TECHNICAL MEMORANDUM ◦ DECEMBER 2019

Upper Tuolumne River Ecosystem Program 2018 Fisheries Monitoring

PREPARED FOR

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Cover photo: Aquatic habitat surveys in upper Tuolumne River, fall 2018

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1 INTRODUCTION

Annual monitoring of fish populations in the upper Tuolumne River Watershed serves as a basis for evaluating aquatic habitat conditions and assists in understanding how releases from the San Francisco Public Utilities Commission (SFPUC) Hetch Hetchy Project facilities affect fish habitat and trout populations over time.

The SFPUC conducted annual monitoring of trout populations for the reach between Hetch Hetchy Reservoir and Kirkwood Powerhouse (the Hetch Hetchy Reach) (Figure 1) from 2007 to 2012; no data were collected in 2013 due to the Rim Fire. In 2014, the monitoring approach for this reach was refined to be more efficient and effective (see Stillwater Sciences 2016), and monitoring was continued in 2015 through 2018. From 2015 and 2018, fish population monitoring was expanded to include additional monitoring reaches using a consistent monitoring approach and methods to those developed for the Hetch Hetchy Reach. These additional reaches include: the Tuolumne River immediately upstream of Hetch Hetchy Reservoir (the Above Hetch Hetchy Reservoir Reach), Cherry Creek from Valley Dam to the confluence with the Tuolumne River (the Cherry Creek Reach), and Eleanor Creek from Lake Eleanor Dam to the confluence with Cherry Creek (the Eleanor Creek Reach) (Figure 1).

Reconnaissance-level fisheries monitoring in the Above Hetch Hetchy Reservoir Reach began in 2016 to aid in understanding annual variation and long-term trends for a population subject to unimpaired flow conditions, and has continued through 2018. The Above Hetch Hetchy Reservoir Reach differs from the lower three sub-reaches in that habitat quantity and quality are governed by the natural flow regime. Annual monitoring of trout populations in the Above Hetch Hetchy Reservoir Reach will serve as a “control” and increase the ability to understand whether changes in trout populations in reaches downstream from the reservoir are the result of management actions. However, it is important to note that fish populations in the Above Hetch Hetchy Reservoir Reach may be influenced by the close proximity to Hetch Hetchy Reservoir, although potential migration barriers have not been evaluated. In addition, the reach upstream of the reservoir is at a higher elevation compared with reaches downstream, and therefore may be influenced by slightly different climactic conditions.

In 2012, the SFPUC conducted an initial fish population monitoring effort in the Cherry Creek Reach upstream of Holm Powerhouse and the Eleanor Creek Reach. In 2016, the SFPUC reinitiated fish population monitoring in the Cherry Creek Reach. Fish monitoring in Cherry Creek was expanded in 2017 to include sites downstream of Holm Powerhouse (expanding the Cherry Creek Reach) and surveys were continued in 2018. Fish population monitoring in the Eleanor Creek Reach was reinitiated in 2017 and continued in 2018.

Given the management emphasis of state and federal regulatory agencies on salmonids and sport fishing values, fish population monitoring is focused on evaluating long-term changes in native Rainbow Trout (*Oncorhnychus mykiss*) and non-native Brown Trout (*Salmo trutta*) populations. Other native fish species known to occur in the upper Tuolumne River include Riffle Sculpin (*Cottus gulosus*), California Roach (*Lavinia symmetricus*), and Sacramento Sucker (*Catostomus occidentalis*). These non-salmonid species are observed infrequently upstream of Preston Falls. Non-salmonid species are recorded when observed during monitoring surveys.

This technical memorandum summarizes the fish population monitoring methods and results for surveys in the Hetch Hetchy Reach, the Above Hetch Hetchy Reservoir Reach, the Cherry Creek

Reach, and the Eleanor Creek Reach during 2018. Fish population monitoring results from previous years are also presented for comparison where appropriate.

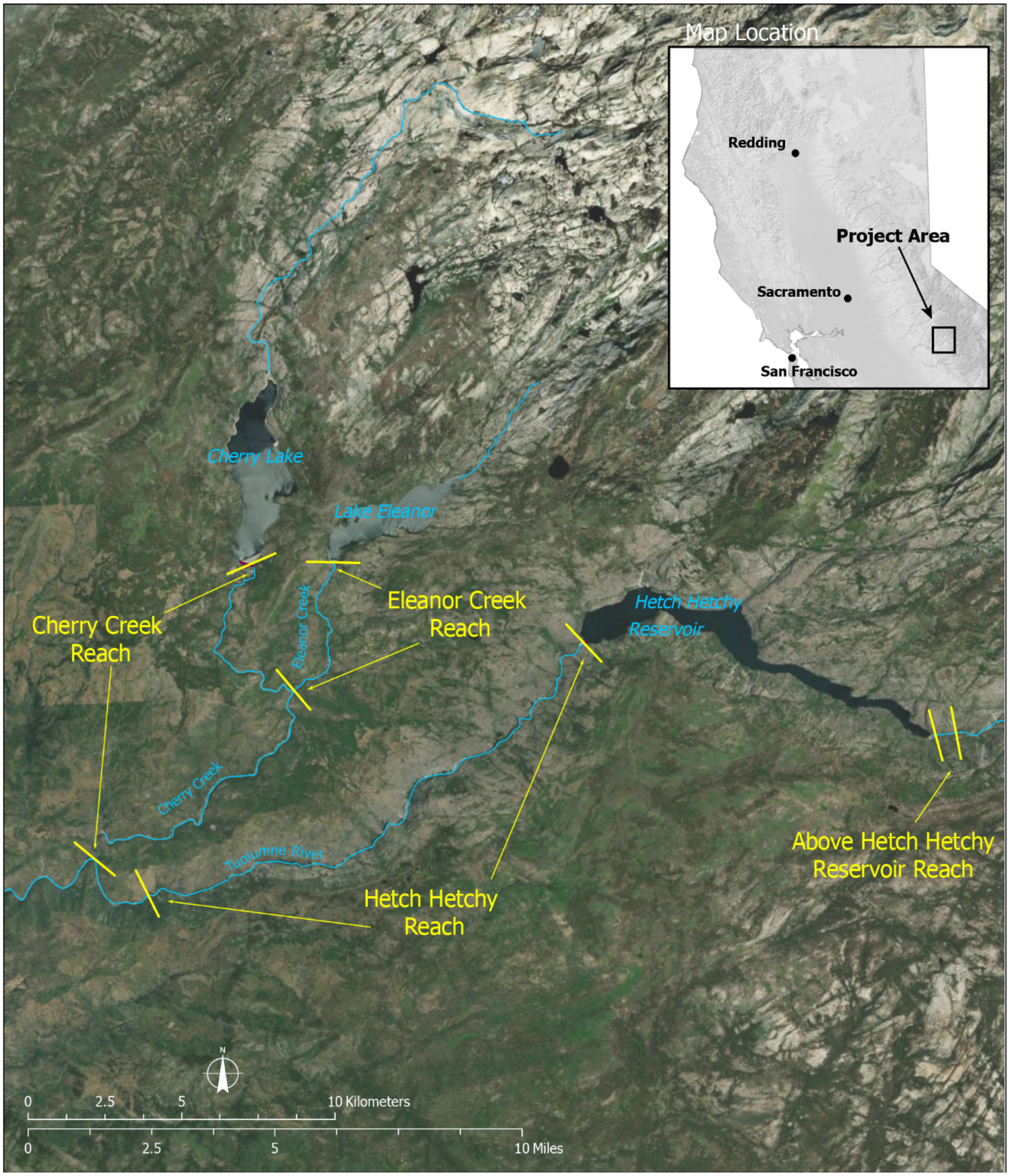

Figure 1. Fisheries monitoring sites in during 2018.

2 APPROACH

The monitoring approach that has been implemented since 2014 was designed to survey Rainbow Trout and Brown Trout populations in sufficient detail to detect meaningful differences over time. The approach focuses on locations likely to provide "good" habitat conditions for trout. In this context, "good" habitat refers to habitats having numerous locations where trout would be expected to use and defend bioenergetically profitable feeding locations and where a variety of trout age and size classes would be present. The results are intended to provide an estimate of trout abundance at the sample locations and a reasonable metric of trout abundance within each sub-reach for tracking population trends over time.

3 METHODS

3.1 Site Selection

Fish monitoring sites were selected within a framework where the stream channel is divided into reaches, sub-reaches, and habitat units (e.g., pool, riffle, run) based on channel morphology and characteristics that influence aquatic habitat conditions such as gradient, confinement, contributing drainage area, and flow. Monitoring sites were selected from within this framework based on criteria developed to meet monitoring objectives and key survey considerations. The primary monitoring objective for the revised approach was to incorporate methods that control for statistical bias and allow sample variance and confidence intervals (CI) to be calculated for abundance estimates. These methods improve the ability to detect differences among sites and (sampled) sub-reaches, and changes over time that are statistically significant; however, no long-term statistical analysis has been completed to date. Key considerations for survey site selection included ease of access, survey efficiency and repeatability, and their representativeness of the monitoring reach. Each monitoring site consists of a single habitat unit (e.g., one pool) to allow comparisons within and between different habitat types. Typically, the full length of a habitat unit is sampled. However, when habitat conditions are relatively homogeneous lengthwise within a unit, a subset of the habitat unit length may be sampled. Monitoring sites within each surveyed reach represent the dominant habitat types in the reach by length and are distributed to capture longitudinal variability. Sample sites were selected using criteria similar to those used to select sites in the Hetch Hetchy Reach, with the intent of achieving similar monitoring objectives. See Stillwater Sciences (2016) for a detailed discussion of site selection methods.

For the Hetch Hetchy Reach, habitat typing performed by the U.S. Fish and Wildlife Service (USFWS) were used to describe the distribution and abundance of aquatic habitat in the reach (USFWS 1992). For the Above Hetch Hetchy Reservoir Reach, habitat typing and site selection were performed by SFPUC during 2016–2018 (unpublished data). In Cherry Creek and Eleanor Creek, the sampling framework was based on habitat typing conducted by McBain Associates in during summer 2016 (Stillwater 2016) during summer 2017 (Stillwater and McBain 2019), respectively.

3.2 Sites Surveyed

3.2.1 Hetch Hetchy Reach

The Hetch Hetchy Reach was divided into 5 sub-reaches (Early Intake, Preston Falls, Gorge, Poopenaut Valley, O'Shaughnessy) (Figure 2). Since 2014, snorkel surveys in the Hetch Hetchy Reach have been performed within three of the five sub-reaches (Early Intake, Preston Falls, and

O'Shaughnessy). Fish population monitoring surveys in the Hetch Hetchy Reach were performed on September 10, 12–13, and 17–20, 2018. A total of 16 monitoring sites in the Hetch Hetchy Reach were surveyed in 2018: six in the Early Intake sub-reach, six in the Preston Falls sub-reach, and four in the O'Shaughnessy sub-reach (Table 1, Figure 2). Sites included deep pool, shallow pool, and pocketwater habitat types, which comprise 82 to 95 percent of habitats in the sub-reaches sampled (Table 2). Run, riffle, cascade, and chute habitat types were not included because (1) they did not meet site selection criteria, and/or (2) there was very little representation of these habitat types within the sub-reaches sampled. Monitoring sites surveyed in the Hetch Hetchy Reach during 2018 were the same as those sampled in 2017 (Stillwater Sciences and McBain Associated 2019).

Average daily streamflow during 2018 monitoring surveys was 86 cubic feet per second (cfs) at the upstream end of the reach (USGS gage 11276500 near Hetch Hetchy) and 90 cfs at the downstream end of the reach (USGS gage 11276600 above Early Intake). Three-pass, bounded count snorkel surveys were conducted in 2018 at all monitoring sites except one pocketwater habitat (229-PW). Field crews generally consisted of five snorkelers and one shore-based safety/data recorder. For each of the three snorkel passes, snorkelers entered the site from downstream and snorkeled in an upstream direction, each within a designated lane. Snorkelers identified, counted, and visually estimated total length of fish observed in their own lane while moving upstream at a slow and uniform pace. Dive slates were used to tally fish observed by species and length class, and fish observation data were recorded with a field computer at the end of each pass. General site habitat characteristics and water quality observations were also recorded for each site.

The length of each monitoring site was estimated with a geographic information system (GIS) using a polygon coverage that defines the upstream and downstream boundaries (provided by the SFPUC), orthorectified aerial photography, and Tuolumne River "center line" stationing. Estimates of surveyed length were used to calculate linear trout density (fish/1,000 feet). Stationing used in 2018 was the same used in 2016 and 2017 and reflects an updated downstream boundary (i.e., station 000+00) at the Wards Ferry Bridge (Table 1). Prior to 2016, the downstream boundary was approximately 2,525 feet downstream of the Wards Ferry Bridge.

In 2018, monitoring coverage by length was 10 percent, 11 percent, and 8 percent of the total length of Early Intake, Preston Falls, and O'Shaughnessy sub-reaches, respectively (Table 3). Within the sub-reaches, 2018 monitoring coverage by length for deep pool, shallow pool, and pocketwater habitat types was 7 to 14 percent, 23 to 33 percent, and 4 to 11 percent of those habitat types, respectively (Table 3).

Table 1. Fish population monitoring sites surveyed in the Hetch Hetchy Reach in 2018.

