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SUNLIGHT BASIN
INSTREAM FLOW STUDY
LEVEL I
PARK COUNTY, WYOMING

Prepared For

Wyoming Water Development Commission
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April 1, 2019

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INSTREAM FLOW STUDY
LEVEL I
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1.0 GENERAL FLOW ANALYSIS

1.1 INTRODUCTION

In 1986, the state of Wyoming passed the Instream Flow Law (W.S. 41-3-1001 to 1014), which enables unappropriated water flowing in any stream in Wyoming to be appropriated and declared a beneficial use as instream flows to maintain or improve fisheries. The Wyoming Game and Fish Commission (WGFC) is responsible for determining flows necessary to maintain fisheries in the state. The Wyoming Game and Fish Department (WGFD) acts under the direction of the WGFC to conduct multidisciplinary studies to inform the selection of stream segments and the identification of flow needs for filing requests. Requests are submitted to the Wyoming Water Development Commission (WWDC), which then completes hydrologic studies to assess the feasibility of each instream flow request. Studies are then provided to the Wyoming State Engineer’s Office (SEO), which conducts public hearings and considers all available information prior to approving or denying each instream flow application. An approved instream flow water right has a priority date corresponding to the date the SEO received and recorded the application, and water rights with senior priority dates must be recognized in the administration of each stream.

Biota Research and Consulting, Inc. (Biota) has been contracted by the WWDC to complete a hydrologic study to assess the feasibility of instream flow requests in three stream segments in the Sunlight Basin in Park County, Wyoming. Stream study segments include reaches of Muddy Creek, Crandall Creek, and Dead Indian Creek (Table 1). The WGFD completed instream flow studies in these three stream segments (Robertson, 2015), developed seasonal flow recommendations for each segment (Table 2), and established a filed priority date of April 20, 2017, for all segments.

Table 1. Instream flow study segment details, Sunlight Basin, Park County, Wyoming.

Segment Name	Temporary Filing Number	Filed Segment Length (mi)	Segment Extents (UTM NAD 83 zone 12, meters)					
			Legal Description	Easting	Northing		Easting	Northing
Muddy Creek	36 2/99	3.1	T57N R106W Sec3	606,104.6E	4,977,992.7N	Downstream to	606,226.4E	4,977,527.2N
			T57N R106W Sec10	606,226.4E	4,977,527.2N	Downstream to	605,130.6E	4,975,986N
			T57N R106W Sec9	605,130.6E	4,975,986N	Downstream to	604,925.6E	4,975,890N
			T57N R106W Sec16	604,925.6E	4,975,890N	Downstream to	604,529E	4,974,907.1N
Crandall Creek	36 1/62	1.74	T56N R107W Sec13	603,830.5E	4,965,384N	Downstream to	603,896.6E	4,965,384.9N
			T56N R106W Sec18	603,896.6E	4,965,384.9N	Downstream to	605,161.2E	4,965,970.3N
			T56N R106W Sec7	605,161.2E	4,965,970.3N	Downstream to	605,527.6E	4,966,098N
			T56N R106W Sec8	605,527.6E	4,966,098N	Downstream to	606,064E	4,966,262.8N
Dead Indian Creek	36 1/83	5.16	T55N R104W Sec30	624,014.7E	4,952,891.1N	Downstream to	624,023.5E	4,953,462.7N
			T55N R104W Sec19	624,023.5E	4,953,462.7N	Downstream to	624,427.4E	4,955,080.5N
			T55N R104W Sec18	624,427.4E	4,955,080.5N	Downstream to	624,897.5E	4,955,962.1N
			T55N R104W Sec17	624,897.5E	4,955,962.1N	Downstream to	625,168E	4,956,703.1N
			T55N R104W Sec8	625,168E	4,956,703.1N	Downstream to	626,357.8E	4,958,328N
			T55N R104W Sec5	626,357.8E	4,958,328N	Downstream to	626,441.8E	4,958,420.9N
			T55N R104W Sec4	626,441.8E	4,958,420.9N	Downstream to	626,606E	4,959,280.6N

Table 2. Monthly flow rates (cubic feet per second) requested by WGFD, Sunlight Basin, Park County, Wyoming (Robertson, 2015).

Segment Name	Temporary Filing Number	Winter Oct 1 to Apr 30 (requested cfs)	Spring May 1 to Jul 15 (requested cfs)	Summer Jul 16 to Sep 30 (requested cfs)
Muddy Creek	36 5/248	1.3	29	3
Segment Name	**Temporary Filing Number**	**Winter Oct 1 to Apr 30 (requested cfs)**	**Spring May 1 to Jun 30 (requested cfs)**	**Summer Jul 1 to Sep 30 (requested cfs)**
Crandall Creek	36 4/248	27	66	55
Dead Indian Creek	36 3/248	13.3	31	28

1.2 PROJECT AREA

Muddy Creek, Crandall Creek, and Dead Indian Creek are all tributaries of the Clarks Fork Yellowstone River. The Muddy Creek Instream Flow Study segment is located approximately 41 miles northwest of Cody, 25 miles west of Clark, and 37 miles East of Tower Junction (Figure 1). The Crandall Creek Instream Flow Study segment is located 37 miles northwest of Cody, 25 miles west of Clark, and 37 miles east of Tower Junction (Figure 1). The Dead Indian Creek Instream Flow Study segment is located approximately 24 miles northwest of Cody, 50 miles east/southeast of Tower Junction, and 16 miles southwest of Clark in Park County, Wyoming (Figure 1). Stream study segments are located on lands owned and administered by the U.S. Forest Service.

Muddy Creek is within the Clarks Fork Yellowstone River-Squaw Creek 12 Code Hydrologic Unit (HUC12, 100700060106), which encompasses approximately 35.5 mi^2. The Muddy Creek study segment is 3.1 miles in length, according to the National Hydrography Dataset (NHD) Flowline data. The segment catchment has a drainage area of 11.9 mi^2, a maximum basin elevation of 10,530 ft, a minimum elevation at the downstream end of the study segment of 7,440 ft, and stream length from the headwaters to the downstream end of the study segment of 8.5 mi (Figures 2 and 3). There are no diversions located within the study catchment (Table 3).

Crandall Creek is within the Lower Crandall Creek HUC12 (100700060203). The Crandall Creek study segment is 1.7 miles in length, according to the National Hydrography Dataset (NHD) Flowline data. The segment catchment has a drainage area of 111.2 mi^2, a maximum basin elevation of 11,580 ft, a minimum elevation at the downstream end of the study segment of 6,490 ft, and stream length from the headwaters to the downstream end of the study segment of 16.7 mi (Figures 4 and 5). There are no diversions located within the study catchment (Table 3).

Dead Indian Creek is within the Dead Indian Creek HUC12 (100700060304). The Dead Indian Creek study segment is 5.2 miles in length, according to the National Hydrography Dataset (NHD) Flowline data. The segment catchment has a drainage area of 61.0 mi^2, a maximum basin elevation of 12,260 ft, a minimum elevation at the downstream end of the study segment of 5,640 ft, and stream length from the headwaters to the downstream end of the study segment of 21.1 mi (Figures 6 and 7). There are no diversions located within the study catchment (Table 3).

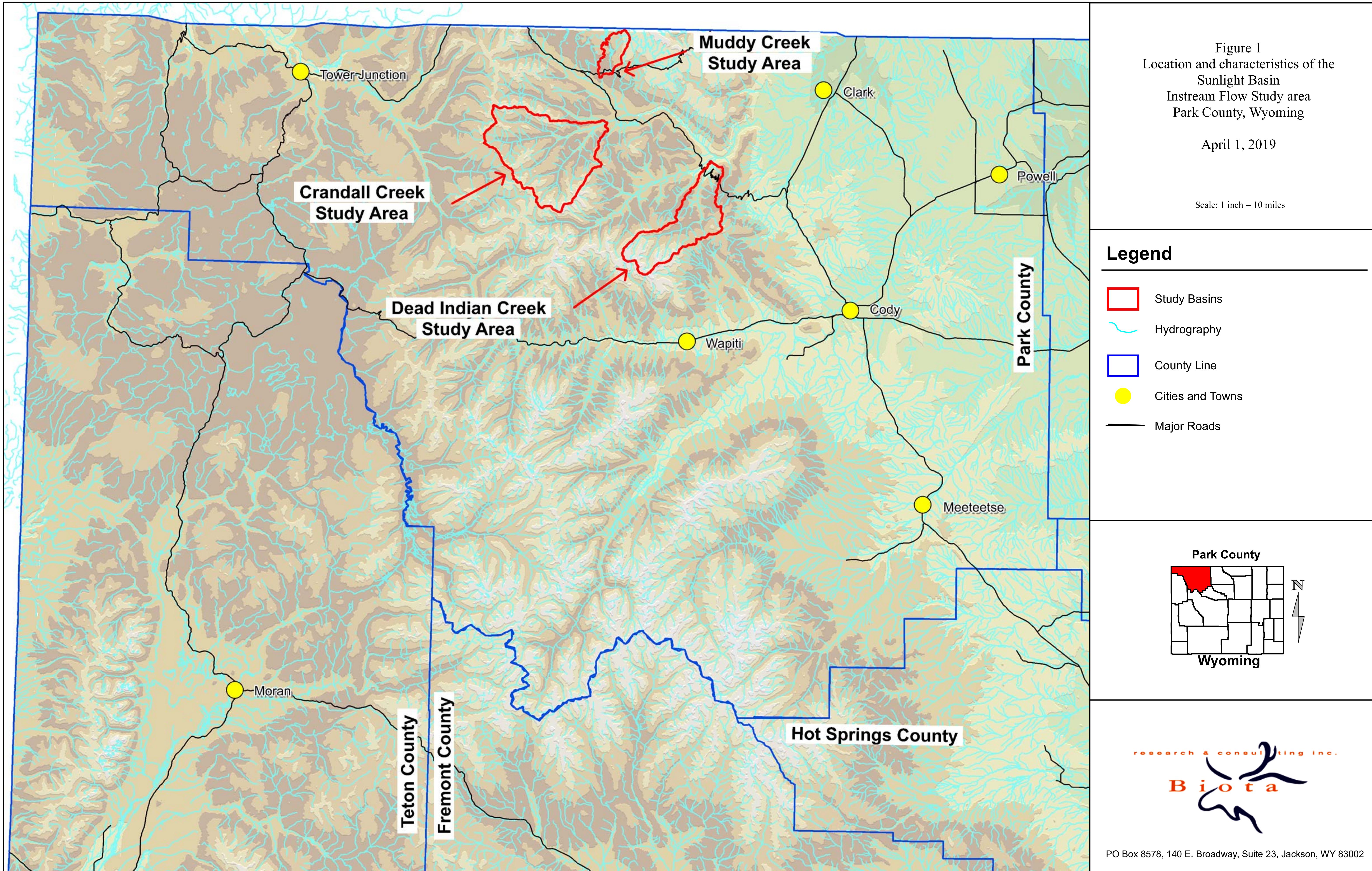


Figure 1
Location and characteristics of the
Sunlight Basin
Instream Flow Study area
Park County, Wyoming

April 1, 2019

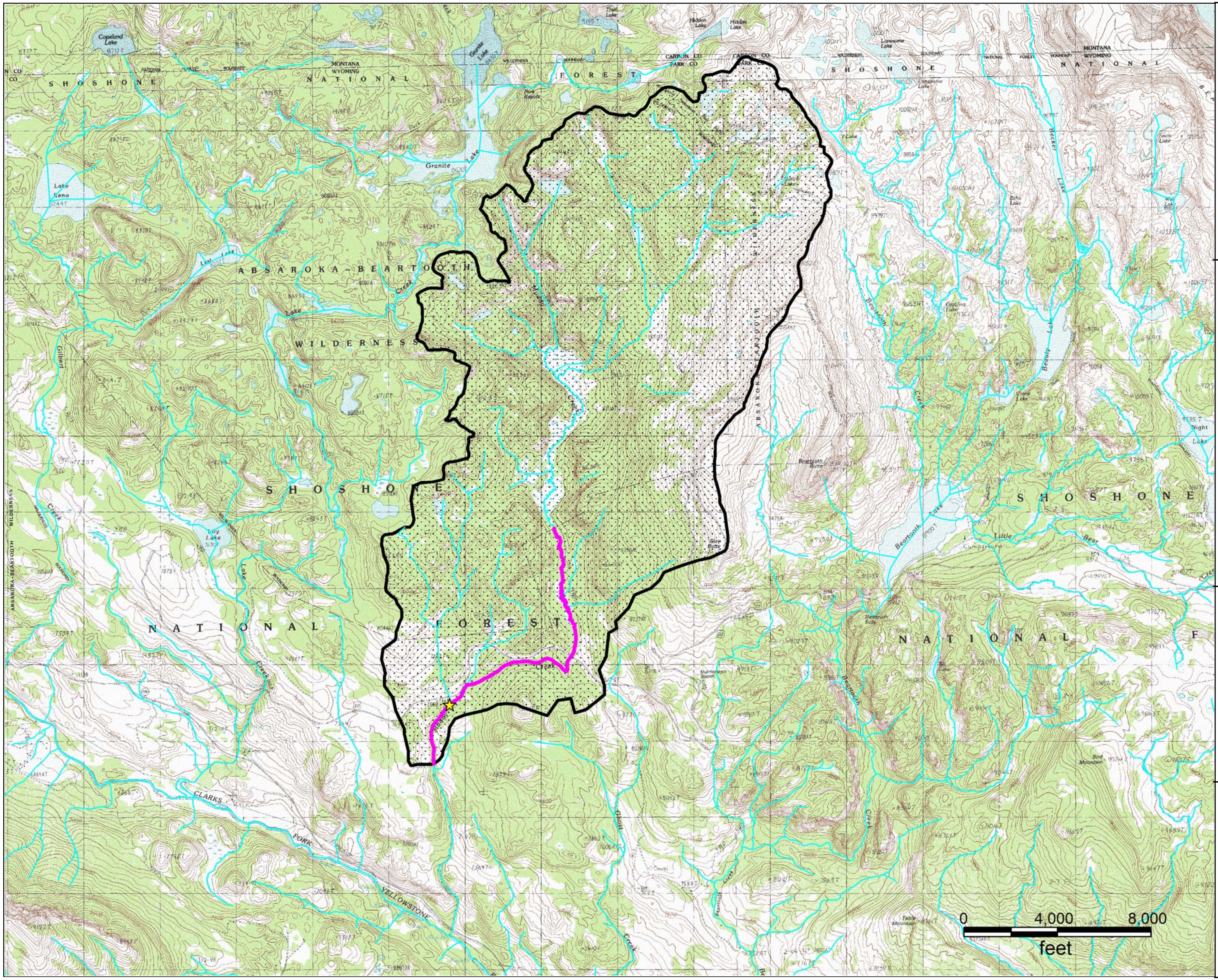


Figure 2
Muddy Creek study catchment
Sunlight Basin study area
Park County, Wyoming

April 1, 2019

Scale: 1 inch = 4,000 feet

Legend

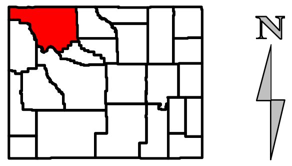
Study Segment

Hydrography

Temporary Gaging Station

Study Catchment

State and Public Lands



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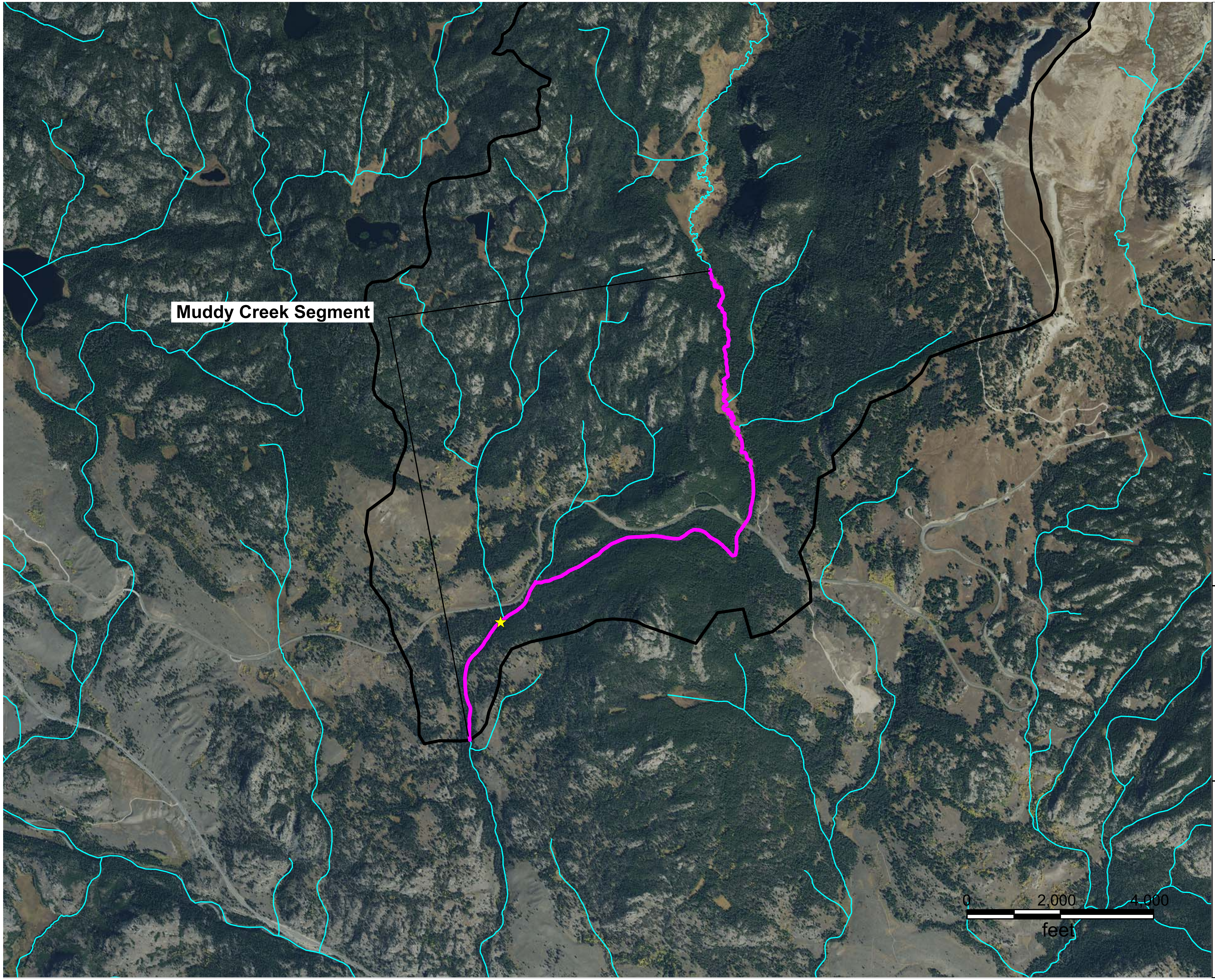


Figure 3
Muddy Creek study segmentment
Sunlight Basin study area
Park County, Wyoming

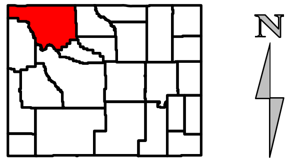
April 1, 2019

Scale: 1 inch = 2,000 feet

Legend

- Study Segment
- Hydrography
- Temporary Gaging Station
- Study Catchment

Park County



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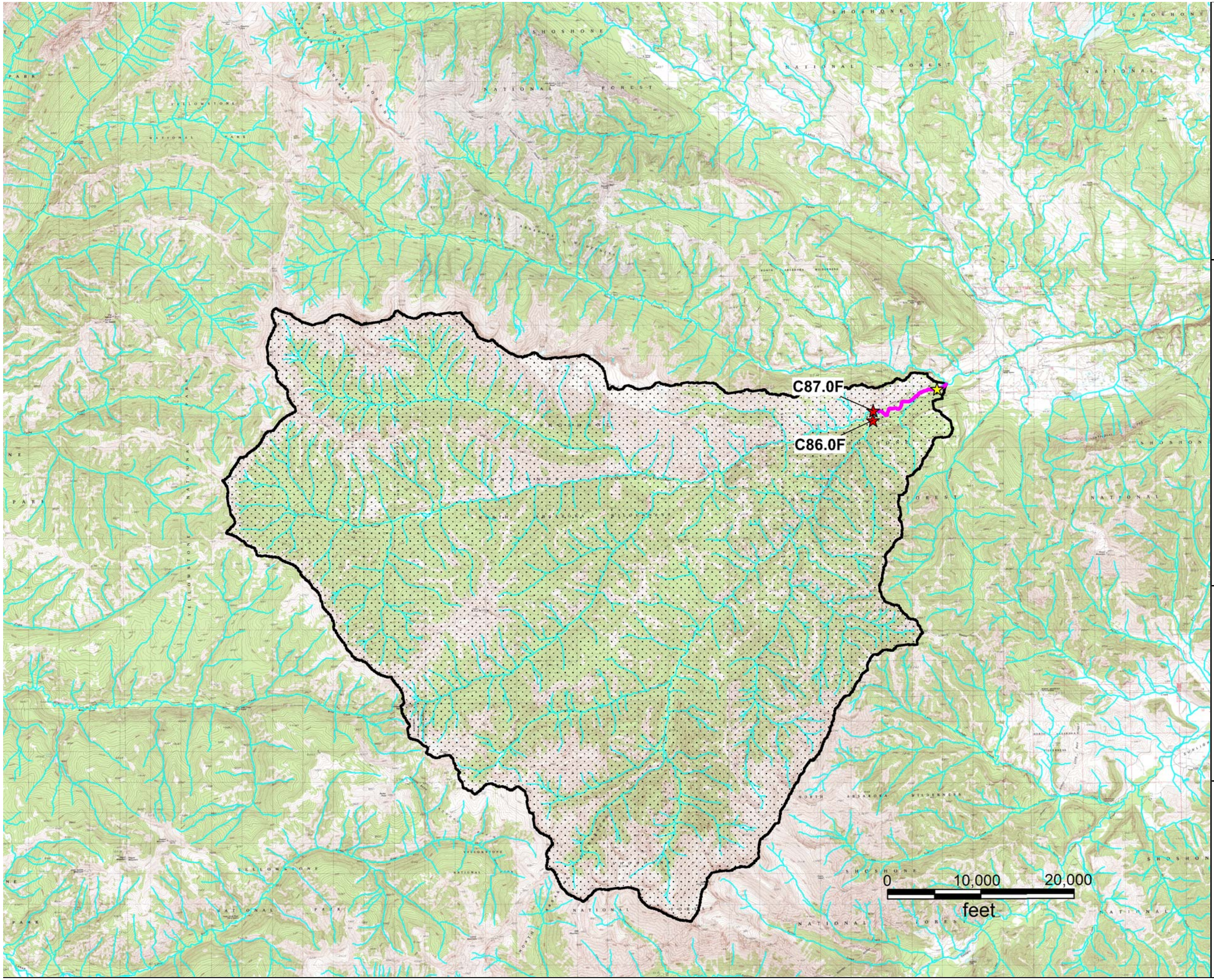

Figure 4
Crandall Creek study catchment
Sunlight Basin study area
Park County, Wyoming

April 1, 2019

Scale: 1 inch = 10,000 feet

Legend

- Study Segment
- Hydrography
- Temporary Gaging Station
- Water Right POD (and Number)
- Study Catchment
- State and Public Lands

Park County

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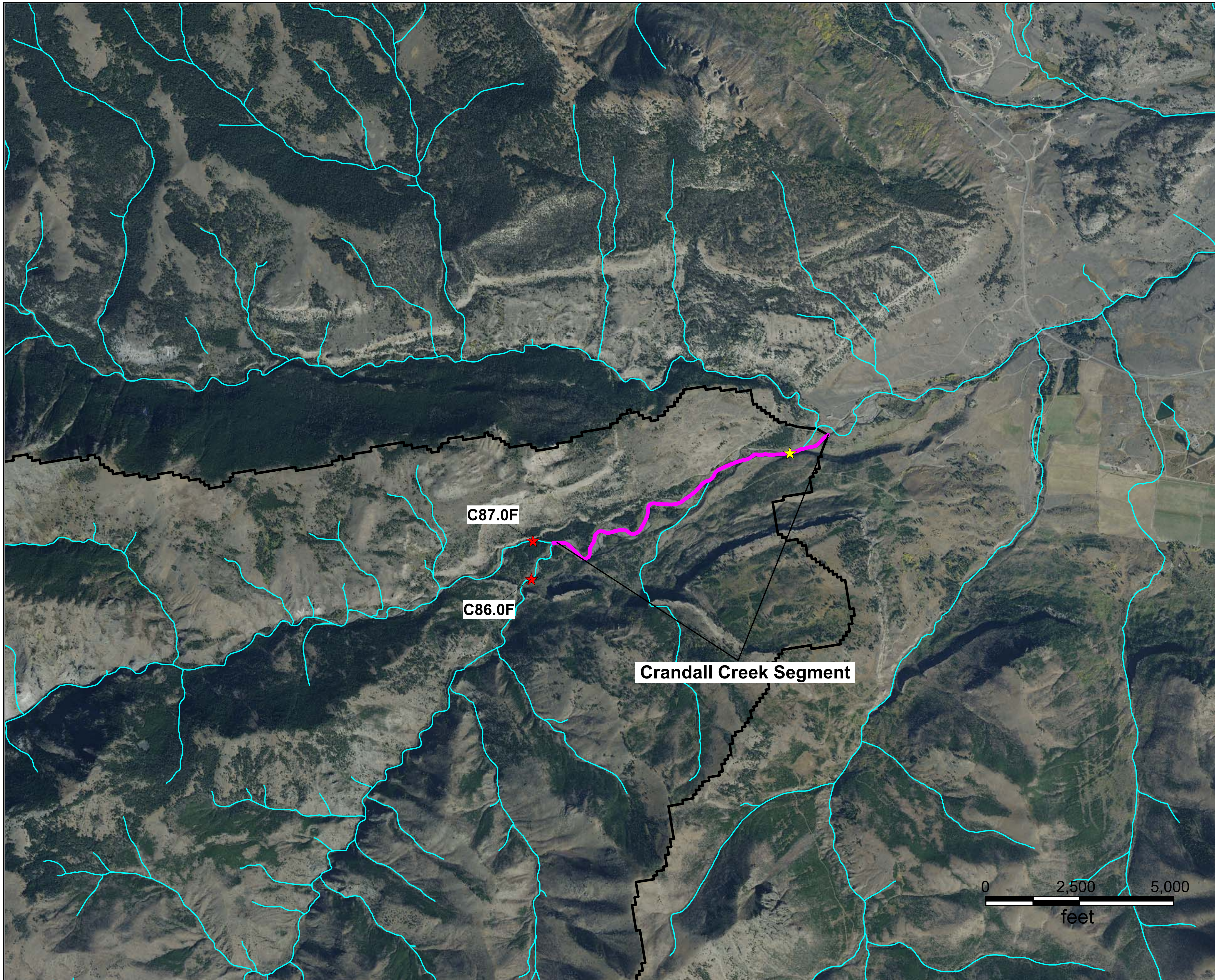


