Sustainability of Trout Populations and Role of Tributaries,

Examining Water-Temperature Habitat Conditions in the Dolores River Basin

Prepared by

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Prepared for

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About the Author. Mountain streams appealed to the author from experience as a boy visiting the Great Smoky Mountains in eastern Tennessee and western North Carolina. In research on the Cumberland Plateau, he examined changes to stream water and groundwater quality from coal surface mining as part of studies at the University of Tennessee, where he finished his PhD in environmental engineering. He has an undergraduate degree in chemistry and a master's degree in water resources development; and since has spent several decades in environmental engineering consulting. He resides in Mancos, CO, just south of the Dolores River basin study area.

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Key Acronyms and Temperature Criteria

30T, 30-minute temperatures

WAT, weekly average temperatures

MWAT, maximum weekly average temperature

TAT, two-hour average temperatures

MTAT, maximum two-hour average temperature

62.6 F, Colorado (CO) chronic criterion

71.1 F, CO acute criterion

64.6 F, brook trout chronic criterion

64.9 F, rainbow trout chronic criterion

67.3 F, brown trout chronic criterion

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I. Purpose

Water temperatures were measured and examined to assess trout habitat conditions in warm weather at the Dolores River basin, a mountainous watershed in southwestern Colorado. The purpose was to determine if portions of the basin became too warm during July-August, and whether thermal relief was available for trout. The Colorado chronic and acute water temperature criteria that apply for the study area were used in making the assessment. Findings were examined for their potential assistance to the planning of trout habitat protection and preservation.

II. Background

Water temperature determines the suitability of a habitat through its role in physiological processes that affect growth, behavior, reproduction, and survival throughout all life stages [1, 2]. Modeling how trout distribution may develop in response to climate change in the western United States has shown that stream temperature, together with flow regime, and biotic interactions, likely will drive shifts in fish species distribution [3]. Therefore, water temperature is important to monitor, especially given a changing climate [2, 4, 5].

Water temperature affects physiological processes in fish that determine growth, food consumption, metabolism, reproduction, and survival [1, 6, 7], and which also influence behavior and habitat selection [1, 2, 8]. Some physiological or biochemical processes, including growth, food consumption, and activity have optimum temperatures. For example, the rate of growth may increase with rising water temperature to a point and then decline [9]. In fact, studies have shown that growth rate is the most sensitive physiological process to water temperature [1, 10].

Water temperatures that are too high, or too low, can lead to death, either immediate or delayed [9, 11]. The temperature extremes that result in death are influenced by the developmental stage of the fish and the temperature range to which it is accustomed [9]. Fish tend to select an environment near their optimal growth temperature, and generally have an optimal range of temperatures [9] or “zone of efficient operation” [12].

Through its effect on growth, temperature plays a key role in determining the age when fish become sexually mature. Variation in the fecundity (number of eggs) of female salmonids is strongly related to their length [11, 13]. Water temperature also has a strong effect on recruitment of individuals from one-year class to the next in high-elevation populations [2, 14, 15, 16].

Water temperature's effects on growth, reproduction, and survival lead to consequences in fish behavior, in general, and to differences in habitat selection among salmonid species and subspecies [11]. Temperature can drive daily movements, seasonal movements, and competitive interactions [2, 17]. Therefore, water temperature is useful as an indicator of habitat suitability. Mean summer water temperature, together with available stream length, can be used to identify potentially suitable habitat for cutthroat trout [2, 13, 14].

Researchers studying cutthroat, brook, rainbow, and brown trout found that stream temperature, flood seasonality, and the presence of other species strongly affected habitat occupancy. The coldest streams were occupied by cutthroat trout and brook; rainbow trout inhabited warmer streams; and brown trout, in the warmest streams [3].

The influence that water temperature has on local and basin-scale habitat selection, species distribution, health, and movements make it a useful parameter for assessing and monitoring trout habitat and populations. Identifying thermal criteria for species is critical to the ability to maintain or restore both native and sport trout fisheries [11]. Not only is water temperature a key driver of the distribution, abundance, and health of a population, but it is also a sensitive indicator, because even small changes can have substantial effects [4, 5, 17].

III. Setting

A. Study Area

1. The Dolore River basin study area is about 500 sq mi in size. It extends from approximately 7000 ft, which is the lowest elevation at which temperatures were measured and is inside the city limits of Dolores, to approximately 14,200 ft in the mountains. The main stem is roughly 60 miles in length. Exhibit 1 shows the study area and its drainage boundary.
2. Within the study area are 44 perennial, trout-bearing streams, as identified in *Climate Change and the Upper Dolores Watershed: A Coldwater-Fisheries Adaptive Management Framework* [18].

B. Data Collection

1. Water temperatures were measured in 2018 and 2019 in the main stem and at tributaries.
2. 2018 data collection
    a. The 2018 data were from four locations in the main stem and 18 locations in nine tributaries, a total of 22 measurement sites.

Exhibit 1. Dolores River Basin Study Area in Southwestern Colorado

Source: U.S. Geological Survey Water Resources Program *StreamStats* [19]

    b. For convenience, the main-stem measurement elevations were referred to as 7000, 7500, 8500, and 9000 ft and were specifically 6964, 7446, 8461, and 9079 ft.
    c. Tributary measurement sites were lowest at Taylor, 7801 ft, and highest at Priest, 10,599 ft.
3. 2019 data collection
    a. The 2019 data were from three locations in the main stem and eight locations in seven tributaries, a total of 11 measurement sites.
    b. The main-stem measurement elevations, 7000, 8000, and 9000 ft nominally, were 6964, 8081, and 9097 ft.
    c. Five 2019 tributary sites were at the same locations measured in 2018 at Slate, Spring, Little Taylor, and Tenderfoot.
    d. Measurements in 2019 also were made at three other tributaries, Bear, Roaring Forks, and Stoner, at locations just upstream from their outfalls at the main stem.

C. Criteria for Comparison

1. The main stem and tributaries in the study area, the Dolores River basin, are classified by Colorado as Cold Stream Tier I (CS-1) waters [20].
2. The CO chronic criterion, 62.6 F, applies for the purpose of protection from sub-lethal warm temperatures that can diminish long-term growth, reproduction, and survival [4, 20, 21].
3. The CO acute criterion, 71.1 F, also applies for protection from lethal exposures to very warm temperatures [4, 20, 21].
4. CO methodology calls for evaluation of weekly average temperatures (WAT) against the CO chronic criterion. WAT is the “mathematical mean of multiple, equally spaced, daily temperatures over a seven-day consecutive period” [21]. The maximum WAT, or MWAT, is the largest of rolling weekly averages.
5. Two-hour average temperatures (TAT) are evaluated against the CO acute criterion. TAT is the “highest two-hour average water temperature recorded during a 24-hour period” [21]. The maximum TAT, or MTAT, is the largest of rolling two-hour averages.
6. Colorado set the criteria to ensure protection of cutthroat trout, in particular, because it was “deemed ecologically and recreationally important” [4].
7. To be clear, this was not an investigation about compliance. It was a study of water-temperature habitat health using basin-applicable criteria.
8. Comparison also was made with chronic criteria for these other basin-resident trout species: rainbow, 64.6 F; brook, 64.9 F; and brown, 67.3 F [4].

D. Tools

1. The tools, devices, and programs used in the study were
    a. Installed sensors for the continuous measurement of water temperatures, at 30-minute intervals, during July-August in 2018 and 2019, creating 33 individual databases.

b. A hand-held sensor for testing temperatures over a range of depth, flow, and shading conditions in sections of three tributaries.
c. The hand-held sensor also to investigate and measure evidence of cold-water plumes in the main stem below discharge from three tributaries.
d. The U.S. Geological Survey (USGS) program *StreamStats* for estimating flows in the main-stem and tributaries; and also for watershed characteristic values, such as, drainage area, maximum elevation [19].
e. *Google Earth* to identify latitude and longitude coordinates and the elevation of sensors placed in the main stem.
f. A global positioning system (GPS) device to determine sensor coordinates and elevations in tributaries. *Google Earth* was not an option because vegetation cover prevented satellite views of many of the tributary sites. The same high-quality GPS instrument was used at the tributaries for consistency.

2. Appendix A shows sensor equipment, some installations, and testing.

IV. Results

A. 30-Minute Temperatures

1. Overview
    a. Exhibit 2 shows a summary of water-temperature data, from continuous measurements at 30-minute intervals, in the main stem and at tributaries during July-August of 2018 and 2019.
    b. The 2018 data are from 22 sites in the main stem and tributaries; the 2019 data are from 11 sites in the main stem and tributaries.
2. Results
    a. Mean, lowest, and highest temperatures
        - Mean main-stem water temperatures decreased as elevation increased.
        - The lowest and highest temperatures showed the same pattern.
        - In 2018, mean water temperatures at the 18 tributary sites were lower than at the four main-stem sites, with one exception.
        - That exception was the mean temperature 57 F at Taylor, 8487 ft. The temperature at 9000 ft in the main stem was the same.
        - In 2019, mean temperatures at the eight tributary sites were lower than in the main-stem at 7000 and 8000 ft, with two exceptions.
        - The two exceptions were the mean values of 60 F at Stoner and 55 F at Roaring Forks.
        - Stoner had the highest mean, highest low, and highest high temperatures observed at any of the tributaries in 2018 and 2019.

Exhibit 2. Data Summary, Main Stem and Tributaries, 2018 and 2019

Year & Identity	Outfall elevation, ft	Site elevation, ft	Mean, F	Lowest value, F	Highest value, F	Variation, F	Monioring period
2018							
1 Main 7000		6964	67	55	80	25	7/1 - 8/31
2 Main 7500		7446	64	52	79	27	7/1 - 8/31
3 Main 8500		8461	59	47	76	29	7/1 - 8/31
4 Main 9000		9079	57	44	72	28	7/1 - 8/31
5 Coal	9190	9207	54	43	67	24	7/1 - 8/31
6		10,064	52	40	71	31	7/1 - 8/31
7 Priest	7974	8067	56	46	67	21	7/1 - 8/31
8		8907	55	46	69	23	7/11 - 8/31
9		10,599	50	42	63	21	7/11 - 8/31
10 Scotch	8530	8530	53	36	65	29	7/1 - 8/31
11 Slate	9502	9502	52	41	66	25	7/1 - 8/31
12		9792	51	39	68	29	7/1 - 8/31
13		10,136	50	38	70	32	7/1 - 8/31
14 Spring	8912	8893	51	46	58	12	7/11 - 8/31
15		9350	53	42	67	25	7/3 - 8/31
16		9920	51	46	58	12	7/4 - 8/31
17 Taylor	7649	7801	56	47	66	19	7/1 - 8/31
18		8487	57	47	73	26	7/10 - 8/31
19 Taylor, Little	8489	8515	54	45	62	17	7/1 - 8/31
20 Tenderfoot	8222	8510	52	34	65	31	7/1 - 8/31
21 Wildcat	8341	8464	55	41	71	30	7/1 - 8/31
22		9083	52	43	68	25	7/1 - 8/31
2019							
1 Main 7000		6964	61	46	73	27	7/4 - 8/31
2 Main 8000		8081	54	40	68	28	7/4 - 8/31
3 Main 9000		9079	50	38	65	27	7/4 - 8/31
4 Bear	7917	7917	52	45	61	16	7/23 - 8/31
5 Roaring Forks	8177	8177	55	45	67	22	7/23 - 8/31
6 Slate	9502	9502	46	37	61	24	7/1 - 8/31
7		9792	45	36	58	22	7/1 - 8/31
8 Spring	8912	9350	52	41	62	21	7/1 - 8/31
9 Stoner	7475	7475	60	48	74	26	7/23 - 8/31
10 Taylor, Little	8489	8515	53	45	64	19	7/1 - 8/31
11 Tenderfoot	8222	8510	50	42	60	18	7/1 - 8/31

        - That is, the Stoner measurement site, which was located just above the tributary's outfall at the main stem, had the warmest temperatures of all the tributary sites in both monitoring years.
    b. Temperature variation
        - Temperature variation at the main-stem sites was roughly the same both years, 25 – 29 F in 2018 and 27 – 28 F in 2019.
        - The greatest temperature variation, 32 and 31 F, was seen at Slate at 10,136 ft and Coal at 10,064 ft. They were two of the three highest-elevation sites monitored.
        - By comparison, temperature variation at the highest site at Priest, 10,599 ft, the third of the highest-elevation sites, was moderate, 21 F.
        - Large variation, 31 and 30 F, also was seen at Tenderfoot at 8510 ft and Wildcat at 8464 ft. They were two of the four tributaries monitored with the smallest flow.
        - The least variation, 12 F, was observed at Spring at both its highest and lowest sites, 9920 and 8893 ft. It was the third of the four tributaries with the smallest flow, along with Tenderfoot and Wildcat. Little Taylor had the least flow.
        - The next least variation, 16 F, was at Bear, at its outfall, 7917 ft. Bear has the largest flow of the Dolores-basin tributaries.

3. Summary and interpretations
    a. Main-stem temperatures decreased as elevation increased, as reasonably expected [3, 7]
    b. Tributary mean temperatures showed a pattern of being colder than main-stem temperatures at equivalent elevations, with only two exceptions.
    c. The high variation in temperatures at the highest Slate site and the upper Coal site likely was because water arriving at those sites has prior, extended exposure to direct solar radiation. The exposure above those locations is apparent in photographs 7 and 8 in Appendix A.
    d. In contrast, the moderate temperature variation at the highest Priest site likely resulted because upstream flow has little opportunity for exposure to direct solar radiation due to tree cover, as seen in photograph 9 in Appendix A.
    e. Similarly large variations in temperature at two of the three smallest tributaries, Tenderfoot and Wildcat, likely was because those small tributaries, having less water mass, were more susceptible than larger tributaries to diurnal fluctuations in ambient air temperatures.
    f. The least variation in temperatures at the highest and lowest Spring sites potentially signaled the temperature dominance of subsurface water input. Photograph 10 in Appendix A shows the highest Spring site.

g. The small temperature variation at Bear may be attributable to its large flow, leaving it less susceptible than smaller-flow tributaries to diurnal fluctuations in ambient air temperatures.
h. At Stoner, property along the lower 2.5 miles is privately owned, with some owners using water diversion rights for warm-weather irrigation of crops.
i. Withdrawal from the tributary reduces downstream flow, leaving water in low-flow conditions susceptible to temperature increases from ambient warm air.
j. Outfall temperatures at Stoner contrasted the with considerably lower temperatures at the Bear outfall, which drains into the main stem just upstream from Stoner. Bear does not experience significant warm-weather water withdrawal.

B. Normality

1. Overview
    a. Means, or averages, are appropriate in representing data that are known to be normally distributed.
    b. Normal in this context refers to data taking a symmetrical, bell shape, with data distributed evenly on each side of the mean value, which is at the peak of the bell shape.
    c. Being normal also includes having percentages of the data within ranges defined by standard deviation values.
    d. Using means is necessary for evaluating against the CO criteria [21].
    e. Mentioning again, this study is not about compliance, but about habitat temperature health, assessed using applicable criteria and protocols.
    f. Determining database normality for purposes of this study was part of developing a basis for confidence in study results.
    g. Normality was assessed by
        - *Comparing the mean and median*. A mean and median that are the same or close is consistent with data having a symmetrical distribution, with half the population lower and half higher than the mean.
        - *Considering skewness*. A skewness value of 0 is indication that data are evenly distributed about the mean, that is, not skewed to lower or higher values on either side of the mean.
        - *Considering kurtosis*. It characterizes peakedness or, conversely, flatness, that is, deviation from the form of a normal distribution. For example, a negative value for kurtosis suggests more data in the middle region and less at the mean and tails. Such data is said to be platykurtic, or flat. Alternatively, a positive value would indicate the data are peaked.
    h. Normality was evaluated for the data as a whole for each of the 33 measurement sites, that is, the 30-minute-interval data.

        i. It was not assessed for the 7-day or 2-hour subsets of the databases.

2. Results
    a. Exhibit 3 shows site elevation (for identification), mean, median, skewness, kurtosis, and the number of measurements for databases from each of the measurement sites.
    b. Main stem
        - Means and medians were the same or within one degree F for each of the site databases, which indicate tendencies to symmetry.
        - Skewness values were 0, also suggesting symmetry.
        - Kurtosis was 0 for three databases, indicating a normal curve. It was -1 for the remaining four, the small negative value marking some flatness in data distribution.
    c. Tributaries
        - As with the main stem, means and medians for the tributary databases were the same or within one degree F of each other.
        - The skewness value was 0 for 21 tributary databases, suggesting symmetry, and 1 for five databases.
        - Kurtosis was 0 for 15 tributary databases, characteristic of a normal distribution. It was a small negative value, -1, for 10 databases, suggesting flatness. It was 1 for one database, indicating a tendency to peaking.
    d. Database size
        - Because measurements were taken every 30 minutes at each of the sites, each database is large.
        - All 33 databases have more than a 1200 measurements, and 25 have nearly 3000 (2833 and 2976).
        - Attributed to what statisticians call the *central limit theorem*, data distribution will approach normal when the number of measurements is large [22].
        - Developing statistical inference from these databases, which were large, was appropriate, even where normality was not perfectly indicated by skewness or kurtosis values.
3. Summary and conclusions
    a. Main-stem databases appeared normal, or approximately so, based on skewness and kurtosis values.
    b. Tributary databases appeared normal, or approximately so, too.
    c. All the databases being large, with more than 1200 to nearly 3000 measurement values in each, the central limit theorem pertained, reinforcing an interpretation of normality.
    d. It was judged appropriate to be confident in using means to represent these databases, for example, for evaluating against criteria and making comparisons among monitoring sites.

