Alaska Department of Environmental Conservation
555 Cordova Street
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DRAFT Total Maximum Daily Load for Turbidity in the Crooked Creek Watershed (Crooked Creek, Boulder Creek, Deadwood Creek and Ketchum Creek) near Central, Alaska

February 2019

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TABLES

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ACRONYMS

AAC	Alaska Administrative Code
ACWA	Alaska Clean Water Action
ADEC	Alaska Department of Environmental Conservation
ADNR	Alaska Department of Natural Resources
ADOT&PF	Alaska Department of Transportation and Public Facilities
APDES	Alaska Pollutant Discharge Elimination System
APMA	Application for Permits to Mine in Alaska
BLM	Bureau of Land Management
BMP	Best Management Practice
CFR	Code of Federal Regulations
cfs	cubic feet per second
CGP	Construction General Permit
CWA	Clean Water Act
EPA	United States Environmental Protection Agency
°F	degrees Fahrenheit
GIS	geographic information system
GP	general permit
km	kilometers
LA	Load Allocation
List	303(d) list
mg/L	milligrams per liter
mm	millimeters
MOS	Margin of Safety
MRLCC	Multi-Resolution Land Characteristics Consortium
MS4	Municipal Separate Storm Sewer System
MSGP	Multi-Sector General Permit
NLCD	National Land Cover Database
NPDES	EPA’s National Pollutant Discharge Elimination System
NRCS	Natural Resources Conservation Service
NTU	nephelometric turbidity unit
STATSGO	State Soil Geographic Data Base
SWPPP	Stormwater Pollution Prevention Plan
TMDL	Total Maximum Daily Load
TSS	total suspended solids
USACE	United States Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WLA	Wasteload Allocation
WQC	water quality criteria
WQS	water quality standards

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Total Maximum Daily Load (TMDL) for Turbidity in the Crooked Creek Watershed, Alaska

TMDL at a Glance

Water Quality Limited?	Yes
Alaska ID Number:	40402-010
Criteria of Concern:	Turbidity
Designated Uses Affected:	(1) Water supply, (2) water recreation and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife
Environmental Indicator:	Total suspended solids
Major Source(s):	Placer mining
Loading Capacity:	Varies by month, see table below
Wasteload Allocation:	Varies by month and source, see table below
Load Allocation:	Varies by month, see table below
Margin of Safety:	Implicit and explicit (5 percent), see table below
Future Wasteload Allocation:	Varies by month and source, see table below
Necessary Reductions:	Varies by month; see table below

Total suspended solids (TSS) numeric targets by month and storm-related conditions

Parameter (units)	Numeric Targets					
	Storm-related	Last week of May	June	July	August	September
TSS (mg/L)	108.9	6.4	6.4	7.8	7.5	7.1

Note: TSS calculated from turbidity threshold values based on the water quality criteria; mg/L = milligrams per liter

TMDL allocation summary for TSS in Crooked Creek subwatershed (not including Boulder, Deadwood and Ketchem Creeks)

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	374,878.7	18,743.9	212.0	320,309.3	35,613.5
Last week of May	13,926.4	696.3	7.9	11,899.2	1,323.0
June	8,690.3	434.5	4.9	7,425.3	825.6
July	10,218.5	510.9	5.8	8,731.1	970.8
August	10,902.8	545.1	6.2	9,315.7	1,035.8
September	8,403.3	420.2	4.8	7,180.0	798.3

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

TMDL allocation summary for TSS in Boulder Creek

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	31,010.1	1,550.5	27.8	26,485.9	2,946.0
Last week of May	1,815.9	90.8	1.6	1,551.0	172.5
June	1,382.1	69.1	1.2	1,180.4	131.3
July	2,014.9	100.7	1.8	1,720.9	191.4
August	1,690.1	84.5	1.5	1,443.5	160.6
September	1,192.7	59.6	1.1	1,018.7	113.3

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

TMDL allocation summary for TSS in Deadwood Creek

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	37,698.1	1,884.9	56.2	32,175.6	3,581.3
Last week of May	2,178.2	108.9	3.3	1,859.1	206.9
June	1,694.9	84.7	2.5	1,446.7	161.0
July	2,461.4	123.1	3.7	2,100.8	233.8
August	1,905.4	95.3	2.8	1,626.3	181.0
September	1,430.6	71.5	2.1	1,221.1	135.9

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

TMDL allocation summary for TSS in Ketchem Creek

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	12,485.4	624.3	17.3	10,657.7	1,186.1
Last week of May	1,191.2	59.6	1.7	1,016.9	113.2
June	721.1	36.1	1.0	615.5	68.5
July	986.7	49.3	1.4	842.3	93.7
August	1,047.6	52.4	1.5	894.3	99.5
September	767.8	38.4	1.1	655.4	72.9

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

Executive Summary

Total Maximum Daily Loads (TMDLs) are established in this document to meet the requirements of Section 303(d)(1)(C) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 Code of Federal Regulations Part 130), which require the establishment of a TMDL for the achievement of water quality standards (WQS) when a waterbody is water quality-limited. This report establishes TMDLs to address turbidity impairments in the Crooked Creek watershed, specifically Crooked Creek, Boulder Creek, Deadwood Creek and Ketchem Creek.

The Crooked Creek watershed, with an area of nearly 350 square miles, is approximately 100 miles northeast of Fairbanks, Alaska. Nearby towns include Central and Circle, Alaska. Alaska's Department of Environmental Conservation (ADEC) first included the Crooked Creek watershed on the CWA section 303(d) list as impaired for turbidity in 1992. ADEC identified seven creeks in the watershed as impaired and placer mining was identified as a known pollutant source. The impaired creeks listed were the mainstem of Crooked Creek and six tributaries from the south: Porcupine, Bonanza, Mammoth, Mastodon, Deadwood, and Ketchem creeks.

Since the original 1992 listing, ADEC collected additional data (in 2014, 2016 and 2017) and developed a new listing methodology for determining turbidity impairments (ADEC 2016a). The data collection project included all of the impaired creeks as well as a reference creek (Bedrock Creek) and another tributary to Crooked Creek with historical flow information (Boulder Creek). The 2016 ADEC turbidity listing methodology requires at least two years of data for the impairment analysis and a reference creek to establish the natural background condition.

The turbidity listing methodology was originally used with the 2014-2016 dataset to assess the impairment status of the seven creeks listed as impaired on the 303(d) list of impaired waters and Boulder Creek against the reference creek, Bedrock. In 2016, Alaska Department of Environmental Conservation determined Boulder and Deadwood Creeks as impaired for turbidity based on the data analysis and decided to proceed with the development of TMDLs; however, ADEC postponed impairment decisions on the other creeks in the watershed (Crooked, Porcupine, Bonanza, Mammoth, Mastodon, and Ketchem creeks) identified in the 303(d) list based on the need for additional data collection. ADEC collected and analyzed the additional data during 2017.

ADEC determined that Crooked Creek and Ketchem Creek were also impaired for turbidity and in need of TMDLs based on the additional data collected in 2017. The TMDLs established in this report will address these impairments. ADEC completed turbidity TMDLs for Boulder and Deadwood creeks in May 2018 (ADEC 2018) and EPA approved these TMDLs in June 2018. However, Boulder Creek and Deadwood Creek TMDLs have been revised based on revisions to the TMDL targets using the most recent data. These revisions will support a watershed-based TMDL approach and keep the TMDL targets for Boulder and Deadwood creeks consistent with the targets for Crooked Creek and Ketchem Creek. The updated Boulder Creek and Deadwood Creek TMDLs are also included in this TMDL document. The 2017 data also indicated that Porcupine, Bonanza, Mammoth and Mastodon creeks are not impaired for turbidity and should be proposed for delisting.

TMDL Development

A TMDL represents the amount of a pollutant the waterbody can assimilate while maintaining compliance with applicable WQS. A TMDL is composed of the sum of individual wasteload allocations (WLAs) for point sources of pollution and load allocations (LAs) for nonpoint sources of pollution and natural background loads. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody. A TMDL may include an allocation for future sources.

Applicable WQS for turbidity in Crooked, Boulder, Deadwood and Ketchem creeks establish water quality criteria (WQC) for the protection of designated uses for water supply, water recreation, and growth and propagation of fish, shellfish, other aquatic life, and wildlife. All designated uses must be addressed unless specifically exempted in Alaska, therefore, the TMDL is required to be developed for the most stringent turbidity criterion, which protects the water recreation use. This criterion states that turbidity may not exceed 5 nephelometric turbidity units (NTU) above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10 percent increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU (18 AAC 70.020(b)(12)(B)(i)).

The turbidity criteria require determination of background/natural turbidity values. Turbidity data from Bedrock Creek were used to establish the natural condition and to calculate turbidity threshold values based on the applicable WQC. Bedrock Creek was selected to determine background/natural conditions because of minimal mining disturbance and a lack of current mining activity. In addition, the Bedrock Creek drainage is topographically and geographically representative of the area as it is located in the middle of the Crooked Creek watershed with similar geology to Crooked, Boulder, Deadwood and Ketchem creeks. Flow and seasonal conditions affect turbidity measurements; therefore, threshold values are based on background conditions present during each month that vary with flow conditions (after spring break-up).

Numeric Targets

The WQC for turbidity are not conducive to the calculation of pollutant loads that are typically used in TMDLs. Therefore, the TMDL numeric targets are expressed as total suspended solids (TSS) concentrations (which do measure mass in a volume of water), using correlations based on watershed-specific data. Turbidity and TSS show a strong correlation in the watershed, which makes TSS an appropriate surrogate for turbidity.

The data were separated into lower turbidity values (less than 15 NTU) and higher measurements (equal to or above 15 NTU) to better reflect the range of conditions observed in the watershed. Correlations were then evaluated for the lower and higher turbidity values and their corresponding TSS measurements. The data were separated at 15 NTU because there was a cluster of measurements below this cutoff that had a shallower slope compared to the measurements above this value, which showed greater variability and a steeper slope. Overall, there is a strong correlation between turbidity and TSS samples collected at the same time throughout the watershed ($R^2 = 0.64$ for turbidity values less than 15 NTU and $R^2 = 0.7$ when turbidity is equal to or above 15 NTU).

The equations derived from the relationships between actual turbidity samples and TSS were used to estimate sediment concentrations as a surrogate for the turbidity threshold values established at Bedrock Creek based on the WQC for each of the open water months and storm-related conditions. Based on the evaluation of data at Bedrock Creek, the turbidity-TSS relationship for turbidity values greater than 15 NTU was used to calculate the storm-related numeric target and the relationship for turbidity less than 15 NTU was used for other conditions. The target TSS concentrations were combined with flow values to determine existing monthly loads and the monthly sediment loading capacity. TSS numeric targets are summarized in the table below for the last week of May through September as well as for storm-related conditions. The targets only apply after spring break up and before the waterbodies freeze in autumn (i.e., when there is flowing water).

TSS numeric targets by month and for storm-related conditions

Parameter (units)	Numeric Targets					
	Storm-related	Last week of May	June	July	August	September
TSS (mg/L)	108.9	6.4	6.4	7.8	7.5	8.1

Note: TSS calculated from turbidity threshold values based on the water quality criteria; mg/L = milligrams per liter

Load Allocation

The TMDLs were based on a load duration curve approach, which was used to evaluate the relationships between season, hydrology, and water quality and to calculate the TSS loading capacity. The load duration curve approach involves calculating the allowable loadings (loading capacity) in the impaired stream by multiplying each flow value by the numeric target for a contaminant. Each water quality sample is converted to a load by multiplying the TSS sample concentration by the average daily flow on the day the sample was collected. The loads are plotted as points on the TMDL curve and can be compared to the allowable loads. Points plotting above the curve represent deviations from the daily allowable load. Points plotting below the curve represent compliance with the daily allowable load. The load duration curve was also used to characterize water quality concentrations and loads by flow regime. These results were then summarized by month and condition using the median load for the TMDL calculations.

Potential Turbidity Sources and TMDL Allocation Summary

Potential sources of turbidity in the Crooked Creek watershed include point sources (such as discharges from active placer mines and/or dredge or fill material permits) and nonpoint sources (such as runoff from historical placer mine sites). These sources receive wasteload and load allocations, respectively, in the TMDL. WLAs are also provided for future growth. Individual point source WLAs are included for each permitted mine draining to Crooked, Boulder, Deadwood and Ketchem creeks. The tables below summarize the overall monthly loading capacity, MOS, WLAs (for current and future sources), and LAs. Section 5 discusses the methodology used to determine the allocations.

TMDL allocation summary for TSS in Crooked Creek subwatershed (not including Boulder, Deadwood and Ketchem creeks)

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	374,878.7	18,743.9	212.0	320,309.3	35,613.5
Last week of May	13,926.4	696.3	7.9	11,899.2	1,323.0
June	8,690.3	434.5	4.9	7,425.3	825.6
July	10,218.5	510.9	5.8	8,731.1	970.8
August	10,902.8	545.1	6.2	9,315.7	1,035.8
September	8,403.3	420.2	4.8	7,180.0	798.3

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

TMDL allocation summary for TSS in Boulder Creek

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	31,010.1	1,550.5	27.8	26,485.9	2,946.0
Last week of May	1,815.9	90.8	1.6	1,551.0	172.5
June	1,382.1	69.1	1.2	1,180.4	131.3
July	2,014.9	100.7	1.8	1,720.9	191.4
August	1,690.1	84.5	1.5	1,443.5	160.6
September	1,192.7	59.6	1.1	1,018.7	113.3

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

TMDL allocation summary for TSS in Deadwood Creek

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	37,698.1	1,884.9	56.2	32,175.6	3,581.3
Last week of May	2,178.2	108.9	3.3	1,859.1	206.9
June	1,694.9	84.7	2.5	1,446.7	161.0
July	2,461.4	123.1	3.7	2,100.8	233.8
August	1,905.4	95.3	2.8	1,626.3	181.0
September	1,430.6	71.5	2.1	1,221.1	135.9

Note: lbs/day = pounds per day, WLA = wasteload allocation; LA = load allocation; * Individual WLAs provided in TMDL section 5.3.

TMDL allocation summary for TSS in Ketchem Creek

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	12,485.4	624.3	17.3	10,657.7	1,186.1
Last week of May	1,191.2	59.6	1.7	1,016.9	113.2
June	721.1	36.1	1.0	615.5	68.5
July	986.7	49.3	1.4	842.3	93.7
August	1,047.6	52.4	1.5	894.3	99.5
September	767.8	38.4	1.1	655.4	72.9

* Individual WLAs provided in Section 5.

Existing TSS loads in Crooked Creek (90th percentile of all data) ranged from 23,019 pounds per day (lbs/day) in August to 145,757 lbs/day in May, while storm-related loads were estimated at 1,896,370 lbs/day. TSS load reductions range between 32 and 87 percent to meet the TMDL targets from the last week of May through September.

Existing TSS loads in Boulder Creek (90th percentile of all data) ranged from 1,288 pounds per day (lbs/day) in May to 40,042 lbs/day in September, while storm-related loads were estimated at 169,089 lbs/day. TSS load reductions range between zero and 97 percent to meet the TMDL targets from the last week of May through September.

Existing TSS loads in Deadwood Creek (90th percentile of all data) ranged from 3,188 lbs/day in May to 15,705 lbs/day in July. Storm-related sediment loads to Deadwood Creek were estimated at 112,261 lbs/day. TSS loads reductions range between 32 and 86 percent to meet the TMDL targets during the last week of May through September.

Existing TSS loads in Ketchem Creek (90th percentile of all data) ranged from 1,101 lbs/day in September to 16,673 lbs/day in July. Storm-related sediment loads to Ketchem Creek were estimated at 99,770 lbs/day. TSS load reductions range between 30 and 94 percent to meet the TMDL targets during the last week of May through September. See Table 5-7 in Section 5 for more details.

TMDL Implementation

Reducing turbidity in the Crooked Creek watershed will involve efforts to control point source and nonpoint source inputs through implementation of best management practices (BMPs) such as miner education and outreach, revegetation and erosion control measures. Follow-up monitoring is recommended to further evaluate sources, track the progress of TMDL implementation, evaluate BMP effectiveness, and track progress of the water quality of Crooked, Boulder, Deadwood and Ketchem creeks toward attaining WQS, and determine whether TMDL assumptions are valid and targets are appropriate. Both the turbidity threshold values and TMDL TSS targets are shown in the table below. The threshold values for turbidity are equivalent to the numeric water quality criteria for turbidity, which were calculated using the median turbidity value for each month and storm-related conditions at the reference watershed, Bedrock Creek. Alaska's applicable WQC (for the contact recreation, which is the most stringent WQC) state that turbidity:

> *May not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than a 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU (contact recreation).*

All months measured at Bedrock Creek had median turbidity measurements below 50 NTU for baseflow and the storm conditions had median turbidity measurements above 50 NTU, therefore, the threshold turbidity values were calculated using the following equations:

Storm-related conditions: ***Median Bedrock Creek NTU + 10% NTU = Threshold Value***

May to September (after spring break-up): ***Median Bedrock Creek NTU + 5 NTU = Threshold Value***

The threshold turbidity values were then used to calculate TSS numeric target concentrations. Continued flow and water quality monitoring is recommended to track TMDL compliance.

Turbidity threshold values and TSS numeric targets

Parameter (units)	Storm-related[a]	Last week of May[b]	June[b]	July[b]	August[b]	September[b]
Turbidity (NTU)	58.6	5.4	5.4	6.8	6.5	6.0
TSS (mg/L)	108.9	6.4	6.4	7.8	7.5	7.1

[a]Storm-related tubidity threshold = median Bedrock Creek storm-related turbidity of 53.3NTU * 1.1 (10% increase).
[b]Monthly turbidity thresholds = median monthly turbidity at Bedrock Creek plus 5NTU (May: 0.4 + 5NTU; June: 0.4 + 5NTU; July: 1.8 + 5NTU; August: 1.5 + 5NTU; and September: 1 + 5NTU).

1. Overview

Section 303(d)(1)(C) of the Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations (40 CFR Part 130 [note: CFR is the Code of Federal Regulations]) require the establishment of a Total Maximum Daily Load (TMDL) to achieve state water quality standards (WQS) when a waterbody is water quality-limited. A TMDL identifies the amount of a pollutant that a waterbody can assimilate and still comply with applicable WQS. TMDLs quantify the amount a pollutant must be reduced to achieve a level (or "load") that allows a given waterbody to fully support its designated uses. TMDLs also include an appropriate margin of safety (MOS) to account for uncertainty or lack of knowledge regarding the pollutant loads and the response of the receiving water. The mechanisms used to address water quality problems after the TMDL is developed can include monitoring and a combination of best management practices (BMPs) for nonpoint sources and/or effluent limits required through EPA's National Pollutant Discharge Elimination System (NPDES) permits (or in Alaska, the Alaska Pollutant Discharge Elimination System [APDES] permits) for point sources.

Alaska's Department of Environmental Conservation (ADEC) first included the Crooked Creek watershed on the CWA Section 303(d) list as impaired for turbidity in 1992. Table 1-1 summarizes the information included in the Alaska 2012 303(d) list (List) for the Crooked Creek watershed (ADEC 2013a). Alaska identified seven creeks in the watershed as impaired and identified placer mining as the known pollutant source.

Table 1-1. Crooked Creek section 303(d) listing information from ADEC's 2012 Integrated Report

Alaska ID Number	Waterbody*	Area of Concern	Water Quality Standard	Pollutant Parameters	Pollutant Sources
40402-010	Crooked Creek Watershed: • Bonanza Creek • Crooked Creek • Deadwood Creek • Ketchem Creek • Mammoth Creek • Mastodon Creek • Porcupine Creek	77 miles	Turbidity	Turbidity	Placer Mining
*In Alaska's 2014/2016 Integrated Report each creek in the Crooked Creek watershed were assigned their own Alaska ID number as follows: Bonanza Creek AK-80401-001 – 4.6 miles; Crooked Creek AK-80401-010 – 28.9 miles; Deadwood Creek AK-80401-010 – 18.9 miles; Ketchem Creek AK-80401-005 – 4.9 miles; Mammoth Creek AK-80401-006 – 4.4 miles; Mastodon Creek AK-80401-002 – 4.9 miles; and Porcupine Creek AK-80401-003 – 12.4.					

Source: ADEC 2013a

ADEC conducted a water quality assessment, *Crooked Creek Water Quality Assessment* (ADEC 1995), that found that the majority of the WQS exceedances at that time were related to runoff during storm events as well as occasional violations of APDES permit conditions for active mines. However, there were major improvements in water quality since the 1980s, mostly as a result of APDES permit limitations on settleable solids and placer mine industry cooperation, as well as enforcement and a field presence (ADEC 1995).

Since the original listing and the 1995 assessment, ADEC collected additional data and developed a new listing methodology to determine turbidity impairments (ADEC 2016a). When applying recent data (collected in 2014, 2016 and 2017) to the new listing methodology, Alaska confirmed that Crooked, Ketchem and Deadwood creeks were impaired and identified Boulder Creek (a waterbody not included on the 303(d) List) as impaired. In addition, Bedrock Creek was identified as an appropriate reference watershed (Figure 1-1).

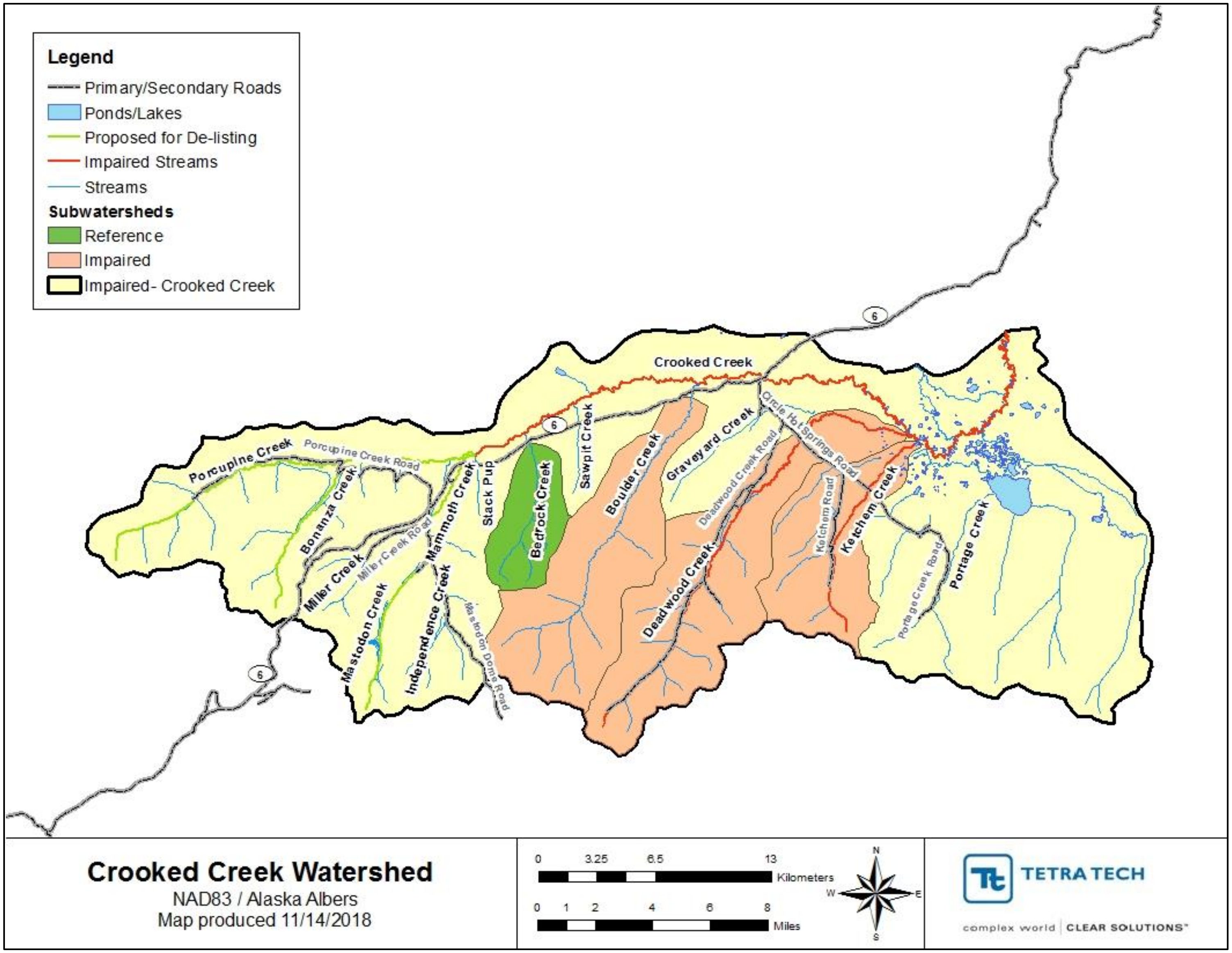


Figure 1-1. Turbidity impairments and reference watershed in the Crooked Creek watershed

ADEC completed TMDLs for Boulder and Deadwood creeks in May 2018 and EPA approved these TMDLs in June 2018. However, the Boulder Creek and Deadwood Creek TMDLs have been revised based on revisions to the TMDL targets using the most recent data. These revisions support a watershed-based TMDL approach and keep the TMDL targets for Boulder and Deadwood creeks consistent with the targets for Crooked Creek and Ketchem Creek. The updated Boulder Creek and Deadwood Creek TMDLs are included in this TMDL document. Additional TMDLs are required for Crooked and Ketchem creeks. This document includes TMDLs for Crooked, Boulder, Deadwood and Ketchem creeks. Based on the water quality data collected in 2014, 2016 and 2017, the other creeks in the watershed on Alaska's 303(d) list of impaired waters (Porcupine, Bonanza, Mammoth and Mastodon creeks) will be proposed for de-listing.

1.1. Location and Identification of TMDL Study Area

The impaired waterbodies of Crooked, Boulder, Deadwood and Ketchem creeks and the reference waterbody, Bedrock Creek, are located within the Crooked Creek watershed. The Crooked Creek watershed is approximately 100 miles northeast of Fairbanks, Alaska. Nearby towns include Central and Circle, Alaska (Figure 1-2). The study area of interest is 343.8 square miles and includes Crooked Creek and the tributaries draining to the creek from the south. These tributaries include Boulder, Deadwood and Ketchem creeks, which are included in this TMDL document, the reference watershed (Bedrock Creek), and the creeks will be proposed for de-listing (Porcupine, Bonanza, Mammoth, and Mastodon creeks). Downstream of these tributaries, Albert, Big Mosquito, and Quartz creeks flow into Crooked Creek from the north, eventually draining into Birch Creek. There are no impaired waterbodies downstream of Crooked Creek. Crooked Creek flows into Birch Creek, which is a Wild and Scenic River.

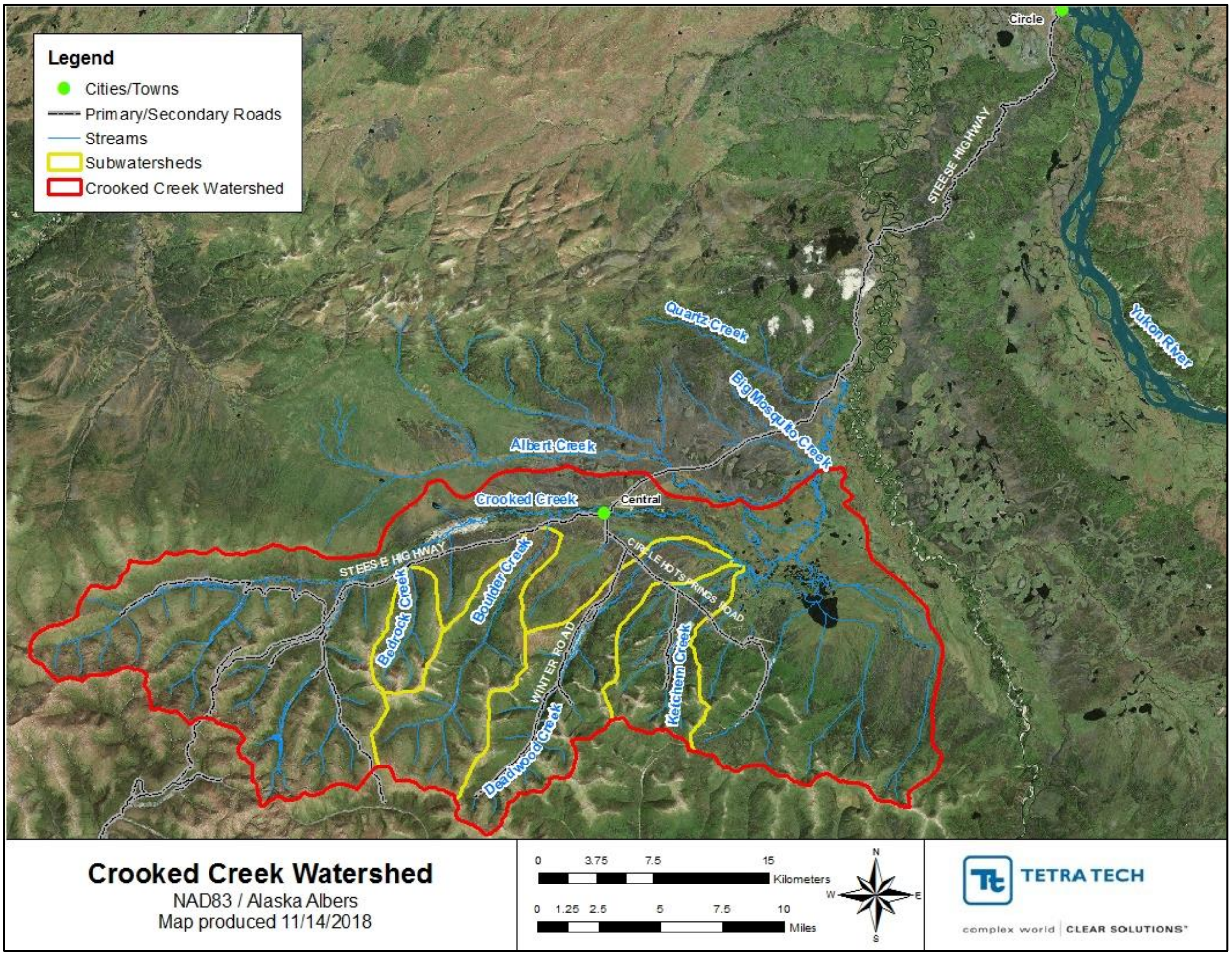


Figure 1-2. Location of the Crooked Creek watershed

Crooked Creek is formed at the confluence of Mammoth and Porcupine creeks, where it has a fairly high gradient and fast flow. It spreads out to a wider, slower moving stream farther downstream near the confluence with Birch Creek (ADEC 2013b). According to a study by Weber (1986), the average substrate size in the upper portion of Crooked Creek is greater than in the lower portion and the upper portion is also less embedded (Weber 1986). Boulder Creek flows northeast as it crosses the Hot Springs fault and then enters the Tintina Fault trench where it meets Crook Creek (Yeend 1991). Deadwood Creek also flows northeast through a valley until it enters the Tintina Fault trench where the valley flattens out into a broad fan before the creek flows into Crooked Creek (Yeend 1991). Ketchem Creek flows northeast, draining the north slope of Ketchem Dome (Yeend 1991). The creek flows out of the highlands and crosses the Hot Springs fault where it flows into a wetland area northeast of Medicine Lake and finally flows into Crooked Creek.

1.2. Population

Population in the Crooked Creek watershed is low, with less than one percent of the watershed designated as developed land in the 2001 U.S. Geological Survey (USGS) National Land Cover Database (NLCD). The town of Central is located in the watershed and the town of Circle is nearby (Figure 1-2). Central and Circle, Alaska are located in the Yukon-Koyukuk census area. The U.S. Census indicates that the population of Central was 96 in the year 2010, while the population in Circle was 104 (U.S. Census Bureau 2017).

1.3. Topography

The Crooked Creek watershed is located in the Yukon-Tanana Upland physiographic province, which consists of rounded hills surrounding a high central area of rugged mountains (USGS 1994). Crooked Creek is formed at the confluence of Porcupine and Mammoth creeks near Porcupine (4,915 feet elevation) and Mastodon (4,418 feet elevation) domes. Crooked Creek flows for 26 miles from its headwaters to its confluence with Birch Creek at an elevation of 400 feet.

1.4. Land Cover and Land Use

The region is highly mineralized. The surrounding area, Circle Mining District, has been placer mined for nearly 100 years. Mining activities are predominantly in the southern half of the watershed, along Crooked Creek and its tributaries. Due to mining activities, the stream channels are characterized by a loss of riparian vegetation and associated soils.

Land cover data were obtained from the 2001 Multi-Resolution Land Characteristics Consortium (MRLCC) NLCD. The NLCD data are based on satellite imagery from 2001. The predominant land cover in the Crooked Creek drainage is forest and shrub (Figure 1-3 and Table 1-2; Homer et al. 2015). Developed areas make up a very small portion of the watershed and are primarily located in the center of the watershed near the town of Central, Alaska. Crooked, Boulder, Deadwood and Ketchem creeks are the focus of this TMDL as they have confirmed turbidity impairments and Bedrock Creek represents natural conditions in the watershed (see Section 2.4.1). Similar to the overall watershed, shrub and evergreen forest dominate the landscape in the Boulder, Deadwood and Ketchem creeks' subwatersheds (Figure 1-3 and Table 1-2) presents land use areas for the entire Crooked Creek watershed as well as the portion of the Crooked Creek watershed receiving allocations outside of the subwatersheds of Boulder, Deadwood and Ketchem creeks. This area represents the Crooked Creek watershed land use areas minus the areas for Boulder, Deadwood and Ketchem creeks, which each have their own individual TMDLs. See section 5.2 for more detail.

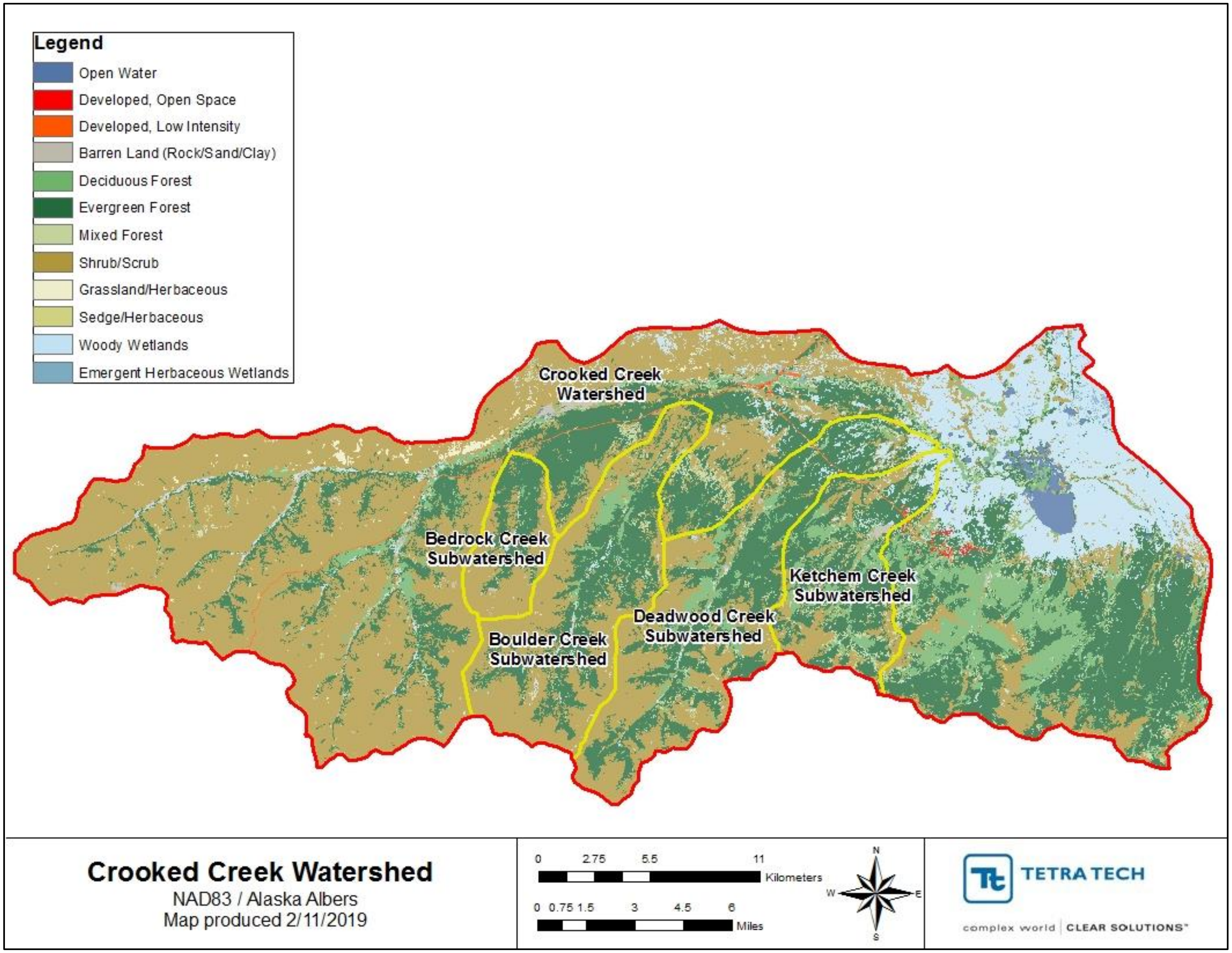


Figure 1-3. Land cover in the Crooked Creek watershed (Source: NLCD 2001)

Table 1-2. Land cover in the Crooked Creek watershed (NLCD 2001)

Land Cover	Entire Crooked Creek watershed		Bedrock Creek subwatershed		Crooked Creek subwatershed (not including Boulder, Deadwood and Ketchem creeks)[a]		Boulder Creek subwatershed		Deadwood Creek subwatershed		Ketchem Creek subwatershed	
	Area (acres)	Percent Cover (%)	Area (acres)	Percent Cover (%)	Area (acres)	Percent Cover (%)	Area (acres)	Percent Cover (%)	Area (acres)	Percent Cover (%)	Area (acres)	Percent Cover (%)
Open Water	1,890	0.9	0.0	0.0	1,876	1.2	0.0	0.0	3.7	0.01	11	0.1
Developed, Open Space	139	0.1	0.0	0.0	130	0.1	0.0	0.0	0.0	0.0	10	0.1
Developed, Low Intensity	643	0.3	0.0	0.0	558	0.3	10	0.1	26	0.1	49	0.4
Barren Land (Rock/Sand/Clay)	1,412	0.6	44	0.7	1,170	0.7	35	0.2	72	0.3	136	1.0
Deciduous Forest	17,457	7.9	74	1.2	12,426	7.8	974	4.6	2,156	8.5	1,900	13.9
Evergreen Forest	66,533	30.2	2,391	37.7	41,739	26.2	7,449	35.1	10,702	42.0	6,642	48.5
Mixed Forest	6,218	2.8	43	0. 7	4,171	2.6	509	2.4	684	2.7	853	6.2
Dwarf Shrub/Scrub	101,337	46.1	3,742	60.0	75,269	47.2	11,946	56.3	10,778	42.3	3,344	24.4
Grassland/Herbaceous	879	0.4	1	0.02	875	0.5	4	0.02	0.0	0.0	0	0.0
Sedge/Herbaceous	532	0.2	3	0.1	385	0.2	36	0.2	74	0.3	37	0.3
Woody Wetlands	22,382	10.2	46	0.7	20,433	12.8	254	1.2	969	3.8	726	5.3
Emergent Herbaceous Wetlands	582	0.3	0.0	0.0	578	0.4	0.0	0.0	4	0.01	0	0.0
Total	**220,004**	**100**	**6,344**	**100**	**159,610**	**100**	**21,217**	**100**	**25,469**	**100**	**13,708**	**100**

[a]This area represents the Crooked Creek watershed land use areas minus the areas for Boulder, Deadwood and Ketchem creeks, which have their own individual TMDLs.

1.5. Soils and Geology

1.5.1. Soils

Data from the Natural Resources Conservation Service (NRCS) were used to characterize soils in the Crooked Creek watershed. General soils data and map unit delineations are available through the State Soil Geographic Data Base (STATSGO). A map unit is composed of several soil series having similar properties. Identification fields in the geographic information system (GIS) coverages can be linked to a database that provides information on chemical and physical soil characteristics. Figure 1-4 shows the map units present in the Crooked Creek watershed. Bedrock Creek consists mostly of map unit s9332, while Boulder and Deadwood creeks consist mostly of map unit s9365 and Ketchem Creek consists mostly of map unit s9366. All three soil types tend to be gravelly and hilly to steep. The entire Crooked Creek watershed consists of large portions of map units s9332 and s9366 as in the Bedrock and Ketchem subwatersheds, as well as map units s9252 and s9269. These soils types are typically located downstream and in the lower portions of Bedrock and Ketchem creeks, respectively, and tend to be loamy and nearly level to rolling.

The hydrologic soil group classification is a means for grouping soils by similar infiltration and runoff characteristics during periods of prolonged wetting. Typically, clay soils that are poorly drained have lower infiltration rates, while sandy soils that are well drained have the greatest infiltration rates. The NRCS has defined four hydrologic groups for soils (Table 1-3). All soils in the Crooked Creek watershed are dominated by hydrologic soil group D, which typically consist of clay soils that hold water and can be shallow over an impermeable layer.

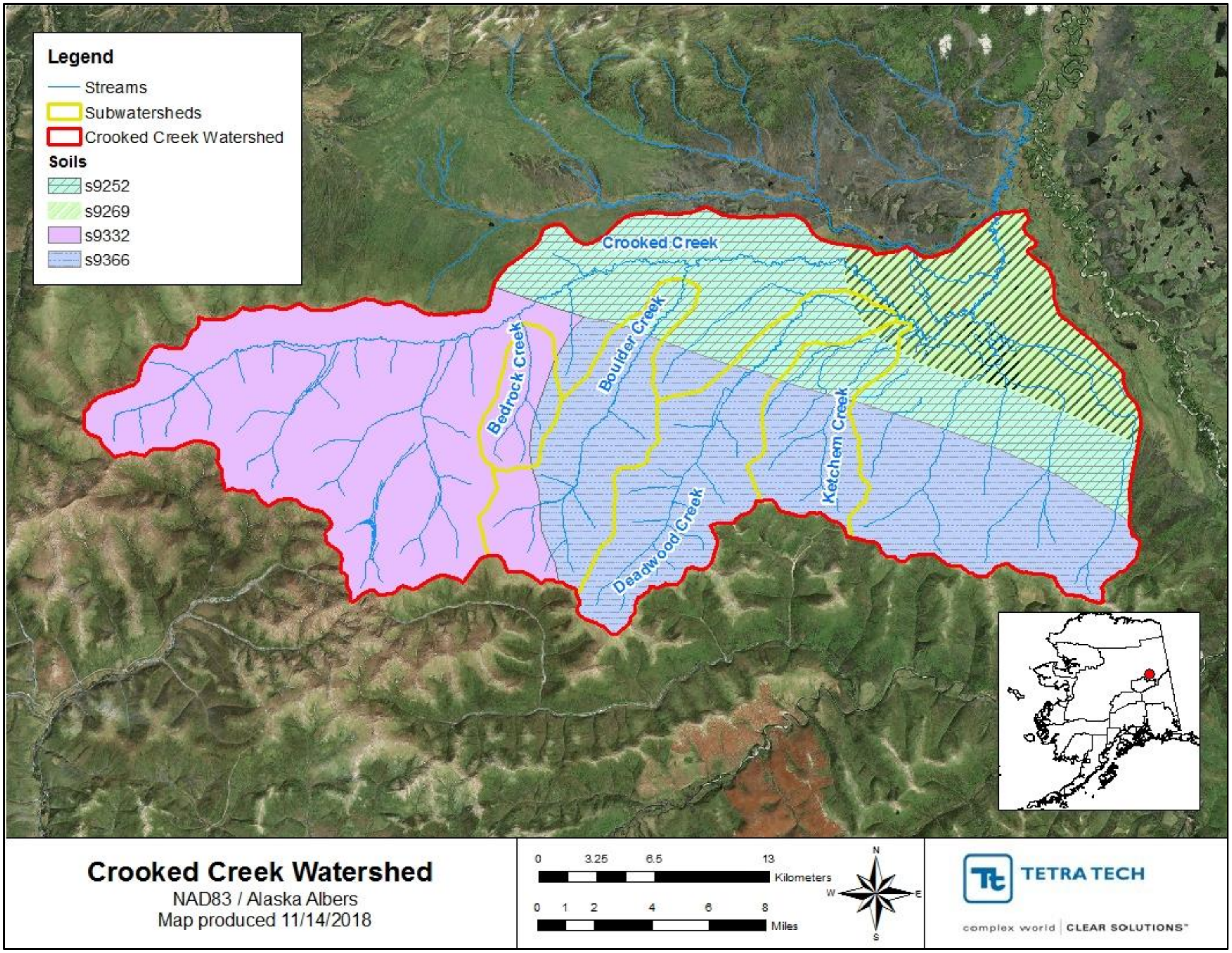


Figure 1-4. Soil map units in the Crooked Creek watershed (Source: NRCS, n.d.)

