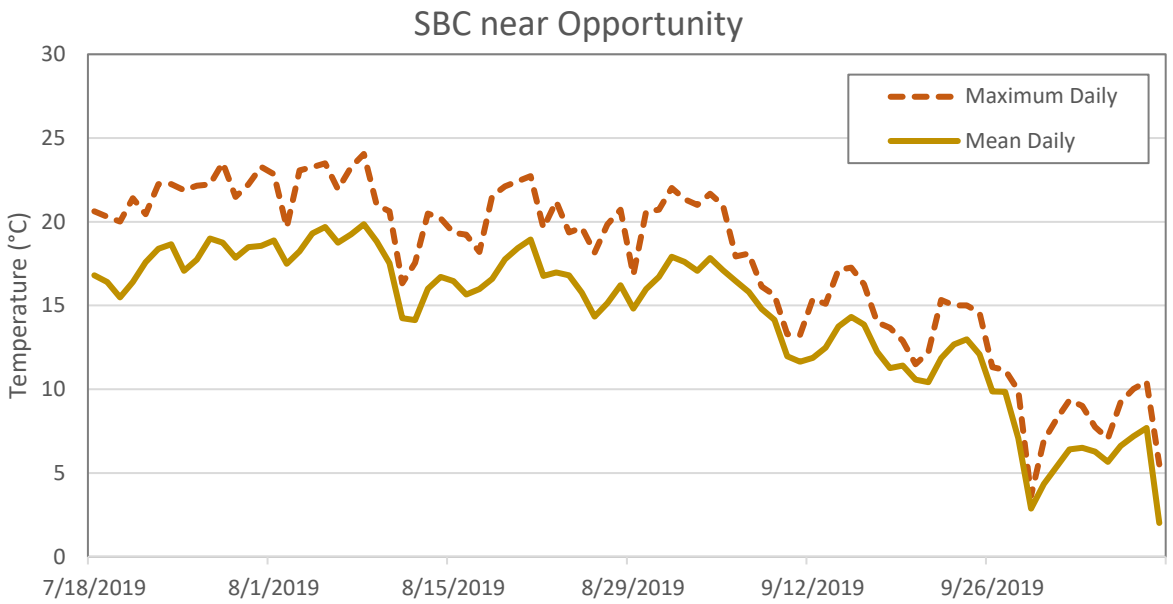
Warm Springs Creek temperature (°C) below Gardiner Ditch, as measured by CFC TruTrack Data Logger.



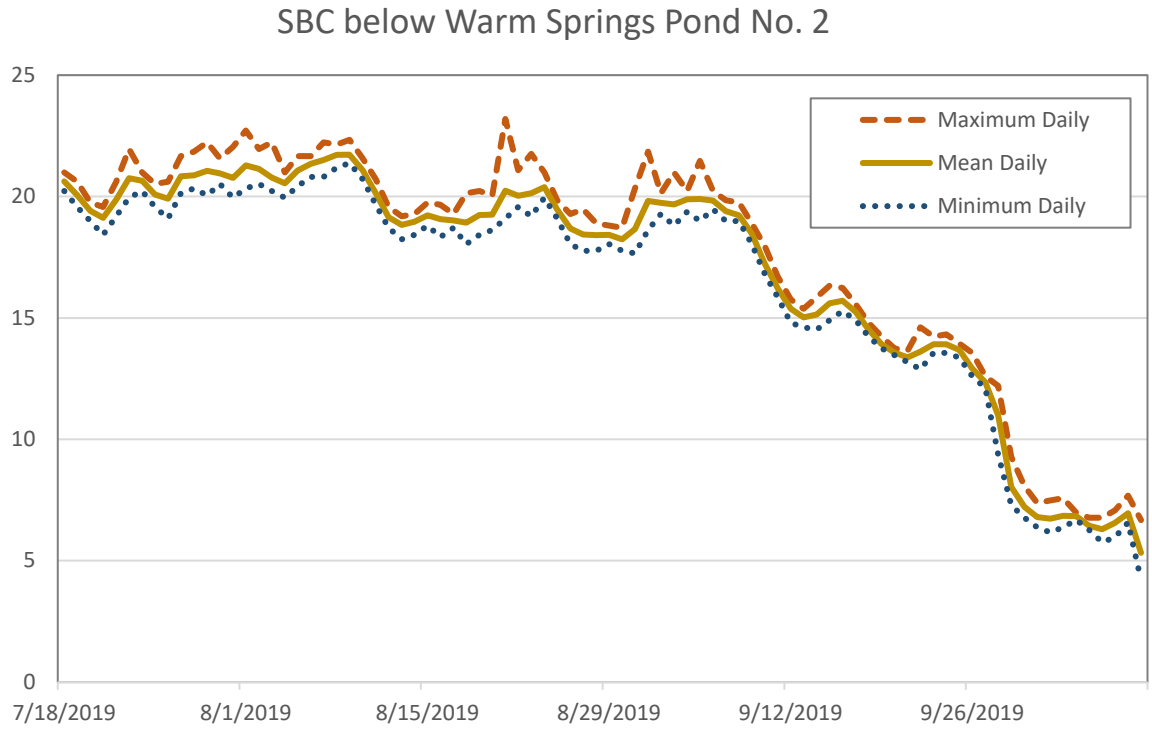
Warm Springs Creek temperature (°C) near confluence with Silver Bow Creek, as measured by FWP Onset Hobo ProV2 temperature probe.