Exhibit 3. Data Statistics, Main Stem and Tributaries

Year & Identity		Site elevation, ft	Mean, F	Median, F	Skewness	Kurtosis	Measurements
	2018						
1	Main 7000	6964	67	66	0	-1	2976
2	Main 7500	7446	64	64	0	-1	2976
3	Main 8500	8461	59	58	0	0	2976
4	Main 9000	9079	57	56	0	-1	2976
5	Coal	9207	54	53	0	0	2976
6		10,064	52	51	1	0	2976
7	Priest	8067	56	56	0	0	2976
8		8907	55	54	0	1	1248
9		10,599	50	50	1	0	1248
10	Scotch	8530	53	53	0	0	2976
11	Slate	9502	52	51	0	-1	2976
12		9792	51	50	0	-1	2976
13		10,136	50	49	1	-1	2976
14	Spring	8893	51	51	0	0	1248
15		9350	53	53	0	0	2852
16		9920	51	51	0	0	2832
17	Taylor	7801	56	56	0	0	2976
18		8487	57	56	0	1	2544
19	Taylor, Little	8515	54	54	0	0	2976
20	Tenderfoot	8510	52	52	0	0	2976
21	Wildcat	8464	55	54	0	-1	2976
22		9083	52	52	1	0	1536
	2019						
1	Main 7000	6964	61	62	0	0	2833
2	Main 8000	8081	54	54	0	0	2833
3	Main 9000	9079	50	49	0	-1	2833
4	Bear	7917	52	52	0	-1	1920
5	Roaring Forks	8177	55	55	0	-1	1920
6	Slate	9502	46	44	1	0	2975
7		9792	45	44	0	0	2975
8	Spring	9350	52	52	0	-1	2975
9	Stoner	7475	60	59	0	-1	1920
10	Taylor, Little	8515	53	53	0	-1	2975
11	Tenderfoot	8510	50	50	0	-1	2975

C. Weekly and Two-Hour Average Temperatures

1. Results
    a. Exhibit 4 presents a summary of weekly average (WAT) and two-hour average (TAT) temperatures, converted from the 30-minute temperature (30T) data, for the July-August monitoring in 2018 and 2019 at the main stem and tributaries.
    b. Exhibits 5 – 8 show 30T and WAT values graphically for each of the four main-stem sites in 2018; and Exhibits 9 – 11 for the three main-stem sites in 2019.
    c. As seen in Exhibit 4, the summary table, main-stem maximum WAT (MWAT) and maximum TAT (MTAT) in 2018 decreased as elevation increased, except at 7000 and 7500 ft, which had the same MTAT, 79 F.
    d. Main-stem MWAT and MTAT in 2019 decreased as elevation increased, without exception.
    e. Minimum WAT and TAT in 2019 did the same, that is, decreased as elevation increased.
    f. Both MWAT and MTAT at the main-stem sites were higher in 2018 than in 2019.
    g. As seen in Exhibit 4, every tributary MWAT in 2018 was lower than at main-stem sites, with two exceptions.
    h. They were 61 F at Taylor, 8487 ft, and 60 F at Priest, 8067 ft.
    i. Every tributary MTAT in 2018 was lower than at main stem sites, except 73 F at Taylor, 8487 ft.
    j. Every tributary MWAT in 2019 was lower than at 7000 and 8000 ft in the main stem, with two exceptions.
    k. They were 63 F at Stoner, 7475 ft, and 57 F at Roaring Forks, 8177 ft.
    l. Every tributary MTAT in 2019 was lower than at the three main-stem sites, with two exceptions.
    m. They were 73 F at Stoner, 7475 ft, and 66 F at Roaring Forks, 8177 ft.
    n. Note that MWAT at the main-stem's 9000-ft site in 2019, 52 F, was 8 F lower than in 2018.
    o. Similarly, MTAT at that site in 2019, 65 F, was 7 F lower than in 2018.
    p. MTAT values showed considerably greater variation than MWAT.
    q. This is because TAT, which is a two-hour average, moderates less of the variation in the measurement data (30T), recorded at 30-minute intervals, than WAT, which averages over seven days.
    r. MWAT and the lowest 30T values decreased with elevation at Slate and Coal, while MTAT and the highest 30T increased.
    s. The greatest TAT variation was in 2018 at the highest Slate site, 37 F, at 10,136 ft; at the main-stem, 35 F, 9000 ft; and at the upper Coal site, 31 F, 10,064 ft.

Exhibit 4. WAT and TAT, Main Stem and Tributaries, 2018 and 2019

Year & Identity	Site elevation, ft	Maximum WAT, F	Minimum WAT, F	WAT variation, F	Maximum TAT, F	Minimum TAT, F	TAT variation, F
2018							
1 Main 7000	6964	71	57	14	79	47	32
2 Main 7500	7446	68	62	6	79	52	27
3 Main 8500	8461	63	57	6	76	47	29
4 Main 9000	9079	60	48	12	72	37	35
5 Coal	9207	57	51	6	67	43	24
6	10,064	56	50	6	71	40	31
7 Priest	8067	60	53	7	67	46	21
8	8907	58	53	5	68	46	22
9	10,599	53	48	5	61	42	19
10 Scotch	8530	57	51	6	65	40	25
11 Slate	9502	54	50	4	65	41	24
12	9792	53	49	4	68	39	29
13	10,136	53	32	21	69	32	37
14 Spring	8893	54	49	5	57	47	10
15	9350	57	49	8	67	42	25
16	9920	54	49	5	58	46	12
17 Taylor	7801	59	52	7	65	50	15
18	8487	61	54	7	73	47	26
19 Taylor, Little	8515	57	43	14	58	41	17
20 Tenderfoot	8510	56	50	6	65	40	25
21 Wildcat	8464	59	52	7	70	42	28
22	9083	54	51	3	67	43	24
2019							
1 Main 7000	6964	65	52	13	72	46	26
2 Main 8000	8081	57	47	10	68	40	28
3 Main 9000	9079	52	44	8	65	38	27
4 Bear	7917	53	51	2	61	45	16
5 Roaring Forks	8177	57	54	3	66	45	21
6 Slate	9502	48	41	7	61	37	24
7	9792	47	41	6	58	36	22
8 Spring	9350	56	47	9	62	41	21
9 Stoner	7475	63	57	6	73	48	25
10 Taylor, Little	8515	55	50	5	60	45	15
11 Tenderfoot	8510	52	48	4	59	42	17