Table 1-3. Characteristics of hydrologic soil groups

Soil group	Characteristics	Minimum infiltration capacity (inches/hour)
A	Sandy, deep, well-drained soils; deep loess; aggregated silty soils	0.30 to 0.45
B	Sandy loams, shallow loess, moderately deep and moderately well-drained soils	0.15 to 0.30
C	Clay loam soils, shallow sandy loams with a low permeability horizon impeding drainage (soils with a high clay content), soils low in organic content	0.05 to 0.15
D	Heavy clay soils with swelling potential (heavy plastic clays), water-logged soils, certain saline soils, or shallow soils over an impermeable layer	0.00 to 0.05

Source: NRCS 1972

1.5.2. Geology

The Crooked Creek watershed is located in the Circle Mining District and is a desirable location for gold mining. Figure 1-5 shows the geology in the watershed. The geology narrative below is summarized from *Gold Placers of the Circle District, Alaska – Past, Present, and Future* (Yeend 1991). The Circle Mining District contains granite, quartzite, quartzite schist, and mafic schist overlain by colluvium, gravel, fan deposits, silt, organic material, and several ages of gold-bearing gravel. The mafic schist appears to be the bedrock source of the gold.

The Tintina fault zone, which crosses the northeast edge of the Crooked Creek watershed, has a major effect on the geology in the Circle Mining District and the watershed itself. The fault zone contains at least three ages of superimposed fan gravel including late Tertiary, late Pleistocene and Holocene, with the Holocene fan gravel being the most gold rich. The largest gold resource remaining in the Circle Mining District is likely in the lower reaches of Crooked Creek and in the alluvial fill within the Tintina fault zone. The Tintina fault zone trends northwest across the northern part of the district. The fault zone separates green schist- and amphibolite- facies metamorphic rocks on the south from weakly metamorphosed rocks on the north. Almost all gold produced in the district has come from south of the Tintina fault zone with some coming from within the fault trench. Both Boulder and Deadwood creeks are located south of the fault zone. The upstream portions of Crooked and Ketchem creeks are located south of the fault zone, while the lower portions of each creek are within the fault zone.

Mining in Crooked Creek has generally been confined to the 8 kilometers (km) (5 miles) of the creek downstream of where the Hot Springs fault crosses Crooked Creek. Quartzitic schist is present upstream from the Hot Springs fault and along the upstream tributaries, while a small granite outcrop is present upstream along Mammoth Creek. A pebble count in Crooked Creek approximately 4 km (2.5 miles) downstream from the Hot Springs fault found a composition of 43 percent quartz-mica schist, 32 percent quartzite, 21 percent quartz, and 4 percent weathered granite. Gold-bearing gravel approximately 2 to 5 meters (7 to 16 feet) thick overlies a clay-rich, altered cobble gravel.

Boulder Creek was likely named for the large boulders of granite in the creek bottom where it crosses a granite outcrop. Boulder Creek and its north-flowing tributaries Slate Creek, Greenhorn Gulch, and Boulder Pup have headwaters in the mafic schist bedrock. Downstream, the creek cuts through both quartzite schist and granite before crossing the Hot Springs fault and entering the Tintina fault trench.

Deadwood Creek is one of the most productive mining areas in the Circle Mining District. Deadwood Creek enters the Tintina fault trench at its intersection with the Hot Springs fault where the valley flattens into a broad fan. The creek meanders through this area before its confluence with Crooked Creek. Placer mining has occurred almost exclusively along the part of the creek that is south of the fault zone. The three principal rock types in the Circle Mining District (mafic schist, quartzite and quartzitic schist, and granite) are well represented in the Deadwood Creek area. Mafic schist is present in the uppermost 5 kilometers (km), quartzite and quartzitic schist crop out in the middle 4 km, and granite crops out in the lower 6 km of the stream valley, south of its intersection with the Hot Springs fault.

Ketchem Creek differs from the other gold-rich creeks in the Circle Mining District because most of its drainage basin, south of the Tintina fault zone, is within granite. Most mining on Ketchem Creek has been done south of the fault. The area exposed by mining is marked by orange clay-rich gravel. Cassiterite grains in a greisen matrix are located within the granite of the Ketchem Creek subwatershed. The largest and most developed greisen vein is approximately 1 meter wide and runs northwest. An east-trending mafic dike intrudes the granite on the east side of Ketchem Creek about a quarter of a mile above its confluence with Holdem Creek. The middle part of Ketchem Creek consists of a coarse-grained porphyritic granite, and granite outcrops are common on the low hills to the northwest. Quartzite and quartzitic schist crop out near the headwaters of Ketchem Creek.

Bedrock Creek, the reference watershed, is one of the few streams in the Crooked Creek watershed where little to no mining has occurred (Yeend 1991; Mindat 2015). Bedrock Creek is surrounded by many gold-producing areas; however, the Bedrock Creek watershed is missing the mafic schist located in many of the surrounding waterbodies. All the creeks that have been mined in the Crooked Creek watershed have headwaters in the mafic schist unit, which may be the source of gold.

1.6. Climate

The climate in the Crooked Creek watershed is typical of interior Alaska with cold, dry winters and warm, short summers (USGS 1994). There are three climate stations in the Crooked Creek watershed – Central 2, Circle Hot Springs and Eagle Summit (Figure 1-6) (WRCC 2017; NWCC 2017). The weather data at the Circle Hot Springs station were used to summarize weather in the watershed because this station has the longest period of record (July 1935 through present).

From 1935 to June 2018, the temperature at Circle Hot Springs ranged from an average minimum of -48 degrees Fahrenheit (˚F) in January to an average maximum of 84˚F in July. The monthly temperatures over time are less extreme, although the average temperatures are below zero during the winter months. The average monthly precipitation ranges from 0.24 inches in March to 2 inches in July with an average annual precipitation amount of 9.7 inches. Average total monthly snowfall ranges from 0 inches in June, July and August to 11.3 inches in October with a total annual average of 47.9 inches. Figure 1-7 and Table 1-4 present a summary of monthly averages for rainfall, snowfall and temperature at the Circle Hot Springs station.

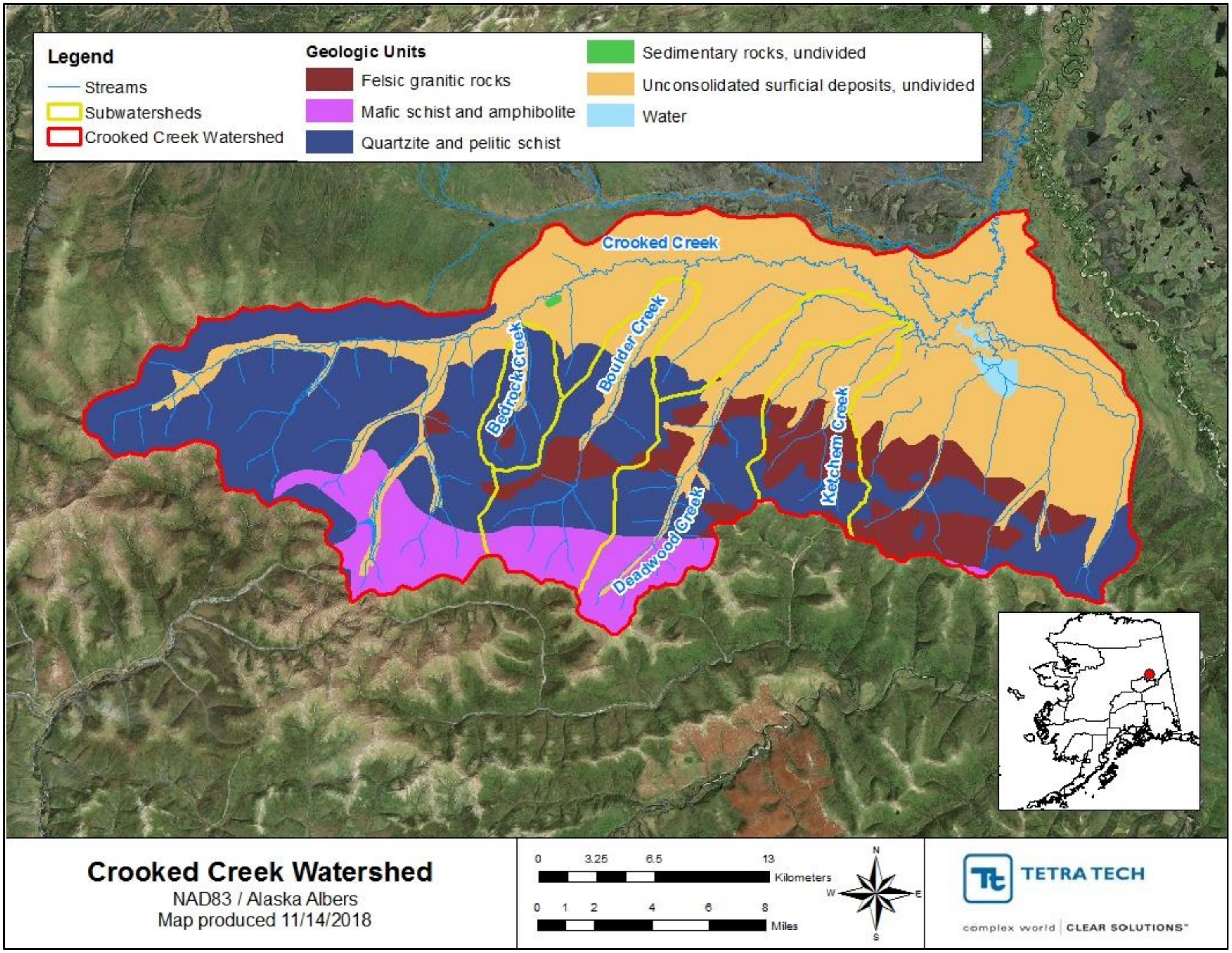


Figure 1-5. Geology in the Crooked Creek watershed (Source: USGS 2017)

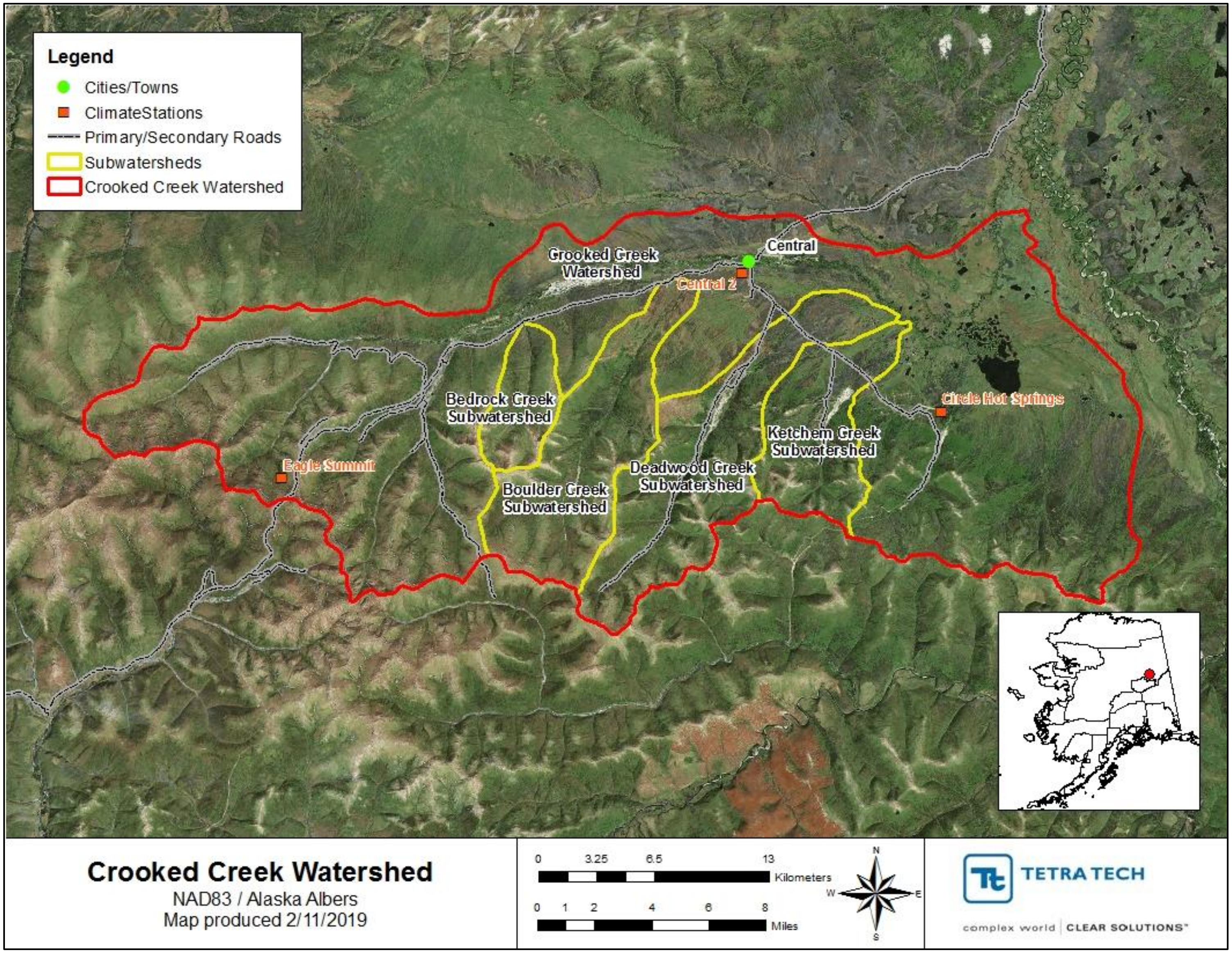


Figure 1-6. Climate stations in the Crooked Creek watershed (WRCC 2017)

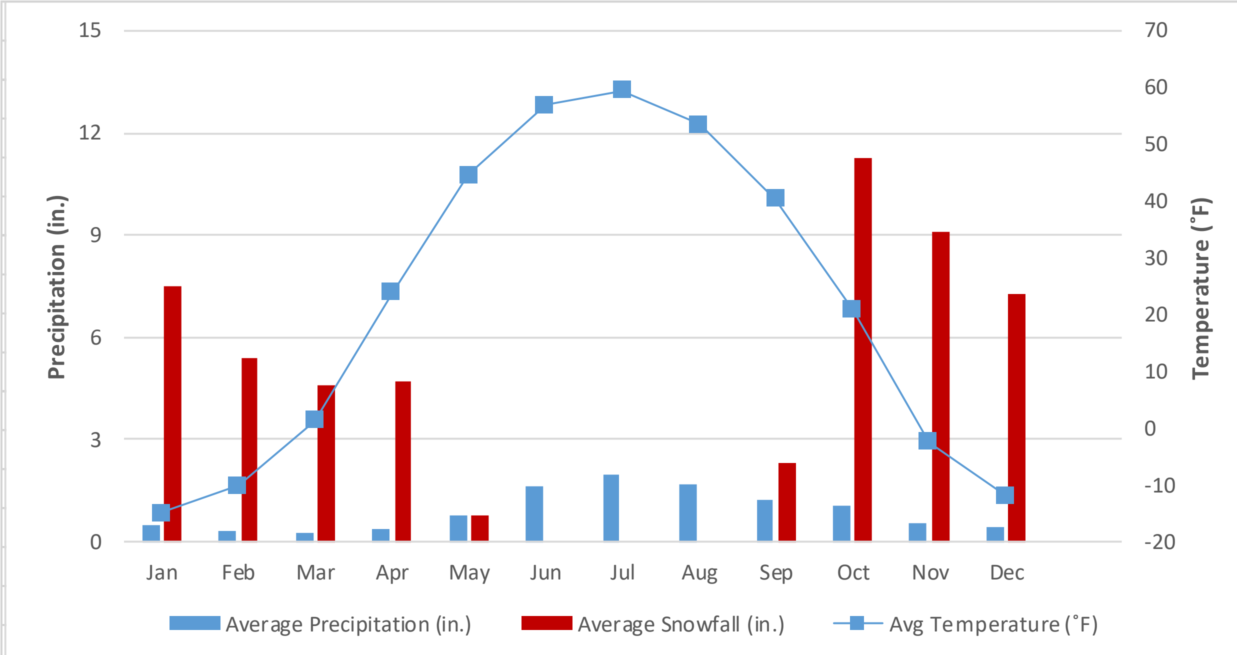


Figure 1-7. Monthly average precipitation and temperatures at Circle Hot Springs station

Table 1-4. Monthly average precipitation, snowfall, and temperatures at the Circle Hot Springs station

Climate Parameter	Month											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Average Precipitation (in)	0.48	0.30	0.24	0.35	0.76	1.62	2.0	1.71	1.25	1.05	0.55	0.44
Average Snowfall (in)	7.5	5.4	4.6	4.7	0.8	0	0	0	2.3	11.3	9.1	7.3
Average Temperature (°F)	-15.0	-10.2	1.4	23.9	44.7	57.0	59.6	53.6	40.4	20.8	-2.4	-11.8

1.7. Hydrology and Waterbody Characteristics

Crooked Creek and its tributaries are characterized by three different flow conditions: spring break-up, base flow, and storm flow (ADEC 2013b). From mid-October through April, Crooked Creek and its tributaries are frozen (USGS 1994). Crooked Creek typically opens up in mid-May following spring break-up. Spring break-up occurs when the snow- and ice-covered streams begin to melt and flow again in the late spring. High flows during spring break-up are expected to contribute to the highest turbidity concentrations in the stream; however, these conditions are not characterized by available data as sampling is not safe. Base flow conditions are the typical conditions in Crooked Creek. These flows consist of snow melt from higher elevations, springs, natural runoff from the watershed, and groundwater recharge. Rainstorms in the watershed typically occur from late-July to September. Due to permafrost, impermeable or saturated ground conditions, and the lack of surface storage in the upper watershed, these summer storms contribute higher flows and sediment loads than base flows and are characterized by increases in turbidity measurements (USGS 1994).

2. Water Quality Standards and TMDL Target

WQS designate the “uses” to be protected (e.g., water supply, recreation, aquatic life) and the “criteria” for their protection (e.g., how much of a pollutant can be present in a waterbody without impairing its designated uses). TMDLs are developed to meet applicable WQS, which may be expressed as either numeric or narrative criteria, for the support of designated uses.

The TMDL target identifies the numeric goals or endpoints for the TMDL that equate to attainment of WQS. The TMDL target may be equivalent to a numeric WQS where one exists, or it may represent a quantitative interpretation of a narrative standard. This section reviews the applicable WQS and identifies an appropriate TMDL target for calculation of the TMDLs to address turbidity impairments for Crooked, Boulder, Deadwood and Ketchem creeks in the Crooked Creek watershed.

2.1. Applicable Water Quality Standards

Title 18, Chapter 70 of the Alaska Administrative Code (AAC) establishes WQS for the waters of Alaska (ADEC 2016b). These include both the designated uses to be protected and the water quality criteria (WQC) necessary to protect the uses. State water quality criteria are defined for both marine and fresh waterbodies. The fresh water criteria apply to Crooked, Boulder, Deadwood and Ketchem creeks and are described below.

2.1.1. Designated Uses

Designated uses for Alaska’s waters are established by regulation and are specified in the State of Alaska Water Quality Standards (18 AAC 70020(a)). For fresh waters of the state, these designated uses include (1) water supply, (2) water recreation and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife. All designated uses must be addressed unless specifically exempted in Alaska. Therefore, the TMDL must use the most stringent of the criteria among all of the uses (as outlined in 18 AAC 70.020(b)). In this case, the most stringent criterion is for contact recreation (see Section 2.1.2). Waterbody assessment included the evaluation of all designated uses and meeting the TMDL target will result in attainment of all designated uses (see Section 3.3).

2.1.2. Water Quality Criteria

Crooked, Boulder, Deadwood and Ketchem creeks do not fully support their designated uses due to elevated turbidity in the water column (see Section 3). Turbidity WQC for all designated uses are applicable to the Crooked Creek watershed. Table 2-1 lists WQC for turbidity, which were the basis for the 303(d) listing.

Table 2-1. Alaska water quality criteria for turbidity in fresh water

Designated Use	Description of Criteria
Turbidity (Not applicable to groundwater)	
(A) Water Supply	
(i) drinking, culinary, and food processing	May not exceed 5 nephelometric turbidity units (NTU) above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 25 NTU.
(ii) agriculture, including irrigation and stock watering	May not cause detrimental effects on indicated use.

Designated Use	Description of Criteria
(iii) aquaculture	May not exceed 25 NTU above natural conditions. For all lake waters, may not exceed 5 NTU above natural conditions.
(iv) industrial	May not cause detrimental effects on established water supply treatment levels.
(B) Water Recreation	
(i) contact recreation	May not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU. May not exceed 5 NTU above natural turbidity for all lake waters.
(ii) secondary recreation	May not exceed 10 NTU above natural conditions when natural turbidity is 50 NTU or less, and may not have more than 20% increase in turbidity when the natural turbidity is greater than 50 NTU, not to exceed a maximum increase of 15 NTU. For all lake waters, turbidity may not exceed 5 NTU above natural turbidity.
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife	
Same as (A)(iii)	

Source: 18 AAC 70.020 (ADEC 2016b)

2.2. Antidegradation

Alaska's WQS also include an antidegradation policy (18 AAC 70.015), which states that, for all state waters, existing water uses and the level of water quality necessary to protect the existing uses must be maintained and protected.

If the quality of a water exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality must be maintained and protected unless the state finds that allowing lower water quality is necessary to accommodate important economic or social development in the area in which the water is located. In allowing such degradation or lower water quality, the state must ensure water quality adequate to fully protect existing uses of the water. The methods of pollution prevention, control, and treatment found to be the most effective and reasonable will be applied to all discharges. All discharges will be treated and controlled to achieve the highest statutory and regulatory requirements (for point sources) and all cost-effective and reasonable BMPs (for nonpoint sources).

If a water is designated as an outstanding national resource, the quality of that water must be maintained and protected. In such waters, no degradation of water quality is allowed. To date, none of the waterbodies in the Crooked Creek watershed have been designated as an outstanding national resource.

2.3. Designated Use Impacts

The Crooked Creek watershed creeks were placed on Alaska's 1992 section 303(d) list for nonattainment of the freshwater quality criteria for turbidity (ADEC 2013a). All designated uses, including (1) water supply, (2) water recreation, and (3) growth and propagation of fish, shellfish, other aquatic life, and wildlife, can be impacted by turbidity. Increased levels of turbidity negatively affect drinking water sources, diminish fish rearing success, and impair recreational uses. High levels of turbidity in drinking water or recreational waters can shield bacteria or other pathogens making chlorine or other treatments less effective at disinfecting the water (ADEC 2016a). Increased turbidity can also change the taste and odors of drinking water, cause staining, clog pipes and interfere with the proper function of appliances such as washing machines, dishwashers and hot water heaters. Turbidity is also related to adverse effects on aquatic life such as phytoplankton and invertebrates, which can in turn have an effect on higher trophic levels leading to reductions in fish populations (ADEC 2016a). Small increases in turbidity can also directly affect fish behavior that affects their growth and survival.

2.4. TMDL Target

The TMDL target is the numeric endpoint used to evaluate the loading capacity and necessary load reductions. It represents attainment of applicable WQS. All designated uses must be addressed unless specifically exempted in Alaska; therefore, the TMDL must use the most stringent WQC. For turbidity, the most stringent criterion is for contact recreation as this designated use allows for a 5 nephelometric turbidity units (NTU) increase above background (or natural condition) when the turbidity is less than 50 NTU and a maximum increase of 15 NTU above background (or natural condition) when the turbidity is above 50 NTU (see Section 2.1.2). The WQC for all other uses, including drinking water, aquaculture, and aquatic life uses, are higher than the contact recreation use. Therefore, the WQC for all uses will be met and all uses will be protected by applying the most stringent WQC. These same WQC apply to the entire watershed and to any downstream waterbodies, therefore, meeting the most stringent WQC in Crooked, Boulder, Deadwood and Ketchem creeks will not result in downstream degradation.

Several factors are important in the identification of the TMDL numeric target. The WQC are based on turbidity and are not conducive to the calculation of loads that are typically used in TMDLs. Therefore, numeric targets are expressed as a surrogate of total suspended solids (TSS) concentrations using a correlation with watershed-specific turbidity values and TSS concentrations. TSS is an appropriate surrogate for turbidity in the Crooked Creek watershed because of the strong correlation between TSS and turbidity (see section 2.4.3) and TSS can be used to measure mass in a volume of water. In addition, turbidity threshold values are included in the implementation section, which ensures streamlined interpretation to permits, supports implementation and supports evaluation of the creeks' progress towards meeting the WQC. For this watershed, flow and seasonal conditions affect turbidity measurements; therefore, Alaska conducted analyses to develop numeric target values for each month with flowing water (after spring break-up) as well as for storm-related conditions. Equations to calculate TMDL numeric targets are also provided if compliance is evaluated during spring break-up, but additional concurrent sampling at Bedrock Creek would be required (see Section 6.2).

2.4.1. Natural Background

As shown in Table 2-1, to establish a numeric TMDL target based on the contact recreation criteria, natural background conditions must be established. Alaska used the calculated natural conditions for turbidity, based on the reference creek, to determine numeric targets based on Alaska's contact recreational WQC for turbidity. The most common method used to determine natural conditions is to compare in-stream data to data from a reference waterbody that has similar physical and geographical characteristics (USEPA 2005). A reference site should be chemically, physically and biologically similar to the impaired watershed and also be relatively undisturbed by human activities (USEPA 2005).

When ADEC initially completed turbidity TMDLs for Boulder and Deadwood creeks in May 2018, Bedrock Creek was selected as the reference watershed that represents natural background conditions in the Crooked Creek watershed (ADEC 2018). While the Boulder and Deadwood creek TMDLs are being revised based on new data in the watershed, Bedrock Creek remains the reference watershed. Because of the physical similarities between the subwatersheds in the Crooked Creek watershed and the similar pollutant sources, Bedrock Creek (Figure 1-1) was used as a reference watershed to represent natural conditions for the Boulder and Deadwood creek TMDLs as well as the Crooked and Ketchem creek TMDLs. The bulleted list below presents the justification for Bedrock Creek to be considered an appropriate reference watershed for Crooked, Boulder, Deadwood and Ketchem creeks.

- Similar physical characteristics (i.e., topography, geography, and geology)
- Minimal historical mining or other disturbances
- No current mining
- Low turbidity concentrations

The Bedrock Creek subwatershed is located within the Crooked Creek watershed and is directly west of the Boulder, Deadwood and Ketchem creeks subwatersheds (see Figure 1-1). Bedrock Creek is a tributary to Crooked Creek. For the purpose of consistency and because of the similarities in land use, geology, soils and topography throughout the Crooked Creek watershed, it was assumed that Bedrock Creek is applicable as a reference watershed to Crooked and Ketchem Creeks as well as Boulder and Deadwood Creeks. The remainder of this section was taken from the original Boulder and Deadwood creek TMDLs report (May 2018) to describe the selection of Bedrock Creek as the reference watershed.

The physical characteristics of the reference watershed are very similar to those of the impaired subwatersheds (Boulder and Deadwood creeks). All three subwatersheds join Crooked Creek between 330-430 feet in elevation. In addition, all three subwatersheds are dominated by shrub and evergreen forest and gravelly, hilly to steep D-type soils (see Sections 1.4 and 1.5). While all three subwatersheds contain quartzite and granite, Bedrock Creek lacks the mafic schist common to those subwatersheds where gold mining has occurred (see Section 1.5.2). The Bedrock Creek watershed has minimal mining disturbance and no current mining activity. In addition, there are no currently active mining claims in the Bedrock Creek watershed (Alaska DNR 2017).

While Bedrock Creek may have had previous mining activity, the mines have not been active in recent years (Yeend 1991; Townsend 1991). The only known mining in Bedrock Creek was work on claims between 1976 and 1978, which consisted of surface trenching on the slightly radioactive zone of the iron-stained schist (Mindat 2015). Bedrock Creek is noted for its absence of gold, even though it is surrounded by gold-producing creeks. Figure 2-1 presents an aerial view of Bedrock, Boulder, and Deadwood creeks in 1986 and Figure 2-2 presents an aerial view of the same subwatersheds 30 years later in 2016. A comparison of Bedrock Creek in 1986 and 2016 shows that the watershed has not changed much in 30 years and there is little to no disturbance, indicating that mining has not been occurring in the watershed. Figure 2-1 and Figure 2-2 indicate that there is some disturbance along both Boulder and Deadwood creeks in 1986 and 2016.

Turbidity data also support the use of Bedrock Creek as a reference watershed. Data show that turbidity in Bedrock Creek is much lower than turbidity sampled downstream in Crooked Creek or in the neighboring tributaries (see Section 3.3). In addition, low turbidity values have been measured on Bedrock Creek after spring break-up; therefore, this station provides the best characterization of natural conditions in the watershed.

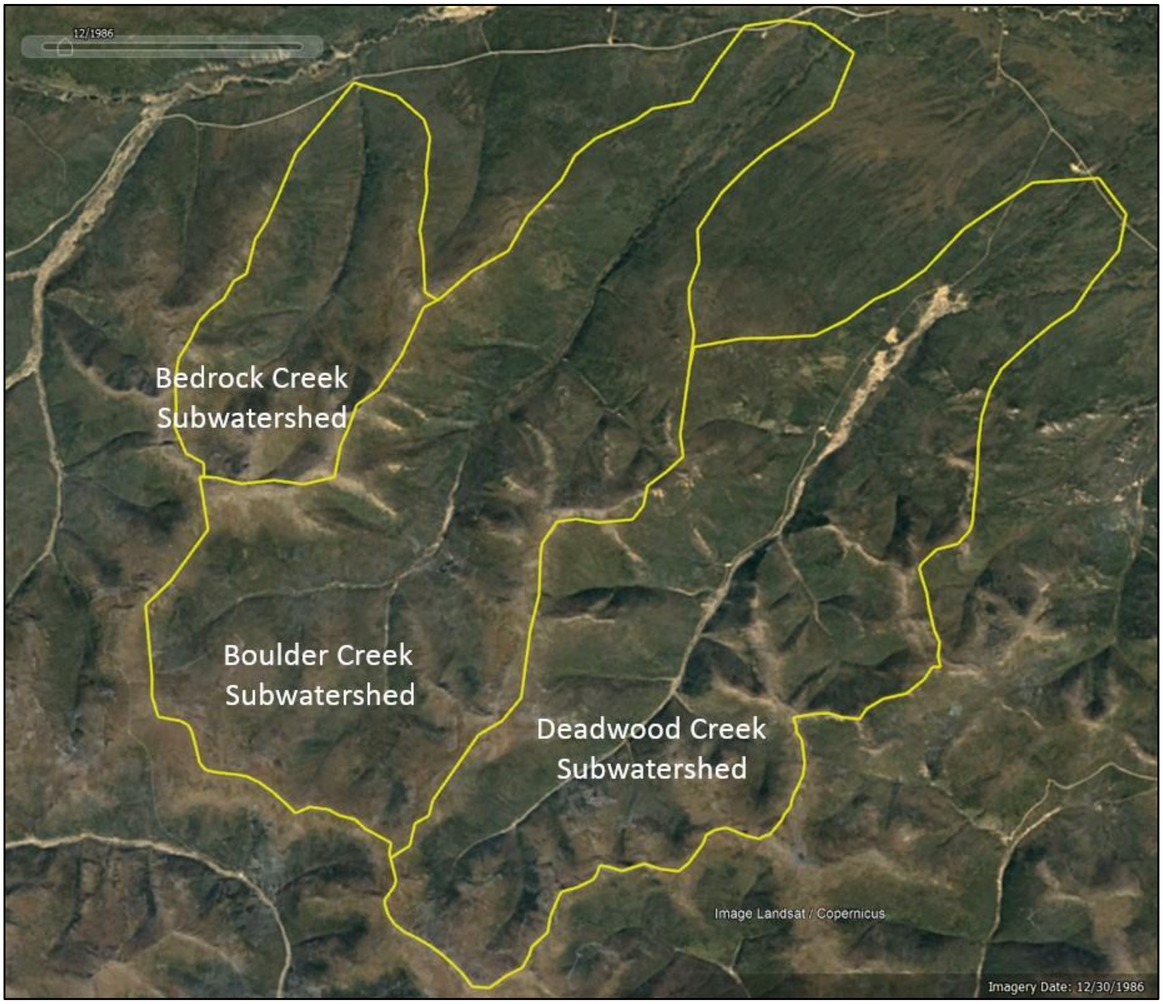


Figure 2-1. Aerial photos of Bedrock, Boulder and Deadwood creeks, 1986 (Source: Google Earth Imagery)

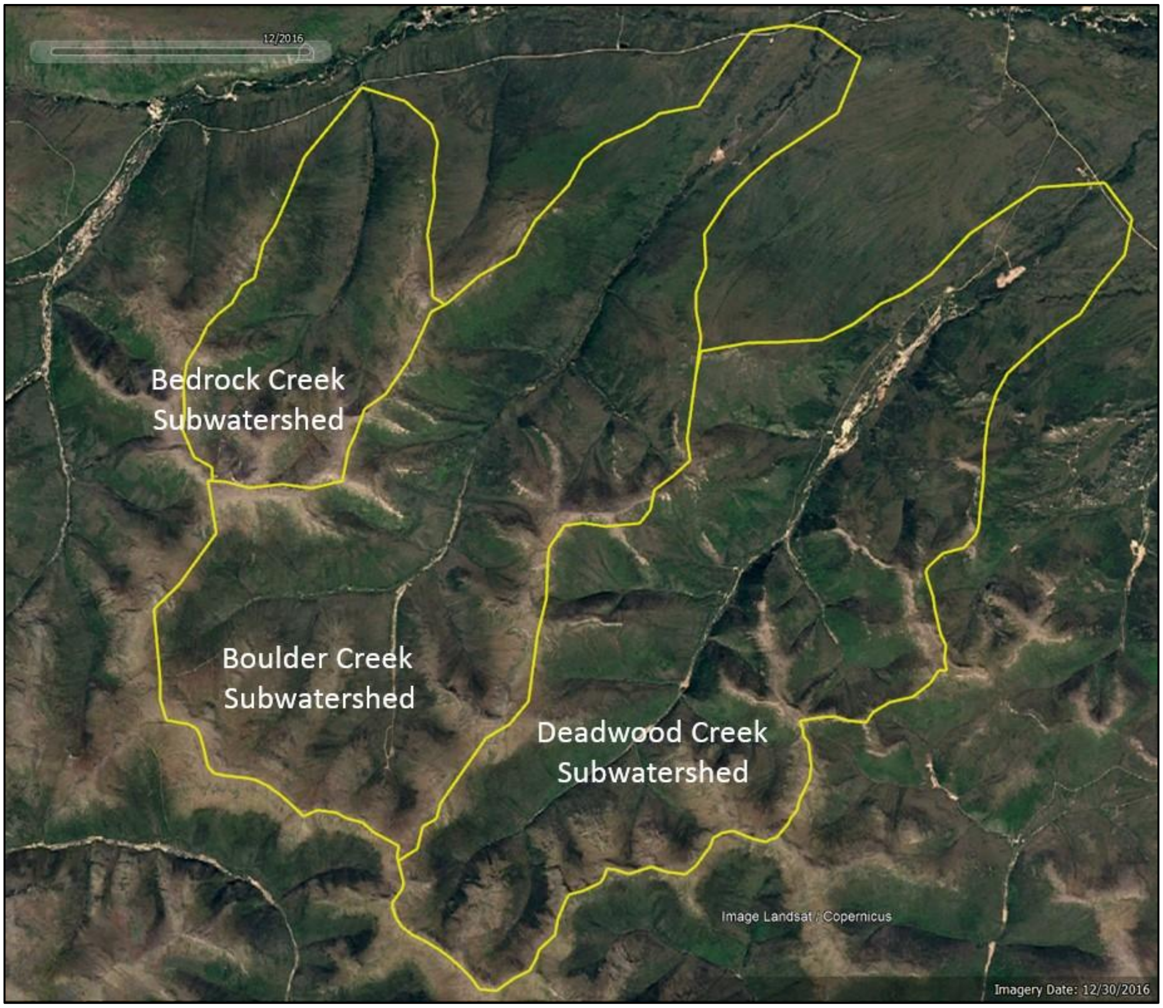


Figure 2-2. Aerial photos of Bedrock, Boulder and Deadwood creeks, 2016 (Source: Google Earth Imagery)

2.4.2. Seasonality

From mid-October through April, Crooked Creek and its tributaries are completely frozen. The creeks generally open up in mid-May, following spring break-up and remain free-flowing until mid-September when streams begin freezing with falling temperatures. This coincides with the period of available data (end of May to mid-September for 2014, 2016 and 2017). The TMDL will be presented based on monthly and storm conditions from the last week of May to September to best utilize available data and accurately represent stream conditions. The TMDL does not apply to Crooked, Boulder, Deadwood and Ketchem creeks from October through spring break-up (typically, the first three weeks of May).

2.4.3. TSS-Turbidity Relationship

Alaska analyzed available turbidity and TSS data in the watershed to evaluate the relationship between these two parameters and excluded four samples from this analysis as field notes indicated these samples were influenced by active upstream activities and do not represent typical conditions in the watershed. For the analyses, TSS grab samples were assigned to a turbidity measurement based on the closest sample time on the sample day. The data were subsequently separated into lower turbidity values (less than 15 NTU) and higher measurements (equal to or above 15 NTU). This was performed to better reflect the range of conditions in the watershed, where lower turbidity values typically reflect baseflow conditions and higher turbidity is generally associated with higher flow conditions that result in more sediment discharges and higher TSS values. A 15 NTU threshold was used as it generally reflects a point in the observed data where the slope changes; the higher values demonstrate a steeper slope than the lower TSS and turbidity values. Specifically, there was a cluster of measurements below the 15 NTU cutoff that had a shallower slope compared to the measurements above this value, which showed greater variability and a steeper slope. The cutoff of 15 NTU is not related to the "not to exceed" maximum increase of 15 NTU in Alaska's turbidity WQC.

For the lower turbidity values, the data show some scatter in the related TSS concentrations. This is not unexpected given the flashy nature of the system. The best fit for these data ($R^2 = 0.64$, $p < 0.05$) was represented using a power equation, which can be used to estimate TSS concentrations associated with available turbidity values below 15 NTU (see equation in Figure 2-3). The higher values demonstrated a strong relationship between turbidity and TSS measurements ($R^2 = 0.70$, $p < 0.05$) and the resulting equation can be used to estimate TSS concentrations for turbidity values equal to or greater than 15 NTU (Figure 2-4). These higher values are expected to represent conditions after spring break-up or during summer storms. Representation of spring break-up and summer storms is important because they characterize water quality during natural seasonal events in the watershed.

The TMDL uses the equations for the relationships presented in Figure 2-3 and Figure 2-4 to estimate TSS concentrations associated with the turbidity WQC, resulting in TSS numeric targets.

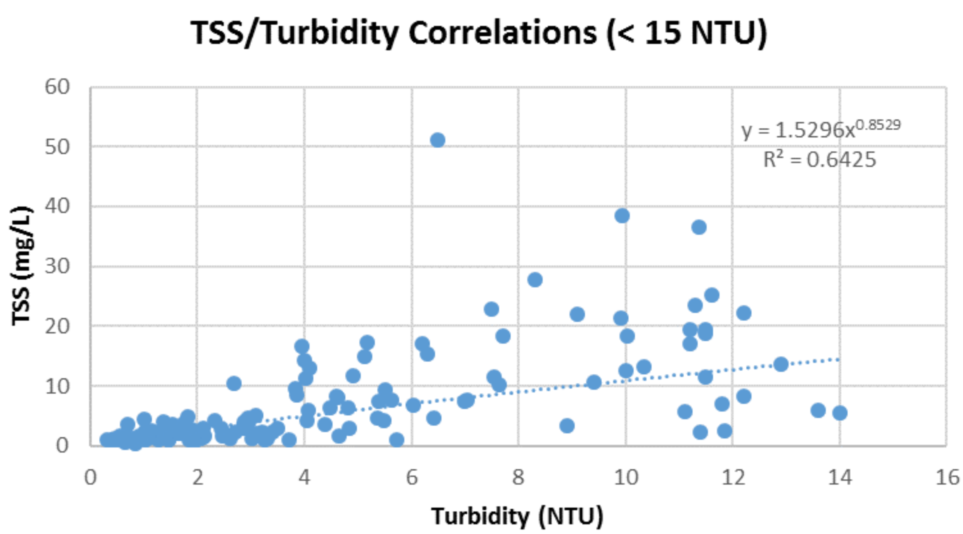


Figure 2-3. TSS and turbidity relationship for the Crooked Creek watershed at lower turbidity values

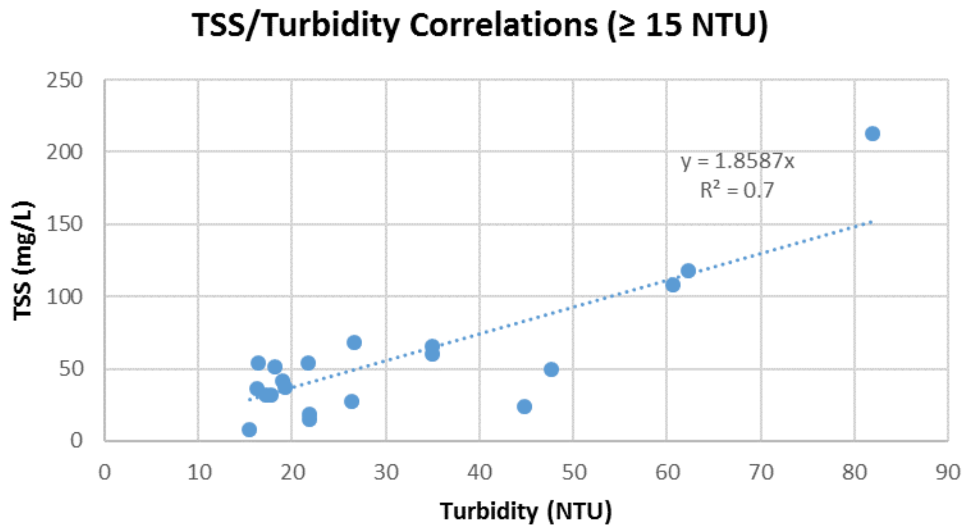


Figure 2-4. TSS and turbidity relationship for the Crooked Creek watershed at higher turbidity values

2.4.4. Numeric Target Calculation

Natural conditions at the Bedrock Creek reference station (Section 2.4.1) were used to determine storm-related and monthly water quality threshold values based on Alaska's recreational WQC for turbidity. To calculate loads, the turbidity thresholds were converted to TSS values using the equations in Figure 2-3 and Figure 2-4 for turbidity values below and above 15 NTU, respectively.