Figure 5
Crandall Creek study segment
Sunlight Basin study area
Park County, Wyoming

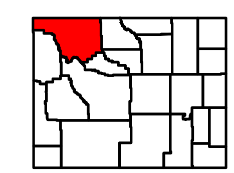
April 1, 2019

Scale: 1 inch = 2,500 feet

Legend

- Study Segment
- Hydrography
- Temporary Gaging Station
- Water Right POD (and Number)
- Study Catchment

Park County



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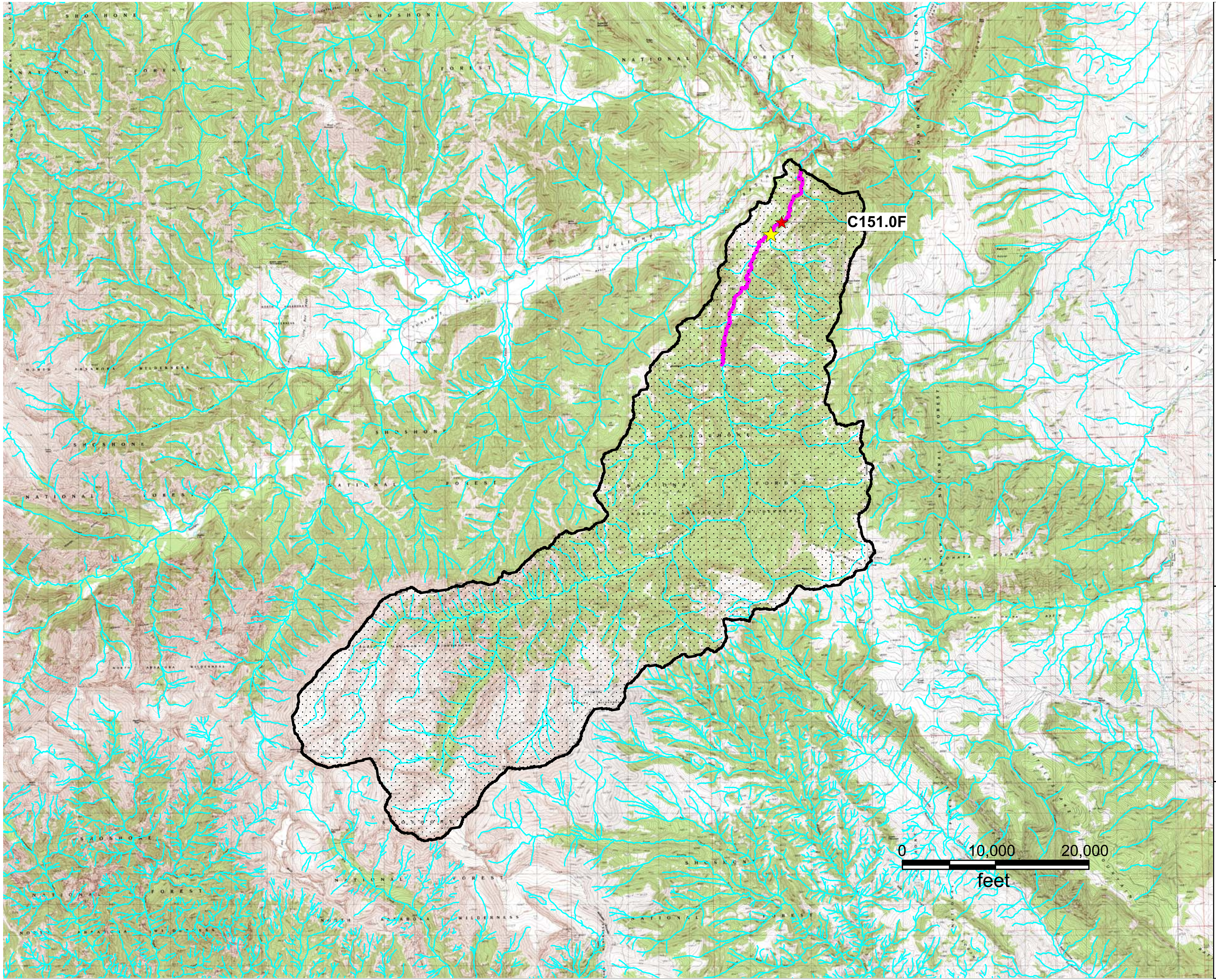

Figure 6
Dead Indian Creek study catchment
Sunlight Basin study area
Park County, Wyoming

April 1, 2019

Scale: 1 inch = 10,000 feet

Legend

- Study Segment
- Hydrography
- Temporary Gaging Station
- Water Right POD (and Number)
- Study Catchment
- State and Public Lands

Park County

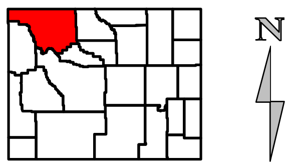

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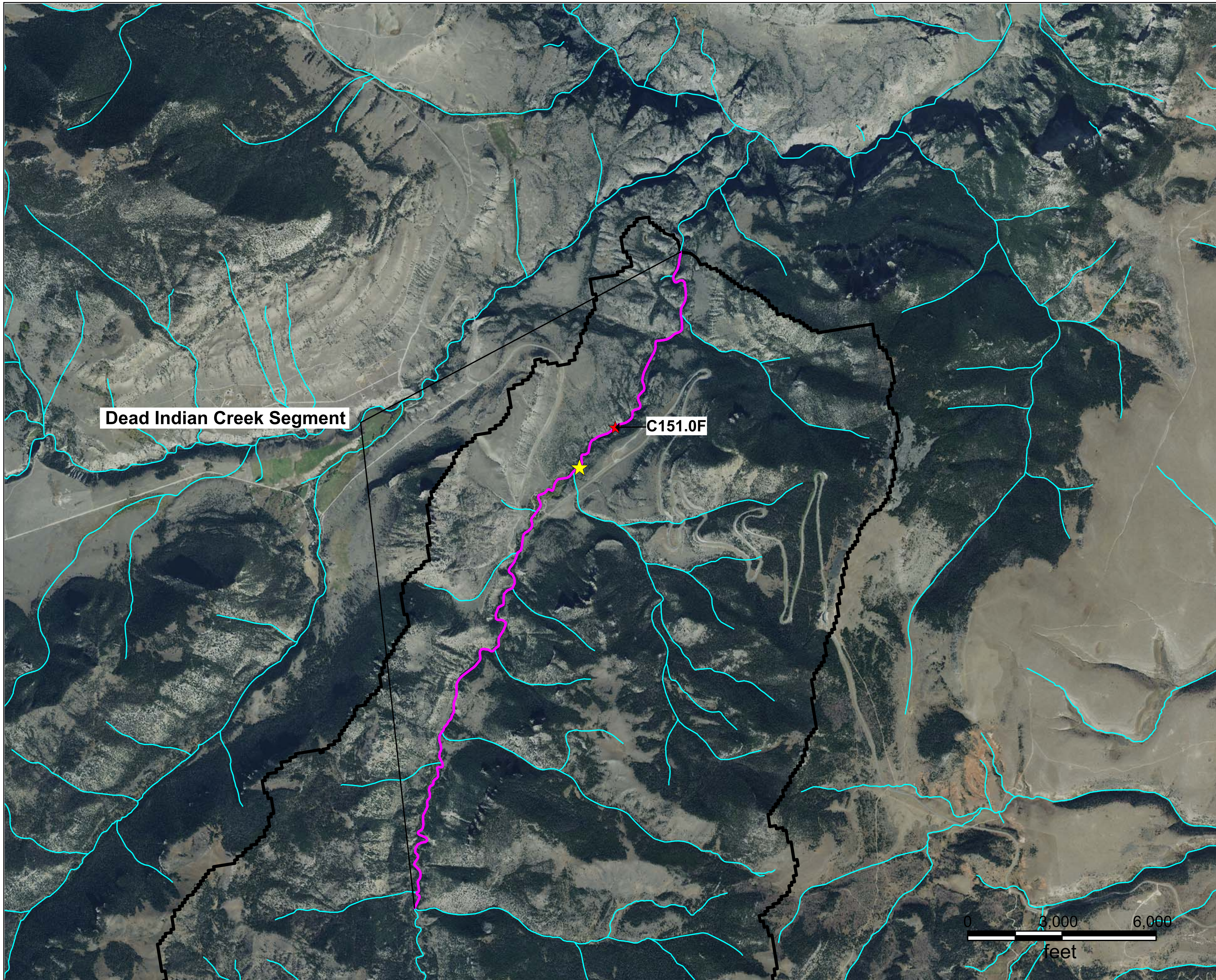
Figure 7
Dead Indian Creek study segment
Sunlight Basin study area
Park County, Wyoming

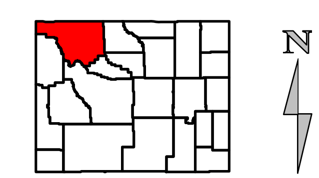
April 1, 2019

Scale: 1 inch = 3,000 feet



Legend

- Study Segment
- Hydrography
- Temporary Gaging Station
- Water Right POD (and Number)
- Study Catchment



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1.3 WATER RIGHTS

Water rights within study segment catchments were initially identified with a search by location (legal description) using the Wyoming State Engineer's Office (SEO) on-line E-Permit database. An in-person search was subsequently completed at the SEO in Cheyenne. That effort included review of the linen plats depicting adjudicated water rights; review of the paper plats depicting unadjudicated permits and applications; and review of the township cards that list permitted wells. All water rights identified within or upstream of the study segment catchments are presented in Table 3 and depicted in Figure 8. The presented 'cancelled' water rights do not affect this investigation but are included in Table 3 to provide a complete record of the water rights inventory completed within the study catchments.

Table 3. Active and cancelled water rights in the Sunlight Basin study area, Park County, Wyoming.

WR Number	Priority Date	Status Summary	Facility Name	Facility Type	Uses	Total Flow(CFS)/ Appropriation(GPM)	Stream Source
C151.0F	02/09/1983	Fully Adjudicated	Dead Indian Creek Instream Flow	Stream	ISF		Dead Indian Creek
C86.0F	02/09/1983	Fully Adjudicated	Hoodoo Creek Instream Flow	Stream	ISF		Hoodoo Creek
C87.0F	02/09/1983	Fully Adjudicated	Crandall Creek Instream Flow	Stream	ISF		Crandall Creek
P25452.0D	06/23/1977	*Cancelled*	Muddy Creek Pump Point Water Haul	Stream		0	Muddy Creek
P17482.0D	05/03/1921	*Cancelled*	Dead Indian Pipe Line	Stream			Dead Indian Creek
P31137.0D	12/27/1993	*Cancelled*	PLH-18(16) Water Haul	Stream		0	Dead Indian Creek
P35196.0D	04/21/2014	*Cancelled*	1507035 Water Haul (2)	Stream		0	Dead Indian Creek
P26532.0D	04/21/1980	*Cancelled*	Sunlight Prospect-#2 Water Haul	Stream		0	Dead Indian Creek
P30581.0D	02/22/1991	*Cancelled*	PREB-1507(25) Water Haul	Stream		0	Dead Indian Creek
P30098.0D	12/27/1988	*Cancelled*	SCP-PS-1507(23) Water Haul	Stream		0	Dead Indian Creek
P6079.0D	06/27/1904	*Cancelled*	No Name Provided (Dead Indian Creek)	Stream	MAN; MIN		Dead Indian Creek

There are adjudicated instream flow rights in the Dead Indian Creek and Crandall Creek study catchments. These instream flow water rights are court awarded rights that enable the U.S. Forest Service to pass certain amounts of water past specific locations on the watercourses in order to provide a drinking water source for livestock. During recent instream flow studies (Biota Research and Consulting, Inc., 2015; Rio Verde Engineering, 2006), these decreed instream flows were acknowledged but were not considered as a consumptive use and were not subtracted from virgin flows during the unappropriated direct flow analysis. These water rights are therefore presented in the water right inventory but are not considered a consumptive use or withdrawal of water during the instream feasibility study.

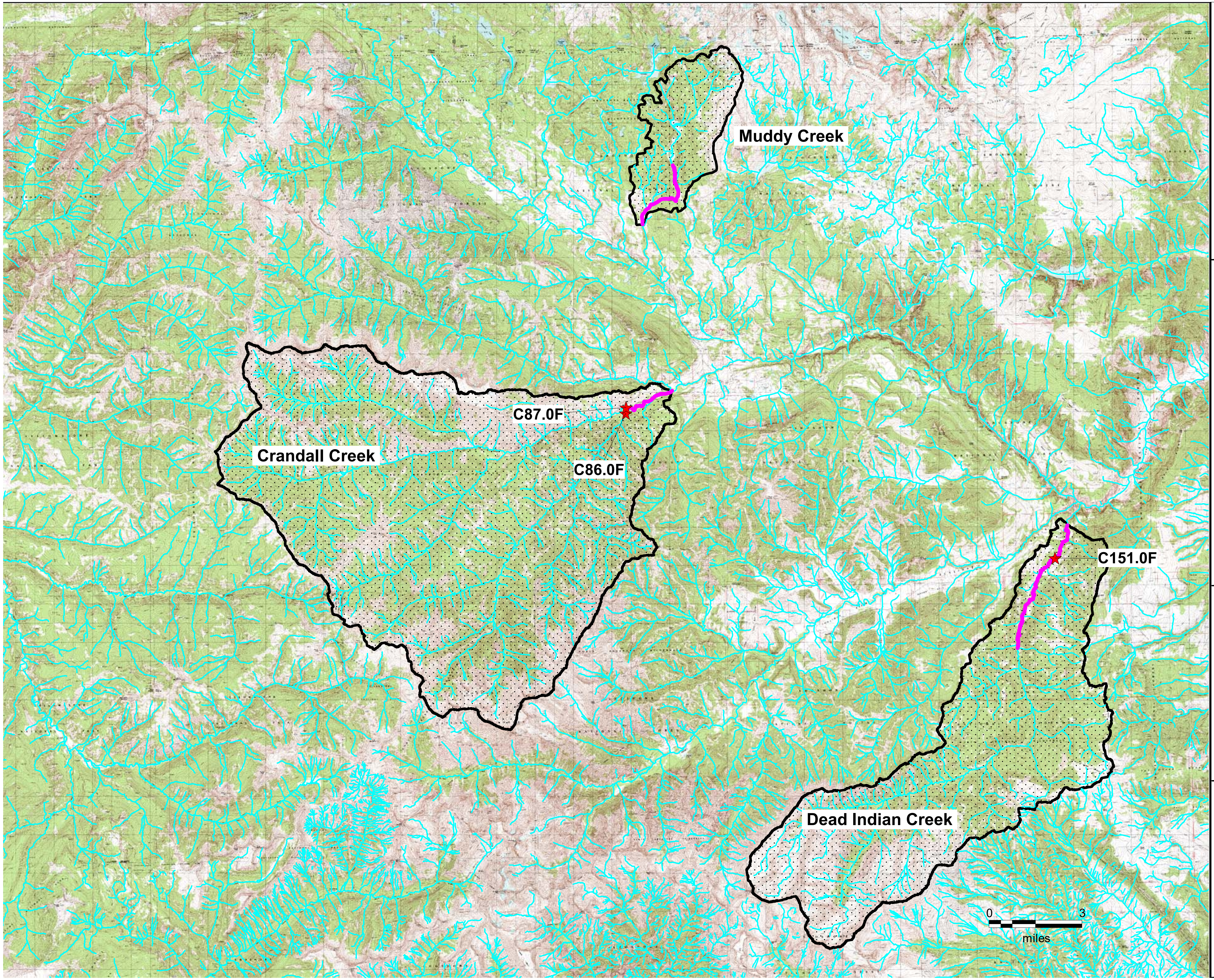


Figure 8
Water Right Location and Number
Sunlight Basin study area
Park County, Wyoming

April 1, 2019

Scale: 1 inch = 3 miles

Legend

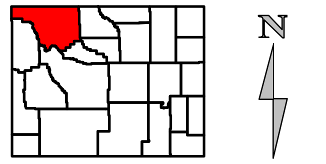
Study Segment

Hydrography

Water Right POD (and Number)

Study Catchment

Park County



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1.4 FLOW RECORDS

Historic diversion rates and flow records were investigated using various available datasets and records, including the following:

1. Wyoming State Engineer's Office;
2. Wyoming Water Resources Data System;
3. Local water commissioners' records, as available;
4. Local irrigators' records, as available;
5. USGS records (online and through correspondence); and
6. Other pertinent records of flow and storage as available.

The SEO indicated that they do not have long-term period of record flow data from any of the stream segments or the diversion located within the study basin. The Wyoming Water Resources Data System (WRDS) does not contain long-term flow records measured within the stream segments. The US Geological Survey maintains multiple stream flow gauging stations in proximity to the study stream segments but does not have current or historic flow measurement records within the study basins.

The lack of quantitative stream flow or diversion records within the project area basin required that the hydrologic regime of study stream segments be quantified using empirical and analytical techniques.

1.5 STREAM GAUGING

Temporary stream gauging stations were established near the downstream end of each of the three study segments. Temporary gauge locations did not coincide exactly with those established by the Wyoming Game and Fish Department during previous studies of the stream segments but were located as close to the downstream end of the study segments as possible. Gauging stations were operational from late June to October of 2017 and from early May to October of 2018. High flow measurements could not be safely collected at the gauging stations due to the large size of the watercourses and the deep swift water experienced during peak flow conditions. The rating curves developed and utilized during this study have the highest level of certainty for conditions within the range of direct discharge measurements. Direct discharge measurements within Muddy Creek ranged from 1.5 to 27.8 cfs, within Crandall Creek ranged from 22.0 to 145.1 cfs, and within Dead Indian Creek ranged from 11.2 to 95.5 cfs.

Temporary stream gauging stations were located in proximity to existing stable hydraulic controls where the relationship between stage and discharge was expected to remain consistent through the study period. Each gauging station was equipped with a staff plate with increments of 0.01 ft., a perforated stilling well enclosed in filter fabric, and a pressure transducer data logger programmed to record stage at 15-min intervals throughout the deployment period. Direct discharge measurements were conducted at each temporary gauging station across a wide range of flow rates during the study period. Direct discharge measurement data were plotted against local (staff plate) stage readings to generate site-specific rating curves that correlate stage to discharge. The stage of zero discharge was then identified and used to shift the rating curve to accurately reflect the relationship of stage to discharge during low flow conditions. The developed rating curves were then used to calculate flow rates from stage data recorded at 15-minute intervals during the deployment period.

1.5.1 Muddy Creek

The temporary gauging station in the Muddy Creek study segment was established on June 27, 2017, within a boulder and large woody debris dominated reach defined as a step-pool system (Figures 9 and 10). A total of 8 direct discharge measurements were performed at the site from June 2017 to October 2018 across a range of discharge rates spanning from 1.5 to 27.8 cfs. A stage-discharge correlation was derived for the Muddy Creek site using direct discharge measurement and stage data (Figure 11). Hydrographs depicting discharge at 15-minute intervals, mean daily discharge, and direct discharge measurement data collected in 2017 and 2018 are presented in Figures 12 and 13.

Figure 9. Muddy Creek gauging station, June 27, 2017, Park County, Wyoming.

Figure 10. Muddy Creek gauging station, September 5, 2018, Park County, Wyoming.

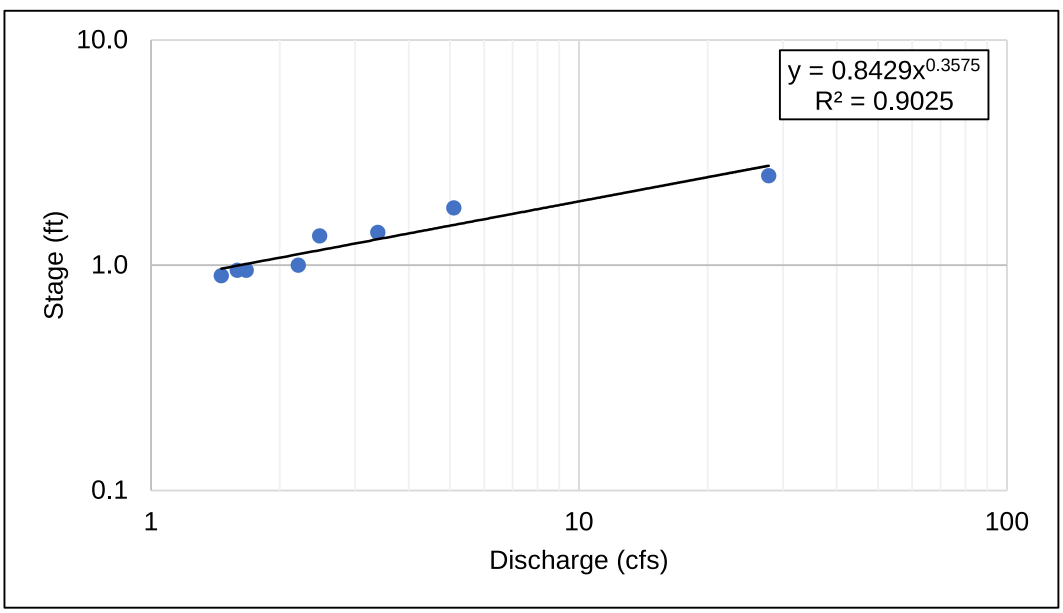


Figure 11. Muddy Creek stage-discharge correlation, Park County, Wyoming.

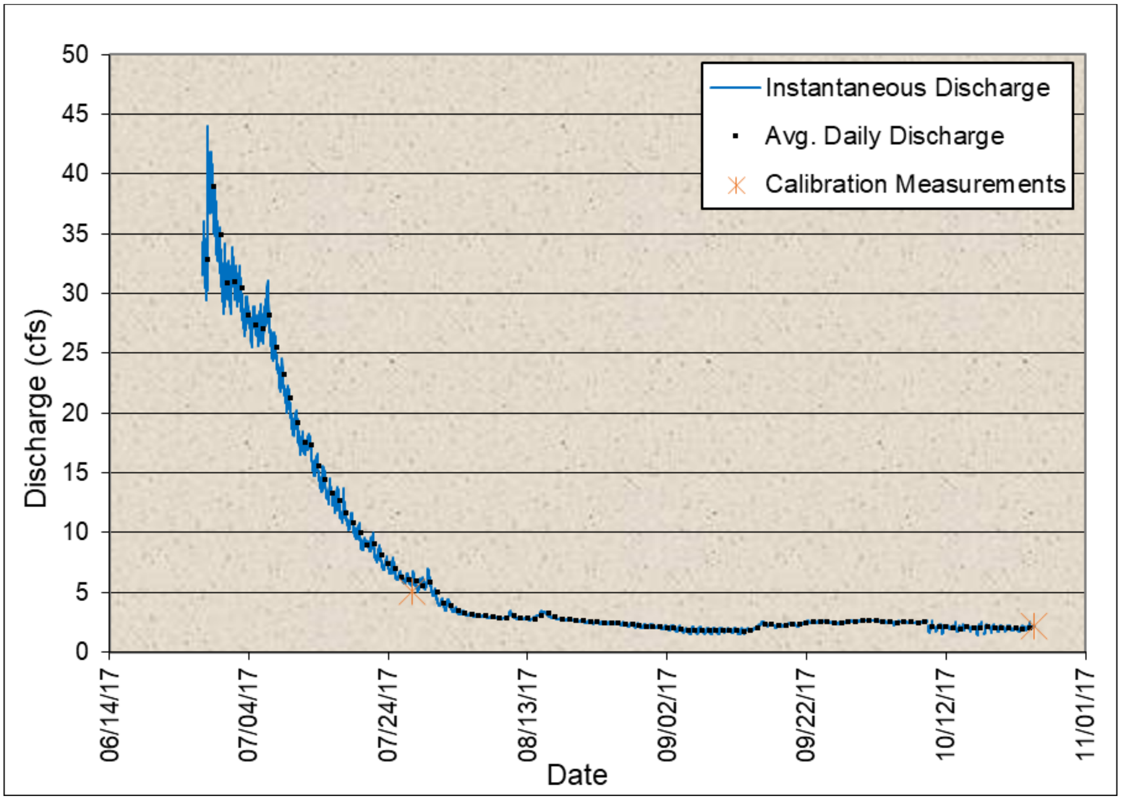


Figure 12. Muddy Creek 2017 hydrograph, Park County, Wyoming.