Exhibit 5. Main Stem, 2018, 7000 ft, 30T, WAT, and CO Chronic Criterion

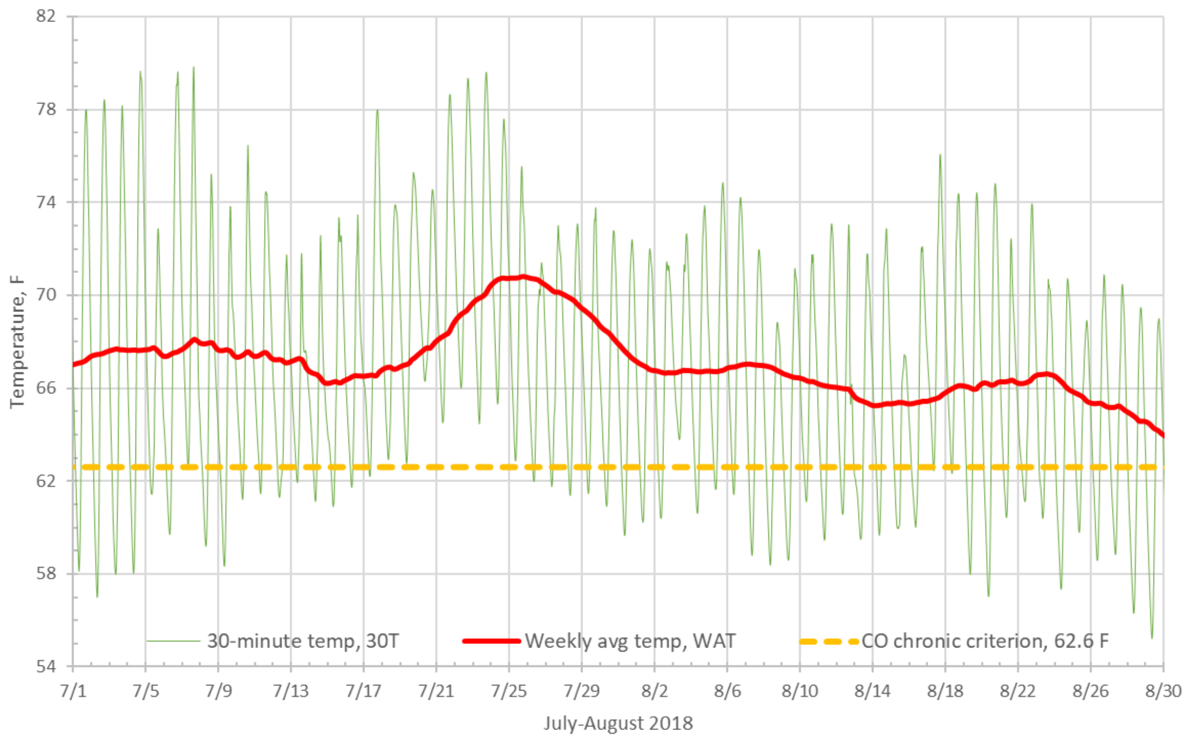


Exhibit 6. Main Stem, 2018, 7500 ft, 30T, WAT, and CO Chronic Criterion

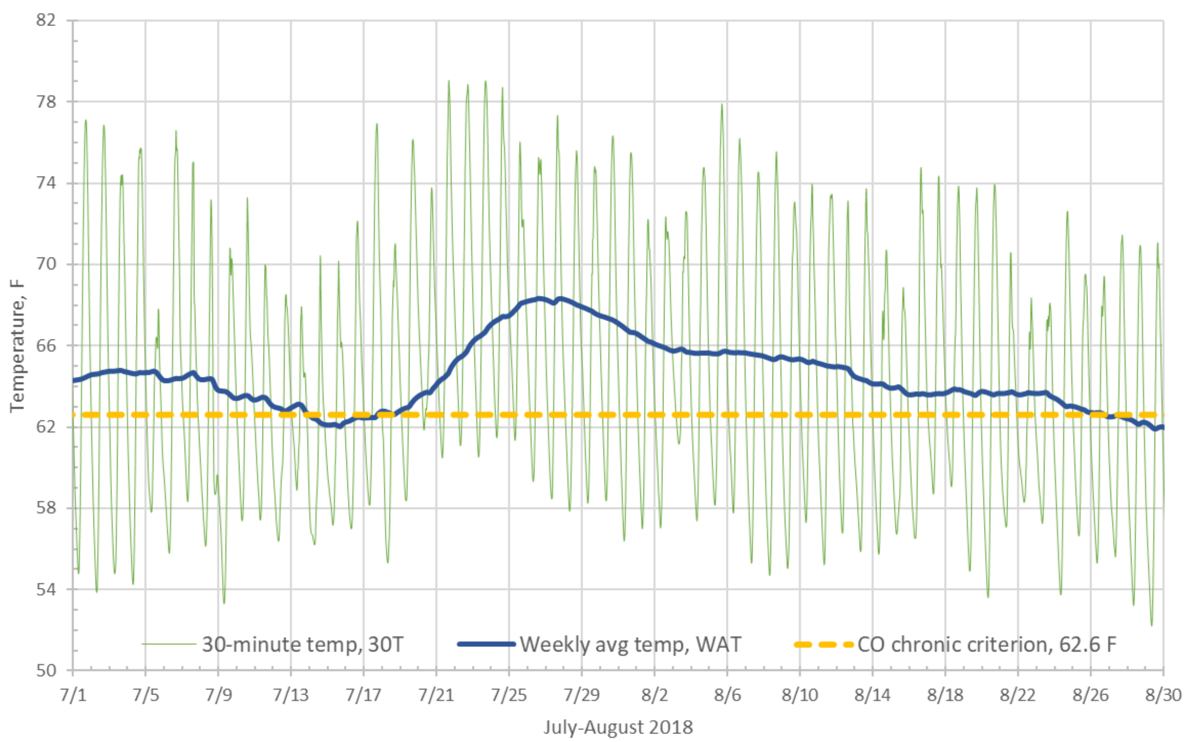


Exhibit 7. Main Stem, 2018, 8500 ft, 30T, WAT, and CO Chronic Criterion

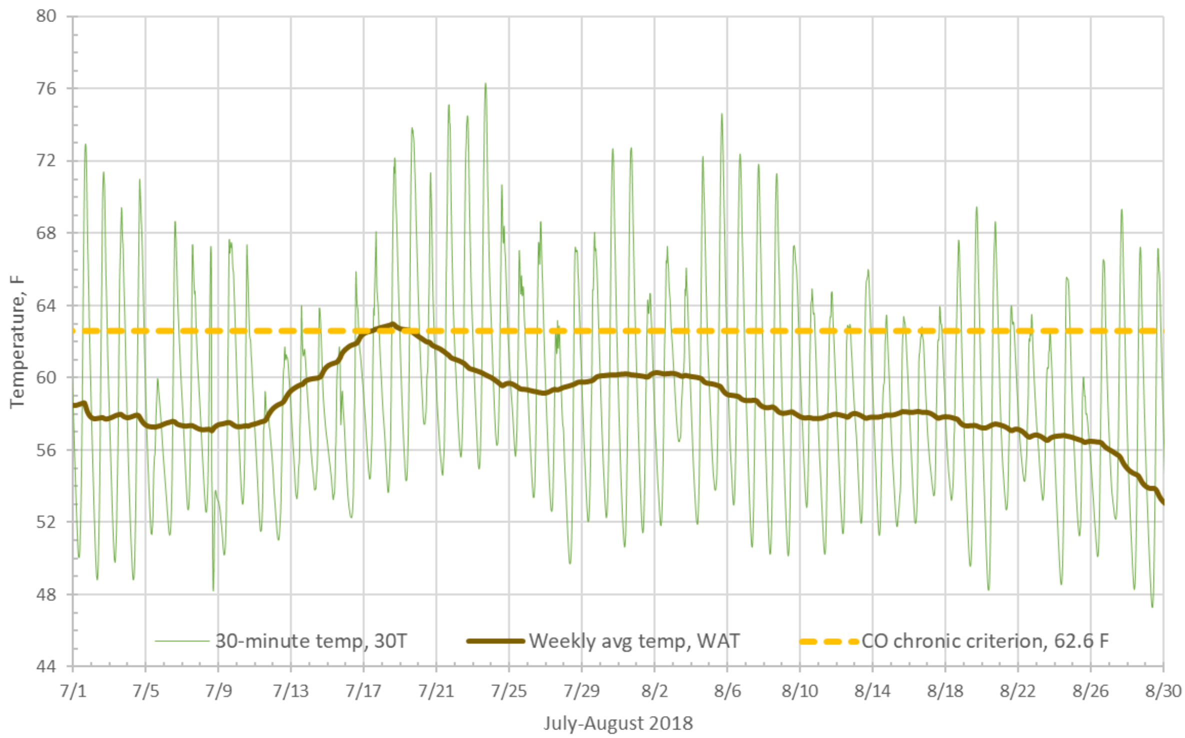


Exhibit 8. Main Stem, 2018, 9000 ft, 30T, WAT, and CO Chronic Criterion

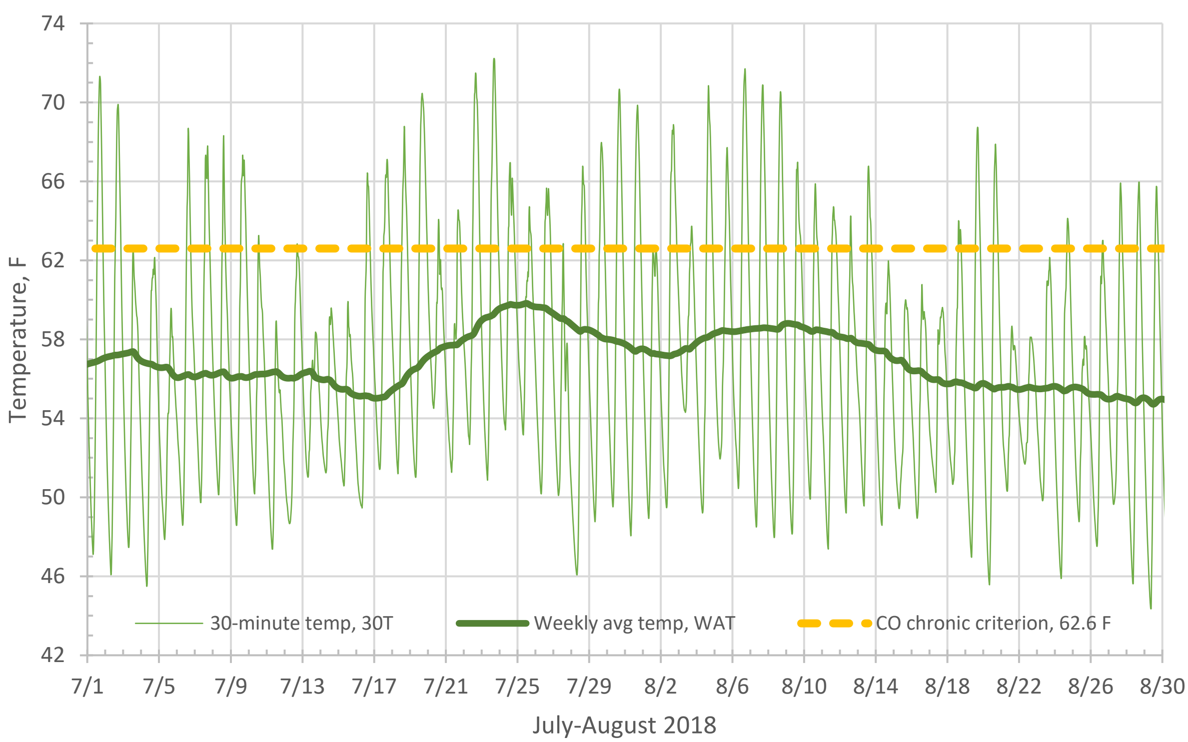


Exhibit 9. Main Stem, 2019, 7000 ft, 30T, WAT, and CO Chronic Criterion

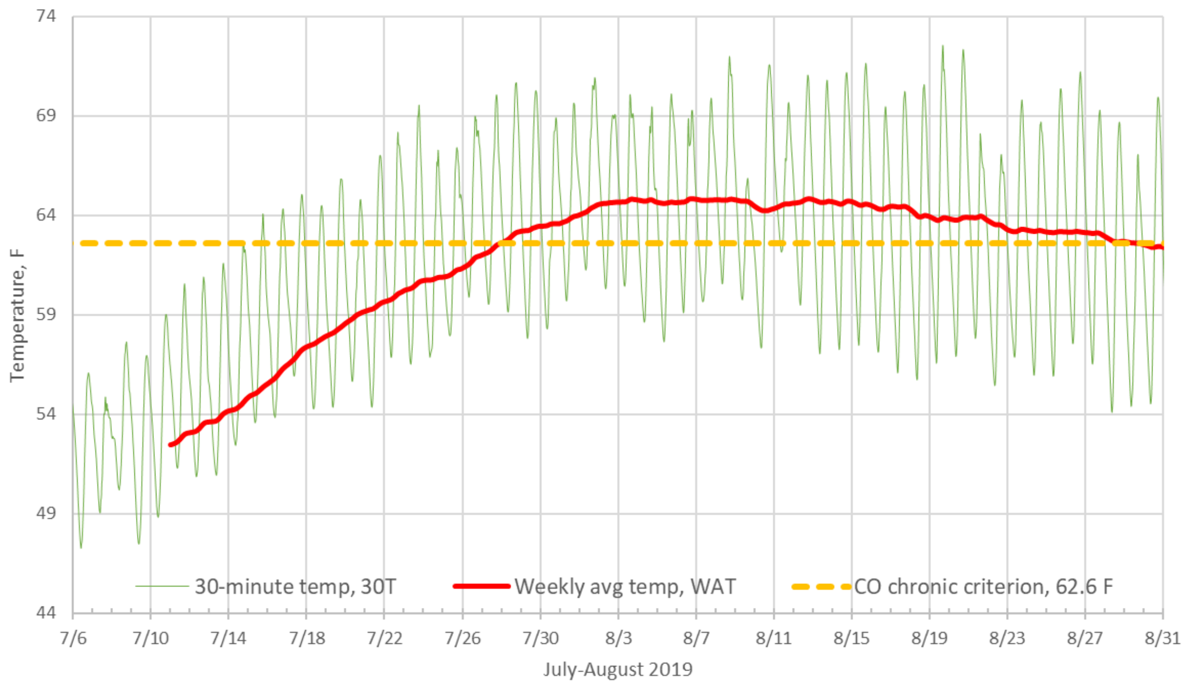


Exhibit 10. Main Stem, 2019, 8000 ft, 30T, WAT, and CO Chronic Criterion

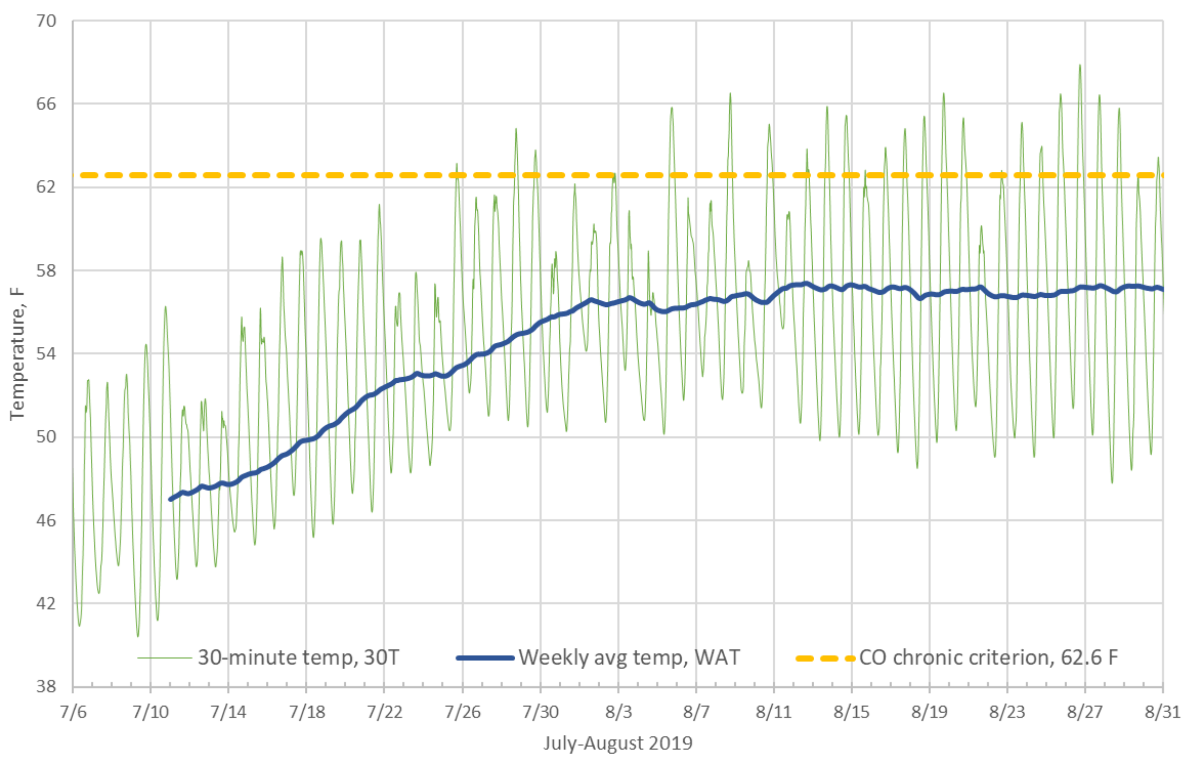
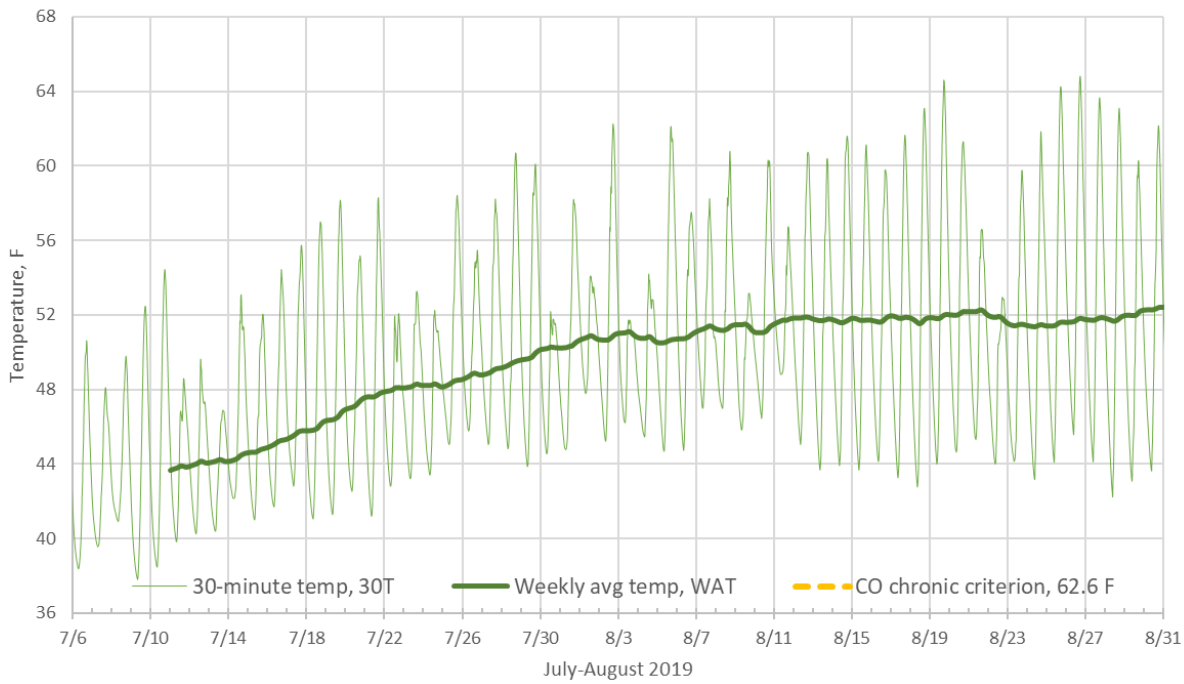


Exhibit 11. Main Stem, 2019, 9000 ft, 30T, WAT, and CO Chronic Criterion



   a. By comparison, the TAT variation in 2018 at the highest Priest site, 10,599 ft, was a moderate 21 F.
   b. The least TAT variation, 10 and 12 F, was observed at the lowest and highest Spring sites, 8893 and 9920 ft.
   c. Those Spring sites also had low WAT variation, 5 F, in 2018.
   d. The least WAT variation in 2019 was at the outfall at Bear, 2 F, and at Roaring Forks, 3 F, 8177 ft.

2. Summary and interpretations
   a. The general decrease in main-stem MWAT and MTAT with increasing elevation, the same pattern shown in the 30T data, was reasonably expected [3, 7].
   b. The higher main-stem MWAT and MTAT values in 2018 as compared with 2019 were reasonably attributable to drought conditions in 2018, which left the lower-flow water in 2018 more susceptible to warming from ambient warm air temperatures and from exposure to direct solar radiation.
   c. The pattern of tributary MWAT and MTAT being lower than in the main stem at equivalent elevations, with a couple of exceptions, gave indication of the opportunity of thermal refuge for trout in tributaries.
   d. The high MTAT and high temperature variation at the high Slate and Coal sites likely resulted from extended exposure of upstream water to direct solar radiation.

e. The moderate TAT and moderate temperature variation, in contrast, at the highest Priest site likely derived because the wooded slope limited the exposure of upstream water to direct solar radiation.
f. Bear and Roaring Forks, which have the least WAT variation at tributary and main-stem sites, have large flows that were less susceptible to fluctuation in ambient air temperatures as compared with Tenderfoot and Wildcat, tributaries having small flows that are more susceptible.

D. Evaluation Against Criteria

1. Overview
    a. In this study, the Colorado chronic criterion, 62.6 F, and the acute criterion, 71.7 F, both applicable to Dolores River basin waters, were used to assess trout habitat temperature conditions [20].
    b. WAT values were calculated from the 30T data for comparison with the chronic criterion and TAT values for evaluation against the acute criterion, as protocol mandates [21].
    c. Exhibits 5 – 8 show WAT for the four main-stem sites in 2018, along with 30T and the CO chronic criterion, which is represented by the horizontal line.
    d. Exhibits 9 – 11 show the same for the three main-stem sites in 2019.
    e. Exhibits 12 and 13 provide a summary graphical comparison of main-stem WAT with the CO chronic criterion for 2018 and 2019.
    f. Exhibits 12 and 13 also enable comparison of WAT with chronic criteria for brook and rainbow trout, 64.6 F (and 64.9 F), and for brown trout, 67.3 F.
    g. Exhibits 14 and 15 show a summary comparison of main-stem TAT with the CO acute criterion for 2018 and 2019.
    h. Exhibits 16 and 17 present a summary comparison of tributary WAT for 2018 and 2019 with the CO chronic criterion.
    i. Exhibits 18 and 19 show a summary comparison of tributary TAT with for 2018 and 2019 the CO acute criterion.
2. Results
    a. Main stem, 2018
        - As seen in Exhibit 12, WAT in 2018 at 7000 ft was higher than the CO chronic criterion during all of July-August; and higher than the brook and rainbow criterion almost all of that period.
        - WAT at 7500 ft was higher than the CO chronic criterion for two-thirds of July-August.
        - It was lower at 8500 ft, except for two days in July; and lower at 9000 ft during all of the monitoring period.
        - As shown in Exhibit 14, TAT in 2018 regularly was higher than the acute criterion at 7000, 7500, and 8500 ft in the main-stem; and rarely higher at 9000 ft.

Exhibit 12. Main Stem, 2018, WAT and CO, Brook & Rainbow, and Brown Trout Chronic Criteria

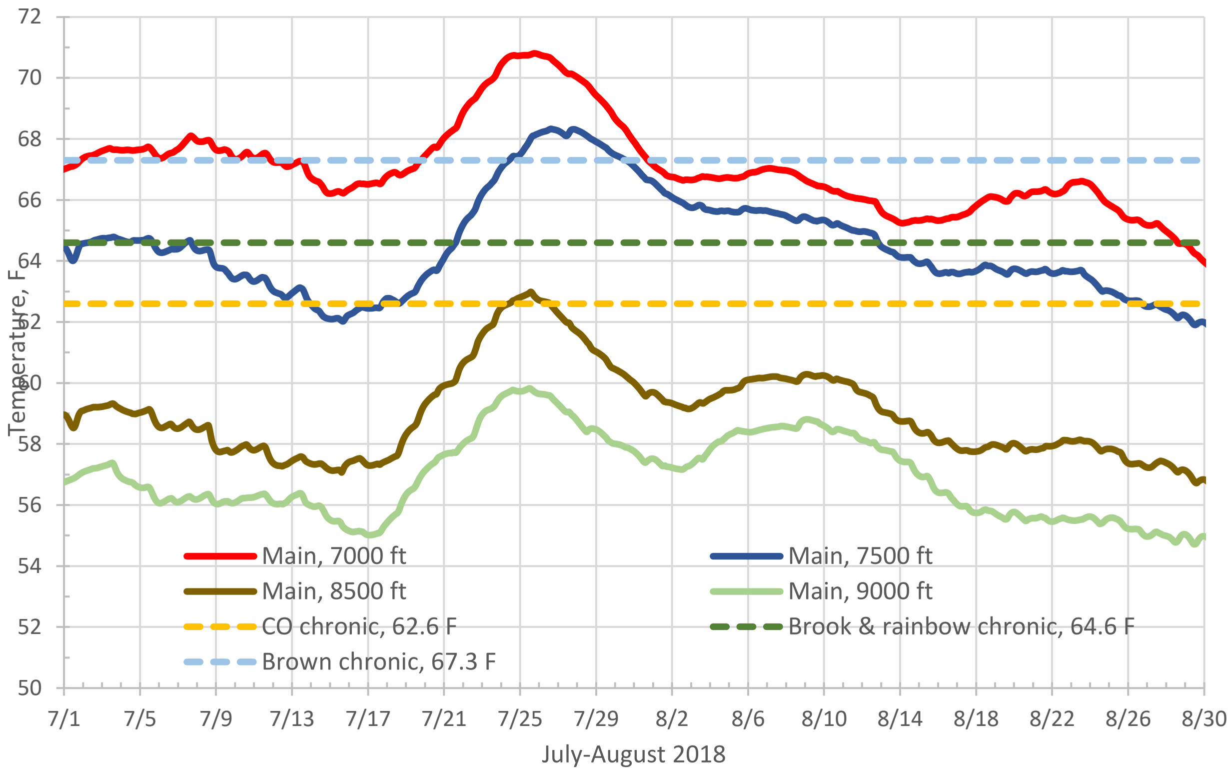


Exhibit 13. Main Stem, 2019, WAT and CO, Brook & Rainbow Trout, and Brown Trout Chronic Criteria

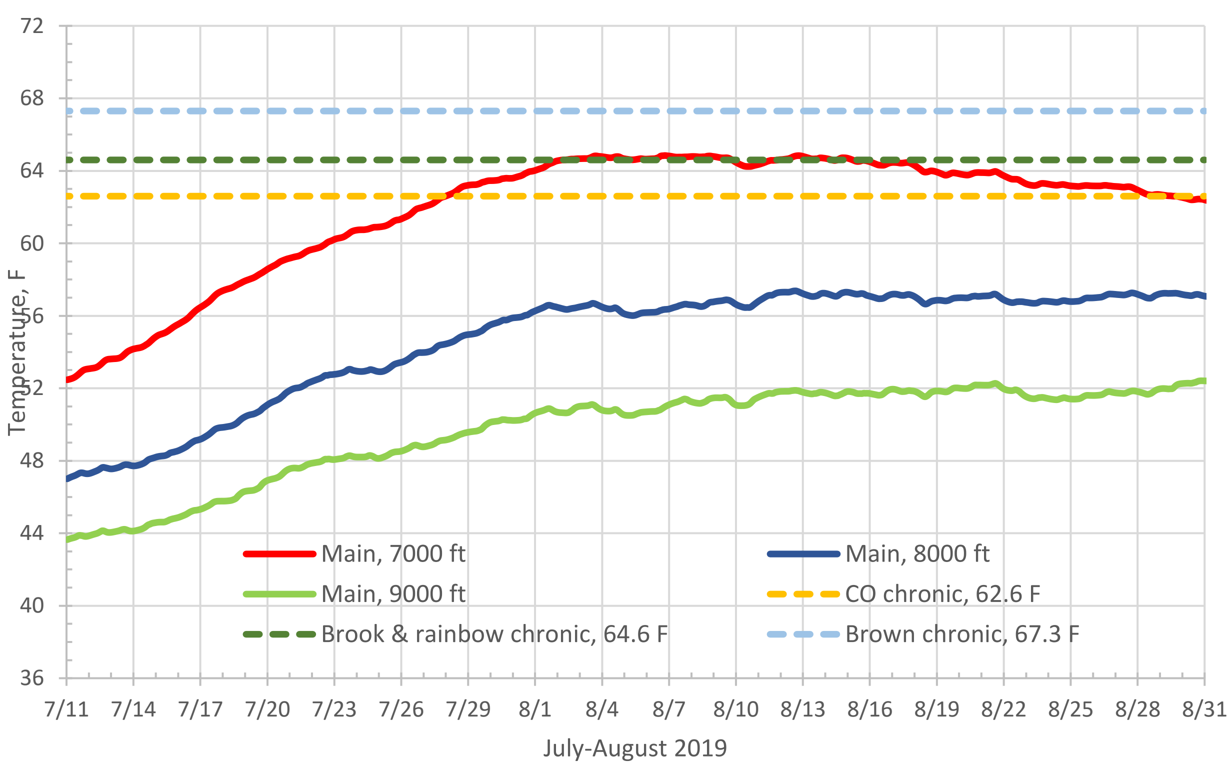


Exhibit 14. Main Stem, 2018, TAT and CO Acute Criterion

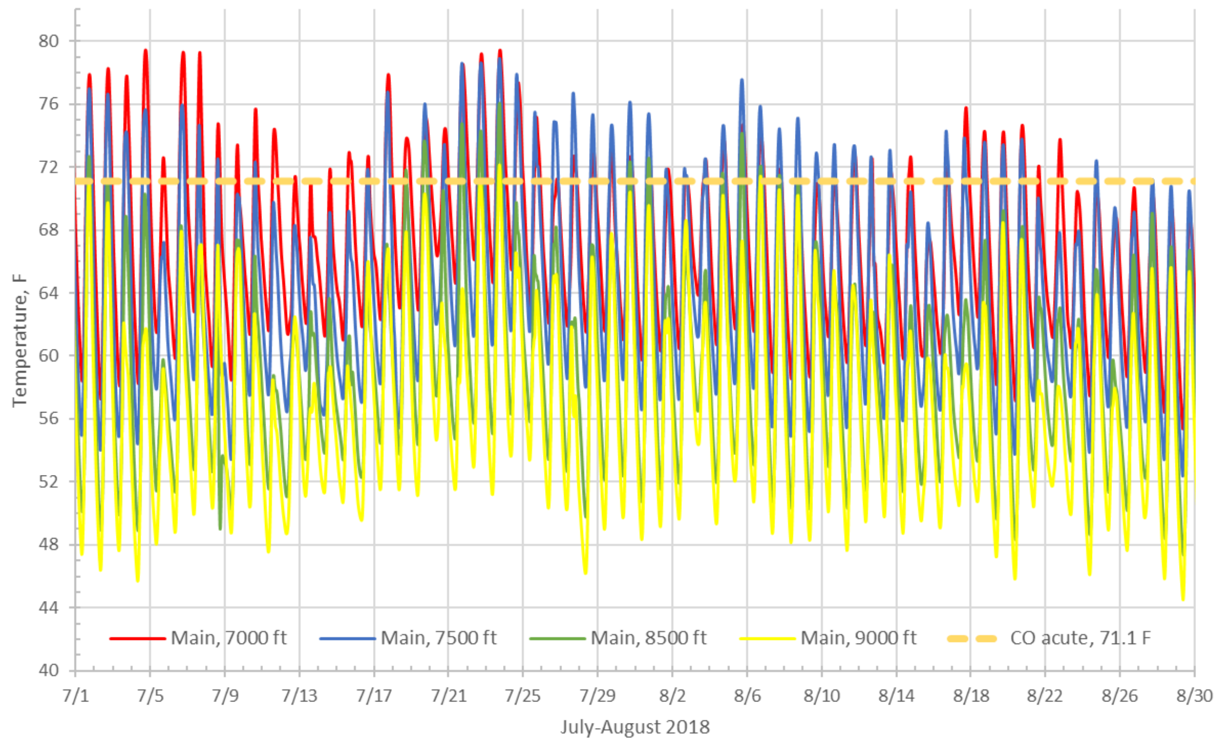
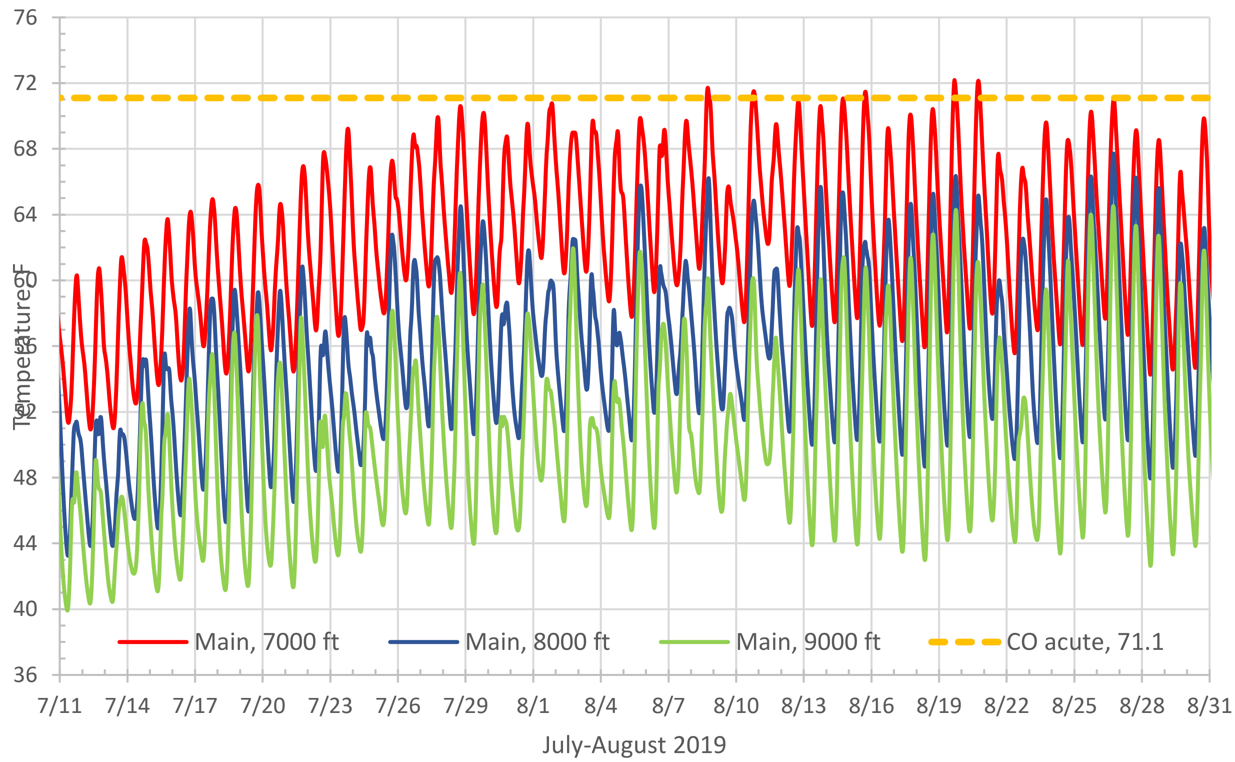