Evaluation of turbidity data at Bedrock Creek provides summary statistics by month and for storm-related conditions. The continuous (i.e., multiple measurements in a single day) turbidity data were aggregated into daily values representing each day analyzed. Specifically, the arithmetic average of the continuous measurements on a given day was used to represent turbidity conditions on that date (note: some negative values were observed in the dataset, associated with very low turbidity values that fell within the error range of the probe; because these were very low observations, they were replaced with zeros in the analyses following an assessment of conditions at the time of sampling and quality assurance checks on the dataset, ensuring that the negative values did not influence the daily average calculations). The average value was used as it is consistent with ADEC's turbidity listing methodology (ADEC 2016a) and it allows for some variability in the measurements (as opposed to the minimum value).

Sampling days were characterized as baseflow or responding to storm-related conditions. Storm-related conditions were identified through evaluation of precipitation at the Circle Hot Springs weather station and measured turbidity values. Daily precipitation for 2014 and 2016 was reported graphically by Western Regional Climate Center (WRCC)[1]. Precipitation values associated with these graphs were estimated for each day with a turbidity measurement in 2014 and 2016. 2017 precipitation data were downloaded from WRCC's *SC ACIS Tool* (http://scacis.rcc-acis.org/). A sampling day was characterized as a storm day if it met the conditions described below. After evaluating the available data, a 15 NTU threshold was used to determine storm-related conditions since this value reflects a clear increase from baseflow turbidity conditions. This threshold also maintains consistency with the TSS-turbidity relationships described in Section 2.4.3.

[1] https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?ak1987

> *A storm day exhibits daily average turbidity greater than or equal to 15 NTU <u>and</u> one the following conditions: (1) daily precipitation on the sampling day is greater than or equal to 0.3 inches or sampling falls within 72 hours after a day with at least 0.3 inches of rainfall* or *(2) at least half of the past 10 days had measurable precipitation.*

For future evaluations of monitoring data, additional evidence of a storm event can be provided to ADEC along with the sampling data. Based on this evidence, ADEC will then determine whether the sampling was influenced by a storm event.

The average daily data were summarized by storm-related conditions and month and presented below using a water quality duration curve with box and whisker plots (Figure 2-5).

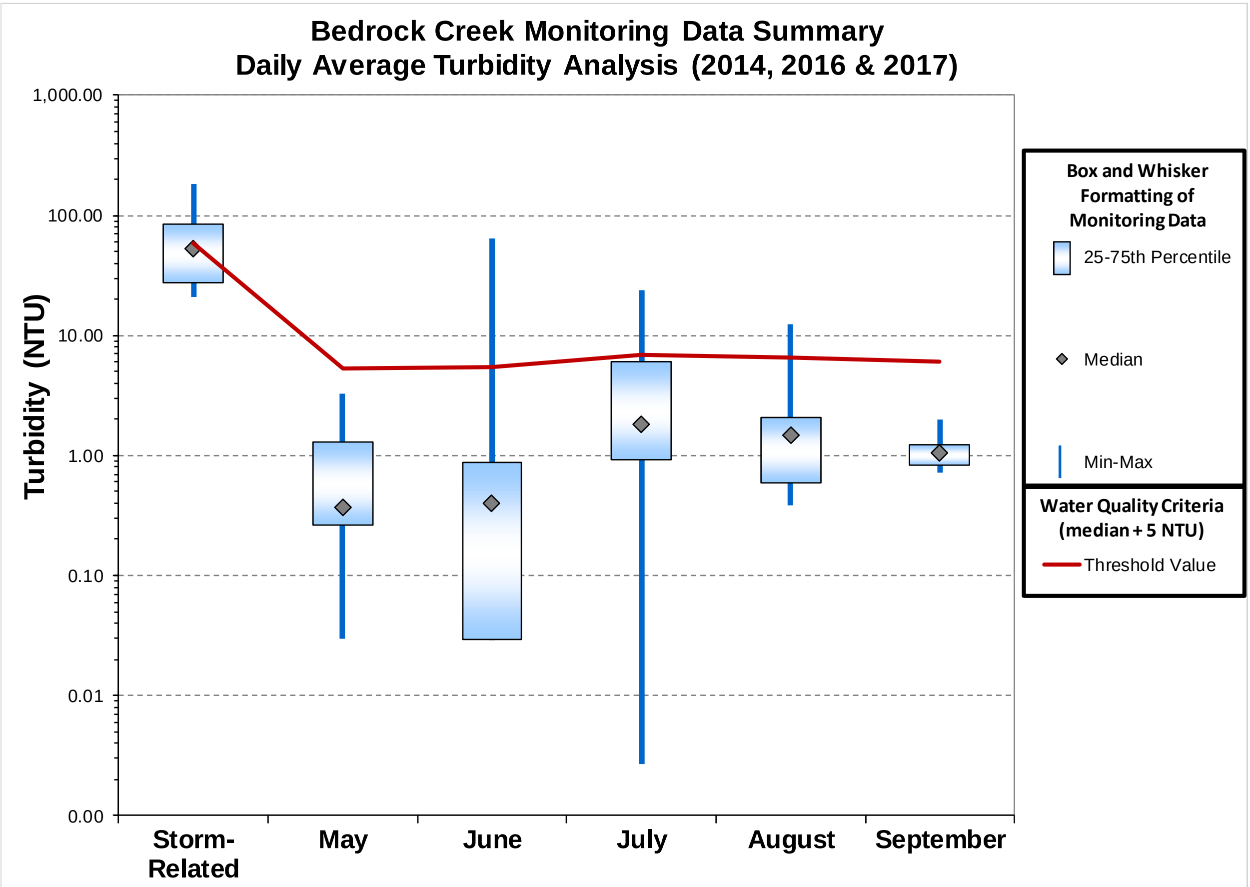


Figure 2-5. TMDL threshold values based on average daily turbidity measurements at Bedrock Creek

To calculate threshold values for turbidity, the median value for each month and storm-related conditions (Table 2-2) were incorporated into the applicable WQC (for the contact recreation, which is the most stringent WQC):

> *May not exceed 5 NTU above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than a 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU (contact recreation).*

The median value was selected because, for turbidity, it is a conservative measurement of central tendency that still allows for some variability in natural conditions. All months measured at Bedrock

Creek had median turbidity measurements below 50 NTU for baseflow; therefore, the threshold values for the last week of May through September are based on the median NTU +5 NTU. For storm conditions, the median turbidity was above 50 NTU, so the threshold value was calculated by adding 10% to the median value. The turbidity threshold values for this TMDL are calculated using the equations below and are presented in Table 2-2.

Storm-related conditions: ***Median Bedrock Creek NTU + 10% NTU = Threshold Value***

May to September (after spring break-up): ***Median Bedrock Creek NTU + 5 NTU = Threshold Value***

Table 2-2. Bedrock Creek turbidity summary statistics and threshold values

Turbidity Statistics	Turbidity Values (NTU)					
	Storm-related conditions	Last week of May	June	July	August	September
Number of Samples	n = 14	n = 9	n = 86	n = 79	n = 69	n = 21
Minimum	20.6	0.0	0.0	0.0	0.4	0.7
25th Percentile	27.2	0.3	0.0	0.9	0.6	0.8
Median	53.3	0.4	0.4	1.8	1.5	1.0
Average	67.5	0.9	1.9	4.5	1.9	1.1
75th Percentile	85.0	1.3	0.9	6.0	2.1	1.2
Maximum	183.3	3.3	64.2	23.8	12.5	2.0
Threshold Value	58.6	5.4	5.4	6.8	6.5	6.0

Note: median values (first blue row) were used to calculate threshold values (bottom row) using the equations: Median Bedrock Creek NTU + 5 NTU = Threshold Value for May through September or Median Bedrock Creek NTU + 10% NTU = Threshold Value for storm-related conditions. Negative values in the dataset were replaced with zeros before calculating average daily values and summary statistics on the average daily values.

The calculated turbidity threshold values (Table 2-2) were used to calculate TSS numeric target concentrations (in milligrams per liter [mg/L]), which were used to determine allowable TSS loads in Crooked, Boulder, Deadwood and Ketchem creeks. Specifically, TSS numeric targets were calculated using the equations representing the relationships between TSS and turbidity (Figure 2-3 and Figure 2-4 for turbidity values below and above 15 NTU, respectively). Following these two equations, the turbidity threshold values for each month and condition (Table 2-2) was used to calculate the corresponding TSS value.

The turbidity-TSS relationship for turbidity values greater than 15 NTU was used to calculate the storm-related TSS numeric target and the relationship for turbidity less than 15 NTU was used for other conditions. Specifically, the storm-related turbidity threshold value, which was above 15 NTU, was multiplied by 1.8587 to obtain the allowable TSS concentration during storm-related conditions (Figure 2-4) and the May through September turbidity values were converted using the equation $y = 1.53x^{0.8529}$, where y is equal to TSS and x is equal to turbidity (Figure 2-3).

The monthly and storm-related turbidity threshold values and TSS TMDL numeric targets are presented in Table 2-3. The TSS values are applied in the TMDL to calculate the loading capacity and for comparison with existing loads to determine required reductions, while the turbidity values are used to support implementation and evaluation of watershed conditions.

Table 2-3. Turbidity threshold values and TSS numeric targets

Parameter (units)	Storm-related[a]	Last week of May[b]	June[b]	July[b]	August[b]	September[b]
Turbidity (NTU)	58.6	5.4	5.4	6.8	6.5	6.0
TSS (mg/L)	108.9	6.4	6.4	7.8	7.5	7.1

[a]Storm-related tubidity threshold = median Bedrock Creek storm-related turbidity of 53.3NTU * 1.1 (10% increase).

[b]Monthly turbidity thresholds = median monthly turbidity at Bedrock Creek plus 5NTU (May: 0.4 + 5NTU; June: 0.4 + 5NTU; July: 1.8 + 5NTU; August: 1.5 + 5NTU; and September: 1 + 5NTU).

3. Data Review

Compiling and analyzing data and information is an essential step in understanding the general water quality conditions and trends in an impaired waterbody. This section outlines and summarizes all the data reviewed, including impairment analyses and temporal and spatial trends.

3.1. Historical Data

After the initial 303(d) listing in 1992, which was based on data from the 1980s, ADEC conducted a water quality assessment of the watershed in 1996. This assessment showed that water quality was improving, likely due to the use of settling ponds and implementation of EPA Effluent Limitations Guidelines within discharge permits. Specifically, the levels of turbidity and TSS in the Crooked Creek watershed dramatically decreased from the mid-1980s to the early 1990s (Townsend 1991; Vohden 1999). Unfortunately, this trend did not continue and Vohden (1999) observed that in the mid-1990s turbidity values began to increase in Crooked Creek near the town of Central and continued increasing during that study.

ADEC staff visited the Crooked Creek watershed in 2013 to evaluate current turbidity conditions and evaluate potential sampling locations. Table 3-1 presents the results of these snapshot sampling events, which are presented as actual measurements or a range for when multiple samples were taken. These data illustrate variable conditions. The top two rows of data are samples on Bedrock Creek, which represents natural conditions. Nearly all measurements were above these values; however, some stations were significantly higher than others. This variability prompted ADEC to initiate a more comprehensive data collection effort in 2014, 2016 and 2017. The shaded rows in Table 3-1 are those waterbodies most relevant to the TMDLs in this document (i.e., reference watershed and impaired streams).

Table 3-1. Turbidity measurements from 2013 ADEC sampling

Sampling Location	Turbidity (NTU)	
	July 2013	August 2013
Bedrock Creek below bridge	0.79	NR
Bedrock Creek at confluence with Crooked Creek	0.73	0.32
Upper Porcupine Creek	0.42-4.61	NR
Middle Porcupine	56.9	NR
Porcupine Creek above Bonanza confluence	18.3-25.9	3.66
Bonanza at Porcupine confluence	0.84	0.38
Porcupine at Mammoth	NR	0.98
Mammoth at Porcupine	NR	2.38
Mammoth Creek at bridge	1.28	0.28
Upper Mammoth	0.35	NR
Lower Mastodon	2.01	NR
Crooked Creek at confluence with Bedrock	1.99	0.49
Stack Pup at bridge	49	23.1
Middle Crooked Creek	NR	0.59
Boulder Creek at bridge	1.15	0.36
Crooked Creek at Central	1.33	0.35
Deadwood Creek at bridge	0.8	0.97

Sampling Location	Turbidity (NTU)	
	July 2013	August 2013
Upper Deadwood	NR	0.32
Ketchem at bridge	26.4	25.4-185
Upper Ketchem	1.1	1.03

Source: ADEC (2013b); NR = No reading

The remainder of this section presents:

- A data inventory (Section 3.2),
- Findings of the impairment assessment using the 2014, 2016 and 2017 sampling results (Section 3.3),
- An evaluation of streamflow that was used to estimate flow conditions throughout the watershed (Section 3.4),
- Detailed data analyses for Crooked, Boulder, Deadwood and Ketchem creeks (Section 3.5).

3.2. Data Inventory of Recent Data

ADEC sampled the Crooked Creek watershed at twenty stations in 2014, eight stations in 2016 and 13 stations in 2017, using a combination of continuous data loggers and instantaneous measurements (Table 3-2; Figure 3-1). Continuous monitoring data provide the best representation of conditions at a station. Grab samples are useful to characterize conditions at a specific point in time and enough samples help to illustrate a more complete picture of water quality at a station. Continuous water levels (i.e., stage) were also measured at stations CCW-16 on Crooked Creek and CCW-14 on Boulder Creek. These data were used to characterize hydrological conditions in the watershed (Section 3.4) and are supplemented by other spot measurements of flow (Table 3-2).

Table 3-2. Recent sampling stations and type of data collected

Station ID	Sample Location	Year(s) with Water Quality Data		Year(s) with Hydrology Data	
		Grab Sampling	Continuous Sampling	Instant. Flow	Continuous Water Level
CCW-1	Upper-Porcupine Creek	2014	—	—	—
CCW-2	Upper-Bonanza	2014, 2017	—	—	—
CCW-3	Bonanza Creek above confluence with Porcupine Creek	2014, 2016, 2017	—	2014	—
CCW-4	Porcupine Creek above confluence with Bonanza Creek	2014, 2017	—	2014	—
CCW-5	Porcupine Creek below confluence with Bonanza Creek	2014, 2016, 2017	2017	—	—
CCW-6	Mastodon Creek above confluence with Independence Creek	2014, 2017	—	—	—
CCW-7	Independence Creek above confluence with Mastodon Creek	2014, 2017	—	—	—
CCW-8	Miller Creek above confluence with Mammoth Creek	2014	—	—	—
CCW-9	Mammoth Creek below Steese bridge	2014, 2016, 2017	2014	2014	—
CCW-10	Stack Pup Creek at Steese bridge	2014	—	—	—
CCW-11	*Crooked Creek at confluence with Bedrock Creek*	2014	—	—	—
CCW-12	*Bedrock Creek above Steese bridge*	2014, 2016, 2017	2014, 2016, 2017	2014	—

Station ID	Sample Location	Year(s) with Water Quality Data		Year(s) with Hydrology Data	
		Grab Sampling	Continuous Sampling	Instant. Flow	Continuous Water Level
CCW-13	*Upper-Deadwood Creek*	2014	—	—	—
CCW-14	*Boulder Creek above Steese bridge*	2014, 2016, 2017	2014, 2016	2014, 2016	2014, 2016
CCW-15	*Mid-Deadwood Creek*	2014	—	—	—
CCW-16	*Crooked Creek at Central BLM Field Station*	2014, 2016, 2017	2014, 2016, 2017	2014, 2016, 2017	2014, 2016, 2017
CCW-17	*Deadwood Creek below Circle Hot Springs Rd bridge*	2014, 2016, 2017	2014, 2016	2014	—
CCW-18	*Upper-Ketchem*	2014	—	—	—
CCW-19	*Mid-Ketchem*	2014, 2017	—	—	—
CCW-20	*Ketchem Creek above Circle Hot Springs Rd bridge*	2014, 2017	2014, 2016, 2017	2014	—

Note: "—" indicates no data were collected at this station for 2014, 2016 or 2017.
Note: The waterbodies of interest in this TMDL are in italics (i.e., Bedrock Creek, Crooked Creek, and Ketchem Creek).

3.3. Turbidity Impairment Assessment

ADEC collected continuous turbidity data at six stations in the Crooked Creek watershed in 2014, five stations in 2016 and four stations in 2017 (ADEC 2013b). ADEC calculated summary statistics by station and these are presented in Table 3-3. This table is based on the raw data (with any negative values replaced by zeros) and illustrates that Bedrock Creek typically has lower turbidity concentrations than the other stations. This station does demonstrate expected responses to storms, which is illustrated by the values associated with the 90th percentile and above (Table 3-3). Based on a visual comparison of continuous time series graphs, this station also appears to return to a lower baseline turbidity level more quickly than other stations (Figure 3-2, Figure 3-3 and Figure 3-4 for 2014, 2016 and 2017, respectively).

Overall, comparison of data collected in 2014, 2016 and 2017 do not demonstrate any clear differences between the three years. The average concentrations at Bedrock Creek, Crooked Creek, Boulder Creek and Deadwood Creek have decreased since 2014, while the highest average turbidity concentration at Ketchem Creek occurred in 2017. There are no continuous 2014 or 2016 Porcupine Creek data available for comparison to the 2017 data. Other statistics do not show any clear trends when comparing data at each station between years.

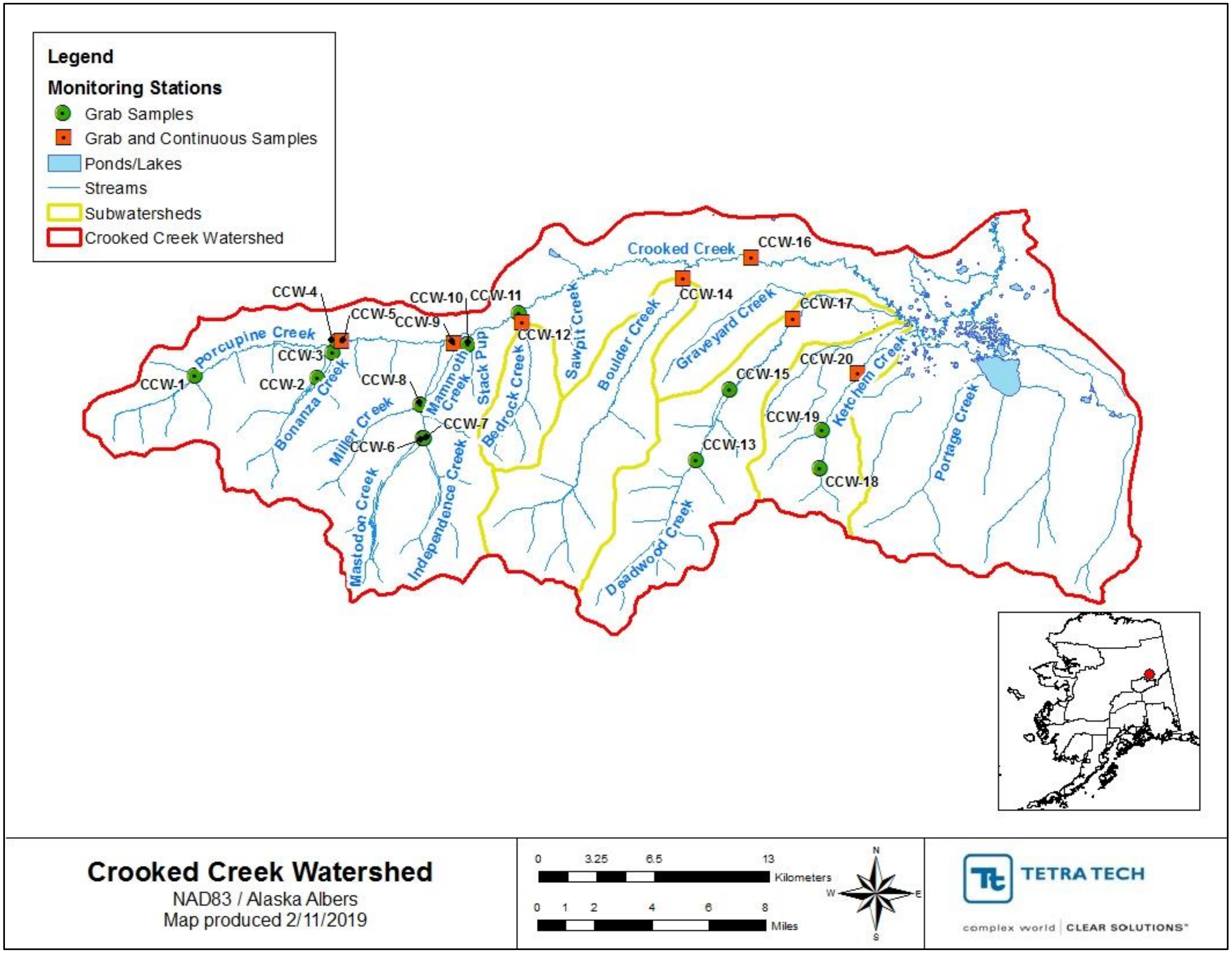


Figure 3-1. Monitoring stations in the Crooked Creek watershed

(Note: See **Table 3-2** for information on which stations have grab samples vs. continuous samples for 2014, 2016 and 2017.)

Table 3-3. Summary statistics for continuous turbidity data by year

Statistic	2014						2016					2017			
	Bedrock[a]	Ketchem	Boulder	Mammoth	Crooked at BLM	Deadwood	Bedrock[a]	Ketchem	Boulder	Crooked at BLM	Deadwood	Bedrock[a]	Ketchem	Crooked at BLM	Porcupine
Number of samples	10,776	4,858	2,418	3,154	1,841	14,334	16,131	16,112	1,522	957	16,113	12,774	13,095	14,224	12,126
Minimum (NTU)	0.28	0.13	0	0.17	0.99	0.24	0	0	4.00	0.50	0	0.25	1.57	0.03	0.00
Maximum (NTU)	3,063	1,169	1,320	13,028	710	15,670	1,563	2,628	227	67	1,219	1,022	3,927	413.85	362.44
Average (NTU)	9.35	48.94	40.64	16.86	10.87	26.86	6.43	8.97	30.26	8.63	24.42	2.06	114.98	4.41	4.48
10th Percentile (NTU)	0.64	17.36	1.16	0.45	1.57	1.53	0	3.64	6.76	3.82	0.86	0.37	9.33	0.19	0.24
25th Percentile (NTU)	0.77	23.94	1.84	0.99	2.41	2.36	0.03	4.38	8.81	4.44	3.43	0.42	15.41	0.49	0.42
50th Percentile (NTU)	1.19	29.89	6.50	1.78	4.39	6.11	1.21	6.29	18.42	6.00	9.52	0.67	35.87	1.16	1.38
75th Percentile (NTU)	5.46	40.45	16.91	3.79	9.80	15.36	2.38	8.92	40.98	9.18	21.70	1.35	119.59	2.70	3.11
90th Percentile (NTU)	19.86	72.55	84.78	15.55	16.56	40.57	7.70	11.13	69.05	17.85	53.33	6.03	245.52	6.35	7.13
95th Percentile (NTU)	33.05	131.56	181.84	40.06	30.35	74.62	17.19	17.00	95.29	24.12	95.67	6.10	295.19	13.87	12.83
99th Percentile (NTU)	141.26	443.12	723.30	102.38	78.16	403.93	92.87	57.47	153.13	41.93	258.56	13.79	1,503.19	73.38	77.97

[a]Shaded column represents natural conditions, which were used for threshold value calculation. Negative values were replaced with zeros before the summary statistics were calculated.

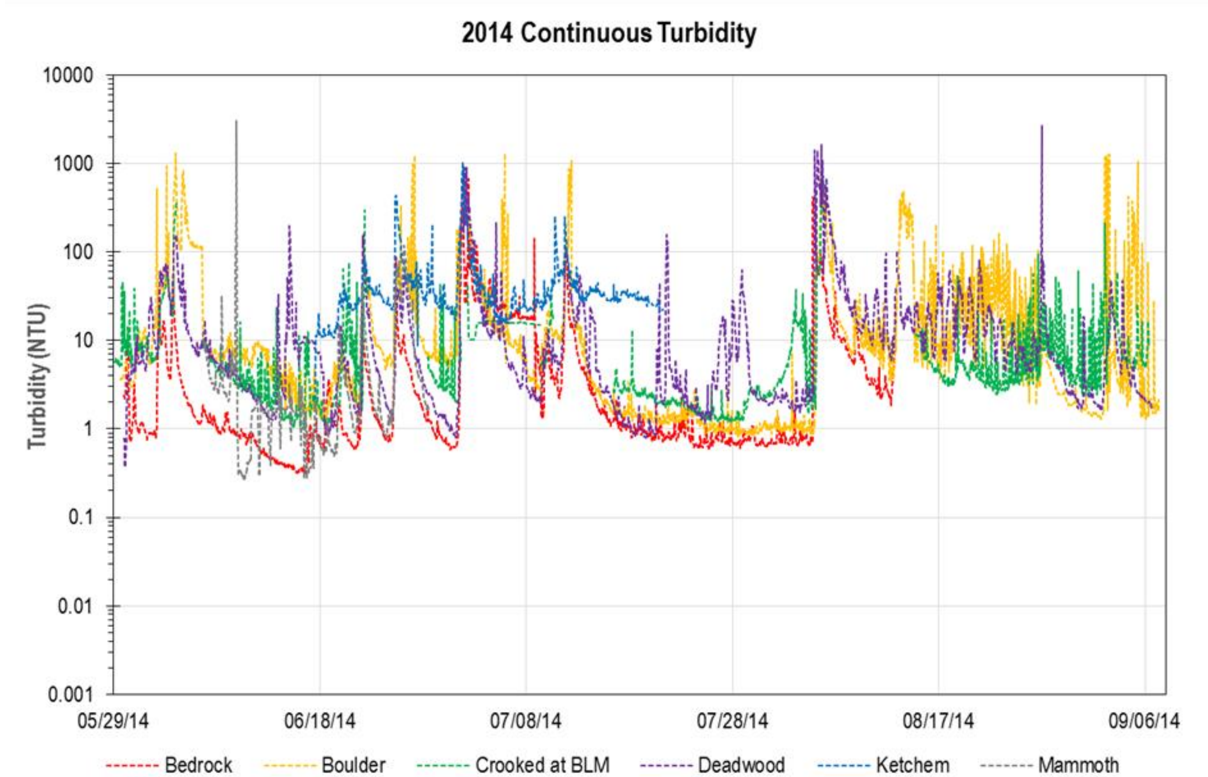


Figure 3-2. Time series of 2014 continuous turbidity measurements (NTU)

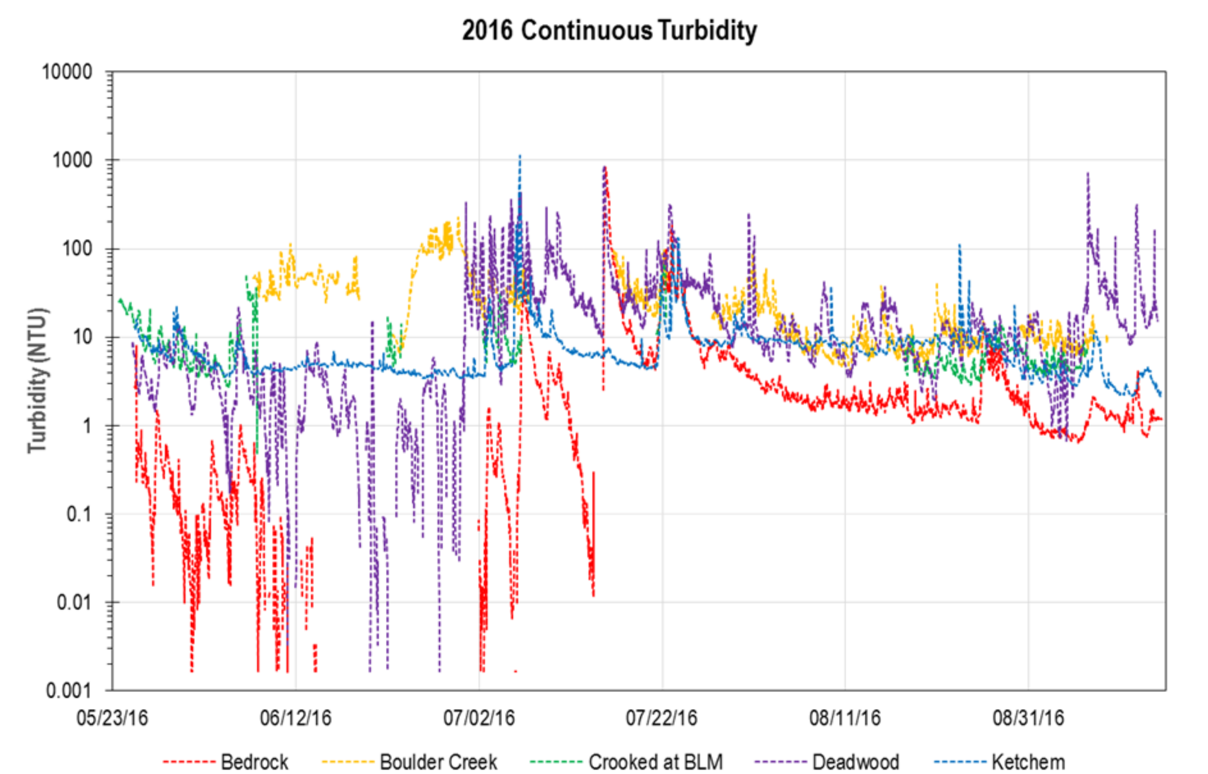


Figure 3-3. Time series of 2016 continuous turbidity measurements (NTU)

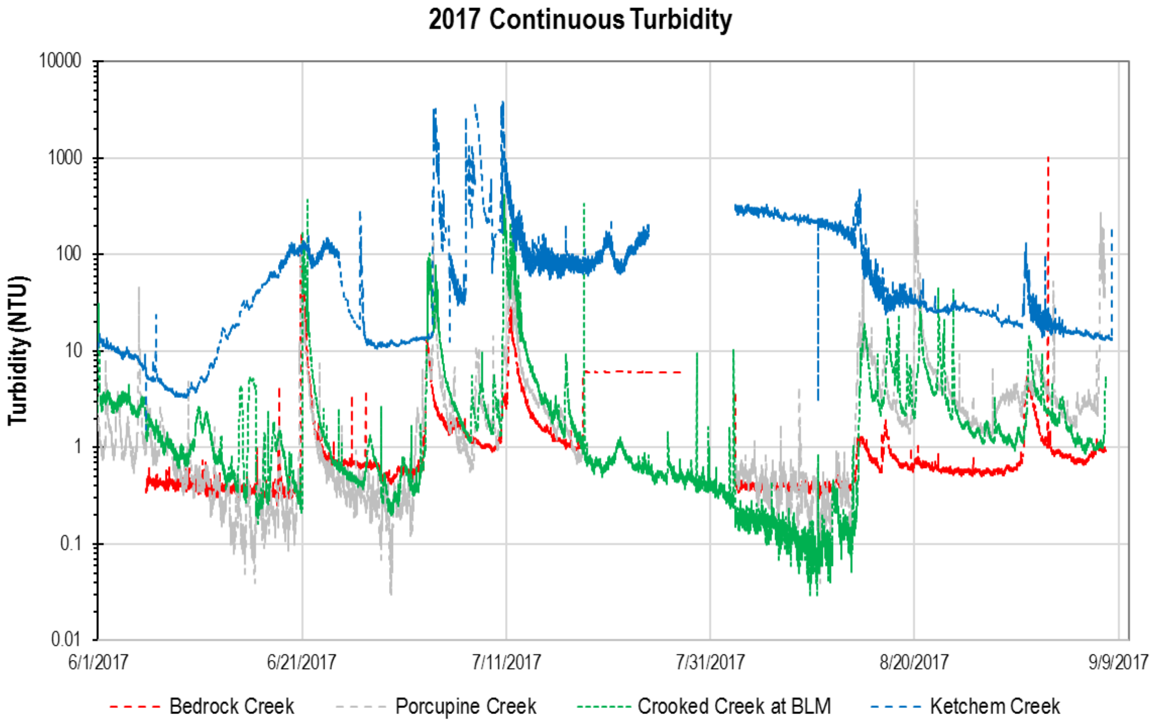


Figure 3-4. Time series of 2017 continuous turbidity measurements (NTU)

All 2014, 2016 and 2017 turbidity data were included in an impairment assessment for each sampled creek using the ADEC listing methodology (ADEC 2016a). These assessments included both grab and continuous measurements at a site, assuming the minimum data requirements from the listing methodology were met (ADEC 2016a).

Table 3-4 presents the results of this assessment when comparing against the most stringent water quality criteria for contact recreation designated uses. This analysis confirms Crooked, Boulder, Deadwood and Ketchem creeks as impaired, thus justifying the need for a TMDL for these creeks (ADEC 2013b, 2016a).

Daily average turbidity values for Crooked, Boulder, Deadwood and Ketchem creeks are shown graphically in Figure 3-5 (note: these daily average data are less flashy than the continuous [i.e., sub-hourly] data presented in the graphs above). This figure shows a comparison to Bedrock Creek, the reference site, illustrating that turbidity conditions at Crooked, Boulder, Deadwood and Ketchem creeks are typically higher than the reference site.

Additional impairment tests were performed on these waterbodies to compare their data to all numeric WQC (Table 3-5). Crooked Creek, Boulder Creek and Deadwood Creek were found to be impaired for drinking water, contact recreation, and secondary recreation designated uses and not impaired for aquaculture and growth and propagation of fish, shellfish, other aquatic life, and wildlife uses. Ketchem Creek was found to be impaired for drinking water, contract recreation, secondary recreation, and aquaculture and growth and propagation of fish, shellfish, other aquatic life, and wildlife designated uses.

The additional turbidity data collected in 2017 determined that the other creeks in the watershed (Porcupine, Bonanza, Mammoth and Mastodon creeks) were not impaired and will be proposed for delisting.

Table 3-4. Impairment status by creek for the Crooked Creek watershed

Waterbody	Sample Type	Decision
Bonanza Creek	Grab	Not impaired; Proposed for delisting
Mammoth Creek	Grab and Continuous	Not impaired; Proposed for delisting
Mastodon Creek	Grab	Not impaired; Proposed for delisting
Porcupine Creek	Grab and Continuous	Not impaired; Proposed for delisting
Ketchem Creek	Grab and Continuous	Impaired; TMDL needed
Deadwood Creek	Grab and Continuous	Impaired; TMDL needed
Boulder Creek	Grab and Continuous	Impaired; TMDL needed
Crooked Creek (BLM)	Grab and Continuous	Impaired; TMDL needed
Bedrock Creek	Grab and Continuous	N/A Reference Site

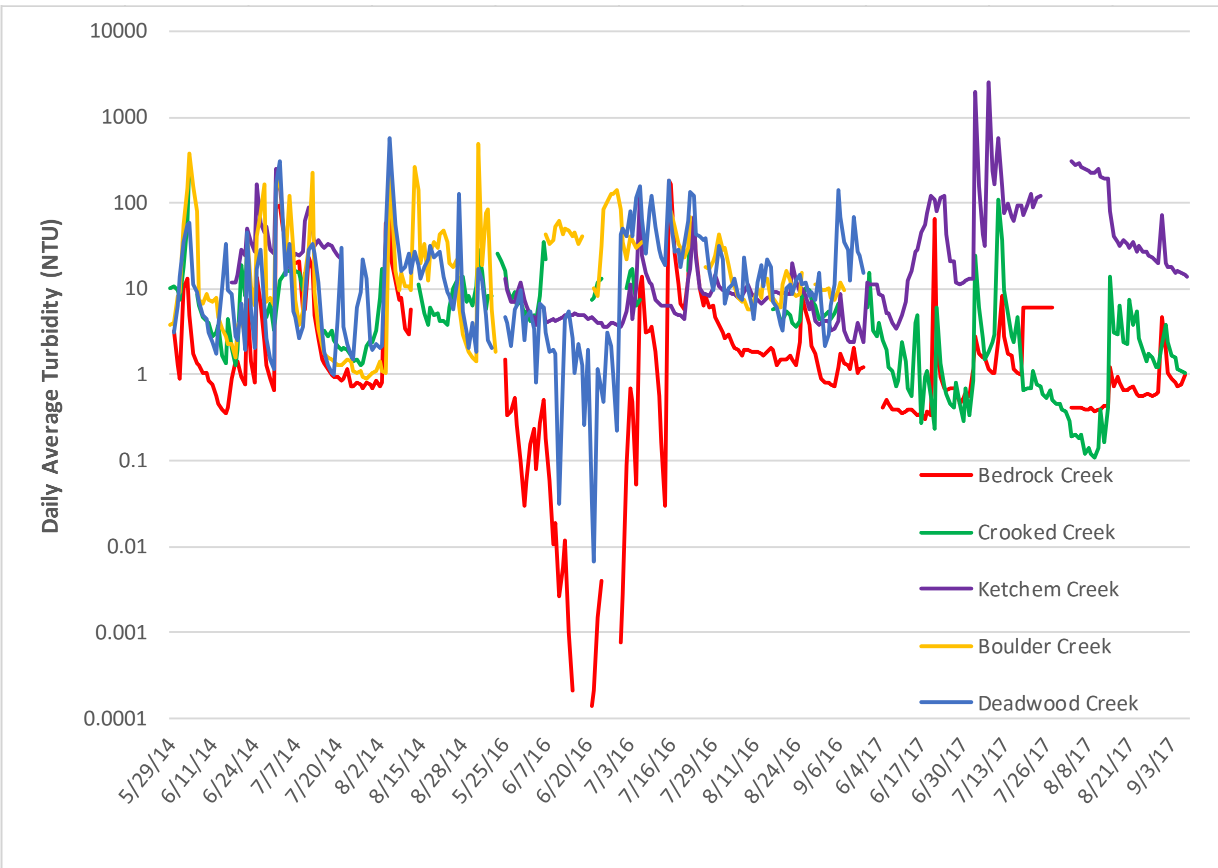


Figure 3-5. Time series comparison of turbidity values at Bedrock, Crooked, Boulder, Deadwood and Ketchem creeks

Table 3-5. Impairment status of Crooked, Boulder, Deadwood and Ketchem creeks for all designated uses

Designated Use	Numeric Criteria used for Evaluation*	Crooked Creek Impairment Status	Boulder Creek Impairment Status	Deadwood Creek Impairment Status	Ketchem Creek Impairment Status
Turbidity (Not applicable to groundwater)					
(A) Water Supply					
(i) drinking, culinary, and food processing	May not exceed 5 NTU above natural conditions.	Impaired	Impaired	Impaired	Impaired
(ii) agriculture, including irrigation and stock watering	May not cause detrimental effects on indicated use.	N/A	N/A	N/A	N/A
(iii) aquaculture	May not exceed 25 NTU above natural conditions.	Not Impaired	Not Impaired	Not Impaired	Impaired
(iv) industrial	May not cause detrimental effects on established water supply treatment levels.	N/A	N/A	N/A	N/A
(B) Water Recreation					
(i) contact recreation	May not exceed 5 NTU above natural conditions.	Impaired	Impaired	Impaired	Impaired
(ii) secondary recreation	May not exceed 10 NTU above natural conditions.	Impaired	Impaired	Impaired	Impaired
(C) Growth and Propagation of Fish, Shellfish, Other Aquatic Life, and Wildlife					
Same as (A)(iii)		Not impaired	Not impaired	Not Impaired	Impaired

N/A = not applicable since WQC is narrative rather than numeric.
*See Table 2-1 for language associated with WQC.

3.4. Hydrology Data Analysis

No continuous flow data were available within the Crooked Creek watershed to characterize flow regimes and calculate TSS loads. However, continuous water level data (not flow measurements) were collected during 2014 and 2016 at sampling stations CCW-16 and CCW-14 on Crooked Creek and Boulder Creek, respectively, and in 2017 at sampling station CCW-16 on Crooked Creek (Figure 3-1 and Table 3-2). Streamflow measures the amount of water flowing through a stream or river at a given time, while water level data measures the height of the water. Crooked Creek and Boulder Creek are the only waterbodies with available water level data in the watershed. The 2014, 2016 and 2017 period of record overlaps with nearly all the continuous turbidity data collected. The 2014 and 2016 water level data were used to develop statistical relationships to estimate continuous flow records for various points throughout the Crooked Creek watershed in the original Boulder and Deadwood creeks TMDLs (ADEC 2018). The 2017 water level data were used to confirm that this approach could be applied to Crooked Creek and Ketchem Creek as well (see section 3.4.2). The available data, methodology, and example flow results are presented below.

3.4.1. Available Hydrology Data

In addition to continuous water level data, available data included limited instantaneous flow measurements (Table 3-2) and cross-sections obtained during stream discharge surveys. While data were available during both 2014 and 2016 for Boulder and Crooked creeks, there were some nuances associated with each location that needed to be addressed to ensure the resulting flow estimates were applicable throughout the watershed. Most importantly, the 2016 Boulder Creek data were flawed because the pressure probe was malfunctioning; therefore, no water level data from 2016 were available for Boulder Creek. Only Crooked Creek had water level data that overlapped with the period of record for the continuous turbidity data (with the exception of July 6, 2016 to July 22, 2016 where data were missing); therefore, it was important to use this station.

The data collected from field surveys at the Crooked Creek BLM site showed considerable variability in the cross-sections obtained from the various field surveys (Figure 3-6). The stream at this location shifts, making it difficult to obtain measurements at the exact same location each time. This also introduces inherent variability in the observed cross-sections. Therefore, ADEC suggested review of the cross-sections collected at Boulder Creek, which had a more consistent cross-section across all survey dates (Figure 3-7).

Unfortunately, continuous water level data were only available for Boulder Creek during 2014. Therefore, the available data were evaluated for both Boulder and Crooked creeks. The results were then compared to determine whether the unit-area flow values estimated using Crooked Creek data were representative of other locations in the watershed (i.e., Boulder Creek).