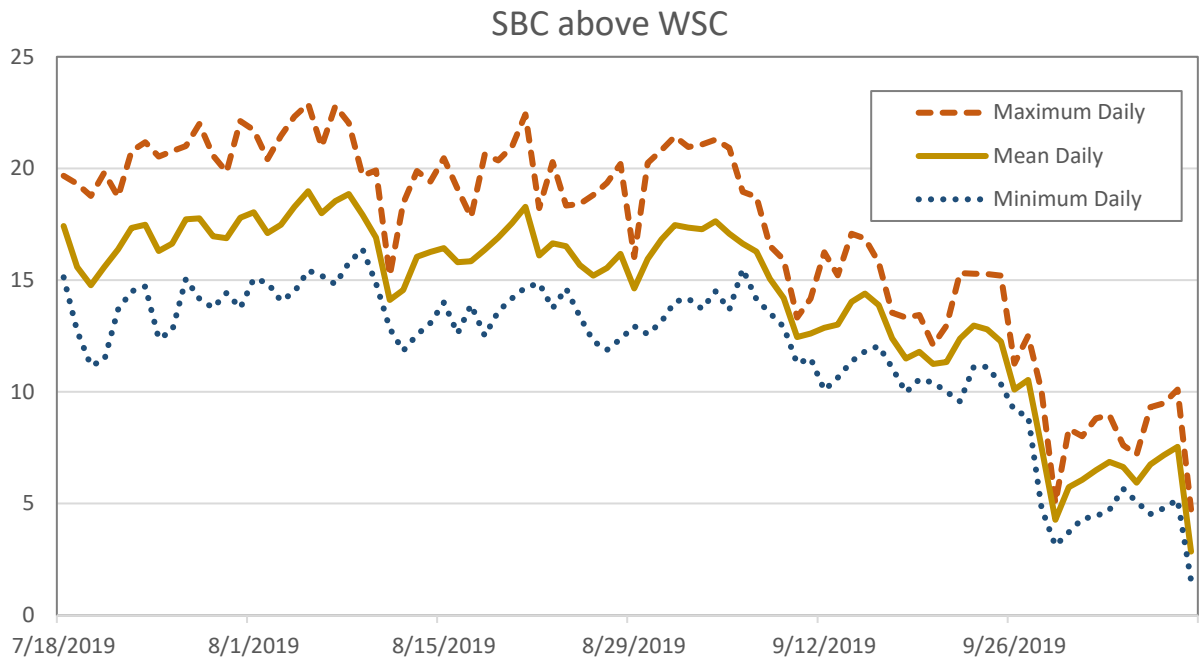
Mill-Willow Bypass temperature (°C) near confluence with Silver Bow Creek, as measured by Onset Hobo ProV2 temperature probe.



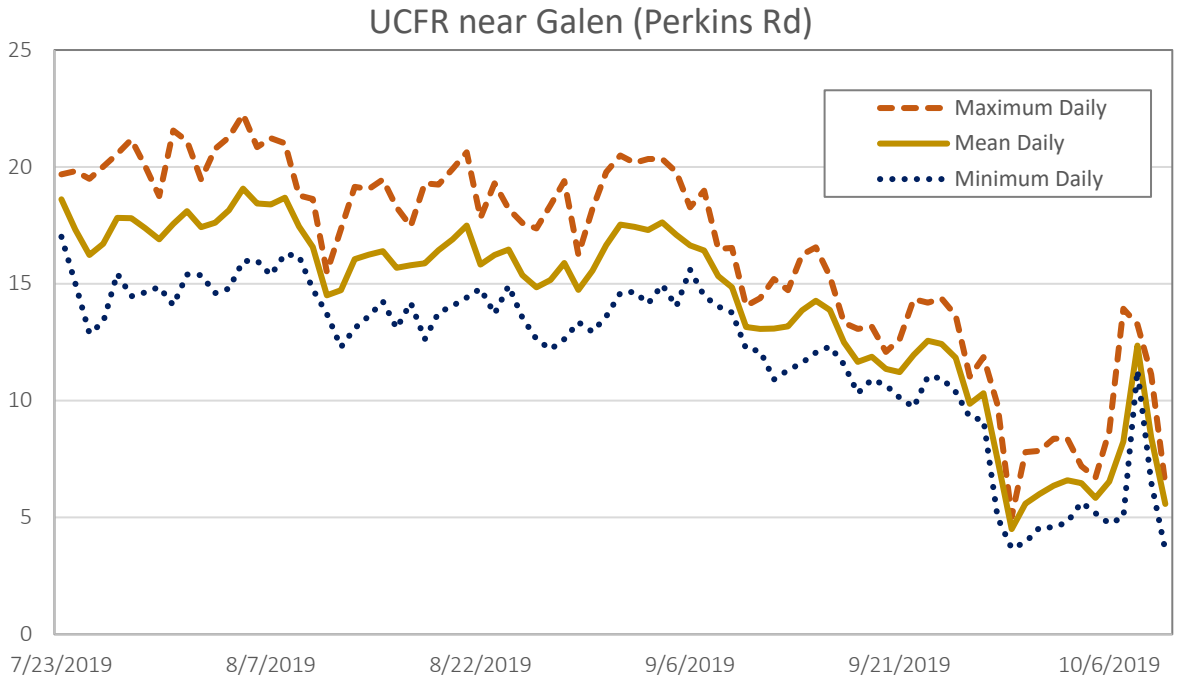
Silver Bow Creek temperature (°C) near Opportunity, as measured by FWP Onset Hobo ProV2 temperature probe