Exhibit 15. Main Stem, 2019, TAT and CO Acute Criterion



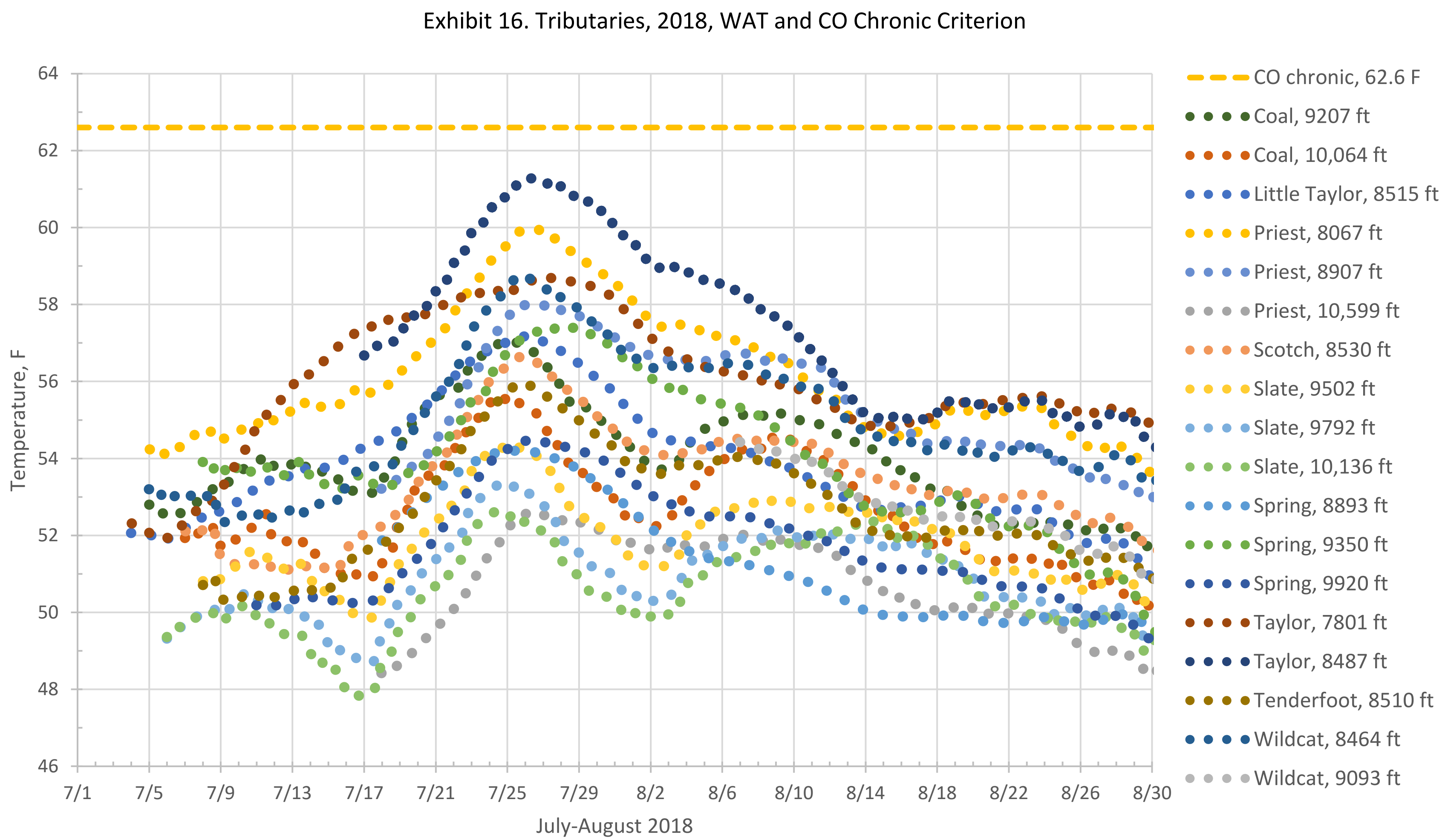


Exhibit 16. Tributaries, 2018, WAT and CO Chronic Criterion
64
62
60
58
56
54
52
50
48
46
Temperature, F
7/1
7/5
7/9
7/13
7/17
7/21
7/25
7/29
8/2
8/6
8/10
8/14
8/18
8/22
8/26
8/30
July-August 2018
CO chronic, 62.6 F
Coal, 9207 ft
Coal, 10,064 ft
Little Taylor, 8515 ft
Priest, 8067 ft
Priest, 8907 ft
Priest, 10,599 ft
Scotch, 8530 ft
Slate, 9502 ft
Slate, 9792 ft
Slate, 10,136 ft
Spring, 8893 ft
Spring, 9350 ft
Spring, 9920 ft
Taylor, 7801 ft
Taylor, 8487 ft
Tenderfoot, 8510 ft
Wildcat, 8464 ft
Wildcat, 9093 ft

Exhibit 17. Tributaries, 2019, WAT and CO Chronic Criterion

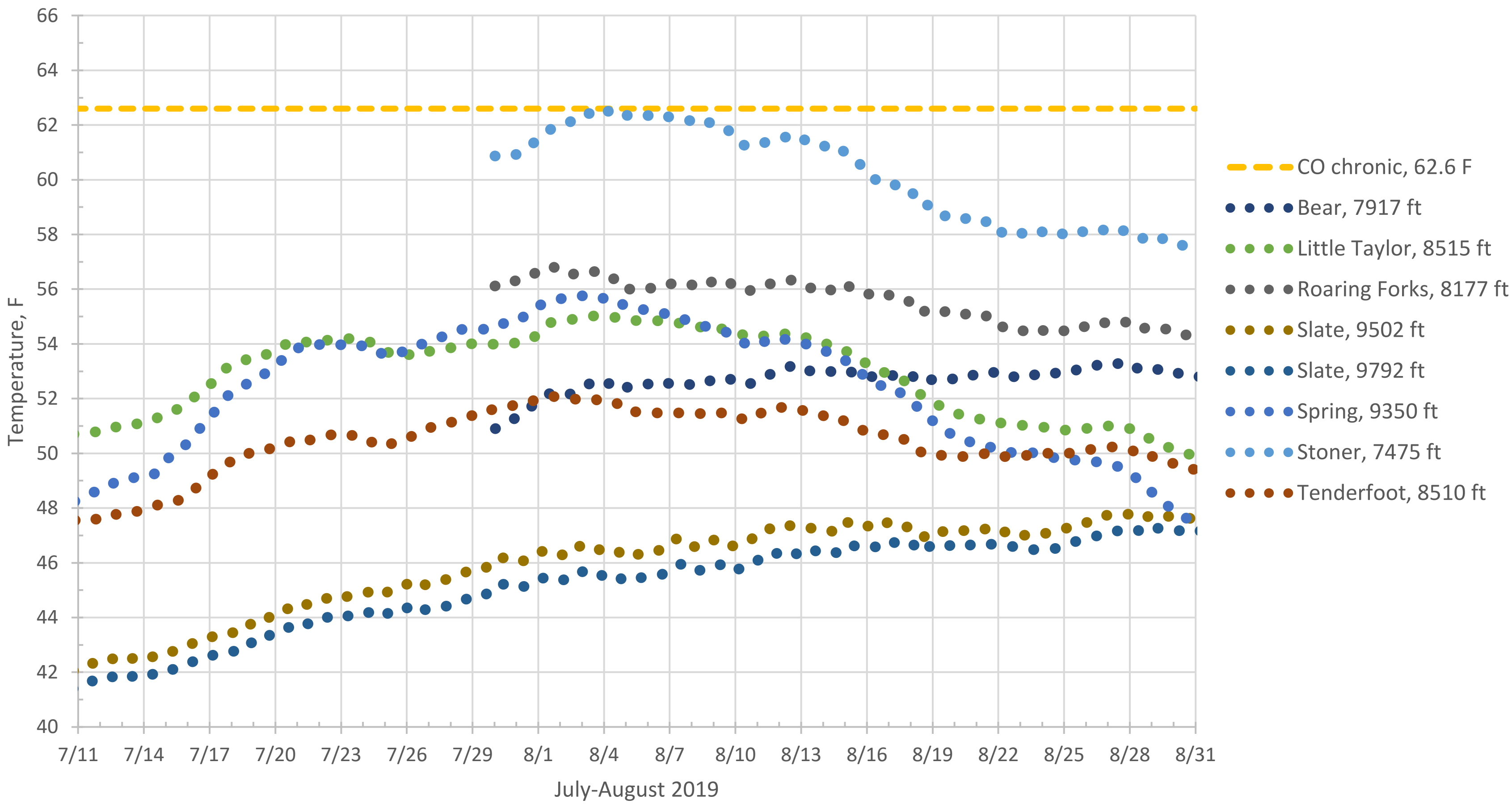


Exhibit 18. Tributaries, 2018, TAT and CO Acute Criterion

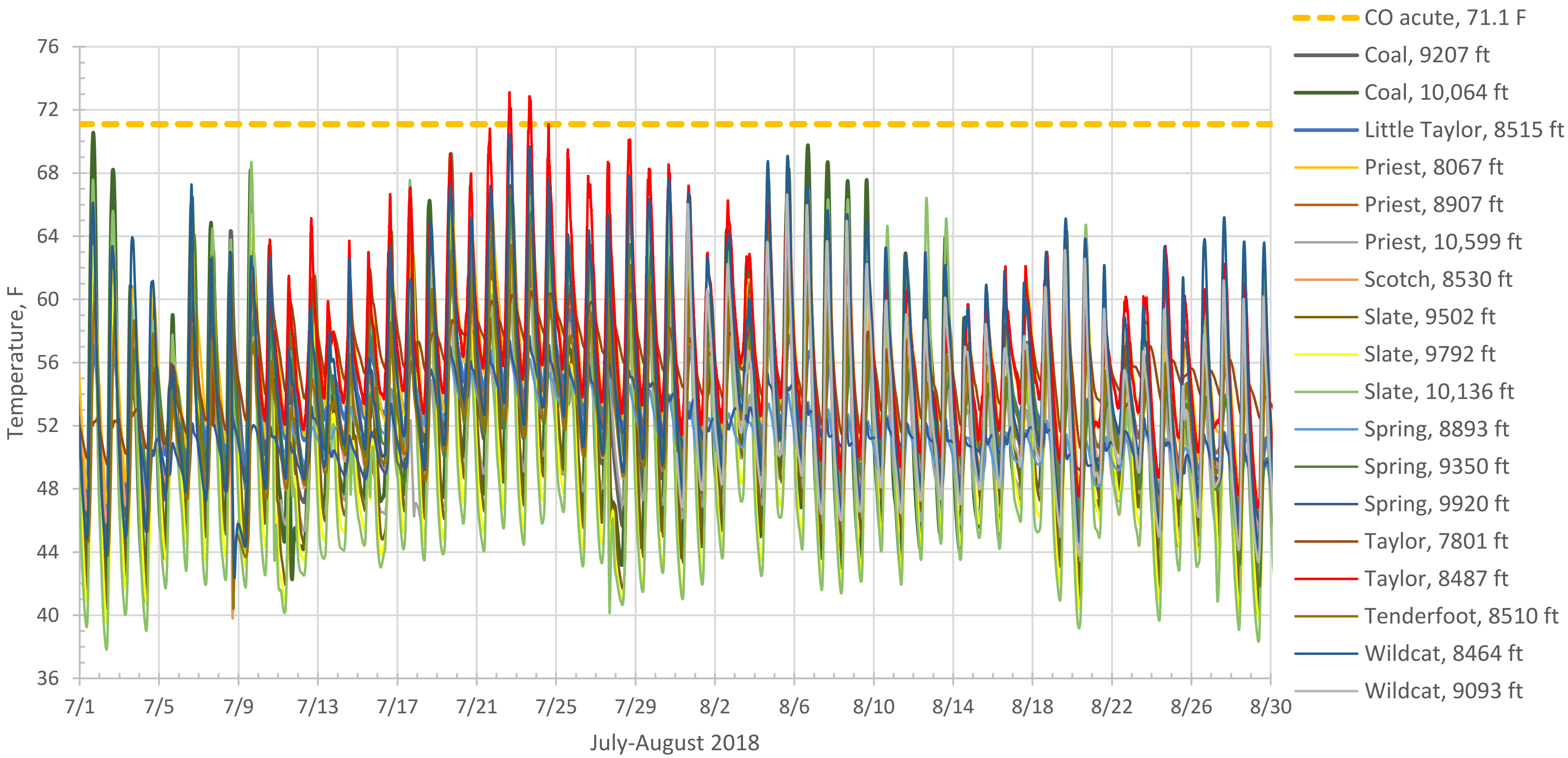
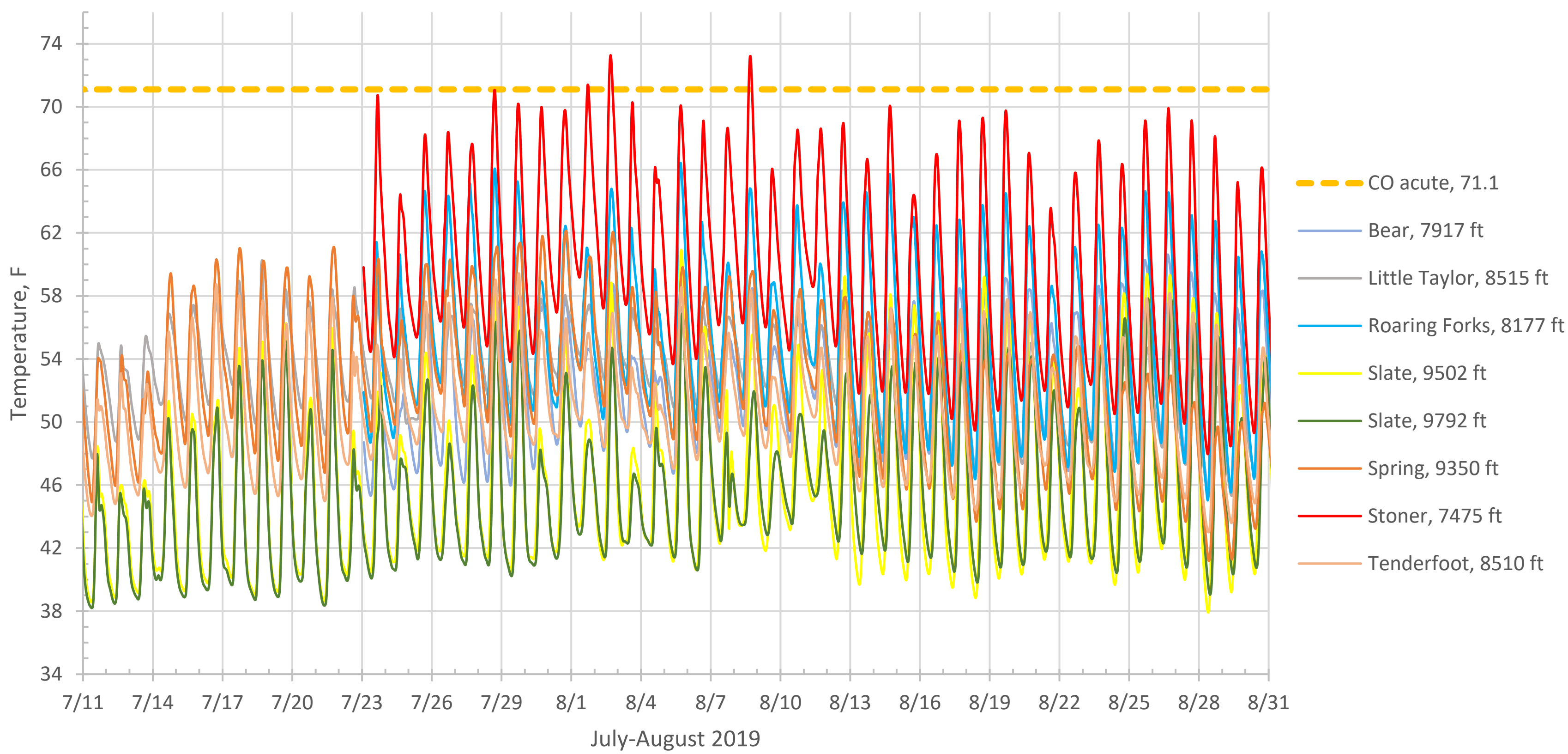