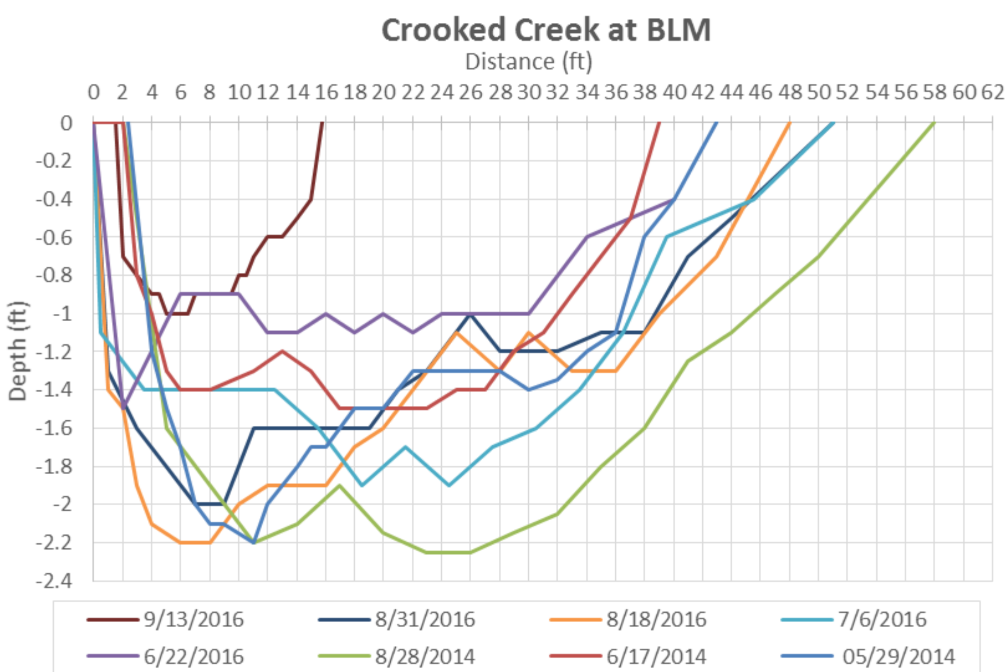


Figure 3-6. Cross-section data at Crooked Creek monitoring station

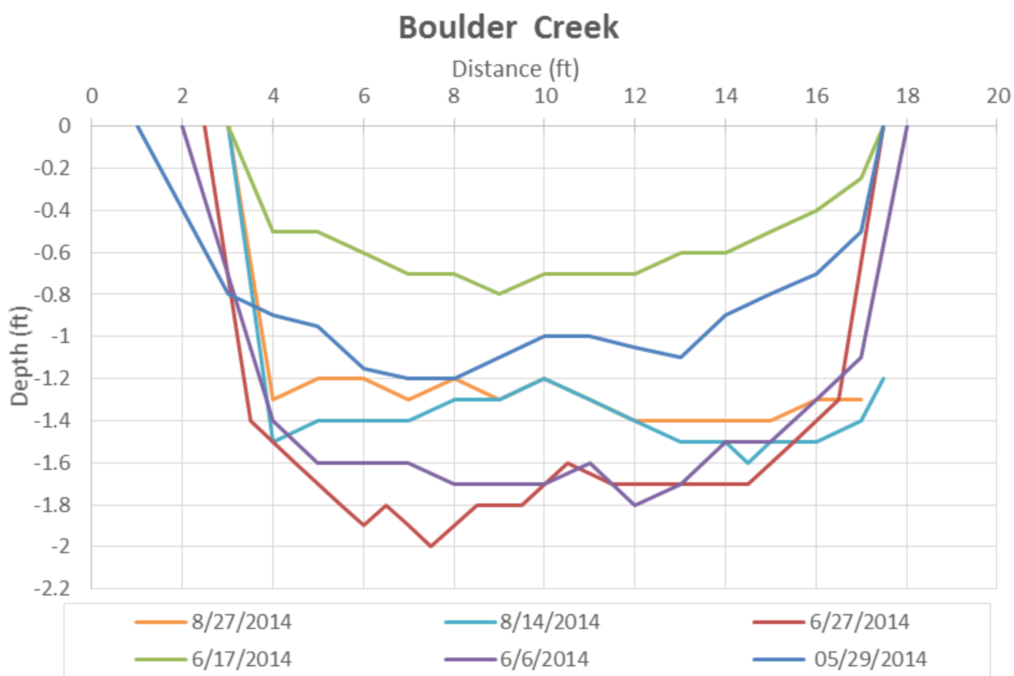


Figure 3-7. Cross-section data at Boulder Creek monitoring station

3.4.2. Methodology to Estimate Flow

The methodology to estimate flows based on continuous water level data first involved establishing a stage-discharge relationship for both Boulder and Crooked creeks using their respective cross-sections. This relationship was then applied to the continuous water level data to obtain estimated continuous flow records. Specific steps associated with this process are described below.

1. **Select representative cross-sections.** Representative cross-sections were selected for both Crooked and Boulder creeks. For Crooked Creek, the August 28, 2014 cross-section was chosen (Figure 3-6) and June 27, 2014 was selected for Boulder Creek (Figure 3-7). These cross-sections represented the largest cross-sections at each site. The largest cross-sections were selected as they are representative of the full suite of flow conditions, including higher flow conditions.

2. **Analyze cross-sections and estimate stage-discharge relationships.** The U.S. Department of Agriculture (USDA) WinXSPRO program was then used to analyze the cross-sections (Hardy et al. 2005). The program computes streamflow at a cross section using the simplified form of the continuity equation where discharge equals the product of velocity and cross-sectional area of flow ($Q=A \times V$). The computation of cross-sectional area is based on geometry and is determined by inputting incremental depths of water (i.e., water level) to a channel cross section. In addition to cross-sectional area, the top width, wetted perimeter, mean depth, and hydraulic radius are computed for each increment of water level. The program uses a resistance-equation approach (e.g., Manning's equation) for single cross section hydraulic analysis, and is capable of analyzing the geometry and hydraulics of a given channel cross section. The Thorne & Zevenbergen equation within the program was used to estimate the Manning's value (Hardy et al. 2005). This option employs a user-supplied diameter for bed material to estimate the roughness value. Weber (1986) reported small cobble with an average particle size of 89 millimeters (mm) for Crooked Creek at Central. This size was used as an initial value and then refined during the analysis to match observed field water level versus flow data. Ultimately, 90 mm was used in the analysis for Crooked Creek and 95 mm was used for Boulder

Creek. This process resulted in estimated flow values for incremental water levels for both Boulder and Crooked creeks.

3. **Verify stage-discharge relationships.** The estimated stage-discharge relationships were then plotted against the observed water level and discharge measurements to verify that the curves were representative of observations. Figure 3-8 and Figure 3-9 illustrate the comparisons for Boulder and Crooked creeks, respectively. The Boulder Creek graph shows 2014 data plotted on the rating curve developed using a cross-section from a 2014 discharge survey (Figure 3-8). For Crooked Creek, a 2014 cross-section date was used to develop the rating curve. This was compared to both the 2014, 2016 and 2017 measurements to validate its use across years (Figure 3-9). These comparisons illustrate that the rating curves provide a reasonable match to the observed measurements for both creeks, thus justifying their use to estimate continuous flow records.

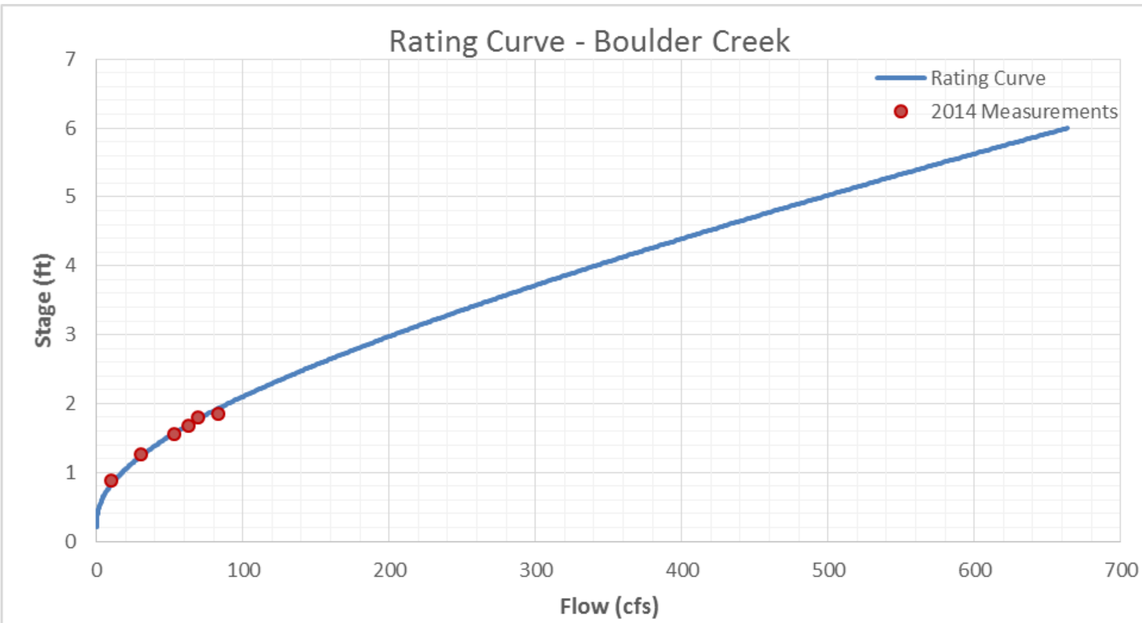


Figure 3-8. Stage-discharge relationship and observations at Boulder Creek

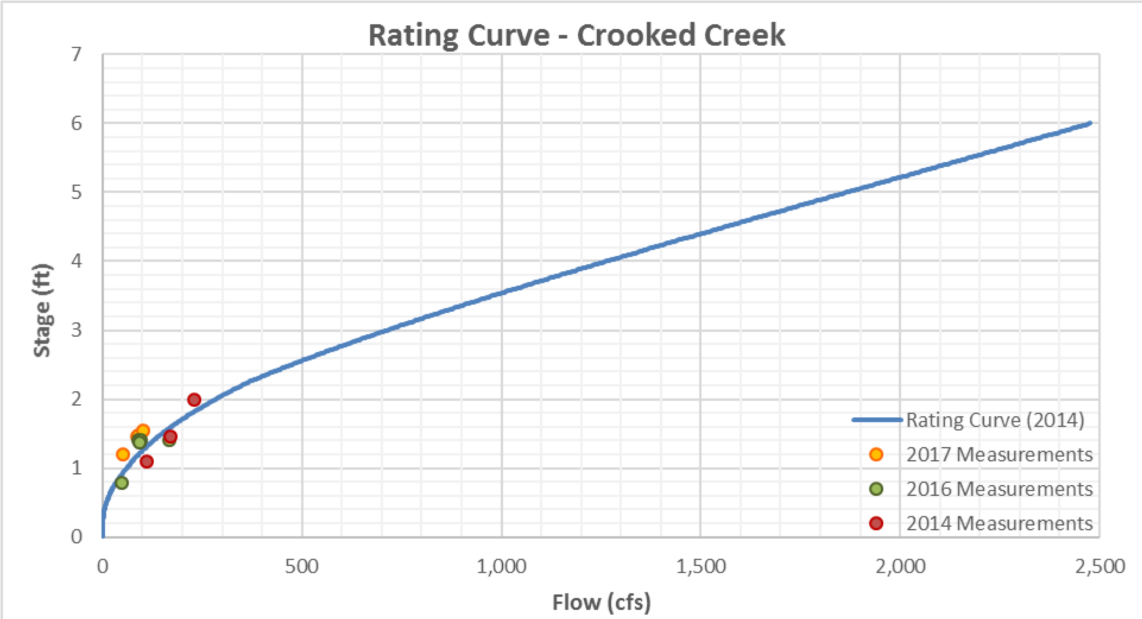


Figure 3-9. Stage-discharge relationship and observations at Crooked Creek

4. **Estimate continuous flow.** Continuous stream level data for 2014 were used to estimate a flow time series (in cubic feet per second [cfs]) using the stage-discharge relationships for each creek (described above in Steps 2 and 3). Specifically, for each stream level measurement, the corresponding flow was obtained from the rating curves. This was performed for both Boulder and Crooked creeks using their corresponding rating curves. The resulting continuous flow for 2014 is shown in Figure 3-10.

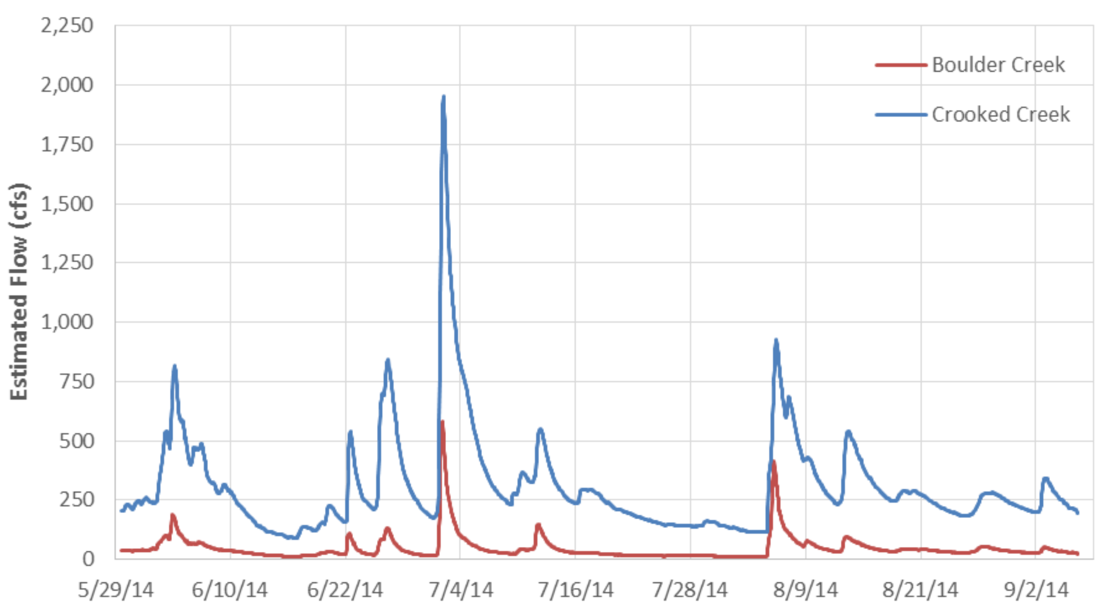
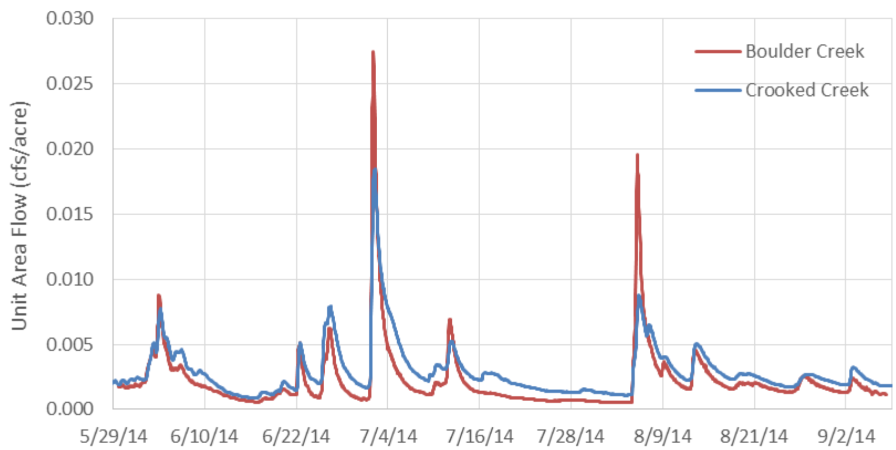


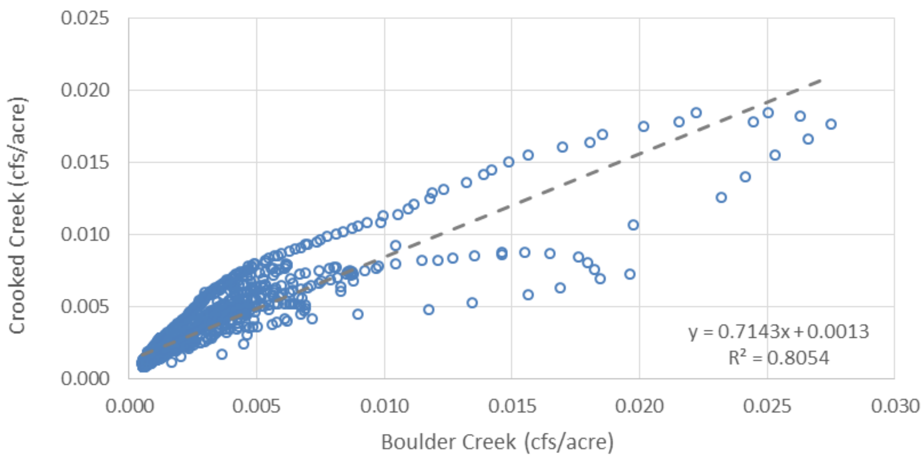
Figure 3-10. Estimated 2014 flows for Boulder and Crooked creeks

5. **Estimate and compare unit area flows.** Unit area flow time-series were then computed for Boulder and Crooked creeks by dividing their flow values estimated in Step #4 by their respective drainage

areas. The drainage areas for Boulder Creek and Crooked Creek at BLM site were 33.17 square miles (21,232 acres) and 165.14 square miles (105,692 acres), respectively. These calculations resulted in the estimated flow per acre in each drainage. They were then compared using several methods, as shown in Figure 3-11, including a time-series comparison, scatter plot, and flow duration curve.

The relationship established using the scatter plot (middle panel of Figure 3-11) indicates that the unit area flows are strongly correlated (R^2 = 0.81). The time-series comparison (top panel of Figure 3-11) demonstrates a consistent pattern and magnitude in the two drainages. Overall, these comparisons indicate that the unit area flow results are similar in Boulder and Crooked creeks. Therefore, it was determined that the Crooked Creek stage-discharge relationship could be used to estimate flows throughout the watershed for TMDL analysis. This verification process was important since the Crooked Creek cross-sections appeared less consistent than those observed at Boulder Creek; however, Crooked Creek was the only site with the 2014, 2016 and 2017 continuous stream height data necessary to calculate continuous flows that overlap with the period of record for the continuous turbidity measurements.





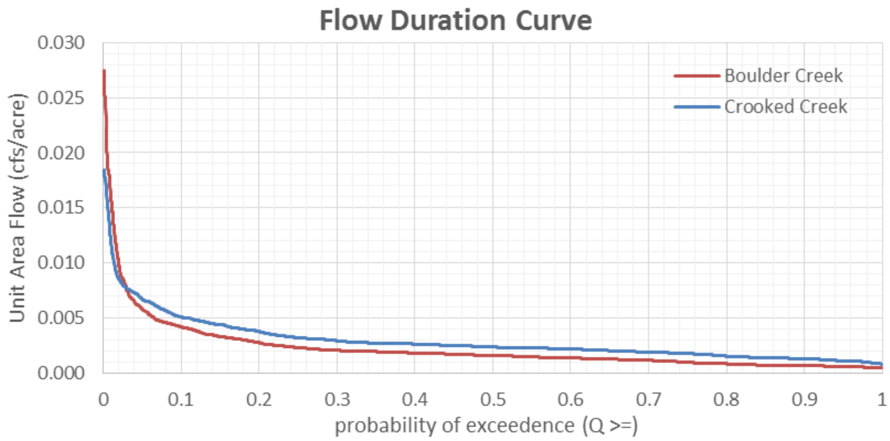


Figure 3-11. Comparisons of estimated unit area flows for Boulder and Crooked creeks in 2014

3.4.3. Flow Estimates

To supplement the 2014 and 2016 results and to overlap with the entire turbidity data period of record, the Crooked Creek rating curve was used to determine the flow corresponding to continuous stream level measurements in Crooked Creek for 2017. For each stream level measurement, the corresponding flow was obtained from the rating curve, resulting in a complete time-series. Continuous water level measurements are missing from July 7, 2016 to July 20, 2016, so the last July 6, 2016 value was carried through until data were available again on July 21, 2016 (Figure 3-12). Continuous 2017 water level measurements are available for June 16th through September 7th (see Figure 3-12 for flow estimates for all three years). This compete flow time-series was then divided by the drainage area to Crooked Creek at BLM (165.14 square miles [105,692 acres]), resulting in a continuous unit area flow time series (Figure 3-13). This continuous unit area flow dataset can be extrapolated to any point in the watershed based on drainage area.

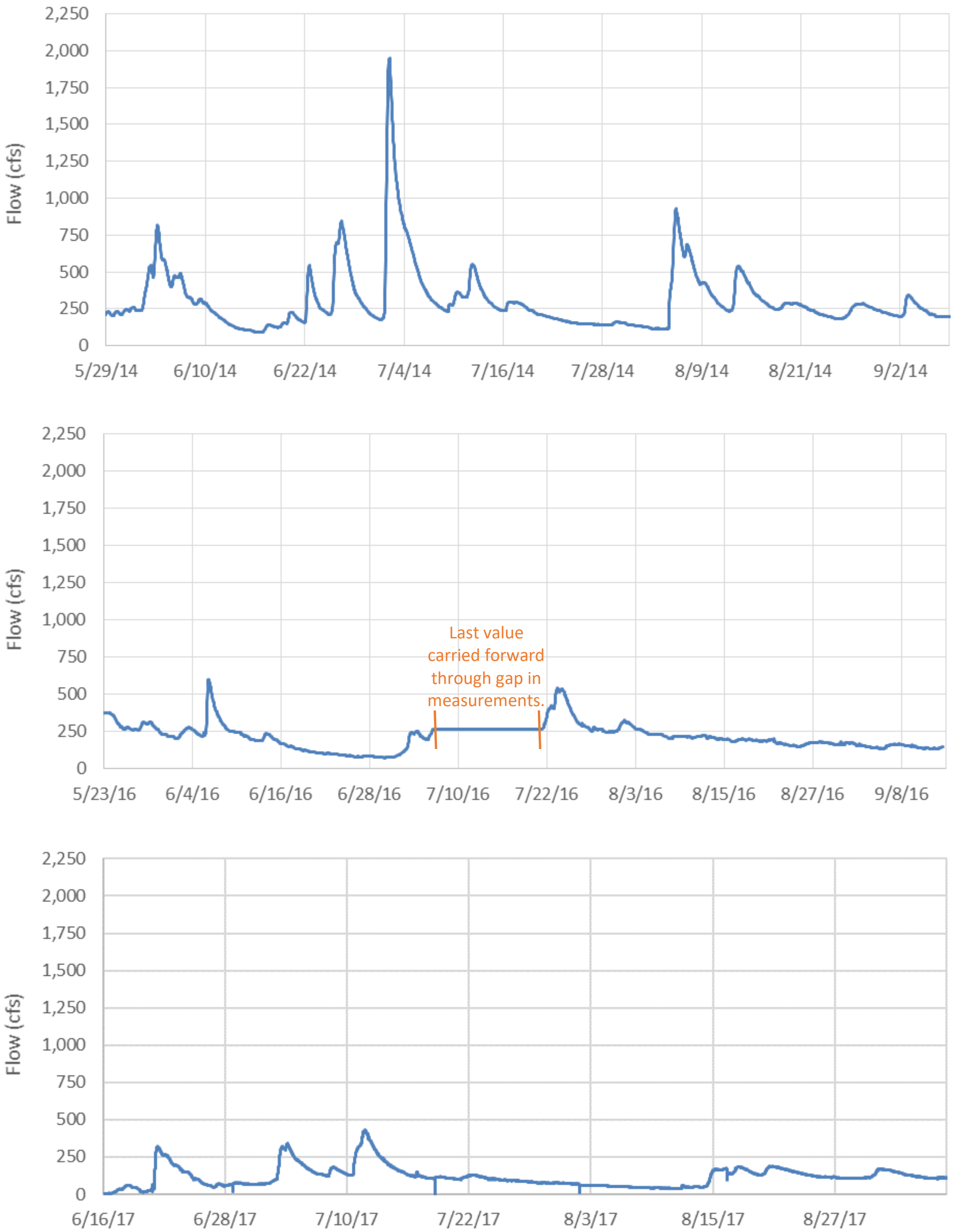


Figure 3-12. Estimated flows at Crooked Creek at BLM (2014, 2016 and 2017)

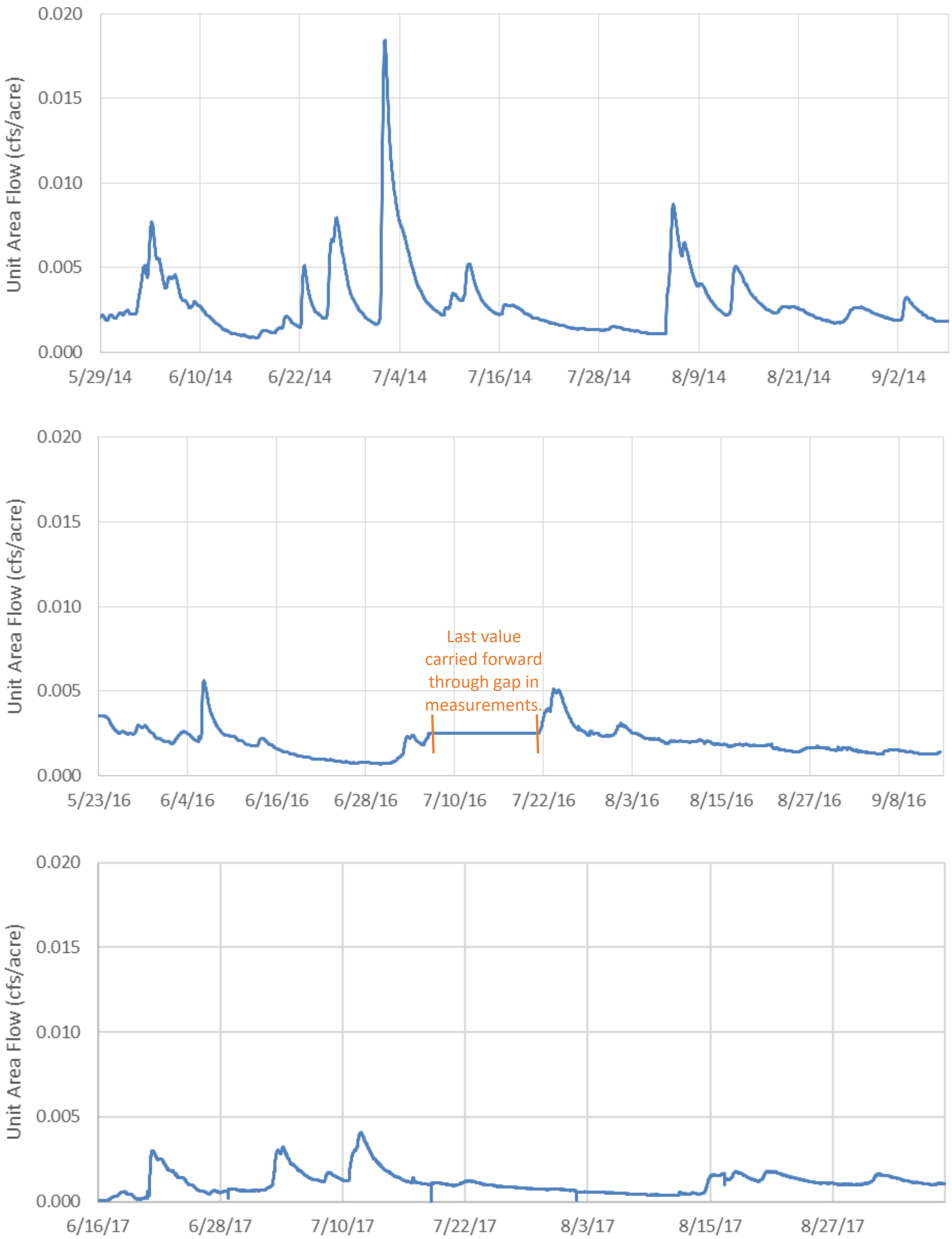


Figure 3-13. Estimated unit area flows at Crooked Creek at BLM (2014, 2016 and 2017)

The precipitation data at the Eagle Summit climate station (Figure 1-6) were used to demonstrate that flow estimates for 2014, 2016 and 2017 are representative of longer-term conditions in the watershed. Eagle Summit data were used because they were the most complete raw weather data available to calculate annual precipitation. The other Circle Hot Springs weather station was missing several days of precipitation data and the Central station did not have precipitation data for 2014, 2016 and 2017. Daily precipitation data were available at the Eagle Summit station from 1999 through 2017. The average annual precipitation at Eagle summit was 18 inches, with a range from 13.4 inches in 2013 to 23.3 in 2011 and 2014. The total precipitation in 2014, 2016 and 2017 were 23.3, 18 and 20 inches, respectively, suggesting that 2014 was a wet year while 2016 and 2017 were average years. These total precipitation values support the estimated flow values presented in Figure 3-12 and Figure 3-13, which show higher flows in 2014 than in 2016 and 2017. Using flow estimates for wet and average years in Crooked and Ketchem creeks will result in the calculation of loading capacities that are protective of dry years as well.

3.5. Data Analyses for Impaired Reaches

The following sections discuss data analyses conducted to evaluate any important trends or impairments of water quality in the Crooked Creek, Boulder Creek, Deadwood Creek and Ketchem Creek subwatersheds. Detailed analyses of turbidity and TSS data are described below, including a comparison to the TMDL threshold values and numeric targets by flow regime for turbidity and TSS, respectively. Data analyzed in this section consist of a combination of both continuous and grab sample data for ease of comparison to the water quality thresholds and targets, including storm-related and month-to-month trends and analyses by flow regime.

Flow duration curves were used to observe the data at specific flow regimes. Flow duration curves are an important analytical tool used to evaluate historical flow conditions. EPA's duration curve guidance document (USEPA 2007) states:

> *"Flow duration curve analysis looks at the cumulative frequency of historic flow data over a specified period. A flow duration curve relates flow values to the percent of time those values have been met or exceeded. The use of "percent of time" provides a uniform scale ranging between 0 and 100. Thus, the full range of stream flows is considered. Low flows are exceeded a majority of the time, while floods are exceeded infrequently.*
>
> *A basic flow duration curve runs from high to low along the x-axis. The x-axis represents the duration amount, or "percent of time", as in a cumulative frequency distribution. The y-axis represents the flow value (e.g. cubic feet per second) associated with that "percent of time" (or duration)…"*

Flow duration curve intervals can be grouped into several broad categories or zones. These zones provide additional insight about conditions and patterns associated with the impairments. The percentages represent the percent of time a flow can be found within the stream, based on historical conditions. A common way to look at the duration curve is by dividing it into five zones: one representing very high flows (0-10%), another for high flow conditions (10-40%), one covering mid-range flows (40-60%), another for low flow conditions (60-90%), and one representing very low flows (90-100%). This particular approach places the midpoints of the high, mid-range, and low flow zones at the 25^{th}, 50^{th}, and 75^{th} percentiles, respectively (i.e., the quartiles). The very high zone is centered at the 5^{th} percentile, while the very low zone is centered at the 95^{th} percentile. In sum, low flows are exceeded a majority of the time, whereas floods or high flows are exceeded infrequently.

Continuous flow records for Crooked, Boulder, Deadwood and Ketchem creeks were developed using the unit-area flow presented in Figure 3-13 above. The continuous unit-area flows were multiplied by the drainage areas for Crooked, Boulder, Deadwood and Ketchem creeks (343.8, 33.2, 39.8 and 21.4 square miles, respectively). These subwatershed-specific flows were evaluated in a flow duration curve framework (USEPA 2007) and are presented in Figure 3-14, Figure 3-17, Figure 3-16 and Figure 3-17. The flow duration curves were applied to both the water quality analyses and the loading capacity calculations presented in Sections 3.5.1, 3.5.4, and 5.

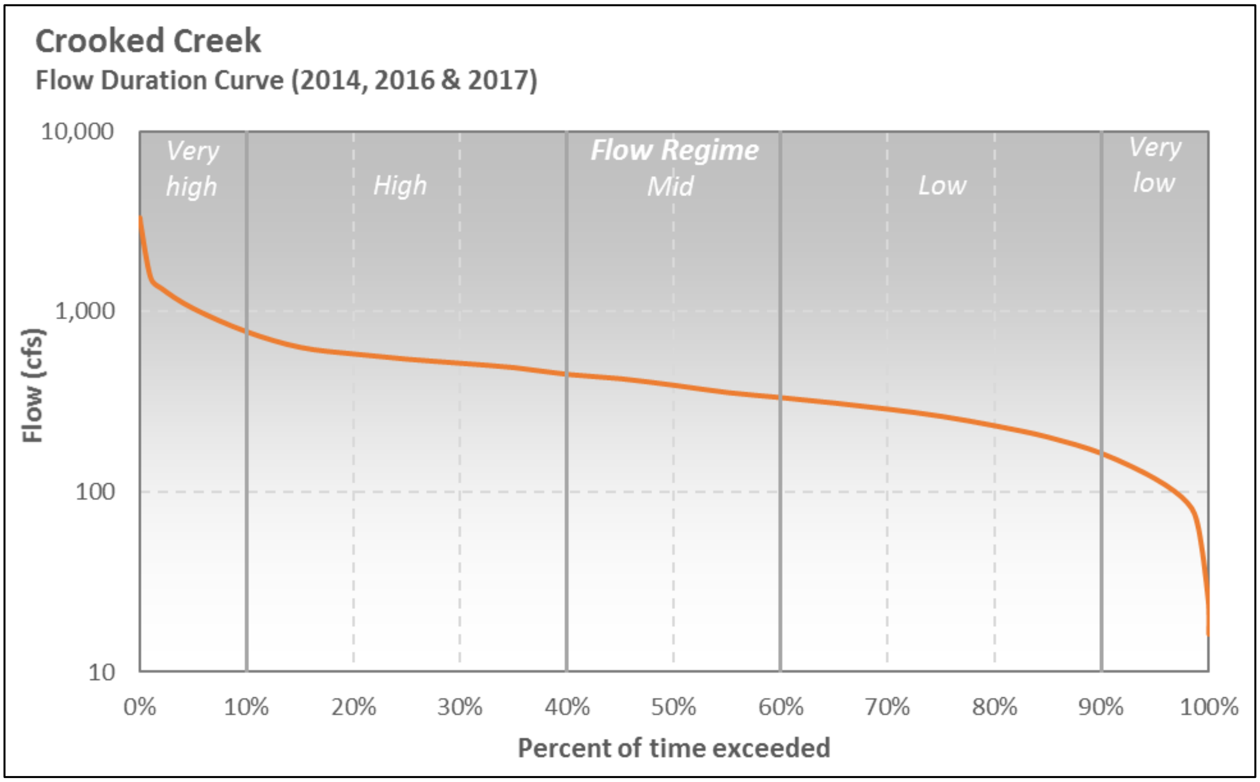


Figure 3-14. Crooked Creek flow duration curve

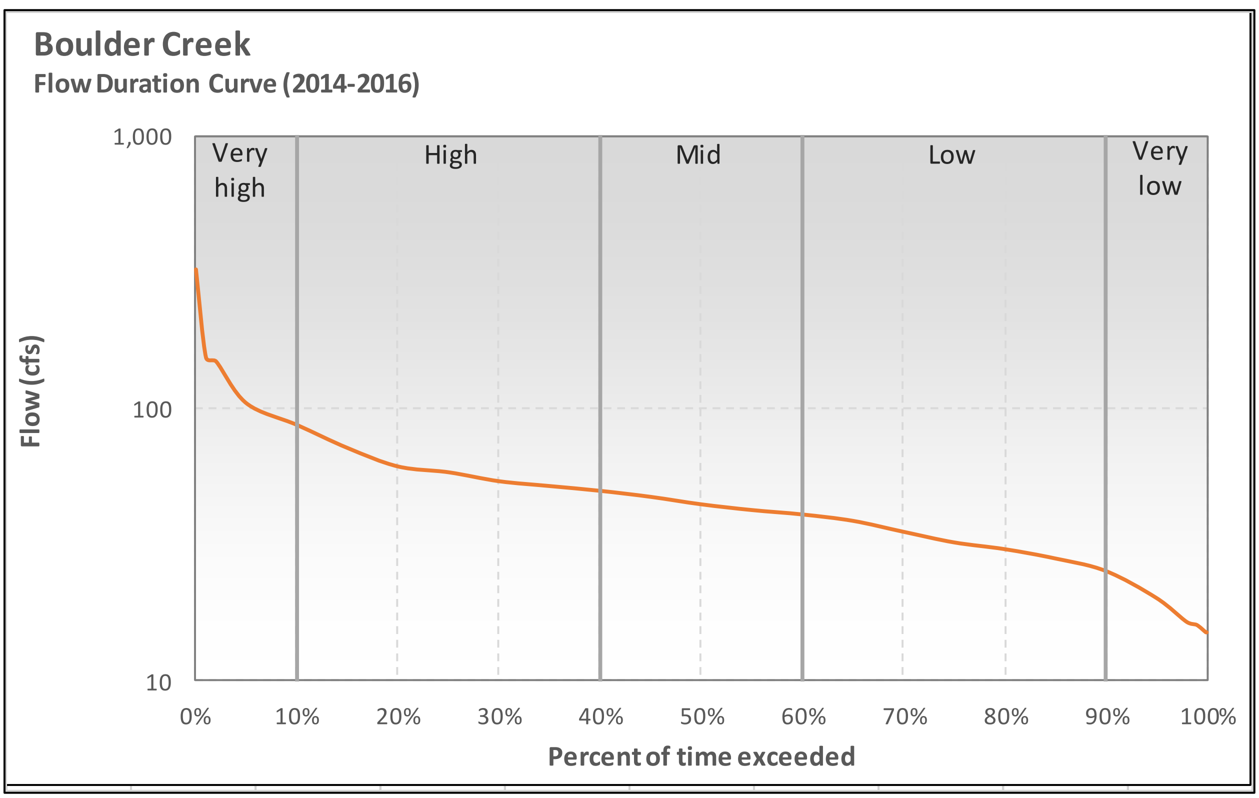


Figure 3-15. Boulder Creek flow duration curve

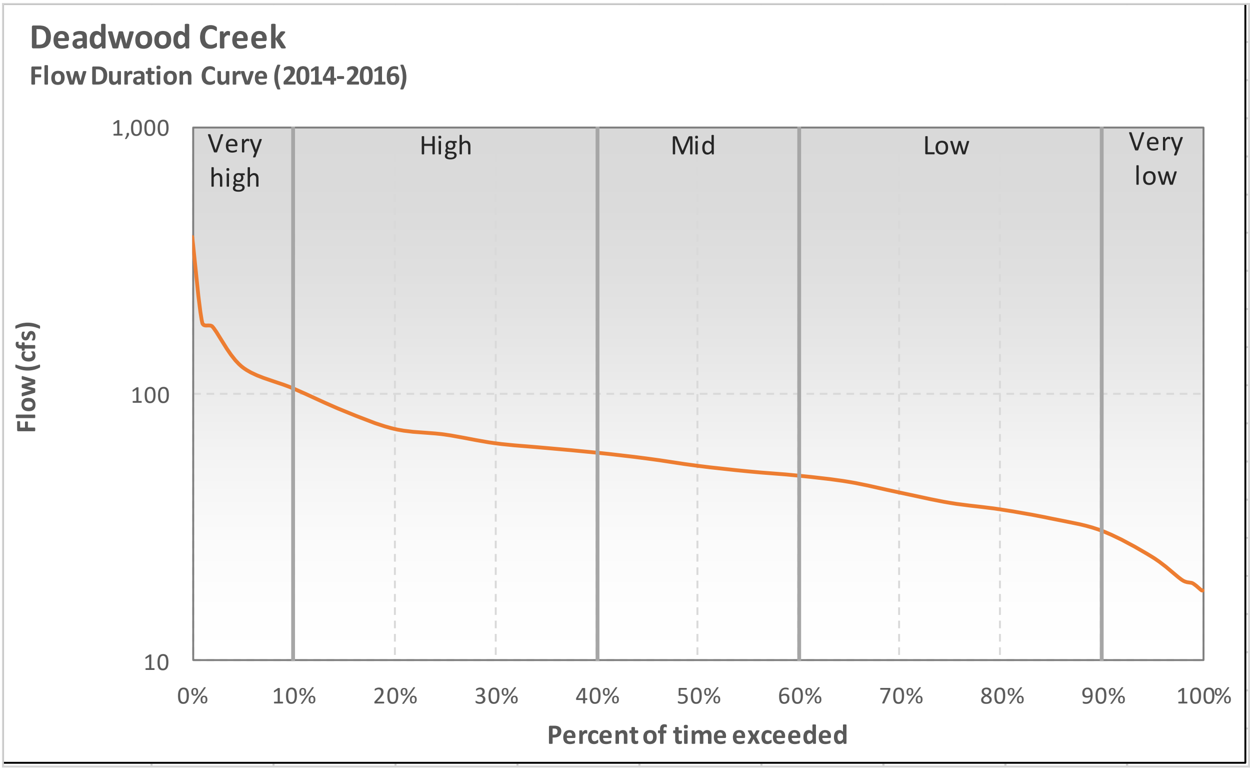


Figure 3-16. Deadwood Creek flow duration curve

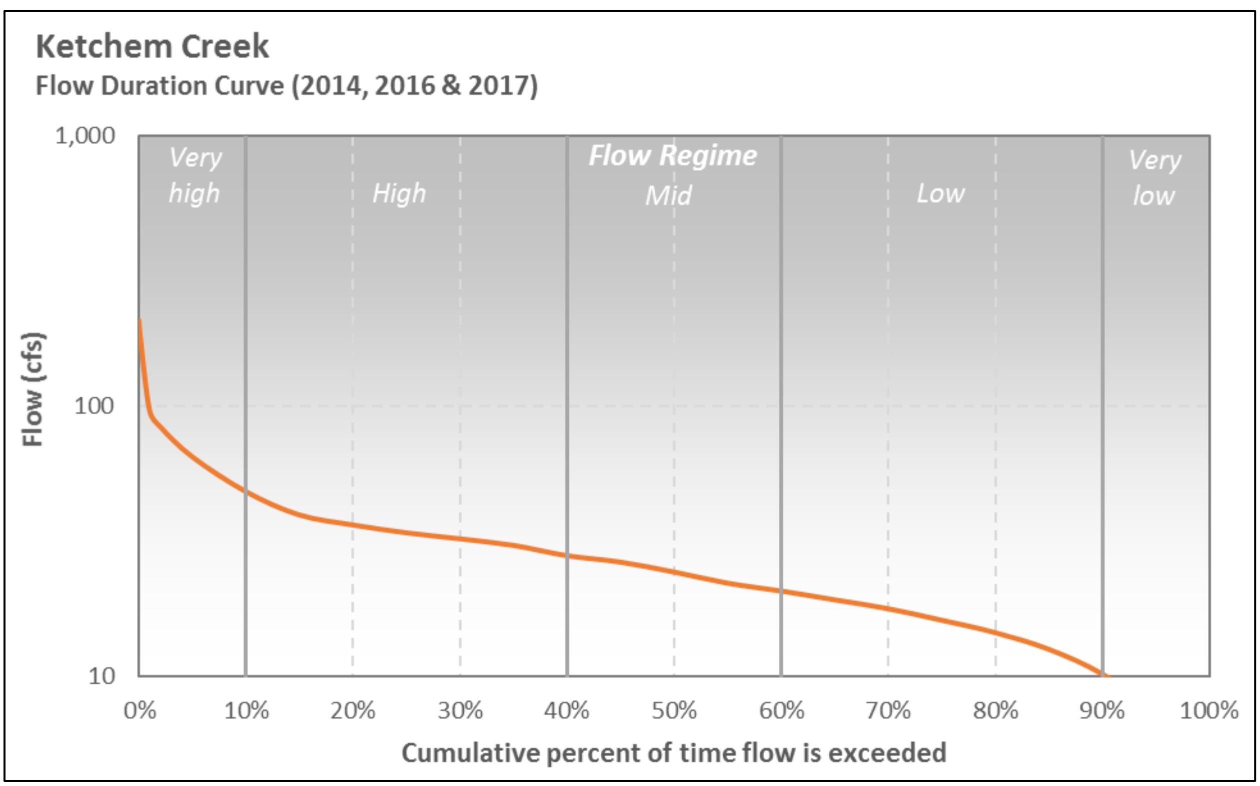


Figure 3-17. Ketchem Creek flow duration curve

3.5.1. Crooked Creek Water Quality Data Analysis

The Crooked Creek watershed is located about 100 miles northeast of Fairbanks, Alaska and drains an area of 343.8 square miles. The town of Central is located in the north-central part of the watershed and the town of Circle is located north of the Crooked Creek watershed. Turbidity and TSS data were collected at sampling station CCW-16 located near the lower end of Crooked Creek below the confluence with Boulder Creek.