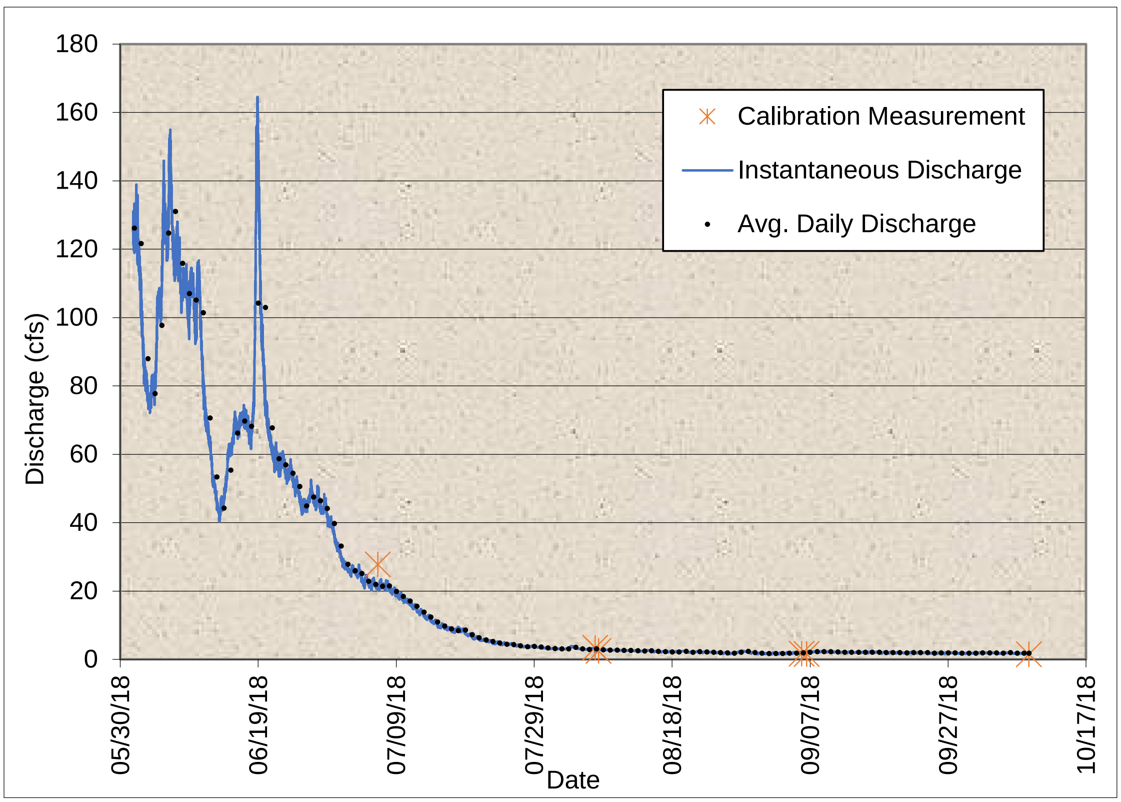


Figure 13. Muddy Creek 2018 hydrograph, Park County, Wyoming.

1.5.2 Crandall Creek

A temporary gauging station was established in the Crandall Creek study segment on June 27, 2017, in a cobble and boulder dominated reach (Figures 14 and 15). This gauging station was utilized to record flow data during the 2017 water year but was later destroyed in the spring runoff of 2018. Site conditions and flooding prevented access to the site and installation of a second temporary gauging station until August 6, 2018. A total of 7 direct discharge measurements were conducted at the site from June 2017 to October 2018 across a range of discharge rates spanning from 22.0 to 145.1 cfs. Stage-discharge correlations were derived for the 2017 and 2018 Crandall Creek gauging stations using direct discharge measurement and stage data (Figures 16 and 17). Hydrographs depicting discharge at 15-minute intervals, mean daily discharge, and direct discharge measurement data collected in 2017 and 2018 are presented in Figures 18 and 19.

Figure 14. Crandall Creek gauging station, June 27, 2017, Park County, Wyoming.

Figure 15. Crandall Creek gauging station, September 5, 2018, Park County, Wyoming.

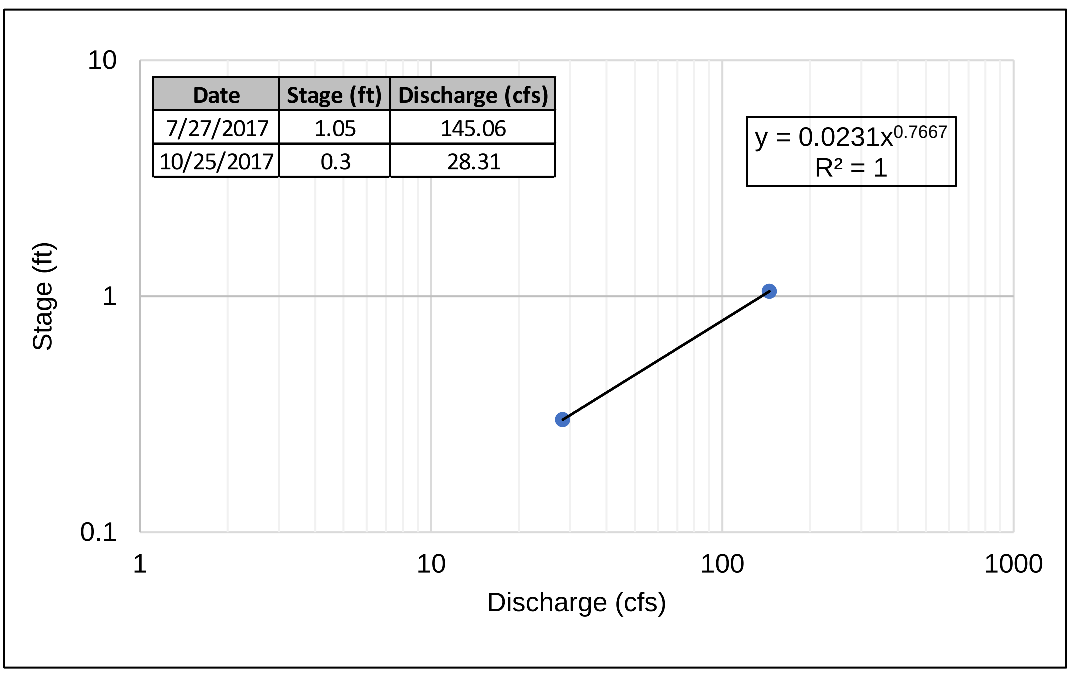
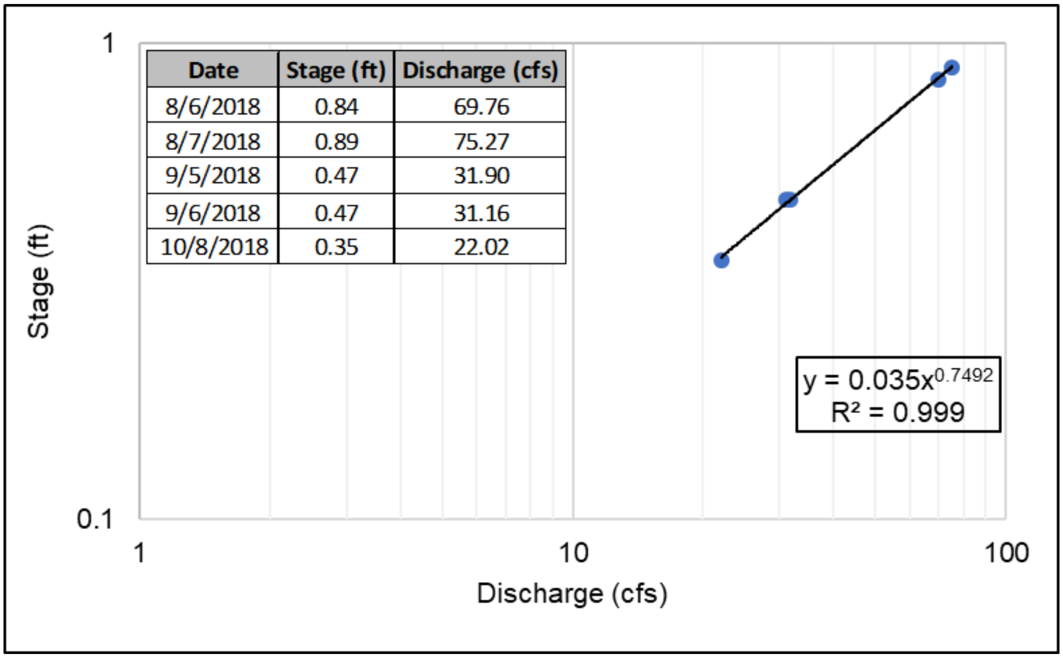


Figure 16. Crandall Creek stage-discharge correlation for 2017, Park County, Wyoming.



Date	Stage (ft)	Discharge (cfs)
8/6/2018	0.84	69.76
8/7/2018	0.89	75.27
9/5/2018	0.47	31.90
9/6/2018	0.47	31.16
10/8/2018	0.35	22.02

Figure 17. Crandall Creek stage-discharge correlation for 2018, Park County, Wyoming.

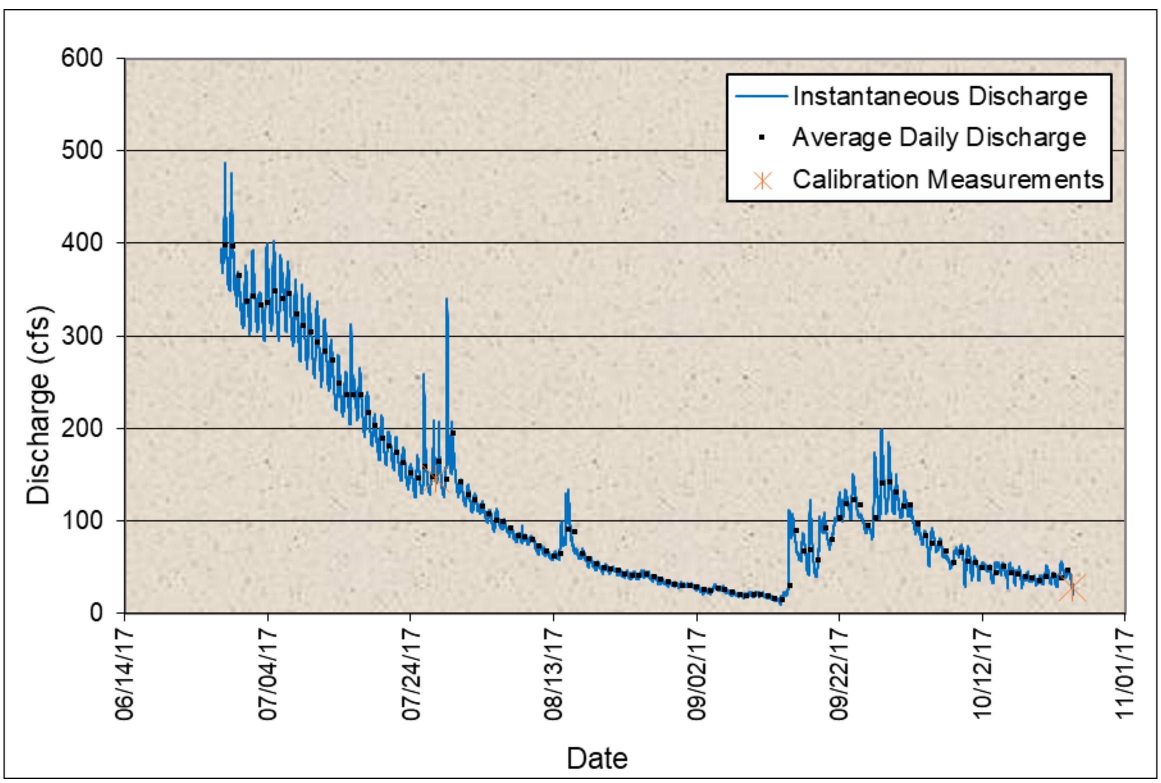


Figure 18. Crandall Creek 2017 hydrograph, Park County, Wyoming.

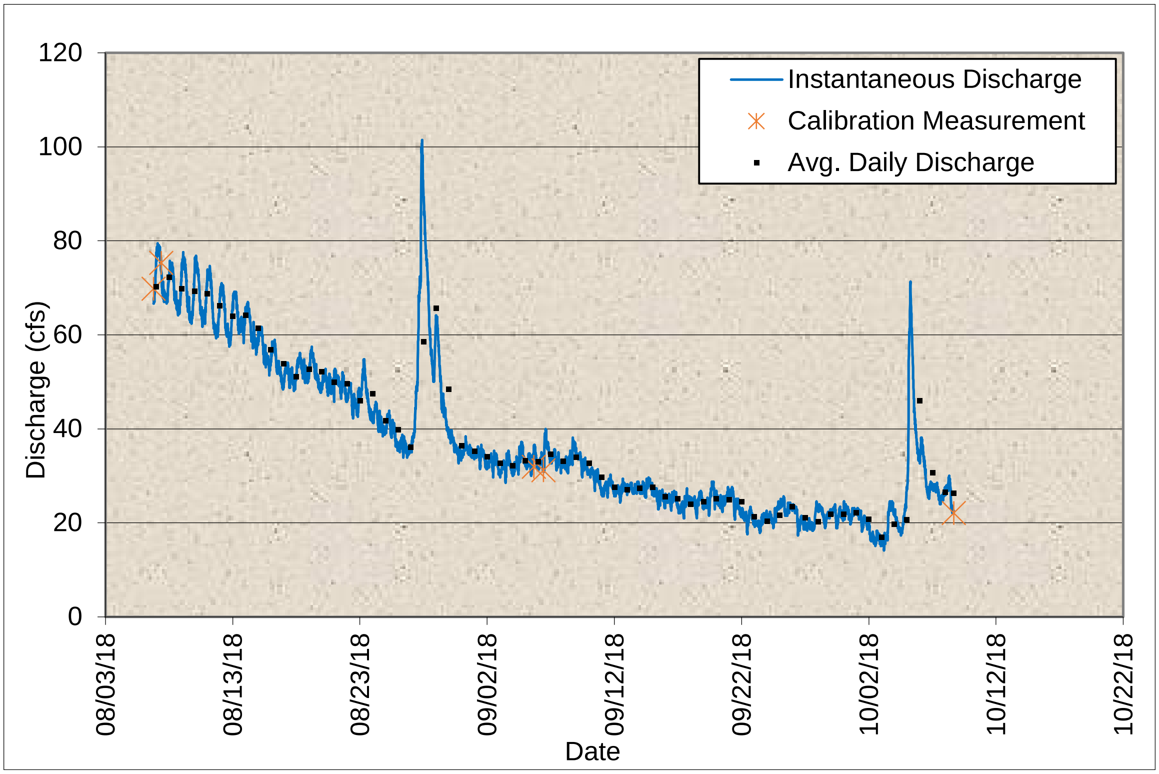


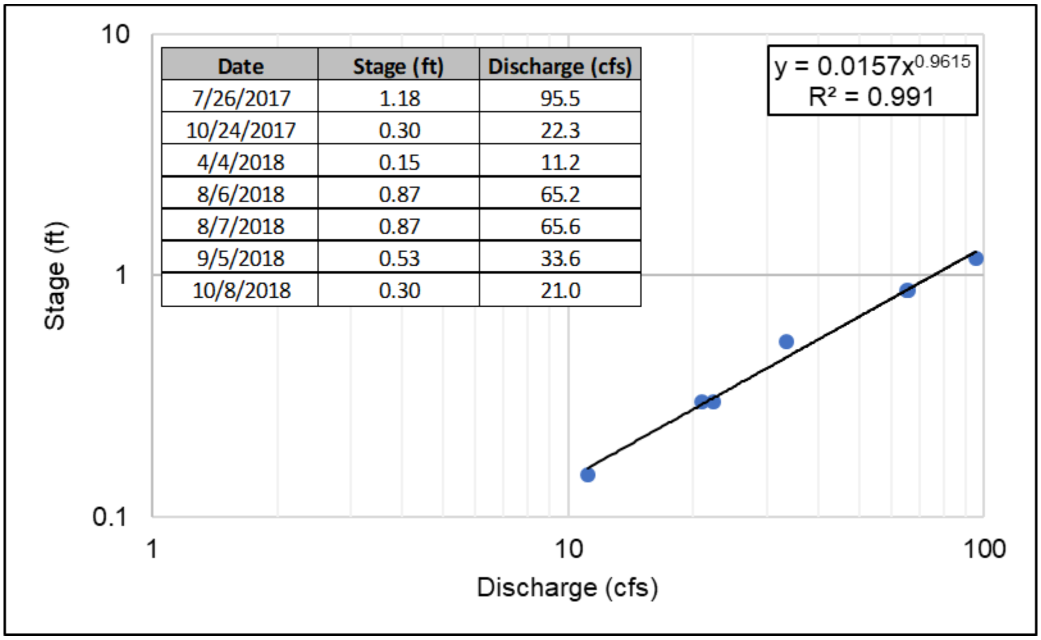
Figure 19. Crandall Creek 2018 hydrograph, Park County, Wyoming.

1.5.3 Dead Indian Creek

The temporary gauging station in the Dead Indian Creek study segment was established on June 27, 2017, in a boulder and large woody debris dominated reach defined as a step-pool system (Figures 20 and 21). A total of 8 direct discharge measurements were performed at the site from June 2017 to October 2018 across a range of discharge rates spanning from 11.2 to 95.5 cfs. A stage-discharge correlation was derived for the Dead Indian Creek site using direct discharge measurements and stage data (Figure 22). Hydrographs depicting discharge at 15-minute intervals, mean daily discharge, and direct discharge measurement data collected in 2017 and 2018 are presented in Figures 23 and 24.

Figure 20. Dead Indian Creek gauging site, June 27, 2017, Park County, Wyoming.

Figure 21. Dead Indian Creek gauging site, October 25, 2017, Park County, Wyoming.



Date	Stage (ft)	Discharge (cfs)
7/26/2017	1.18	95.5
10/24/2017	0.30	22.3
4/4/2018	0.15	11.2
8/6/2018	0.87	65.2
8/7/2018	0.87	65.6
9/5/2018	0.53	33.6
10/8/2018	0.30	21.0

Figure 22. Dead Indian Creek stage-discharge correlation, Park County, Wyoming.

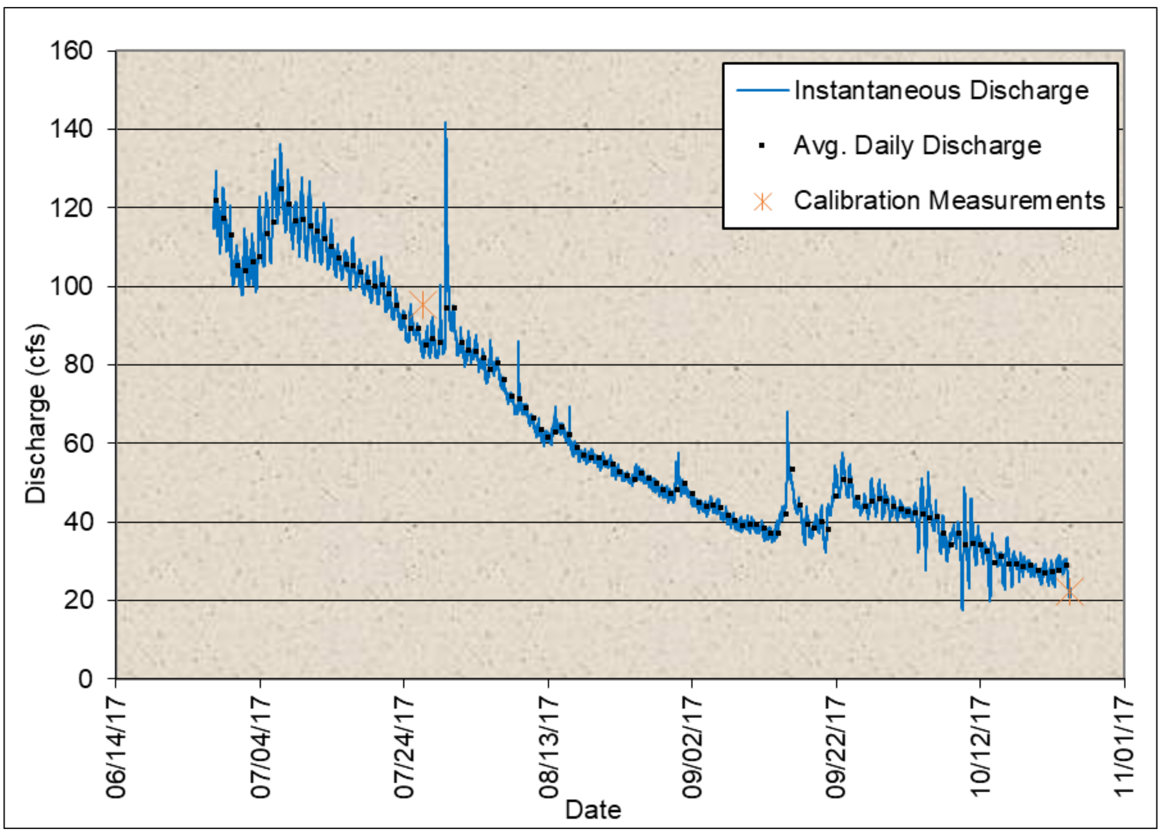


Figure 23. Dead Indian Creek 2017 hydrograph, Park County, Wyoming.

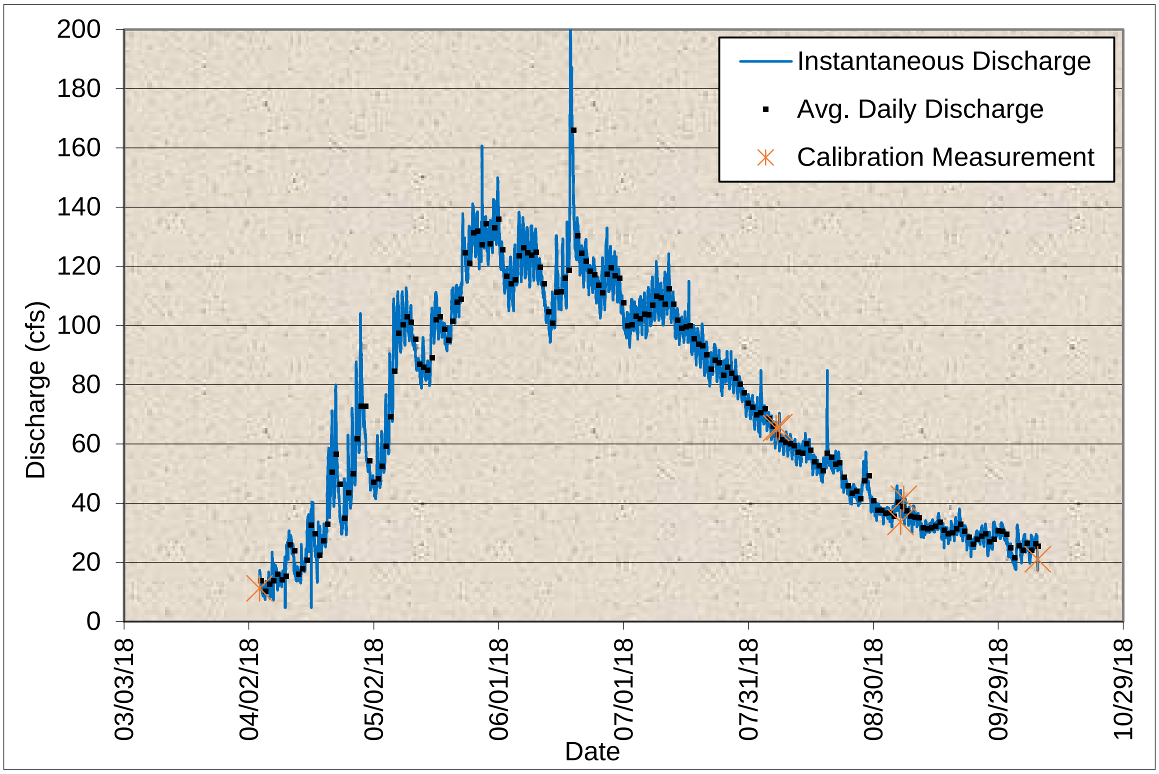


Figure 24. Dead Indian Creek 2018 hydrograph, Park County, Wyoming.

1.6 HYDROLOGY

Hydrologic investigations focused on the quantification of virgin flows within study segments, or the surface water resource available within the sub-basins prior to any diversion withdrawals, consumptive uses, depletions, or return flows. Two methodologies were used to assess hydrologic conditions within study segments, including: (1) concurrent discharge measurement techniques to establish a correlation between an established gauging station and the study segments (as presented in Lowham 2009); and (2) regional regression equations to calculate hydrologic conditions based upon catchment attributes (as presented in Miselis et al. 1999). Historic gauge data used in the analyses were reviewed to identify complete annual flow records. The complete annual records were then classified as “dry,” “average,” or “wet” years with the wettest and driest years identified as the upper and lower 20% of the study period years on an annual flow basis. Hydrologic modelling within study segments utilized historic gauge data from complete and average years.

1.6.1 Concurrent Discharge Approach

The concurrent discharge approach enables estimation of stream flows at ungauged streams based upon an empirically-derived correlation between the ungauged stream and a proximate active gauging station. The technique requires identification of an active stream gauging station in the vicinity with a long period of record, referred to as the reference gauge. The reference gauge should be located near the study area and should have similar physical and climatic characteristics to those of the study area.

The selection of a suitable reference gauge for correlation with the Sunlight Basin study segments was completed based upon investigation of proximate gauge location, drainage area, basin orientation, elevation, and period of record. Several regional active and inactive US Geological Survey (USGS) gauges were investigated as potential reference gauges (Figure 25). The Sunlight Creek near Painter, Wyoming gauge (USGS # 06206500) was selected for use as a reference gauge for Crandall Creek and Dead Indian Creek. The USGS Sunlight Creek gauge is not currently maintained by the USGS but was temporarily activated and maintained by Biota during the duration of this instream flow study. The Soda Butte at Park Boundary at Silver Gate gauge (USGS # 06187915) was selected for use as a reference gauge for Muddy Creek, and it is an active gauge maintained by the USGS. These reference gauge selections were made due to the proximity of the gauges to the study segments, the absence of diversions in the gauge catchments, and the similarity of the gauge catchment size and elevation to those of the study segments. The Sunlight Creek and Soda Butte Creek reference gauge attributes are presented in Table 4.