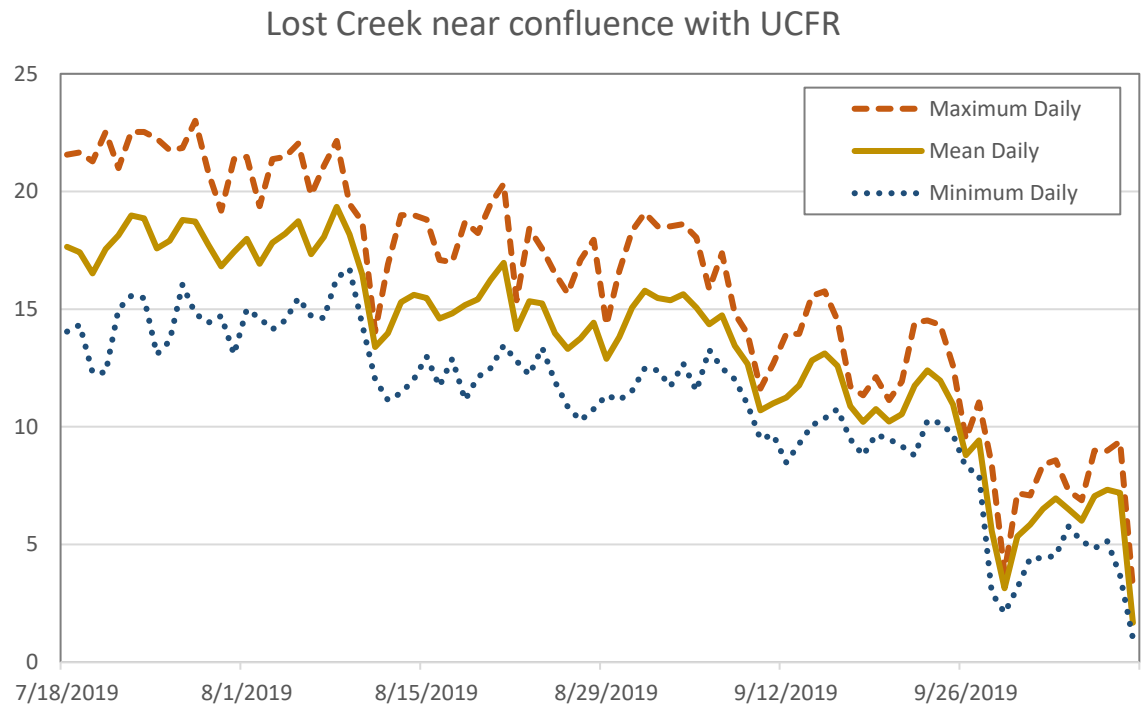
Silver Bow Creek temperature (°C) below Warm Springs Pond 2 outlet, as measured by FWP Onset Hobo Pendant temperature probe (minimum daily temperature not provided).



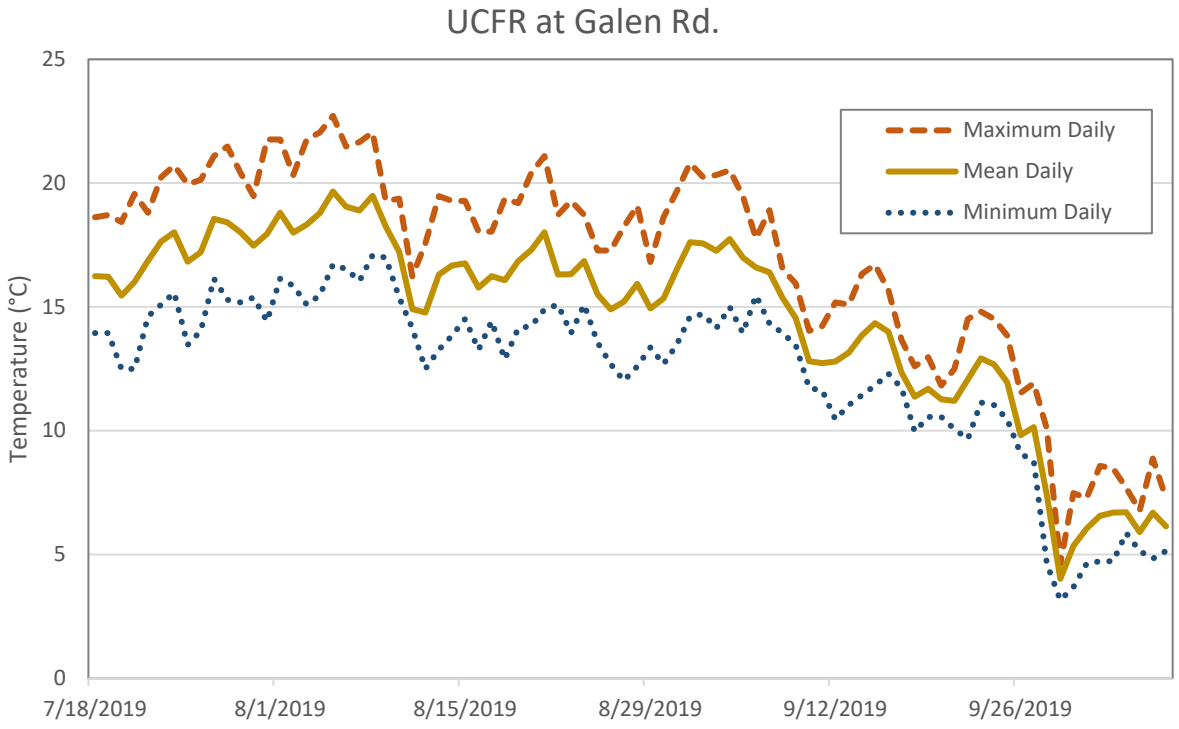
Silver Bow Creek temperature (°C) above confluence with Warm Springs Creek, as measured by Onset Hobo ProV2 temperature probe.