Continuous turbidity data were collected at this station during 2014, 2016 and 2017 (Table 3-6 summarizes the average daily values). Fewer data were available for 2016 than 2014 and 2017 (Table 3-6). Though the median measured turbidity in 2014, 2016 and 2017 were 6 NTU, 7 NTU and 1 NTU, respectively, the range of data in 2014, 1 NTU to 305 NTU, was greater than in 2016 and 2017 (4 to 48 NTU in 2016 and 0.1 to 107 NTU in 2017) (Table 3-6). Average monthly and storm-related turbidity measurements for 2014, 2016 and 2017 equaled or exceeded their respective threshold values except for July and August, which had average turbidity values below the threshold (Table 3-7). Specifically, when comparing individual observed turbidity measurements to the threshold, the percent exceedance ranges from 20% in July to 92% in May, while storm samples exceeded the threshold 25% of the time (Table 3-7).

Table 3-6. Summary statistics for Crooked and Bedrock creeks average daily turbidity measurements by year

Summary Statistic	Crooked Creek by Year			Bedrock Creek by Year (Reference Condition)		
	2014	2016	2017	2014	2016	2017
Number of observations	82	48	100	75	112	90
Average turbidity (NTU)	14.2	9.9	3.7	9.3	6.2	2.2
Minimum turbidity (NTU)	1.3	3.7	0.1	0.4	0.0	0.3
10th percentile turbidity (NTU)	1.9	4.2	0.2	0.7	0.0	0.4
25th percentile turbidity (NTU)	3.2	4.9	0.5	0.8	0.1	0.4
Median turbidity (NTU)	6.0	7.1	1.2	1.3	1.3	0.7
75th percentile turbidity (NTU)	11.3	10.3	2.7	7.4	2.3	1.5
90th percentile turbidity (NTU)	16.5	18.3	6.0	22.9	8.2	6.0
Maximum turbidity (NTU)	304.7	47.6	107.0	95.4	183.3	64.2

Table 3-7. Summary statistics for Crooked Creek average daily turbidity in 2014, 2016 and 2017

Summary Statistic	Month/Condition					
	Storm-related	May	June	July	August	September
Number of observations	12	13	62	56	68	19
Average turbidity (NTU)	71.1	11.2	5.4	4.2	4.8	6.4
Minimum turbidity (NTU)	16.0	4.9	0.2	0.3	0.1	1.1
10th percentile turbidity (NTU)	16.4	6.1	0.6	0.6	0.2	1.2
25th percentile turbidity (NTU)	16.8	7.4	1.1	0.8	1.5	2.1
Median turbidity (NTU)	30.9	9.7	3.2	2.2	4.2	4.9
75th percentile turbidity (NTU)	70.3	10.5	6.0	5.2	6.5	7.5
90th percentile turbidity (NTU)	181.5	20.4	11.5	13.6	10.3	11.7
Maximum turbidity (NTU)	304.7	25.5	45.8	16.3	17.5	29.4
Turbidity threshold (NTU)	58.6	5.4	5.4	6.8	6.5	6.0

Summary Statistic	Month/Condition					
	Storm-related	May	June	July	August	September
Percent exceeding WQS	25%	92%	27%	20%	25%	32%

Note: See Table 2-2 for comparison with Bedrock Creek summary statistics by month and storm-conditions.

Corresponding flow values were determined for each day with a turbidity measurement using the continuous flow record shown in Figure 3-14. The turbidity data were then evaluated by flow regime (Table 3-8). The highest turbidity observations occurred at the very high and high flow regimes (see Figure A-1 in Appenidx A for a graphic representation of these data).

Table 3-8. Summary statistics for Crooked Creek turbidity measurement by flow regime in 2014, 2016 and 2017

Summary Statistic	Flow Regime				
	Very high	High	Mid	Low	Very low
Number of Observations	15	59	43	70	27
Average turbidity (NTU)	59.4	9.8	6.0	3.1	0.6
Minimum turbidity (NTU)	6.4	0.2	1.4	0.3	0.1
10th percentile turbidity (NTU)	9.8	3.7	2.0	0.7	0.1
25th percentile turbidity (NTU)	13.6	4.9	3.1	1.2	0.2
Median turbidity (NTU)	16.6	7.5	5.1	1.9	0.4
75th percentile turbidity (NTU)	52.9	13.7	7.6	4.1	0.5
90th percentile turbidity (NTU)	156.7	19.0	10.6	6.9	0.9
Maximum turbidity (NTU)	304.7	36.9	19.4	17.5	5.1

Turbidity data are represented graphically in Figure A-1 through Figure A-4 in Appendix A for 2014, 2016 and 2017. The water quality duration curve (Figure A-1) plots the flow percentiles associated with measured turbidity levels in relation to the threshold values for the month or condition during which the sample was taken. The daily flow estimated for Crooked Creek and its associated flow percentile (Figure 3-14) were included in the analyses with the turbidity measurement collected on the same day. A duration curve accounts for how stream flow patterns affect changes in water quality (USEPA 2007). Displaying water quality data and the daily average flow on the date of the sample (expressed as a flow duration curve interval) provides insight into the conditions associated with water quality impairments. Points of observed data that plot above the threshold, numeric target, or loading capacity lines represent an exceedance of the standard/assimilative capacity while values below are in compliance and the individual points in this plot have different symbols for storm-related conditions and month. The target/threshold lines across the plots are not smooth because they vary for storm-related conditions and by month and were determined for each individual sampling event.

For Crooked Creek, higher turbidity levels were observed during the higher flow regimes and these values were frequently associated with storm conditions. Turbidity samples associated with the highest 10% and 20% of flows (i.e., in the upper end of the high flow regime) were either at or above threshold levels, while samples taken during the very high flow regime were typically above the threshold (Figure A-1). Figure A-2, Figure A-3 and Figure A-4 present the data in a time series analysis over the observed months of May through September for 2014, 2016 and 2017, respectively, indicating the samples that were associated with storm conditions. The 2014 and 2017 data do not appear to follow a seasonal trend except that the storm-related values are typically higher than the non-storm measurements. In 2014 and 2017, more samples are observed below the threshold level (Figure A-2 and Figure A-4) than in 2016 (Figure

A-3). Turbidity samples in 2016 also appear to exhibit a stronger seasonal trend with higher turbidity values in June and July and decreasing levels in August and September (Figure A-3).

Grab samples were collected at two water quality stations on Crooked Creek (Crooked Creek below Bedrock [CCW-11] and Crooked Creek at BLM [CCW-16]) in 2014 and 2016 and at Crooked Creek at BLM (CCW-16) in 2017. Four TSS grab samples were taken in Crooked Creek below Bedrock in 2014 in June and August and seven TSS grab samples were collected at that same station in 2016 between June and August (Table 3-9). Six TSS grab samples were collected at Crooked Creek at BLM in 2014 between June and August, seven samples were collected at that same station in 2016 between June and September and 8 samples were collected at in 2017 between June and August. Measured TSS ranged from 1 mg/L at Crooked Creek below Bedrock and Crooked Creek at BLM to 118 mg/L at Crooked Creek at BLM, and were collected during four of the five flow regimes; very high, high, low and very low (Figure 3-18; six samples are not included in the graph because they did not have associated flow values). Six of the 21 samples at Crooked Creek at BLM exceeded the target TSS concentration. Two of the samples collected were determined to be storm-related. These samples were collected in June and July 2016; however, they did not exceed the storm-related TSS numeric target.

Table 3-9. Summary statistics for Crooked Creek 2014, 2016 and 2017 TSS measurements

Years	2014 – Crooked Creek below Bedrock	2014 – Crooked Creek at BLM	2016 – Crooked Creek below Bedrock	2016– Crooked Creek at BLM	2017 Crooked Creek at BLM
Number of observations	4	6	7	7	8
Average TSS (mg/L)	11.0	25.0	11.9	24.5	3.6
Minimum TSS (mg/L)	9.3	2.5	1.0	2.2	1.0
10th percentile TSS (mg/L)	9.9	3.6	1.4	2.3	1.1
25th percentile TSS (mg/L)	10.8	5.5	1.9	2.6	2.2
Median TSS (mg/L)	11.5	11.5	16.7	3.7	4.0
75th percentile TSS (mg/L)	11.7	44.3	19.9	21.2	4.6
90th percentile TSS (mg/L)	11.7	59.9	21.6	62.4	5.4
Maximum TSS (mg/L)	11.7	65.7	22.0	118.0	6.4

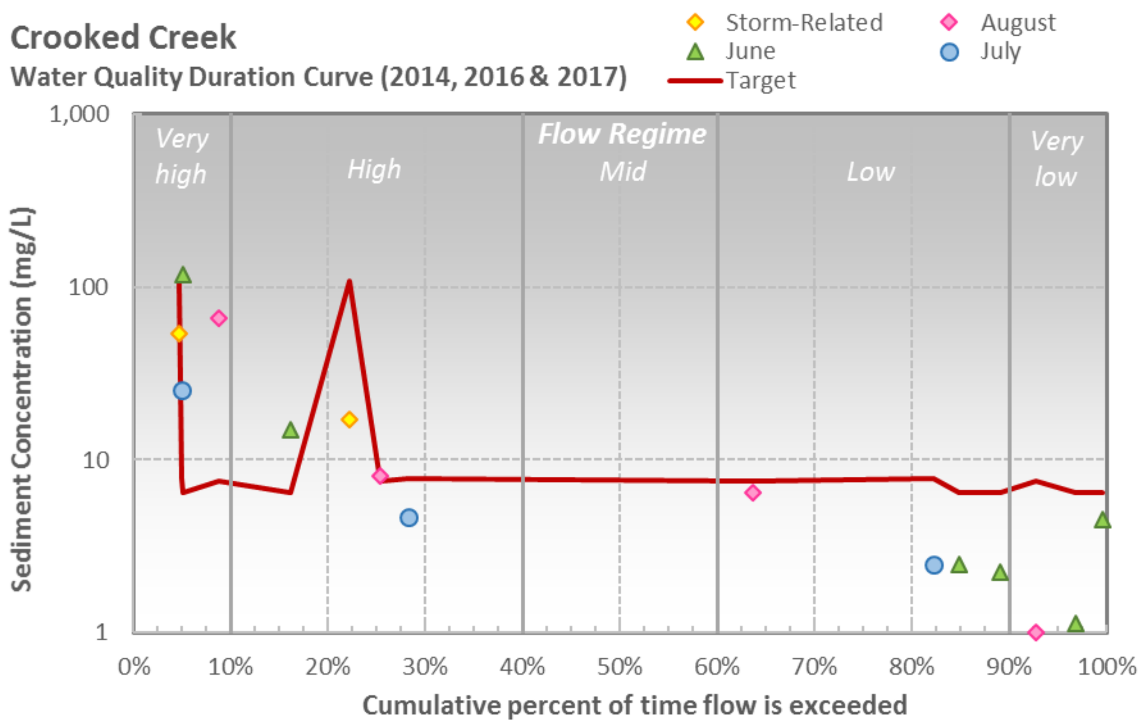


Figure 3-18. TSS values for Crooked Creek as a function of flow (2014, 2016 and 2017)

3.5.2. Boulder Creek Water Quality Data Analysis

The Boulder Creek subwatershed is located west of the town of Central and drains an area of 33.2 square miles. Turbidity and TSS data were collected at sampling station CCW-14 located near the outlet of the subwatershed above Steese Bridge slightly upstream of the confluence of Boulder Creek and Crooked Creek.

Continuous turbidity data were collected at this station during both 2014 and 2016 (

Table 3-10 summarizes the average daily values). Fewer data were available for 2016 than 2014; approximately 30 fewer days had data in 2016 (

Table 3-10). Though the median measured turbidity in 2014 and 2016 were 8 NTU and 20 NTU, respectively, the range of data in 2014, 1 NTU to 479 NTU, was greater than in 2016, 6 NTU to 139 NTU (

Table 3-10). Average monthly and storm-related turbidity measurements for 2014 and 2016 equaled or exceeded their respective threshold values (Table 3-11). Specifically, when comparing the observed turbidity measurements to the threshold, the percent exceedance ranges from 29% in July to 80% in September, while storm samples exceeded the threshold 35% of the time (Table 3-11).

Table 3-10. Summary statistics for Boulder and Bedrock creeks average daily turbidity measurements by year

Summary Statistic	Boulder Creek by Year		Bedrock Creek by Year (Reference Condition)	
	2014	2016	2014	2016
Number of observations	102	76	75	112
Average turbidity (NTU)	40.2	30.7	9.3	6.2
Minimum turbidity (NTU)	0.9	5.7	0.4	0.0
10th percentile turbidity (NTU)	1.3	7.6	0.7	0.0
25th percentile turbidity (NTU)	2.1	9.8	0.8	0.1
Median turbidity (NTU)	7.7	20.3	1.3	1.3
75th percentile turbidity (NTU)	32.4	41.5	7.4	2.3
90th percentile turbidity (NTU)	133.2	65.5	22.9	8.2
Maximum turbidity (NTU)	478.9	139.1	95.4	183.3

Table 3-11. Summary statistics for Boulder Creek average daily turbidity in 2014 and 2016

Summary Statistic	Month/Condition					
	Storm-related	May	June	July	August	September
Number of observations	55	3	37	28	40	15
Average turbidity (NTU)	73.6	5.4	23.4	14.6	8.7	49.6
Minimum turbidity (NTU)	15.2	3.7	1.6	0.9	1.0	1.4
10th percentile turbidity (NTU)	18.8	3.8	2.7	1.0	1.6	3.5
25th percentile turbidity (NTU)	27.0	3.9	6.3	1.3	6.0	7.7
Median turbidity (NTU)	40.5	4.1	8.2	1.6	8.2	9.9
75th percentile turbidity (NTU)	97.7	6.2	42.2	8.0	11.2	15.3
90th percentile turbidity (NTU)	153.0	7.5	49.2	29.4	13.1	81.2
Maximum turbidity (NTU)	385.5	8.3	102.0	226.0	29.9	478.9
Turbidity threshold (NTU)	58.6	5.4	5.4	6.8	6.5	6.0
Percent exceeding WQS	35%	33%	76%	29%	68%	80%

Note: See Table 2-2 for comparison with Bedrock Creek summary statistics by month and storm-conditions.

Corresponding flow values were determined for each day with a turbidity measurement using the continuous flow record used to develop Figure 3-14. The turbidity data were then evaluated by flow regime (Table 3-12). The highest turbidity observations occur at the very high, high and very low flow regimes (see Figure A-5 in Appendix A for a graphic representation of these data).

Table 3-12. Summary statistics for Boulder Creek turbidity measurement by flow regime in 2014 and 2016

Summary Statistic	Flow Regime				
	Very high	High	Mid	Low	Very low
Number of Observations	19	53	30	55	19
Average turbidity (NTU)	133.8	31.1	25.0	11.7	41.7
Minimum turbidity (NTU)	9.6	1.5	1.3	0.9	1.0
10th percentile turbidity (NTU)	16.2	3.0	2.1	1.1	1.3
25th percentile turbidity (NTU)	41.2	7.6	5.8	2.2	2.3
Median turbidity (NTU)	122.6	17.1	10.4	8.0	10.0

Summary Statistic	Flow Regime				
	Very high	High	Mid	Low	Very low
75th percentile turbidity (NTU)	197.5	29.9	38.9	12.7	85.4
90th percentile turbidity (NTU)	265.8	43.9	54.2	32.3	127.5
Maximum turbidity (NTU)	385.5	478.9	85.4	50.1	139.1

Turbidity data are represented graphically in Figure A-5 through Figure A-7 in Appendix A for 2014 and 2016. The water quality duration curve (Figure A-5) plots the flow percentiles associated with measured turbidity levels in relation to the threshold values for the month or condition during which the sample was taken. The daily flow estimated for Boulder Creek and its associated flow percentile (Figure 3-14) was included in the analyses with the turbidity measurement collected on the same day. A duration curve accounts for how stream flow patterns affect changes in water quality (USEPA 2007). Displaying water quality data and the daily average flow on the date of the sample (expressed as a flow duration curve interval), provides insight into the conditions associated with water quality impairments. Points of observed data that plot above the threshold, numeric target, or loading capacity lines represent an exceedance of the standard/assimilative capacity while values below are in compliance and the individual points in this plot have different symbols for storm-related conditions and month. The target/threshold lines across the plots are not smooth because they vary for storm-related conditions and by month and were determined for each individual sampling event.

For Boulder Creek, higher turbidity levels were observed during the higher flow regimes and these values were frequently associated with storm conditions. Turbidity samples associated with the highest 10% and 20% of flows (i.e., in the upper end of the high flow regime) were either at or above threshold levels, while samples taken during the very high flow regime were typically above the threshold (Figure A-5). Figure A-6 and Figure A-7 present the data in a time series analysis over the observed months of May through September for 2014 and 2016, respectively, indicating the samples that were associated with storm conditions. The 2014 data do not appear to follow a seasonal trend except that the storm-related values are typically higher than the non-storm measurements. In 2014, more samples are observed below the threshold level than in 2016 (Figure A-6). As shown in Figure A-7, non-storm 2016 turbidity data exceeded the monthly threshold in all samples but four and about half of the storm samples exceeded the storm-related threshold value. Turbidity samples in 2016 also appear to exhibit a stronger seasonal trend with higher turbidity values in June and July and decreasing levels in August and September.

Fourteen TSS grab samples were taken in Boulder Creek in 2014 and 2016 (

Table 3-13). Measured TSS ranged from 2 mg/L to 68 mg/L, and were taken during all five flow regimes (Figure 3-19). Six of the 14 samples exceeded the target TSS concentration; five of these samples were taken during very high and high flows and exceedances were observed in all months except May (Figure 3-19). Two of the samples collected were determined to be storm-related. The highest measurement was collected in July and was the maximum value of the 2016 dataset, while the other storm sample was collected in August 2014. Neither storm sample exceeded the storm-related TSS numeric target.

Table 3-13. Summary statistics for Boulder Creek TSS measurements (2014 & 2016)

Years	2014	2016
Number of observations	6	8
Average TSS (mg/L)	12.8	26.3
Minimum TSS (mg/L)	1.7	2.3
10th percentile TSS (mg/L)	2.0	5.7
25th percentile TSS (mg/L)	3.2	7.3
Median TSS (mg/L)	9.5	21.0
75th percentile TSS (mg/L)	14.7	37.0
90th percentile TSS (mg/L)	26.9	56.5
Maximum TSS (mg/L)	38.5	68.0

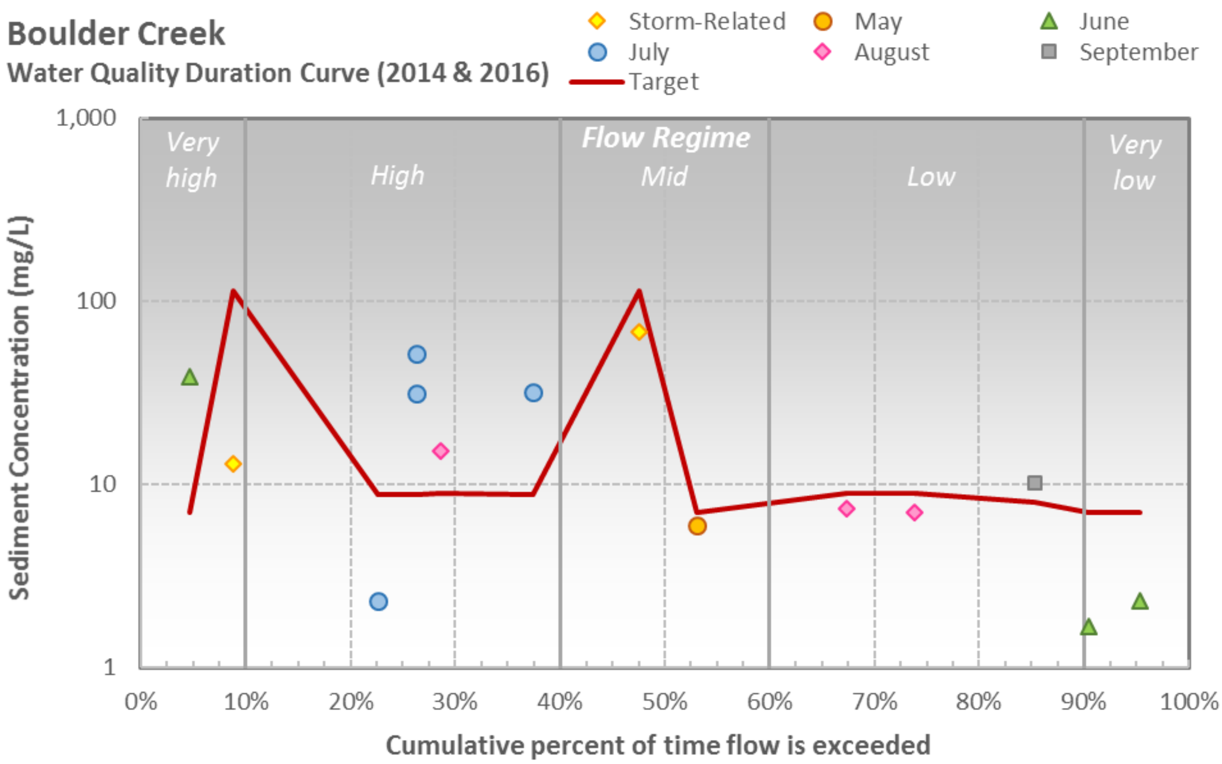


Figure 3-19. TSS values for Boulder Creek as a function of flow (2014 & 2016)

3.5.3. Deadwood Creek Water Quality Data Analysis

The Deadwood Creek subwatershed is located southeast of the town of Central and drains an area of approximately 39.8 square miles. Turbidity and TSS data were collected at sampling station CCW-17 located at the outlet of the subwatershed in Deadwood Creek below Circle Hot Springs Road Bridge near the confluence of Deadwood and Graveyard creeks.

For continuous turbidity measurements, unlike Boulder Creek, more data were available for 2016 than 2014 and the number of days with data were similar (Table 3-14). Though the median of the average daily measured turbidity in 2014 and 2016 were similar, 9 NTU and 10 NTU, respectively, the range of data in

2014, 1 NTU to 569 NTU, was greater than in 2016, 0 NTU to 187 NTU (Table 3-14). Average monthly turbidity measurements for 2014 and 2016 exceeded the threshold value for July through September as well as during storm-related conditions, while the median value only exceeded in August and September (Table 3-15). When comparing the observed turbidity measurements to the monthly thresholds, the percent exceedance ranges from 30% in June to 67% in August and storm-related conditions had a 31% exceedance rate (Table 3-15).

Table 3-14. Summary statistics for Deadwood and Bedrock creeks average daily turbidity measurements by year

Summary Statistic	Deadwood Creek by Year		Bedrock Creek by Year (Reference Condition)	
	2014	2016	2014	2016
Number of observations	100	113	75	112
Average turbidity (NTU)	25.5	24.3	9.3	6.2
Minimum turbidity (NTU)	1.0	0.0	0.4	0.0
10th percentile turbidity (NTU)	1.9	1.2	0.7	0.0
25th percentile turbidity (NTU)	2.8	3.9	0.8	0.1
Median turbidity (NTU)	8.5	10.3	1.3	1.3
75th percentile turbidity (NTU)	23.5	28.1	7.4	2.3
90th percentile turbidity (NTU)	39.5	65.1	22.9	8.2
Maximum turbidity (NTU)	568.9	186.8	95.4	183.3

Table 3-15. Summary statistics for Deadwood Creek average daily turbidity in 2014 and 2016

Summary Statistic	Month/Condition					
	Storm-related	May	June	July	August	September
Number of observations	61	9	54	30	43	16
Average turbidity (NTU)	67.4	5.0	5.0	11.6	10.0	13.7
Minimum turbidity (NTU)	14.8	2.2	0.0	1.0	2.0	1.9
10th percentile turbidity (NTU)	17.8	2.5	0.5	1.5	3.1	2.1
25th percentile turbidity (NTU)	25.4	3.1	1.3	2.3	6.0	2.9
Median turbidity (NTU)	34.6	4.7	2.6	5.1	9.1	9.2
75th percentile turbidity (NTU)	66.0	6.4	5.7	13.2	12.0	15.8
90th percentile turbidity (NTU)	139.3	7.1	9.4	30.2	15.0	26.1
Maximum turbidity (NTU)	568.9	9.6	46.6	51.6	47.0	68.4
Turbidity threshold (NTU)	58.6	5.4	5.4	6.8	6.5	6.0
Percent exceedance	31%	44%	30%	43%	67%	63%

Note: See Table 2-2 for comparison with Bedrock Creek summary statistics by month and storm-conditions.

Consistent with the Boulder Creek analysis, daily flow values for Deadwood Creek were determined for each day with a turbidity measurement based on the continuous flow record (Figure 3-16). The turbidity data were summarized by flow regime (

Table 3-16). The highest turbidity observations occur at the very high through mid flow regimes, and, as shown in Figure A-8 in Appendix A, the highest values are consistently storm-related.

Table 3-16. Summary statistics for Deadwood Creek turbidity measurement by flow regime in 2014 and 2016

Summary Statistic	Flow Regime				
	Very high	High	Mid	Low	Very low
Number of observations	22	63	41	65	22
Average turbidity (NTU)	79.6	20.0	28.0	15.4	12.0
Minimum turbidity (NTU)	6.2	0.8	0.0	0.9	0.0
10th percentile turbidity (NTU)	9.3	2.0	2.1	1.8	0.2
25th percentile turbidity (NTU)	16.4	3.8	4.5	2.4	0.8
Median turbidity (NTU)	30.8	9.8	11.9	7.3	2.1
75th percentile turbidity (NTU)	56.6	24.1	28.7	13.3	10.2
90th percentile turbidity (NTU)	242.3	38.6	66.0	29.1	43.5
Maximum turbidity (NTU)	568.9	167.6	186.8	139.3	51.6

Turbidity data for 2014 and 2016 are also represented graphically in Figure A-8 to Figure A-10 in Appendix A. The water quality duration curve in Figure A-8 makes a connection between the flow and turbidity conditions on each sampling date using the flow estimates and percentiles presented in Figure 3-16. The water quality duration curve shows increased levels of turbidity in the higher flow regimes, which are typically associated with storms (represented by the yellow diamonds). Most of the other baseflow monthly samples in the very high and high flow regimes are below their respective threshold values. The highest values shown in the mid and low flow regimes are related to storms; however, these flow regimes also frequently exceed the monthly baseflow thresholds, as demonstrated by the symbols that fall above the red threshold line (Figure A-8).

Figure A-9 and Figure A-10 in Appendix A present the 2014 and 2016 turbidity data in a time series analysis over the observed months of May through September. These figures also demonstrate which samples were identified as storm-related. The storm-related samples consistently have the highest turbidity levels. In 2014, the data do not appear to follow a seasonal trend and more samples are below the threshold level in July through September than in the same months for 2016 (Figure A-9). The 2016 turbidity data appear to exhibit a stronger seasonal trend (Figure A-10). Most of the 2016 turbidity samples are below the threshold for June and then increase in July through September with almost all baseflow observations and half of the storm-related measurements exceeding the numeric threshold values.

Fourteen TSS grab samples were taken in Deadwood Creek in 2014 and 2016 (

Table 3-17). Measured TSS concentrations ranged from 1 to 60 mg/L. Six of the 14 samples exceeded the target TSS concentration and all three storm-related samples were below their respective numeric target (Figure 3-20). The exceedances were observed in four of the five flow regimes and in four different months (May, June, August, and September).

Table 3-17. Summary statistics for Deadwood Creek TSS measurements (2014 & 2016)

Years	2014	2016
Number of observations	7	7
Average TSS (mg/L)	12.7	27.7
Minimum TSS (mg/L)	1.7	1.1
10th Percentile TSS (mg/L)	2.2	3.8
25th Percentile TSS (mg/L)	3.1	8.6
Median TSS (mg/L)	8.5	19.5
75th Percentile TSS (mg/L)	17.8	48.0
90th Percentile TSS (mg/L)	25.6	56.5
Maximum TSS (mg/L)	36.7	60.3

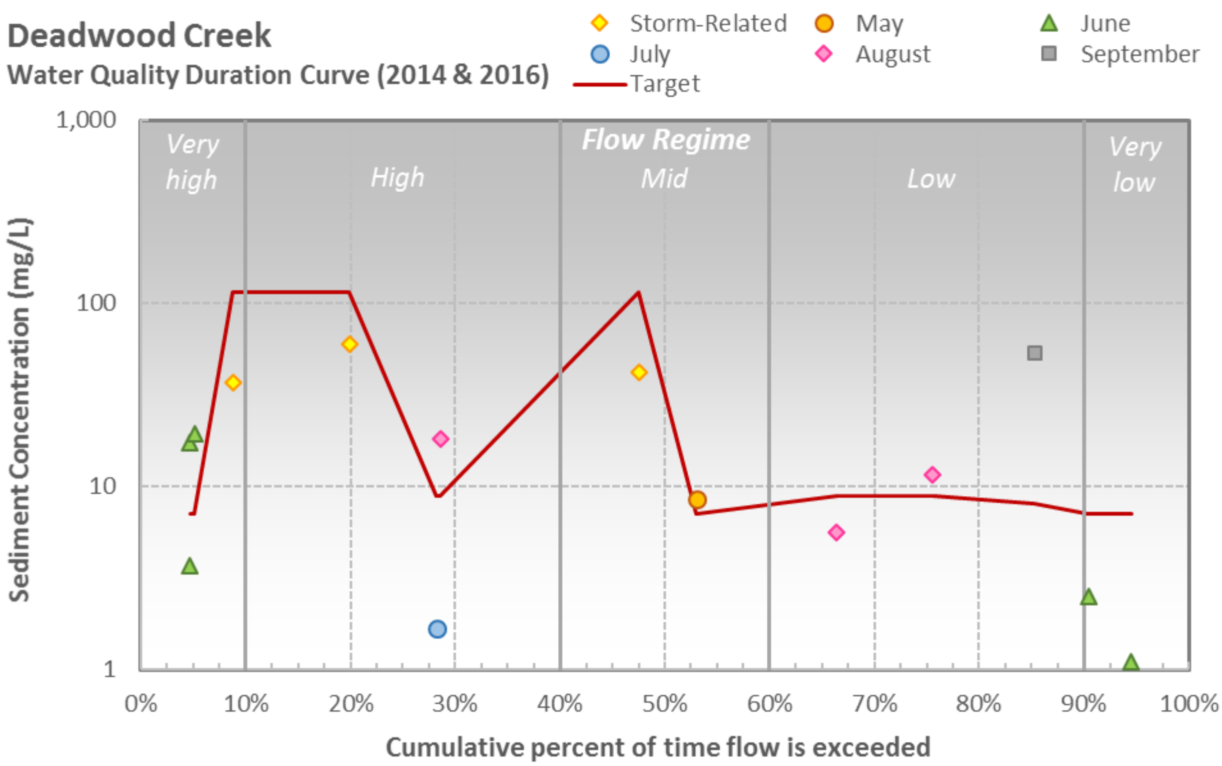


Figure 3-20. TSS values for Deadwood Creek as a function of flow (2014 & 2016)

3.5.4. Ketchem Creek Water Quality Data Analysis

The Ketchem Creek subwatershed is located southeast of the town of Central and drains an area of approximately 21 square miles. Turbidity and TSS data were collected at sampling station CCW-20 located in Ketchem Creek at Circle Hot Springs Road.

For continuous turbidity measurements, more data were available for 2016 than 2014 and 2017 (Table 3-18). The median of the average daily measured turbidity in 2014 and 2017 (30 NTU and 35 NTU, respectively) were higher than the median value for 2016 (6 NTU). The range of data in 2017, 3 NTU to 2,629 NTU, was greater than in 2014 and 2016, 12 to 254 NTU and 2 to 135 NTU, respectively (Table 3-18). Average monthly turbidity measurements for 2014, 2016 and 2017 exceeded the threshold value for May through August as well as during storm-related conditions, while the median value also exceeded in May, June, July, and August, but not during storm-related conditions or the month of September (Table 3-19). When comparing the observed turbidity measurements to the monthly thresholds, the percent exceedance ranges from 19% in September to 100% in May and storm-related conditions had a 33% exceedance rate (Table 3-19).

Table 3-18. Summary statistics for Ketchem and Bedrock creeks average daily turbidity measurements by year

Summary Statistic	Ketchem Creek by Year			Bedrock Creek by Year (Reference Condition)		
	2014	2016	2017	2014	2016	2017
Number of observations	35	113	92	75	112	90
Average turbidity (NTU)	47.8	9.0	128.8	9.3	6.2	2.2
Minimum turbidity (NTU)	11.9	2.4	3.4	0.4	0.0	0.3
10th percentile turbidity (NTU)	19.5	3.8	11.0	0.7	0.0	0.4
25th percentile turbidity (NTU)	25.3	4.3	15.6	0.8	0.1	0.4
Median turbidity (NTU)	30.2	6.4	35.1	1.3	1.3	0.7
75th percentile turbidity (NTU)	48.6	9.1	116.4	7.4	2.3	1.5
90th percentile turbidity (NTU)	76.9	12.0	237.7	22.9	8.2	6.0
Maximum turbidity (NTU)	253.5	135.1	2,628.8	95.4	183.3	64.2

Table 3-19. Summary statistics for Ketchem Creek average daily turbidity in 2014, 2016 and 2017

Summary Statistic	Month/Condition					
	Storm-related	May	June	July	August	September
Number of observations	49	8	68	58	41	16
Average turbidity (NTU)	165.2	9.6	20.4	36.2	68.3	5.1
Minimum turbidity (NTU)	15.2	6.9	3.4	4.0	3.8	2.4
10th percentile turbidity (NTU)	17.7	7.1	3.9	5.3	6.9	2.4
25th percentile turbidity (NTU)	24.7	7.5	3.4	8.7	8.3	3.0
Median turbidity (NTU)	32.9	9.0	6.1	19.9	9.1	3.7
75th percentile turbidity (NTU)	82.4	11.8	21.0	59.2	20.0	4.2
90th percentile turbidity (NTU)	200.9	12.4	55.0	92.9	247.2	11.3
Maximum turbidity (NTU)	2,628.8	13.1	124.7	158.5	303.3	14.9
Turbidity threshold (NTU)	58.6	5.4	5.4	6.8	6.5	6.0
Percent exceedance	33%	100%	51%	79%	93%	19%

Note: See Table 2-2 for comparison with Bedrock Creek summary statistics by month and storm-conditions.

Consistent with the Crooked Creek analysis, daily flow values for Ketchem Creek were determined for each day with a turbidity measurement based on the continuous flow record (Figure 3-17). The turbidity data were summarized by flow regime (

Table 3-20). The highest turbidity observations occur at the very high through mid flow regimes, and, as shown in Figure A-11 in Appendix a, high turbidity observations were observed in all flow regimes. The highest values are storm-related except at very low flows.

Table 3-20. Summary statistics for Ketchem Creek turbidity measurement by flow regime in 2014, 2016 and 2017

Summary Statistic	Flow Regime				
	Very high	High	Mid	Low	Very low
Number of observations	17	56	46	66	24
Average turbidity (NTU)	82.3	65.7	82.9	33.6	131.2
Minimum turbidity (NTU)	6.0	3.8	3.8	2.4	3.7
10th percentile turbidity (NTU)	14.0	4.6	4.8	3.5	11.6
25th percentile turbidity (NTU)	23.1	7.9	7.0	4.2	18.8
Median turbidity (NTU)	44.5	10.9	8.9	15.1	100.7
75th percentile turbidity (NTU)	59.1	31.9	28.1	35.2	238.3
90th percentile turbidity (NTU)	168.0	84.2	89.4	93.5	275.4
Maximum turbidity (NTU)	583.2	2,022.5	2,628.8	238.0	303.3

Turbidity data for 2014, 2016 and 2017 are also represented graphically in Figure A-11 to Figure A-14 in Appendix A. The water quality duration curve in Figure A-11 makes a connection between the flow and turbidity conditions on each sampling date using the flow estimates and percentiles presented in Figure 3-17. The water quality duration curve shows increased levels of turbidity in all flow regimes, with the highest turbidity observations in the very high to mid flow regimes. The highest values shown in the very high to low flow regimes are related to storms; however, these flow regimes also frequently exceed the monthly baseflow thresholds, as demonstrated by the symbols that fall above the red threshold line (Figure a-11).

Figure A-12, Figure A-13 and Figure A-14 present the 2014, 2016 and 2017 turbidity data in a time series analysis over the observed months of May through September. These figures also demonstrate which samples were identified as storm-related. The storm-related samples consistently have the highest turbidity levels. In 2014, the data do not appear to follow a seasonal trend and most samples are above the threshold (Figure a-12). The 2016 and 2017 turbidity data appear to exhibit a stronger seasonal trend, with the highest observations occurring in July (Figure A-13 and Figure A-14).

Six TSS grab samples were taken in Ketchem Creek in 2014 between May and August and seven samples were taken in 2017 between June and August (

Table 3-21). TSS data were not collected in 2016. Measured TSS concentrations ranged from 1 to 109 mg/L. Six of the 13 samples exceeded the target TSS concentration and all storm-related samples were below their respective numeric target (Figure 3-21; two samples are not shown in this graph as they do not have associated flow measurements). The six samples exceeding the target were collected throughout the monitoring season (in May, June, July and August).

Table 3-21. Summary statistics for 2014 and 2017 Ketchem Creek TSS measurements

Years	2014	2017
Number of observations	6	7
Average TSS (mg/L)	38.3	14.6
Minimum TSS (mg/L)	2.5	1.0
10th Percentile TSS (mg/L)	4.9	2.5
25th Percentile TSS (mg/L)	9.2	4.5
Median TSS (mg/L)	20.9	8.6
75th Percentile TSS (mg/L)	59.3	17.0
90th Percentile TSS (mg/L)	89.3	33.3
Maximum TSS (mg/L)	108.5	49.9

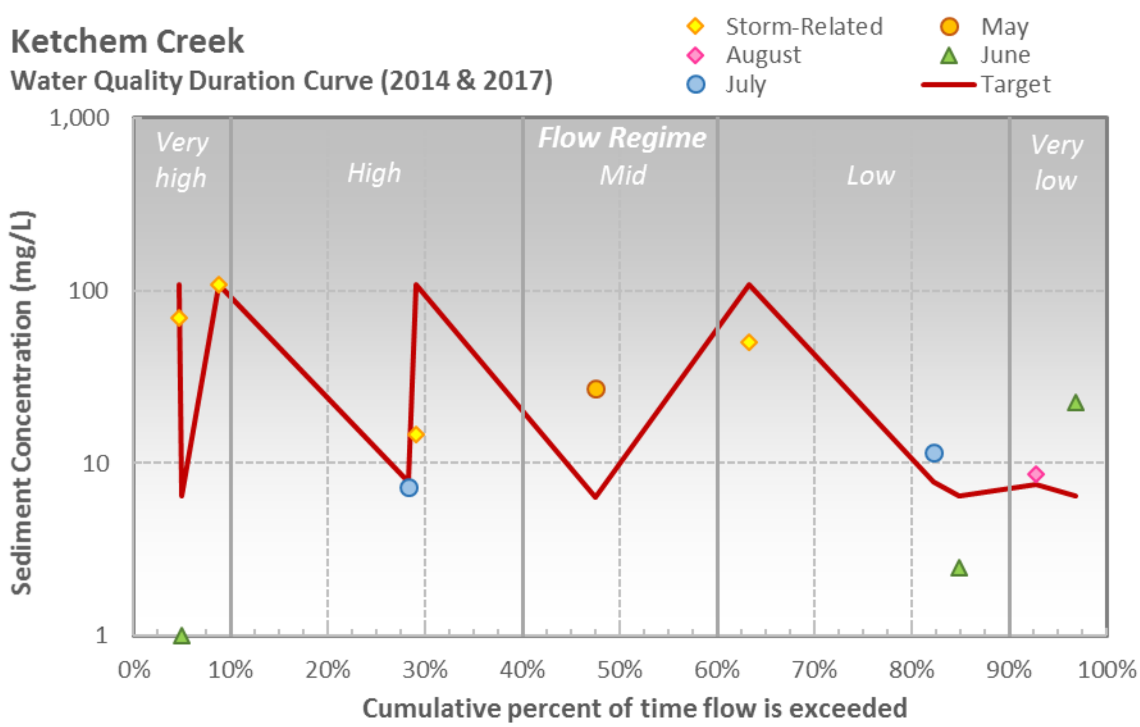


Figure 3-21. TSS values for Ketchem Creek as a function of flow (2014 and 2017)

4. Source Assessment

This section discusses the potential sources of turbidity, including point and nonpoint sources, to the Crooked Creek, Boulder Creek, Deadwood Creek and Ketchem Creek subwatersheds. While historical and active mining are the expected primary sources (ADEC 2013a), other possible sources could include stormwater (from construction, industrial and transportation activities), tributaries, and winter road maintenance. The following sections summarize the available information to date for these potential sources.

4.1. Point Sources

Potential point sources, which are permitted dischargers into the waterbody, of turbidity include active placer mines, stormwater, and fill material. While all sources are discussed below, placer mining is the major anthropogenic point source contributor of turbidity to the watershed.

4.1.1. Active Placer Mines

The Crooked Creek watershed, including Crooked, Boulder, Deadwood and Ketchem creeks, is located in the highly mineralized Circle Mining District that has been placer mined for nearly 100 years. Placer mining strips away vegetation and soil to gain access to gravels that contain heavily eroded minerals such as gold. The process uses large volumes of water for processing material, resulting in sediment-laden wastewater. Process water is routed through a settling pond system and recycled. APDES permits only authorize discharge of excess water that cannot be contained and recycled. Permit limits allow discharge of water containing sediment, but this discharge water must meet WQC for turbidity; therefore, discharges to streams from fully compliant mines are minimal.

In the mid-1980s, placer mines made significant progress in reducing metals, sediments, and turbidity discharged to receiving waters. In addition, the number of active placer mines in the Circle Mining District declined from 60 in 1987 to 23 in 1998 (Vohden 1999). Since 2004, placer mining has become more profitable due to the rise in gold value; therefore, the number of permits has increased again over the past decade. Including the drainage to Portage Creek, there were 22 active permits in the watershed in 2018 (down from about 40 in 2009).

Placer mining along Crooked Creek only dates back to the 1980s (Yeend 1991). Gold was known to be in the Crooked Creek watershed, but it was believed that the gold was spread too thin in the wide floodplain to be worth mining. Mining on Deadwood Creek has been occurring since the original gold discovery in the watershed in 1894. It is unknown when mining began on Boulder Creek and Ketchem Creek. However, it is known that there was some mining on Boulder Creek and Ketchem Creek in the 1930s and has probably occurred on and off since then (Yeend 1991).

Placer mining operations vary in size. Many placer mines operate as a small family business. Approximately 27 percent of placer operations are operated by a single permit holder with no additional employees; 30 percent have two employees; and 44 percent have three or more employees (ADEC 2015). They may actively discharge, discharge only during storm events, or have zero discharge (100% recycle) systems. Mines with discharges are required to have coverage under an APDES permit. In addition, there is wide variability in data on water quality effects of placer mining. This is due to differences in the type of mine operation, the material being mined, the type of sediment controls employed, and the number and size of mines on a particular stream (USGS 1994).