Site ID[1]	Habitat type[1]	Longitudinal stationing[2] (feet)		Surveyed length (feet)
		Downstream	Upstream	
Early Intake sub-reach				
11-SP	shallow pool	1483+48	1485+01	153
13-DP	deep pool	1485+98	1487+93	194
18-PW	pocketwater	1512+49	1514+45	197
27-SP	shallow pool	1533+85	1536+59	274
34-DP	deep pool	1556+96	1558+67	170
37-PW	pocketwater	1565+91	1567+24	133
Preston Falls sub-reach				
44-PW	pocketwater	1578+64	1580+33	169
46-DP	deep pool	1580+66	1581+94	129
49-SP	shallow pool	1584+53	1586+10	157
56-DP	deep pool	1593+73	1596+20	246
74-DP	deep pool	1652+21	1654+71	249
76-SP	shallow pool	1656+32	1657+78	146
O'Shaughnessy sub-reach				
223-DP	deep pool	2004+60	2006+96	236
227-DP	deep pool	2009+52	2011+02	150
229-PW	pocketwater	2012+24	2014+40	217
267-SP	shallow pool	2077+05	2079+60	255

1 Based on USFWS habitat typing data. Monitoring site numbers refer to sequential habitat unit numbers from Kirkwood Powerhouse to O'Shaughnessy Dam (data provided to Stillwater Sciences by McBain Associates).
2 Stationing is based on the GIS center line for the Tuolumne River from the Wards Ferry Bridge upstream of Don Pedro Reservoir (River Mile [RM] 0) upstream to O'Shaughnessy Dam.

Table 2. Habitat type composition of study sub-reaches in the Hetch Hetchy Reach.

Study sub-reach	Habitat type composition by length (percent)						
	Deep pool	Shallow pool	Run	Riffle	Cascade	Pocketwater[1]	Chute
Early Intake	23	12	5	0	0	60	0
Preston Falls	66	12	2	1	2	16	1
O'Shaughnessy	55	11	<1	7	4	16	6

1 Includes habitats classified as PW (pocketwater) and PW/CA (pocketwater/cascade).

Table 3. Percent length of sub-reaches surveyed by habitat type in the Hetch Hetchy Reach.

Sub-reach	Sub-reach length surveyed by habitat type (percent length)			Total sub-reach length surveyed (percent length)
	Deep pool	Shallow pool	Pocketwater	
Early Intake	14	33	4	10
Preston Falls	10	24	10	11
O'Shaughnessy	7	23	11	8

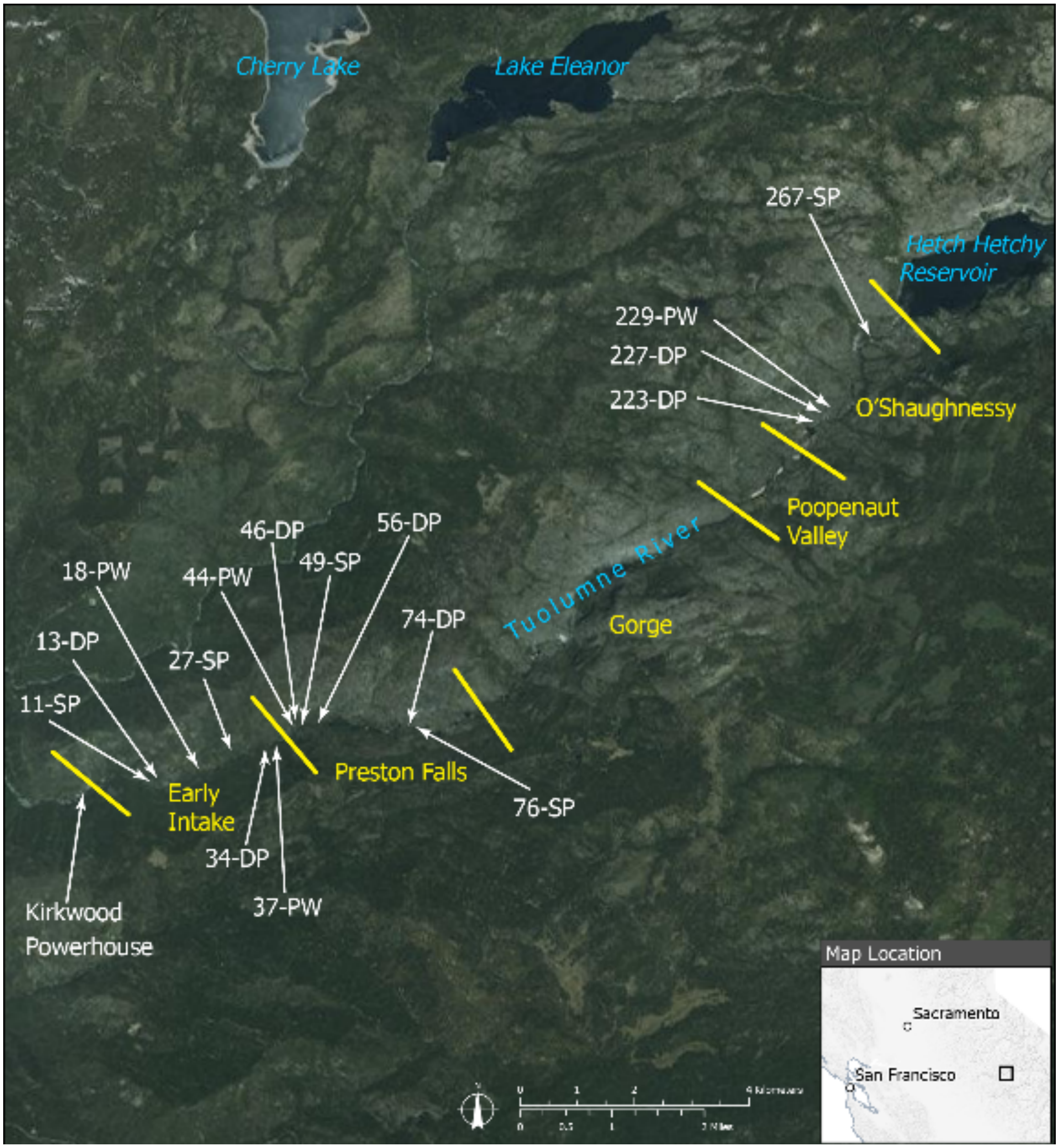

Figure 2. Fish population monitoring site locations surveyed in the Hetch Hetchy Reach in 2018.

3.2.2 Above Hetch Hetchy Reservoir Reach

Fish population monitoring surveys in the Above Hetch Hetchy Reservoir Reach were performed on September 11, 2018 when average daily streamflow was 17 cfs (USGS gage 11274790 above Hetch Hetchy). Five monitoring sites were surveyed in the Above Hetch Hetchy Reservoir Reach during 2018: two pocketwaters (510-PW and 517-PW), one shallow pool (511-SP), and two deep pools (514-DP and 518-DP) (Table 4, Figure 3). In 2018, modifications to the sites surveyed in the Above Hetch Hetchy Reservoir Reach in 2017 included removing one pocketwater site (505-PW) and adding one pocketwater site (517-PW) and one deep pool site (518-DP). Snorkel surveys were conducted at each of the five monitoring sites using methods similar to those described above for the Hetch Hetchy Reach. Three-pass methods were used at one monitoring site (511-SP), two-pass methods were used at three monitoring sites (510-PW, 514-DP, 517-PW), and one-pass methods were used at one monitoring site (518-DP).

Table 4. Fish population monitoring sites surveyed in the Above Hetch Hetchy Reservoir Reach in 2018.

Site ID[1]	Habitat type[2]	Longitudinal stationing[3] (feet)		Surveyed length (feet)
		Downstream	Upstream	
510-PW	pocketwater	2549+28	2550+32	105
511-SP	shallow pool	2550+33	2551+71	138
514-DP	deep pool	2556+30	2557+76	146
517-PW	pocketwater	2560+52	2562+43	190
518-DP	deep pool	2562+43	2562+96	54

[1] Monitoring site identification numbers refer to sequential habitat unit numbers from Kirkwood Powerhouse to O'Shaughnessy Dam (data provided to Stillwater Sciences by McBain Associates).
[2] Habitat type designations are based on USFWS habitat typing data.
[3] Stationing is based on the GIS center line for the Tuolumne River from the Wards Ferry Bridge upstream of Don Pedro Reservoir (RM 0) upstream to O'Shaughnessy Dam.

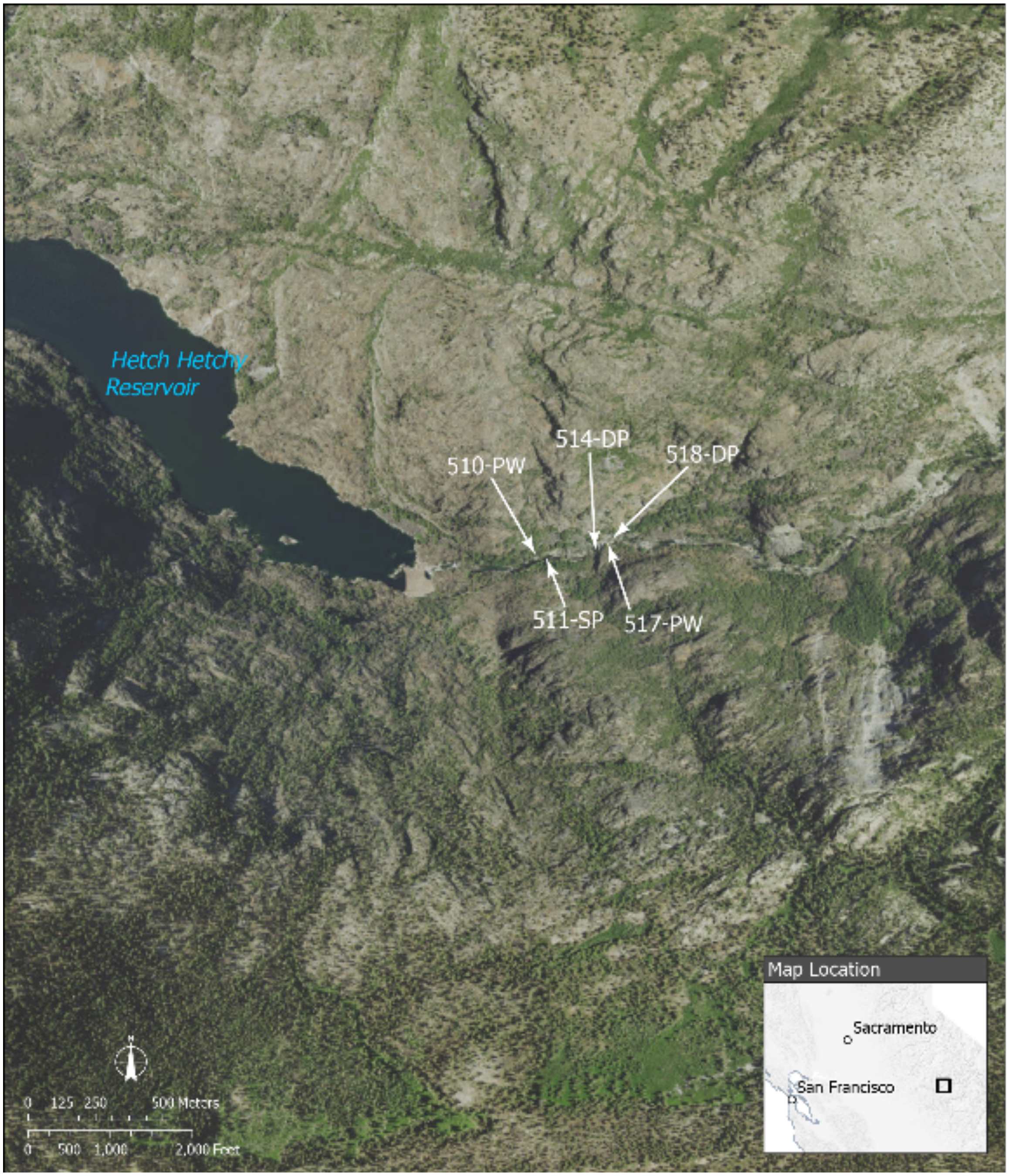

Figure 3. Fish population monitoring site locations surveyed in the Above Hetch Hetchy Reservoir Reach in 2018.

3.2.3 Cherry Creek and Eleanor Creek Reaches

The Cherry Creek Reach was divided into three sub-reaches: Upper Cherry sub-reach, Lower Cherry sub-reach, and Holm Powerhouse sub-reach (Figure 4). Fish population monitoring surveys in the Cherry Creek Reach were performed on October 2–5, 2018 when daily average streamflow was 6 cfs at the upstream end of the reach (USGS gage 11277300 below Valley

Dam), 24 to 29 cfs above Holm Powerhouse near the downstream end of the reach (USGS gage 11278300 above Holm Powerhouse), and 147 to 153 cfs below Holm Powerhouse at the downstream end of the reach (USGS gage 11278400 below Holm Powerhouse) (see Section 6.3 for additional information on stream gages). A freshet occurring in the Cherry Creek and Eleanor Creek basins on October 3, 2018 resulted in a short-term spike in streamflow and increased turbidity. Turbidity mostly cleared in the Lower Cherry sub-reach over the course of two days, but poor visibility (about 6 feet) was encountered when snorkeling the deep pool (14-DP) in the Holm Powerhouse sub-reach in the late afternoon on October 5, 2018. Snorkel surveys employed three-pass methods similar to those used in the Hetch Hetchy Reach, with two snorkelers.