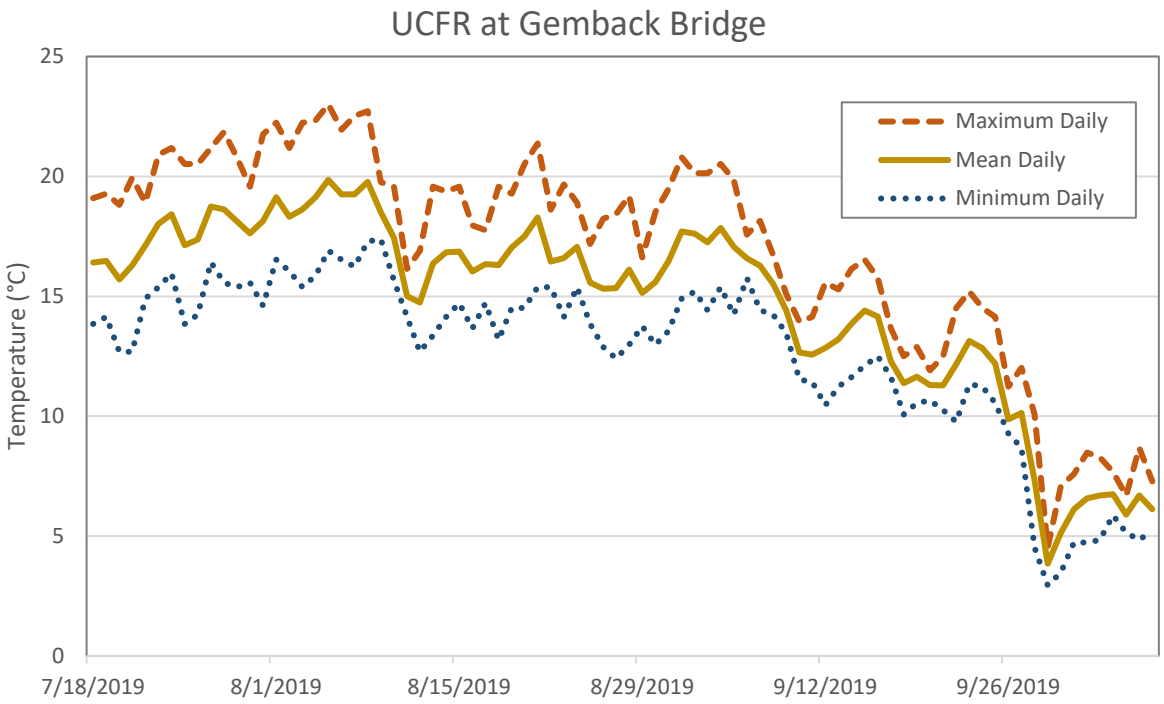
Clark Fork River temperature (°C) near Galen at Perkins Road, as measured by Onset Hobo ProV2 temperature probe.



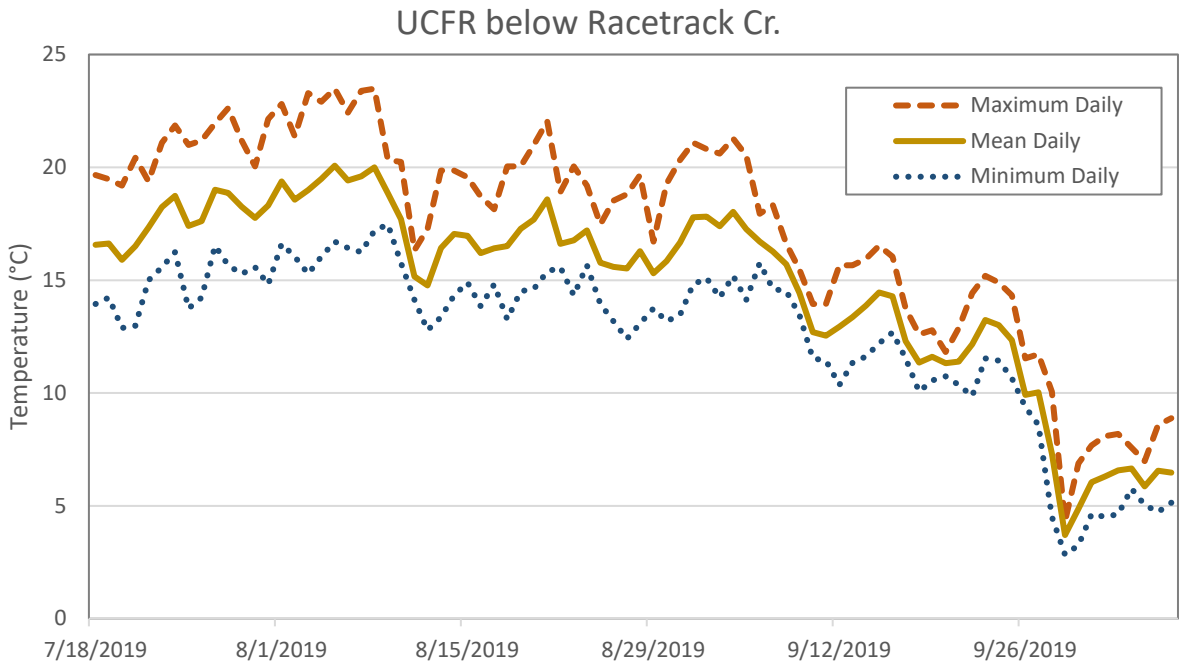
Lost Creek temperature (°C) near confluence with Clark Fork River, as measured by CFC Onset Hobo Water Level Logger.