The active placer mines with APDES permits on Crooked, Boulder, Deadwood and Ketchem creeks are summarized in Table 4-1, illustrated in Figure 4-1, and discussed below. Figure 4-1 also illustrates the state and Bureau of Land Management (BLM) (hereafter referred to as federal) mining claims and leases. Only placer mines with active APDES permits are listed in Table 4-1. It is possible that there may be additional active, but non-discharging, facilities without APDES permits in the Crooked, Boulder, Deadwood and Ketchem creeks subwatersheds.

All permittees discharging to the Crooked Creek watershed are covered under the Mechanical Placer Miners General Permit (AKG370000) except two that fall under the Medium Suction Dredge General Permit (AKG371000). In addition, one permittee (AKG370007) discharging to Switch Creek, a tributary of Deadwood Creek, has a mixing zone and a unique set of effluent limits. All other permittees follow the normal discharge limits within the general permits. Permit limits in the general permits ensure protection of WQS; therefore, under optimal (i.e., full compliance) conditions, these facilities should not contribute turbidity at levels above WQS to the creeks.

Table 4-1. Placer mining permits in the Crooked, Deadwood, Boulder and Ketchem creeks subwatersheds

Permit Number	Receiving Water	Mixing Zone	TMDL Subwatershed	Effective Date	Expiration Date	Facility Latitude	Facility Longitude
AKG370940	Boulder Creek	No	Boulder Creek	03/01/2016	07/31/2020	65.4836	-145.0442
AKG370027	Crooked Creek	No	Crooked Creek	08/01/2015	07/31/2020	65.57242	-145.01941
AKG370C16	Crooked Creek	No	Crooked Creek	06/29/2016	07/31/2020	65.579	-144.9544
AKG370691	Deadwood Creek	No	Deadwood Creek	08/01/2015	07/31/2020	65.449167	-144.948056
AKG370305	Deadwood Creek	No	Deadwood Creek	08/01/2015	07/31/2020	65.50034	-144.86625
AKG370961	Deadwood Creek	No	Deadwood Creek	08/01/2015	07/31/2020	65.5373	-144.7634
AKG370A39	Deadwood Creek	No	Deadwood Creek	08/01/2015	07/31/2020	65.52435	-144.80365
AKG370C75	Deadwood Creek	No	Deadwood Creek	03/16/2018	07/31/2020	65.50649	-144.85515
AKG370C89	Deadwood Creek	No	Deadwood Creek	06/04/2018	07/31/2020	65.44	-144.9678
AKG370945	Easley Creek	No	Ketchem Creek	08/01/2015	07/31/2020	65.496	-144.755
AKG371445[a]	Fortythree Pup	No	Deadwood Creek	02/01/2016	01/31/2021	65.41213	-145.01324
AKG370950	Greenhorn Gulch	No	Boulder Creek	03/01/2016	07/31/2020	65.437	-145.072
AKG370754	Ketchem Creek	No	Ketchem Creek	08/01/2015	07/31/2020	65.504423	-144.70073
AKG371627[a]	Mastodon Creek	No	Crooked Creek	05/24/2018	01/31/2021	65.49341	-145.26749
AKG370C84	Mastodon Creek	No	Crooked creek	05/24/2018	07/31/2020	65.4853	-145.2768
AKG370185	Miller Creek	No	Crooked Creek	08/01/2015	07/31/2020	65.51317	-145.29429
AKG370541	Porcupine Creek	No	Crooked Creek	08/01/2015	07/31/2020	65.5597	-145.29255
AKG370977	Porcupine Creek	No	Crooked Creek	08/01/2015	07/31/2020	65.546389	-145.511944
AKG370B89	Porcupine Creek	No	Crooked Creek	02/01/2016	07/31/2020	65.55863	-145.39025

Permit Number	Receiving Water	Mixing Zone	TMDL Subwatershed	Effective Date	Expiration Date	Facility Latitude	Facility Longitude
AKG370C73	Porcupine Creek	No	Crooked Creek	02/21/2018	07/31/2020	65.555	-145.23
AKG370B83	Rebel Creek	No	Crooked Creek	02/01/2016	07/31/2020	65.5293	-145.40848
AKG370007	Switch Creek	Yes	Deadwood Creek	08/01/2015	07/31/2020	65.4681	-144.8956

[a] Permit covered by Medium Suction Dredge General Permit (AKG371000); all other permits covered by Mechanical Placer Miners General Permit (AKG370000).

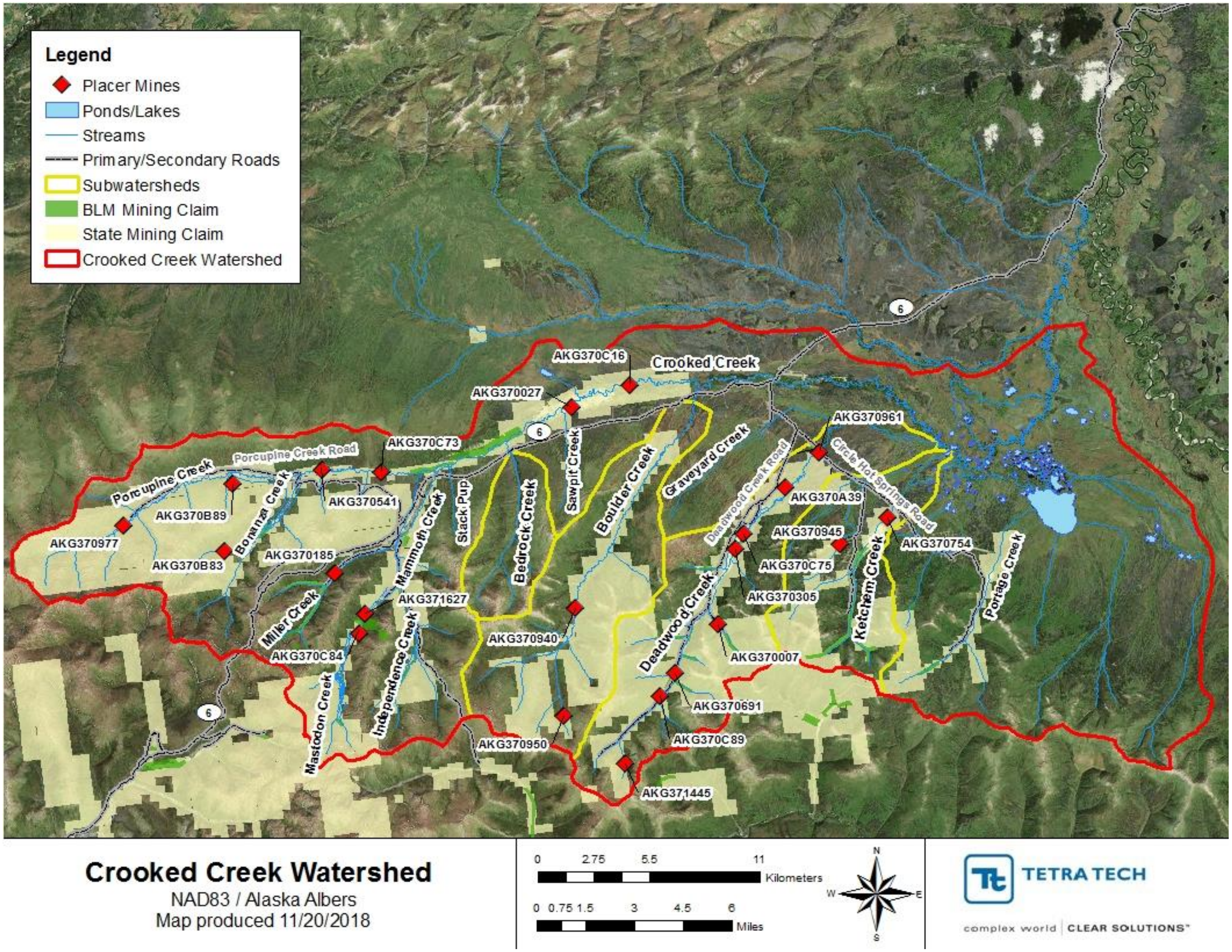


Figure 4-1. APDES permitted sources of turbidity to Crooked Creek watershed (ADNR 2017)

4.1.2. Stormwater

In addition to mining sources, stormwater runoff from construction or industrial activities or highways are other potential sources of turbidity in the watershed. Although there are currently no large population areas or urbanized areas in the watershed, it may be a future source and is included in future WLAs.

Stormwater carries pollutants to receiving waterbodies through surface runoff, which is generated when precipitation from rain and snowmelt events flows over land or impervious surfaces (paved streets, parking lots, and building rooftops) and does not percolate into the ground. As the runoff flows over the land or impervious surfaces, it accumulates debris, chemicals, sediment or other pollutants that could adversely affect water quality if the runoff is discharged untreated. Unlike most constant point sources (e.g., wastewater treatment plant discharges), stormwater is precipitation-driven. Stormwater permits regulate point source discharges of stormwater into receiving waters. These discharges require coverage under the NPDES or, in Alaska, the APDES program. In addition, for municipalities meeting specific size requirements, Municipal Separate Storm Sewer System (MS4) permits are issued. MS4s are applied to municipalities with populations greater than 100,000 as well as U.S. Census Bureau-defined urbanized areas.

Industrial Stormwater

Industrial activities can also generate contaminated stormwater. There are no industrial stormwater permittees subject to the Multi-Sector General Permit (MSGP) that discharge directly into Crooked, Boulder, Deadwood or Ketchem creeks; therefore, there is no waste load allocation (WLA) for industrial stormwater included in this TMDL. Future allocations for industrial activities will be included in the future WLAs, which provide a reserve load by TMDL subwatershed from which future permittees can draw.

Construction Stormwater

Construction activities can also result in stormwater discharge. At the time this TMDL was developed (September 2018), there were no active authorizations under the APDES Construction General Permit (CGP) in the Crooked, Boulder, Deadwood or Ketchem creeks subwatersheds; therefore, there is no WLA for construction stormwater included in this TMDL. Any future construction activities will be included in the future WLA, which provides a reserve load by TMDL subwatershed from which future construction permittees can draw. These construction facilities must meet WQC for turbidity at all times.

Transportation/Highway Stormwater

There is one highway in the watershed, Steese Highway, that is downstream of Boulder and Deadwood creeks and runs parallel to Crooked Creek. The highway crosses Crooked Creek below Boulder Creek. The highway does not run through the Ketchem Creek subwatershed (Figure 1-2 and Figure 4-1). The highway is a gravel road with the exception of approximately a half mile of pavement in in the town of Central. This highway does not have ADPES permits at this time and will not be designated a WLA in this TMDL. Future allocations for transportation activities will be included in the future WLAs, which provide a reserve load by TMDL subwatershed from which future transportation permittees can draw.

4.1.3. Fill Material

Activities that involve dumping, placing, depositing, or discharging dredged material or fill material into waters or wetlands of the U.S. require federal authorization under a CWA Section 404 permit through the U.S. Army Corps of Engineers (USACE). In Alaska, the USACE has a general permit (GP) (GP-2014-55; USACE 2014) for authorizing placement of dredged and/or fill material in waters of the U.S., including wetlands and streams, associated with mechanical placer mining activities. Discharges of dredge and/or fill material at these sites have the potential to contribute to the turbidity impairment and are therefore covered by WLAs based on their impacted area in this TMDL.

There are 20 current fill material permits located in the Crooked Creek watershed . Fill permits are illustrated in Figure 4-2. Seven of these permits overlap with active APDES mechanical placer mining permits (Section 4.1.1); therefore, their mining WLAs are assumed to address their fill permit contributions. For the 13 additional fill material permits, a WLA is assigned based on the maximum allowable impacted area (5 acres). In addition, any future fill material sites will be able to draw from the future WLA (if an application for a fill material permit is received in the future without a corresponding placer mining permit, the future mining permit will draw from the future mining WLA).

4.2. Nonpoint Sources

Nonpoint sources in the Crooked Creek watershed include historical mining activities, tributaries and winter road maintenance. These sources, specific to the Crooked, Boulder, Deadwood and Ketchem creeks subwatersheds, are discussed below.

4.2.1. Historic Mining

The majority of anthropogenic nonpoint sources of sediment that effect the Crooked Creek watershed are related to historical mining and include abandoned mines, reclaimed mines, overburden piles, and other disturbed areas (ADEC 2013b). Mine sites that are not stabilized or reclaimed can result in increased sediment loads, especially during high water flow and surface runoff. Major sources of sediment include abandoned settling ponds, cutbanks, overburden piles, and disturbed areas that have not been stabilized. Abandoned settling ponds frequently wash out, releasing accumulated sediments to streams. In addition, reestablishment of diverted stream channels can increase sediment loads and upland surface erosion and runoff can occur where sites have not been adequately reclaimed or stabilized. This can include roads, camps, overburden, and disturbed areas (USGS 1994).

4.2.2. Tributary Inputs/Runoff

Upland surface erosion can occur in areas that are not adequately stabilized. This eroded sediment can be transported through tributaries to the main-stems of creeks. In undisturbed areas, tributary sources of sediment are expected to be minimal. However, in disturbed areas (many of which are associated with historical mining [Section 4.2.1]), these sources are more significant (Noll and Vohden 1994) and specific loading varies by land use, slope, and other site-specific factors. Until vegetation recovers, these areas are susceptible to increased sediment loads due to bare soil.

4.2.3. Winter Road Maintenance

Another source of sediment to creeks within the watershed is winter road maintenance practices. The Alaska Department of Transportation and Public Facilities (ADOT&PF) does not apply sand to roadways in the Crooked Creek watershed area because the roads are gravel. They plow the roads with serrated grates and the plowed snow could transport sediment from thawing roadways to nearby creeks. In addition, snow dumps, the practice of plowing snow from roadways to centralized storage sites, can provide a chronic source of sediment, particularly when they are located close to a creek. When located near a creek, snow dumps act as low discharge point sources, delivering sediment directly to the stream through snowmelt.

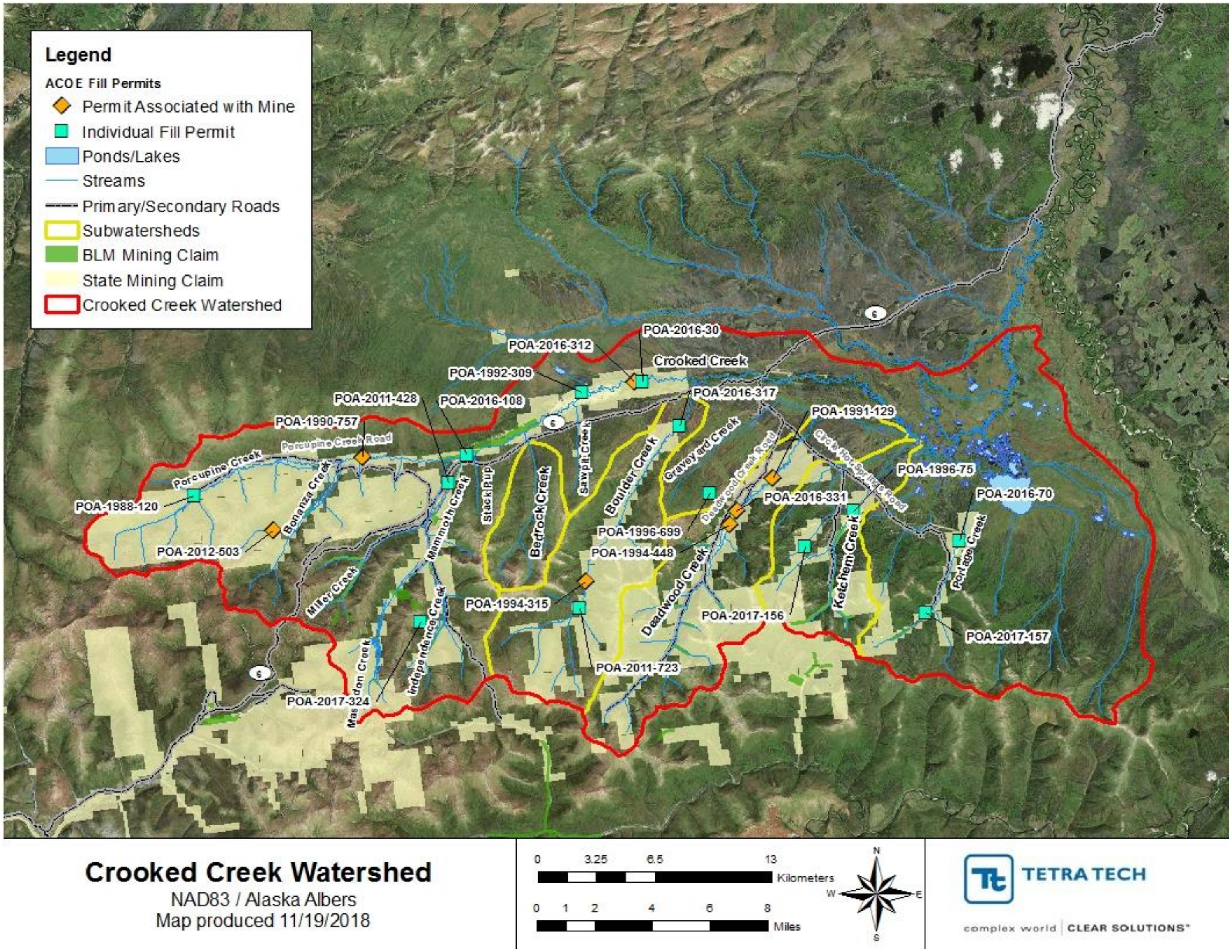


Figure 4-2. USACE fill permits in the Crooked Creek watershed

5. TMDL Allocation Analysis

A TMDL represents the total amount of a pollutant that can be assimilated by a receiving waterbody while still achieving WQS—also called the *loading capacity*. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL's loading capacity must be established and thereby provide the foundation for establishing water quality-based controls.

A TMDL for a given pollutant and waterbody is composed of the sum of individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background loads, and an allocation for future sources (if determined necessary). In addition, the TMDL must include an implicit or explicit margin of safety (MOS) to account for the uncertainty in the relationship between pollutant levels and the quality of the receiving waterbody. The TMDL components are illustrated using the following equation:

$$TMDL = \Sigma\ WLAs + \Sigma\ LAs + MOS + Future\ Growth\ Allocation$$

5.1. Linkage Analysis

A waterbody's loading capacity represents the greatest amount of a pollutant that a waterbody can receive without exceeding the applicable WQC (40 CFR 130.2(f)). Establishing the relationship between instream water quality and source loading is an important component of TMDL development. It allows the determination of the relative contribution of sources and the evaluation of potential changes to water quality resulting from implementation of various management options. The TMDLs for Crooked, Boulder, Deadwood and Ketchem creeks were developed using the duration curve method to assure compliance with the TMDL numeric targets at varying flow conditions.

As discussed above, a duration curve methodology was considered to be well suited for the determination of the loading capacities based on the need for analysis of extreme seasonal flow variations. Additionally, this methodology provides a sound technique to determine reductions required to meet the numeric target concentrations. According to EPA's load duration curve guidance (USEPA 2007):

> *"The duration curve approach allows for characterizing water quality concentrations (or water quality data) at different flow regimes. The method provides a visual display of the relationship between stream flow and loading capacity. Using the duration curve framework, the frequency and magnitude of water quality standard exceedances, allowable loadings, and size of load reductions are easily presented and can be better understood.*
>
> *The duration curve approach is particularly applicable because stream flow is an important factor in determination of loading capacities. This method accounts for how stream flow patterns affect changes in water quality over the course of a year (i.e., seasonal variation that must be considered in TMDL development). Duration curves also provide a means to link water quality concerns with key watershed processes that may be important considerations in TMDL development…"*

The primary benefit of duration curves in TMDL development is to provide insight regarding patterns associated with season, hydrology and water quality concerns. The duration curve approach is particularly applicable because water quality is often a function of stream flow. For instance, sediment concentrations typically increase with rising flows as a result of various factors, such as channel scour from higher water velocities or sediment from the land carried to the stream by runoff during a storm event. The use of duration curves in water quality assessment creates a framework that enables data to be characterized by flow conditions. The method is useful in TMDL implementation because it provides guidance in choosing the best BMPs for various flow and water quality combinations.

The duration curve analysis utilizes flow duration intervals, as discussed in Section 3.5, to identify flow regimes for 2014, 2016 and 2017. The loading capacity can be presented as a concentration (equivalent to the TMDL numeric target) or load (calculated by multiplying instream flow values by the numeric target concentration and a conversion factor). This step forms a trendline based on flow conditions, which represents the loading capacity of the stream at varying flow conditions.

In addition, loads were calculated for points of observed data, corresponding to the water quality duration curves presented in Section 3.5.1, 3.5.2, 3.5.3 and 3.5.4 above for Crooked, Boulder, Deadwood and Ketchem creeks, respectively. These loads were compared to the loading capacity curve. Points that plot above this line represent an exceedance of the loading capacity while loads below are in compliance. Details associated with the load duration curve analyses for these TMDLs are presented in the Loading Capacity section below.

5.2. Loading Capacity

The loading capacity for a given pollutant is the greatest amount of pollutant that a waterbody can receive without exceeding the applicable WQS, as represented by the TMDL numeric target. TMDLs are typically expressed on a mass loading basis (e.g., pounds per day). The pollutant for the Crooked Creek watershed is turbidity. Turbidity is a measure of the water’s optical properties that cause light to be scattered or absorbed and does not incorporate a measurement of mass. Therefore, it does not lend itself to developing a loading capacity and allocations to different sources. Because turbidity does not work well as the basis for calculating a target loading capacity, turbidity TMDLs typically use a surrogate parameter, such as TSS, to establish the load and percent reduction. Turbidity can be affected by different suspended particles such as clay, silt, and microorganisms, many of which are the same substances that form TSS. Turbidity can also be affected by algae. Algae have been noted on sensors during monitoring. However, because of the strong relationship between TSS and turbidity and the lack of algae data, TSS is assumed to be the dominant source of turbidity.

Local TSS data provide a measure of the amount of sediment suspended in the stream at a given moment in time. Because Alaska has not developed numeric criteria for TSS, statistical relationships between turbidity and TSS for turbidity values above and below 15 NTU were developed and applied. These relationships were based on local data because sediment properties can vary significantly from stream to stream. As described in Section 2.4.3, strong TSS-turbidity relationships have been established for the Crooked Creek watershed (Figure 2-3 and Figure 2-4).

The loading capacities for Crooked, Boulder, Deadwood and Ketchem creeks are derived from the WQS, which state that turbidity may not exceed 5 NTUs above natural conditions when the natural turbidity is 50 NTU or less, and may not have more than a 10% increase in turbidity when the natural turbidity is more than 50 NTU, not to exceed a maximum increase of 15 NTU. By relating sediment (expressed as TSS) and turbidity, a single measure, the TSS load, can be used to represent the turbidity impairment. The loading analysis provides an estimate of the existing sediment load, accounting for various in-stream processes (e.g., transport, deposition) that affect the fate of sediment delivered to the stream from the watershed. To obtain a substantial TSS record for TMDL analyses, the average daily continuous turbidity data for each creek were identified as below or above 15 NTU and then converted to TSS using the equations presented in Figure 2-3 and Figure 2-4, respectively. These calculated TSS values were then used to develop load duration curves as part of the TMDL linkage analysis. See section 2.4.3 for more information on the turbidity-TSS relationship.

Allowable pollutant loads were determined through the use of load duration curves. Discussions of load duration curves are presented in *An Approach for Using Load Duration Curves in the Development of TMDLs* (USEPA 2007).

Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 present the load duration curves for Crooked Creek, Boulder Creek, Deadwood Creek and Ketchem Creek, respectively. These plots show the existing loads by storm-related condition and month with different symbols. The load duration curve approach involves calculating allowable loadings in the impaired stream using the following steps:

1. A flow duration curve for the stream is developed by generating a flow frequency table and plotting the data points to form a curve. The data reflect a range of natural occurrences from extremely high flows to extremely low flows.
2. The flow curve is translated into allowable loads (i.e., loading capacity or TMDL) by multiplying each flow value[2] (in cubic feet per second [cfs]) by the numeric target[3] for a contaminant (mg/L), then multiplying by conversion factors to yield results in the proper unit (i.e., pounds per day or year). The resulting points are plotted to create a loading capacity curve. Note that the baseflow numeric targets are based on medians of the monthly average turbidity concentrations in Bedrock Creek and do not account for the WQC allowance for a 10 percent increase in turbidity when natural turbidity is greater than 50 NTU during baseflow conditions (see Section 6.2 for options if or when this occurs). There are separate numeric targets calculated for storm-related conditions. The median of those daily average turbidity values was used to calculate the target and this value was over 50 NTU, so the numeric target added 10% to the median value.
3. Each water quality sample is converted to a load by multiplying the water quality sample concentration by the average daily flow on the day the sample was collected. Then, the loads are plotted as points on the TMDL curve and can be compared to the allowable loads (from step 2). Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 illustrate the load duration curves for TSS in the TMDL subwatersheds using the daily average observed turbidity values converted to TSS using the relationships described in Section 2.4.3.
4. Points plotting above the curve represent deviations from the numeric target and the daily allowable load. Those plotting below the curve represent compliance with standards and the daily allowable load. The load duration curve was also used to characterize loads by flow regime. The results of these comparisons are similar to the findings presented for the continuous turbidity measurements as the TSS concentrations were converted from the turbidity values.
5. The area beneath the TMDL curve is interpreted as the loading capacity of the stream. The difference between this area and the area representing the current loading conditions is the load that must be reduced to meet numeric targets.
6. The final step is to determine where reductions need to occur. Those exceedances at the right side of Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 occur during low flow conditions. Exceedances on the left side of the figures occur during higher flow events, and might be derived from sources such as runoff. This side of the curve contains the highest frequency of storm events. Using the load duration curve approach allows ADEC to determine which implementation practices are most effective for reducing loads on the basis of flow regime. If loads are considerable during wet-weather events (including snowmelt), implementation efforts can target those BMPs that most effectively reduce stormwater runoff. Figure 5-1, Figure 5-2, Figure 5-3

[2] Flow values were calculated using the unit area flows described in Section 3.4.3 and presented in Figure 3-14 and Figure 3-17.
[3] Numeric targets for storm-related conditions and non-storm conditions during the last week of May through September are presented in Table 2-3. Days were identified as storm-related or not before the targets were selected.

and Figure 5-4 illustrate that reductions are needed during all flow regimes for Crooked and Ketchem creeks, but the largest load reductions are required during storm events in the very high flow regime in Crooked Creek and storm events in the mid to high flow regimes in Ketchem Creek.

To calculate the TMDLs, the median value of the allowable load for each month and the storm-related conditions was calculated for Crooked, Boulder, Deadwood and Ketchem creeks. The allowable loads are based on the estimated flow for each day with data multiplied by the TMDL numeric target and a conversion factor. Using the median loading value is similar to using the median flow for that month. These allowable loads (or loading capacities) are the maximum values allowed each day during that month or condition. Monthly TMDLs allow for easy translation to implementation and compliance assessment, while storm-related TMDLs account for the naturally high sediment loads expected during storm and high-flow conditions. Crooked, Boulder, Deadwood and Ketchem creeks are typically frozen from mid-October through April and the creeks generally open up in mid-May following spring break-up. The waterbodies remain free-flowing until mid-September when streams begin freezing again. The TMDLs are presented for monthly and storm conditions from the last week of May through September to best utilize available data and accurately represent stream conditions. The TMDL targets do not apply to Crooked, Boulder, Deadwood and Ketchem creeks from October through spring break-up (typically, the first three weeks of May); therefore, the TMDLs were calculated for the months when the creeks have flowing water (last week of May through September).

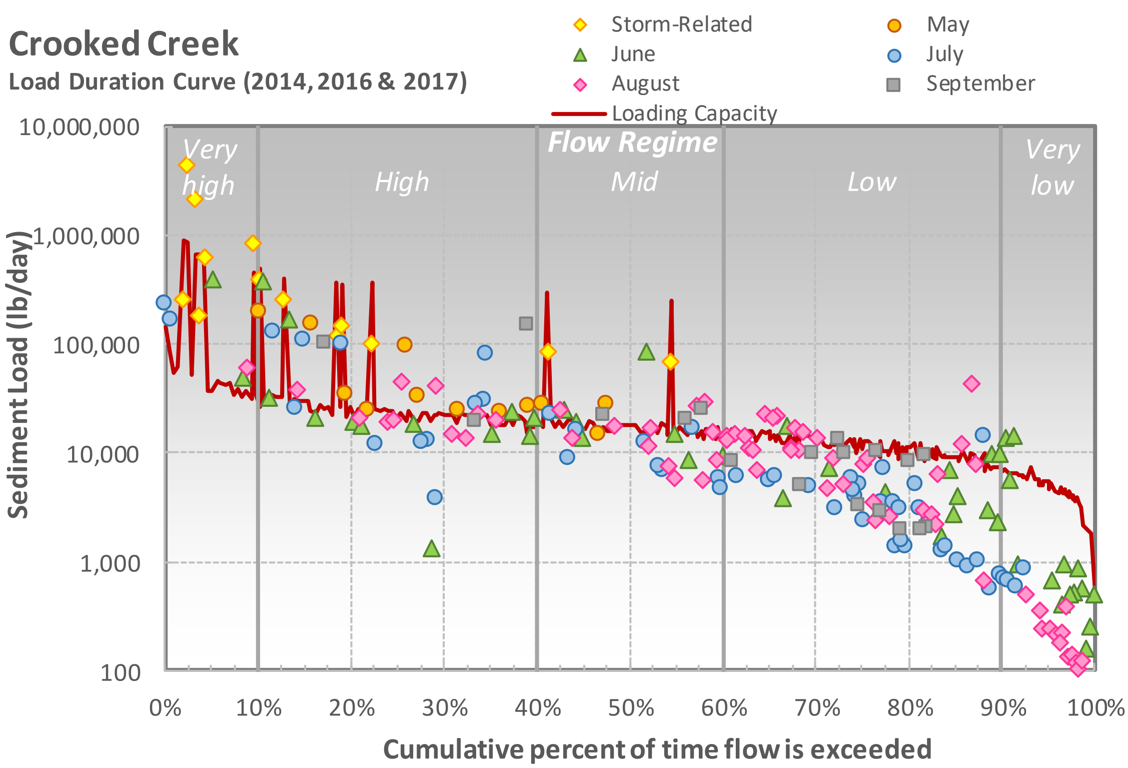


Figure 5-1. Allowable and existing sediment loads as a function of flow in the Crooked Creek subwatershed

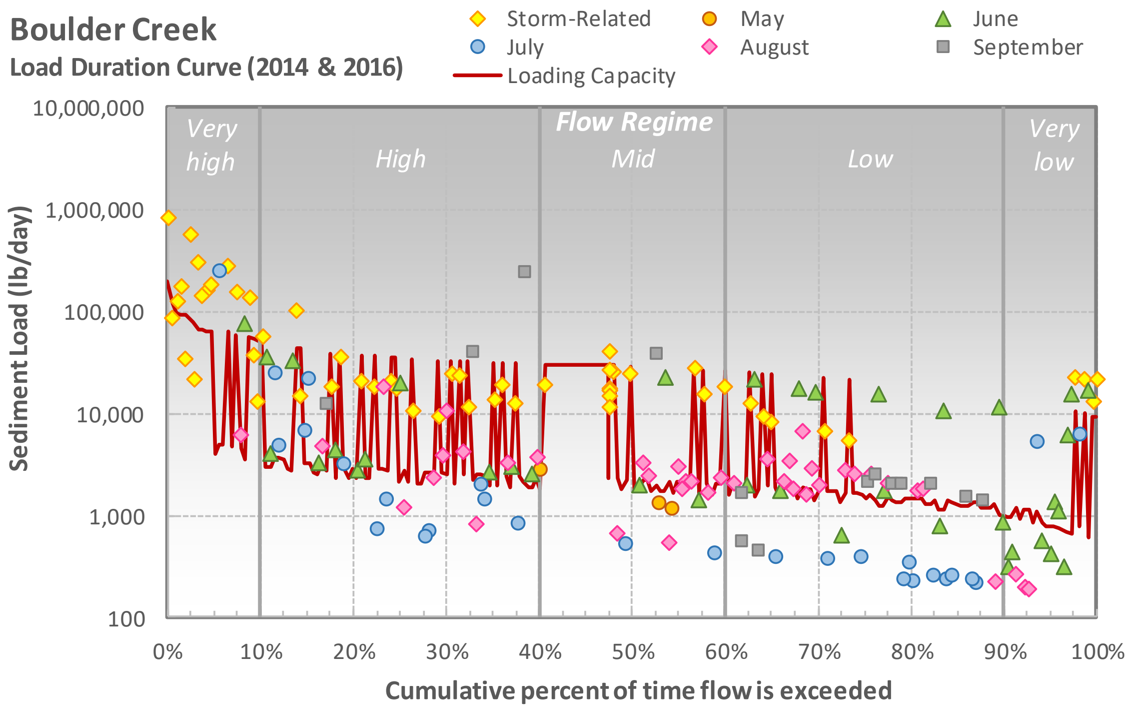


Figure 5-2. Allowable and existing sediment loads as a function of flow in the Boulder Creek subwatershed

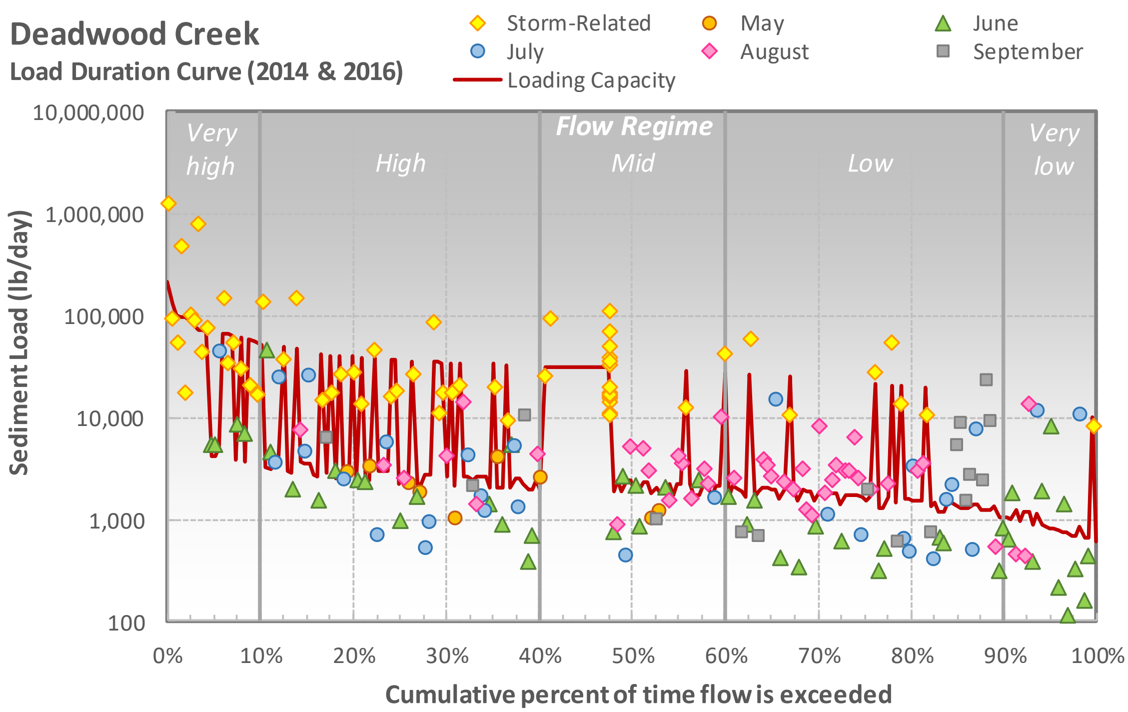


Figure 5-3. Allowable and existing sediment loads as a function of flow in the Deadwood Creek subwatershed

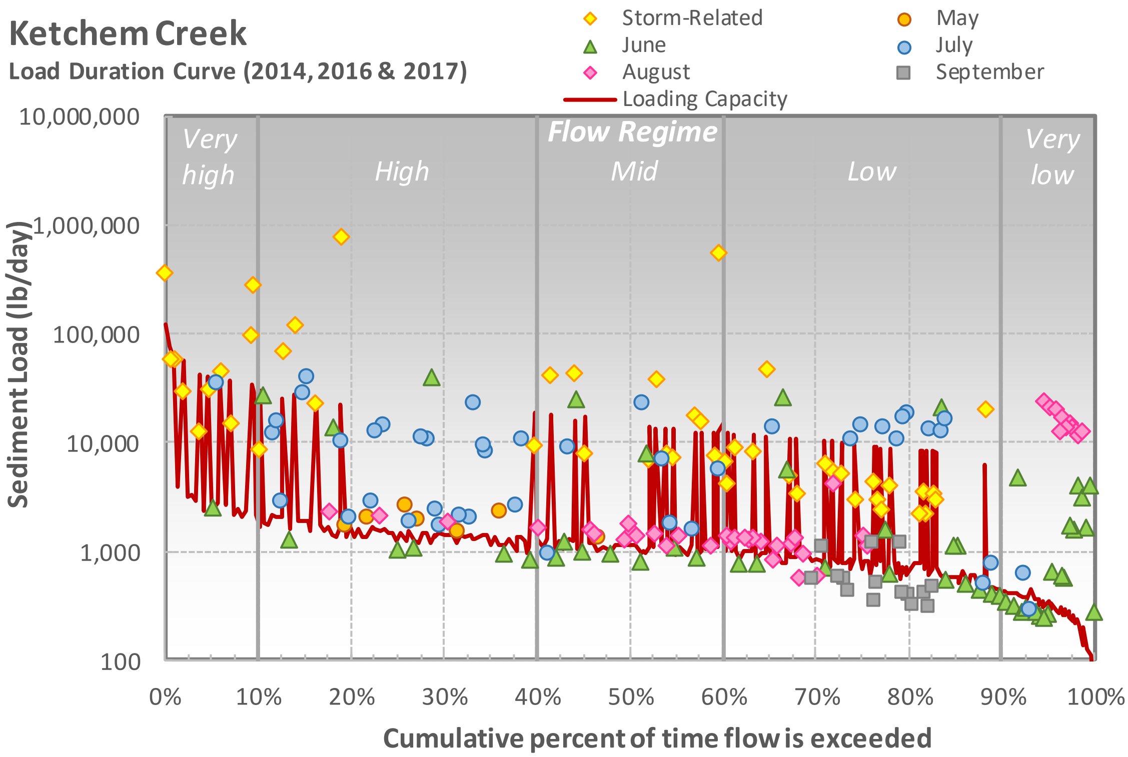


Figure 5-4. Allowable and existing loads as a function of flow in the Ketchem Creek subwatershed

Conceptually, the loading capacity represents the sum of WLAs, LAs, MOS, and an allocation for future growth. The allowable load is a finite mass of pollutant that can be divided into individual loads for each source, that when combined represent the total loading capacity. Therefore, when the loading capacity is expressed as a load, the MOS is first subtracted, and then the remaining allowable load is divided among WLAs for point sources and LAs for nonpoint sources as well as a future growth allocation. The existing in-stream loads integrate all source contributions and do not distinguish loads from specific sources.

The loading capacities and allocations for Crooked, Boulder, Deadwood and Ketchem creeks are presented in Table 5-1, Table 5-2, Table 5-3 and Table 5-4, respectively (see Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 for context on these values and associated existing conditions). The Boulder, Deadwood and Ketchem creeks' subwatersheds are all located within the larger Crooked Creek watershed; therefore, the loading capacity and allocations for the area of the Crooked Creek watershed outside of these three subwatershed needed to be determined to support this TMDL for Crooked Creek (that is presented in Table 5-1). This was completed by calculating the loading capacity for the entire Crooked Creek watershed (including Boulder, Deadwood and Ketchem creeks as well as all other tributaries to Crooked Creek) based on the load duration curve for the full drainage area and then subtracting the loading capacities for Boulder, Deadwood and Ketchem creeks that were calculated in separate TMDLs for those subwatersheds. Loading capacities for each of these drainages are presented in Table 5-5 .

To calculate allocations for Crooked, Boulder, Deadwood and Ketchem creeks, the MOS was first subtracted from the loading capacity in Table 5-1, Table 5-2, Table 5-3 and Table 5-4, respectively. Then the remaining load was separated into the allocations to point and nonpoint sources were calculated. The individual WLAs and Future Growth WLAs assigned to particular permits or sources, respectively, are presented in Section 5.3, followed by discussion on the LA (Section 5.4) and other TMDL components (Sections 5.5 through 5.9). To further guide implementation and compliance, the loading capacity and allocations are provided as concentrations in Table 5-6. The turbidity threshold values associated with this table are described in Section 2.4.4 and illustrated in Figure 2-5.

Table 5-1. TMDL allocation summary for TSS in Crooked Creek subwatershed (not including Boulder, Deadwood and Ketchem creeks)

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	374,878.7	18,743.9	212.0	320,309.3	35,613.5
Last week of May	13,926.4	696.3	7.9	11,899.2	1,323.0
June	8,690.3	434.5	4.9	7,425.3	825.6
July	10,218.5	510.9	5.8	8,731.1	970.8
August	10,902.8	545.1	6.2	9,315.7	1,035.8
September	8,403.3	420.2	4.8	7,180.0	798.3

*See individual WLAs by source in Table 5-8.

Table 5-2. TMDL allocation summary for TSS in Boulder Creek subwatershed

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	31,010.1	1,550.5	27.8	26,485.9	2,946.0
Last week of May	1,815.9	90.8	1.6	1,551.0	172.5
June	1,382.1	69.1	1.2	1,180.4	131.3
July	2,014.9	100.7	1.8	1,720.9	191.4
August	1,690.1	84.5	1.5	1,443.5	160.6
September	1,192.7	59.6	1.1	1,018.7	113.3

*See individual WLAs by source inTable 5-9.

Table 5-3. TMDL allocation summary for TSS in Deadwood Creek subwatershed

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	37,698.1	1,884.9	56.2	32,175.6	3,581.3
Last week of May	2,178.2	108.9	3.3	1,859.1	206.9
June	1,694.9	84.7	2.5	1,446.7	161.0
July	2,461.4	123.1	3.7	2,100.8	233.8
August	1,905.4	95.3	2.8	1,626.3	181.0
September	1,430.6	71.5	2.1	1,221.1	135.9

*See individual WLAs by source in Table 5-10.

Table 5-4. TMDL allocation summary for TSS in Ketchem Creek subwatershed

Month/Condition	Loading Capacity (lbs/day)	Margin of Safety (lbs/day)	Combined WLA (lbs/day)*	LA (lbs/day)	Future Growth WLA (lbs/day)
Storm-related	12,485.4	624.3	17.3	10,657.7	1,186.1
Last week of May	1,191.2	59.6	1.7	1,016.9	113.2
June	721.1	36.1	1.0	615.5	68.5
July	986.7	49.3	1.4	842.3	93.7
August	1,047.6	52.4	1.5	894.3	99.5
September	767.8	38.4	1.1	655.4	72.9

*See individual WLAs by source in Table 5-11.

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Table 5-5. Loading capacity totals for TSS in the entire Crooked Creek watershed and subwatersheds

Month/Condition	Loading Capacity (lbs/day)				
	Entire Crooked Creek watershed	Boulder Creek subwatershed	Deadwood Creek subwatershed	Ketchem Creek subwatershed	Crooked Creek subwatershed (minus loading capacities for Boulder, Deadwood and Ketchem creeks)[a]
Storm-related	456,072.3	31,010.1	37,698.1	12,485.4	374,878.7
Last week of May	19,111.7	1,815.9	2,178.2	1,191.2	13,926.4
June	12,488.4	1,382.1	1,694.9	721.1	8,690.3
July	15,681.5	2,014.9	2,461.4	986.7	10,218.5
August	15,545.9	1,690.1	1,905.4	1,047.6	10,902.8
September	11,794.4	1,192.7	1,430.6	767.8	8,403.3

[a]This area represents the Crooked Creek watershed loads minus the areas for Boulder, Deadwood and Ketchem creeks, which have their own individual TMDLs.