Exhibit 19. Tributaries, 2019, TAT and CO Acute Criterion



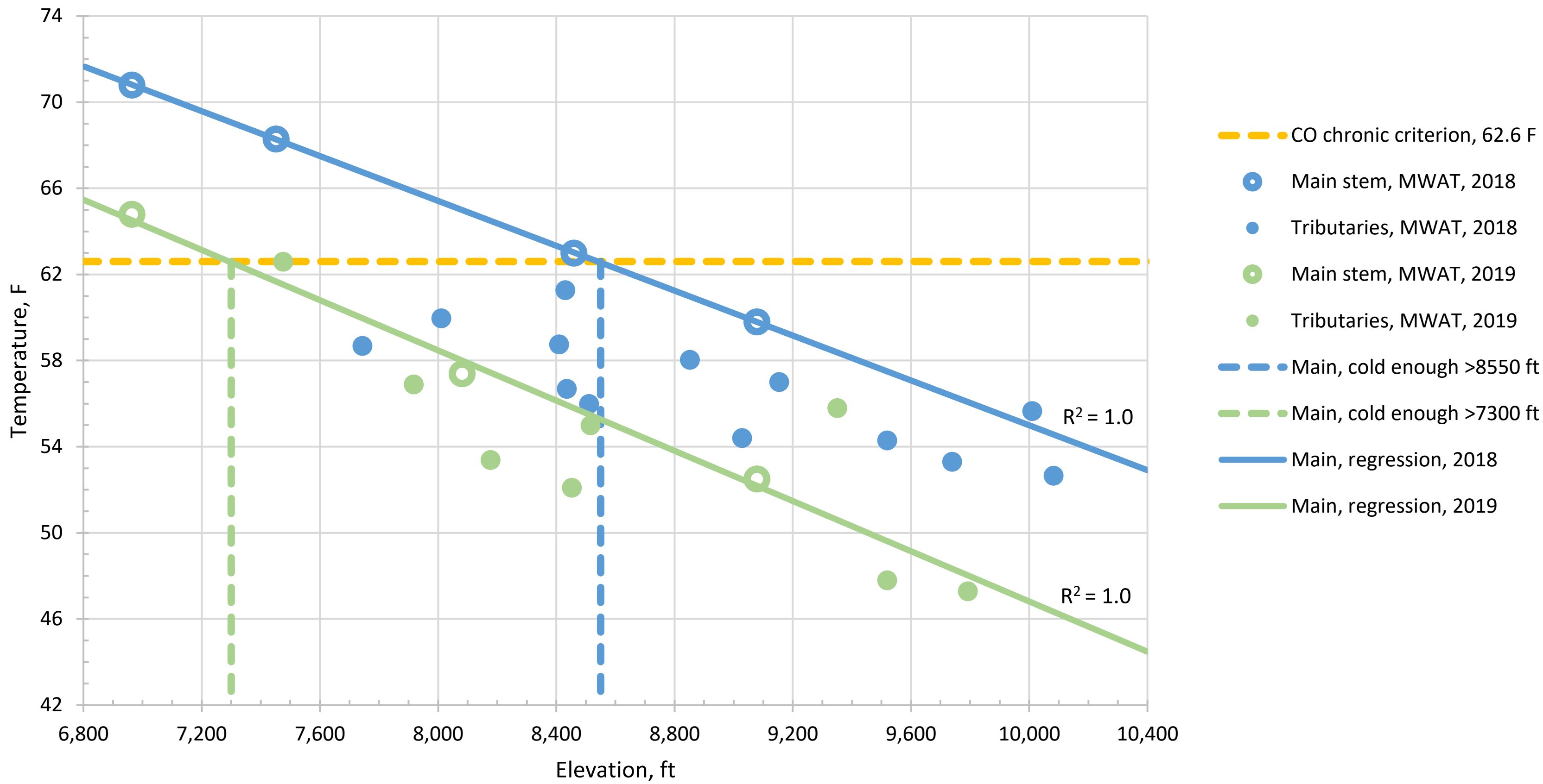
b. Main stem, 2019
    - As seen in Exhibit 13, WAT in 2019 was higher than the CO chronic criterion at 7000 ft for two-thirds of July-August; and higher than the brook and rainbow criterion for one-third of that time.
    - WAT was lower than both criteria at 8000 and 9000 ft during all of July-August.
    - As shown in Exhibit 15, TAT was at the CO acute criterion or higher at 7000 ft in the main stem on six days during the monitoring period; and never higher at 8000 and 9000 ft.

c. Tributaries, 2018
    - As seen in Exhibit 16, WAT in 2018 was lower than the CO chronic criterion at all the tributaries during July-August.
    - As shown in Exhibit 18, TAT was higher than the CO acute criterion only at Taylor, 8430 ft, on 2 days.
    - As seen in Exhibit 4, MTAT in 2018 at the highest Slate and Coal sites, 69 and 71 F at 10,136 and 10,064 ft, was at the CO acute criterion or just below it.
    - In contrast with the high MTAT, MWAT in 2018 at those Slate and Coal sites was 10 and 7 F lower than the CO chronic criterion.
    - Also seen in Exhibit 4, MWAT and MTAT in 2018 at the highest tributary site, Priest at 10,599 ft, were 10 F below both the CO chronic and acute criteria.

d. Tributaries, 2019
    - As seen in Exhibit 17, WAT in 2019 was lower than the CO chronic criterion at all the tributaries, except Stoner, 7475 ft, where it was the same as the criterion on one day in July.
    - As shown in Exhibit 19, TAT in 2019 was equal to the acute criterion or higher only at Stoner on four days in July and August.

e. Combined main stem and tributaries, MWAT
    - Exhibit 20 shows main-stem and tributary MWAT values for 2018 and 2019, along with the CO chronic criterion.
    - It also shows best-fit regression lines for the 2018 and 2019 main-stem MWAT values.
    - The regression lines enable the interpolation of water temperatures between the elevations at which they were measured.
    - In 2018, there was continuously cold-enough water in the main stem above 8550 ft during July-August, based on comparison with the CO chronic criterion; and in 2019, above 7300 ft.

Exhibit 20. Main Stem and Tributaries, MWAT, 2018 and 2019, CO Chronic Criterion, and Cold-Enough Water, Main Stem

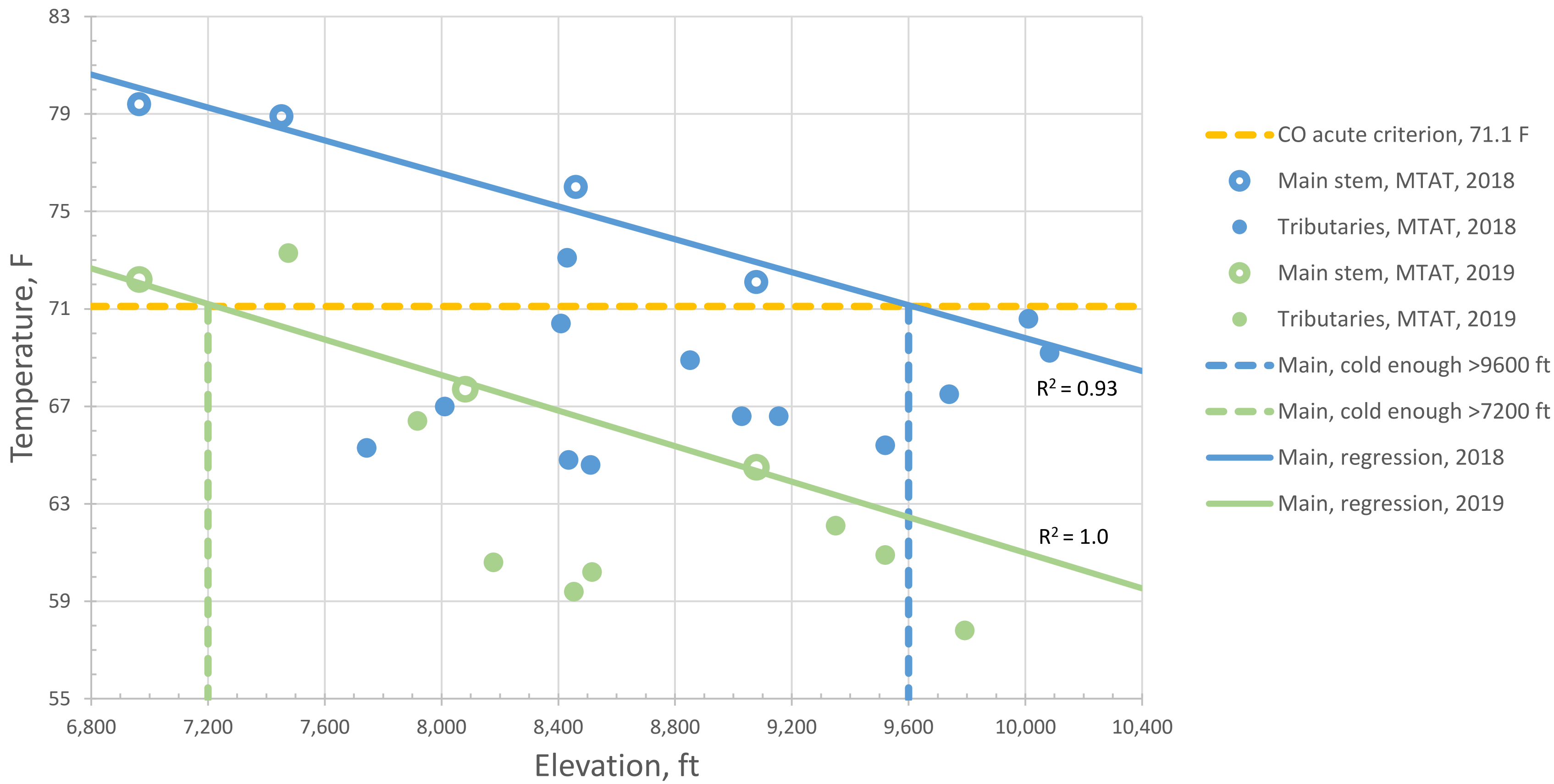


- For a sense of how much water was too warm, approximately two-thirds, or 40 of the main stem's 60 miles, is below 8550 ft and one-third is below 7300 ft.
- Main-stem flow in July-August 2018 was the second lowest since 1952 due to severe drought [23].
- In 2018, there was continuously cold-enough water in all the tributaries, with temperatures being 3 – 10 F below the CO chronic criterion. Tributary temperatures were colder the main stem up to approximately 10,000 ft.
- In 2019, there was continuously cold-enough water in all the tributaries, with temperatures being 6 – 16 F colder than the CO chronic criterion, except at Stoner, which had the same MWAT value as the criterion.
- In 2019, only two tributary sites were warmer than the main-stem, which were Stoner at 7574 ft and Taylor at 8530 ft.

f. Combined main stem and tributaries, MTAT
  - Exhibit 21 shows main-stem and tributary MTAT values for 2018 and 2019, along with the CO acute criterion.
  - In 2018, there was continuously cold-enough water in the main stem above 9600 ft during July-August, based on comparison with the CO acute criterion; and in 2019, above 7200 ft.
  - In 2018, there was continuously cold-enough water in all the tributaries, based on the CO acute criterion; and tributary temperatures were colder than the main stem up to approximately 10,000 ft.
  - In 2019, there was continuously cold-enough water in all the tributaries, based on the CO acute criterion, except at Stoner; and tributaries were colder than the main stem, also except at Stoner.

3. Summary and interpretations
   a. The main-stem elevations at which there was cold-enough water were 1200 ft (MWAT) and 2400 ft (MTAT) higher in 2018 than in 2019. They marked the greater susceptibility of main-stem water temperatures in 2018 to warming from ambient air temperatures and direct solar radiation due to low-flow conditions from drought.
   b. It was likely brook and rainbow trout that were dealing with the warm main-stem temperatures. Cutthroat trout probably were absent, perhaps except at the higher elevations. This would be due to their history of unsuccessful competition with non-native species [7].
   c. As seen in Exhibits 20 and 21, the regression lines used to interpret elevations of cold-enough water showed good fit with the data. Three had r^2 values of 1.0 and the fourth, 0.93. This and the earlier-described judgement of sufficient normality in the data support confidence in use of the lines to estimate elevations above which there was continuously

Exhibit 21. Main Stem and Tributaries, MTAT, 2018 and 2019, CO Acute Criterion, and Cold



cold-enough water in the main stem and to compare tributary temperatures with those in the main-stem at equivalent elevations.

d. The tributary WAT and TAT values show the same pattern already observed in 30-minute values, with tributaries colder than the main stem up to 10,000 ft, and colder than the CO chronic and acute criteria, with only two exceptions.

e. This meant that as too-warm temperatures extended up the main stem during warm weather in 2018 and 2019, tributaries remained available as cold-water refuge for trout, even in drought conditions.

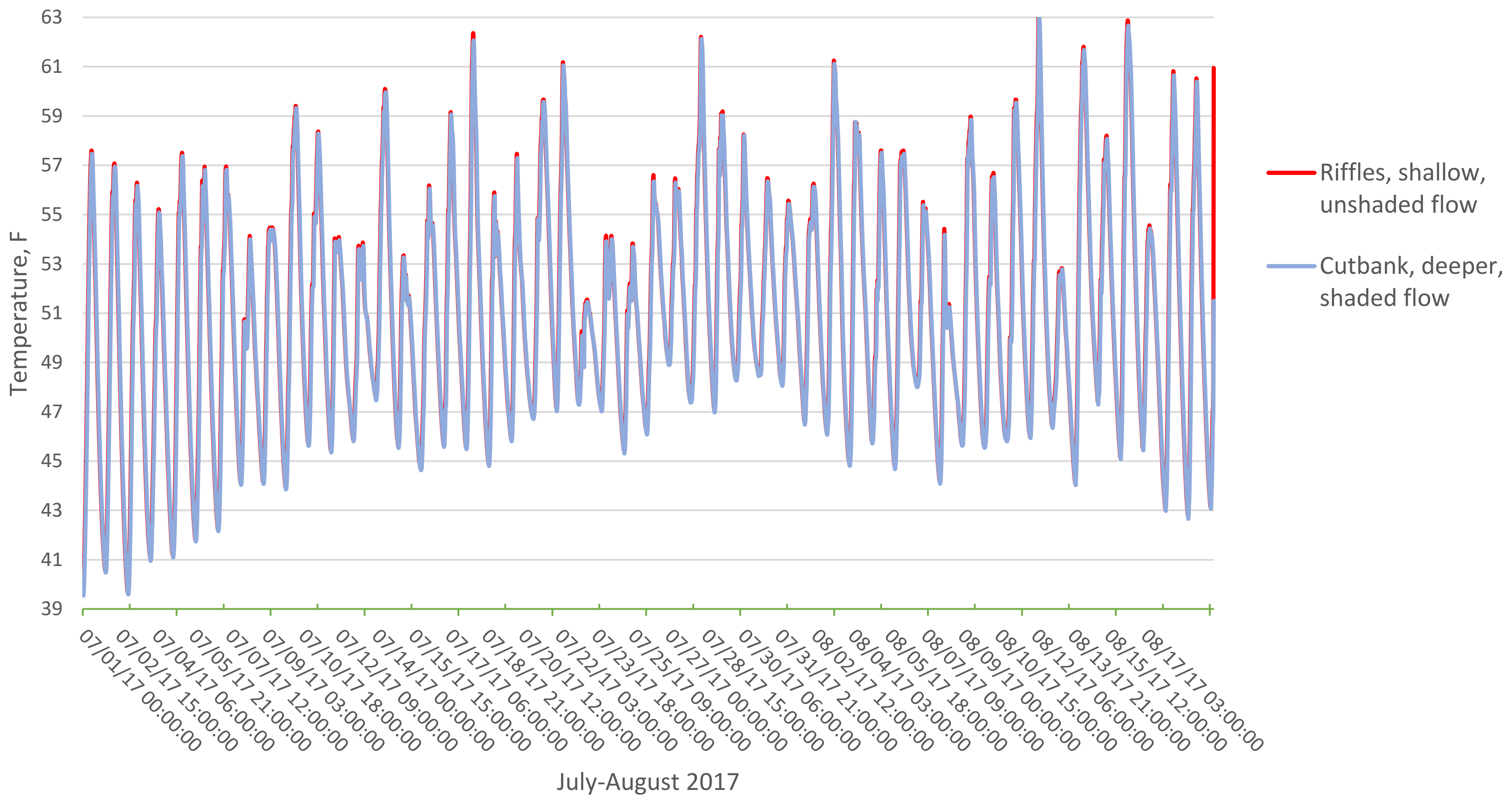
f. MTAT at the highest Slate and Coal sites was at the CO acute criterion or just below it. In contrast, MTAT at the highest Priest site was 10 F below the CO acute criterion. As described earlier, flow arriving at the highest Slate and Coal sites had prior, extended exposure to direct solar radiation, evident in photographs 7 and 8 of Appendix A. Flow arriving at the highest Priest site had no such exposure, having descended a wooded slope, as seen in photograph 9 of Appendix A.

f. The lowest and highest Spring sites were 3 and 4 F below the CO acute criterion and had the smallest TAT variation. They were 7 F below the CO chronic criterion and had small WAT variation. As noted previously, this likely signaled the strong influence on surface-water temperatures of subsurface water input, which has less temperature fluctuation than surface water. The sensor location at the highest Spring site is shown in photograph 10 of Appendix A, at a likely origin of subsurface water input.

E. Nearby Thermal Relief?

1. Overview
    a. Is local thermal relief available for trout?
    b. That is, are there colder water temperatures nearby in a stream where trout can go as a summer day heats up?
    c. In particular, can colder temperature be expected where the water is deeper, has faster flow, or is shaded?
    d. In a limited investigation, the possibility of nearby water temperature differences was tested in the main stem and at three tributaries.
2. Main stem
    a. Two sensors were installed at 9000 ft in the main stem.
    b. One was placed near the bottom of a shaded cutbank and the other at unshaded riffles nearby. The cutbank sensor was 14 inches deeper.
    c. Water temperatures were measured continuously, at 30-minute intervals, over 49 days in July-August 2017.
    d. Monitoring results are shown in Exhibit 22.
    e. No differences were discerned between temperatures at the cutbank and those at the riffles.

Exhibit 22. Main Stem, 2017, 9000 ft, Water Temperatures at Riffles with Shallow, Unshaded Flow and at Cutbank with Deeper, Shaded Flow



3. Tributaries
    a. Using a hand-held sensor, water temperatures were measured where stream depth, flow rate, and shading differed, with an example of testing shown in photograph 3 in Appendix A.
    b. This was done at three tributaries, Priest, Tenderfoot, and Ryman.
    c. At each tributary, the measurement section was approximately 100 ft in length and began roughly 200 – 400 yd upstream from the tributary's outfall at the main stem. Stream depths were 4 – 18 in in those sections.
    d. The hand-held sensor was moved through all stream depth, flow rate, and shade conditions.
    e. Priest
        - Temperatures were measured on August 29, 2018, between about 3:30 and 4:30 pm.
        - The air temperature at 3:30 was 68 F and there was no wind.
        - Water temperatures were 55 F at all depth, flow, and shade conditions.
        - Measurements were made again on August 31, 2018, between about 2:00 and 2:30 pm.
        - The air temperature at 2:00 pm was 75 F and there was a light breeze.
        - Water temperatures were 52 F at all depth, flow, and shade conditions.
    f. Tenderfoot
        - Temperatures were measured on August 31, 2018, between 12:30 and 1:15 pm.
        - The air temperature at 12:30 pm was 75 F and there was no wind.
        - Water temperatures were 53 F at all depth, flow, and shade conditions.
    g. Ryman
        - Temperatures were measured on August 31, 2018, between 11:15 am and noon.
        - The air temperature at 11:15 am was 72 F and there was no wind.
        - Water temperatures were 52 F at all depth, flow, and shade conditions.
    h. No differences in water temperatures due to stream depth, flow rate, or shading conditions were found at the tested sections.
    i. Based on this limited investigation at one location in the main stem and at sections in three tributaries, the preliminary conclusion was that no nearby thermal relief is available for trout.

F. Refuge Requiring Movement

1. Overview
    a. Given that there is colder water in tributaries and upstream in the main stem, is there evidence that trout will move to it?
    b. Is colder water at tributaries signaled to trout?
2. Studies by others
    a. Using radio telemetry, researchers determined that brook trout in the Shavers Fork of the Cheat River in mountainous West Virginia moved as much as 300-500 ft/day seeking colder water during peak summer temperatures [24, 25].
    b. Based on visual counts and electrofishing, a researcher documented that rainbow and brown trout at the Firehole River in Wyoming moved to cool-water tributaries and main-stem areas upstream during the summer for refuge from elevated river temperatures [26].
    c. From application of radio telemetry, researchers reported that a Colorado cutthroat trout population in Milk Creek, a tributary of the Yampa River in northwest Colorado, moved a median range of 3 mi and a median total of 3.7 mi seeking colder water in the summer [27].
    d. Making use of implanted radio transmitters, researchers found "large aggregations" of brook and rainbow trout had moved to tributary confluences for thermal relief from warm water in the main stem, the Moose River, in the Adirondacks in New York [28].
3. Cold-water signal
    a. No resources were on hand in this study for assessing fish movement using radio telemetry.
    b. Instead, a portable temperature sensor was used to determine if there were cold-water plumes in the main stem where cold-water tributaries discharged into it.
    c. If so, the plumes might serve as signals to trout where there was cold-water relief from too-warm main-stem temperatures during warm-weather conditions.
    d. Using the hand-held sensor, water temperatures were measured at the confluence of the three largest tributaries with the main stem.
    e. Those tributaries are Stoner, Bear, and Roaring Forks, with outfalls at 7475, 7917, and 8177 ft.
    f. The measurements were made on September 13, 2019, beginning with Bear at approximately 2 pm, followed by Roaring Forks at 3 pm, and Stoner at 4 pm.
    g. The relative flows on this date, based on visual estimation, were in this order, highest to lowest: Bear, Stoner, and Roaring Forks.
    h. Bear
        - A cold-water plume was found in the main stem where Bear discharges into it.