Habitat characteristics and survey conditions were recorded for each monitoring site and included weather, underwater visibility (feet), dominant and subdominant substrate types (silt, sand, gravel, cobble, and boulder), instream cover types (percent boulder, bubble curtain, undercut bank, large woody debris, instream vegetation, bedrock ledge), water temperature (degrees Celsius [^{o}C]), and maximum depth. In addition, photos and Global Positioning System (GPS) points at the upstream and downstream end of each reach were taken to document the extent of each site.

Fish population monitoring surveys in the Eleanor Creek Reach were performed on October 2–4, 2018 when daily average streamflow was 12 cfs (USGS gage 11278000 in Eleanor Creek near Hetch Hetchy). Due to its relatively short length (4 river miles) and lack of any operational inputs (e.g., powerhouses), Eleanor Creek was not separated into sub-reaches like the Hetch Hetchy and Cherry Creek reaches. Snorkel surveys employed the three-pass method using a similar survey approach with two to three snorkelers and one shore safety/data recorder. It is important to note that the 2012 Eleanor Creek snorkel surveys only employed a one-pass method, and reported abundances are based on direct enumeration. As a result, CI could not be calculated for the 2012 survey data. In addition, each sample site in 2012 covered multiple habitat units and types compared with one habitat unit type per sample site in 2017 and 2018. Due to the survey methods used in 2012, it was not possible to make comparisons at the habitat unit scale or by habitat type. Therefore, for reporting purposes, comparisons between the 2012 and the 2017 and 2018 surveys in Eleanor Creek are limited to linear density at the reach level.

A total of 12 monitoring sites were sampled in the Cherry Creek Reach—three in the Upper Cherry sub-reach, seven in the Lower Cherry sub-reach, and two in the Holm Powerhouse sub-reach—and a total of six monitoring sites were selected in the Eleanor Creek Reach (Table 5, Figure 4). The length of each monitoring site was estimated with GIS using a polygon coverage of surveyed site lengths, orthorectified aerial photography, and GIS “center line” stationing (Table 5). The total length surveyed in each sub-reach was 542 feet in the Upper Cherry sub-reach, 1,250 feet in the Lower Cherry sub-reach, 375 feet in the Holm Powerhouse sub-reach, and 589 feet in the Eleanor Creek Reach, which was 2 percent, 4 percent, 10 percent and 3 percent of the total length of each reach, respectively (Table 6). Monitoring sites included shallow pool, deep pool, boulder garden, and run habitat types. These four habitat types represented 71 percent of the total length of the Upper Cherry sub-reach,77 percent of the Lower Cherry sub-reach, 27 percent of the Holm Powerhouse sub-reach, and 70 percent in the Eleanor Creek Reach (Table 7). Monitoring sites did not include riffle, cascade, and chute habitat types because (1) they did not meet site selection criteria (e.g., could not be effectively sampled), and/or (2) there was very little representation of these habitat types within the reaches sampled. Monitoring sites surveyed in the Cherry Creek and Eleanor Creek reaches in 2018 were the same as those surveyed in 2017 (Stillwater Sciences and McBain Associated 2019).

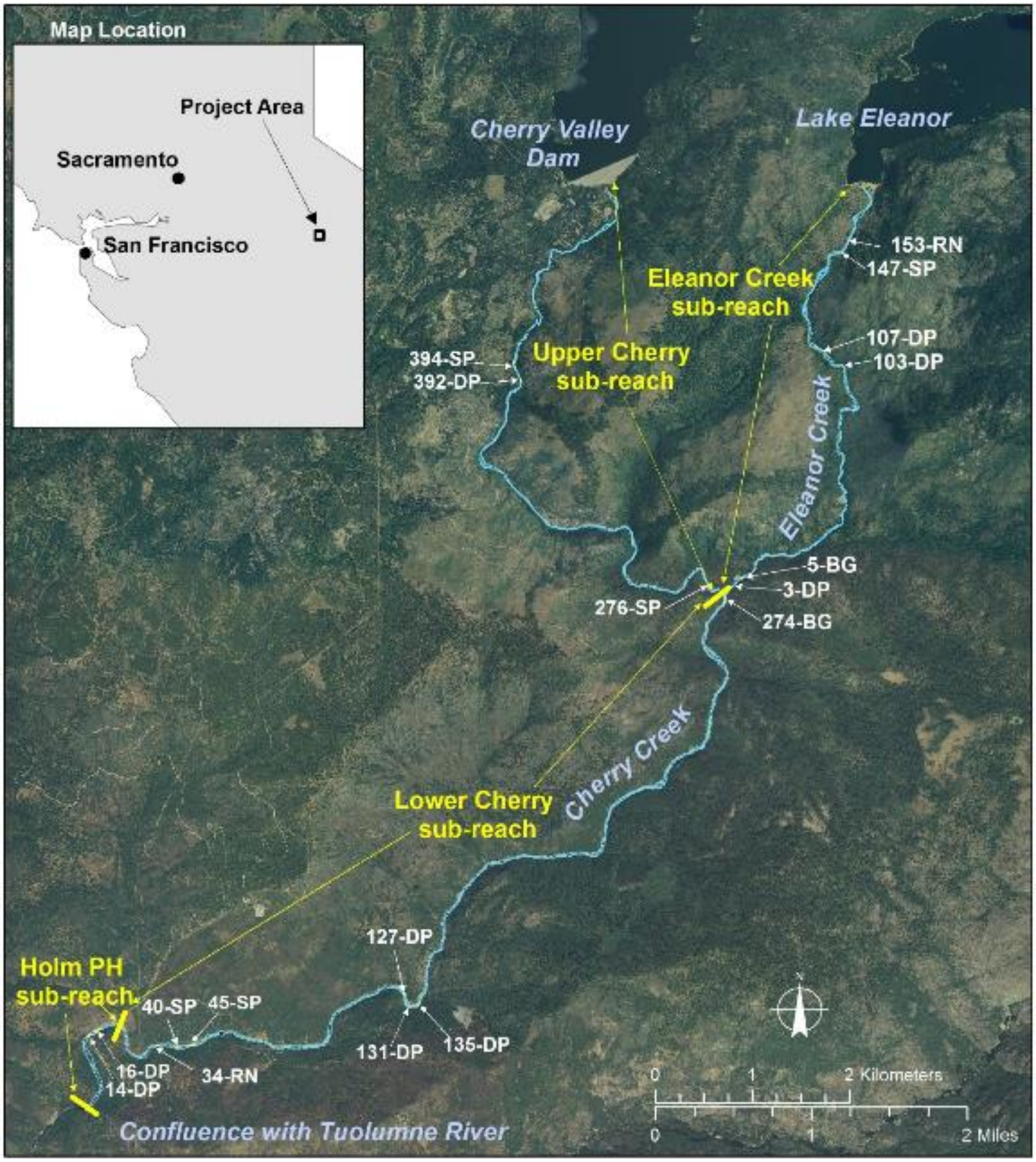

Figure 4. Fish population monitoring site locations surveyed in Cherry Creek and Eleanor Creek reaches in 2018.

Table 5. Fish population monitoring sites in the Cherry Creek and Eleanor Creek reaches.

Site ID[1]	Habitat type[1]	Stationing[2]		Surveyed length (feet)
		Downstream	Upstream	
Upper Cherry sub-reach				
394-SP[3]	shallow pool	547+90	550+55	265
392-DP	deep pool	543+17	545+36	219
276-SP[3]	shallow pool	383+45	384+03	58
Lower Cherry sub-reach				
274-BG[3]	boulder garden	379+72	382+05	233
135-DP	deep pool	169+12	170+72	160
131-DP[3]	deep pool	165+83	167+32	149
127-DP	deep pool	160+00	161+45	145
45-SP	shallow pool	72+36	75+07	271
40-SP[3]	shallow pool	67+70	69+51	181
34-RN	run	61+06	62+17	111
Holm Powerhouse sub-reach				
16-DP	deep pool	30+93	33+16	223
14-DP	deep pool	27+78	29+30	152
Eleanor Creek Reach				
153-RN	run	172+07	172+70	63
147-SP	shallow pool	167+27	168+37	110
107-DP	deep pool	123+35	124+32	97
103-DP	deep pool	113+96	114+85	89
5-BG	boulder garden	8+92	10+29	137
3-DP	deep pool	5+58	6+51	93

1 Monitoring site numbers refer to sequential habitat unit numbers from the Tuolumne River confluence to Valley Dam.
2 Stationing is based on the GIS center line for Cherry Creek from the Tuolumne River confluence (RM 0) upstream of Valley Dam (RM 11).
3 Monitoring sites surveyed in 2012.

Table 6. Percent length of sub-reaches surveyed by habitat type in the Cherry Creek and Eleanor Creek reaches.

Sub-reach	Sub-reach length surveyed by habitat type (percent length)				Total sub-reach length surveyed (percent length)[1]
	Deep pool	Shallow pool	Boulder garden	Run	
Upper Cherry	5	7	0	0	2
Lower Cherry	5	10	2	7	4
Holm Powerhouse	39	n/a	n/a	n/a	10
Eleanor Creek	6	9	3	5	3

1 Excludes islands, medial bars, and sand filled pools (<1 percent in Cherry Creek).
n/a Habitat type not present in sub-reach

Table 7. Percent length of habitat types in the Cherry Creek Reach. Excludes islands, medial bars, and sand-filled pools (<1 percent in Cherry Creek).

Sub-reach	Habitat type (percent length)										
	Cascade	Chute	Deep pool[1]	Shallow pool[1]	Glide/pool tail	Run[1]	Boulder garden[1]	High-gradient riffle	Low-gradient riffle	Side channel	Backwater
Upper Cherry	2	8	16	19	3	7	29	8	5	3	1
Lower Cherry	10	3	27	13	1	4	33	8	0	0	1
Holm Powerhouse	13	0	27	0	0	0	0	53	7	0	0
Eleanor Creek	9	0	23	6	7	25	16	11	3	0	9

[1] Habitat types selected for monitoring in Cherry Creek.

3.3 Length and Age

Length-frequency data were used to determine a length threshold for differentiating between age-0 and age-1 and older trout in the Hetch Hetchy, Above Hetch Hetchy Reservoir, Cherry Creek, and Eleanor Creek reaches to inform the interpretation of results. Differentiating between these two age classes improves the ability to understand how habitat conditions (e.g., flow and water temperature) influence trout populations in the monitoring reaches, since different environmental pressures influence trout abundance and survival for these age classes.

Length-frequency distributions can be used to estimate age groups for Rainbow Trout and Brown Trout by identifying age-specific length thresholds based on the relative abundance of different length classes. Since species-specific spawning and emergence occur annually over a relatively short period (2 to 3 months), there is a temporal gap between year classes of the same species that translates to differences in length frequency between age classes. Thereby, troughs in length-frequency distributions can be used as cut-off points or length thresholds between age groups. This is particularly effective for differentiating between age-0 and age-1 trout of the same species for a given location. Length-frequency distributions in past annual Upper Tuolumne River Ecosystem Program (UTREP) fisheries monitoring reports identified a length threshold of 125 millimeters (mm) to differentiate between age-0 and age-1 Rainbow and Brown Trout since 2014. Results from annual monitoring include reporting length-frequency distributions to check that continuing to use the 125-mm threshold for differentiating between age-0 and age-1 trout remains reasonable, while understanding that environmental conditions vary annually and results may deviate from this rule periodically. This check also serves to identify whether there is a fundamental shift in length-at-age that requires consideration of how annual monitoring results are reported.

3.4 Population Estimates

Abundance and linear density were estimated to assess trout populations at the habitat unit, sub-reach, and reach scales, and to evaluate changes and trends in populations over time. To assess whether potentially meaningful changes or trends in trout population abundance are evident, comparisons of trout density were evaluated at the sub-reach scale based on 2014–2018 monitoring data. Two-sample t-tests were used to assess whether differences in abundance are statistically significant at a p-value ≤0.05. Site 38-DP was not included in the year-to-year comparisons presented in this section, since it was only surveyed in 2016 and likely will not be monitored in the future.

The three-pass snorkel survey method (Routledge 1982) was used to estimate trout population abundance in all reaches and years except on Cherry and Eleanor creeks in 2012. Fewer than three passes were performed at some sites when sampling time was limited. The standardization of snorkel survey methods across reaches and years allows for comparable results and trend assessments. Employing multi-pass snorkel methods allows for variance to be estimated and CI to be calculated, which improves the ability to determine whether changes to trout populations over time are meaningful.

The three-pass method allows abundance estimates and CI to be computed using a bounded counts estimator (Routledge 1982). This method assumes that each trout is observable, that there is a reasonable chance of seeing all trout during a single pass, and that no trout are counted twice during a single pass. There are various ways of deriving the estimator. For this application, the following formula was used:

$$\tilde{y}_B = d_{[m]} + (d_{[m]} - d_{[m-1]})$$

where $d_{[m]}$ is the maximum number of trout counted during any of the passes, and $d_{[m-1]}$ is the second highest count; counts are arranged in ascending order as:

$$d_{[1]} \leq d_{[2]} \leq d_{[3]} \leq \cdots \leq d_{[m-1]} \leq d_{[m]}.$$

The bounded-counts estimate of the mean squared error is estimated as in Robson and Whitlock (1964) as:

$$\widehat{\mathrm{MSE}} = \left(d_{[m]} - d_{[m-1]}\right)^2$$

This was used as a surrogate for the square of the standard error (SE), for reporting population estimates in the form “Estimate (±SE)” and calculating nominal CI as “Estimate 1.96 × SE”.