Table 5-6. Concentration-based TSS TMDL allocation summary for Crooked, Boulder, Deadwood and Ketchem creeks and turbidity threshold values

Month/ Condition	TSS Loading Capacity and Allocations (mg/L)				Turbidity Threshold Values (NTU)
	Loading Capacity	Combined WLA	LA	Future Growth WLA	
Storm-related	108.9	108.9	108.9	108.9	58.6
Last week of May	6.4	6.4	6.4	6.4	5.4
June	6.4	6.4	6.4	6.4	5.4
July	7.8	7.8	7.8	7.8	6.8
August	7.5	7.5	7.5	7.5	6.5
September	7.1	7.1	7.1	7.1	6.0

A required percent reduction was calculated by comparing the observed measurements in Crooked and Ketchem creeks to the loading capacity (which was based on the numeric targets). These reductions are provided for guidance and reference only (compliance will be determined based on attainment of the allocations, not reductions). Figure 5-1 and Figure 5-4 also illustrate the flow condition associated with the required reductions, which may be useful to identify and guide implementation activities. To calculate reductions, the daily average observed turbidity values were converted to TSS using the relationships described in Section 2.4.3. These values were then converted to loads using the corresponding flow and summarized for storm-related events and on a monthly basis. The 90th percentile existing TSS load (representing existing conditions) was compared to the associated loading capacity (Table 5-1, Table 5-2, Table 5-3 and Table 5-4) to determine the required reduction using the equation below:

$$\text{Percent Reduction} = \frac{(\text{Existing Load} - \text{Loading Capacity})}{(\text{Existing Load})} \times 100$$

The 90th percentile monthly existing TSS load was used because it represents a conservative assumption for required reductions. The 90th percentile represents the worst case scenario as opposed to the average conditions. Table 5-7 presents the reductions required in each impaired reach to meet the storm-related and monthly loading capacities, which are also provided for reference. In Crooked Creek, storm-related loads and May require the largest percent reductions. These exceedances are typically associated with the mid to very high flow regimes (Figure 5-1). In Boulder Creek, September and June require the largest percent reductions. These exceedances are typically associated with the high and low flow regimes (Figure 5-2). Estimated existing loads in May were below the loading capacity. While this indicates that no reductions are required in May, the existing load estimate is based on limited observations. The highest percent reductions required in Deadwood Creek were in September and July and were generally observed during the low flow regime (Figure 5-3). The highest percent reductions required in Ketchem Creek were in June, July and August and were observed during all flow regimes (Figure 5-4). The Crooked, Boulder, Deadwood and Ketchem creeks storm-related existing loads and loading capacity are much higher than the other conditions. Therefore, the total amount of sediment load reduction is much higher under these conditions even though the percent reduction may not be as high (Table 5-7). Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 illustrate the storm-related exceedances for Crooked, Boulder, Deadwood and Ketchem creeks, respectively.

Table 5-7. Reductions required to meet TSS TMDLs

Month/ Condition	Crooked Creek subwatershed			Ketchem Creek subwatershed		
	Loading Capacity (lbs/day)	90th Percentile Observed Load[a] (lbs/day)	Required Reduction (%)	Loading Capacity (lbs/day)	90th Percentile Observed Load (lbs/day)	Required Reduction (%)
Storm-related	456,072.3	1,896,369.9	76%	12,485.4	99,769.7	87%
Last week of May	19,111.7	145,757.2	87%	1,191.2	2,226.9	47%
June	12,488.4	23,415.8	47%	721.1	6,337.8	89%
July	15,681.5	28,396.5	45%	986.7	16,672.9	94%
August	15,545.9	23,018.5	32%	1,047.6	12,477.7	92%
September	11,794.4	24,446.3	52%	767.8	1,100.5	30%
Month/ Condition	**Boulder Creek subwatershed**			**Deadwood Creek subwatershed**		
	Loading Capacity (lbs/day)	**90th Percentile Observed Load[a] (lbs/day)**	**Required Reduction (%)**	**Loading Capacity (lbs/day)**	**90th Percentile Observed Load (lbs/day)**	**Required Reduction (%)**
Storm-related	31,010.1	169,089.4	82%	37,698.1	112,261.0	66%
Last week of May	1,815.9	1,288.1	0%	2,178.2	3,188.2	32%
June	1,382.1	20,703.3	93%	1,694.9	5,453.5	69%
July	2,014.9	6,316.7	68%	2,461.4	15,705.4	84%
August	1,690.1	4,676.9	64%	1,905.4	7,291.6	74%
September	1,192.7	40,042.2	97%	1,430.6	9,892.4	86%

[a]The concentrations used for these load calculations are from station CCW-16 (Figure 3-1). This station is approximately two-thirds along the length of the creek and is assumed to represent water quality conditions at the mouth of the watershed. The flows used to calculate loads are based on the full drainage area.

5.3. Wasteload Allocations

The WLA is the portion of the loading capacity allocated to point source discharges to the waterbody that are covered (or should be covered) by NPDES/APDES permits. As discussed above, placer mining is the primary source impacting turbidity in the Crooked Creek watershed. Some placer mines also have USACE general permits for dredge and/or fill material. Other potential point sources include permitted stormwater runoff; however, there are currently no stormwater-related permits in the Crooked and Ketchem creek drainages so these potential sources are included in a future growth WLA (Section 5.6). Each permitted facility in the Crooked Creek watershed receives a WLA in the TMDL based on an estimate of their TSS allowable load to the impaired watershed that they are located in (Table 5-8, Table 5-9, Table 5-10 and

Table 5-11 for Crooked, Boulder, Deadwood and Ketchem creeks, respectively). This calculation incorporates an area-weighted portion of the total load that can be allocated (i.e., loading capacity minus the MOS) using the assumed disturbed area for each point source. .

Table 5-8. Individual current and future wasteload allocations for TSS in Crooked Creek (not including Boulder, Deadwood and Ketchem creeks)

Permit[a]	Name	Receiving Water	Type	Disturbed Area (Acres)	Area Weighted TSS WLA (lbs/day)					
					Storm-related	Last week of May	June	July	Aug.	Sept.
Crooked Creek										
AKG370027	Willis Crooked Creek Mine Site	Crooked Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370C16/ POA-2016-312	Glover Crooked Creek Mine Site	Crooked Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-2016-30	Koppenberg Mining & Manufacturing	Crooked Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-1992-309	Willis Mine Service	Crooked Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-2016-108	Jim Holmes	Crooked and Mammoth creeks	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-1996-699	Karl Hanneman	Crooked Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-2017-324	Chris Pemberton and Brad Sundstrom	Independence Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-2011-428	Jim Holmes	Mammoth Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370185	Wilkinson Miller Creek Mine Site	Miller Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370541/ POA-1990-757	Pacific Mining Porcupine Creek Mine Site	Porcupine Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370977	Underwood Porcupine Creek Mine Site	Porcupine Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370B89	Turgeon Porcupine Creek Mine Site	Porcupine Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-1988-120	Les and Dave Underwood	Porcupine Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG371627	Jack Scoby	Mastodon Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370C84	Jack Scoby	Mastodon Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370C73	Brad Stone	Porcupine Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3

Permit[a]	Name	Receiving Water	Type	Disturbed Area (Acres)	Area Weighted TSS WLA (lbs/day)					
					Storm-related	Last week of May	June	July	Aug.	Sept.
POA-2016-70	George Seuffert	Portage Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
POA-2017-157	Rodney James and Gene Hume	Portage Creek	Fill Material	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
AKG370B83/ POA-2012-503	Kinzer Rebel Creek Mine Site	Rebel Creek	Placer Mine	5[b]	11.2	0.4	0.3	0.3	0.3	0.3
Future Growth WLA for Crooked Creek										
N/A	Future WLA for Mines		Placer Mine	280[b]	623.2	23.2	14.4	17.0	18.1	14.0
N/A	Future WLA for Construction, Industrial, and Transportation Stormwater and Fill Material		Construction, Industrial, and Transportation Stormwater and Fill Material	N/A	34,990.2	1,299.9	811.1	953.8	1,017.6	784.3
Total Future Growth WLA for Crooked Creek				N/A	35,613.5	1,323.0	825.6	970.8	1,035.8	798.3

N/A = not applicable.
[a] AKG permit numbers are associated with APDES permits while POA numbers are USACE permits.
[b] Discussions with ADEC and EPA determined that placer mining operations typically do not disturb more than five acres at a time. In addition, the maximum wetland area that a fill material can disturb is 5 acres. For the purposes of calculating WLAs it is assumed that mining operations and fill material sites will disturb five acres.
[c] Permit covered by Medium Suction Dredge General Permit (AKG371000); all other permits covered by Mechanical Placer Miners General Permit (AKG370000).

Table 5-9. Individual current and future wasteload allocations for TSS in Boulder Creek

Permit[a]	Name	Receiving Water	Type	Disturbed Area (Acres)	Area Weighted TSS WLA (lbs/day)					
					Storm-related	Last week of May	June	July	Aug.	Sept.
Boulder Creek										
AKG370940/ POA-1994-315	Brad Sundstrom	Boulder Creek	Placer Mine/Fill Material	5[b]	6.9	0.4	0.3	0.5	0.4	0.3
AKG370950	Robert Croskrey	Greenhorn Gulch	Placer Mine	5[b]	6.9	0.4	0.3	0.5	0.4	0.3
POA-2016-317	Creighton Lapp	Boulder Creek	Fill Material	5[b]	6.9	0.4	0.3	0.5	0.4	0.3
POA-2011-723	Keith Wright	Boulder Creek	Fill Material	5[b]	6.9	0.4	0.3	0.5	0.4	0.3
Future Growth WLA for Boulder Creek										
N/A	Future WLA for Mines		Placer Mine	50[b]	70.7	4.1	3.2	4.6	3.9	2.7
N/A	Future WLA for Construction, Industrial, and Transportation Stormwater and Fill Material		Construction Industrial, and Transportation Stormwater and Fill Material	N/A	2,875	168.4	128.1	186.8	156.7	110.6
Total Future Growth WLA for Ketchem Creek				N/A	2,946	172.5	131.3	191.4	160.6	113.3

N/A = not applicable.
[a] AKG permit numbers are associated with APDES permits while POA numbers are USACE permits.
[b] Discussions with ADEC and EPA determined that placer mining operations typically do not disturb more than five acres at a time. For the purposes of calculating WLAs it is assumed that mining operations will disturb five acres.

Table 5-10. Individual current and future wasteload allocations for TSS in Deadwood Creek

Permit[a]	Name	Receiving Water	Type	Disturbed Area (Acres)	Area Weighted TSS WLA (lbs/day)					
					Storm-related	Last week of May	June	July	Aug.	Sept.
Deadwood Creek										
AKG370A39/ POA-1991-129	Ryan Eiden	Deadwood Creek	Placer Mine/Fill Material	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
AKG370C75/POA-2016-331	Marc Stringfellow	Deadwood Creek	Placer Mine/Fill Material	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
AKG370305/ POA-1994-448	Scott Thomas	Deadwood Creek	Placer Mine/Fill Material	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
AKG370961	Rob Goreham	Deadwood Creek	Placer Mine	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
AKG371445[c]	David Herren	Fortythree Pup	Placer Mine	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
AKG370007[d]	Ron Wrede	Switch Creek	Placer Mine	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
				N/A[d]	30.9	30.9	30.9	30.9	30.9	30.9
AKG370691	Darell Hocutt	Deadwood Creek	Placer Mine	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
AKG370C89	Blake Harmon	Deadwood Creek	Placer Mine	5[b]	7.0	0.4	0.3	0.5	0.4	0.3
Future Growth WLA for Deadwood Creek										
N/A	Future WLA for Mines		Placer Mine	80[b]	111.0	6.4	5.0	7.2	5.6	4.2
N/A	Future WLA for Construction, Industrial, and Transportation Stormwater and Fill Material		Construction Industrial, and Transportation Stormwater and Fill Material	N/A	3,470.3	200.5	156.0	226.6	175.4	131.7
Total Future Growth WLA for Ketchem Creek				N/A	3,581.3	206.9	161.0	233.8	181.0	135.9

N/A = not applicable.

[a] AKG permit numbers are associated with APDES permits while POA numbers are USACE permits.

[b] Discussions with ADEC and EPA determined that placer mining operations typically do not disturb more than five acres at a time. For the purposes of calculating WLAs it is assumed that mining operations will disturb five acres.

[c] Permit covered by Medium Suction Dredge General Permit (AKG371000); all other permits covered by Mechanical Placer Miners General Permit (AKG370000).

[d] Permit AKG370007 has a mixing zone and a unique set of effluent limits that are incorporated into its permit. The turbidity permit limit is 66 NTU and the permitted flow is 20 gallons per minute (gpm). The turbidity value was converted to a TSS concentration based on the regression equation presented in Figure 2-4 and a TSS load was calculated using the permitted flow value. This is a WLA calculation consistent with the mixing zone in the permit. It must be met at the point of discharge (at the start of the mixing zone). At the downstream boundary of the mixing zone, the WLA calculated based on the 5 disturbed acres must be attained; this WLA is presented in the row above the mixing zone-based WLA.

Table 5-11. Individual current and future wasteload allocations for TSS in Ketchem Creek

Permit[a]	Name	Receiving Water	Type	Disturbed Area (Acres)	Area Weighted TSS WLA (lbs/day)					
					Storm-related	Last week of May	June	July	Aug.	Sept.
Ketchem Creek										
AKG370945	Baisdon Easley Mine Site	Easely Creek	Placer Mine	5[b]	4.3	0.4	0.2	0.3	0.4	0.3
AKG370754	Olson Ketchem Creek Mine Site	Ketchem Creek	Placer Mine	5[b]	4.3	0.4	0.2	0.3	0.4	0.3
POA-1996-75	Steve Olson	Ketchem Creek	Fill Material	5[b]	4.3	0.4	0.2	0.3	0.4	0.3
POA-2017-156	James and Linda Baisdon	Easely Creek	Fill Material	5[b]	4.3	0.4	0.2	0.3	0.4	0.3
Future Growth WLA for Ketchem Creek										
N/A	Future WLA for Mines		Placer Mine	40[b]	34.4	3.3	2.0	2.7	2.9	2.1
N/A	Future WLA for Construction, Industrial, and Transportation Stormwater and Fill Material		Construction Industrial, and Transportation Stormwater and Fill Material	N/A	1,151.7	109.9	66.5	91.0	96.6	70.8
Total Future Growth WLA for Ketchem Creek				N/A	1,186.1	113.2	68.5	93.7	99.5	72.9

N/A = not applicable.
[a] AKG permit numbers are associated with APDES permits while POA numbers are USACE permits.
[b] Discussions with ADEC and EPA determined that placer mining operations typically do not disturb more than five acres at a time. For the purposes of calculating WLAs it is assumed that mining operations will disturb five acres.

For Crooked Creek, there are 19 permitted placer mines and/or fill material sites in the subwatershed, each with an assumed disturbed area of five acres. The total area of permitted placer mining and/or fill material (95 acres) represents 0.06 percent of the 159,610 acres of the Crooked Creek subwatershed included in this TMDL, therefore, 0.06 percent of the loading capacity minus the MOS was calculated to be the combined WLA (for example, 7.9 lbs/day for the last week of May) (see Table 5-1). The combined WLA was divided by 19 to represent the individual allocations (0.4 lbs/day for the last week of May) for each of the 19 permittees (see Table 5-8).

A similar approach was used to calculate WLAs for the Boulder Creek, Deadwood Creek and Ketchem Creek subwatersheds. For Boulder Creek, there are four permitted placer mines and/or fill material sites in the subwatershed, each with an assumed disturbed area of five acres. The total area of permitted placer mining and/or fill material (20 acres) represents 0.09 percent of the entire 21,218-acre Boulder Creek subwatershed, therefore, 0.09 percent of the loading capacity minus the MOS was calculated to be the combined WLA (for example, 1.6 lbs/day for the last week of May) (see Table 5-2). The combined WLA was divided by four to represent the individual allocations (0.4 lbs/day for the last week of May) for each of the four permittees (see Table 5-9).

There are eight permitted facilities in the Deadwood Creek subwatershed. Assuming five disturbed acres each, the permitted areas make up 0.16 percent of the 25,458-acre subwatershed. The loading capacity minus MOS was multiplied by 0.16 percent to calculate the combined WLA. This value was then divided by 8 to obtain the individual WLAs in Table 5-10. In addition, one mine in Deadwood Creek includes a mixing zone in its permit. Specifically, permit AKG370007 has a mixing zone and a unique set of effluent limits in its permit. The effluent limits must be met at the discharge (i.e., at the beginning of the mixing zone) and an alternative WLA was calculated associated with these limits. The turbidity permit limit in the effluent is 66 NTU and the permitted flow is 20 gallons per minute (gpm). The turbidity effluent limit was converted to a TSS concentration based on the greater than 15 NTU regression equation discussed in Section 2.4.3 and an alternative TSS WLA was calculated using the permitted flow value. At the downstream boundary of the mixing zone, the WLA calculated based on the 5 disturbed acres must be attained, consistent with the other permits in the watershed.

There are four permitted facilities in the Ketchem Creek subwatershed (two for placer mining and two fill permits). Assuming five disturbed acres each, the permitted areas make up 0.15 percent of the 13,707-acre subwatershed. The loading capacity minus MOS was multiplied by 0.15 percent to calculate the combined WLA. This value was then divided by four to obtain the individual WLAs in Table 5-11.

A future WLA is included in the TMDL as a reserve allocation for any new permits. Separate future WLAs are provided for each TMDL subwatershed based on the calculations described below. The future WLA is the sum of the anticipated future allowable load from the sources discussed below and permittees from any of these sources can work with ADEC to draw upon this reserve allocation. The future growth WLA includes placer mines, construction, industrial stormwater, transportation and fill material for the Crooked, Boulder, Deadwood and Ketchem creeks subwatersheds. This total future growth WLA is calculated as 10 percent of the loading capacity minus the MOS. ADEC retains the discretion to limit or deny permit issuance or requests for reserve allocations pending an adequate demonstration(s) of turbidity reductions and TMDL effectiveness. There is no information available for construction, industrial stormwater, transportation or fill material to calculate a specific WLA for each of these sources; therefore, they are assigned the balance of the future growth WLA after the future WLA for mines is subtracted.

Specific future growth WLAs for mining were determined based on the number of federal and state mining claims in the Crooked, Boulder, Deadwood and Ketchem creek subwatersheds. To determine a reserve allocation for future growth of placer mines it was assumed that if every owner requested an active permit, the maximum number of placer permits possible in the Boulder, Deadwood, Ketchem, and Crooked creeks subwatersheds would be 12, 24, 10 and 66, respectively. Therefore, 10 mines (50 disturbed acres) were included in the future WLA for Boulder Creek subwatershed (making up the difference between the current APDES permits [2] and the total assumed, possible permits [12], and assuming a five-acre disturbed area per future permit) to consider future placer mines. Sixteen mines (80 disturbed acres) were included in the future WLA for Deadwood Creek subwatershed (making up the difference between the current APDES permits [8] and the total assumed, possible permits [24], and assuming a five-acre disturbed area per future permit) to consider future placer mines. Eight mines (40 disturbed acres) were included in the future WLA for Ketchem Creek subwatershed (making up the difference between the current APDES permits [2] and the total assumed, possible permits [10], and assuming a five-acre disturbed area per future permit) to consider future placer mines. Fifty six (280 disturbed acres) were included in the future WLA for the Crooked Creek subwatershed based on the difference between the current APDES permits (10) and the total assumed, possible permits (66), and assuming a five-acre disturbed area per future permit. Each TMDL subwatershed is assigned a proportion of the reserve load based on the area of mining claims currently in the subwatersheds. The 50 disturbed acres in the Boulder Creek subwatershed represent 0.24% of the total subwatershed area for the future growth WLAs. The 80 disturbed acres in the Deadwood Creek subwatershed, 40 disturbed acres in the Ketchem Creek subwatershed, and 280 disturbed acres in the Crooked Creek subwatershed represent 0.31% 0.29% and 0.18% of the total watershed areas, respectively, for the future growth WLAs.

5.4. Load Allocations

The LA is the portion of the loading capacity allocated to nonpoint source discharges to the waterbody. The LA is not assigned to a specific source. As discussed above, historical and active mining is the primary source impacting turbidity in the Crooked Creek watershed (historical mining is assigned a load allocation, while active, permitted mining is assigned a wasteload allocation [Section 5.3]). Other potential nonpoint sources include tributary inputs and winter road maintenance. The difference between the loading capacity (minus the MOS) and the WLAs (both current and future) was used to assign an overall LA (Table 5-1 and Table 5-4). Individual LAs for historical mining, tributary inputs and winter road maintenance are not provided in this TMDL because specific contributing areas and sediment loading have not been quantified for these sources. If specific source information is collected for these nonpoint sources in the future, the grouped LA can be divided into individual LAs. See Section 6.2.2 for recommendations on future monitoring in the watershed to support individual LAs.

5.5. Margin of Safety

A MOS must be included in a TMDL to account for any uncertainty or lack of knowledge regarding the pollutant loads and the response of the receiving water. The MOS can be implicit (e.g., incorporated into the TMDL analysis through conservative assumptions) or explicit (e.g., expressed in the TMDL as a portion of the loading) or a combination of both. This TMDL includes both an implicit and explicit MOS.

The TMDL includes an explicit 5 percent MOS. A 5 percent explicit MOS is used because the use of load duration curves is expected to provide accurate information on the loading capacity of the stream, but this estimate of the loading capacity could be subject to potential error associated with the method used to estimate flows within the watershed. The explicit MOS was calculated as 5 percent of the loading capacity. The remaining load is the amount of load available for allocations.

In addition to the explicit MOS, the TMDL relies on the use of conservative assumptions associated with the selection of a numeric target for the TMDL. The daily average of the continuous turbidity data was used to represent turbidity concentrations on a given day to be consistent with ADEC’s listing methodology; however, the storm-related or monthly medians of the daily average turbidity observations at Bedrock Creek were used to establish the threshold values and then calculate the TSS numeric targets, rather than the average values. The median of the turbidity observations at Bedrock Creek ranges from 0.4 to 1.8 NTU depending on the month, which is substantially lower than the average values of 0.9 to 4.5 NTU (the storm-related median value is 53.3 NTU while the average is 67.5 NTU). Using the lower turbidity value (i.e., the median value) to establish the background turbidity in the creek represents a conservative approach because it means that the load reductions required to meet the turbidity standard are more likely to be overestimates than underestimates.

Another conservative assumption is that using flow estimates for wet and average years in the Crooked Creek watershed will result in the calculation of loading capacities that are protective of dry years as well. The TMDL will also largely be implemented based on compliance with the concentration-based targets and allocations. The monthly concentrations are expected to be met regardless of the flow condition unless it can be confirmed that the samples were collected on a storm-related day. Including a higher storm-related target considers this intermittent natural condition, while expecting the system to achieve baseline conditions during other periods of each month.

5.6. Future Growth WLA

Developed areas currently include the town of Central, which is a census designated place with a population of less than 200. This small community is not currently subject to a MS4 permit due to its population size and additional growth is not expected to change this. However, additional development is a possibility in the watershed and it is assumed that this development will require permits. Therefore, future growth WLAs for mines, construction, other industrial activities, transportation, and fill material are included, which provide a reserve load from which future permittees can draw (see additional discussion in Section 5.3). Alaska DEC will follow its process regarding notifications, public participation and comment periods for any future point sources in the watershed. Proposed changes will be discussed with EPA and the TMDL will be updated to reflect additional WLAs.

5.7. Seasonal Variation and Critical Conditions

Seasonal variation and critical conditions associated with pollutant loadings, waterbody response, and impairment conditions can affect the development and expression of a TMDL. Therefore, TMDLs must be developed with consideration of seasonal variation and critical conditions to ensure the waterbody will maintain water quality standards under all expected conditions.

This TMDL includes monthly and storm-related numeric targets to account for seasonal differences. These conditions cover the entire period of flowing water; therefore, the numeric targets address the entire range of observed flows. For the Crooked Creek watershed, the times of highest loading and worst impairment are expected to be during the spring break-up period and during stormflow conditions. As discussed in Section 3.4.3, annual precipitation values were evaluated to determine the representativeness of using data from 2014, 2016 and 2017. This comparison established that 2014 was a wet year and 2016 and 2017 were average years, indicating that these years are representative of critical conditions in the watershed. Average and wet years are considered to be representative of critical conditions because turbidity is often a function of stream flow. Precipitation causes an increase in stream flow that can result in an increase in sediment and turbidity concentrations because of channel scour from higher water velocities or sediment washed off the surrounding land and carried to the stream by storm runoff. Data were unavailable to perform additional flow-precipitation relationships, especially given the flashy nature of precipitation in the watershed.

The TMDL does capture the critical conditions when exceedances are most likely to occur (both in frequency and magnitude), while at the same time it is conservative as compliance is anticipated through comparison to the concentration-based allocations.

5.8. Daily Load

A TMDL is required to be expressed as a daily load; the amount of a pollutant the waterbody can assimilate during a daily time increment and meet WQS. The TMDL for TSS is presented as the maximum daily load allowed during the months of May, June, July, August and September as well as storm-related conditions.

5.9. Reasonable Assurance

EPA requires that there is reasonable assurance that TMDLs can be implemented when the TMDL is a mixed source TMDL (USEPA 1991). A mixed source TMDL is a TMDL developed for waters that are impaired by both point and nonpoint sources. The WLA in a mixed source TMDL is based on the assumption that nonpoint source load reductions will occur. Reasonable assurance is necessary to determine that a TMDL’s WLAs and LAs, in combination, are established at levels that provide a high degree of confidence that the goals outlined in the TMDL can be achieved. This TMDL is a mixed source TMDL and, therefore, a reasonable assurance discussion has been included.

Education, outreach, technical and financial assistance, permit administration, and permit enforcement will all be used to ensure that the goals of this TMDL are met. Although it is anticipated that improvements to water quality will take decades because of the extreme disturbance in the headwaters from historical mining activities, the following rationale helps provide reasonable assurance that the Crooked Creek watershed TMDL goals will be met.

5.9.1. Programs to Achieve Point Source Reductions

Permit compliance frequently requires implementation of BMPs, monitoring, and reporting. Requirements differ by permit type. Opportunities and resources associated with both placer mining and construction site stormwater control are discussed below. These activities already support this TMDL and add to the assurance that turbidity will meet Alaska WQS.

Placer Mining Permit Enforcement: Mining activities in the state of Alaska require permits and licenses from several state and federal agencies.

- **ADEC:** ADEC authorizes point sources discharges of mine waters through the APDES General Permit (ADEC 2015).
    - ADEC inspects mine permittees in the watershed as part of their compliance and enforcement program. Since ADEC began oversight of APDES permits (2010), they have been working more closely with the mining community. As needed, ADEC's mine inspections include educating mine operators on BMPs to manage wastewater as well as follow-up visits to ensure compliance with permit requirements and improvements to water quality.
    - The APDES General Permit requires BMPs that prevent or minimize the generation and the potential for the release of pollutants from placer mines to the waters of the United States (ADEC 2015). Permit limits allow discharge of water containing sediment, but this discharge water must meet water quality criteria for turbidity; therefore, under optimal (i.e., full compliance) conditions, these facilities would not contribute turbidity above natural conditions to Crooked Boulder, Deadwood and Ketchem creeks.
        - Drainage waters from the mines must be collected in treatment ponds or other diversion structures and they must prevent pollutants from being discharged into local waters.
        - Wastewater at placer mines is routed through a settling pond system and recycled – only excess water that cannot be contained is discharged; therefore, discharges to a stream from fully compliant mines should be minimal.
        - Discharges must not cause resuspension of sediments, excessive erosion of the streambank or streambed, or downstream flooding.
        - All berms, dikes, dams, and similar water retention structures must be constructed appropriately so that that they can reject the passage of water. These structures must also be maintained to continue to be effective.
        - The permittee must also ensure that, after the mining season, all unreclaimed mine areas, including ponds, are in a condition that will not cause degradation to the receiving waters.
    - **ADEC follow up**: ADEC has the legal authority to require more stringent placer mine permit conditions. Although ADEC is authorized under Alaska Statutes Chapter 46.03 to impose strict requirements or issue enforcement actions to achieve compliance with state WQS, it is the goal of all participants in the Crooked Creek TMDL process to achieve clean water through cooperative efforts, including continued inspections and education through the APDES permit process.

- **Alaska Department of Natural Resources (ADNR):** Reviews and approves mine plans on State land. Requires reclamation of all mining operations on State mining claims under Alaska Statute 27.19. A reclamation plan is required for all disturbances over 5 acres. Reclamation requirements are found in the Application for Permits to Mine in Alaska (APMA; http://dnr.alaska.gov/mlw/mining/placer.cfm). Permitted miners are required to report each year on the volume of material disturbed and the total acreage reclaimed.

- **Bureau of Land Management, U.S. Park Service and U.S. Forest Service**: responsible for approving plans of operation on federal land. Requires that reclamation plans for placer mines on federal claims be consistent with 43 CFR 3809.420, Performance Standards for Surface Management regulations. Requirements and guidance materials can be found at https://www.blm.gov/programs/energy-and-minerals/mining-and-minerals/locatable-materials/surface-management/alaska

- **U.S. Army Corps of Engineers**: The Mechanical Placer Mining General Permit (POA-2014-55) authorizes miners to place fill material into waters of Alaska, including wetlands and streams, for the purpose of mechanical placer mining. In addition to the many management practices required to manage soils erosion from the mining sites, placer mining operations in Alaska's impaired waterbodies also have water quality reporting requirements until the impaired waterbodies are removed from the 303(d) list. See www.poa.usace.army.mil for the requirements of the Corps of Engineers General Permit POA-2014-55.

In addition to the permit compliance and enforcement actions, a series of fact sheets and other stream bank protection resources are available to help mine owners implement the permit requirements.

- dnr.alaska.gov/mlw/factsht/
- www.adfg.alaska.gov/index.cfm?adfg=streambankprotection.main

Construction Stormwater: The ADEC APDES Construction General Permit[4] requires the development of a Stormwater Pollution Prevention Plan (SWPPP) to manage materials, equipment, and runoff from construction sites. To ensure compliance with the TMDL, construction sites need to implement stormwater controls described in their SWPPP and maintain erosion and sediment controls as necessary.

- **Alaska Stormwater Guide:** The diversity of Alaska's geography, geology, and climate can make designing and implementing stormwater controls particularly challenging. The *Alaska Stormwater Guide* (ADEC 2011) provides detailed guidance on the implementation of stormwater BMPs to comply with WQS. *The Stormwater Guide* addresses some of the unique challenges posed by the diversity of Alaska's climate, soils, and terrain, and makes recommendations about the design and selection of stormwater BMPs in an effort to optimize their effectiveness. Chapter 2 of *The Stormwater Guide* provides stormwater considerations for the various climatic regions in Alaska. The Crooked Creek watershed is in the interior Alaska region.

5.9.2. Programs to Achieve the NPS Reductions

The load from the area not associated with point sources was assigned a LA. Recommended BMPs are presented in Section 6 and in the programs described below.

[4] http://dec.alaska.gov/water/wnpspc/stormwater/sw_construction.htm

- **ADEC Monitoring to Evaluate Progress:** The implementation section includes a description of monitoring recommendations to evaluate progress and make adjustments.
- **Alaska Clean Water Action (ACWA) grants** (funded through EPA's CWA Section 319 program) can provide funding to support nonpoint source pollution control practices. More information on ACWA grants can be found at http://dec.alaska.gov/water/acwa/acwa_index.htm.
- **Abandoned Mine Lands Program** funding is available for reclamation of both coal and non-coal abandoned mines (http://dnr.alaska.gov/mlw/mining/aml/).
- **BLM Alaska Mineral Program** has recently (November 2014) developed guidance to facilitate compliance with laws, regulations, and national policies regarding reclamation on BLM lands. BLM's goal is to ensure effective reclamation and to ensure that placer mining operations are adequately bonded. The guidelines establish WQS for rehabilitating placer-mined streams. Additional information is available at https://www.blm.gov/alaska.

To provide additional assurance beyond existing programs and planned activities, the actions described in the Implementation Section (Section 6) are provided to help permittees and property owners better understand how to implement the WLAs and LAs in the TMDL. Given the widespread disturbance in the impaired reaches, it is anticipated that measurable improvements could take decades to achieve. The implementation section of this TMDL describes BMPs that can be used to achieve these actions.

6. Implementation and Monitoring Recommendations

The implementation of management measures in the Crooked Creek watershed is needed to improve water quality to the point where Crooked, Boulder, Deadwood and Ketchem creeks can support their designated uses. Additional monitoring throughout the watershed is desired to measure water quality progress, to measure BMP effectiveness and to verify TMDL assumptions. This section presents recommendations for additional implementation and monitoring to assist in meeting the turbidity threshold values and TSS numeric targets (Table 2-3) and ultimately the WQS for Crooked, Boulder, Deadwood and Ketchem creeks.

6.1. Implementation

Active placer mining (point source) and landscape and stream channel disturbance from historical placer mining (nonpoint source) are the two main sources of elevated turbidity in Crooked, Boulder, Deadwood and Ketchem creeks. Implementation recommendations are organized by point source and nonpoint source below with the options listed in order of priority. Additional implementation options for minor point and nonpoint sources are also identified. Other watershed sources of sediment are limited. There is minimal development, few construction projects, and the population (less than 100 people) is decreasing. Figure 5-1, Figure 5-2, Figure 5-3 and Figure 5-4 can be used to prioritize implementation activities based on flow conditions and months with the highest loading.

6.1.1. Point Source Implementation Options

Discharges from active placer mines are one of the main sources of turbidity in Crooked, Boulder, Deadwood and Ketchem creeks. Efforts to reduce discharges from active placer mines should focus on:

1. **Educating placer miners on turbidity criteria.** This TMDL establishes TSS targets and includes turbidity threshold values for Crooked and Ketchem creeks.
    - Notify permittees of the new criteria within 45 days of TMDL approval.
    - Incorporate the monthly and storm-related WLAs into future APDES permits.
2. **Identifying and reducing/eliminating non-compliant discharges**. ADEC APDES compliance inspection and enforcement activities are intended to reduce/eliminate non-compliant discharges from active mine sites, particularly during storm events. In addition, permit technical assistance may be needed to help miners apply appropriate BMPs.
    - Continue increased inspections by the compliance and enforcement program in the area in an overall effort to improve compliance with WQS.
        i. Conduct follow up monitoring of at least 2 active permittees within the Crooked, Boulder, Deadwood or Ketchem creeks subwatersheds to assess compliance with the TMDL. Loads in Table 5-1, Table 5-2, Table 5-3 and Table 5-4 or concentrations in Table 5-6 will be used to assess compliance.
    - Evaluate the causes of non-compliance.
        i. Inspect active placer mine sites under a variety of conditions to determine under what situations non-compliant discharges are most likely to occur including, but not limited to: high flow conditions and storm events; seasonal closures and spring break-up; and post-reclamation. Work with the appropriate land management agency to ensure reclamation meets requirements.

  ii. Provide technical support on appropriate BMPs, such as settling ponds and erosion control measures, to non-compliant miners as needed.

- Assess the effectiveness of BMPs.
  i. Document existing BMPs, if they are working, and how effective they are during compliance and enforcement and general mine site visits.

3. **Educating placer miners on best management practices to improve water management.** Poor water management practices on active placer mine sites may lead to non-compliant discharges.
   - Best management practices for water management are listed in the general permit (ADEC 2015) and described in detail in the Best Management Practices handbook (ADEC 2017).
   - Finalize the draft Best Management Practices handbook, share with all permittees, and post to the ADEC permitting webpage by the end of 2019.
   - Continue a strategy of annual local outreach meetings, water sampling trainings, and presentations, as well as promoting the draft Best Management Practices handbook as a tool to aid with permit compliance by the ADEC APDES permitting, compliance and enforcement, and nonpoint source staff.

4. **Explore the feasibility of closing mining on Bedrock Creek to maintain as an on-going reference creek.**

6.1.2. Nonpoint Source Implementation Options

The most significant nonpoint source of turbidity to Crooked Creek, Boulder Creek, Deadwood Creek and Ketchem Creek is sediment runoff from historically disturbed sites. Prior to the implementation of reclamation requirements, little to no work was done to reclaim sites after mining. The Crooked Creek area has a long history of mining since the early 1900s, and many areas with historical disturbance. Other nonpoint sources of sediment are minimal, but also identified below (see number 2.). Efforts to reduce nonpoint source inputs should focus on:

1. **Quantifying areas of historical disturbance and identifying restoration opportunities.** Sites that have been disturbed due to dredging, mining or other land disturbance activity likely have a higher erosion potential and may contribute to elevated turbidity. See Table 6-1 for an implementation schedule.
2. **Quantifying other sources of sediment and working with the appropriate agencies to minimize inputs.** Efforts described below are on-going.
   - **Transportation/Highway and Winter Road Maintenance (Alaska Department of Transportation and Public Facilities):** Erosion, sediment, and runoff control for transportation and highways includes construction site BMPs, general maintenance BMPs, permanent control BMPs, and long-term operation and maintenance of BMPs.
     - Construction site BMPs for preventing sediment from transportation and highways include straw bale barriers, filter fabrics, silt fences, sediment basins, and stabilized entrances.
     - General maintenance BMPs include seeding with grass and fertilizing, seeding with grass and overlaying with mulch or mats, wildflower cover, and sodding.
     - Permanent erosion, sediment, and runoff control for transportation and highways include grassed swales, filter strips, terracing, check dams, detention

ponds or basins, infiltration trenches, infiltration basins, constructed wetlands, salt and sand storage, and housekeeping BMPs.

- Operation and maintenance of transportation and highway BMPs should include regularly scheduled inspection and maintenance of both temporary and permanent erosion prevention BMPs and the removal of temporary BMPs (USEPA 1995).
- In addition, preventing runoff of sediment should be a priority. When feasible, maintenance crews should keep sand out of streams. This can be achieved through the use of filtration and retention BMPs as well as treatment options that minimize the loss of sand from the road surface.

- **Residential and Commercial Development (Alaska DEC Stormwater Program):**
  - Encourage application of green infrastructure and other BMPs to reduce erosion and increase vegetative cover and infiltration of water on-site.
- **ATV Trail Use (Alaska DNR and Bureau of Land Management):**
  - Educate trail users on appropriate trail use and the impacts of degradation on water quality. Encourage trail users to minimize use during wet weather or on wet areas of the trails during the summer.

Table 6-1. Schedule for implementing nonpoint source management measures.

Action Item	Milestones	Organization	Performance Measures	
			What	When*
Quantify areas of historical disturbance and identify restoration opportunities.	Use GIS, photos and on-the-ground field surveys to map areas of disturbance.	ADEC	Obtain/prioritize funding for staff time	Spring 2019
			Conduct field surveys	Summer 2019
			Create maps	Fall/Winter 2019-20
	Estimate sediment loading from erosion.	ADEC	Obtain/prioritize funding for staff time	Fall/Winter 2019-20
	Work with the appropriate land management agency to identify land ownership status.	ADEC and land management agency (BLM or DNR)	Obtain/prioritize funding for staff time	Spring 2020
			Convene meetings to obtain information from land managers	

	Create a list of potential restoration needs. BLM has developed guidance to support reclamation effectiveness monitoring. These guidelines are available at https://www.blm.gov/policy/im-ak-2015-004. Restoration may include revegetation or construction of other erosion control measures.	ADEC	Obtain/prioritize funding for staff time	Summer 2020
			Create report of restoration needs by priority	Summer 2020
	Prepare an estimated budget of restoration costs and benefits (in sediment erosion reduction).	ADEC	Obtain/prioritize funding for staff time	Fall/Winter 2020-21
			Obtain estimates for restoration work including design, construction, monitoring and maintenance	Fall/Winter 2020-21
			Prepare summary of potential restoration costs for needs identified above	Fall/Winter 2020-21
	Work with the appropriate land management agency to prioritize sites for restoration.	ADEC and land management agency (BLM or DNR)	Obtain/prioritize funding for staff time	Spring 2021
			Convene follow up meetings to discuss restoration priorities with land managers	Spring 2021
	Pursue funding for projects.	ADEC and land management agency (BLM or DNR)	Obtain/prioritize funding for staff time	2021-2022
			Research funding opportunities	2021-2022
			Apply for funding for priority projects	2021-2022

	Implement high priority restoration projects.	ADEC and land management agency (BLM or DNR)	Obtain funding for high priority projects	2022-2025
			Implement restoration projects	2022-2025

*Implementation of all measures is dependent on funding and staff availability.

6.2. Monitoring Recommendations

Sediment-related impacts on designated uses are often difficult to characterize. For this reason, sediment-related TMDLs are likely to have uncertainty associated with selection of numeric targets representative of the desired in-stream condition and estimates of source loadings and waterbody assimilative capacity. The amount of available data used in this TMDL was limited and that resulted in the use of correlations and estimates rather than site-specific data for TSS and flow.

Future data collection and monitoring could address uncertainties in the TMDL numeric targets, and further quantify point and nonpoint source loading. This information could be used to refine the TMDL targets or threshold values and to assess success of implementation actions.

Additional monitoring data could:

- Address uncertainties with data used to develop the TMDL TSS numeric targets and turbidity threshold values.
    - Verify the water depth to flow relationship.
    - Provide flow data.
    - Verify the natural background conditions.
    - Provide high flow TSS and turbidity data.
- Quantify point and nonpoint source loading.
- Assess success of implementation actions.
    - Indicate improvements in water quality.

6.2.1. Refining TMDL Targets and Alternate Target Assessment and Threshold Values

Additional monitoring could support future load reduction estimates using site-specific data to more accurately represent Crooked, Boulder, Deadwood and Ketchem creeks. In particular, flow data (cfs), TSS data (mg/L), and turbidity data (NTU) taken simultaneously during all flows regimes at the Bedrock Creek (CCW-12), Crooked Creek (CCW-16), Boulder Creek (CCW-14), Deadwood Creek (CCW-17) and Ketchem Creek (CCW-20) stations would be beneficial.

In addition, monitoring during high flow storm events could provide data to verify threshold values and TSS targets for higher flows. Monitoring earlier in the spring could provide information on spring break up, when sites may be at higher risk for erosion. Currently, the TMDL only applies from late May – September.

Periods when the natural background turbidity exceeded 50 NTUs is represented by the storm-related threshold value and TMDL numeric TSS target. However, an alternative threshold or target could be calculated to reflect even higher natural turbidity conditions if they are observed. Specifically, if future data collected at Bedrock Creek show a turbidity value greater than 50 NTU, then the alternative equations presented below should be used to identify the threshold values (which are then used to calculate TSS numeric targets) to assess potentially impaired segments for concurrent days.

The WQC allows for a 10 percent increase in turbidity when natural turbidity is more than 50 NTU, with a maximum increase of 15 NTU (note: this condition could occur in Bedrock Creek during the spring break-up in May or during storm events). Therefore, if sampling is performed and the natural turbidity at Bedrock Creek is observed above 50 NTU, then the threshold value can be calculated using the equations below (note: if measured turbidity in Bedrock Creek is below 50 NTU or associated with a storm event, then the threshold values and numeric targets in Table 2-3 apply):

During spring break-up if measured Bedrock Creek turbidity is 50-150 NTU:

Bedrock Creek NTU + 10% = Threshold Value

During spring break-up if measured Bedrock Creek turbidity is above 150 NTU*:

Bedrock Creek NTU + 15 NTU = Threshold Value

*A 10% increase in a turbidity of 150 NTU is equal to 15 NTU; a 15 NTU increase applies when the natural condition turbidity measurement is above 150 NTU.