Table 4. Reference gauge and study site attributes including straight-line distance from reference gauge (miles), elevation at the reference gauge or at the downstream end of the study segment (ft), and drainage area at the reference gauge or the downstream end of the study segment.

Site	Distance from Reference Gauge (miles)	Elevation (ft)	Drainage Area (sq mi)
Sunlight Creek Reference Gauge	n/a	6,700	135.0
Crandall Creek	9.8	6,490	111.2
Dead Indian Creek	5.5	5,640	61.0
Soda Butte Creek Reference Gauge	n/a	7,340	30.9
Muddy Creek	17.0	7,440	11.9

Direct discharge measurements and flow data collected at temporary gauging sites within the study segments (presented in Section 1.5 Stream Gauging) were used to develop correlations between flows at the ungauged study segments and the reference gauges. A correlation function using mid-month (the 15th day) mean daily flow data has been demonstrated to accurately represent mean monthly flows, but more accurate results can be obtained by incorporating additional data from the 5th and 25th of each month (Lowham 2009). Therefore, correlations between ungauged study segments and the reference gauge were developed using mean daily flow data from the 5th, 15th, and 25th of each month that the gauges were operational in 2017 and 2018. To facilitate this analysis, a temporary stream gauging station was established and operated during the study period at the location of the inactive USGS gauge in Sunlight Creek near Painter, Wyoming, #06206500. Direct discharge measurement data collected in the study segments by the Wyoming Game and Fish Department in 2014 were also incorporated into the correlation for Muddy Creek because the inclusion of those data increases the temporal duration of data utilized in the correlations (Figure 26).

The correlations between study segments and reference stream gauges are most accurate within the range of flows measured directly at the temporary stream gauging stations. The daily and monthly flow predictions based upon the concurrent discharge method (and the weighted average method) that extend beyond (above or below) the range of empirical data comprising the correlations have more uncertainty than flow predictions that are within the range of incorporated empirical data.

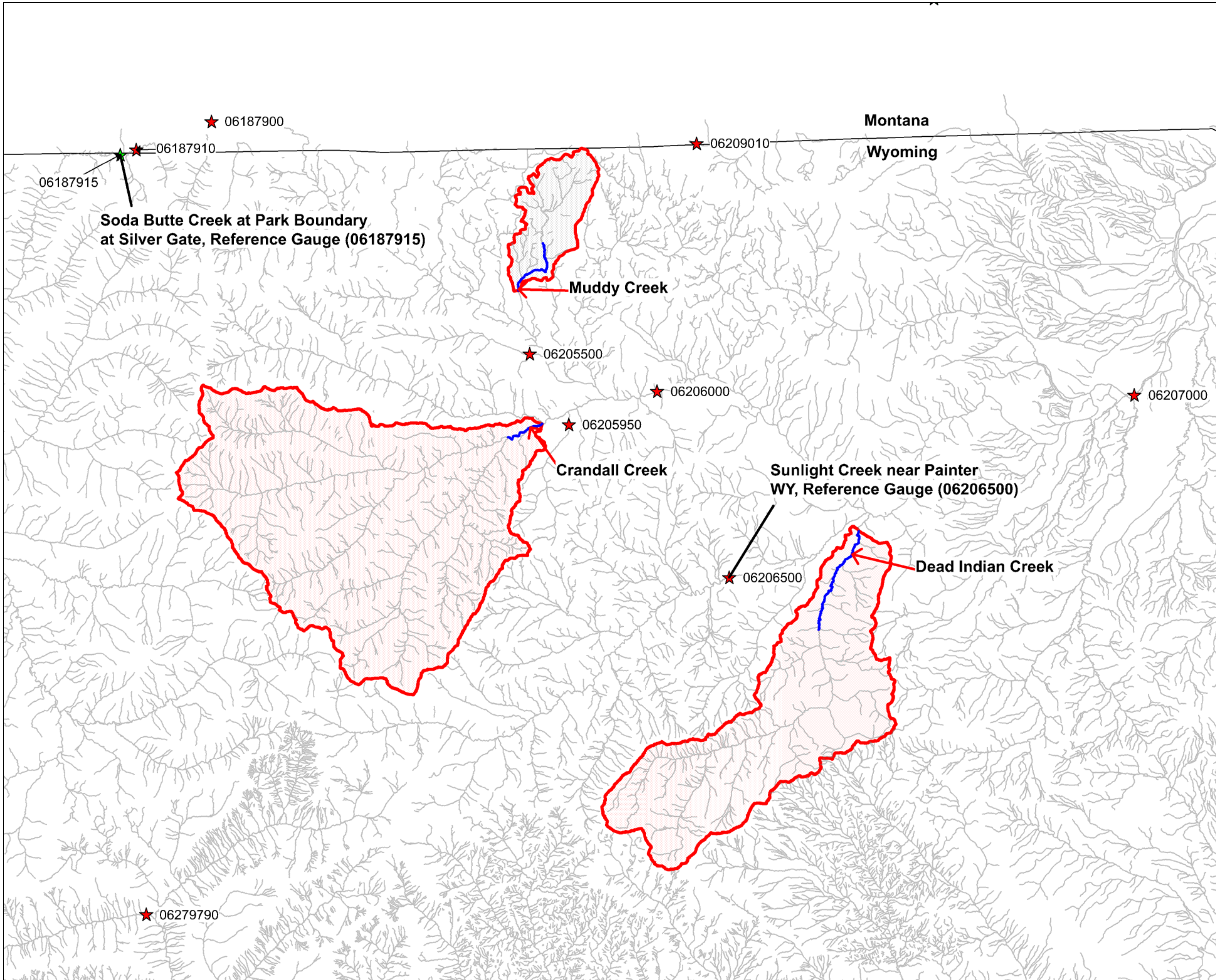


Figure 25
Established Stream Gauging Stations
Park County, Wyoming

April 1, 2019

Scale: 1 inch = 20,000 feet

Legend

Study Segment

Hydrography

Active USGS Gauge

Inactive USGS Gauge

Study Catchment

Park County

N

Wyoming

research & consulting inc.

Biota

PO Box 8578, 140 E. Broadway, Suite 23, Jackson, WY 83002

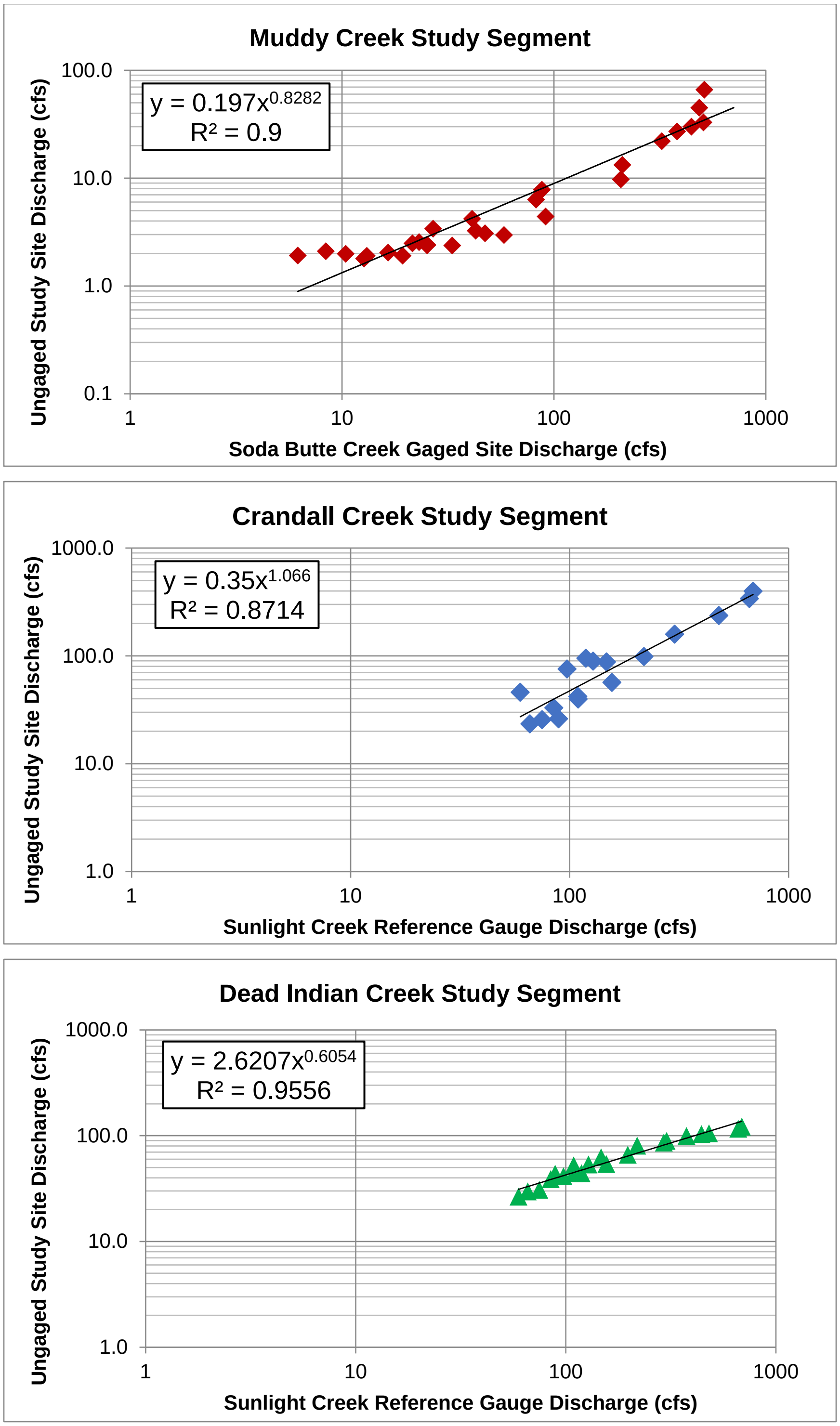


Figure 26. Concurrent discharge correlation equations between stream study segments and reference gauges (USGS Soda Butte Creek #06187915 and USGS Sunlight Creek #06206500).

The Muddy Creek correlation equation under-predicts flows in Muddy Creek during low flow conditions. The development of a separate correlation to describe the low end of the curve was considered but was not applied because the under-prediction is observed during only three data points. Those three data points are measurements from the month of September (two in 2018 and one in 2017). October flow conditions are accurately predicted by the presented correlation, and there is not adequate low flow data to define a separate robust correlation to account for three under-predicted data points specific to September conditions.

1.6.2. Regional Regression Equation Approach

Regional regression equations were utilized to calculate hydrologic conditions based on basin characteristics. Equations presented in the following publication were determined to be applicable to the study segment sub-watersheds:

1. *Development of Improved Hydrologic Models for Estimating Streamflow Characteristics of the Mountainous Basins in Wyoming* (Miselis et. al., 1999);

The Miselis 1999 publication examines the mountainous regions of Wyoming and presents mountain range-specific regression equations for mean annual flow, mean monthly flows, minimum monthly flows, and monthly duration values (Q90, Q50, Q10). Regression equations considered during this investigation include those developed for the Absaroka Mountains and the Mountainous Regions of Wyoming that correlate stream flow to basin characteristics including drainage area, precipitation, and stream length. Both the mountain range-specific equations for the Absaroka Mountains and the statewide equations for the Mountainous Regions of Wyoming can be applied to the study segment watersheds. Note that only regression equations that were deemed statistically significant with p-value less than 0.05 were considered. Equations for the Absaroka Mountains and the Mountainous Regions of Wyoming that used mean basin elevation were not considered because they have p-values greater than 0.05 (0.109 and 0.406 respectively) reflecting the fact that there is no correlation between basin elevation and streamflow.

The Miselis (1999) regression equations were used to calculate mean annual flow at the Sunlight Creek reference gauge (USGS #06206500) based upon sub-basin attributes of drainage area (135 sq mi), mean annual precipitation (25 in), and stream length (22 mi). The predicted mean annual flow rates derived from regression equations were compared to the “average” year mean annual flow rate calculated from complete annual datasets from 15 “average” years (1930, 1946-1950, 1952-1954, 1958-1959, 1962-1964, and 1968) (Table 5). It should be noted that reference gauge data from 1932 and 1971 were not included in this analysis because the annual records are incomplete, and data was lacking for October, November, and December. The difference between predicted and measured mean annual flow ranged from -53% to 125%.

The Miselis (1999) regression equations were used to calculate mean annual flow at the Soda Butte Creek reference gauge (USGS #06187915) based upon sub-basin attributes of drainage area (30.9 sq mi), mean annual precipitation (37.7 in), and stream length (7.6 mi). The predicted mean annual flow rates were compared to the mean annual flow calculated from 12 complete “average” years (1999-2000, 2002-2003, 2005--2010, 2012, and 2015) of measured flow data at the reference gauge site (Table 6). The difference between predicted and measured mean annual flow ranged from -71% to 2793%.

The Sunlight Creek reference gauge analysis results indicate that the regression equations that most accurately predict mean annual flow are the (Miselis 1999) regression equations for the Absaroka Mountains based upon stream length or drainage area. Both regression equations yielded similar results. However, due to the coarseness of the delineated watercourse line in the NHD data and the higher standard error for the stream length equation, the regression equation based upon drainage area was selected for this analysis. This regression equation accurately predicts mean annual flow at the Sunlight Creek reference gauge. This regression equation was used to calculate mean annual flow in the Dead Indian Creek and Crandall Creek study segments (Table 7).

The Soda Butte Creek reference gauge analysis results indicate that the regression equation that most accurately predicts mean annual flow is the equation for the Mountainous Regions of Wyoming based on drainage area. That regression equation under-predicts mean annual flow in Soda Butte Creek by 57%. However, this regression equation has a relatively high r-squared value (of 78.2) and an average standard error (of 31.4%). Thus, the regression equation based upon drainage area for the Mountainous Regions of Wyoming was selected for use during this analysis and was used to calculate mean annual flow in the Muddy Creek study segment (Table 7).

Calculated mean annual flow rates in the study segments were used to quantify mean monthly and mean daily flow rates in the study segments using dimensionless data from the reference gauge. The reference gauge monthly flow rates from complete average years were divided by the reference gauge mean annual flow and were then multiplied by the study segment mean annual flow to derive study segment mean monthly flows. Similarly, reference gauge mean daily flow data from complete average years were divided by the reference gauge mean annual flow and were then multiplied by the study segment mean annual flow to derive study segment mean daily flows. These dimensionless analysis techniques enabled quantification of mean monthly and mean daily flow rates in the study segments to inform monthly flow availability and flow duration analyses.

Table 5. Mean annual flow (QAA) from complete average year empirical data and regional regression correlations using basin characteristics of basin elevation (BE), drainage area (DA), precipitation (P), and stream length (SL) at the USGS Sunlight Creek gauge (#06206500).

Methodology	Equation	QAA (cfs)	Difference (predicted vs. measured, as percent)	Standard Error (Miselis 1999)
USGS Gage Data, 15 "Average" years	n/a	121.3	0%	n/a
Miselis et al. (1999): Absaroka Mountains, Drainage Area	**$0.43441\ DA^{1.15}$**	**122.4**	**1%**	**19.0%**
Miselis et al. (1999): Absaroka Mountains, Precipitation	$0.00014\ P^{4.5}$	273.4	125%	64.2%
Miselis et al.(1999): Absaroka Mountains, Stream Length	$0.4804\ SL^{1.8}$	125.3	3%	43.2%
Miselis et al. (1999): Mountainous for WY, Drainage Area	$1.20976\ DA^{0.894}$	97.1	-20%	31.4%
Miselis et al. (1999): Mountainous for WY, Precipitation	$0.07589\ P^{2.06}$	57.5	-53%	65.2%
Miselis et al. (1999): Mountainous for WY, Stream Length	$0.82452\ SL^{1.51}$	87.8	-28%	40.9%

Table 6. Mean annual flow (QAA) from complete average year empirical data and regional regression correlations using basin characteristics of basin elevation (BE), drainage area (DA), precipitation (P), and stream length (SL) at the USGS Soda Butte Creek gauge (#06187915).

Methodology	Equation	QAA (cfs)	Difference (predicted vs. measured, as percent)	Standard Error (Miselis 1999)
USGS Gage Data, 12 "Average" years	n/a	61.0	0%	n/a
Miselis et al. (1999): Absaroka Mountains, Drainage Area	$0.43441\ DA^{1.15}$	22.46	-63%	19.0%
Miselis et al. (1999): Absaroka Mountains, Precipitation	$0.00014\ P^{4.5}$	1736.46	2747%	64.2%
Miselis et al.(1999): Absaroka Mountains, Stream Length	$0.4804\ SL^{1.8}$	18.50	-70%	43.2%
Miselis et al. (1999): Mountainous Regions of WY, Drainage Area	$\mathbf{1.20976\ DA^{0.894}}$	**26.0**	**-57%**	**31.4%**
Miselis et al. (1999): Mountainous Regions of WY, Precipitation	$0.07589\ P^{2.06}$	134.1	120%	65.2%
Miselis et al. (1999): Mountainous Regions of WY, Stream Length	$0.82452\ SL^{1.51}$	17.6	-71%	40.9%

Table 7. Study segment catchment attributes and mean annual flow calculated using Miselis (1999) equations for the Absaroka Mountains based upon drainage area (Crandall Creek and Dead Indian Creek), and the Miselis (1999) equations for Mountainous Regions of WY based upon drainage area (Muddy Creek).

Study Segment	Stream Length (miles)	Drainage Area (sq mi)	Mean Annual Precip. (in)	Mean Annual Flow from Regression Eqn(cfs)
Muddy Creek	8.5	11.9	30.6	11.1
Crandall Creek	16.7	111.2	31.1	97.9
Dead Indian Creek	21.1	61.0	28.0	49.1

1.6.3 Hydrologic Analysis Results

Flow data from the reference gauges (USGS Sunlight Creek near Painter Wyoming #06206500 and USGS Soda Butte Creek at Park Boundary at Silver Gate #06187915) periods of record were analyzed to identify wet, dry, and average water years based on mean annual flow. Only years with complete periods of record were considered. The complete years of record with mean annual flow in the 20th percentile or less were classified as 'dry', years with mean annual flow in the 80th percentile or greater were classified as' wet', and years between the 20th and 80th percentile were classified as 'average' water years. The mean daily flow data from all years classified as 'average' were used to calculate mean monthly flows at the reference gauges (Tables 8 and 9). The regional regression equation methodology was used to calculate mean monthly flow in each study segment by dividing the reference gauge mean monthly flows by the reference gauge mean annual flow, then multiplying the dimensionless flow by the study segment mean annual flow. The concurrent discharge correlation equation methodology was used to calculate mean monthly flows in the study segments by applying the correlation equations to the reference gauge mean monthly flows.

Flow values used to develop the concurrent discharge correlations include the entire range of flows measured within the study segments, but do not include the entire range of flows modeled within the study segments. Extrapolation beyond the range of measured flows increases uncertainty of the hydrologic modelling. The range of direct flow measurements within the study segments includes:

Muddy Creek: 1.5 – 27.8 cfs
Crandall Creek: 22.0 – 145.1 cfs
Dead Indian Creek: 11.2 – 95.5 cfs

There is variability in the results obtained using the regression equations and those obtained using the concurrent discharge approach. The difference between regression equation and concurrent discharge approach results ranges from -101% to 60%, with an average of 13%. Due to the discrepancy in results obtained from the regional regression and concurrent discharge techniques, methods to combine results using a weighted average approach were investigated. The regression and concurrent discharge estimates are assumed to be independent for the analysis period (Parrett et al, 1990; U.S. Water Resource Council, 1981). Therefore, the regression equation and concurrent discharge method results were weighted proportionally to the inverse of their standard error to create a weighted average (Parrett et al, 1990; U.S. Water Resource Council, 1981). This approach incorporates two investigation methodologies (regional regression equations and concurrent discharge measurement techniques) and is described as an appropriate technique in Parrett et al (1990). Additionally, weighted average estimates have been found to have smaller variances and are more reliable than the individual estimates alone (Parrett et al. 1990, Miselis et al. 1999). The average percent difference between actual and estimated flows for the concurrent discharge analysis using measurements from the 5th, 15th, and 25th of each month is 11.00% (Lowham 2009) and was used as an estimate of the standard error for all three study sites. Standard error values for the regional regression analyses are 19.02% for the Dead Indian Creek and Crandall Creek sites and 31.36% for the Muddy Creek site (Miselis et al. 1999). The following equation (Equation 1) was used to determine the weighted average of the two estimates:

(Equation 1)

$$Z = \frac{x\,SE_y + y\,SE_x}{SE_y + SE_x}$$

Where Z = weighted average
x = estimate using concurrent discharge approach
y = estimate using regional regression equations
SE_y = standard error for the regional regression equations (Miselis, 1999)
SE_x = standard error estimated using the average percent difference between actual and estimated flows from concurrent discharge approach (Lowham, 2009)

Results of mean monthly flows calculated using both the regional regression equations, the concurrent discharge methodology, and the weighted average analyses are presented in Table 10. The resultant weighted averages were utilized for subsequent analysis during the instream flow study.

Table 8. Mean monthly flow during complete average years at the USGS Sunlight Creek reference gauge (#06206500).

Time Period	Sunlight Creek Mean Monthly Flow (cfs)
January	22.0
February	19.6
March	20.9
April	47.0
May	203.6
June	504.2
July	330.9
August	122.7
September	63.3
October	51.0
November	33.6
December	24.7

Table 9. Mean monthly flow during complete average years at the USGS Soda Butte Creek reference gauge (#06187915).

Time Period	Soda Butte Crk Creek Mean Monthly Flow (cfs)
January	3.3
February	2.4
March	2.3
April	12.3
May	143.9
June	352.0
July 1-15	212.9
July 16-31	86.3
August	29.5
September	13.2
October	10.0
November	7.0
December	4.1

Table 10. Study segment mean monthly flow (cfs) rates estimated using regional regression equations, concurrent discharge measurement, and weighted average approaches.

Methodology	Jan	Feb	Mar	Apr	May	Jun	July 1-15	July 16-31	Aug	Sep	Oct	Nov	Dec
Muddy Creek Study Segment													
Regional Regression Equation, Mountainous Regions of WY, Drainage Area (Miselis 1999)	0.6	0.4	0.4	2.2	26.1	63.9	38.6	15.7	5.4	2.4	1.8	1.3	0.7
Concurrent Discharge (Avg. yrs)	0.5	0.4	0.4	1.6	12.1	25.3	16.7	7.9	3.3	1.7	1.3	1.0	0.6
Weighted Average	**0.6**	**0.4**	**0.4**	**1.7**	**15.7**	**35.3**	**22.4**	**9.9**	**3.8**	**1.9**	**1.5**	**1.1**	**0.7**
Dead Indian Creek Study Segment													
Regional Regression Equation, Absaroka Mountains, Drainage Area (Miselis 1999)	8.9	7.9	8.5	19.0	82.4	204.0	133.9		49.6	25.6	20.6	13.6	10.0
Concurrent Discharge (Avg. yrs)	17.0	15.9	16.5	27.0	65.5	113.4	87.9		48.2	32.3	28.3	22.0	18.3
Weighted Average	**14.0**	**13.0**	**13.6**	**24.1**	**71.7**	**146.6**	**104.8**		**48.7**	**29.8**	**25.5**	**18.9**	**15.3**
Crandall Creek Study Segment													
Regional Regression Equation, Absaroka Mountains, Drainage Area (Miselis 1999)	17.8	15.8	16.9	37.9	164.3	407.0	267.1		99.0	51.1	41.2	27.1	19.9
Concurrent Discharge (Avg. yrs)	9.4	8.4	9.0	21.2	101.2	266.1	169.9		59.0	29.1	23.1	14.8	10.7
Weighted Average	**12.5**	**11.1**	**11.9**	**27.3**	**124.3**	**317.7**	**205.5**		**73.7**	**37.2**	**29.7**	**19.3**	**14.1**

2.0 UNAPPROPRIATED DIRECT FLOW ANALYSIS

Unappropriated direct flows calculated using the weighted average approach (which incorporated regional regression methods and concurrent discharge methods from complete average years) were determined by subtracting appropriated flows from virgin flows. The diversion of appropriated water does not occur within the study catchments (appropriated flows equal zero), so unappropriated direct flows are equivalent to virgin flows.

2.1 DEPLETIONS AND CONSUMPTIVE USE

Depletions to stream flow include flow loss from consumptive use, deep groundwater loss, or out of basin diversions. There are no depletions due to irrigation or storage, and there are no depletions due to municipal or industrial uses in the study catchments.

2.2 RETURN FLOWS

Return flow is defined as the portion of diverted surface water that returns to the stream. There are no in-basin irrigated lands or return flows.

2.3 AVERAGE YEAR MEAN MONTHLY FLOW ANALYSIS

Mean monthly flows were calculated in each study stream segment for complete average water years using the weighted average methodology (Equation 1). The results quantify the unappropriated direct flows because the diversion of appropriated water does not occur within the study catchments, so there are no consumptive uses, depletions, or return flows. Unappropriated direct flows were compared to the instream flow request to identify shortages or surpluses of available surface water resources.

2.3.1 Muddy Creek

Muddy Creek has sufficient unappropriated flows to accommodate the instream flow request for April, June, July 16 through August, and October in an average year. The system has insufficient unappropriated direct flows to accommodate the instream flow request from November through March, in May, July 1-15, and in September in average years. The results are depicted in tabular and graphical form in Table 11 and Figures 27 and 28.