Abundance estimates were used to calculate linear trout density (i.e., fish/1,000 feet) to normalize for length and allow comparisons of abundance between individual monitoring sites and reaches. Linear density was calculated for each monitoring site by dividing site abundance by site length (resulting in trout abundance per foot of stream), and then multiplying by 1,000 to calculate linear trout density (fish/1,000 feet) for the site. A weighted mean was used for calculating linear density at the reach level.

3.5 Streamflow and Water Temperature

Streamflow and water temperature at gages in each of the monitoring reaches provide information on habitat conditions and their influence on trout populations in the monitoring reaches.

4 RESULTS AND DISCUSSION

4.1 Length and Age

4.1.1 Hetch Hetchy Reach

The length-frequency distributions for Rainbow Trout and Brown Trout in 2018 are consistent with those observed during 2014–2017 with regard to differentiating between age-0 and age-1 and older trout. The 2018 length-frequency distributions indicate a greater number of Rainbow Trout and Brown Trout ≤125 mm compared with 2017, suggesting relatively higher age-0 recruitment for both species in 2018 (Figure 5). For Rainbow Trout >125 mm, the length-frequency distribution pattern in 2018 suggests a threshold of 225 to 250 mm for differentiating between age-1 and age-2 and older trout. In addition, the relative frequency of Rainbow Trout >300 mm was greater in 2016–2018 compared with 2014–2015. For Brown Trout >125 mm, the length-frequency distribution pattern in 2018 is difficult to interpret due to low overall observation frequency, but it is not inconsistent with data from previous years.

The 2018 length-frequency distributions suggest that age-1 and older Rainbow Trout and Brown Trout were mostly >150 mm (Figure 5). Age-0 Brown Trout are expected to be slightly larger than Rainbow Trout at the same time of year because Brown Trout typically spawn in the fall and emerge earlier than Rainbow Trout, which spawn in the spring. Therefore, compared with Rainbow Trout, Brown Trout have additional opportunities to feed and grow as water temperatures warm throughout the spring and early summer. In addition, larger age-0 juveniles can have a competitive advantage over smaller ones. By age-1, length differences between the trout species may or may not be evident due to variable growth rates and strongly overlapping length distributions. Furthermore, field observations of trout lengths were recorded using 25-mm length categories. Therefore, minor differences in length frequency between the two species may not be apparent in length-frequency distributions.

Variability in the length-frequency distributions for Rainbow Trout and Brown Trout between 2014 and 2018 are likely the result of variable environmental conditions (e.g., flow and water temperature) and their influence on spawning, juvenile survival, and growth. It is common for length distributions to overlap between age classes because trout emerge at different times and grow at different rates based on competition and environmental conditions. Based on 2014–2018 length-frequency distributions, the length threshold between age-0 and age-1 trout appears to vary between about 125 and 175 mm, depending on the species and year (Figure 5).

For results presented in this document, the 125-mm threshold was used to differentiate between age-0 and age-1 and older trout, for the following reasons:

1. Length-frequency distribution patterns were generally consistent during 2014–2018 with regard to differentiating between age-0 and age-1 and older trout based on apparent length thresholds and considering the use of 25-mm length categories;
2. Using the 125-mm length threshold is consistent with previous annual fisheries monitoring reports (e.g., Stillwater Sciences 2016, Stillwater Sciences and McBain Associates 2017, Stillwater Sciences and McBain Associates 2019).
3. There is potential for environmental stochasticity to affect individual growth rates and length-frequency data; therefore, minor annual variations are expected and would not necessarily warrant using a different length threshold.

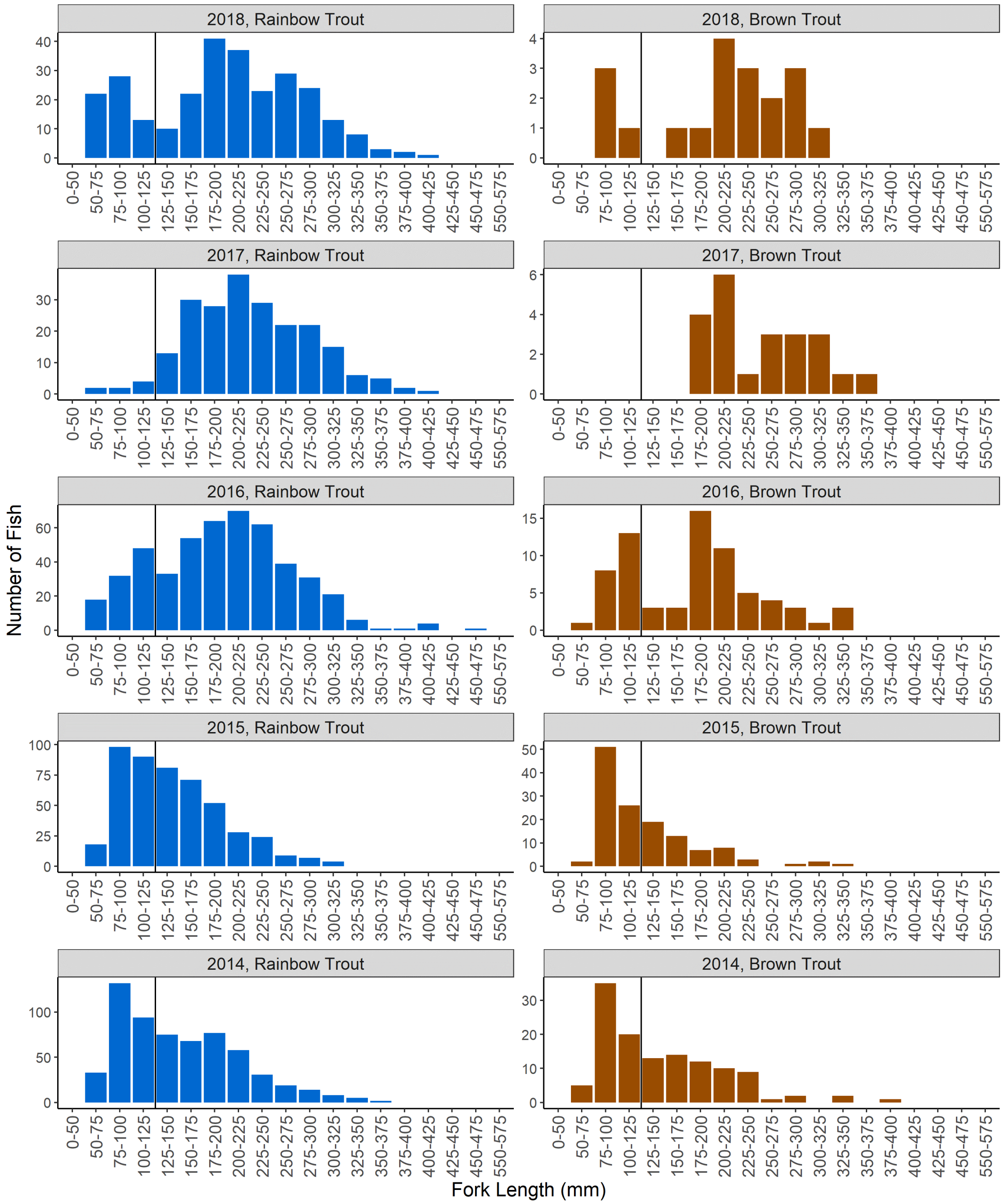

Figure 5. Length-frequency distributions of Rainbow Trout and Brown Trout observed at monitoring sites in the Hetch Hetchy Reach for monitoring years 2014-2018 (first pass only). The vertical black line indicates the 125-mm size threshold used to differentiate between age-0 and age-1 and older trout. Note that the y-axis scale is optimized for viewing the detail of each data set.

4.1.2 Above Hetch Hetchy Reservoir Reach

Sample sizes of trout length observations in the Above Hetch Hetchy Reservoir Reach were too small to develop meaningful length-frequency distributions to assess trout length-at-age specific to this reach.

4.1.3 Cherry Creek and Eleanor Creek Reaches

During snorkel survey efforts in Cherry Creek in 2018, both Rainbow Trout and Brown Trout were observed, unlike during surveys in 2012 and 2016 when only Rainbow Trout were seen. Due to the limited occurrence of Brown Trout in Cherry Creek and the absence of Brown Trout observations in Eleanor Creek, length-frequency distributions were only developed for Rainbow Trout. Length-frequency data for 2018 in the Cherry Creek and Eleanor Creek reaches indicate that 125 mm is a reasonable length threshold for differentiating between age-0 and age-1 and older Rainbow Trout (Figure 6). Length-frequency for 2018 was generally consistent with previous years (i.e., 2012, 2016, and 2017). The 125-mm length threshold for differentiating between age-0 and age-1 and older trout is also generally consistent with length-frequency data for Rainbow Trout in the Hetch Hetchy Reach during 2014–2018.

Length-frequency data for 2018 generally show similar distribution patterns to previous years, with at least moderate recruitment of age-0 trout ≤125 mm (similar to 2016) and most age-1 trout in the 125- to 225-mm size range. A similar distribution of larger trout in the 225-to-300-mm and >300-mm size ranges was observed in 2018 compared with 2017, which coincided with the 2017 addition of the Holm Powerhouse sub-reach, where numerous large trout were observed. In 2018, the relative abundance of Rainbow Trout <50 mm was higher than in 2016 and 2017 but lower than in 2012, and the relative abundance of Rainbow Trout 50 to 75 mm was low compared with the other years. Annual variability in relative abundance of trout <75 mm is likely explained by spawning timing and growth, which is influenced by flow and water temperature (see Sections 5.3.3 and 5.4.3) in addition to survey timing.

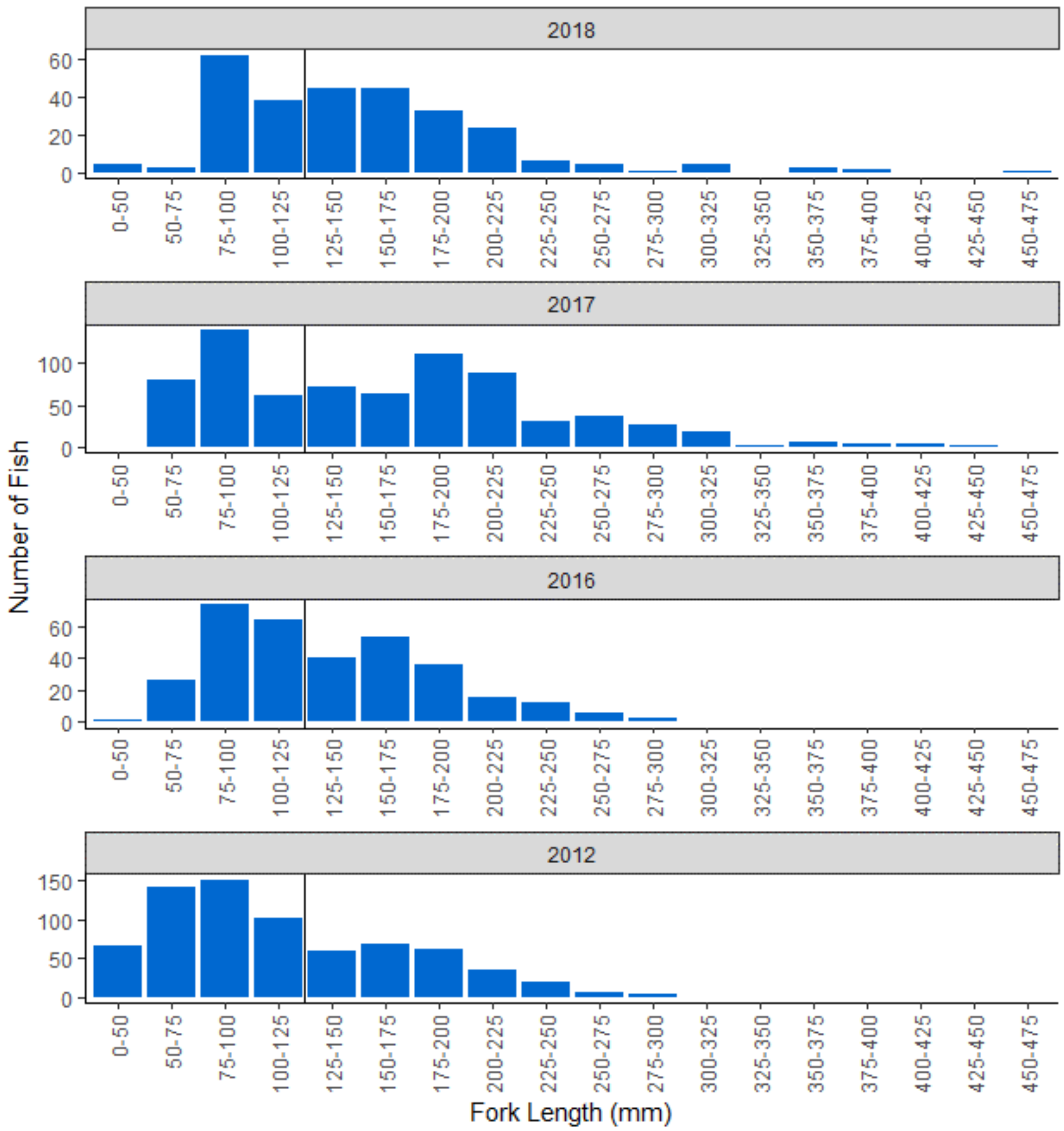

Figure 6. Length-frequency distributions of Rainbow Trout observed at monitoring sites in the Cherry Creek and Eleanor Creek reaches for monitoring years 2012 and 2016–2018 (first pass only). The line indicates the approximate threshold between age-0 and age-1 and older trout. Note that the y-axis scale is optimized for viewing the detail of each data set. Only the Cherry Creek Reach was surveyed in 2016.