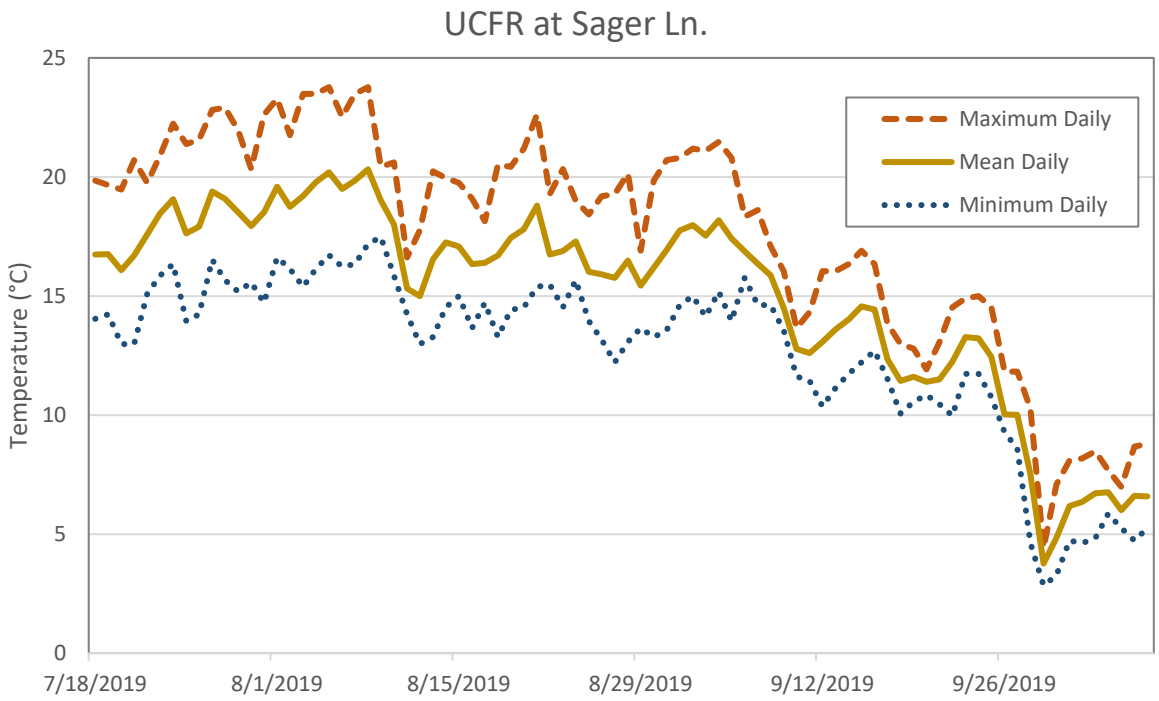
Clark Fork River temperature (°C) at Galen Rd., as measured by CFC Onset Hobo Water Level Logger.



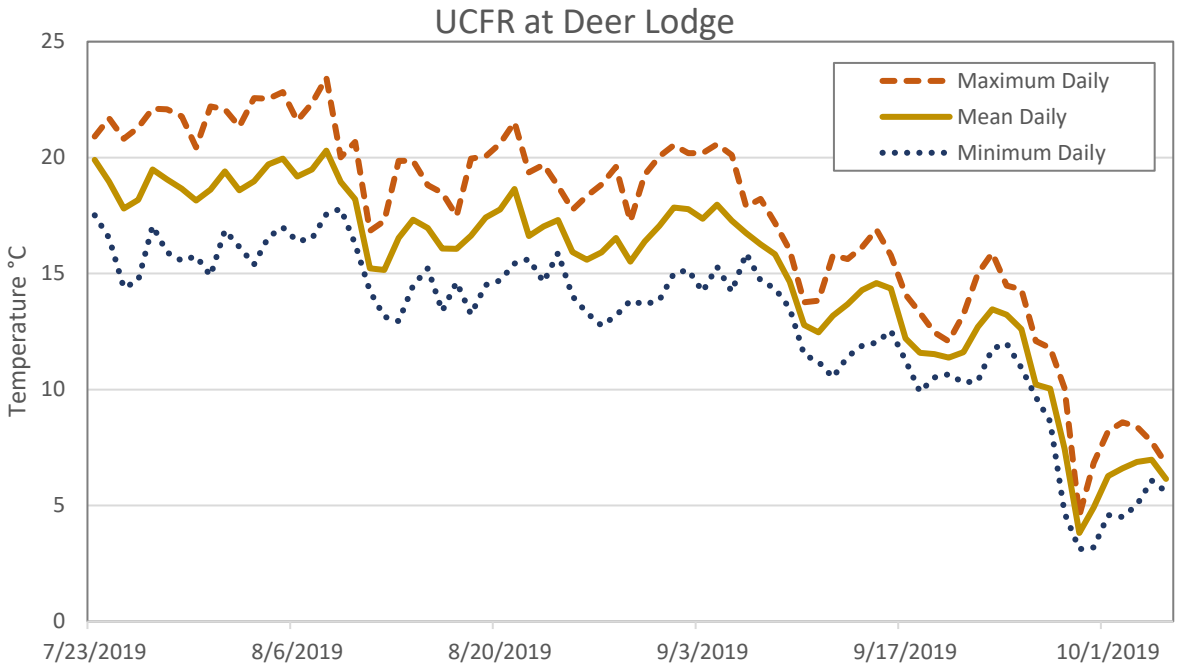
Clark Fork River temperature (°C) at Gemback Bridge, as measured by CFC Onset Hobo Water Level Logger.