Table 11. Muddy Creek study segment mean monthly flow analysis.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul 1-15	Jul 16-31	Aug	Sep	Oct	Nov	Dec
Mean Monthly Flow (cfs)	0.6	0.4	0.4	1.7	15.7	35.3	22.4	9.9	3.8	1.9	1.5	1.1	0.7
Appropriated Flow (cfs)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Return Flow (cfs)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unappropriated Direct Flow (cfs)	0.6	0.4	0.4	1.7	15.7	35.3	22.4	9.9	3.8	1.9	1.5	1.1	0.7
Instream Flow Request (cfs)	1.3	1.3	1.3	1.3	29.0	29.0	29.0	3.0	3.0	3.0	1.3	1.3	1.3
Shortage/Surplus (cfs)	-0.7	-0.9	-0.9	0.4	-13.3	6.3	-6.6	6.9	0.8	-1.1	0.2	-0.2	-0.6

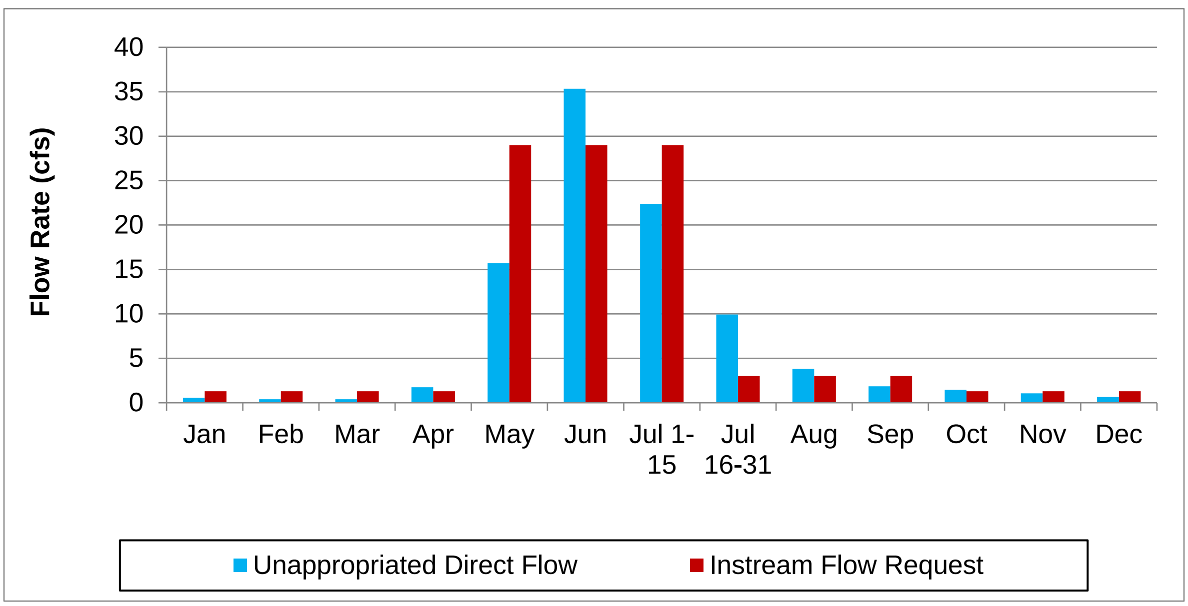


Figure 27. Muddy Creek study segment unappropriated direct flow and instream flow request.

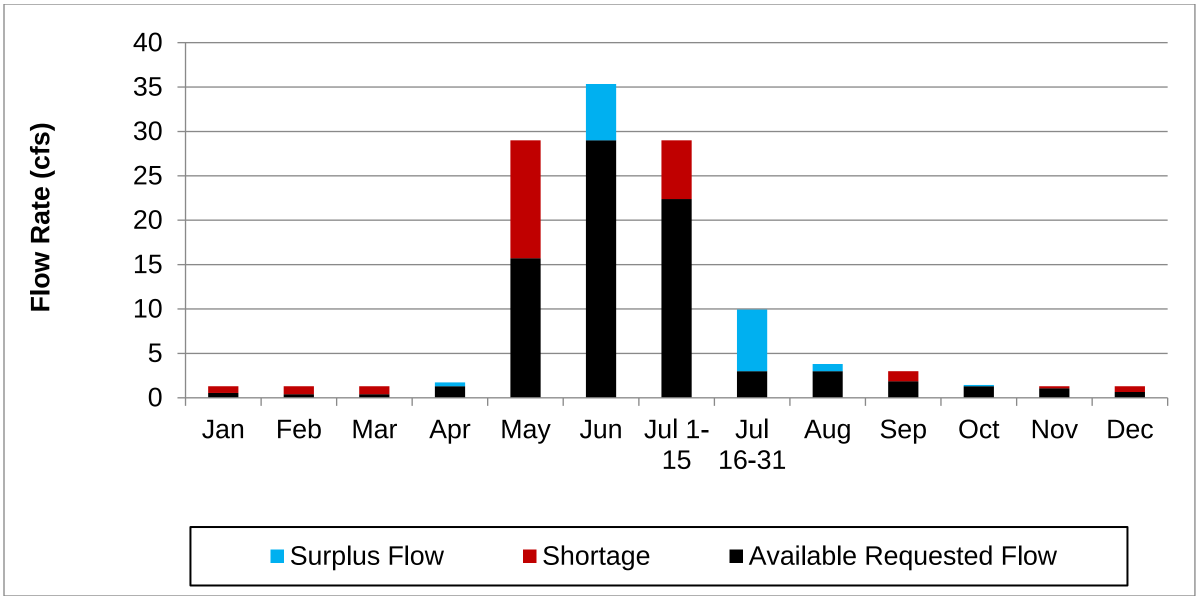


Figure 28. Muddy Creek study segment instream flow request and availability.

2.3.2 Crandall Creek

Crandall Creek has sufficient unappropriated flows to satisfy the instream flow request from April through August, and in October in average years. The system has insufficient unappropriated direct flows to accommodate the instream flow request from November through March, and in September in average years. Results are depicted in tabular and graphical form in Table 12 and Figures 29 and 30.

Table 12. Crandall Creek study segment mean monthly flow analysis.

Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Mean Monthly Flow (cfs)	12.5	11.1	11.9	27.3	124.3	317.7	205.5	73.7	37.2	29.7	19.3	14.1
Appropriated Flow (cfs)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Return Flow (cfs)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unappropriated Direct Flow (cfs)	12.5	11.1	11.9	27.3	124.3	317.7	205.5	73.7	37.2	29.7	19.3	14.1
Instream Flow Request (cfs)	27.0	27.0	27.0	27.0	66.0	66.0	55.0	55.0	55.0	27.0	27.0	27.0
Shortage/Surplus (cfs)	-14.5	-15.9	-15.1	0.3	58.3	251.7	150.5	18.7	-17.8	2.7	-7.7	-12.9

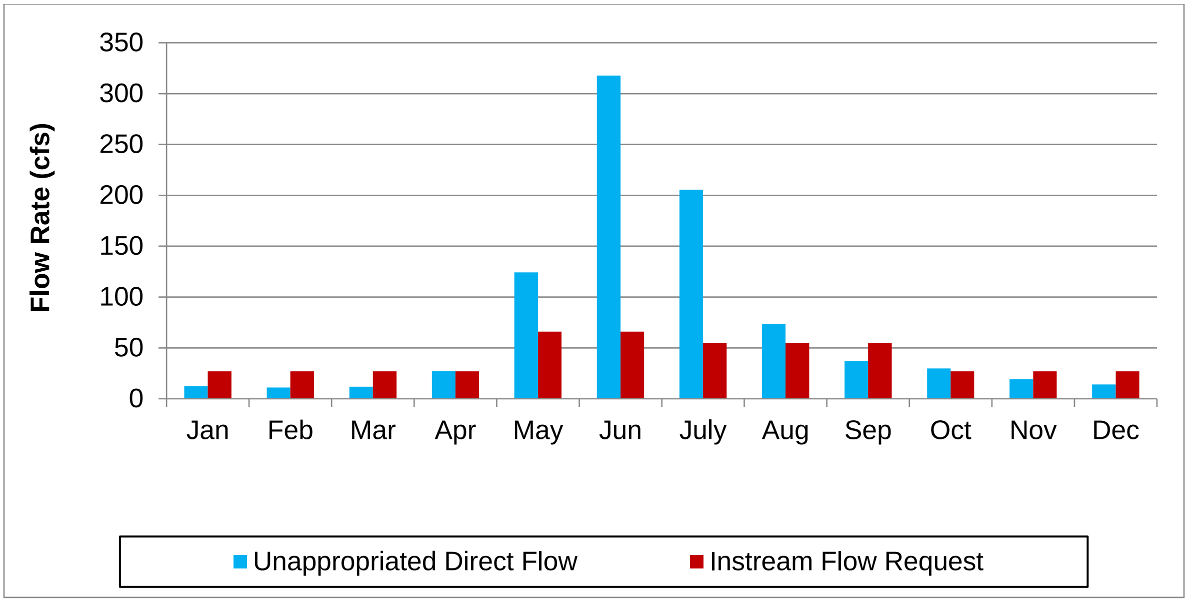


Figure 29. Crandall Creek study segment unappropriated direct flow and instream flow request.

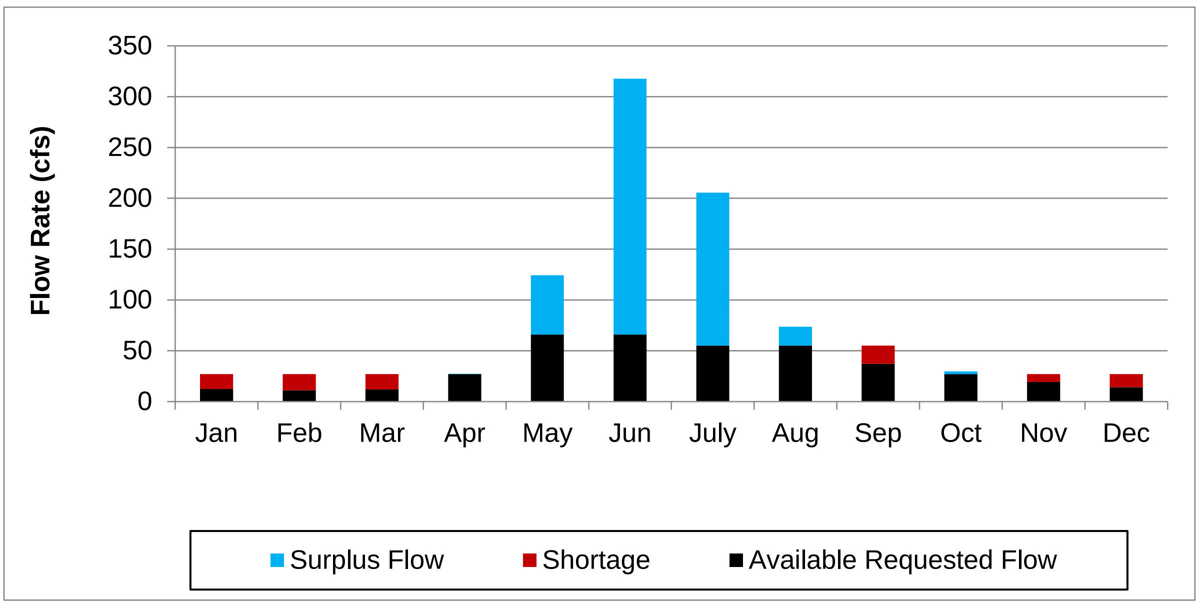


Figure 30. Crandall Creek study segment instream flow request and availability.

2.3.3 Dead Indian Creek

Dead Indian Creek has sufficient unappropriated flows to accommodate the instream flow request from March through January in an average year. The system has insufficient unappropriated direct flows to accommodate the instream flow request in February in average years. Results are depicted in tabular and graphical form in Table 13 and Figures 31 and 32.

Table 13. Dead Indian Creek study segment mean monthly flow analysis.

Parameter	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Mean Monthly Flow (cfs)	14.0	13.0	13.6	24.1	71.7	146.6	104.8	48.7	29.8	25.5	18.9	15.3
Appropriated Flow (cfs)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Return Flow (cfs)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unappropriated Direct Flow (cfs)	14.0	13.0	13.6	24.1	71.7	146.6	104.8	48.7	29.8	25.5	18.9	15.3
Instream Flow Request (cfs)	13.3	13.3	13.3	13.3	31.0	31.0	28.0	28.0	28.0	13.3	13.3	13.3
Shortage/Surplus (cfs)	0.7	-0.3	0.3	10.8	40.7	115.6	76.8	20.7	1.8	12.2	5.6	2.0

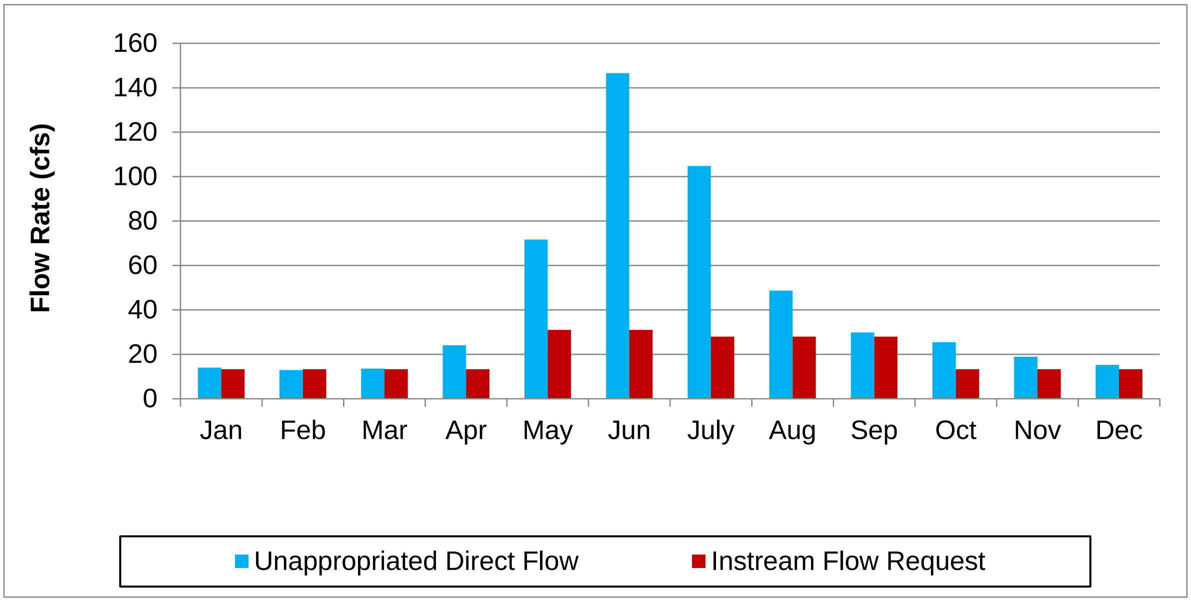


Figure 31. Dead Indian Creek study segment unappropriated direct flow and instream flow request.

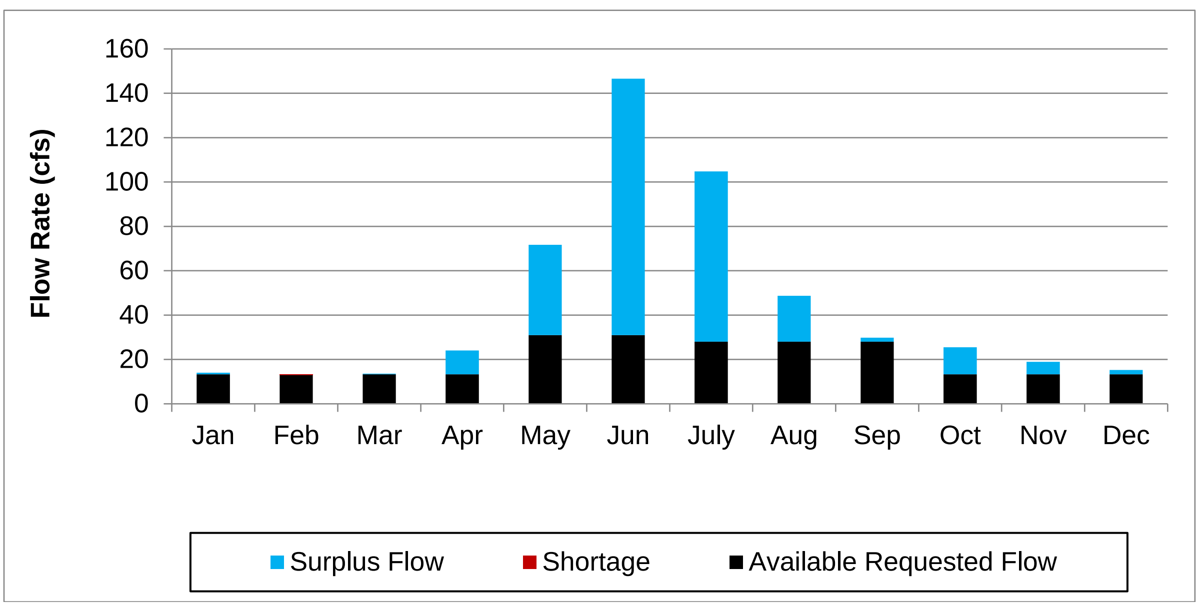


Figure 32. Dead Indian Creek study segment instream flow request and availability.

2.4 FLOW SHORTAGE, STORAGE ANALYSIS, AND DESIGN

The Dead Indian Creek and Crandall Creek sites have substantial surpluses of unappropriated direct flow during the months of May, June, and July in average years. Study segment catchments were assessed to investigate potential to establish water storage facilities that could retain surplus water during spring months and release stored water during fall and winter months to provide unappropriated flows to satisfy the instream flow request. Assessment found that study watercourses are confined by steep colluvial hill slopes throughout the upstream portions of the catchments. Consistently steep bounding topographic conditions in the upper basins precludes economically viable opportunities for off-channel storage of surface water that could be operated to store surplus flows during spring months and release flows to provide additional surface water resources during fall and winter months. Preliminary designs and cost analyses of storage facilities are therefore not provided.

2.5 DAILY UNAPPROPRIATED FLOW EXCEEDANCE ANALYSIS

Unappropriated direct flow exceedance was quantified within each stream study segment to identify the mean daily flow rate as percentage of time during each month. The regional regression equation methodology was used to calculate mean daily flows in the study segments by dividing the reference gauge mean daily flow record from complete average years by the reference gauge mean annual flow, then multiplying the dimensionless flow by the study segment mean annual flow. The concurrent discharge correlation equation methodology was used to calculate mean daily flows in the study segments by applying the correlation equations (that relate study segment and reference gauge flow rates) to the reference gauge mean daily flow record from complete average years. A weighted average approach (Equation 1) was then used to combine results obtained from the regression equation and concurrent discharge methods to determine mean daily flow rates in the study segments. The results were used to identify the percent exceedance of the instream flow request. Analyses also identified the 20% and 50% exceedance unappropriated direct flows, or the flows in each stream study segment that occur one fifth or half of the time during each month, respectively.

Table 14 presents a summary of flow duration analysis results by month in each segment. Periods during which the instream flow request surpasses the 20% exceedance unappropriated direct flow are highlighted in green, while months during which the instream flow request is less than the 20% exceedance unappropriated direct flow are highlighted in red. Appendix A includes flow duration curves generated for each study segment during each month of the year.

Table 14. Monthly mean daily unappropriated flow exceedance summary, Sunlight Basin Instream Flow Study.

Parameter	Jan	Feb	March	April	May	June	July 1-15	July 16-31	Aug	Sept	Oct	Nov	Dec
Muddy Creek													
Requested Instream Flow (cfs)	1.3	1.3	1.3	1.3	29	29.0	29.0	3.0	3.0	3.0	1.3	1.3	1.3
Percent Exceedance of Requested Flow (%)	0%	0%	1%	40%	16%	64%	22%	100%	55%	6%	61%	18%	2%
Est. 50% Exceedance (cfs)	0.5	0.4	0.3	1.1	12.5	34.9	20.0	8.4	3.2	1.7	1.4	1.0	0.6
Est. 20% Exceedance (cfs)	0.7	0.5	0.5	2.4	25.9	45.8	30.1	12.8	4.9	2.2	1.7	1.3	0.8
Crandall Creek													
Requested Instream Flow (cfs)	27.0	27.0	27.0	27.0	66.0	66.0	55.0		55.0	55.0	27.0	27.0	27.0
Percent Exceedance of Requested Flow (%)	2%	0%	0%	22%	66%	100%	100%		64%	12%	42%	7%	1%
Est. 50% Exceedance (cfs)	11.3	10.7	11.3	20.1	100.1	290.2	187.0		66.1	32.6	24.8	18.3	14.2
Est. 20% Exceedance (cfs)	14.8	12.5	13.6	29.0	187.7	442.9	280.5		98.2	47.1	35.0	22.5	16.0
Dead Indian Creek													
Requested Instream Flow (cfs)	13.3	13.3	13.3	13.3	31.0	31.0	28.0		28.0	28.0	13.3	13.3	13.3
Percent Exceedance of Requested Flow (%)	43%	24%	33%	90%	81%	100%	100%		96%	44%	100%	99%	67%
Est. 50% Exceedance (cfs)	12.6	12.1	12.6	19.0	62.2	141.8	100.5		45.4	27.0	22.1	17.8	14.8
Est. 20% Exceedance (cfs)	15.3	13.5	14.4	24.8	100.8	198.6	138.0		61.3	35.3	28.4	20.6	16.1

3.0 CONCLUSIONS

Analysis of the hydrologic regimes in the Sunlight Basin Instream Flow Study segments was completed using regional regression equations and concurrent discharge measurement techniques. Results obtained from the two applied methods varied by stream study segment and by season. In order to resolve discrepancy in methodological findings, a weighted average approach was applied to combine obtained results. Results of the weighted average analyses indicate that mean monthly unappropriated direct flows are sufficient to satisfy the instream flow requests in Dead Indian Creek for all months except February, and the requested instream flow rates are in excess of the 20% exceedance flow during all months. In Crandall Creek the requested instream flow rates are in excess of the 20% exceedance flow during September and the winter months from November to March. In Muddy Creek the requested instream flow rates are in excess of the 20% exceedance flow during May, September, and the winter months from November to March.

Direct discharge measurements and continuous stream gauging data collected in the study segments during 2017 and 2018 provide empirical data that precisely quantify hydrologic regime during the study period. Regional regression equations that derive hydrologic attributes based upon catchment parameters are a standard hydrologic investigation tool that have been applied consistently across countless basins in Wyoming. The application of a weighted average approach to combine these methodologies provides results based upon robust empirical stream flow data and the application of regional regression equations.

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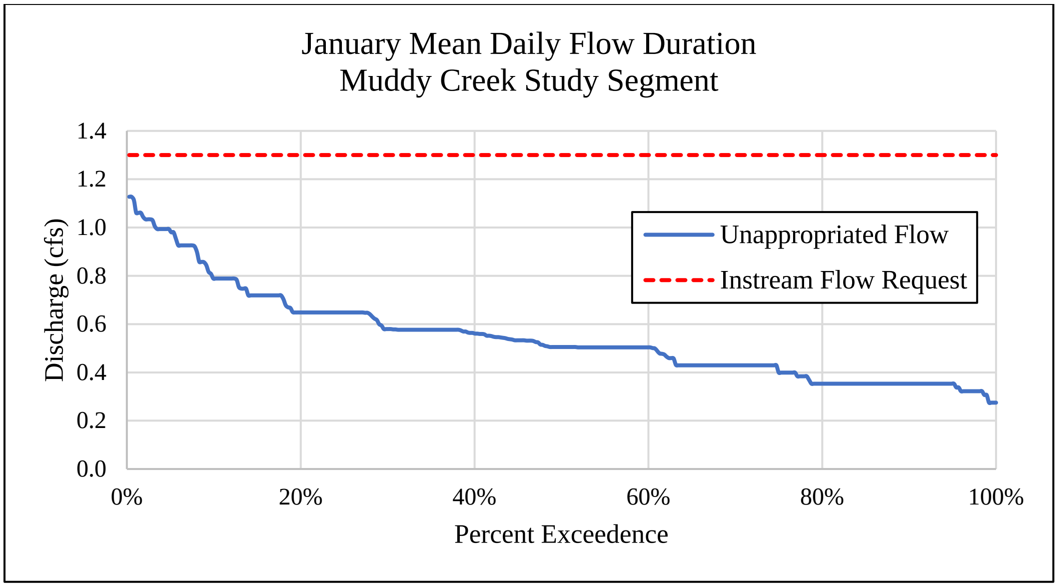
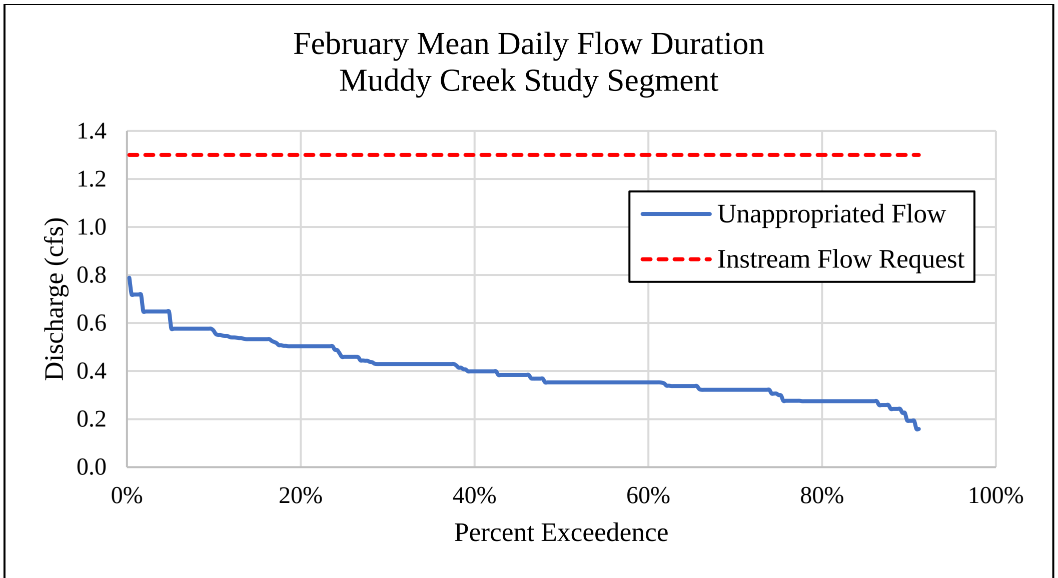
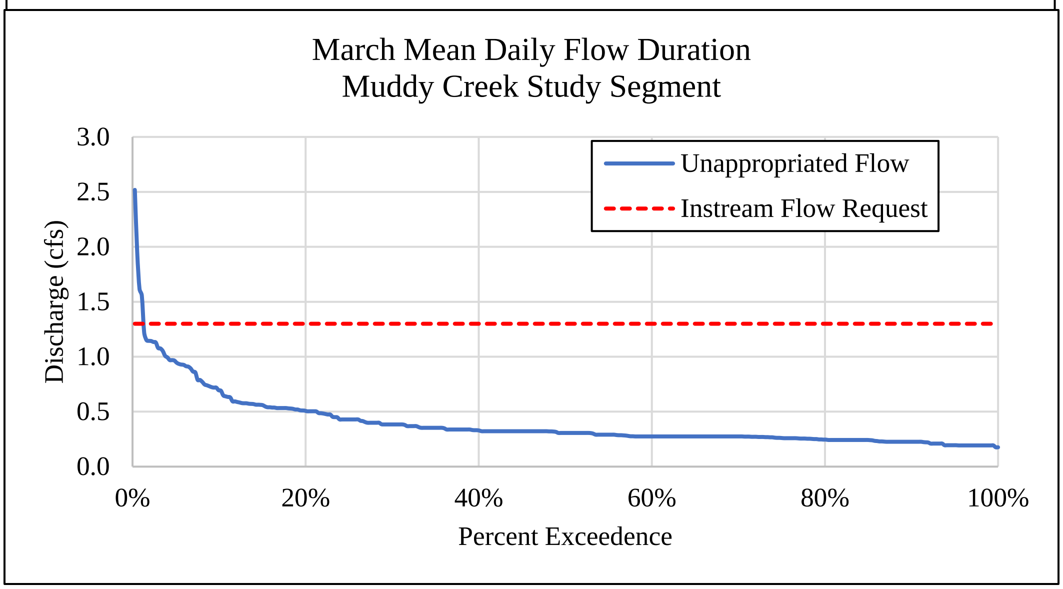
APPENDIX A