6.2.2. Point and Nonpoint Source Monitoring

ADEC authorizes wastewater discharge from placer mining operations to surface waters through the APDES General Permit. APDES inspections for active placers mines should focus on storm events when permit violations are most likely to occur. However, inspections are also important during non-storm conditions. Non-storm conditions dominate the majority of the period that the TMDLs apply (late May through September) and inspections should confirm that dischargers are able to retain water during non-storm conditions. Additional data collection by the permit holder and associated annual reporting should be encouraged by ADEC.

During all APDES compliance and enforcement and general mine site inspections, the following information should be collected:

- Turbidity, and TSS when possible, above and below the mine site and of any discharge.
- Turbidity, and TSS when possible, at Bedrock Creek (CCW-12).
- Water level and discharge at Bedrock Creek and the inspection site.
- Documentation of existing BMPs and their effectiveness.
- If sampling is conducted associated with storm-related conditions, evidence should be provided, such as nearby daily precipitation data for the sampling date and the preceding 10 days. This information will be used by ADEC to identify the applicable threshold value or numeric target (i.e., the storm-related value or the monthly baseflow threshold or target).

Nonpoint source monitoring should focus on areas identified with historical mining disturbance. If possible, data may also be collected to evaluate runoff from highways and roads to ensure compliance with WQS. Data collection to assess nonpoint source loading and to inform future restoration activities should include:

- Turbidity, and TSS when possible, above and below the disturbance area.
- Water level and discharge.
- Stream channel cross section measurements.
- Stream longitudinal profile measurements.
- Pebble counts.
- Watershed area, land cover and proportion of disturbance.
- Riparian habitat assessment.
- Documentation of existing BMPs and their effectiveness

More information on data collection procedures and additional resources for restoration projects can be found at www.stream-mechanics.com and in BLM guidance for reclamation monitoring available at https://www.blm.gov/policy/im-ak-2015-004.

If future development occurs, construction and/or industrial stormwater monitoring may be required. The following describes the permit related monitoring that would be required:

- **Construction:** Consistent with the CGP, construction facilities are required to ensure that their discharge does not exceed specific WLAs or LAs. If a permittee discharges to a waterbody that is included on the state's CWA Section 303(d) list (Category 5 on the Integrated Report) as impaired for turbidity or sediment, and if that permittee disturbs more than twenty (20) acres of land at one time (including noncontiguous land disturbances that take place at the same time and are part of a larger common plan of development or sale), then that permittee must conduct turbidity sampling at locations as required by Part 3 of Permit No. AKR100000 to evaluate compliance with the WQS for turbidity.
- **Fill Material:** Discharge of dredged or fill material to waters and wetlands of the United States within Alaska requires a CWA Section 404 Permit from the USACE. To meet Section 404 Permit requirements, steps must be taken to avoid or minimize impacts to aquatic resources; compensation must be provided for unavoidable impacts. Compliance with the permit will ensure these discharges meet the TMDL WQS.
- **Industrial:** Industrial stormwater discharges are covered under the MSGP[5]. The MSGP requires that discharges are controlled to meet applicable WQS. Monitoring specifics are dependent on the industrial sector and are applicable to a specific discharge.

6.2.3. Ambient Monitoring

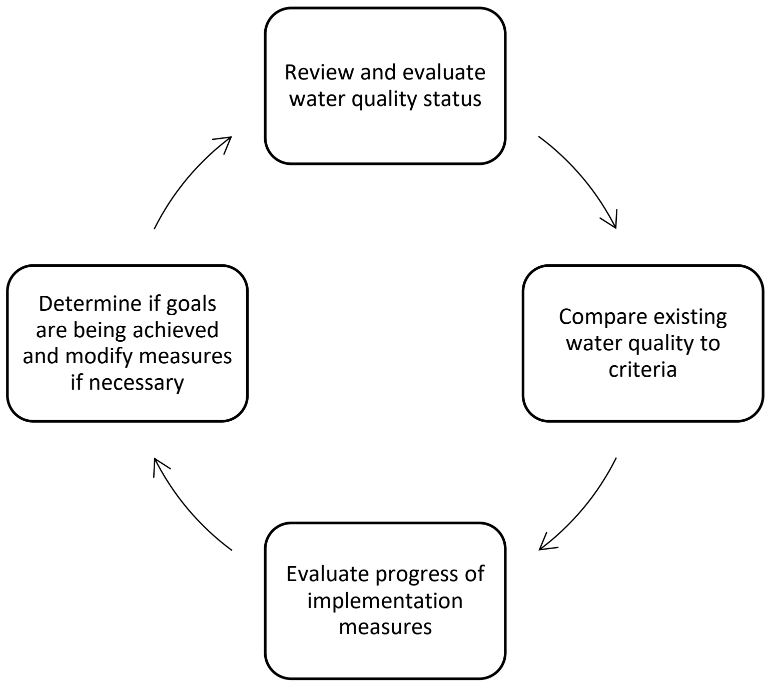
In addition to the data collection recommended for Crooked, Boulder, Deadwood and Ketchem creeks and the reference watershed, Bedrock Creek, to determine compliance with the TMDL, additional data may be collected throughout the Crooked Creek watershed to confirm the decision to de-list several other waterbodies in the watershed: Bonanza Creek, Mammoth Creek, Mastodon Creek and Porcupine Creek. The data collected in these waterbodies should include flow (cfs), stream level, TSS (mg/L) and turbidity (NTU). Whenever possible, flow and turbidity measurements should be taken through continuous sampling protocols, while TSS data are generally represented with grab samples.

[5] http://dec.alaska.gov/water/wnpspc/stormwater/docs/AKG060000_-_2015_MSGP_Permit.pdf

6.2.4. Adaptive Management

This implementation plan assumes that the activities described above will yield water quality improvement. The feedback loop concept is a mechanism for evaluating the success of this plan and whether the goal of improving water quality is being achieved. For each year of data collection (point or nonpoint source) this model will be implemented. See Figure 6-1.

Figure 6-1. Adaptive management feedback loop



7. Public Comments

The notice for the public review period was posted on XXXX X, 2019, and the review period closed on --XXX X, 2019. The notice was posted in the local newspaper, Fairbanks Daily Newsminer, on ADEC's website, and on the State of Alaska's Public Notice Web Site. A fact sheet was also available on ADEC's website.

Comments on the TMDLs were received from XXXX. Comments and additional information submitted during this public comment period were used to inform or revise this TMDL document. See XXXX for detailed information on the response to comments.

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Appendix A

Data Analysis Figures for Crooked, Boulder, Deadwood and Ketchem Creeks

Crooked Creek Data Analyis Figures:

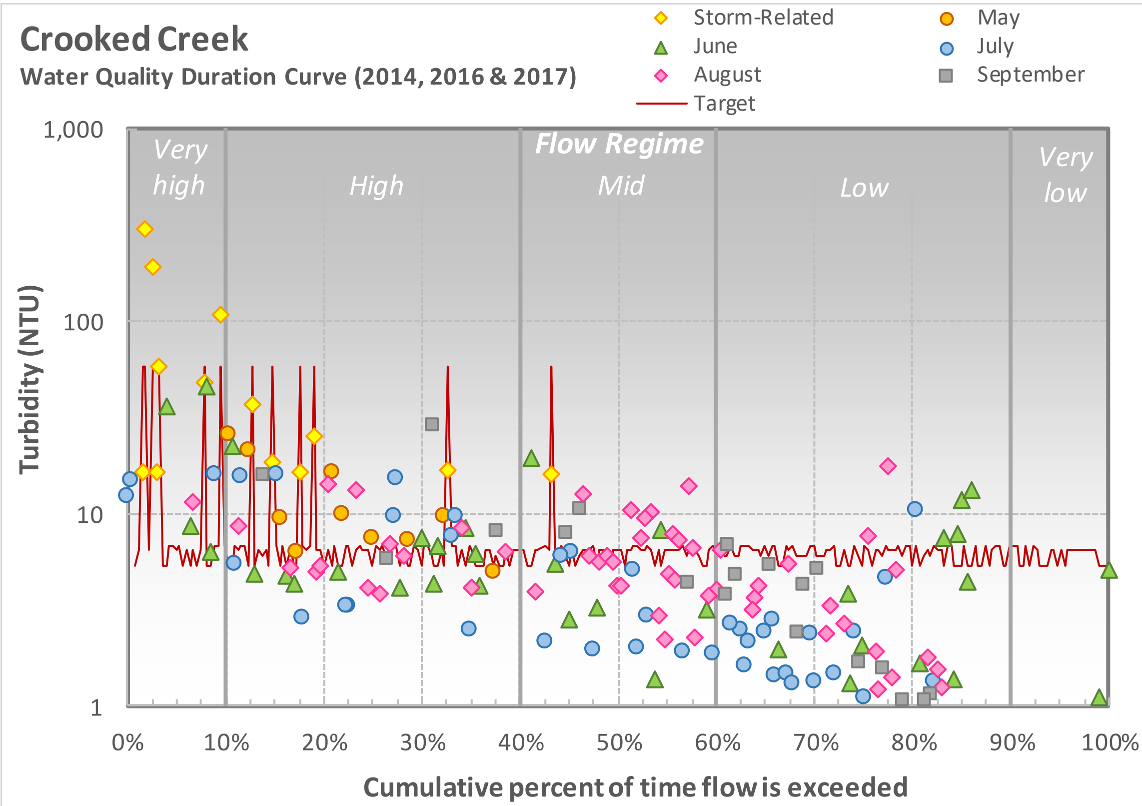

Figure A-1. Turbidity values for Crooked Creek as a function of flow (2014, 2016 & 2017)

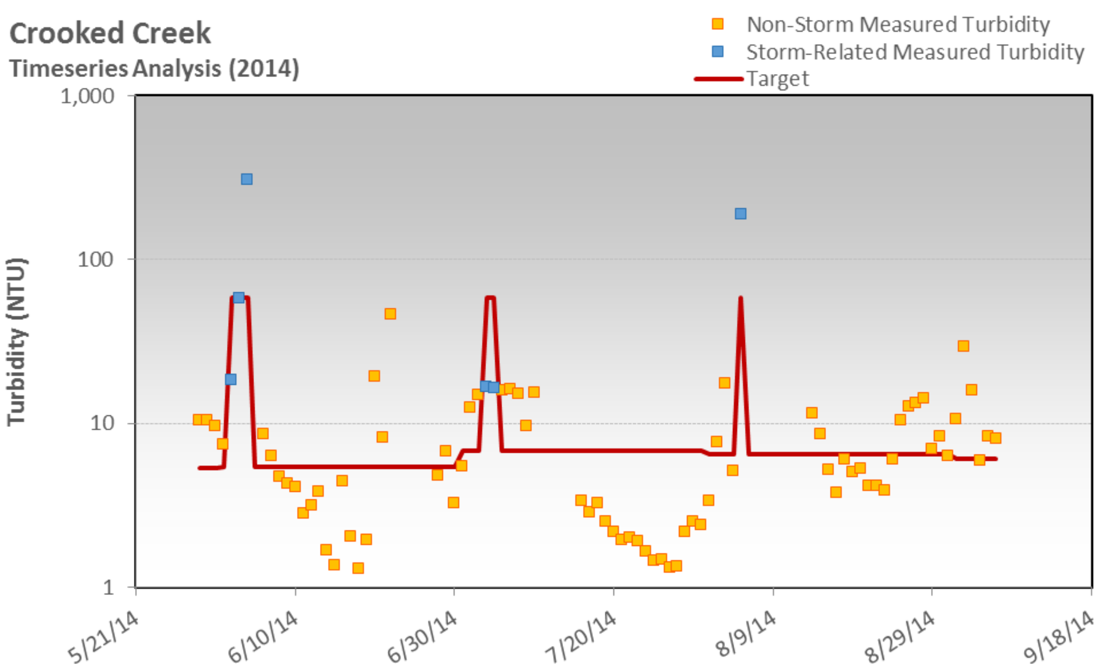

Figure A-2. Measured turbidity time series analysis for Crooked Creek (2014)

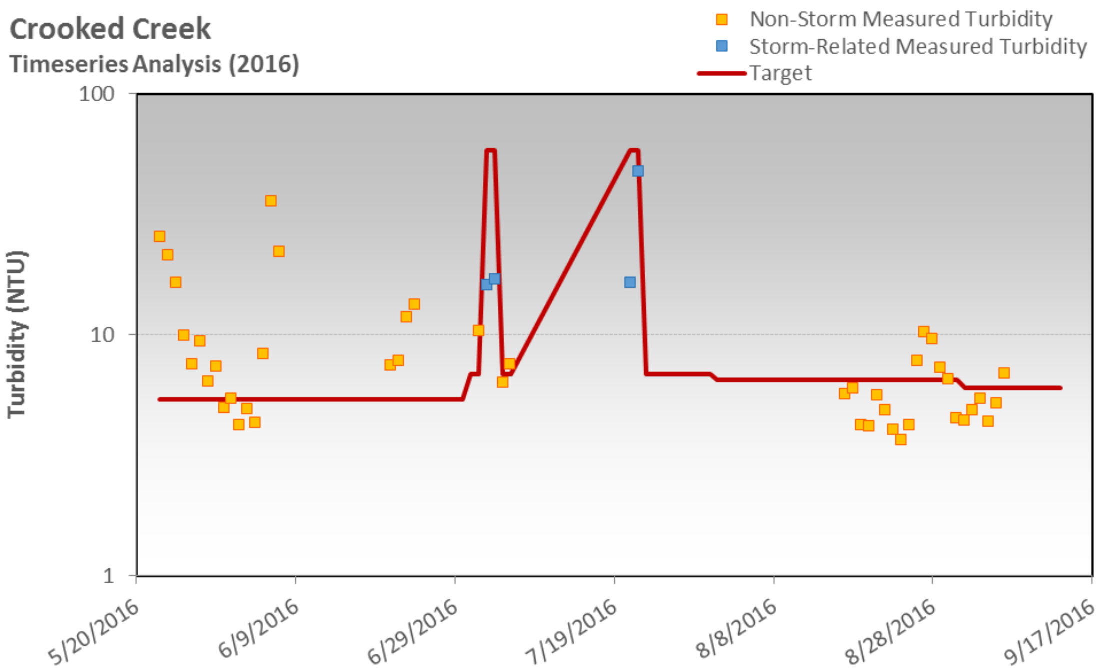

Figure A-3. Measured turbidity time series analysis for Crooked Creek (2016)

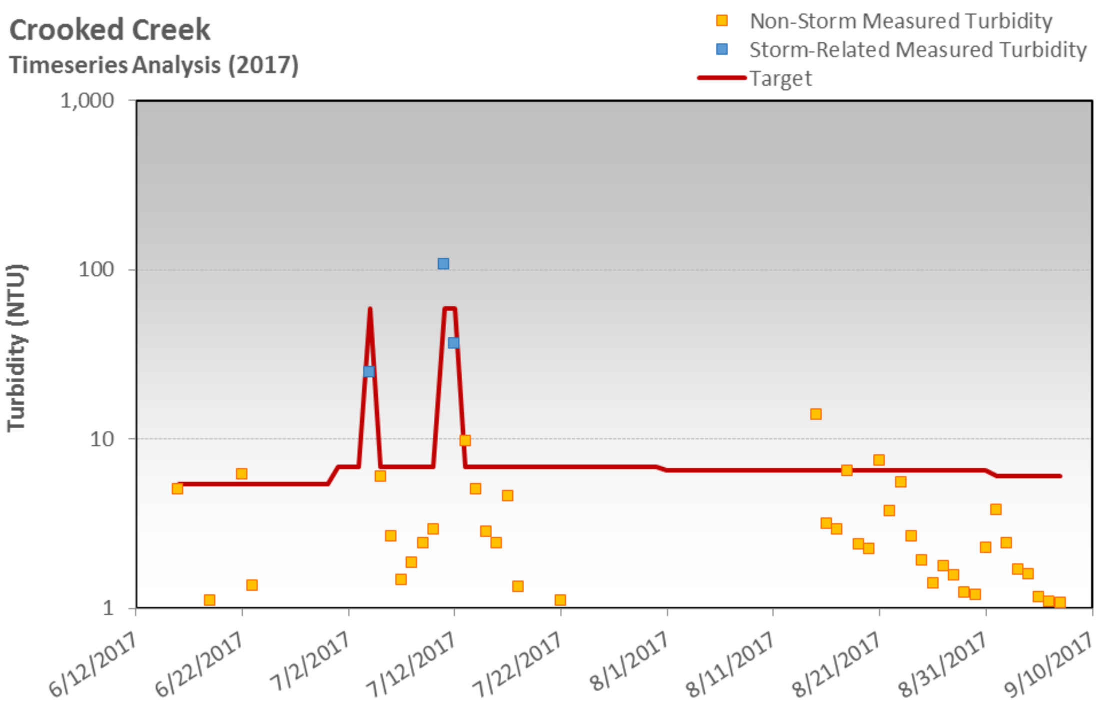

Figure A-4. Measured turbidity time series analysis for Crooked Creek (2017)

Boulder Creek Data Analysis Figures:

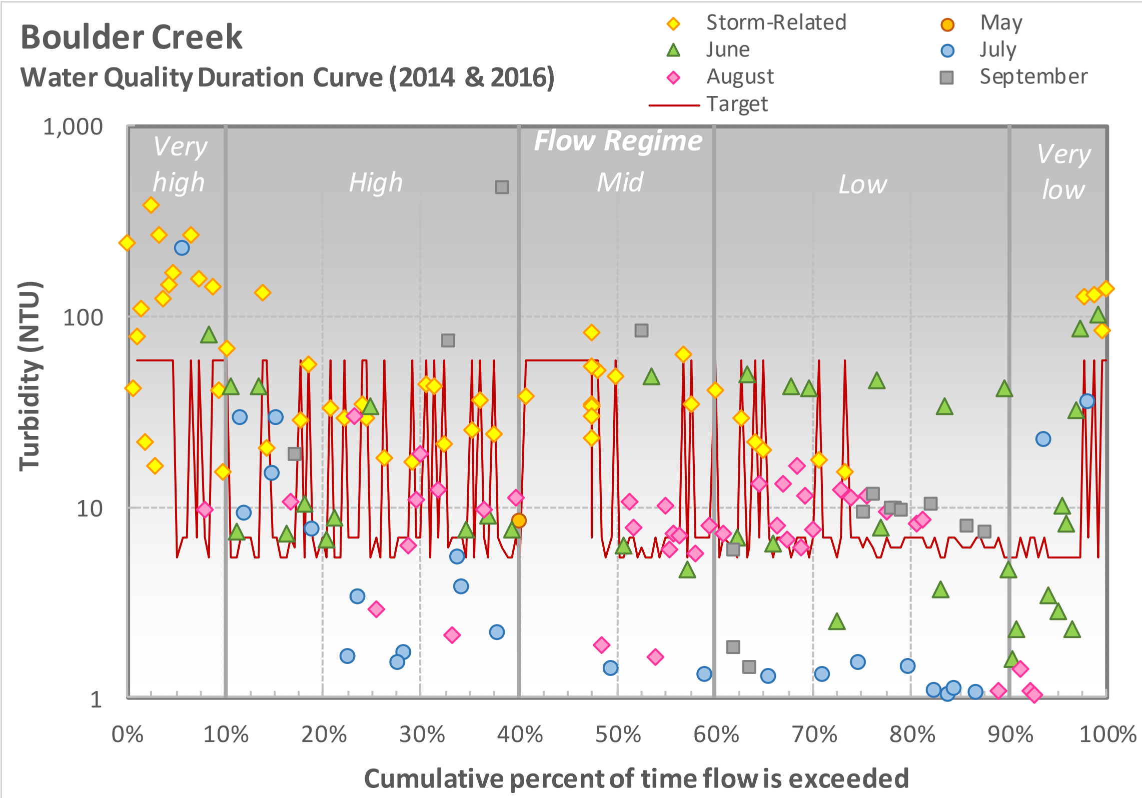

Figure A-5. Turbidity values for Boulder Creek as a function of flow (2014 & 2016)

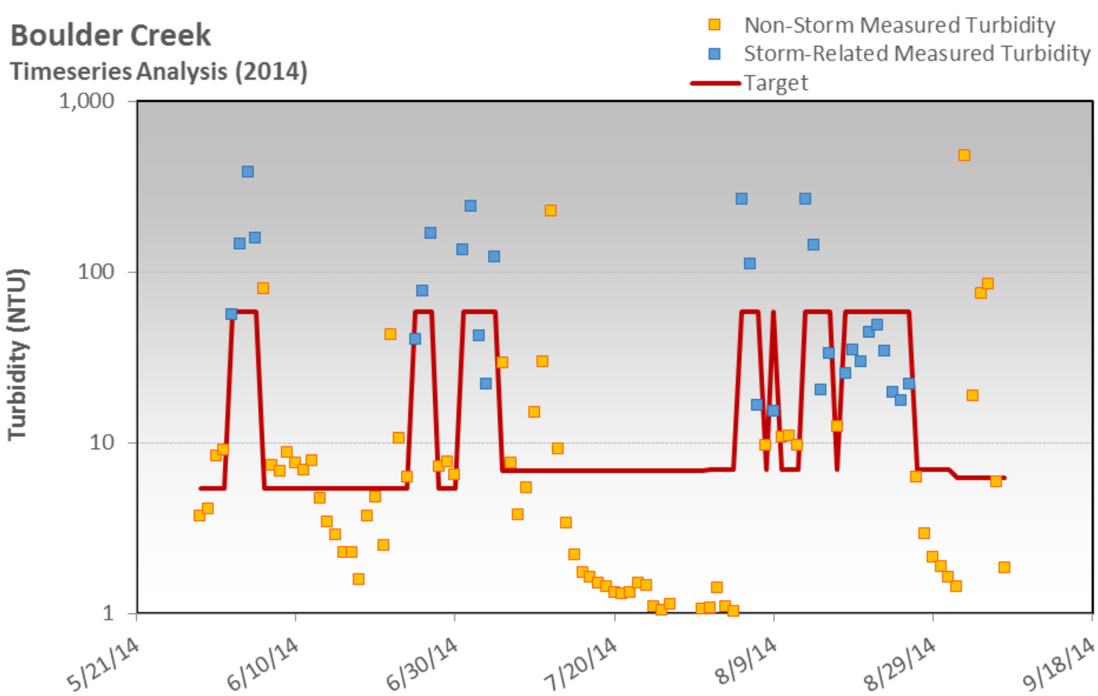

Figure A-6. Measured turbidity time series analysis for Boulder Creek (2014)

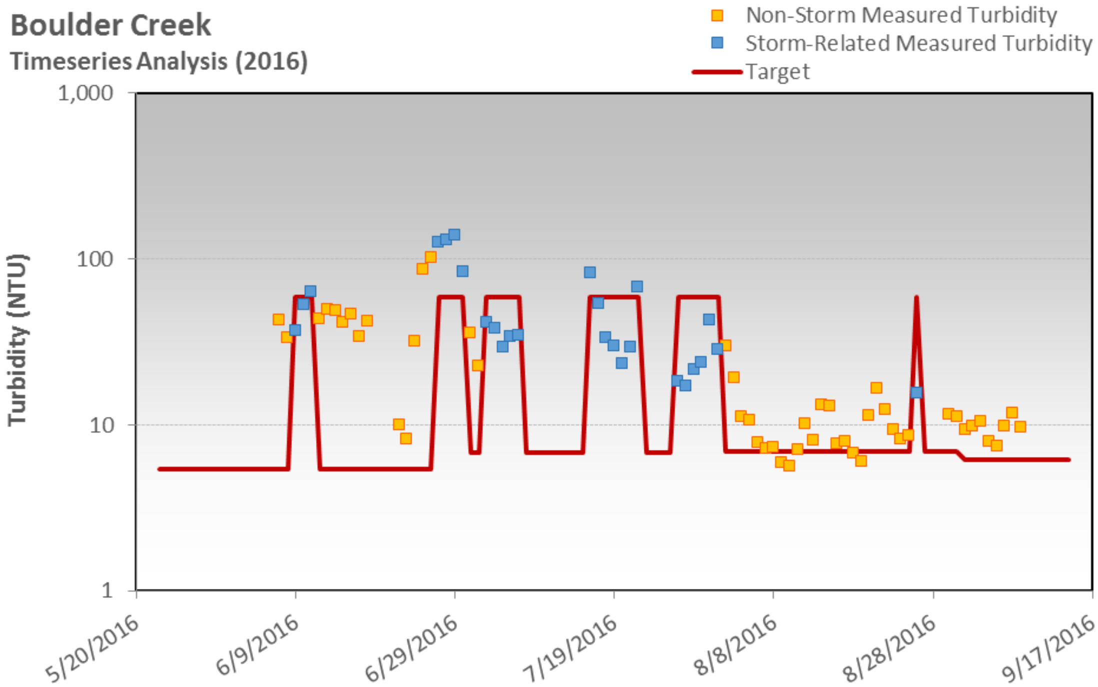

Figure A-7. Measured turbidity time series analysis for Boulder Creek (2016)

Deadwood Creek Data Analysis Figures:

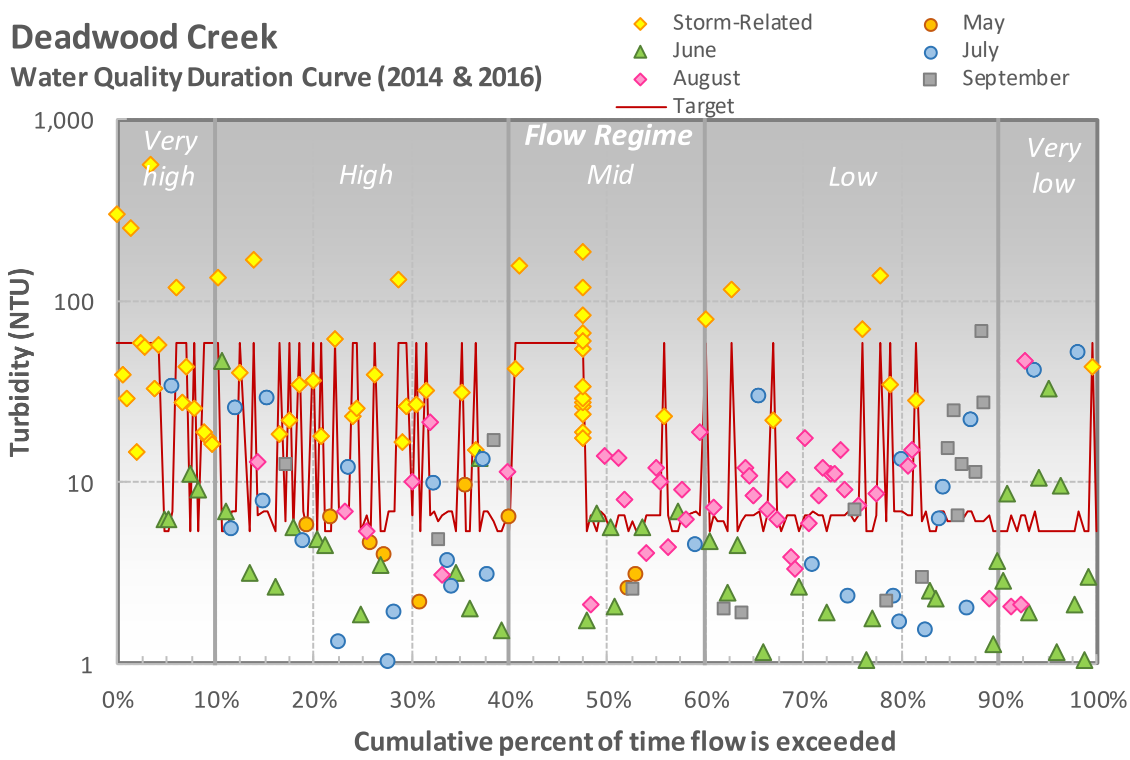

Figure A-8. Turbidity values for Deadwood Creek as a function of flow (2014 & 2016)

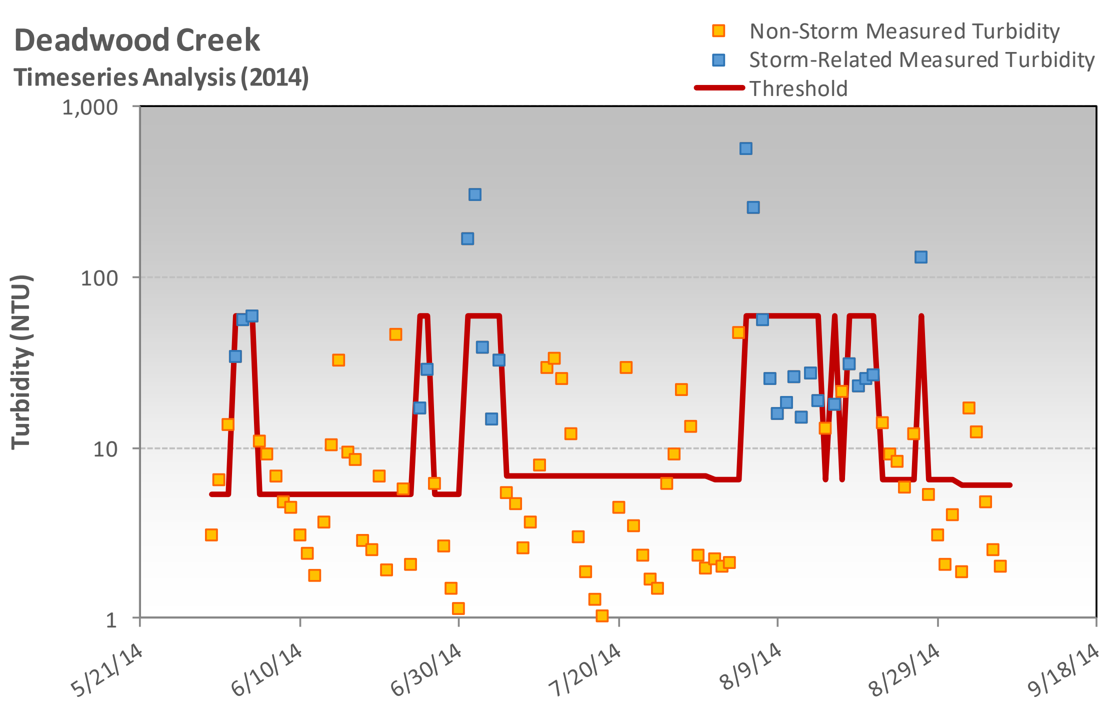

Figure A-9. Measured turbidity time series analysis for Deadwood Creek (2014)

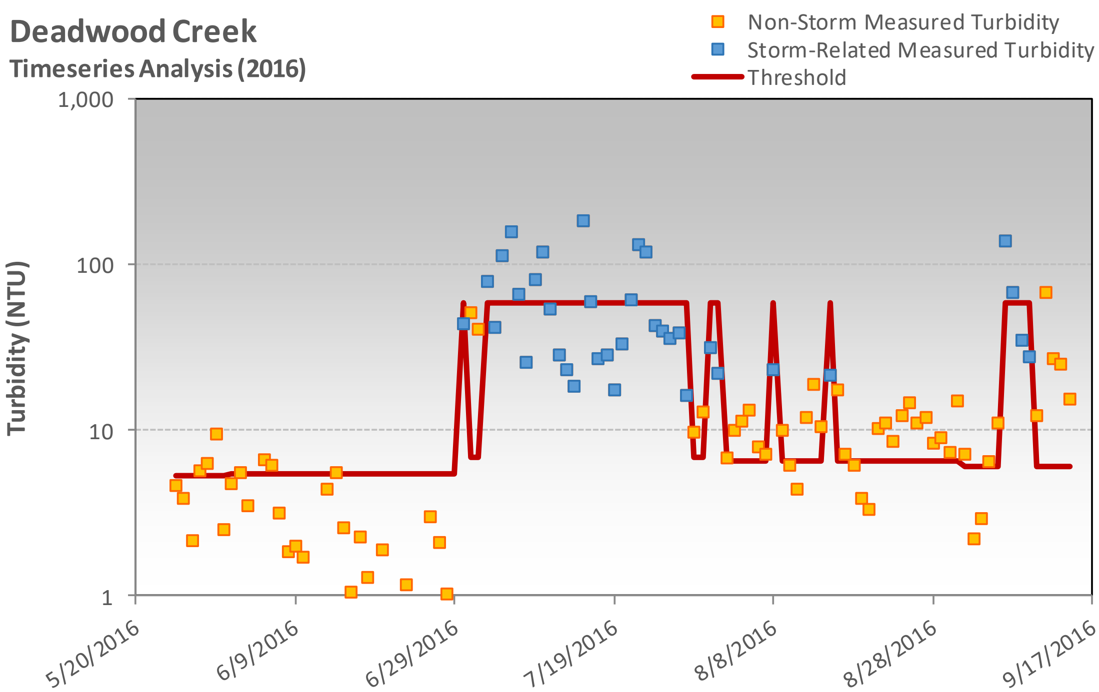

Figure A-10. Measured turbidity time series analysis for Deadwood Creek (2016)

Ketchem Creek Data Analysis Figures:

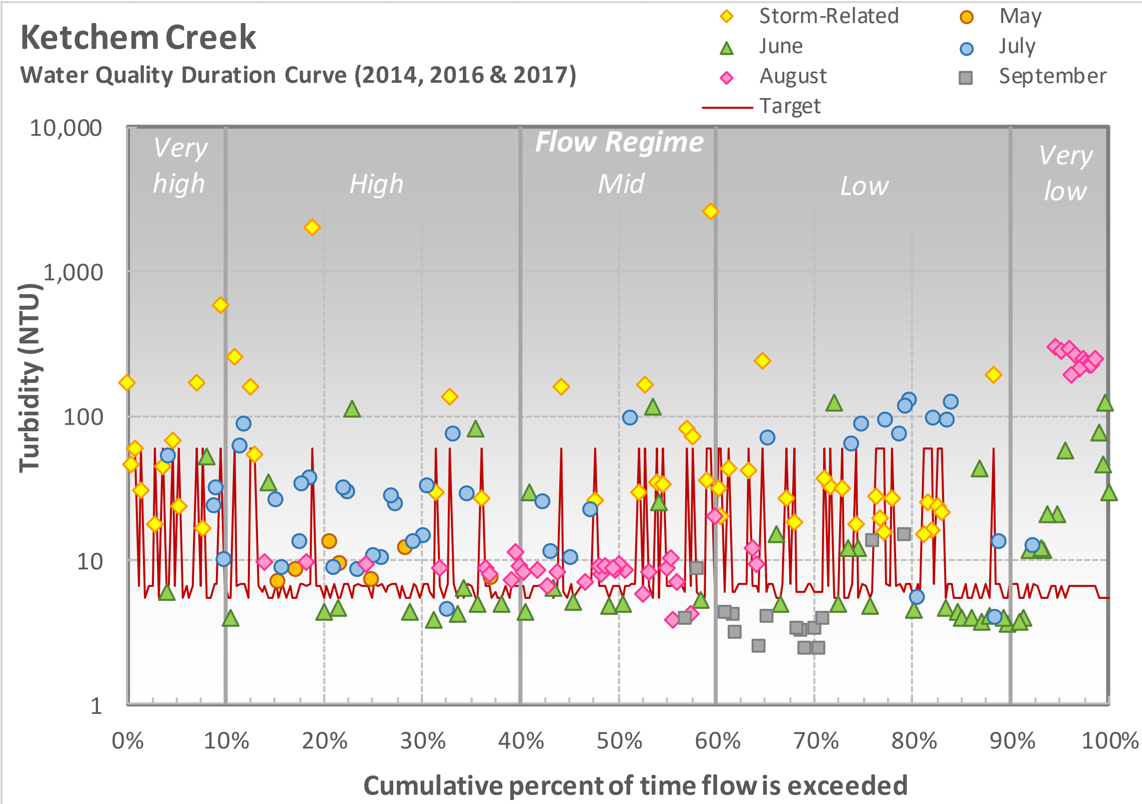

Figure A-11. Turbidity values for Ketchem Creek as a function of flow (2014, 2016 & 2017)

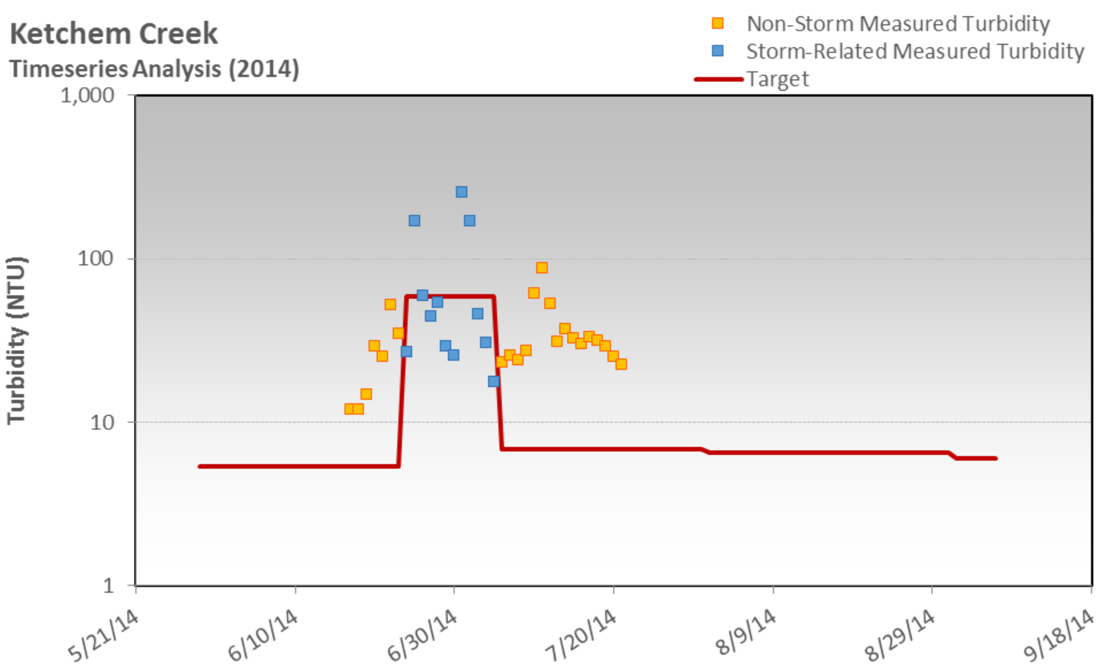

Figure A-12. Measured turbidity time series analysis for Deadwood Creek (2014)

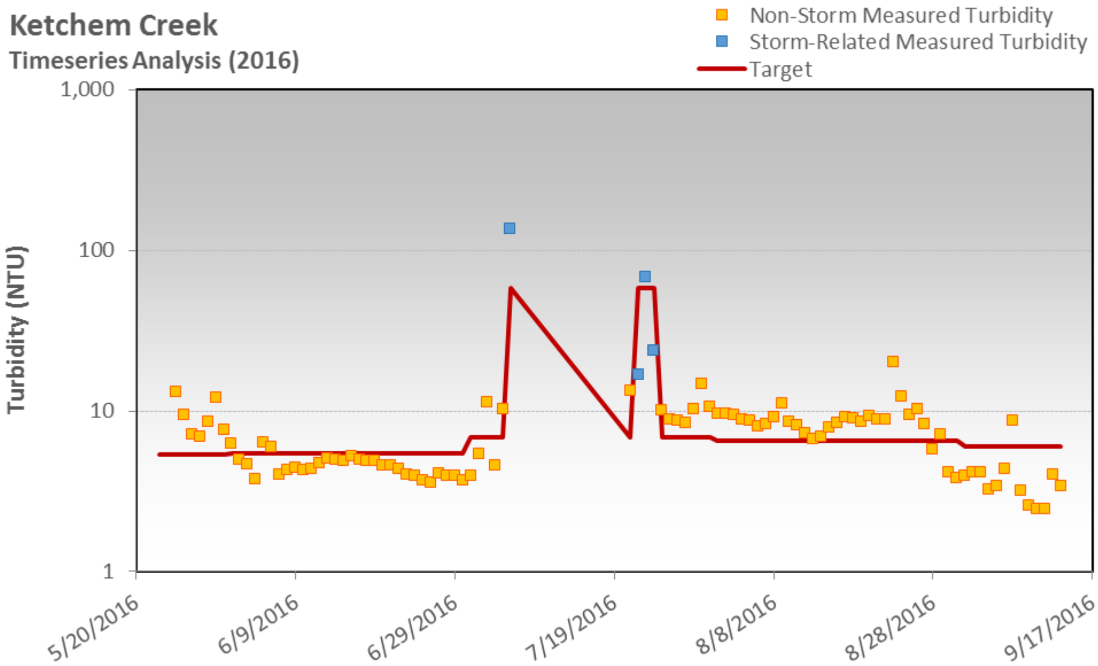

Figure A-13. Measured turbidity time series analysis for Ketchem Creek (2016)

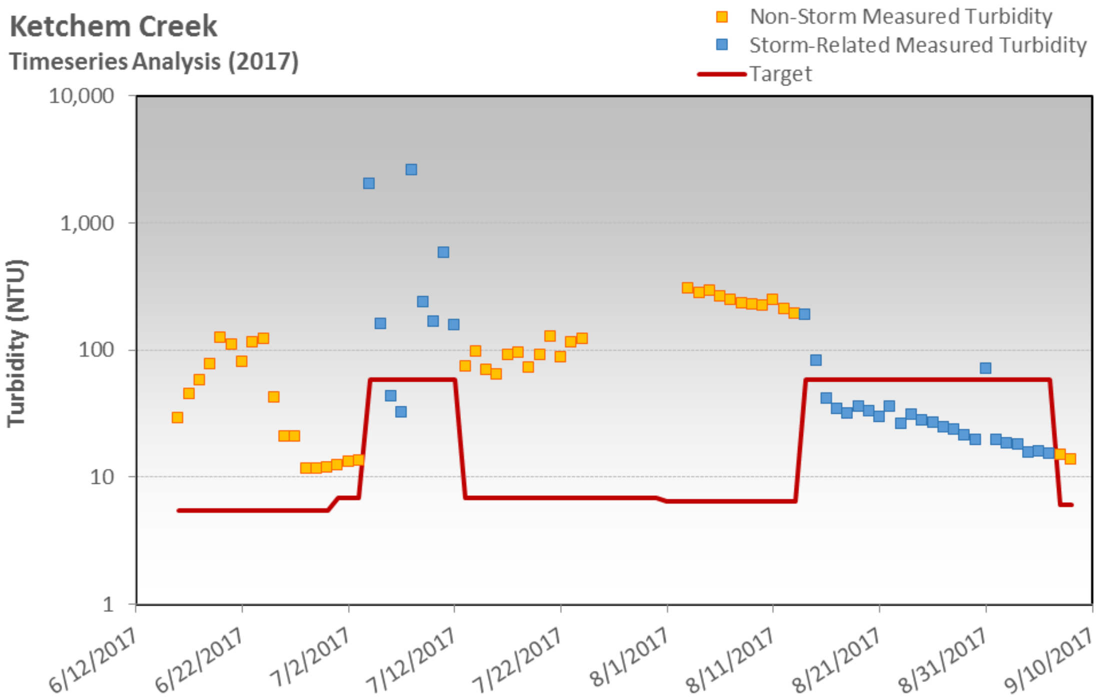

Figure a-14. Measured turbidity time series analysis for Ketchem Creek (2017)