Clark Fork River temperature (°C) below Racetrack Creek, as measured by CFC Onset Hobo Water Level Logger.



Clark Fork River temperature (°C) at Sager Lane, as measured by CFC Onset Hobo Water Level Logger.



Clark Fork River temperature (°C) at Deer Lodge, as measured by CFC Onset Hobo ProV2 temperature probe.

Appendix F: WCE W3T Technical Memo

Technical Memorandum

Date: December 5, 2019

To: Morgan Case, Trout Unlimited

From: Rankin Holmes, Watercourse Engineering, Inc.
Brooke Mejica, Watercourse Engineering, Inc.
Mike Deas, Watercourse Engineering, Inc.

Re: Application of W3T to Warm Springs Creek – Model Status Summary

Introduction

The Water Temperature Transaction Tool (W3T) is used to evaluate stream temperatures under a variety of flow scenarios based on cross-section form, channel slope and aspect, riparian and topographic shade, flow and temperature of stream inflows, and diversion quantities. These data were acquired, assessed, and used to construct a W3T model for Warm Springs Creek, Montana, a tributary to the Upper Clark Fork River near Anaconda, Montana. The model will be developed for the 2019 summer season and can be updated for application to other time periods. This memorandum provides a report on the status of data development and initial model implementation for the Warm Springs Creek application.

Project Area

Warm Springs Creek is located in Deer Lodge County in western Montana, near the town of Anaconda (Figure 1). The project area comprises a 25.5 mile reach of Warm Springs Creek (WSC) and includes a 2.65 mile reach of Silver Lake Channel that conveys flow from Silver Lake to WSC, joining WSC at approximately river mile (RM) 22.1. From the top of the study reach WSC flows generally from west to east, turns to the southeast at approximately RM 14, then turns to flow in a northeasterly direction from Anaconda to the confluence with the Upper Clark Fork River. In addition to four tributary streams flowing into WSC in the study reach, several diversions and diversion return flows convey water out of or into WSC.

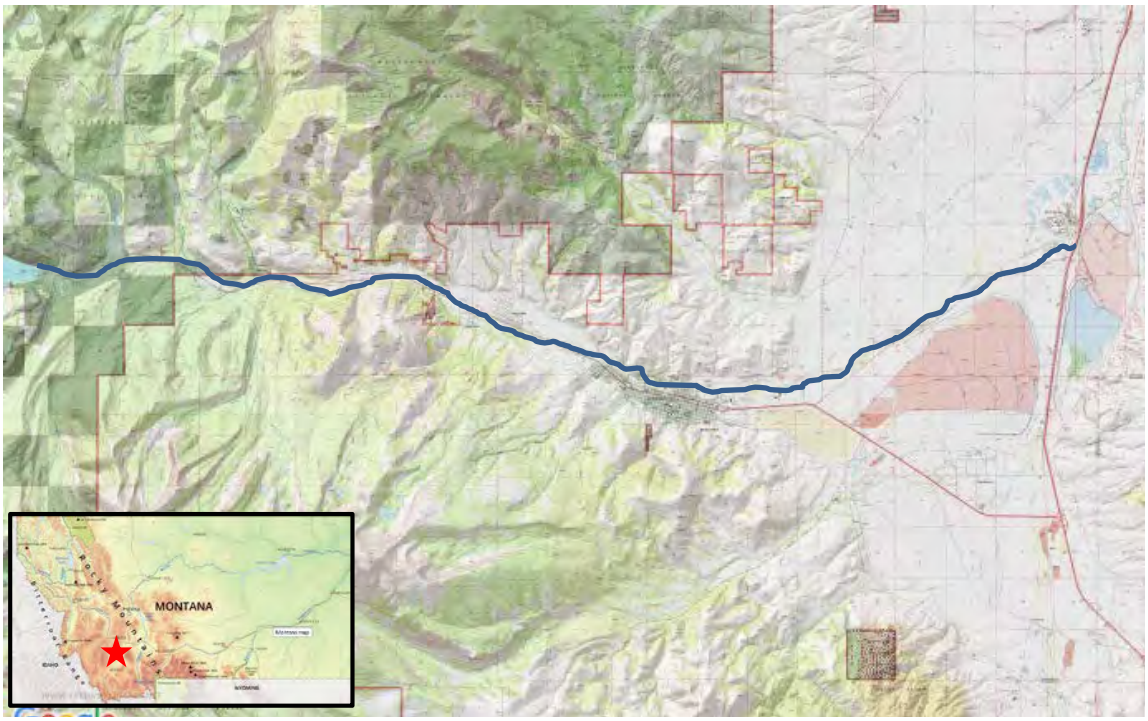


Figure 1. Project Area (red star in inset map shows location in Montana and blue line shows the modeled reach).