4.2 Abundance and Linear Density Estimates

Age-0 trout (≤125 mm total length) abundance commonly fluctuates from year to year based on spawning and incubation success as well as environmental conditions (e.g., flows) soon after emergence. These annual fluctuations in age-0 abundance can reduce the ability to detect meaningful trends in trout populations when considered in combination with age-1 and older trout (>125 mm total length). However, age-0 trout abundance can be a useful indication of potential recruitment to older age classes and can aid in understanding how environmental conditions affect year class success. Age-1 and older trout abundance provides a meaningful metric for assessing population abundance and trends because these trout have demonstrated their ability to survive through at least one summer and winter and are more likely to contribute to the adult population and reproduce compared with age-0 trout. Therefore, annual trout population abundance results are presented separately for age-0 and age-1 and older trout.

To reduce repetition in the presentation of results and overall document length, abundance results are presented in tabular format and linear density results are presented in figures. This streamlining measure causes descriptions of results to include linear density values that are not presented in corresponding tables.

4.2.1 Hetch Hetchy Reach

4.2.1.1 2018 monitoring

Trout >125 mm

The 2018 fish population monitoring results for trout abundance, relative abundance, and density are presented below for trout >125 mm (Tables 8–10, Figures 7–9). Total abundance estimates for all sites combined were 262, 35, and 290 for Rainbow Trout, Brown Trout, and all trout, respectively (Tables 9 and 10). Note that estimates for "all trout" include unidentified trout that are not included in the species-specific estimates. Rainbow Trout were more abundant than Brown Trout within each site, sub-reach, and habitat type. The ratio of Rainbow Trout to Brown Trout was 7.5:1 for all sites combined and ranged from 4.4:1 for the O'Shaughnessy sub-reach to 12.1:1 for the Early Intake sub-reach. No Brown Trout >125 mm were observed at three of the sixteen sites (11-SP, 44-PW, and 267-SP).

Rainbow Trout density in the Early Intake, Preston Falls, and O'Shaughnessy sub-reaches was 98, 73, and 71 fish/1,000 feet, respectively (Figure 7). Rainbow Trout density by habitat type was greatest in pocketwaters (92 fish/1,000 feet), followed by shallow pools (82 fish/1,000 feet), and deep pools (77 fish/1,000 feet) (Figure 7). Brown Trout densities by sub-reach ranged from 8 fish/1,000 feet in the Early Intake sub-reach to 16 fish/1,000 feet in the O'Shaughnessy sub-reach (Figure 8). Brown Trout density by habitat type was greatest in pocketwaters (15 fish/1,000 feet), followed by deep pools (12 fish/1,000 feet) and shallow pools (6 fish/1,000 feet) (Figure 8). Since Rainbow Trout density was substantially greater than Brown Trout density, density patterns for "all trout" generally follow those for Rainbow Trout (Figures 7 and 9). Density estimates for all trout >125 mm ranged from 20 fish/1,000 feet at site 74-DP to 180 fish/1,000 feet at site 37-PW (Figure 9).

Table 8. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by site in the Hetch Hetchy Reach in 2018 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow Trout	**Brown Trout**	**All trout[1]**
Early Intake sub-reach				
11-SP	shallow pool	20 (±2)	0 (±0)	20 (±2)
13-DP	deep pool	28 (±2)	2 (±2)	28 (±2)
18-PW	pocketwater	8 (±2)	2 (±2)	12 (±6)
27-SP	shallow pool	24 (±2)	2 (±2)	26 (±4)
34-DP	deep pool	20 (±4)	2 (±2)	24 (±8)
37-PW	pocketwater	21 (±8)	2 (±0)	24 (±10)
Preston Falls sub-reach				
44-PW	pocketwater	12 (±2)	0 (±0)	12 (±2)
46-DP	deep pool	19 (±0)	2 (±2)	21 (±2)
49-SP	shallow pool	3 (±2)	2 (±2)	4 (±2)
56-DP	deep pool	19 (±0)	3 (±2)	23 (±4)
74-DP	deep pool	5 (±0)	2 (±2)	5 (±0)
76-SP	shallow pool	22 (±2)	2 (±2)	24 (±4)
O'Shaughnessy sub-reach				
223-DP	deep pool	19 (±2)	4 (±2)	21 (±2)
227-PW	deep pool	5 (±0)	3 (±2)	8 (±0)
229-SP	pocketwater	25 (±4)	7 (±6)	26 (±2)
267-SP	shallow pool	12 (±6)	0 (±0)	12 (±6)

1 Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

Table 9. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by sub-reach in the Hetch Hetchy Reach in 2018 (95 percent CI).

Sub-reach	Trout >125 mm (age-1 and older)		
	Rainbow Trout	**Brown Trout**	**All trout[1]**
Early Intake	121 (±10)	10 (±4)	134 (±15)
Preston Falls	80 (±3)	11 (±4)	89 (±7)
O'Shaughnessy	61 (±7)	14 (±7)	67 (±7)
Total	**262 (±13)**	**35 (±9)**	**290 (±17)**

1 Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

Table 10. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by habitat type in the Hetch Hetchy Reach in 2018 (95 percent CI).

Habitat type	Trout >125 mm (age-1 and older)		
	Rainbow Trout	**Brown Trout**	**All trout[1]**
Shallow pool	81 (±7)	6 (±3)	86 (±9)
Deep pool	115 (±5)	18 (±5)	130 (±9)
Pocketwater	66 (±9)	11 (±6)	74 (±12)
Total	**262 (±13)**	**35 (±9)**	**290 (±17)**

[1] Note that estimates for "all trout" include observations of unidentified trout.

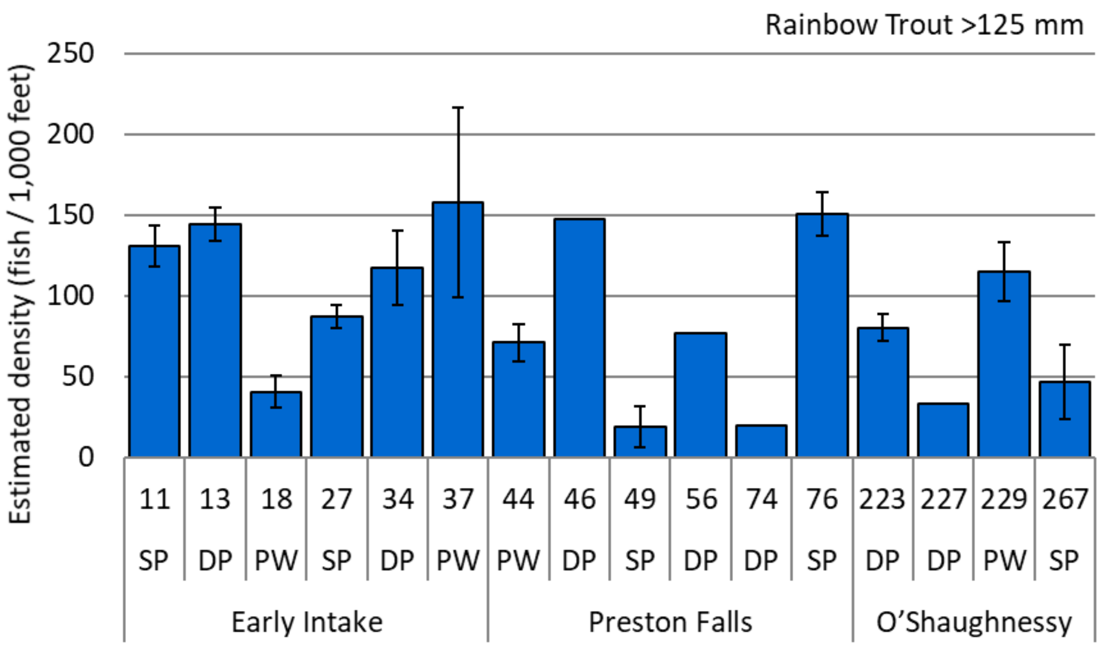

Figure 7. Estimated linear density of Rainbow Trout >125 mm by site in the Hetch Hetchy Reach in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

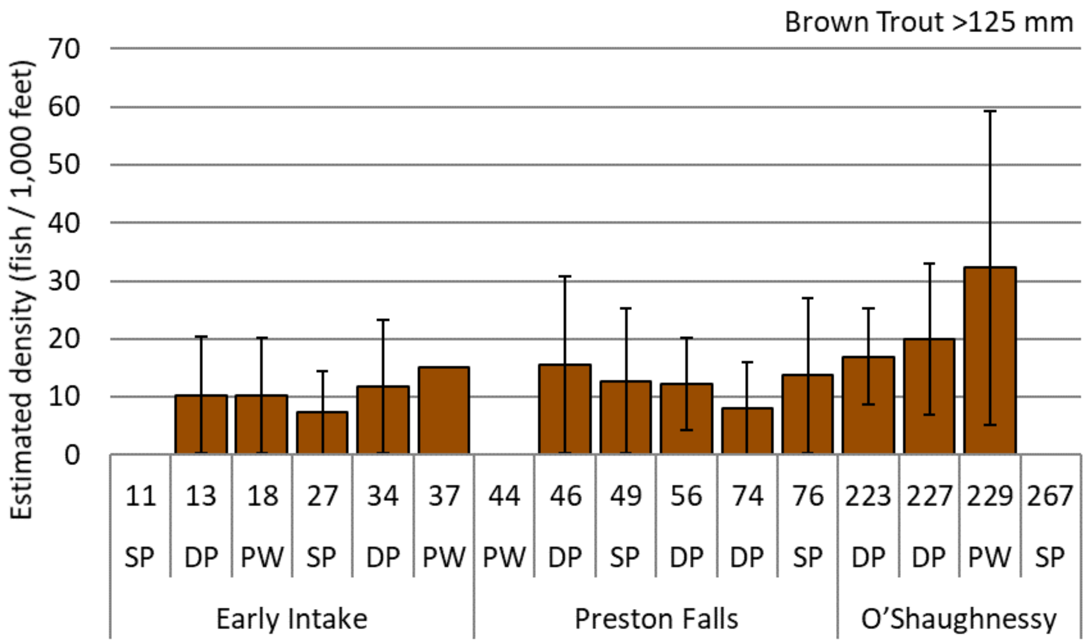

Figure 8. Estimated linear density of Brown Trout >125 mm by site in the Hetch Hetchy Reach in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

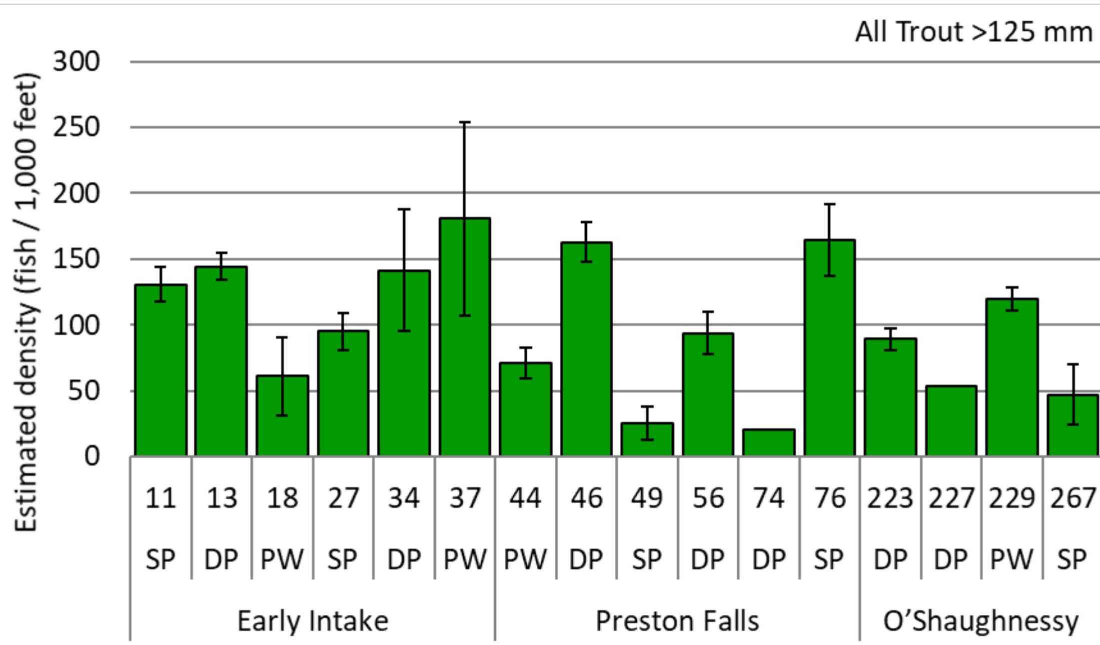

Figure 9. Estimated linear density of all trout >125 mm by site in the Hetch Hetchy Reach in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

Trout ≤125 mm

As described in Section 5.1, trout ≤125 mm are primarily comprised of trout in their first year of life (age-0) and provide an indication of spawning success and age-0 recruitment. The 2018 fish population monitoring results for trout abundance, relative abundance, and density are presented below for trout ≤125 mm (Tables 11–13, Figures 10–12). The 2018 fish population monitoring results for Rainbow Trout ≤125 mm indicate that age-0 trout abundance was relatively low overall in 2018, with estimated abundance ranging from 1 at site 46-DP to 16 at site 37-PW (Table 11). Rainbow Trout ≤125 mm were observed at all monitoring sites. Brown Trout ≤125 mm were observed at 8 of the 16 monitoring sites in the Hetch Hetchy Reach in 2018 (Table 11). Abundance of Brown Trout ≤125 mm was relatively low overall in 2018, with estimated abundance ranging from 1 at sites 27-SP and 74-DP to 5 at site 34-DP (Table 11).