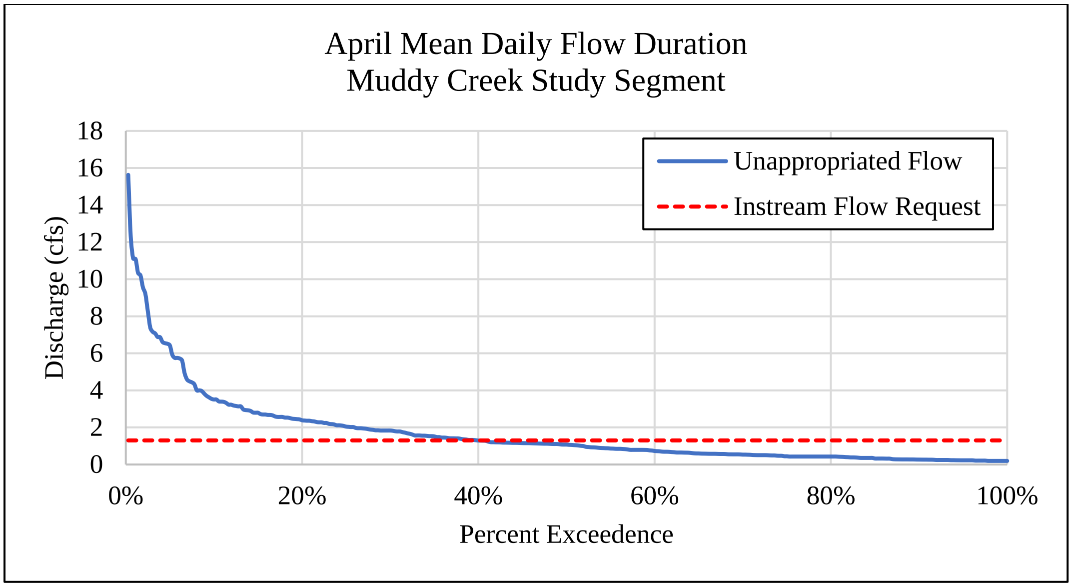
MEAN DAILY FLOW DURATION CURVES

Flow duration curves were developed using mean daily flows from “average” years as described in sections 1.6 and 2.5. Flow values were obtained from published USGS gauge data from the two reference gauges selected for this study: 1) The Sunlight Creek near Painter Wyoming gauge (USGS # 06206500) which was selected for use as a reference gauge for Crandall Creek and Dead Indian Creek; and 2) The Soda Butte at Park Boundary at Silver Gate gauge (USGS # 06187915) which was selected for use as a reference gauge for Muddy Creek.

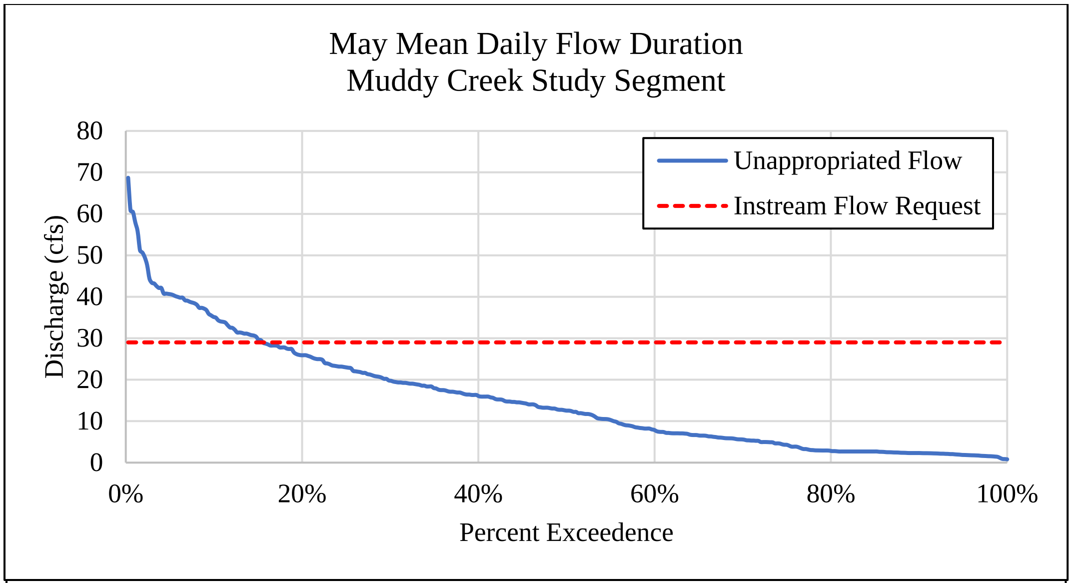


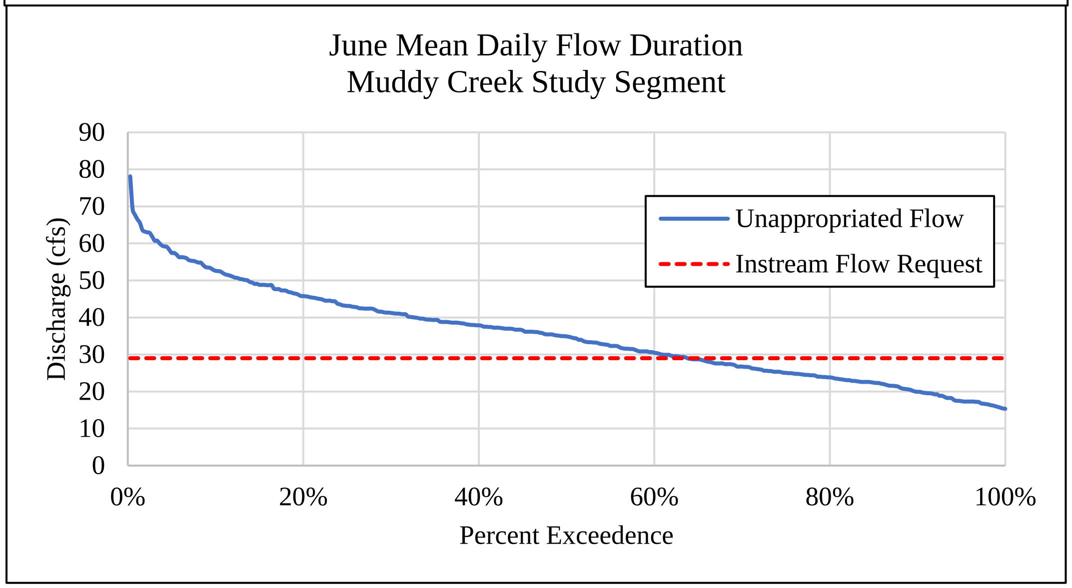

February Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

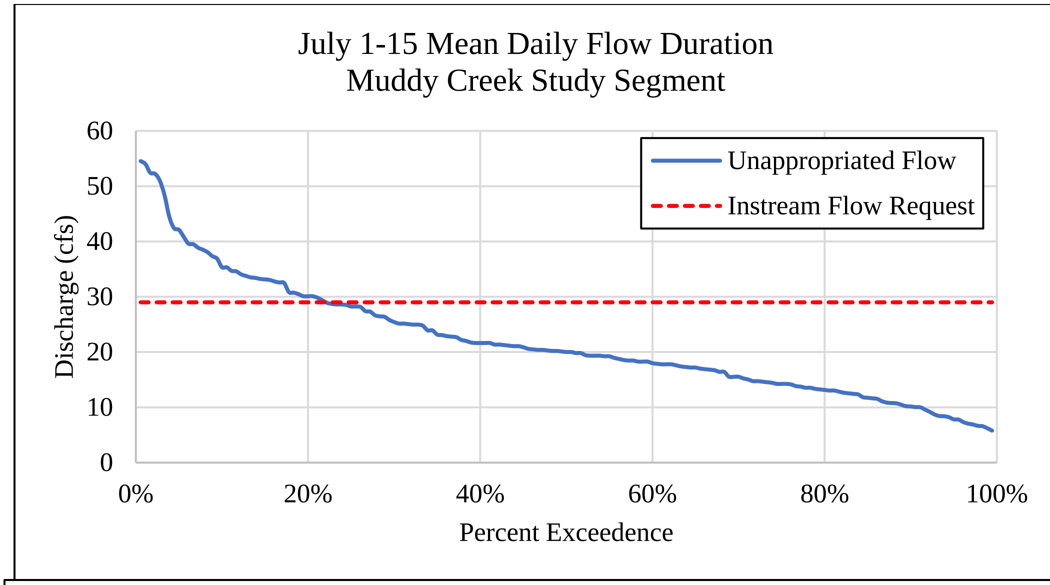

March Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

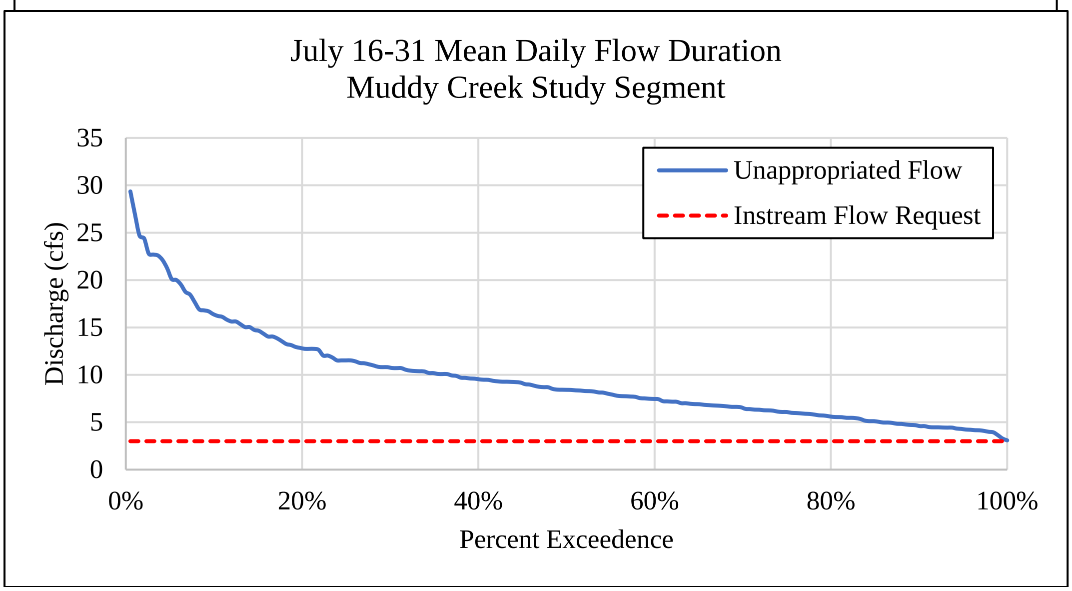


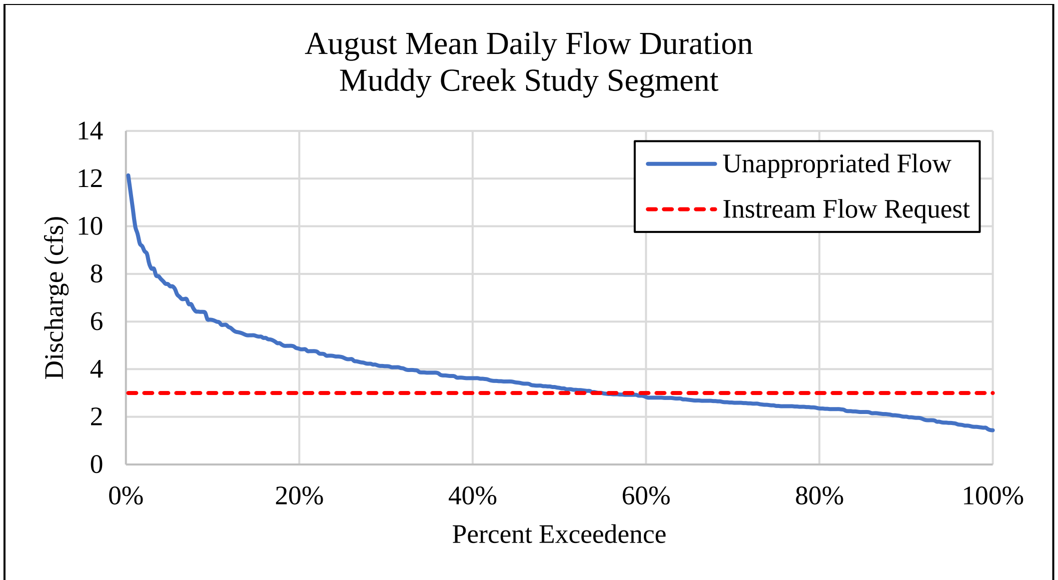
April Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
18
16
14
12
10
8
6
4
2
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

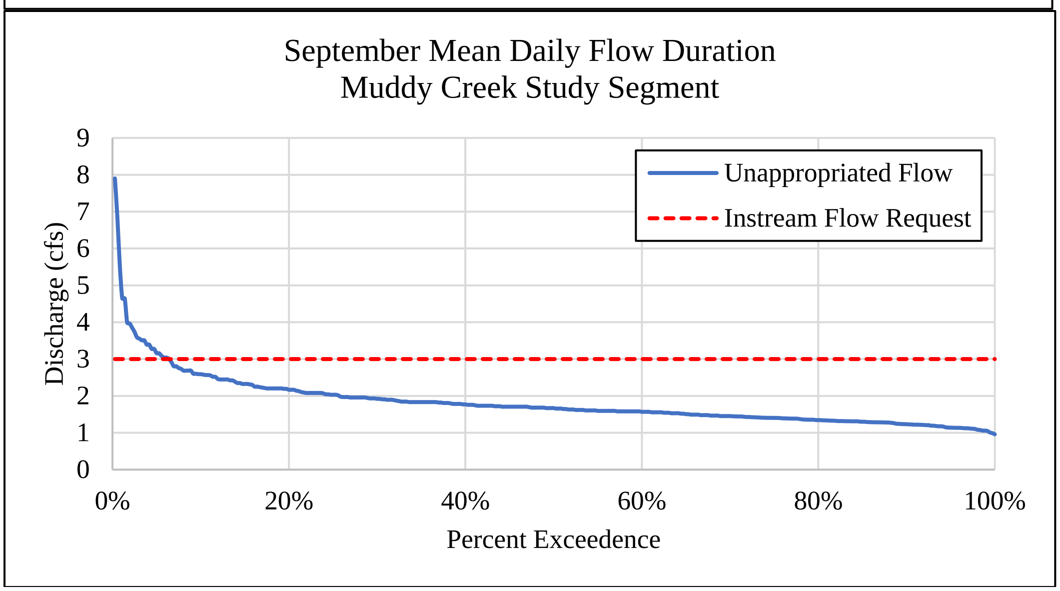

May Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
0
10
20
30
40
50
60
70
80
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

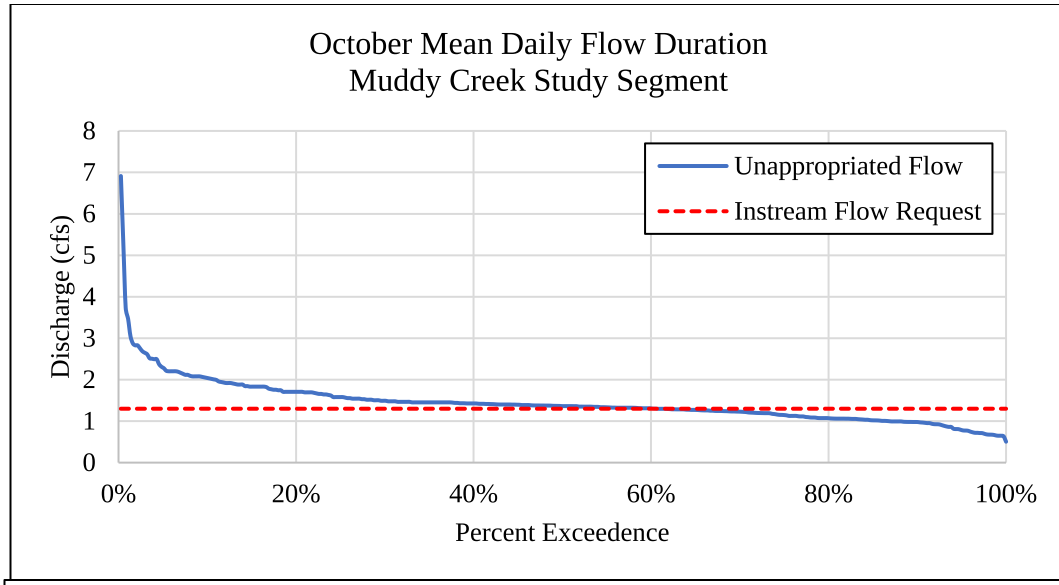

June Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
0
10
20
30
40
50
60
70
80
90
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

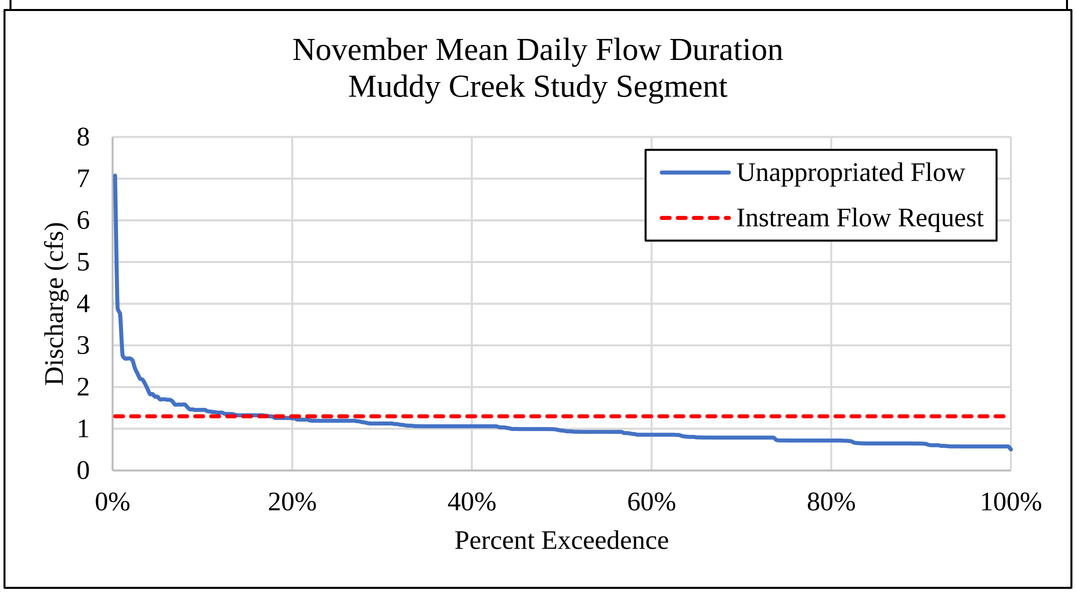

July 1-15 Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
60
50
40
30
20
10
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

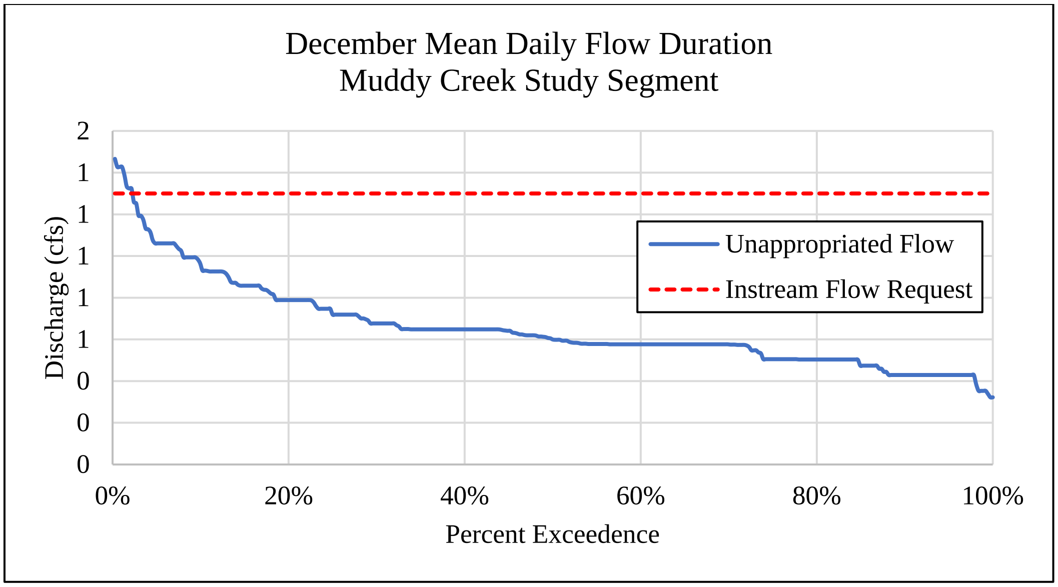

July 16-31 Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
35
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

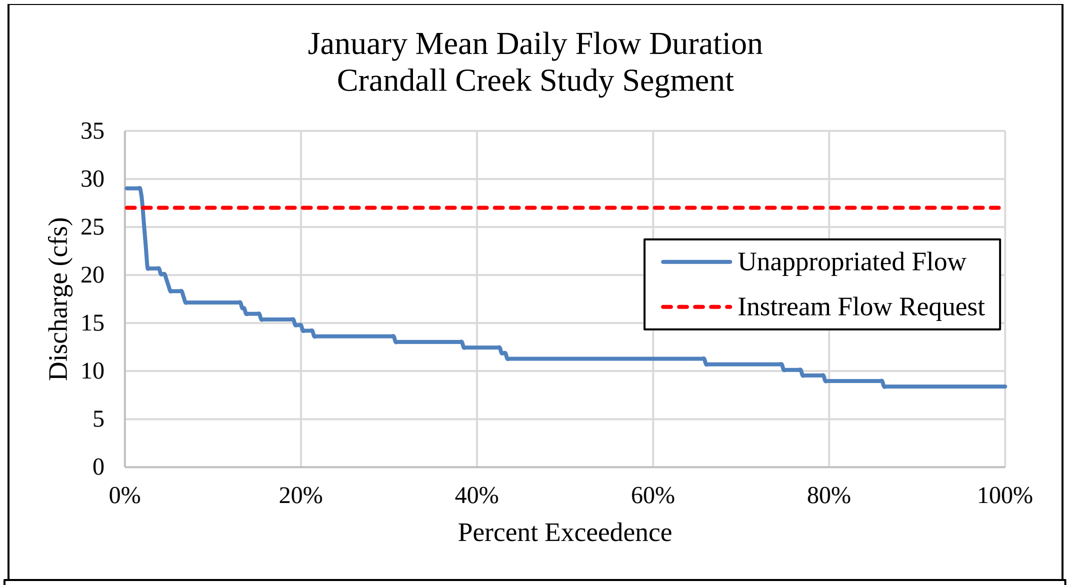

August Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
14
12
10
8
6
4
2
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

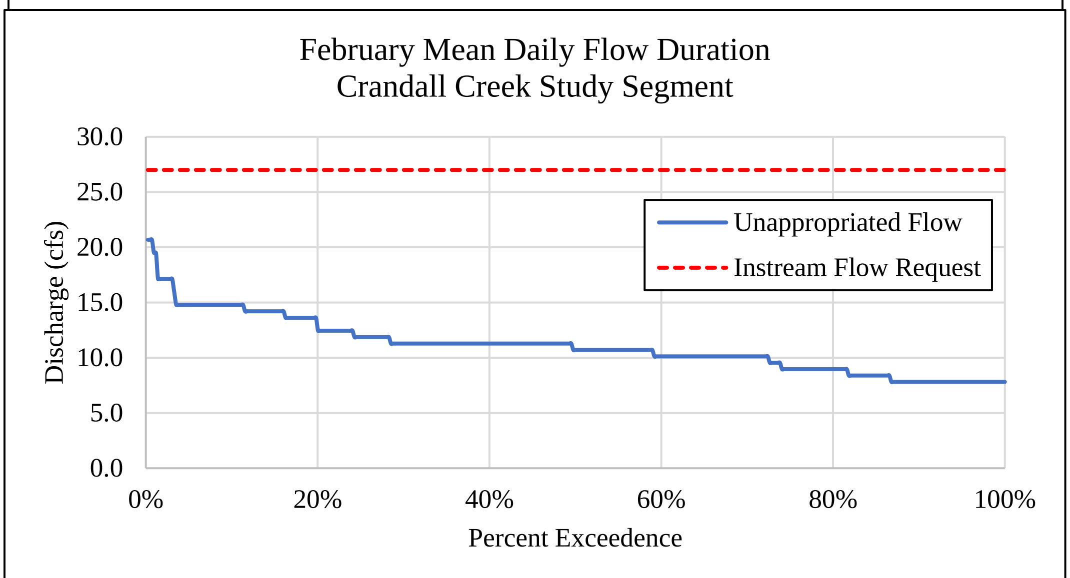

September Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
9
8
7
6
5
4
3
2
1
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