Model Reaches

The project reach will be broken up into three major sub-reaches, which will be modeled by three individual W3T models. These will include: 1) the channel conveying Silver Lake flows from the ditch below Silver Lake dam to Cable Creek above the Warm Springs Creek confluence; 2) Warm Springs Creek at the confluence with Cable Creek to Warm Springs Creek near Anaconda; and 3) Warm Springs Creek near Anaconda to Warm Springs Creek near the mouth with the Upper Clark Fork River (Silver Bow Creek). For each scenario applied, results from the upper sub-model will be applied as input into middle sub-model and model results from the middle sub-model will be applied as input into the lower sub-model.

Warm Springs Creek W3T Model Development Status

The model requires five different kinds of data acquired from various sources: meteorology, channel geometry, shade, flow, and water temperature. Types of data, specific data required, and the scope of data are detailed in Table 1. All time series data are hourly and are set to Mountain Standard Time.

Table 1. W3T data types and their scope.

Data type	Specific datasets	Units	Scope
Meteorological	Air temperature	°C	Entire reach
	Cloudiness	percent as a fraction	
	Wind	m/s	
	Relative humidity	percent as a fraction	
	Wet bulb temperature	°C	
	Evaporative coefficients(1)	unitless	
Channel geometry	Representative cross-section	ft/ft	Each sub-reach
	Channel slope	m/m	
	Manning roughness, n[1]	no units	
Shade: Topographic [2]	Elevation angle	degrees	Entire reach
Shade: Riparian [3]	Width of riparian zones	m	Entire reach
	Height of emergent vegetation	m	Each zone in each direction
	Density of emergent vegetation	percent as a fraction	
	Elevation at ground	m	
Water temperatures	Inflow water temperatures	°C	Specific to each inflow or location
	Instream water temperatures(1)	°C	
Flows	Inflow rates	cfs	Specific to each inflow, diversion or location
	Diversion rates	cfs	
	Instream flow rates(1)	cfs	

[1]Typically used for model calibration and/or verification
[2]Specified for compass directions east, south, and west
[3]Specified for each band, or zone, of vegetation away from stream in each compass direction (see Watercourse (2013) for details)

Data development is ongoing and is summarized here, with schedule for completion of data development, model calibration, model application, and summary report in Table 2.

- Meteorological data: Meteorological data have been acquired and adjusted for three sites. Meteorological data used in the model will be determined during model calibration.

- Geometry: Channel cross section data have been acquired and will be adjusted for input into the model. Location and elevation data have been acquired for the river path and gradient will be calculated from these data.

- Shading: Topographic shade angles were calculated from location and elevation data (via Google Earth). Satellite imagery and site photos have been inspected and general riparian shade codes have been chosen for the three sub-models. These riparian shade codes will be adjusted during model calibration, as needed.

- Water Temperatures: Water temperature data has been acquired, and most datasets have been inspected and converted into hourly, on-the-hour time-series data for model input and calibration points. Hourly water temperature data will be organized into a comprehensive workbook for entry into the model.

- Flows: Flow data have been acquired and inspected. The development of three rating curves is underway. Continuous discharge will be calculated for these three sites and averaged for each modeled period/s. Flow rates for the modeled period/s will be estimated for each input (i.e., headwater, tributaries, and other return flows) and output (i.e., diversions, natural losses) based on a flow balance.

- Model Reach Configuration: Each of the three sub-models will be divided into a maximum of thirteen sub-reaches based on large-scale changes to aspect, geometry, shading, inputs, outputs, calibration points, and additional points of interest where model output data are desired. Thus far, monitoring points have been located and river miles (and feet from the top, required by the model) have been calculated for these points. River miles will be calculated for additional points as additional sub-reach break points are identified. Basic reach configurations (i.e., determination of and locations for each sub-reach break point) and will be modified once all data have been developed.

Table 2. Schedule for completion of W3T data development, model calibration, model application, and summary report.