Estimated densities of Rainbow Trout ≤125 mm ranged from 8 fish/1,000 feet at site 46-DP to 120 fish/1,000 feet at site 37-PW (Figure 10). The density of Rainbow Trout ≤125 mm was greatest in the Early Intake sub-reach (50 fish/1,000 feet) and least in the O'Shaughnessy sub-reach (27 fish/1,000 feet) (Figure 10). Estimated densities of Brown Trout ≤125 mm were relatively low and ranged from 0 fish/1,000 feet at six sites to 30 fish/1,000 feet at site 37-PW (Figure 11). Calculated confidence intervals (CI) are relatively wide for abundance and density estimates of Brown Trout ≤125 mm due to the low sample size and high variation between snorkel passes in 2018 (Table 13, Figure 11). The highest density of both Rainbow Trout and Brown Trout ≤125 mm by habitat type was found in pocketwater habitats (Figures 10 and 11).

Table 11. Abundance estimates for Rainbow Trout and Brown Trout ≤125 mm by site in the Hetch Hetchy Reach in 2018 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-0)		
		Rainbow Trout	Brown Trout	All trout [1]
Early Intake sub-reach				
11-SP	shallow pool	7 (±0)	0 (±0)	7 (±0)
13-DP	deep pool	5 (±2)	0 (±0)	5 (±2)
18-PW	pocketwater	14 (±6)	4 (±4)	22 (±12)
27-SP	shallow pool	6 (±4)	1 (±0)	9 (±6)
34-DP	deep pool	14 (±8)	5 (±4)	12 (±2)
37-PW	pocketwater	16 (±2)	4 (±4)	22 (±6)
Preston Falls sub-reach				
44-PW	pocketwater	12 (±4)	0 (±0)	11 (±2)
46-DP	deep pool	1 (±0)	0 (±0)	1 (±0)
49-SP	shallow pool	10 (±4)	0 (±0)	10 (±4)
56-DP	deep pool	14 (±8)	4 (±4)	12 (±4)
74-DP	deep pool	10 (±8)	1 (±0)	18 (±16)
76-SP	shallow pool	6 (±2)	0 (±0)	6 (±2)
O'Shaughnessy sub-reach				
223-DP	deep pool	5 (±4)	2 (±2)	4 (±2)
227-DP	deep pool	2 (±2)	0 (±0)	2 (±2)
229-PW	pocketwater	9 (±2)	2 (±2)	13 (±6)
267-SP	shallow pool	7 (±6)	0 (±0)	11 (±10)

[1] Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

Table 12. Abundance estimates for Rainbow Trout and Brown Trout ≤125 mm by sub-reach in the Hetch Hetchy Reach in 2018 (95 percent CI).

Sub-reach	Trout ≤125 mm (age-0)		
	Rainbow Trout	Brown Trout	All trout[1]
Early Intake	62 (±11)	14 (±7)	77 (±15)
Preston Falls	53 (±13)	5 (±4)	58 (±17)
O'Shaughnessy	23 (±8)	4 (±3)	30 (±12)
Total	**138 (±18)**	**23 (±8)**	**165 (±25)**

[1] Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

Table 13. Abundance estimates for Rainbow Trout and Brown Trout ≤125 mm by habitat type in the Hetch Hetchy Reach in 2018 (95 percent CI).

Habitat type	Trout ≤125 mm (age-0)		
	Rainbow Trout	**Brown Trout**	**All trout[1]**
Shallow pool	36 (±8)	1 (±0)	43 (±12)
Deep pool	51 (±14)	12 (±6)	54 (±17)
Pocketwater	51 (±8)	10 (±6)	68 (±15)
Total	**138 (±18)**	**23 (±8)**	**165 (±25)**

[1] Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

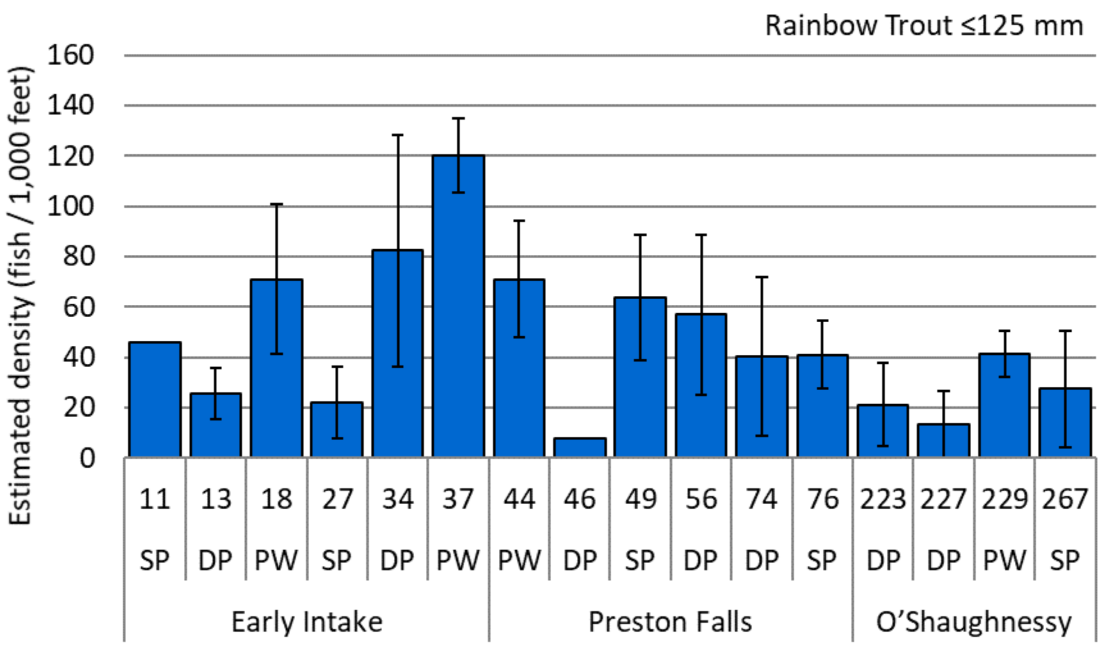

Figure 10. Estimated linear density of Rainbow Trout ≤125 mm by site in the Hetchy Reach in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

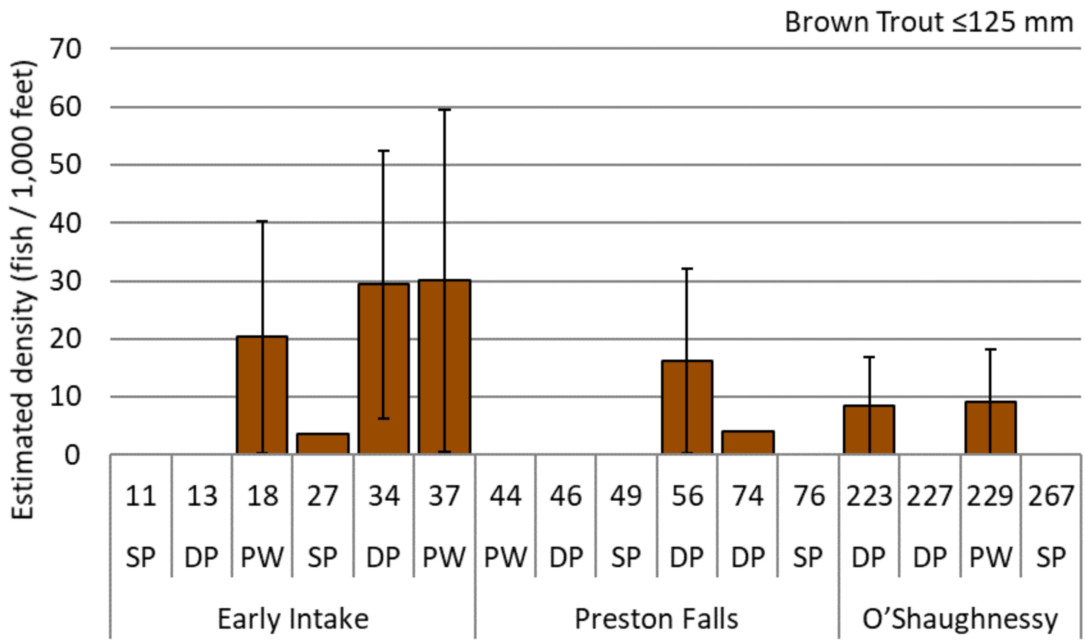

Figure 11. Estimated linear density of Brown Trout ≤125 mm by site in the Hetch Hetchy Reach in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

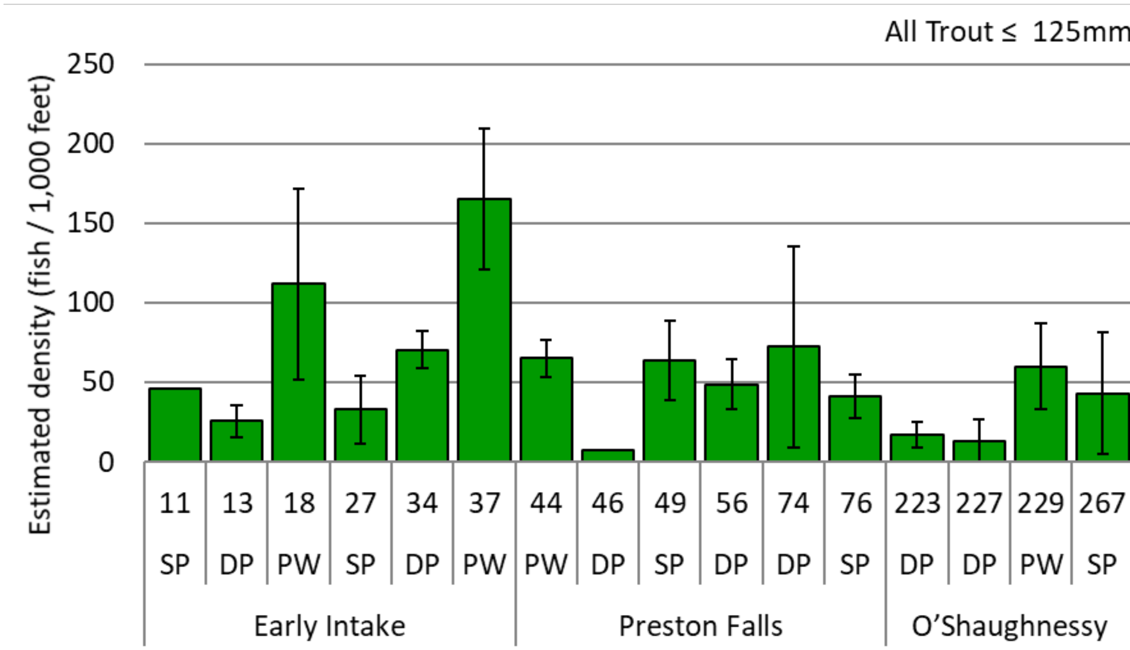

Figure 12. Estimated linear density of all trout ≤125 mm by site in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, PW = pocketwater.)

4.2.1.2 Reach-level comparisons of 2014-2018 monitoring results in the Hetch Hetchy Reach

Trout >125 mm

Rainbow Trout densities in the Early Intake and O'Shaughnessy sub-reaches generally show similar patterns over the 2014–2018 monitoring period, with lowest densities in 2015 and highest densities in 2016 (Figure 13). In 2018, Rainbow Trout densities in the Early Intake and O'Shaughnessy sub-reaches were the second lowest observed during the previous four years (2014–2017). Rainbow Trout density in the Preston Falls sub-reach generally shows a declining trend from 2014 to 2018. In 2014 and 2015, Rainbow Trout density was significantly higher in the Preston Falls sub-reach compared with the other sub-reaches and years (i.e., 2016–2018). Total Rainbow Trout densities for all sub-reaches show a declining trend over the 2014–2018 monitoring period, with the highest total density in 2014 and lowest total density in 2018 (Figure 13).

In 2018, Brown Trout densities in the Early Intake and Preston Falls sub-reaches were the lowest observed during the 2014–2018 monitoring period while density in the O'Shaughnessy sub-reach was the highest observed during this period (Figure 13). The lowest densities for Brown Trout in the O'Shaughnessy sub-reach occurred in 2015. Brown Trout densities in the O'Shaughnessy sub-reach were consistently relatively low (<20 fish/1,000 feet) during 2014–2018. In contrast, Brown Trout density in the Preston Falls sub-reach was relatively high during 2014–2016, with the highest density in 2015 at 84 fish/1,000 feet, which was the highest Brown Trout density observed for a sub-reach during the 2014–2018 monitoring period. Total Brown Trout densities show a similar pattern to the Preston Falls sub-reach, with the highest density in 2015 and declining densities from 2014 through 2018.

Densities for all trout generally show similar patterns to those for Rainbow Trout, with similar relationships in the Early Intake and O'Shaughnessy sub-reaches and a declining trend over the five-year monitoring period for the Preston Falls sub-reach (Figure 14).