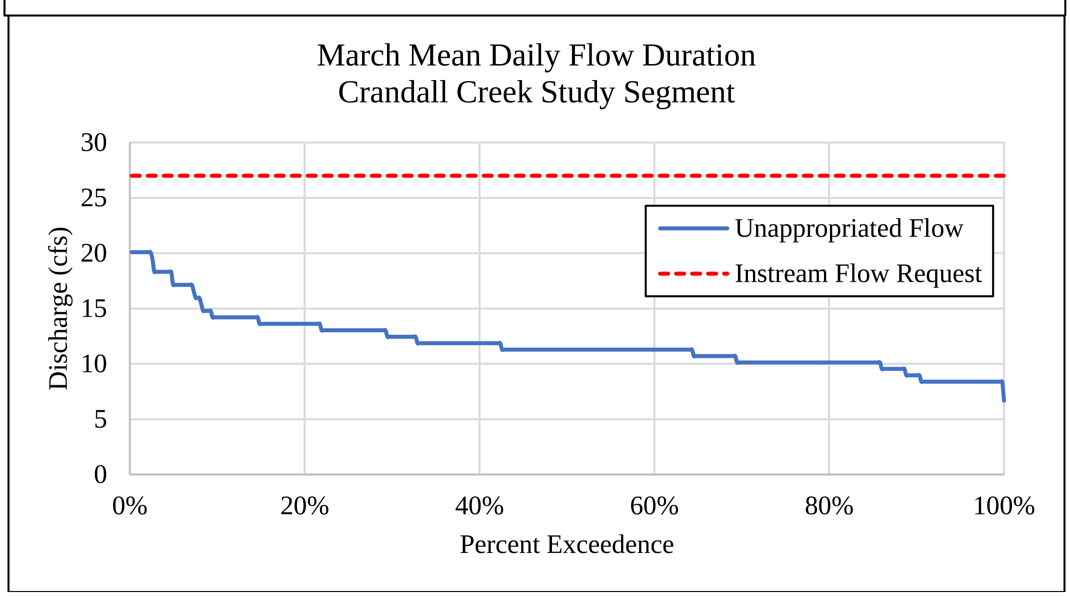

October Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
0
1
2
3
4
5
6
7
8
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

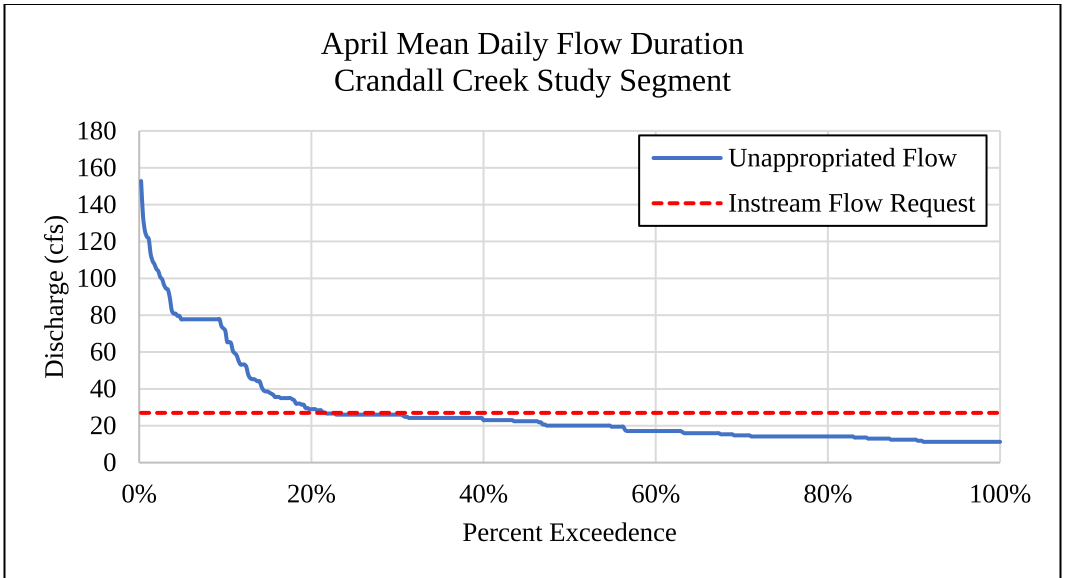

November Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
0
1
2
3
4
5
6
7
8
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

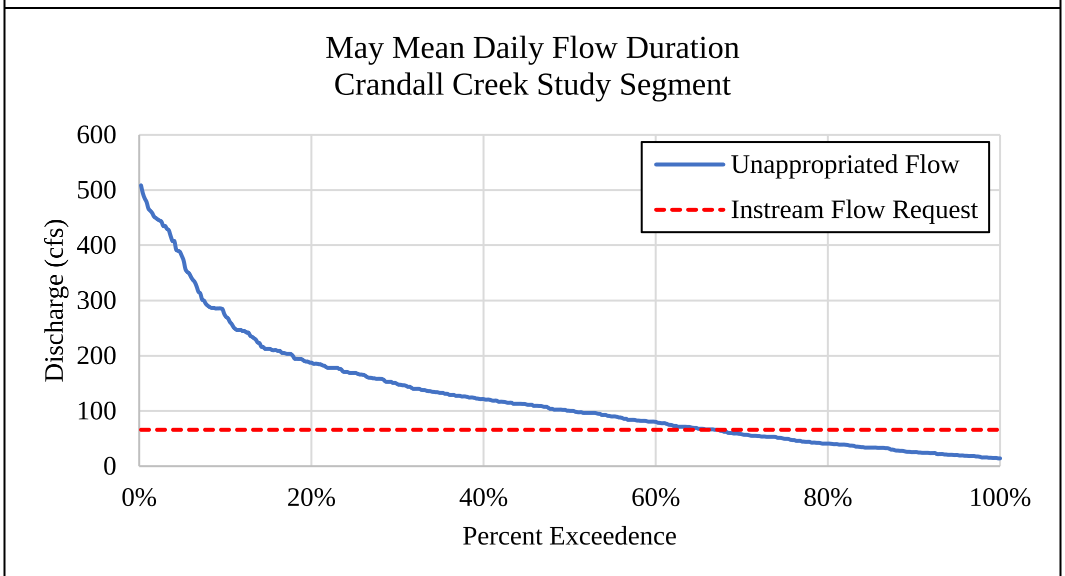

December Mean Daily Flow Duration
Muddy Creek Study Segment
Discharge (cfs)
2
1
1
1
1
1
0
0
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

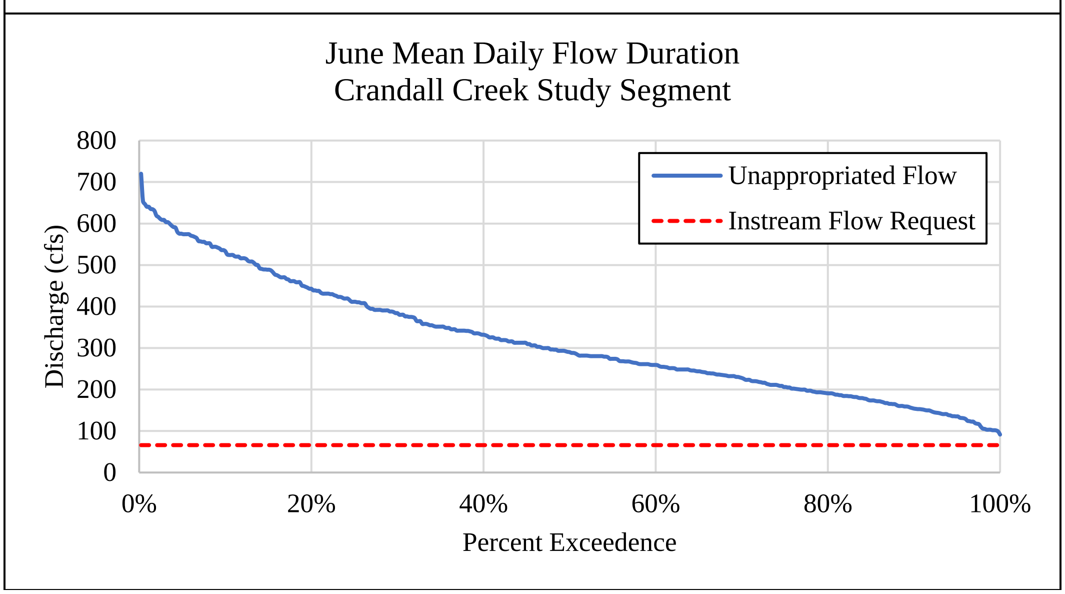

January Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
35
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

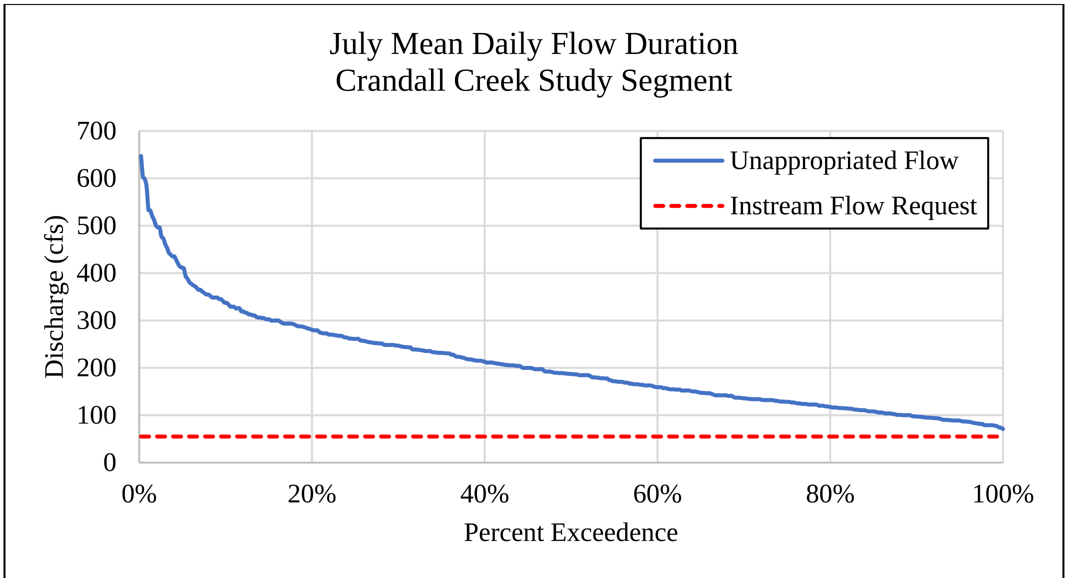

February Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
30.0
25.0
20.0
15.0
10.0
5.0
0.0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

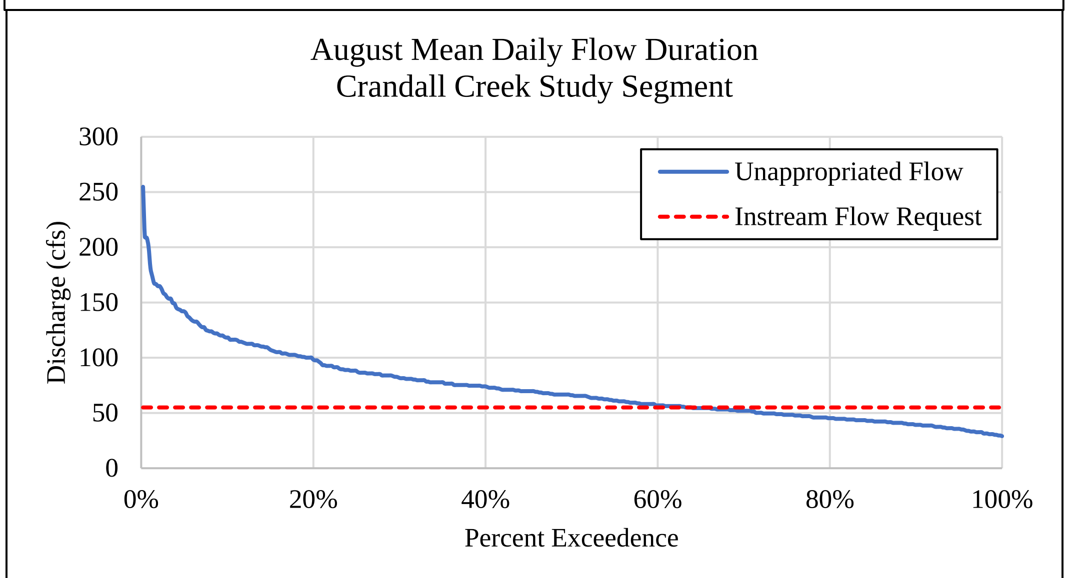

March Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

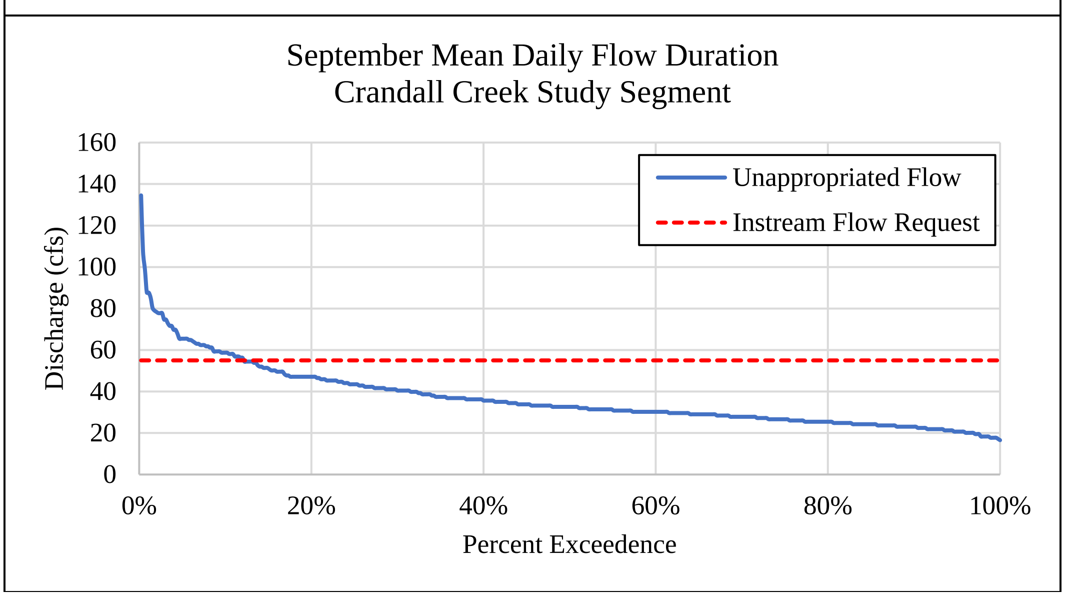

April Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
180
160
140
120
100
80
60
40
20
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

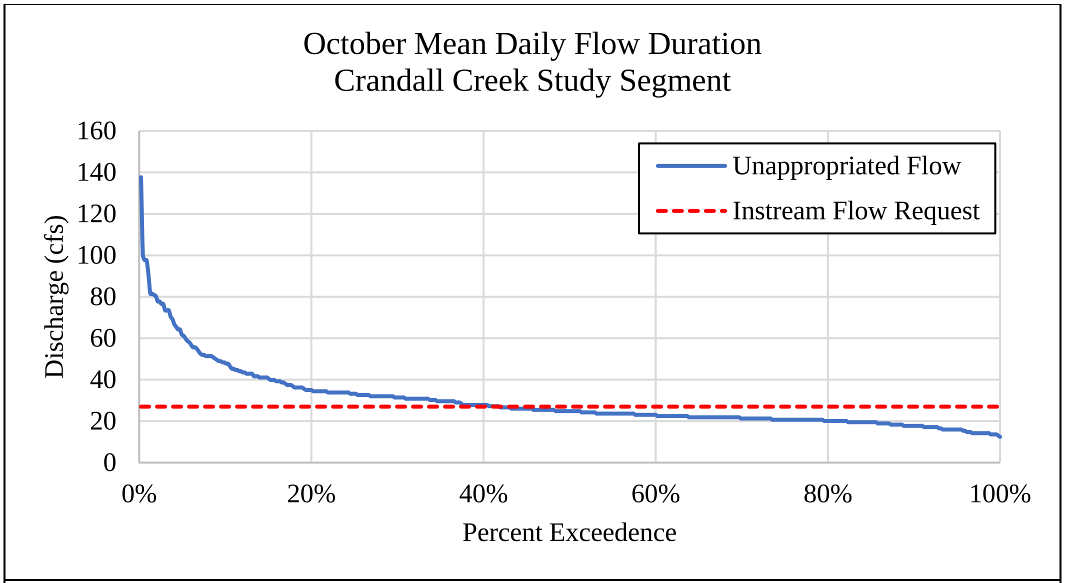

May Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
600
500
400
300
200
100
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

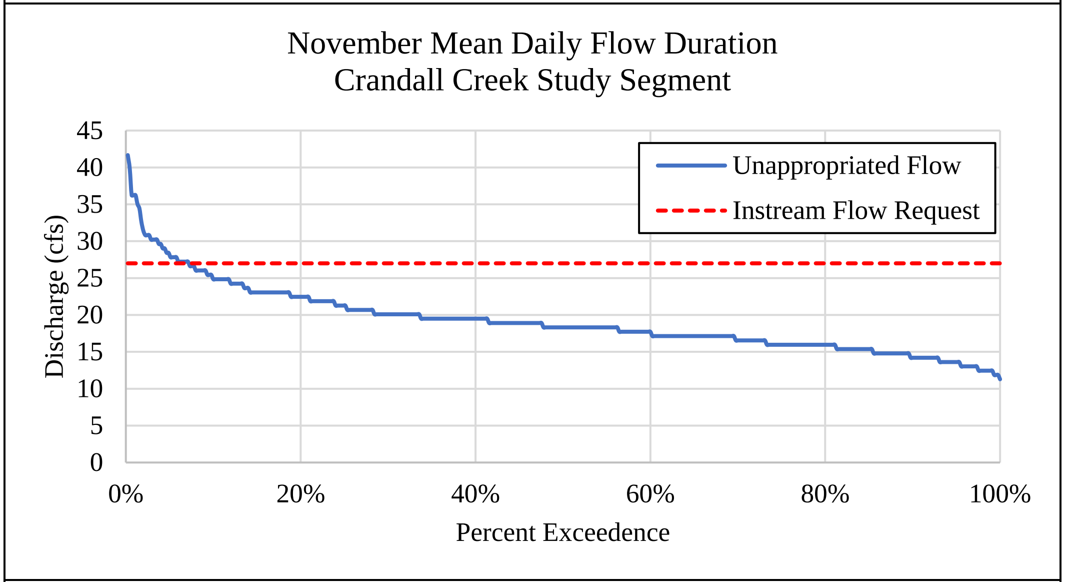

June Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
800
700
600
500
400
300
200
100
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

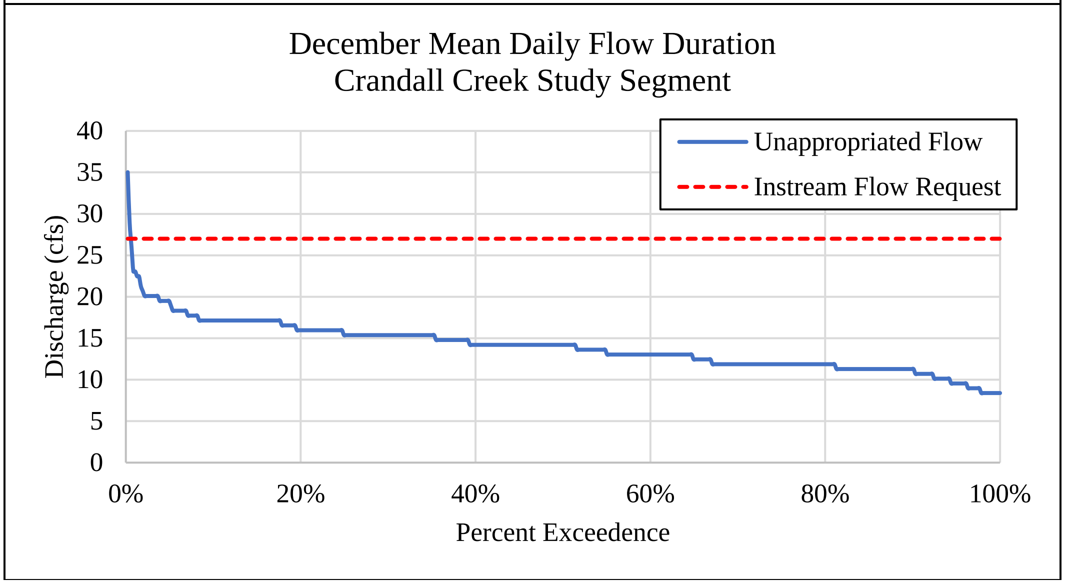

July Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
700
600
500
400
300
200
100
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

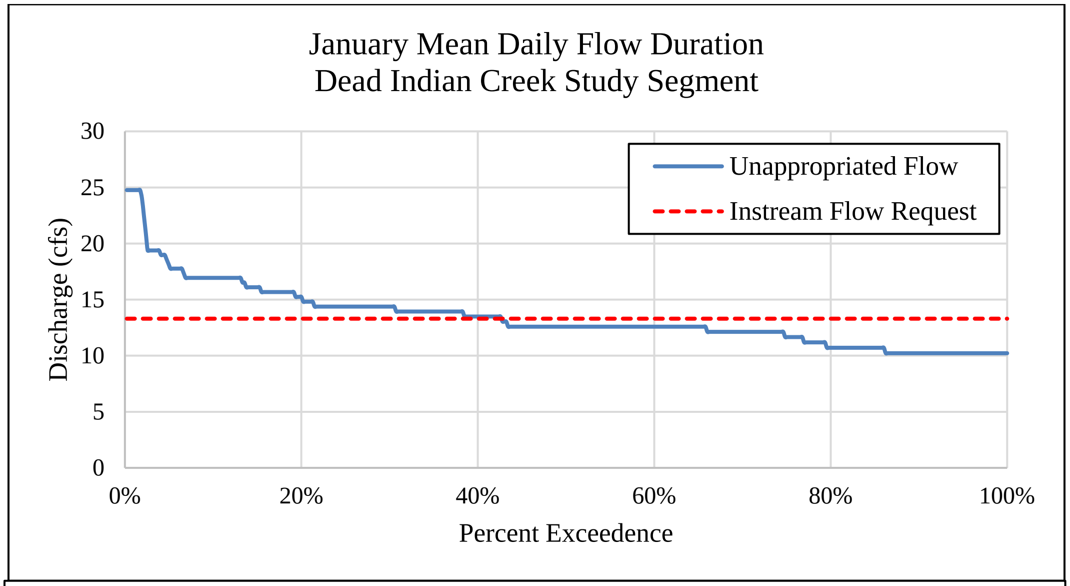

August Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
300
250
200
150
100
50
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

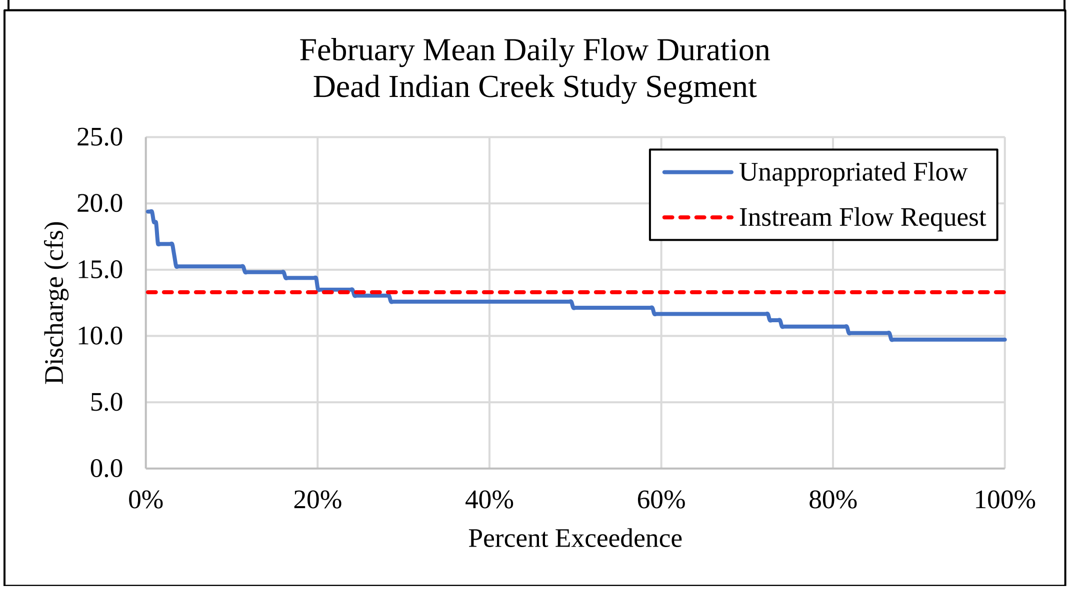

September Mean Daily Flow Duration
Crandall Creek Study Segment
Discharge (cfs)
160
140
120
100
80
60
40
20
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