Data Development	Data type	Specific datasets	Status	Completion Date
	Meteorological	Air temperature	Complete	-
		Cloudiness	Development Required	Dec 13, 2019
		Solar Radiation	Complete	-
		Wind	Adjustment Required	Dec 13, 2019
		Relative humidity	Complete	-
		Wet bulb temperature	Complete	-
	Channel geometry	Representative cross-section	Adjustment Required	Dec 10, 2019
		Channel slope	Development Required	Dec 10, 2019
	Shade: Topographic	Elevation angle	Complete	-
	Shade: Riparian	Height of emergent vegetation Density of emergent vegetation Elevation at ground	Initial Values and Aspects Determined	-
	Water temperatures	Inflow water temperatures Instream water temperatures	Acquired, Complete Organization	Dec 10, 2019
	Flows	Inflow rates Diversion rates Instream flow rates[1]	Development In Progress	Dec 10, 2019
	Reach Configuration	Sub-reach break points	Development In Progress	Dec 24, 2019
Model Calibration	**Data type**	**Adjustments to**	**Status**	**Completion Date**
	Meteorological	Confirm or change applied station (choose 1 of 3)	TBD	Jan 10, 2019
		Adjust evaporation coefficients as needed	TBD	
	Channel geometry	Change applied cross sections or adjustments to cross sections	TBD	Jan 10, 2019
		Manning roughness, n	TBD	
	Shade: Riparian	Adjust applied shade codes	TBD	Jan 10, 2019
	Flows	Adjust unknowns as needed	TBD	Jan 10, 2019
	Parameters	Adjust bed conduction as needed	TBD	Jan 10, 2019
Model Application	**Modeled Periods**		**Status**	**Completion Date**
	Initial periods chosen (late July, early August, mid-August), adjust as needed		TBD	Jan 15, 2019
Summary Report	**Status**			**Completion Date**
	In Progress; Complete once Data Development, Model Calibration and Model Application are complete			Jan 15, 2019

Development of each data type is detailed below.

Meteorological Data

Meteorological data from three stations [Yankee Flat, Anaconda (K3U3) and Deer Lodge (DLRM)] will be compared for use within the W3T model. Meteorological data have been

downloaded, data gaps filled (by linear interpolation) and post-processed for input into the model. Data post-processing includes development of cloudiness from solar radiation data, estimation of wet bulb air temperature from air temperature and relative humidity, and adjustment of wind speed data for anemometer height.

Channel Geometry

Channel cross section geometry information is available from flow measurements that range from about 11 cfs to 110 cfs, taken in July through September 2019 at nine locations in Warm Springs Creek and its tributaries (Table 2). Channel form will be derived from the distances and depths recorded during the highest flow measurement at each location. Channel geometry (surface area, volume, and depth) will be estimated by fitting 21 points to each cross section, including an extension above the water surface to include an estimation of channel geometry under higher flow conditions. A representative cross section will be selected for each sub-reach.

The channel gradients for each sub-reach will be derived from longitudinal profile data estimated from Google Earth. Within the project area, WSC flows generally from west to east, turns to the southeast at approximately RM 14, then turns to flow in a northeasterly direction from Anaconda to the confluence with the Upper Clark Fork River. The aspect of the river has implications for estimating the amount solar radiation reaching the water surface in each sub-reach and is utilized by riparian shading codes applied in each direction.

Table 3. Field flow measurements at nine locations in the Warm Springs Creek study area.

Stream Name	Site Name	7/18/2019	7/25/2019	8/1/2019	8/16/2019	8/26/2019	9/12/2019
Warm Springs Creek	Silver Lake release[1]	--	--	15.06	31.88[2]	30.21	0
Unnamed tributary of Cable Creek	West of Cable Mountain	--	2.77	15.44	37.12	--	--
Cable Creek	Near mouth	--	--	22.9	39.38	--	--
Twin Lakes Creek	Near mouth	--	--	11.46	16.66	--	--
Warm Springs Creek	Below Cable Creek[1]	34.12	29.99	42.65	62.38	54.18	22.51
Warm Springs Creek	Above Meyers Dam[1]	110.2	89.21	83.78	106.67	101.79	72.05
Warm Springs Creek	Below Gardiner Ditch	107	59.9	--	--	--	--
Warm Springs Creek	Below WMA Ditch	93.46	--	46.8	60.58	--	--

Lost Creek	Below Gardiner Ditch	--	--	13.91	--	--	--

[1]Level logger location
[2]Adjusted for measurement error

Topographic Shade

Topographic shading is defined for each sub-reach by providing the angle from the water surface to large topographic features to the east, west, and south (the north direction is assumed to not provide any topographic shade). Topography provides relatively little shade to most parts of the Warm Springs Creek study reach (less than 15 degrees from the water surface to any large topographic feature to the east, west, and south). Several short reaches receive moderate topographic shade. Topographic shading was developed using the profile feature in Google Earth.

Riparian Shade

Riparian shade will be determined by the distribution and structure of the vegetation along the banks of the stream. Examination of Google Earth satellite imagery and site photos suggests that the upper reaches of WSC are bordered by coniferous vegetation providing moderate shade to the water surface. The middle reach of WSC is bordered by a mix of coniferous and deciduous vegetation that appear to provide only modest shade to the creek. The lower reach of WSC is bordered primarily by a narrow band of deciduous vegetation that separates the creek from open pasture. Light riparian shade is provided to the water surface over the majority of the lower reach. Adjustments will be made to shading during model calibration, as needed.

Water Temperature Data

Time series water temperature data was collected for at least thirteen locations in the study reach. The water temperature data will be used for model boundary conditions (inflow at top of model reach and tributary inflows) as well as for model calibration.

Flow Data

Flow in Warm Springs Creek was measured at nine locations between July and September 2019 (Table 3). Level loggers were installed at three of those locations to measure stage hourly or sub-hourly over that same time period. Rating curves were developed for the three level logger locations and were used to produce time series flow data sets. USGS gage 12323760, Warms Springs Creek near Anaconda, provides additional time series flow data.

References

Watercourse Engineering, Inc. (Watercourse). 2013. Water Temperature Transaction Tool (W3T): Technical and User's Guide (v1.0). Prepared for the National Fish and Wildlife Foundation. September.