- Directly below the Bear outfall and reaching approximately half-way across the main stem, the water temperature was 2.3 F colder than just above the outfall in the main stem.
- That is, the main-stem temperature at the outfall was 54.1 F, and just upstream of the outfall, 57.4 F.
- This difference in temperature beginning at the Bear Creek discharge, the cold-water plume, extended 20 ft downstream in the main stem.

i. Stoner
- No cold-water plume was detected in the main stem at the Stoner outfall.
- The temperature in Stoner just upstream from its outfall was 63.7 F, and in the main stem just below the outfall, 62.6 F.

j. Roaring Forks
- A small cold-water plume was detected in the main stem at the Roaring Forks outfall.
- Directly below the outfall and reaching roughly half-way across the main stem, the water temperature was 1.2 F colder than in the main stem just above the outfall.
- That amount of temperature difference extended 5-6 ft downstream.
- Any evidence of the cold-water plume disappeared completely by 20 ft downstream.

G. Most Favorable Tributaries

1. Overview

a. Which tributaries appropriately might be considered for applying resources for maximum effectiveness and efficiency in protecting and preserving trout populations?

b. That is, where would success be most likely and consequential.

c. Based on study results, tributaries above 7500 ft have cold-enough water for temperature-safe trout habitat. That would be 41 of the basin’s 44 perennial, trout-bearing tributaries. There clearly is no shortage of tributaries for consideration.

d. Temporary dewatering at tributaries is normal, seasonally, for example, by evaporation during warm-weather months and from reduced runoff and subsurface-water recharge when precipitation is infrequent or low.

e. Dewatering, however, can leave small tributaries, or large sections of them, temporarily dry, particularly during drought conditions, resulting in locations and durations of lost trout habitat.

f. What tributaries are most resilient to dewatering? Which have the most water to lose before habitat is lost? That is, which streams have the largest flows?

g. And what watershed characteristics “explain” large flow?

2. Results
    a. The USGS online program *StreamStats* [19] was this study's source for information about flow and other watershed characteristics.
    b. Appendix B shows values for the 12 characteristics used in this study for each of the 44 perennial, trout-bearing streams, listed alphabetically.
    c. Those characteristics are outfall elevation, maximum watershed elevation, watershed drainage area, stream length, mean watershed slope, percent vegetation cover, mean annual precipitation, mean July flow, mean August flow, combined July-August mean flow, mean annual flow, and time of concentration (TOC).
    d. Exhibit 23 identifies the 10 tributaries having the largest mean flows in July-August and annually.
    e. They are Bear, East Fork, Fish, Stoner, Roaring Forks, Barlow, Scotch, Slate, Coal, and Snow Spur.
    f. Rough Canyon was the ninth largest in July-August flow, but it is a tributary of Roaring Forks and so it is not shown by itself in the exhibit.
    g. Next was determination of whether characteristics considered singly or in combination identified the same 10 streams seen in Exhibit 23.
    h. Fourteen sorts were made of these eight watershed characteristics: drainage area, stream length, maximum watershed elevation, precipitation, vegetation cover, slope (having separate sorts that favored the smallest and the largest slopes), time of concentration (TOC) (separately favoring the smallest and the largest TOCs), and outfall elevation (favoring the highest elevation).
    i. The West Fork was not part of the sorting because streams flowing into it already were included individually. Lost Canyon was not part of the sorting because it flows into the main stem below the lowest main-stem measurement site, which put it outside the study area.
    j. Exhibit 24 identifies the top 10 tributaries from each of the 14 sorts.
    k. Only drainage area and maximum elevation, considered together and favoring the largest of each, identified exactly the tributaries with the largest flows.
    g. Appendix C shows in spreadsheet form the results for all the tributaries when sorted by July-August mean flow, from largest to smallest flow.
    h. Appendix D shows the results from sorting the tributaries for the combination of largest drainage area and highest maximum elevation.
    i. As can be seen in Appendix D, proportion scores are summed to produce total scores so streams can be compared using a combination of watershed characteristics.
    j. From Exhibit 24, note that drainage area and maximum elevation considered separately did not produce a correlation with the largest-flow tributaries, as seen in the columns numbered 6 and 8.
    k. As well, evaluating drainage area and maximum elevation with stream length, column 2, and with stream length and precipitation, column 3,

Exhibit 23. Top 10 Tributaries in Flow

Tributary	July-August mean flow	Annual mean flow
1 Bear	●	●
2 East Fork	●	●
3 Fish	●	●
4 Stoner	●	●
5 Roaring Forks	●	●
6 Barlow	●	●
7 Scotch	●	●
8 Slate	●	●
9 Coal	●	●
10 Snow Spur		●

yielded similar results, but not the exact correlation that was obtained with just drainage area and maximum elevation in combination.

l. That is, only largest drainage area and highest maximum elevation, considered together, produced a list of the same tributaries as sorted by largest July-August and annual flows.
m. Also note that while sorting with drainage area and maximum elevation, as shown in Appendix D, produced the same group of 10 tributaries, it is not the same ordering of them as seen in Appendix C for July-August flow. The same ordering of tributaries would not be expected since *StreamStats* uses sophisticated regression equations to generate estimated flows.
n. The spreadsheet, in contrast, makes use of simple linear relationships among watershed characteristics for assessing patterns, if any. The purpose and capacity of the spreadsheet, which this study calls an adjustable algorithm, is for comparison of flow and other watershed characteristics among the tributaries, not flow calculation.
o. Tributaries with the highest maximum elevations have flows that begin above tree lines. High maximum elevations can mean snow melt contributions to subsurface water recharge and to springtime tributary flow. It also can result in summertime warming of water in the upper reaches of tributaries from exposure to direct solar radiation.

Exhibit 24. Top 10 Tributaries in Flow and 15 More from Sorting Other Characteristics

Tributary	July-August mean flow	Annual mean flow	1. Area, length, max elev, pptn	2. Area, length, max elev	3. Area, length	4. Area, max elev	5. Area, pptn	6. Area	7. Length	8. Max elev	9. Area, max elev, veg cover	11. Area, max 0elev, slope (sm)	11. Area, max elev, slope (lg)	12. Area, max elev, TOC (sm)	13. Area, max elev, TOC (lg)	14. Area, max elev, outfall elev (hi)
1 Bear	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
2 East Fork	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
3 Fish	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
4 Stoner	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●
5 Roaring Forks	●	●	●	●	●	●	●	●	●		●		●	●	●	●
6 Barlow	●	●		●	●	●		●			●	●				
7 Scotch	●	●	●	●	●	●	●	●	●		●		●			
8 Slate	●	●	●			●				●						●
9 Rough Canyon	●			●												
10 Coal	●	●	●	●		●			●	●	●				●	●
11 Snow Spur		●	●		●	●	●	●		●	●	●			●	●
12 Taylor			●	●	●			●	●						●	
13 Priest					●			●	●		●					
14 Meadow										●		●				
15 Nash												●				
16 Kilpacker							●			●			●	●		●
17 Silver													●	●		
18 Horse													●			
19 Twin, North							●			●				●		●
20 Twin, South							●			●				●		
21 Marguerite													●	●		
22 Groundhog															●	
23 Little Fish									●						●	
24 Willow												●				
25 Coke Oven												●				

p. Those tributaries that also have the lowest outfalls have more shaded water and a greater capacity to moderate warm water arriving from above a tree line.

q. Tributaries with the lowest outfalls and highest maximum elevations tend to be those with the greatest stream length.

r. Exhibit 25 shows the 10 tributaries with the largest flows listed by outfall elevation and stream length.

3. Summary and interpretations

   a. The tributaries with the largest flows have the largest drainage areas and highest maximum elevations, based on the correlation assessment.

   b. Having the highest elevations means exposing upper reaches of tributary flows that were above tree lines to warming from exposure to direct solar radiation.

Exhibit 25. Outfall Elevations and Stream Lengths of the Top 10 Tributaries in Flow and in the Combination of Largest Drainage Area and Highest Maximum Elevation

Tributary		Outfall elevation, ft	Stream length, mi
1	Stoner	7467	19.0
2	Bear	7895	15.6
3	Fish	8119	14.6
4	Roaring Forks	8167	9.3
5	Scotch	8530	7.6
6	Coal	9190	6.4
7	Barlow	9311	6.0
8	Slate	9502	5.7
9	East Fork	9603	7.0
10	Snow Spur	9603	6.0

c. Mixing with downstream waters protected from such exposure by shading could moderate the warmed temperatures of arriving water.

d. Tributaries with the lowest outfalls, or similarly, greatest stream length, have the greatest capacity, that is, the most amount of shaded, cooler flow, for moderating warmed waters.

e. Stoner has active water diversion for warm-weather irrigation. This diminishes flow at its outfall, likely resulting in higher temperatures and presenting no opportunity for cold-water refuge from the main stem.

f. Roaring Forks is on Colorado's monitoring and evaluation (M&E) list for possible arsenic and copper contamination [29].

g. Some tributaries have existing state and federal protection
    - Being designated by Colorado as Outstanding Waters.
    - Having protected minimum flows under the Colorado In-Stream Flow Program.
    - Having been determined by U.S. Fish & Wildlife Service to host GB-lineage cutthroat trout.

h. So, additionally important in prioritizing tributaries are
    - Whether they have active, or potential, water diversions.
    - Possible contamination from human activities or natural processes.

- Existing obligations to protect certain tributaries, as recognized and administered by state and federal agencies.

V. Overall Summary and Conclusions

A. Patterns in Temperatures

1. Main-stem warm-weather water temperatures in the study area decreased with increasing elevation, as reasonably expected.
2. Tributary water temperatures were colder than in the main stem at equivalent elevations, and stayed colder up to approximately 10,000 ft.
3. Water temperatures at high elevations in tributaries were high and variable where there was prior, extended exposure to direct solar radiation. Without such exposure, water temperatures and temperature variation were moderate, by comparison.
4. Tributaries with the smallest flows had high water-temperature variation. They had less water mass and were more susceptible than larger tributaries to diurnal fluctuations in ambient air temperatures.
5. The tributary with the largest flow had the lowest and most stable water temperatures of the tributaries, along with one of the smallest tributaries where subsurface water input apparently dominated stream temperatures.
6. Where there was water diversion, reduction in tributary flow left downstream water temperatures susceptible to warm ambient air temperatures.
7. Drought conditions raised temperatures in the main stem and in tributaries.

B. Comparisons with Criteria

1. Based on comparison with criteria that apply for the study area, water temperatures were too warm during warm weather in a significant portion of the main stem, that is, in the lower two-thirds of its length in 2018, during drought, and the lower one-third in 2019.
2. Tributaries large and small were cold-enough for trout habitat throughout their lengths during warm weather, including in drought conditions, with one exception.
3. The exception was Stoner, a large tributary, which had outfall temperatures that occasionally reached the CO chronic and acute criteria or were just below them. They were higher temperatures than observed at other tributaries, and were attributed to water withdrawal that left downstream temperatures in the tributary susceptible to increase from ambient warm air.
4. By contrast, water temperatures were stable and stayed well below the CO chronic and acute criteria at Bear, the tributary with the largest flow, which discharges into the main stem several hundred feet upstream from Stoner.
5. Tributary temperatures at high elevations where water had prior, extended exposure to direct solar radiation were variable and were at the CO acute

criterion or just below it. Temperatures at those sites were well below the CO chronic criterion, however.

6. Tributary temperatures at a similarly high-elevation site that did not have the prior exposure to direct solar radiation were lower than both the CO chronic and acute criteria.

C. Thermal Relief, Refuge

1. Nearby thermal relief for trout in deeper, faster, or shaded flow conditions does not appear to exist, based on limited investigation using installed sensors at an upstream elevation in the main stem and a hand-held sensor at downstream sections of three tributaries.
2. Temperatures in this study indicated that cold-water refuge is available, however, in tributaries and upstream in the main stem, including throughout drought conditions. Researchers at other study areas have documented that trout will move a considerable distance seeking refuge.
3. The presence of colder water in large tributaries in this study area was signaled by cold-water plumes, the largest of which extended 20 ft downstream in the main stem below the tributary discharge.

D. Candidates for Resources

1. Tributaries with larger flows have habitat that is more resilient to dewatering than smaller ones because they have more water to lose before habitat is lost.
2. Larger-flow tributaries also have larger drainage areas and higher maximum elevations, likely important characteristics in their resilience to dewatering.
3. High maximum elevations generally result in contributions from snowmelt to stream flow, including baseflow, but also means potential exposure of water at the higher elevations to direct solar radiation.
4. Larger-flow tributaries tend to have longer stream lengths and, consequently, greater capacities to moderate warm temperatures after upstream exposure to direct solar radiation.
5. Larger-flow tributaries have more volume than smaller ones both to receive trout seeking thermal relief from the main stem and to continue the accommodation of populations already resident there.
6. Larger-flow tributaries appear to be potentially attractive candidates for consideration in the planning of resources to be directed at trout habitat protection and preservation.

VI. Looking Forward

Five tributaries produce 40 percent of the flow at perennial, trout-bearing streams in the Dolores River basin. Ten tributaries account for 60 percent. For context, the combined flow of the ten is equivalent to the flow in the main-stem at 7450 ft, just below the Stoner outfall. At that elevation, warm-weather water temperatures in tributaries, aside from Stoner, are 8 F colder than in the main stem. Tributaries stay colder up to 10,000 ft and, except for Stoner, their temperatures remain 3 – 16 F below the CO chronic criterion throughout the warm-weather period, July-August. Tributaries as particular units of basin hydrology would appear to rise in relevance pertaining to trout habitat as concerns increase for the consequences of thermal and hydrologic stress in the main stem. As previously described, during drought conditions in 2018, main-stem water temperatures were too warm up to 8550 ft, based on comparison with the CO chronic criterion.

Maybe trout use tributaries as off-ramps for access to cold-water thermal relief during too-warm temperatures in the main stem. Or perhaps functioning as reserve is the key role of tributaries, hosting populations that can assist in rebuilding those diminished in the main stem by thermal stress. Such stress is reasonably expected to become more frequent and intense due to climate change. Either way, attention to protecting and preserving habitat in tributaries appears warranted and may be important, perhaps key, in maintaining trout populations in the main stem.

Resources for actions to preserve trout habitat understandably are limited. Where should they be applied for the greatest effectiveness and efficiency—for the most success? Results from this study suggest that consideration be given to directing actions at tributaries having the largest flows. They can accommodate the largest trout populations. They have the most water to lose before habitat is lost. They have the largest drainage area for collecting precipitation and producing stream flow. They have the highest maximum elevations, where snow may accumulate, the melting of which recharges subsurface water for baseflow and adds to springtime and early summer surface water flow. They have the greatest lengths of shaded, cooler water, which can moderate temperatures from warm waters arriving from above tree lines. Tributaries with the largest flows appear to be attractive candidates for the consideration of actions that can have the greatest positive effect and efficiency in trout habitat protection and preservation.

Some degree of devil—or opportunity—is in details, not surprisingly.

Stoner is the fourth largest of the tributaries in estimated flow and, at 19 mi, has the greatest length. Warm-weather water temperatures at the outfall, however, are too warm to be attractive to trout for thermal relief. Water diversion likely reduces actual flow approaching the outfall during warm weather. It leaves the low-flow, downstream section of the tributary susceptible to warming from ambient air temperatures. It is possible, perhaps likely, that water temperatures upstream from the diversion are satisfactory. That can be determined by measurements. If so, Stoner could be important in preserving, even cultivating, reserve trout populations. It may develop that the amount of water diverted can be reduced in the future. Perhaps diversion can be ended; an example would be from properties put into conservancy.

Roaring Forks has the fifth largest flow and the fourth greatest length of the 10 largest-flow tributaries. It is listed by Colorado under Regulation 93, Section 303(D) for monitoring and evaluation, cited as having possible arsenic and copper contamination [29]. That question can be resolved by testing. A fish count could be conducted for more evidence about habitat health. The watershed slopes are steep and wooded. Tree-falls across the stream at intervals extending a couple of miles above the outfall currently may hinder trout passage. Blockage from tree-falls can be removed. Water diversion is not a factor because private property at the outfall is in conservancy.

Scotch has the seventh largest flow and the fifth greatest length of the 10 largest-flow tributaries. Former beaver activity at a high elevation in the watershed has left the remains of a vegetated flood plain, along with dam structures. Restoring this flood plain to collect and hold water could enhance recharge of subsurface water, which could assist in maintaining tributary baseflow, a part of preserving trout habit.

Slate and Coal have the eighth and ninth largest flows, setting aside Rough Canyon, it being a tributary of Roaring Forks, which has the fifth largest flow. At high-elevations at Slate and Coal, exposure to direct solar radiation increases warm-weather water temperatures. The result is temperatures that are at the CO acute criterion or just below it and are highly variable. Warm-weather fishing in those waters potentially could further stress trout populations. That could be discouraged by notification to trout organizations and outfitters, directing individuals to lower elevations where the water is shaded; or it could be prohibited in those exposed sections.

The East Fork has the second largest flow and the sixth greatest length of the 10 largest-flow tributaries. No temperature measurements were made in this study at that tributary. It is the closest of the large flows to Telluride, CO, and the proximity contributes to its popularity as a fishing destination. There is risk of over-fishing. As well, the area may be a target for future development. That is, construction of resorts and housing may be contemplated, various factors of which could degrade water quality and result in loss of cold-water habitat. It has the most upstream portion of flow in the main stem. Considered as a tributary, it is second only to Bear among all the perennial, trout-bearing streams in the amount of cold-water refuge that it can provide. Protection of this habitat would seem important.

Bear has the largest flow and the second greatest length, after Stoner. Its outfall elevation is the second lowest of the 10 largest-flow tributaries, also after Stoner. Temperatures in 2019 were 10 F below both the CO chronic and acute criteria. Bear has the most stable water temperatures, aside from observations of lower variation at two measurement sites at Spring, the temperatures at which likely are subsurface-water dominated. There appears to be no significant amount of water diversion currently occurring at Bear. With a relatively low-elevation outfall, it is available early to trout moving up the main stem seeking thermal relief. It is a large-flow, long-stream-length, temperature-stable, low-elevation-accessible, cold-water trout habitat and refuge, a virtual poster child of those favorable features. It is a strong candidate for consideration of actions to further protect and preserve it as habitat. A vulnerability, such as it is, may be its proximity to the Hermosa Creek Wilderness Area. Wildfires there in 2018 extended into the Bear Creek watershed and erosion from fire damage temporarily degraded water quality.

Consideration of tributaries with the largest flows—and by extension, the largest drainage areas, highest maximum elevations, and greatest stream lengths—appears useful as part of developing plans to effectively and efficiently protect and preserve trout habitat, this having particular relevance as warm-weather habitat in the main stem is increasingly stressed from climate change, thermally and hydrologically.