T-tests were conducted to compare average densities between years within sub-reaches. Results indicate numerous year-to-year differences that are statistically significant (Table 14) and suggest that trout populations are highly variable annually. Statistically significant differences between years were greatest in the Preston Falls sub-reach. The extent to which differences in abundance may be influenced by differences in annual flow conditions (e.g., magnitude, timing, duration), summer water temperature, and recovery from the Rim Fire has not been evaluated.

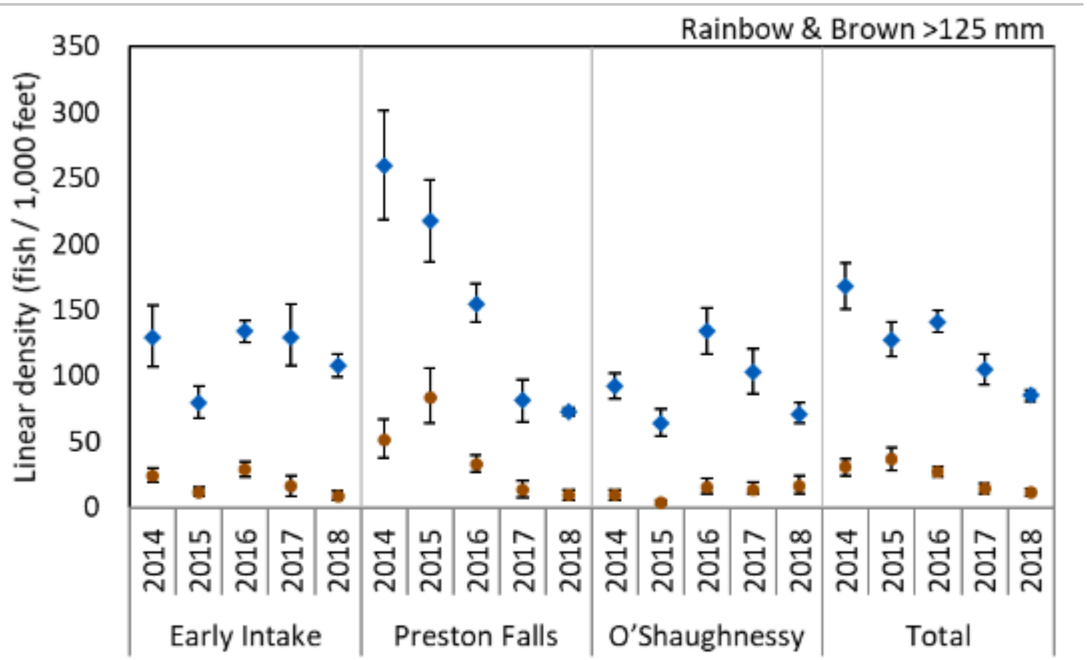

Figure 13. Estimated linear density of Rainbow Trout (blue diamonds) and Brown Trout (brown circles) >125 mm by sub-reach in the Hetch Hetchy Reach for monitoring years 2014–2018. (Error bars indicate 95 percent CI.)

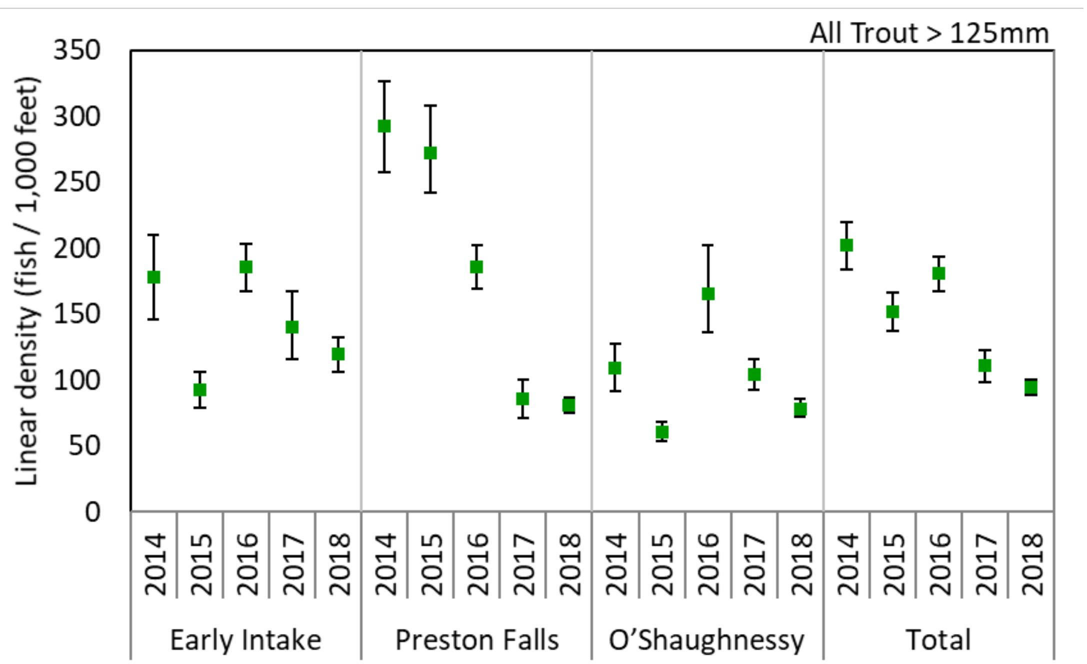

Figure 14. Estimated linear density of all >125 mm by sub-reach in the Hetch Hetchy Reach for monitoring years 2014–2018. (Error bars indicate 95 percent CI.)

Table 14. T-test results (p-values) comparing average density estimates by sub-reach for Rainbow Trout, Brown Trout, and all trout >125 mm during 2014–2018. Significant values (p-value ≤0.05) are identified with bold text.

Sub-reach	Comparison	Rainbow Trout	Brown Trout	All trout
Early Intake	2014 vs. 2015	**0.0077**	**0.0037**	**0.0030**
	2014 vs. 2016	**0.027**	0.13	**0.038**
	2014 vs. 2017	0.93	0.11	0.13
	2014 vs. 2018	**0.044**	**<0.001**	**0.0069**
	2015 vs. 2016	0.12	0.052	**0.0085**
	2015 vs. 2017	**0.0094**	0.33	**0.017**
	2015 vs. 2018	**0.044**	0.25	0.13
	2016 vs. 2017	**0.031**	0.61	0.52
	2016 vs. 2018	0.42	**0.0069**	0.068
	2017 vs. 2018	**0.057**	0.11	0.071
Preston Falls	2014 vs. 2015	0.15	0.053	0.44
	2014 vs. 2016	**0.0034**	0.080	**<0.001**
	2014 vs. 2017	**<0.001**	**0.0050**	**<0.001**
	2014 vs. 2018	**<0.001**	**0.0042**	**<0.001**
	2015 vs. 2016	**0.0092**	**0.0084**	**0.0035**
	2015 vs. 2017	**<0.001**	**0.0021**	**<0.001**
	2015 vs. 2018	**<0.001**	**0.0015**	**<0.001**
	2016 vs. 2017	**<0.001**	**0.0022**	**<0.001**
	2016 vs. 2018	**<0.001**	**<0.001**	**<0.001**
	2017 vs. 2018	0.37	0.39	0.59
O'Shaughnessy	2014 vs. 2015	**0.013**	0.070	**0.0088**
	2014 vs. 2016	**0.018**	0.18	0.055
	2014 vs. 2017	0.36	0.27	0.66
	2014 vs. 2018	**0.028**	0.21	0.055
	2015 vs. 2016	**0.0029**	**0.040**	**0.012**
	2015 vs. 2017	**0.021**	**0.024**	**0.0023**
	2015 vs. 2018	0.35	0.054	**0.026**
	2016 vs. 2017	**0.062**	0.69	0.053
	2016 vs. 2018	**0.0037**	0.91	**0.020**
	2017 vs. 2018	**0.035**	0.64	**0.026**
Total	2014 vs. 2015	**0.0012**	0.29	**<0.001**
	2014 vs. 2016	**<0.001**	**0.049**	**<0.001**
	2014 vs. 2017	**<0.001**	**<0.001**	**<0.001**
	2014 vs. 2018	**<0.001**	**<0.001**	**<0.001**
	2015 vs. 2016	0.73	**0.010**	0.49
	2015 vs. 2017	**0.019**	**<0.001**	**<0.001**
	2015 vs. 2018	**<0.001**	**<0.001**	**<0.001**
	2016 vs. 2017	**0.013**	**0.0032**	**<0.001**
	2016 vs. 2018	**<0.001**	**<0.001**	**<0.001**
	2017 vs. 2018	**0.0019**	0.15	**0.0062**

Trout ≤125 mm

The density of trout ≤125 mm provides insight into annual spawning success and recruitment of age-0 Rainbow Trout and Brown Trout. Within each sub-reach, densities of Rainbow Trout and Brown Trout ≤125 mm show similar patterns of year-to-year relative density over the five-year monitoring period (Figure 15), suggesting that Rainbow Trout and Brown Trout ≤125 mm are responding similarly to environmental pressures within each sub-reach. However, these patterns of relative density are different for each sub-reach, suggesting that there are important differences in habitat quality and/or quantity between the sub-reaches. Rainbow Trout and Brown Trout densities in the Early Intake sub-reach show a declining trend from 2014 to 2017 and rebound in 2018 to approximately 2016 levels. In the Preston Falls sub-reach, Rainbow Trout and Brown Trout densities were highest in 2015 and lowest in 2017. In 2014 and 2015, Rainbow Trout and Brown Trout densities in the Preston Falls sub-reach were significantly higher compared with densities in the Early Intake and O'Shaughnessy sub-reaches over the five-year monitoring period. Densities of trout ≤125 mm in the O'Shaughnessy sub-reach were highest in 2014 and lowest in 2017.

Total Rainbow Trout and Brown Trout densities in 2018 were the second lowest observed during 2014–2018, with the lowest densities for both species occurring in 2017. No Brown Trout ≤125 mm were observed in the Hetch Hetchy Reach during 2017. These results indicate improved recruitment of age-0 trout in 2018 compared with 2017. The primary factor contributing to low age-0 recruitment in 2017 was likely the effects of high flow conditions during Water Year (WY) 2017, which had relatively high flow conditions compared with the past decade (see Section 5.3.1) and the highest average annual discharge at Tuolumne River Above Early Intake gage for the period of record (1971–2018).

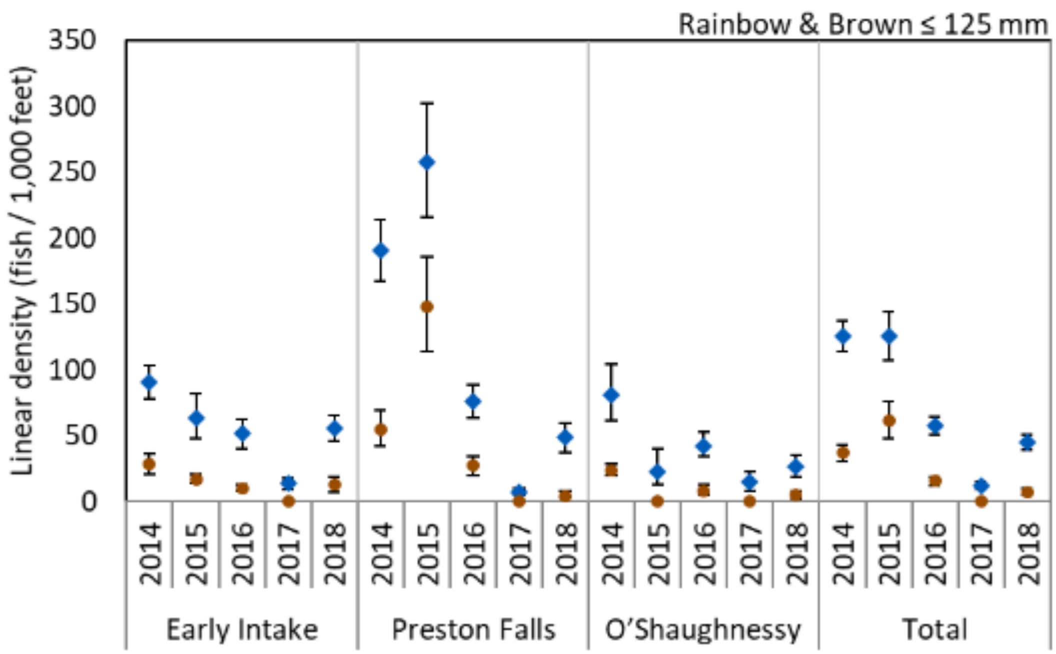

Figure 15. Estimated linear density of Rainbow Trout (blue diamonds) and Brown Trout (brown circles) ≤125 mm by sub-reach for monitoring years 2014–2018. (Error bars indicate 95 percent CI.)

4.2.2 Above Hetch Hetchy Reservoir Reach

4.2.2.1 2018 Monitoring

Trout >125 mm

For the Above Hetch Hetchy Reservoir Reach, abundance of Rainbow Trout >125 mm ranged from 0 trout at site 517-PW to 6 trout at site 518-DP (Table 15). No Brown Trout >125 mm were observed at the five monitoring sites sampled in the Above Hetch Hetchy Reservoir Reach during 2018. Rainbow Trout abundance was greatest in deep pool habitat and least in pocketwater habitat (Table 16). Site-specific densities of Rainbow Trout >125 mm ranged from 0 to 111 fish/1,000 feet and averaged 30 fish/1,000 feet (Figure 16).