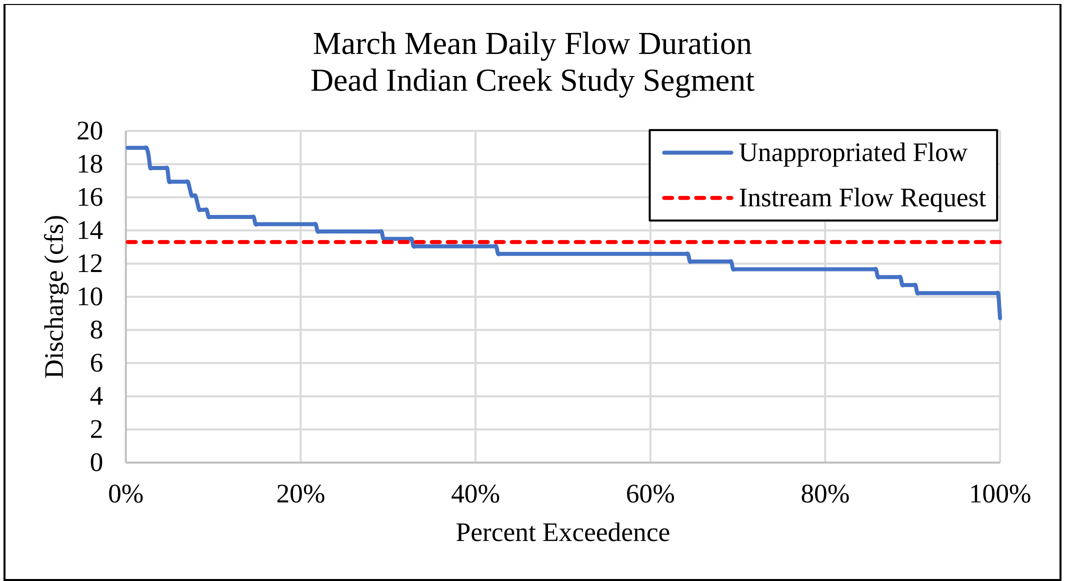

October Mean Daily Flow Duration
Crandall Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
160
140
120
100
80
60
40
20
0
0%
20%
40%
60%
80%
100%
Percent Exceedence

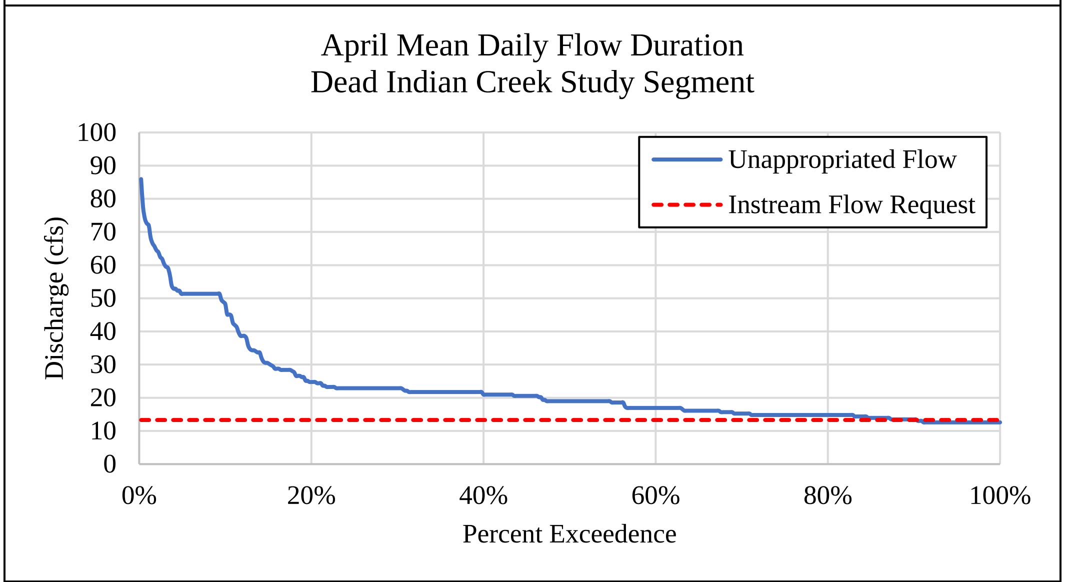

November Mean Daily Flow Duration
Crandall Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
45
40
35
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence

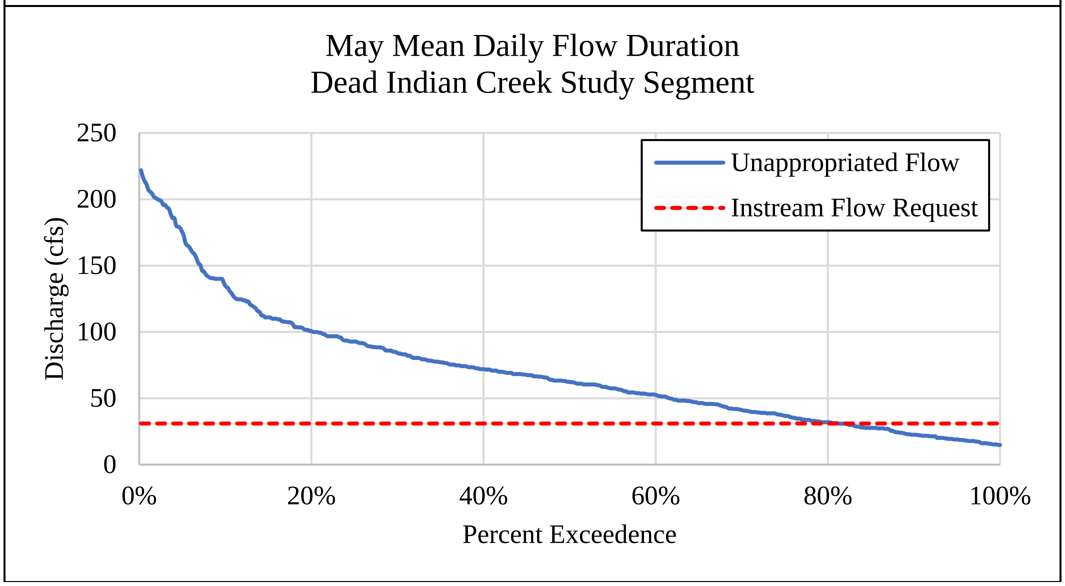

December Mean Daily Flow Duration
Crandall Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
40
35
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence

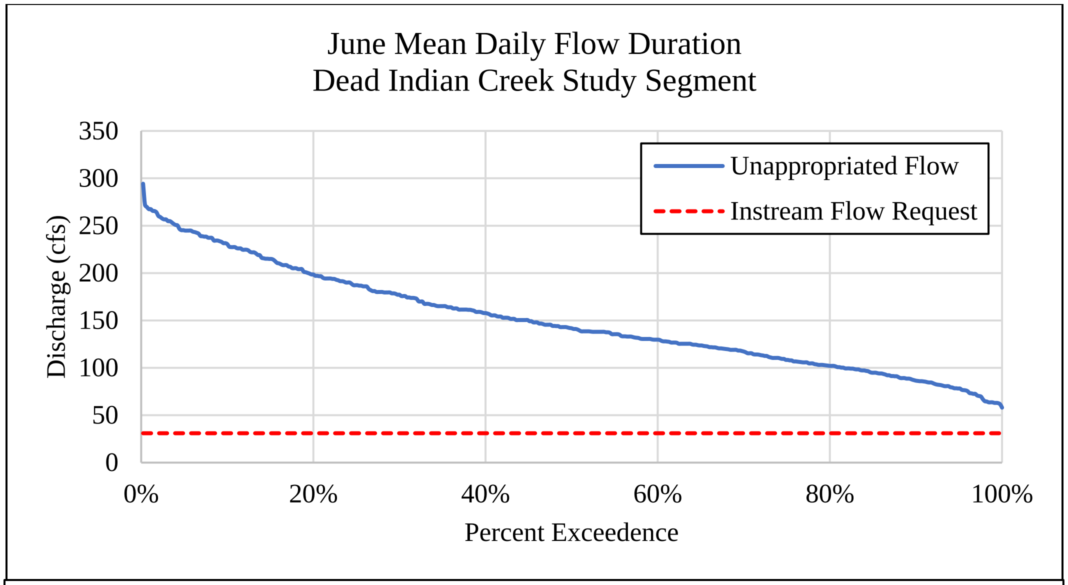

January Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

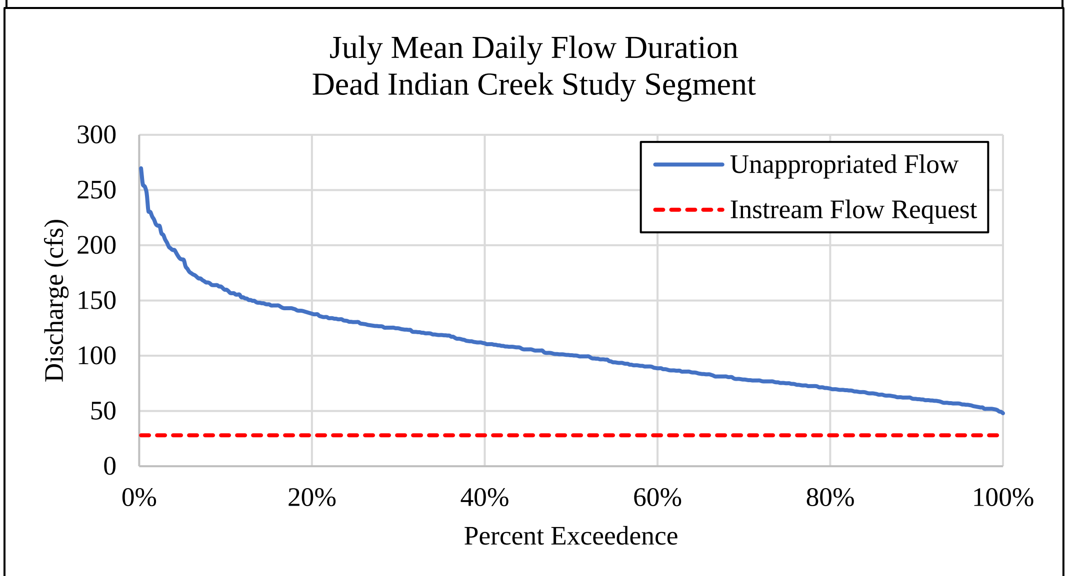

February Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
25.0
20.0
15.0
10.0
5.0
0.0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

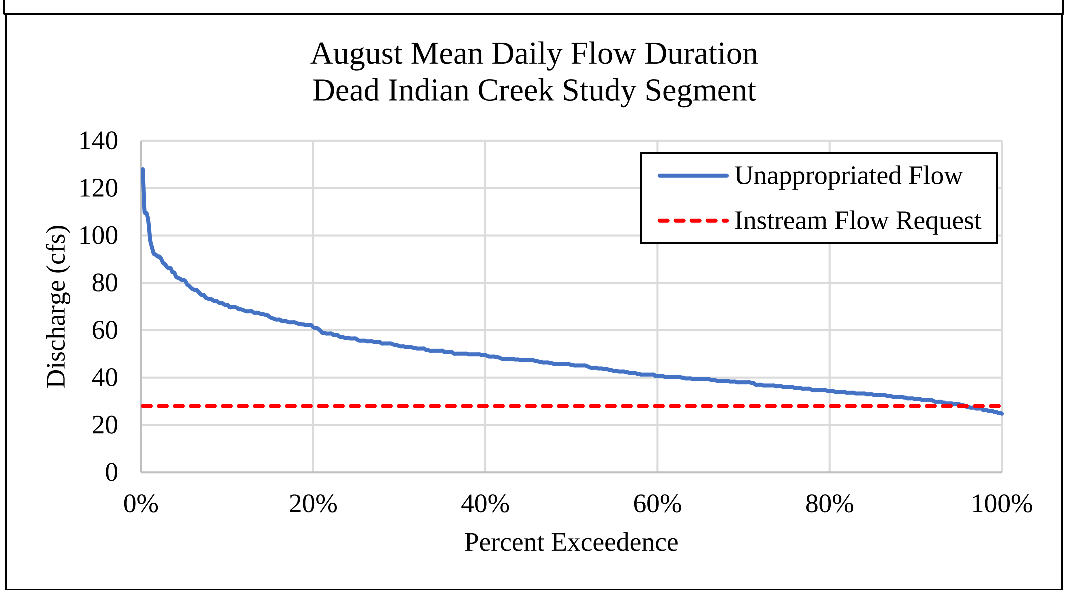

March Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
20
18
16
14
12
10
8
6
4
2
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

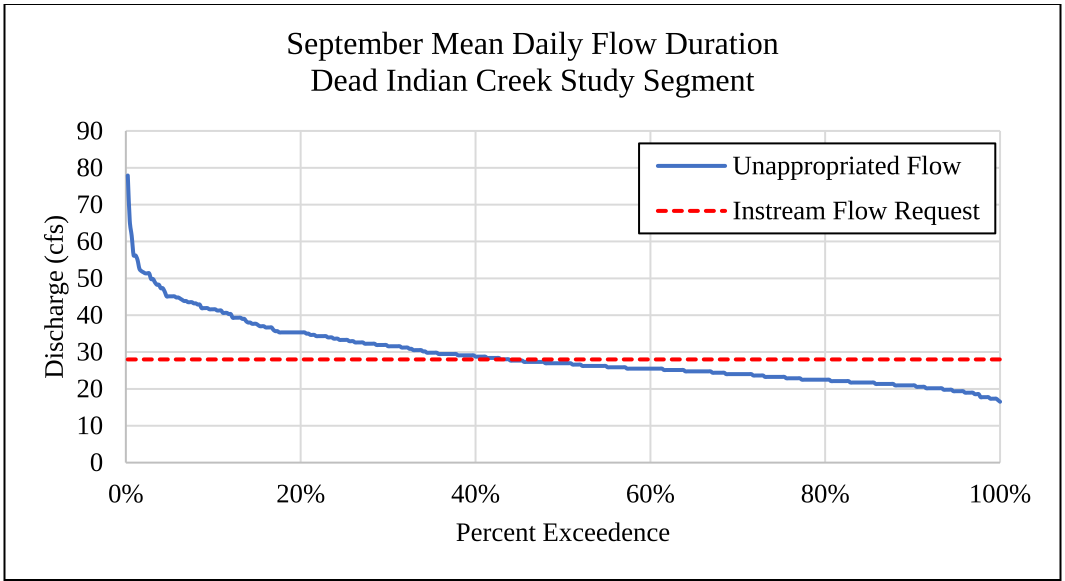

April Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
100
90
80
70
60
50
40
30
20
10
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

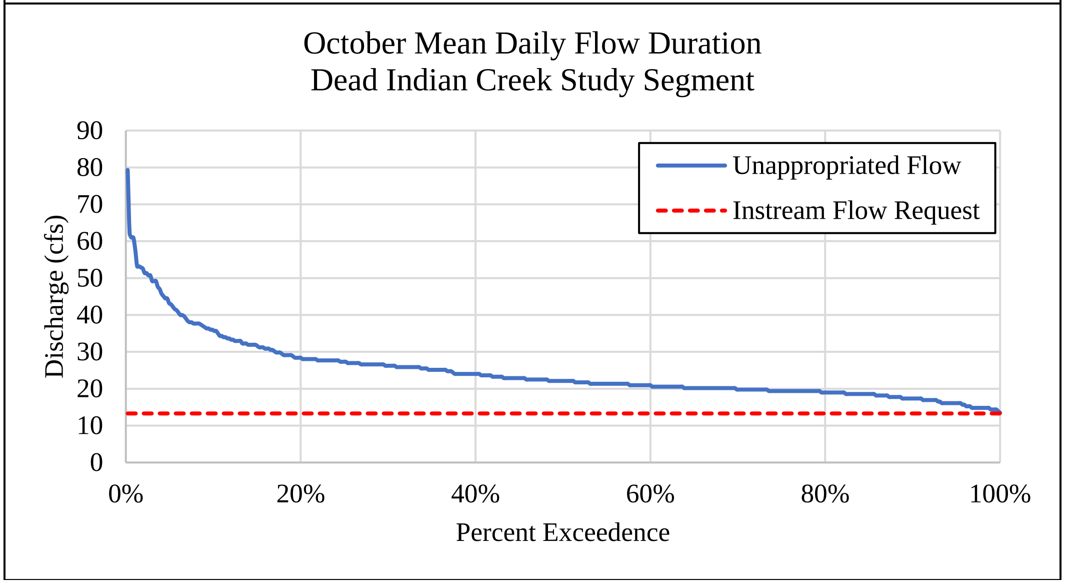

May Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
250
200
150
100
50
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request

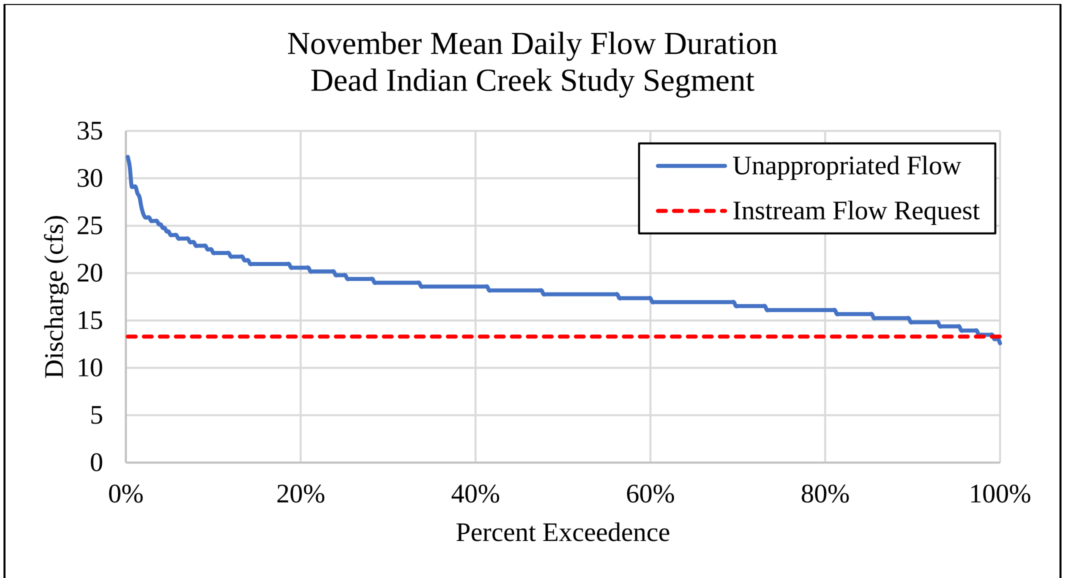

June Mean Daily Flow Duration
Dead Indian Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
350
300
250
200
150
100
50
0
0%
20%
40%
60%
80%
100%
Percent Exceedence

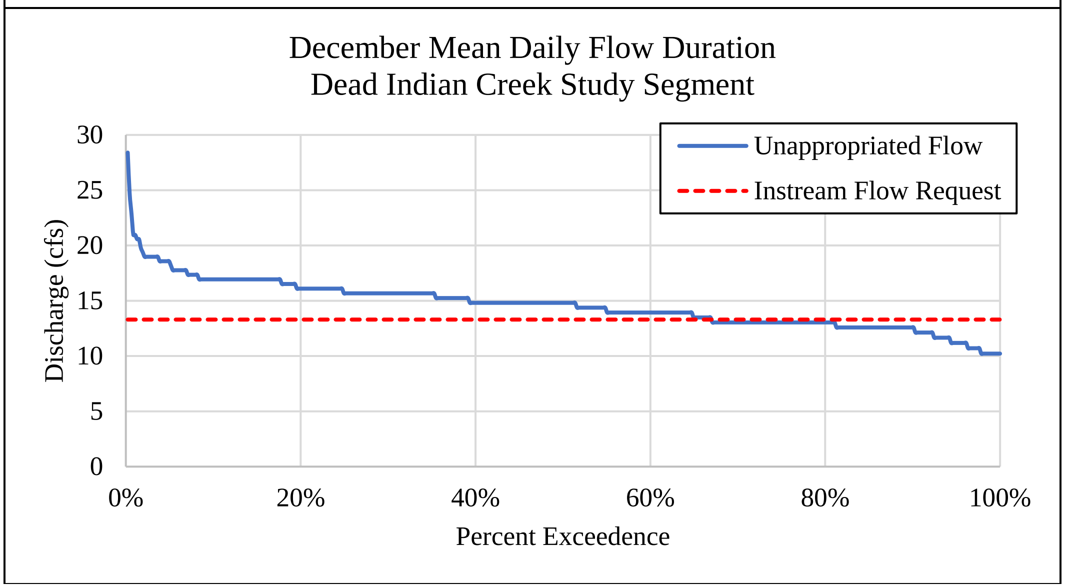

July Mean Daily Flow Duration
Dead Indian Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
300
250
200
150
100
50
0
0%
20%
40%
60%
80%
100%
Percent Exceedence


August Mean Daily Flow Duration
Dead Indian Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
140
120
100
80
60
40
20
0
0%
20%
40%
60%
80%
100%
Percent Exceedence


September Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
90
80
70
60
50
40
30
20
10
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request


October Mean Daily Flow Duration
Dead Indian Creek Study Segment
Discharge (cfs)
90
80
70
60
50
40
30
20
10
0
0%
20%
40%
60%
80%
100%
Percent Exceedence
Unappropriated Flow
Instream Flow Request


November Mean Daily Flow Duration
Dead Indian Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
35
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence


December Mean Daily Flow Duration
Dead Indian Creek Study Segment
Unappropriated Flow
Instream Flow Request
Discharge (cfs)
30
25
20
15
10
5
0
0%
20%
40%
60%
80%
100%
Percent Exceedence

APPENDIX B

CONCURRENT DISCHARGE

Measured flow values used in the concurrent discharge method are presented below. See section 1.6.1 for a description of the method.

MUDDY CREEK

Direct Discharge Measurement Date	Soda Butte Reference Gauge	Muddy Cr Study Segment	Data Source
7/10/2014	445.6	30.0	WGFD
7/27/2014	87.7	7.8	WGFD
8/14/2014	41.1	4.2	WGFD
9/27/2014	26.9	3.4	WGFD
6/27/2017	507.7	32.9	Biota
7/5/2017	381.1	27.1	Biota
7/15/2017	210.2	13.3	Biota
7/25/2017	82.4	6.3	Biota
8/5/2017	47.3	3.1	Biota
8/15/2017	42.7	3.3	Biota
8/25/2017	25.2	2.4	Biota
9/5/2017	12.7	1.8	Biota
9/15/2017	25.2	2.4	Biota
9/25/2017	21.5	2.5	Biota
10/5/2017	23.1	2.6	Biota
10/15/2017	16.5	2.0	Biota
6/5/2018	705.0	124.7	Biota
6/15/2018	513.0	66.2	Biota
6/25/2018	485.0	44.9	Biota
7/5/2018	323.0	22.0	Biota
7/15/2018	207.0	9.7	Biota
7/25/2018	91.3	4.4	Biota
8/5/2018	58.1	3.0	Biota
8/15/2018	33.1	2.4	Biota
8/25/2018	19.3	1.9	Biota
9/5/2018	13.1	1.9	Biota
9/15/2018	8.4	2.1	Biota
9/25/2018	6.2	1.9	Biota
10/5/2018	10.4	2.0	Biota

CRANDALL CREEK

Direct Discharge Measurement Date	Sunlight Cr Reference Gauge	Crandall Cr Study Segment	Data Source
7/25/2014	gauge offline	177.0	WGFD
8/16/2014	gauge offline	80.0	WGFD
9/26/2014	gauge offline	66.0	WGFD
6/27/2017	688.1	398.8	Biota
7/5/2017	661.7	340.3	Biota
7/15/2017	480.2	236.6	Biota
7/25/2017	301.6	158.9	Biota
8/5/2017	218.4	98.8	Biota
8/15/2017	147.3	87.9	Biota
8/25/2017	109.0	42.1	Biota
9/5/2017	89.0	26.1	Biota
9/15/2017	128.1	89.3	Biota
9/25/2017	118.7	95.3	Biota
10/5/2017	97.4	75.6	Biota
7/6/2018	442.1	gauge offline	Biota
7/15/2018	375.0	gauge offline	Biota
7/25/2018	292.9	gauge offline	Biota
8/5/2018	197.1	gauge offline	Biota
8/15/2018	156.0	56.8	Biota
8/25/2018	109.3	39.8	Biota
9/5/2018	84.7	33.0	Biota
9/15/2018	74.8	25.6	Biota
9/25/2018	65.9	23.4	Biota
10/5/2018	59.5	46.0	Biota

DEAD INDIAN CREEK

Direct Discharge Measurement Date	Sunlight Cr Reference Gauge	Dead Indian Cr Study Segment	Data Source
7/24/2014	n/a	117.0	WGFD
8/15/2014	n/a	67.0	WGFD
9/11/2014	n/a	42.0	WGFD
9/27/2014	n/a	36.0	WGFD
6/27/2017	688.1	122.1	Biota
7/5/2017	661.7	116.4	Biota
7/15/2017	480.2	105.5	Biota
7/25/2017	301.6	89.3	Biota
8/5/2017	218.4	80.4	Biota
8/15/2017	147.3	62.4	Biota
8/25/2017	109.0	52.5	Biota
9/5/2017	89.0	43.7	Biota
9/15/2017	128.1	53.4	Biota
9/25/2017	118.7	44.1	Biota
10/5/2017	97.4	41.4	Biota
7/5/2018	442.1	103.6	Biota
7/15/2018	375.0	99.5	Biota
7/25/2018	292.9	86.0	Biota
8/5/2018	197.1	66.0	Biota
8/15/2018	156.0	54.0	Biota
8/25/2018	109.3	44.1	Biota
9/5/2018	84.7	38.9	Biota
9/15/2018	74.8	30.9	Biota
9/25/2018	65.9	29.7	Biota
10/5/2018	59.5	26.5	Biota