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Appendices

Appendix A. Sensor Equipment, Installations, and Testing

1. Temperature sensor in a protective PVC case made from plumbing fittings

2. Installing a PVC case with sensor at riffles in the main stem,
using two weights to secure the placement

Appendix A. Continued

3. Testing for variations in tributary water temperature using a hand-held sensor

4. Installation using a highly portable black mesh bag and locally collected rocks

Appendix A. Continued

5. Installation at the lowest Slate site using epoxy to attach the PVC case with sensor

6. Installation with two methods at the highest Slate site, for comparison, one using a portable mesh bag with rocks and a PVC sensor case and the other using epoxy to attach a PVC case

Appendix A. Continued

7. Highest Slate sensor location, in rapids to the right of the seated individual, downstream of extended exposure of tributary water to direct solar radiation

8. Highest Coal sensor location, at the base of the rock where the individual stands, downstream of extended exposure of tributary water to direct solar radiation

9. Highest Priest sensor location, downstream of the road culvert at the yellow pin, and downstream of a wooded slope that limits exposure of tributary water to direct solar radiation

10. Highest Spring sensor location, with sensor ready for placement, at tributary headwaters where subsurface water input likely accounts for the stable water temperatures observed

Appendix B. Inventory of Watershed Characteristics for the Dolores River Basin's 44 Perennial, Trout-Bearing Streams

Tributary	Sort, in/out: 1/0	Outfall elevation, ft	Score	Max. elev, ft, x 1000	Score	Drainage area, sq mi	Score	Stream length, mi	Score	Slope, mean, %	Score	Vegetation cover, %	Score	Precip., in, annual	Score	Flow, cfs, July	Score	Flow, cfs, August	Score	Flow, cfs, Jul-Aug	Score	Flow, cfs, annual	Score	Time of Conc. (TOC), hr	Score	Total
1 Barlow	1	9311	0.92	12.6	0.89	9.68	0.21	6.04	0.32	23.5	0.43	95.0	0.96	35.0	0.80	25.10	0.36	10.40	0.34	17.75	0.36	13.40	0.26	2.29	0.38	6.23
2 Bear	1	7895	0.78	13.2	0.93	33.70	0.74	15.60	0.82	41.6	0.76	90.9	0.92	37.5	0.85	**68.80**	1.00	**30.30**	1.00	**49.55**	1.00	**51.50**	1.00	4.28	0.20	10.01
3 Bear, Little	1	8634	0.85	11.3	0.80	3.42	0.08	4.42	0.23	27.2	0.50	98.5	1.00	33.4	0.76	5.61	0.08	2.48	0.08	4.05	0.08	4.52	0.09	1.95	0.44	4.99
4 Burnett	1	8603	0.85	12.3	0.87	2.80	0.06	3.55	0.19	48.6	0.89	93.5	0.95	34.8	0.79	5.43	0.08	2.33	0.08	3.88	0.08	4.27	0.08	1.15	0.75	5.66
5 Clear	1	9243	0.91	11.4	0.80	1.24	0.03	2.62	0.14	25.7	0.47	93.2	0.95	30.9	0.70	1.69	0.02	0.76	0.03	1.23	0.02	1.43	0.03	1.10	0.78	4.88
6 Coal	1	9190	0.91	13.8	0.97	6.41	0.14	6.42	0.34	26.9	0.49	88.9	0.90	37.5	0.85	15.10	0.22	6.35	0.21	10.73	0.22	11.40	0.22	2.71	0.32	5.79
7 Coke Oven	1	9310	0.92	11.9	0.84	3.34	0.07	4.06	0.21	19.2	0.35	**98.6**	1.00	35.8	0.82	7.08	0.10	3.00	0.10	5.04	0.10	5.46	0.11	2.34	0.37	4.99
8 East Fork	1	9603	0.95	13.7	0.96	17.00	0.37	7.03	0.37	30.0	0.55	84.6	0.86	41.0	0.93	50.70	0.74	20.70	0.68	35.70	0.72	36.10	0.70	2.82	0.30	8.14
9 Fall (Dunton)	1	8836	0.87	12.3	0.87	4.15	0.09	4.21	0.22	38.1	0.70	92.6	0.94	39.2	0.89	11.90	0.17	4.80	0.16	8.35	0.17	8.71	0.17	1.41	0.61	5.86
10 Fall (east)	1	8478	0.84	11.3	0.80	1.05	0.02	2.71	0.14	47.0	0.86	97.0	0.98	28.9	0.66	1.15	0.02	0.54	0.02	0.85	0.02	1.01	0.02	**0.86**	1.00	5.37
11 Fish	1	8119	0.80	13.3	0.94	36.20	0.79	14.60	0.77	31.9	0.58	87.0	0.88	32.0	0.73	41.50	0.60	20.20	0.67	30.85	0.62	34.20	0.66	5.78	0.15	8.20
12 Fish, Little	1	8427	0.83	12.0	0.85	7.73	0.17	6.31	0.33	34.0	0.62	90.9	0.92	32.8	0.75	11.10	0.16	5.08	0.17	8.09	0.16	9.01	0.17	3.54	0.24	5.38
13 Grindstone	1	9165	0.91	11.6	0.82	1.82	0.04	2.52	0.13	38.7	0.71	94.6	0.96	37.1	0.85	4.67	0.07	1.90	0.06	3.29	0.07	3.53	0.07	1.12	0.77	5.44
14 Groundhog	1	8734	0.86	12.2	0.86	4.62	0.10	5.52	0.29	23.3	0.43	91.0	0.92	31.0	0.71	5.66	0.08	2.65	0.09	4.16	0.08	4.75	0.09	4.54	0.19	4.70
15 Horse	1	8860	0.88	12.3	0.87	4.93	0.11	3.91	0.21	53.4	0.97	92.4	0.94	39.4	0.90	14.10	0.20	5.71	0.19	9.91	0.20	10.30	0.20	1.43	0.60	6.26
16 Kilpacker	1	9839	0.97	**14.2**	1.00	2.62	0.06	4.19	0.22	53.6	0.98	48.7	0.49	43.8	1.00	11.60	0.17	4.31	0.14	7.96	0.16	7.97	0.15	1.00	0.86	6.21
17 Lizard Head	1	10047	0.99	12.9	0.91	2.15	0.05	3.19	0.17	26.4	0.48	93.5	0.95	36.8	0.84	5.24	0.08	2.15	0.07	3.70	0.07	3.98	0.08	1.72	0.50	5.18
18 Lost Canyon	1	6928	0.68	11.2	0.79	74.00	1.62	31.70	1.67	13.5	0.25	93.5	0.95	26.0	0.59	37.60	0.55	21.40	0.71	29.50	0.60	35.20	0.68	12.16	0.07	9.15
19 Lost Cyn@DV	1	10004	0.99	11.2	0.79	1.11	0.02	2.20	0.12	16.8	0.31	95.7	0.97	36.0	0.82	2.66	0.04	1.08	0.04	1.87	0.04	2.04	0.04	1.34	0.64	4.81
20 Marguerite	1	9028	0.89	12.3	0.87	1.60	0.04	2.40	0.13	**54.8**	1.00	90.6	0.92	38.5	0.88	4.68	0.07	1.85	0.06	3.27	0.07	3.46	0.07	0.90	0.96	5.93
21 Meadow	1	9209	0.91	13.0	0.92	4.10	0.09	4.90	0.26	17.8	0.32	95.9	0.97	35.2	0.80	8.05	0.12	3.46	0.11	5.76	0.12	6.27	0.12	2.99	0.29	5.03
22 Morrison	1	9079	0.90	11.8	0.83	3.69	0.08	4.87	0.26	19.4	0.35	97.6	0.99	37.0	0.84	8.68	0.13	3.62	0.12	6.15	0.12	6.57	0.13	3.34	0.26	5.01
23 Nash	1	8732	0.86	12.1	0.85	5.77	0.13	6.10	0.32	17.3	0.32	93.4	0.95	30.6	0.70	6.60	0.10	3.14	0.10	4.87	0.10	5.60	0.11	2.65	0.32	4.85
24 Priest	1	7974	0.79	11.5	0.81	9.61	0.21	7.81	0.41	39.1	0.71	94.8	0.96	30.7	0.70	10.70	0.16	5.15	0.17	7.93	0.16	9.05	0.18	2.27	0.38	5.63
25 Rio Lado	1	8068	0.80	10.9	0.77	3.45	0.08	3.75	0.20	40.9	0.75	96.5	0.98	29.7	0.68	3.72	0.05	1.78	0.06	2.75	0.06	3.22	0.06	1.36	0.63	5.10
26 Roaring Fks	1	8167	0.81	11.8	0.83	19.60	0.43	9.30	0.49	36.6	0.67	96.2	0.98	34.1	0.78	29.70	0.43	13.70	0.45	21.70	0.44	23.60	0.46	2.68	0.32	7.08
27 Rough Cyn	1	8991	0.89	11.8	0.83	5.20	0.11	5.15	0.27	36.1	0.66	98.0	0.99	39.8	0.91	15.50	0.23	6.21	0.20	10.86	0.22	11.20	0.22	1.80	0.48	6.01
28 Ryman	1	8396	0.83	11.0	0.77	5.73	0.13	5.12	0.27	45.9	0.84	96.2	0.98	30.2	0.69	6.26	0.09	3.00	0.10	4.63	0.09	5.36	0.10	1.40	0.61	5.50
29 Scotch	1	8530	0.84	12.6	0.89	12.10	0.27	7.65	0.40	45.6	0.83	93.7	0.95	32.3	0.74	15.80	0.23	7.41	0.24	11.61	0.23	13.00	0.25	2.06	0.42	6.29
30 Silver	1	9313	0.92	12.7	0.89	4.94	0.11	4.57	0.24	53.6	0.98	94.1	0.95	39.9	0.91	14.90	0.22	5.95	0.20	10.43	0.21	10.80	0.21	1.40	0.61	6.45
31 Silver & JBull	1	8460	0.84	12.1	0.85	6.22	0.14	4.81	0.25	45.9	0.84	93.0	0.94	33.3	0.76	9.65	0.14	4.35	0.14	7.00	0.14	7.78	0.15	1.37	0.63	5.82
32 Slate	1	9502	0.94	**14.2**	1.00	5.14	0.11	5.74	0.30	38.7	0.71	77.2	0.78	40.5	0.92	16.30	0.24	6.48	0.21	11.39	0.23	11.70	0.23	2.05	0.42	6.09

Appendix B. Continued

33 Snow Spur	1	9603	0.95	13.2	0.93	9.68	0.21	6.04	0.32	23.5	0.43	95.0	0.96	35.0	0.80	11.50	0.17	5.02	0.17	8.26	0.17	13.40	0.26	2.92	0.29	5.65
34 Spring	1	8912	0.88	10.7	0.75	4.22	0.09	5.57	0.29	22.8	0.42	92.6	0.94	30.9	0.70	5.18	0.08	2.42	0.08	3.80	0.08	4.36	0.08	2.27	0.38	4.77
35 Stoner	1	7467	0.74	12.3	0.87	**45.60**	1.00	**19.00**	1.00	25.4	0.46	92.9	0.94	29.7	0.68	39.00	0.57	20.10	0.66	29.55	0.60	33.70	0.65	5.88	0.15	8.31
36 Straight	1	9757	0.96	12.6	0.89	1.32	0.03	2.95	0.16	47.2	0.86	81.8	0.83	36.5	0.83	3.25	0.05	1.32	0.04	2.29	0.05	2.48	0.05	1.14	0.75	5.50
37 Taylor	1	7649	0.76	10.8	0.76	12.90	0.28	10.50	0.55	28.3	0.52	84.1	0.85	29.5	0.67	12.00	0.17	6.00	0.20	9.00	0.18	10.50	0.20	3.51	0.25	5.40
38 Taylor, Little	1	8489	0.84	10.6	0.75	2.97	0.07	4.82	0.25	25.3	0.46	87.1	0.88	29.3	0.67	2.96	0.04	1.41	0.05	2.19	0.04	2.71	0.05	2.04	0.42	4.52
39 Tenderfoot	1	8222	0.81	11.2	0.79	2.75	0.06	3.90	0.21	43.8	0.80	92.1	0.93	29.5	0.67	3.10	0.05	1.48	0.05	2.29	0.05	2.57	0.05	1.20	0.72	5.18
40 Twin, North	1	10119	1.00	13.7	0.96	3.18	0.07	3.82	0.20	41.9	0.76	65.7	0.67	42.9	0.98	12.90	0.19	4.88	0.16	8.89	0.18	8.96	0.17	1.37	0.63	5.97
41 Twin, South	1	**10122**	1.00	13.7	0.96	2.56	0.06	3.41	0.18	38.0	0.69	62.9	0.64	**43.9**	1.00	11.50	0.17	4.26	0.14	7.88	0.16	7.88	0.15	1.31	0.66	5.81
42 West Fork	1	7366	0.73	14.2	1.00	169.00	3.71	37.60	1.98	30.6	0.56	89.7	0.91	30.6	0.70	144.00	2.09	75.50	2.49	109.75	2.21	122.00	2.37	9.63	0.09	18.84
43 Wildcat	1	8341	0.82	11.9	0.84	5.27	0.12	5.34	0.28	47.7	0.87	97.3	0.99	31.3	0.71	6.58	0.10	3.08	0.10	4.83	0.10	5.51	0.11	1.45	0.59	5.62
44 Willow	1	8976	0.89	11.3	0.80	5.33	0.12	5.86	0.31	18.0	0.33	91.6	0.93	30.6	0.70	6.13	0.09	2.91	0.10	4.52	0.09	5.21	0.10	3.11	0.28	4.72
Best		**10122**	1.00	**14.2**	1.00	**45.60**	1.00	**19.00**	1.00	**54.8**	1.00	**98.6**	1.00	**43.9**	1.00	**68.80**	1.00	**30.30**	1.00	**49.55**	1.00	**51.50**	1.00	**0.86**	1.00	
Weight			1		1		1		1		1		1		1		1		1		1		1		1	

Appendix C. Tributaries Sorted by July-August Mean Flow

Tributary	Sort, in/out: 1/0	Outfall elevation, ft	Score	Max. elev, ft, x 1000	Score	Drainage area, sq mi	Score	Stream length, mi	Score	Slope, mean, %	Score	Vegetation cover, %	Score	Precip., in, annual	Score	Flow, cfs, July	Score	Flow, cfs, August	Score	Flow, cfs, Jul-Aug	Score	Flow, cfs, annual	Score	Time of Conc. (TOC), hr	Score	Total
1 Bear	1	7895	0.00	13.2	0.00	33.70	0.00	15.60	0.00	41.6	0.00	90.9	0.00	37.5	0.00	**68.80**	0.00	**30.30**	0.00	**49.55**	1.00	**51.50**	0.00	4.28	0.00	1.00
2 East Fork	1	9603	0.00	13.7	0.00	17.00	0.00	7.03	0.00	30.0	0.00	84.6	0.00	41.0	0.00	50.70	0.00	20.70	0.00	**35.70**	0.72	36.10	0.00	2.82	0.00	0.72
3 Fish	1	8119	0.00	13.3	0.00	36.20	0.00	14.60	0.00	31.9	0.00	87.0	0.00	32.0	0.00	41.50	0.00	20.20	0.00	**30.85**	0.62	34.20	0.00	5.78	0.00	0.62
4 Stoner	1	7467	0.00	12.3	0.00	**45.60**	0.00	**19.00**	0.00	25.4	0.00	92.9	0.00	29.7	0.00	39.00	0.00	20.10	0.00	**29.55**	0.60	33.70	0.00	5.88	0.00	0.60
5 Roaring Fks	1	8167	0.00	11.8	0.00	19.60	0.00	9.30	0.00	36.6	0.00	96.2	0.00	34.1	0.00	29.70	0.00	13.70	0.00	**21.70**	0.44	23.60	0.00	2.68	0.00	0.44
6 Barlow	1	9311	0.00	12.6	0.00	9.68	0.00	6.04	0.00	23.5	0.00	95.0	0.00	35.0	0.00	25.10	0.00	10.40	0.00	**17.75**	0.36	13.40	0.00	2.29	0.00	0.36
7 Scotch	1	8530	0.00	12.6	0.00	12.10	0.00	7.65	0.00	45.6	0.00	93.7	0.00	32.3	0.00	15.80	0.00	7.41	0.00	**11.61**	0.23	13.00	0.00	2.06	0.00	0.23
8 Slate	1	9502	0.00	**14.2**	0.00	5.14	0.00	5.74	0.00	38.7	0.00	77.2	0.00	40.5	0.00	16.30	0.00	6.48	0.00	**11.39**	0.23	11.70	0.00	2.05	0.00	0.23
9 Rough Cyn	1	8991	0.00	11.8	0.00	5.20	0.00	5.15	0.00	36.1	0.00	98.0	0.00	39.8	0.00	15.50	0.00	6.21	0.00	**10.86**	0.22	11.20	0.00	1.80	0.00	0.22
10 Coal	1	9190	0.00	13.8	0.00	6.41	0.00	6.42	0.00	26.9	0.00	88.9	0.00	37.5	0.00	15.10	0.00	6.35	0.00	**10.73**	0.22	11.40	0.00	2.71	0.00	0.22
11 Silver	1	9313	0.00	12.7	0.00	4.94	0.00	4.57	0.00	53.6	0.00	94.1	0.00	39.9	0.00	14.90	0.00	5.95	0.00	10.43	0.21	10.80	0.00	1.40	0.00	0.21
12 Horse	1	8860	0.00	12.3	0.00	4.93	0.00	3.91	0.00	53.4	0.00	92.4	0.00	39.4	0.00	14.10	0.00	5.71	0.00	9.91	0.20	10.30	0.00	1.43	0.00	0.20
13 Taylor	1	7649	0.00	10.8	0.00	12.90	0.00	10.50	0.00	28.3	0.00	84.1	0.00	29.5	0.00	12.00	0.00	6.00	0.00	9.00	0.18	10.50	0.00	3.51	0.00	0.18
14 Twin, North	1	10119	0.00	13.7	0.00	3.18	0.00	3.82	0.00	41.9	0.00	65.7	0.00	42.9	0.00	12.90	0.00	4.88	0.00	8.89	0.18	8.96	0.00	1.37	0.00	0.18
15 Fall (Dunton)	1	8836	0.00	12.3	0.00	4.15	0.00	4.21	0.00	38.1	0.00	92.6	0.00	39.2	0.00	11.90	0.00	4.80	0.00	8.35	0.17	8.71	0.00	1.41	0.00	0.17
16 Snow Spur	1	9603	0.00	13.2	0.00	9.68	0.00	6.04	0.00	23.5	0.00	95.0	0.00	35.0	0.00	11.50	0.00	5.02	0.00	8.26	0.17	13.40	0.00	2.92	0.00	0.17
17 Fish, Little	1	8427	0.00	12.0	0.00	7.73	0.00	6.31	0.00	34.0	0.00	90.9	0.00	32.8	0.00	11.10	0.00	5.08	0.00	8.09	0.16	9.01	0.00	3.54	0.00	0.16
18 Kilpacker	1	9839	0.00	**14.2**	0.00	2.62	0.00	4.19	0.00	53.6	0.00	48.7	0.00	43.8	0.00	11.60	0.00	4.31	0.00	7.96	0.16	7.97	0.00	1.00	0.00	0.16
19 Priest	1	7974	0.00	11.5	0.00	9.61	0.00	7.81	0.00	39.1	0.00	94.8	0.00	30.7	0.00	10.70	0.00	5.15	0.00	7.93	0.16	9.05	0.00	2.27	0.00	0.16
20 Twin, South	1	**10122**	0.00	13.7	0.00	2.56	0.00	3.41	0.00	38.0	0.00	62.9	0.00	**43.9**	0.00	11.50	0.00	4.26	0.00	7.88	0.16	7.88	0.00	1.31	0.00	0.16
21 Silver & JBull	1	8460	0.00	12.1	0.00	6.22	0.00	4.81	0.00	45.9	0.00	93.0	0.00	33.3	0.00	9.65	0.00	4.35	0.00	7.00	0.14	7.78	0.00	1.37	0.00	0.14
22 Morrison	1	9079	0.00	11.8	0.00	3.69	0.00	4.87	0.00	19.4	0.00	97.6	0.00	37.0	0.00	8.68	0.00	3.62	0.00	6.15	0.12	6.57	0.00	3.34	0.00	0.12
23 Meadow	1	9209	0.00	13.0	0.00	4.10	0.00	4.90	0.00	17.8	0.00	95.9	0.00	35.2	0.00	8.05	0.00	3.46	0.00	5.76	0.12	6.27	0.00	2.99	0.00	0.12
24 Coke Oven	1	9310	0.00	11.9	0.00	3.34	0.00	4.06	0.00	19.2	0.00	**98.6**	0.00	35.8	0.00	7.08	0.00	3.00	0.00	5.04	0.10	5.46	0.00	2.34	0.00	0.10
25 Nash	1	8732	0.00	12.1	0.00	5.77	0.00	6.10	0.00	17.3	0.00	93.4	0.00	30.6	0.00	6.60	0.00	3.14	0.00	4.87	0.10	5.60	0.00	2.65	0.00	0.10
26 Wildcat	1	8341	0.00	11.9	0.00	5.27	0.00	5.34	0.00	47.7	0.00	97.3	0.00	31.3	0.00	6.58	0.00	3.08	0.00	4.83	0.10	5.51	0.00	1.45	0.00	0.10
27 Ryman	1	8396	0.00	11.0	0.00	5.73	0.00	5.12	0.00	45.9	0.00	96.2	0.00	30.2	0.00	6.26	0.00	3.00	0.00	4.63	0.09	5.36	0.00	1.40	0.00	0.09
28 Willow	1	8976	0.00	11.3	0.00	5.33	0.00	5.86	0.00	18.0	0.00	91.6	0.00	30.6	0.00	6.13	0.00	2.91	0.00	4.52	0.09	5.21	0.00	3.11	0.00	0.09
29 Groundhog	1	8734	0.00	12.2	0.00	4.62	0.00	5.52	0.00	23.3	0.00	91.0	0.00	31.0	0.00	5.66	0.00	2.65	0.00	4.16	0.08	4.75	0.00	4.54	0.00	0.08
30 Bear, Little	1	8634	0.00	11.3	0.00	3.42	0.00	4.42	0.00	27.2	0.00	98.5	0.00	33.4	0.00	5.61	0.00	2.48	0.00	4.05	0.08	4.52	0.00	1.95	0.00	0.08
31 Burnett	1	8603	0.00	12.3	0.00	2.80	0.00	3.55	0.00	48.6	0.00	93.5	0.00	34.8	0.00	5.43	0.00	2.33	0.00	3.88	0.08	4.27	0.00	1.15	0.00	0.08
32 Spring	1	8912	0.00	10.7	0.00	4.22	0.00	5.57	0.00	22.8	0.00	92.6	0.00	30.9	0.00	5.18	0.00	2.42	0.00	3.80	0.08	4.36	0.00	2.27	0.00	0.08

Appendix C. Continued

33 Lizard Head	1	10047	0.00	12.9	0.00	2.15	0.00	3.19	0.00	26.4	0.00	93.5	0.00	36.8	0.00	5.24	0.00	2.15	0.00	3.70	0.07	3.98	0.00	1.72	0.00	0.07
34 Grindstone	1	9165	0.00	11.6	0.00	1.82	0.00	2.52	0.00	38.7	0.00	94.6	0.00	37.1	0.00	4.67	0.00	1.90	0.00	3.29	0.07	3.53	0.00	1.12	0.00	0.07
35 Marguerite	1	9028	0.00	12.3	0.00	1.60	0.00	2.40	0.00	**54.8**	0.00	90.6	0.00	38.5	0.00	4.68	0.00	1.85	0.00	3.27	0.07	3.46	0.00	0.90	0.00	0.07
36 Rio Lado	1	8068	0.00	10.9	0.00	3.45	0.00	3.75	0.00	40.9	0.00	96.5	0.00	29.7	0.00	3.72	0.00	1.78	0.00	2.75	0.06	3.22	0.00	1.36	0.00	0.06
37 Tenderfoot	1	8222	0.00	11.2	0.00	2.75	0.00	3.90	0.00	43.8	0.00	92.1	0.00	29.5	0.00	3.10	0.00	1.48	0.00	2.29	0.05	2.57	0.00	1.20	0.00	0.05
38 Straight	1	9757	0.00	12.6	0.00	1.32	0.00	2.95	0.00	47.2	0.00	81.8	0.00	36.5	0.00	3.25	0.00	1.32	0.00	2.29	0.05	2.48	0.00	1.14	0.00	0.05
39 Taylor, Little	1	8489	0.00	10.6	0.00	2.97	0.00	4.82	0.00	25.3	0.00	87.1	0.00	29.3	0.00	2.96	0.00	1.41	0.00	2.19	0.04	2.71	0.00	2.04	0.00	0.04
40 Lost Cyn@DV	1	10004	0.00	11.2	0.00	1.11	0.00	2.20	0.00	16.8	0.00	95.7	0.00	36.0	0.00	2.66	0.00	1.08	0.00	1.87	0.04	2.04	0.00	1.34	0.00	0.04
41 Clear	1	9243	0.00	11.4	0.00	1.24	0.00	2.62	0.00	25.7	0.00	93.2	0.00	30.9	0.00	1.69	0.00	0.76	0.00	1.23	0.02	1.43	0.00	1.10	0.00	0.02
42 Fall (east)	1	8478	0.00	11.3	0.00	1.05	0.00	2.71	0.00	47.0	0.00	97.0	0.00	28.9	0.00	1.15	0.00	0.54	0.00	0.85	0.02	1.01	0.00	**0.86**	0.00	0.02
43 Lost Canyon	0	6928	0.00	11.2	0.00	74.00	0.00	31.70	0.00	13.5	0.00	93.5	0.00	26.0	0.00	37.60	0.00	21.40	0.00	29.50	0.00	35.20	0.00	12.16	0.00	0.00
44 West Fork	0	7366	0.00	14.2	0.00	169.00	0.00	37.60	0.00	30.6	0.00	89.7	0.00	30.6	0.00	144.00	0.00	75.50	0.00	109.75	0.00	122.00	0.00	9.63	0.00	0.00
	Best	**10122**	0.00	**14.2**	0.00	**45.60**	0.00	**19.00**	0.00	**54.8**	0.00	**98.6**	0.00	**43.9**	0.00	**68.80**	0.00	**30.30**	0.00	**49.55**	1.00	**51.50**	0.00	**0.86**	0.00	
	Weight		0		0		0		0		0		0		0		0		0		1		0		0	

Appendix D. Tributaries Sorted by Combined Drainage Area and Maximum Watershed Elevation

Tributary	Sort, in/out: 1/0	Outfall elevation, ft	Score	Max. elev, ft, x 1000	Score	Drainage area, sq mi	Score	Stream length, mi	Score	Slope, mean, %	Score	Vegetation cover, %	Score	Precip., in, annual	Score	Flow, cfs, July	Score	Flow, cfs, August	Score	Flow, cfs, Jul-Aug	Score	Flow, cfs, annual	Score	Time of Conc. (TOC), hr	Score	Total
1 Stoner	1	7467	0.00	**12.3**	0.87	**45.60**	1.00	**19.00**	0.00	25.4	0.00	92.9	0.00	29.7	0.00	39.00	0.00	20.10	0.00	29.55	0.00	33.70	0.00	5.88	0.00	**1.87**
2 Fish	1	8119	0.00	**13.3**	0.94	**36.20**	0.79	14.60	0.00	31.9	0.00	87.0	0.00	32.0	0.00	41.50	0.00	20.20	0.00	30.85	0.00	34.20	0.00	5.78	0.00	**1.73**
3 Bear	1	7895	0.00	**13.2**	0.93	**33.70**	0.74	15.60	0.00	41.6	0.00	90.9	0.00	37.5	0.00	**68.80**	0.00	**30.30**	0.00	**49.55**	0.00	**51.50**	0.00	4.28	0.00	**1.67**
4 East Fork	1	9603	0.00	**13.7**	0.96	**17.00**	0.37	7.03	0.00	30.0	0.00	84.6	0.00	41.0	0.00	50.70	0.00	20.70	0.00	35.70	0.00	36.10	0.00	2.82	0.00	**1.34**
5 Roaring Fks	1	8167	0.00	**11.8**	0.83	**19.60**	0.43	9.30	0.00	36.6	0.00	96.2	0.00	34.1	0.00	29.70	0.00	13.70	0.00	21.70	0.00	23.60	0.00	2.68	0.00	**1.26**
6 Scotch	1	8530	0.00	**12.6**	0.89	**12.10**	0.27	7.65	0.00	45.6	0.00	93.7	0.00	32.3	0.00	15.80	0.00	7.41	0.00	11.61	0.00	13.00	0.00	2.06	0.00	**1.15**
7 Snow Spur	1	9603	0.00	**13.2**	0.93	**9.68**	0.21	6.04	0.00	23.5	0.00	95.0	0.00	35.0	0.00	11.50	0.00	5.02	0.00	8.26	0.00	13.40	0.00	2.92	0.00	**1.14**
8 Barlow	1	9311	0.00	**12.6**	0.89	**9.68**	0.21	6.04	0.00	23.5	0.00	95.0	0.00	35.0	0.00	25.10	0.00	10.40	0.00	17.75	0.00	13.40	0.00	2.29	0.00	**1.10**
9 Coal	1	9190	0.00	**13.8**	0.97	**6.41**	0.14	6.42	0.00	26.9	0.00	88.9	0.00	37.5	0.00	15.10	0.00	6.35	0.00	10.73	0.00	11.40	0.00	2.71	0.00	**1.11**
10 Slate	1	9502	0.00	**14.2**	1.00	**5.14**	0.11	5.74	0.00	38.7	0.00	77.2	0.00	40.5	0.00	16.30	0.00	6.48	0.00	11.39	0.00	11.70	0.00	2.05	0.00	**1.11**
11 Taylor	1	7649	0.00	10.8	0.76	12.90	0.28	10.50	0.00	28.3	0.00	84.1	0.00	29.5	0.00	12.00	0.00	6.00	0.00	9.00	0.00	10.50	0.00	3.51	0.00	1.04
12 Priest	1	7974	0.00	11.5	0.81	9.61	0.21	7.81	0.00	39.1	0.00	94.8	0.00	30.7	0.00	10.70	0.00	5.15	0.00	7.93	0.00	9.05	0.00	2.27	0.00	1.02
13 Kilpacker	1	9839	0.00	**14.2**	1.00	2.62	0.06	4.19	0.00	53.6	0.00	48.7	0.00	43.8	0.00	11.60	0.00	4.31	0.00	7.96	0.00	7.97	0.00	1.00	0.00	1.06
14 Fish, Little	1	8427	0.00	12.0	0.85	7.73	0.17	6.31	0.00	34.0	0.00	90.9	0.00	32.8	0.00	11.10	0.00	5.08	0.00	8.09	0.00	9.01	0.00	3.54	0.00	1.01
15 Twin, North	1	10119	0.00	13.7	0.96	3.18	0.07	3.82	0.00	41.9	0.00	65.7	0.00	42.9	0.00	12.90	0.00	4.88	0.00	8.89	0.00	8.96	0.00	1.37	0.00	1.03
16 Twin, South	1	**10122**	0.00	13.7	0.96	2.56	0.06	3.41	0.00	38.0	0.00	62.9	0.00	**43.9**	0.00	11.50	0.00	4.26	0.00	7.88	0.00	7.88	0.00	1.31	0.00	1.02
17 Silver	1	9313	0.00	12.7	0.89	4.94	0.11	4.57	0.00	53.6	0.00	94.1	0.00	39.9	0.00	14.90	0.00	5.95	0.00	10.43	0.00	10.80	0.00	1.40	0.00	1.00
18 Meadow	1	9209	0.00	13.0	0.92	4.10	0.09	4.90	0.00	17.8	0.00	95.9	0.00	35.2	0.00	8.05	0.00	3.46	0.00	5.76	0.00	6.27	0.00	2.99	0.00	1.01
19 Silver & JBull	1	8460	0.00	12.1	0.85	6.22	0.14	4.81	0.00	45.9	0.00	93.0	0.00	33.3	0.00	9.65	0.00	4.35	0.00	7.00	0.00	7.78	0.00	1.37	0.00	0.99
20 Nash	1	8732	0.00	12.1	0.85	5.77	0.13	6.10	0.00	17.3	0.00	93.4	0.00	30.6	0.00	6.60	0.00	3.14	0.00	4.87	0.00	5.60	0.00	2.65	0.00	0.98
21 Horse	1	8860	0.00	12.3	0.87	4.93	0.11	3.91	0.00	53.4	0.00	92.4	0.00	39.4	0.00	14.10	0.00	5.71	0.00	9.91	0.00	10.30	0.00	1.43	0.00	0.97
22 Groundhog	1	8734	0.00	12.2	0.86	4.62	0.10	5.52	0.00	23.3	0.00	91.0	0.00	31.0	0.00	5.66	0.00	2.65	0.00	4.16	0.00	4.75	0.00	4.54	0.00	0.96
23 Wildcat	1	8341	0.00	11.9	0.84	5.27	0.12	5.34	0.00	47.7	0.00	97.3	0.00	31.3	0.00	6.58	0.00	3.08	0.00	4.83	0.00	5.51	0.00	1.45	0.00	0.95
24 Fall (Dunton)	1	8836	0.00	12.3	0.87	4.15	0.09	4.21	0.00	38.1	0.00	92.6	0.00	39.2	0.00	11.90	0.00	4.80	0.00	8.35	0.00	8.71	0.00	1.41	0.00	0.96
25 Rough Cyn	1	8991	0.00	11.8	0.83	5.20	0.11	5.15	0.00	36.1	0.00	98.0	0.00	39.8	0.00	15.50	0.00	6.21	0.00	10.86	0.00	11.20	0.00	1.80	0.00	0.95
26 Lizard Head	1	10047	0.00	12.9	0.91	2.15	0.05	3.19	0.00	26.4	0.00	93.5	0.00	36.8	0.00	5.24	0.00	2.15	0.00	3.70	0.00	3.98	0.00	1.72	0.00	0.96
27 Burnett	1	8603	0.00	12.3	0.87	2.80	0.06	3.55	0.00	48.6	0.00	93.5	0.00	34.8	0.00	5.43	0.00	2.33	0.00	3.88	0.00	4.27	0.00	1.15	0.00	0.93
28 Willow	1	8976	0.00	11.3	0.80	5.33	0.12	5.86	0.00	18.0	0.00	91.6	0.00	30.6	0.00	6.13	0.00	2.91	0.00	4.52	0.00	5.21	0.00	3.11	0.00	0.91
29 Ryman	1	8396	0.00	11.0	0.77	5.73	0.13	5.12	0.00	45.9	0.00	96.2	0.00	30.2	0.00	6.26	0.00	3.00	0.00	4.63	0.00	5.36	0.00	1.40	0.00	0.90
30 Morrison	1	9079	0.00	11.8	0.83	3.69	0.08	4.87	0.00	19.4	0.00	97.6	0.00	37.0	0.00	8.68	0.00	3.62	0.00	6.15	0.00	6.57	0.00	3.34	0.00	0.91
31 Coke Oven	1	9310	0.00	11.9	0.84	3.34	0.07	4.06	0.00	19.2	0.00	**98.6**	0.00	35.8	0.00	7.08	0.00	3.00	0.00	5.04	0.00	5.46	0.00	2.34	0.00	0.91
32 Straight	1	9757	0.00	12.6	0.89	1.32	0.03	2.95	0.00	47.2	0.00	81.8	0.00	36.5	0.00	3.25	0.00	1.32	0.00	2.29	0.00	2.48	0.00	1.14	0.00	0.92

Appendix D. Continued

33 Marguerite	1	9028	0.00	12.3	0.87	1.60	0.04	2.40	0.00	**54.8**	0.00	90.6	0.00	38.5	0.00	4.68	0.00	1.85	0.00	3.27	0.00	3.46	0.00	0.90	0.00	0.90
34 Bear, Little	1	8634	0.00	11.3	0.80	3.42	0.08	4.42	0.00	27.2	0.00	98.5	0.00	33.4	0.00	5.61	0.00	2.48	0.00	4.05	0.00	4.52	0.00	1.95	0.00	0.87
35 Spring	1	8912	0.00	10.7	0.75	4.22	0.09	5.57	0.00	22.8	0.00	92.6	0.00	30.9	0.00	5.18	0.00	2.42	0.00	3.80	0.00	4.36	0.00	2.27	0.00	0.85
36 Grindstone	1	9165	0.00	11.6	0.82	1.82	0.04	2.52	0.00	38.7	0.00	94.6	0.00	37.1	0.00	4.67	0.00	1.90	0.00	3.29	0.00	3.53	0.00	1.12	0.00	0.86
37 Tenderfoot	1	8222	0.00	11.2	0.79	2.75	0.06	3.90	0.00	43.8	0.00	92.1	0.00	29.5	0.00	3.10	0.00	1.48	0.00	2.29	0.00	2.57	0.00	1.20	0.00	0.85
38 Rio Lado	1	8068	0.00	10.9	0.77	3.45	0.08	3.75	0.00	40.9	0.00	96.5	0.00	29.7	0.00	3.72	0.00	1.78	0.00	2.75	0.00	3.22	0.00	1.36	0.00	0.84
39 Clear	1	9243	0.00	11.4	0.80	1.24	0.03	2.62	0.00	25.7	0.00	93.2	0.00	30.9	0.00	1.69	0.00	0.76	0.00	1.23	0.00	1.43	0.00	1.10	0.00	0.83
40 Taylor, Little	1	8489	0.00	10.6	0.75	2.97	0.07	4.82	0.00	25.3	0.00	87.1	0.00	29.3	0.00	2.96	0.00	1.41	0.00	2.19	0.00	2.71	0.00	2.04	0.00	0.81
41 Fall (east)	1	8478	0.00	11.3	0.80	1.05	0.02	2.71	0.00	47.0	0.00	97.0	0.00	28.9	0.00	1.15	0.00	0.54	0.00	0.85	0.00	1.01	0.00	**0.86**	0.00	0.82
42 Lost Cyn@DV	1	10004	0.00	11.2	0.79	1.11	0.02	2.20	0.00	16.8	0.00	95.7	0.00	36.0	0.00	2.66	0.00	1.08	0.00	1.87	0.00	2.04	0.00	1.34	0.00	0.81
43 West Fork	0	7366	0.00	14.2	0.00	169.00	0.00	37.60	0.00	30.6	0.00	89.7	0.00	30.6	0.00	144.00	0.00	75.50	0.00	109.75	0.00	122.00	0.00	9.63	0.00	0.00
44 Lost Canyon	0	6928	0.00	11.2	0.00	74.00	0.00	31.70	0.00	13.5	0.00	93.5	0.00	26.0	0.00	37.60	0.00	21.40	0.00	29.50	0.00	35.20	0.00	12.16	0.00	0.00
Best		**10122**	0.00	**14.2**	1.00	**45.60**	1.00	**19.00**	0.00	**54.8**	0.00	**98.6**	0.00	**43.9**	0.00	**68.80**	0.00	**30.30**	0.00	**49.55**	0.00	**51.50**	0.00	**0.86**	0.00	
Weight			0		1		1		0		0		0		0		0		0		0		0		0	