Table 15. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by site in the Above Hetch Hetchy Reservoir Reach in 2018 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow Trout	**Brown Trout**	**All trout**
510-PW[1]	pocketwater	1	0	1
511-SP	shallow pool	3 (±0)	0 (±0)	3 (±0)
514-DP[1]	deep pool	1	0	1
517-PW[1]	pocketwater	0	0	0
518-DP[2]	deep pool	6	0	6

[1] Habitats sampled with two snorkel passes.
[2] Habitats sampled with one snorkel pass.

Table 16. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by habitat type in the Above Hetch Hetchy Reservoir Reach in 2018 (95 percent CI).

Habitat type	Trout >125 mm (age-1 and older)		
	Rainbow Trout	**Brown Trout**	**All trout**
Shallow pool	3 (±0)	0 (±0)	3 (±0)
Deep pool	7	0	7
Pocketwater	1	0	1
Total	**11**	**0**	**11**

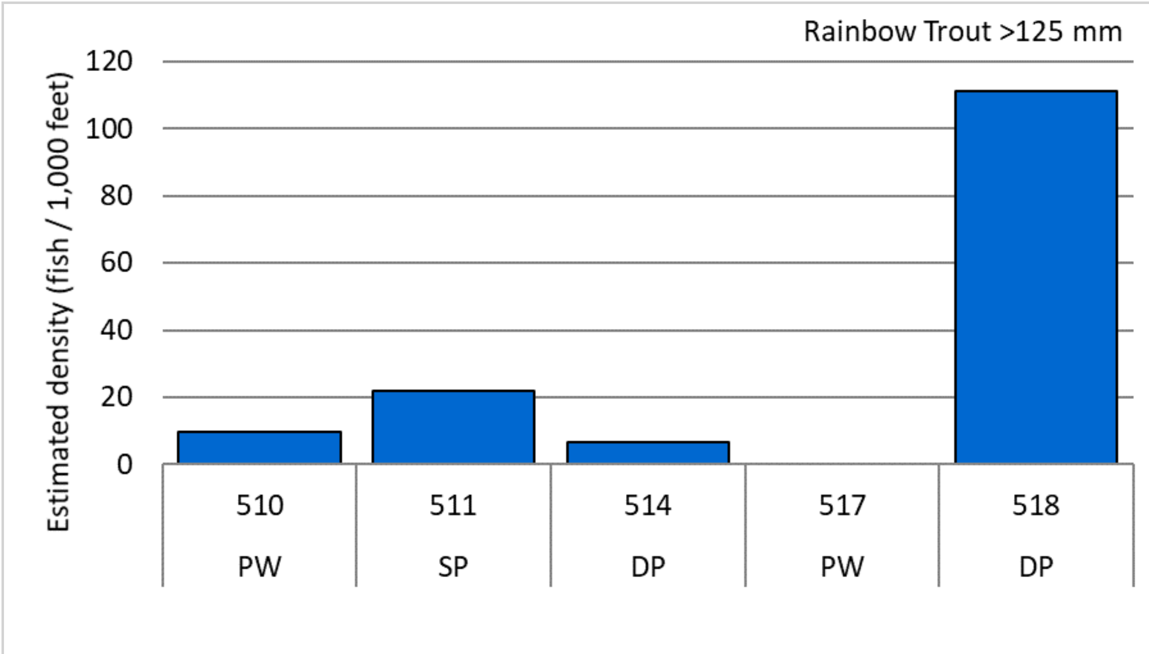

Figure 16. Estimated linear density of Rainbow Trout >125 mm by site in the Above Hetch Hetchy Reservoir Reach in 2018. (PW = pocketwater, SP = shallow pool, DP = deep pool.)

Trout ≤125 mm

For the Above Hetch Hetchy Reservoir Reach, abundance of Rainbow Trout ≤125 mm ranged from 0 trout at sites 514-DP and 517-PW to 11 trout at site 510-PW (Table 17). No Brown Trout ≤125 mm were observed at the five monitoring sites sampled in the Above Hetch Hetchy Reservoir Reach during 2018. Rainbow Trout abundance was greatest in pocketwater habitat and least in deep pool habitat (Table 18). The density of Rainbow Trout ≤125 mm ranged from 0 to 105 fish/1,000 feet and averaged 29 fish/1,000 feet (Figure 17).

Table 17. Abundance estimates for Rainbow Trout and Brown Trout ≤125 mm by site in the Above Hetch Hetchy Reservoir Reach in 2018 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-1 and older)		
		Rainbow Trout	Brown Trout	All trout
510-PW[1]	pocketwater	11	0	11
511-SP	shallow pool	3 (±0)	0 (±0)	3 (±0)
514-DP[1]	deep pool	0	0	0
517-PW[1]	pocketwater	0	0	0
518-DP[2]	deep pool	1	0	1

[1] Habitats sampled with two passes.
[2] Habitats sampled with one pass.

Table 18. Abundance estimates for Rainbow Trout and Brown Trout ≤125 mm by habitat type in the Above Hetch Hetchy Reservoir Reach in 2018 (95 percent CI).

Habitat type	Trout >125 mm (age-1 and older)		
	Rainbow Trout	**Brown Trout**	**All trout**
Shallow pool	3 (±0)	0 (±0)	3 (±0)
Deep pool	1	0	1
Pocketwater	11	0	11
Total	**15**	**0**	**15**

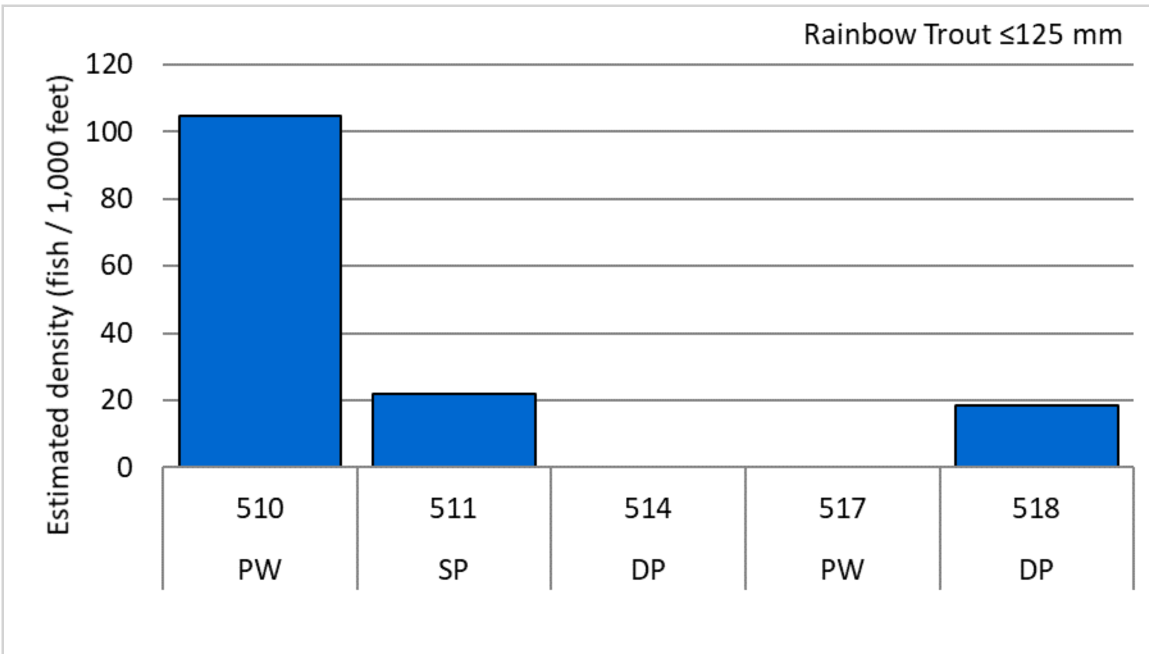

Figure 17. Estimated linear density of Rainbow Trout ≤125 mm by site in the Above Hetch Hetchy Reservoir Reach in 2018. (PW = pocketwater, SP = shallow pool, DP = deep pool.)

4.2.2.2 Reach-level comparisons of 2016–2018 monitoring results in the Above Hetch Hetchy Reservoir Reach

Trout >125 mm

Over the three-year monitoring period, linear density of Rainbow Trout >125 mm in the Above Hetch Hetchy Reservoir Reach was substantially higher in 2016 with 121 fish/1,000 feet, compared with 2017 and 2018 when linear densities were 16 and 17 fish/1,000 feet, respectively (Figure 18). Linear density of Brown Trout >125 mm over the three-year monitoring period was similar during 2016 and 2017 with 5 and 4 fish/1,000 feet, respectively. No Brown Trout >125 mm were observed at monitoring sites surveyed in the Above Hetch Hetchy Reservoir Reach in 2018.

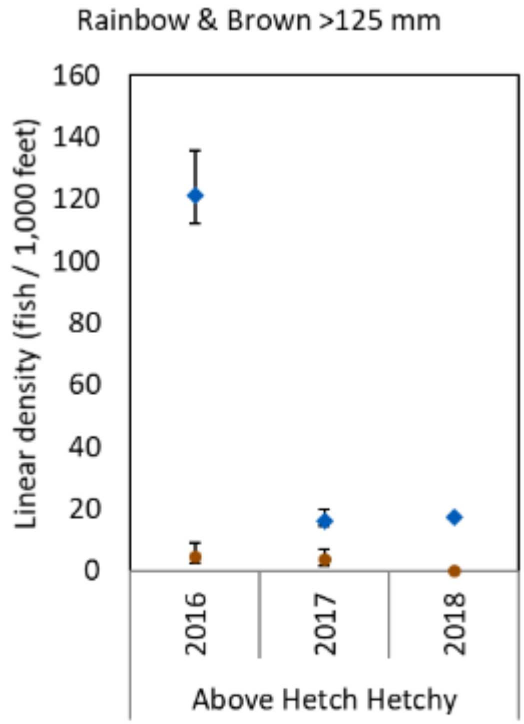

Figure 18. Estimated linear density of Rainbow Trout (blue diamonds) and Brown Trout (brown circles) >125 mm in the Above Hetch Hetchy Reservoir Reach for monitoring years 2016–2018. (Error bars indicate 95 percent CI.) Note that minor shifts in monitoring sites occurred annually.

Trout ≤125 mm

Linear density of Rainbow Trout ≤125 mm over the three-year monitoring period was greatest in 2016, with 47 fish/1,000 feet, compared with 24 fish/1,000 feet in 2018 (Figure 19). In 2017, no Rainbow Trout ≤125 mm were observed at monitoring sites surveyed in the Above Hetch Hetchy Reservoir Reach. Linear density of Brown Trout ≤125 mm in 2016 was 9 fish/1,000 feet. No Brown Trout ≤125 mm were observed at monitoring sites surveyed in the Above Hetch Hetchy Reservoir Reach in 2017 and 2018.

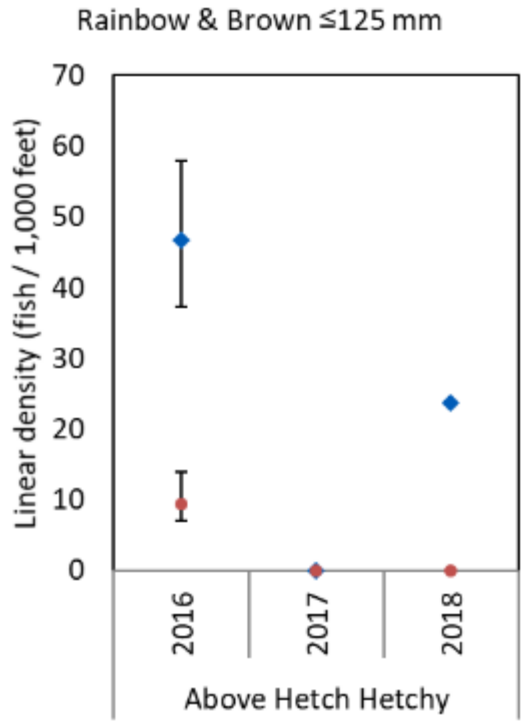

Figure 19. Estimated linear density of Rainbow Trout (blue diamonds) and Brown Trout (brown circles) ≤125 mm in the Above Hetch Hetchy Reservoir Reach for monitoring years 2016–2018. (Error bars indicate 95 percent CI.) Note that minor shifts in monitoring sites occurred annually. No Rainbow Trout or Brown Trout ≤125 mm were observed in the Above Hetch Hetchy Reservoir Reach in 2017.

4.2.3 Cherry Creek and Eleanor Creek Reaches

4.2.3.1 2018 Monitoring

Trout >125 mm

The 2018 fish population monitoring results for trout abundance and linear density in the Cherry Creek and Eleanor Creek reaches are presented below for trout >125 mm (Tables 19–21, Figure 20). Rainbow Trout made up nearly all of trout >125 mm observed in the Cherry Creek and Eleanor Creak reaches in 2018. Abundance estimates in 2018 for trout >125 mm for all sites in the Cherry Creek and Eleanor Creek reaches combined were 302 Rainbow Trout and 2 Brown Trout (Tables 20 and 21). Abundance estimates for Rainbow Trout >125 mm ranged from two trout at sites 3-DP, 5-BG, and 127-DP to 61 trout at site 107-DP (Table 19). Rainbow Trout abundance was greatest in the Lower Cherry sub-reach (Table 20) and deep pool habitat (Table 21).

In 2018, estimated linear density of Rainbow Trout >125 mm ranged from 14 fish/1,000 feet at site 127-DP to 626 fish/1,000 feet at site 107-DP (Figure 20). Average density of Rainbow Trout >125 mm by sub-reach was greatest in the Eleanor Creek sub-reach (211 fish/1,000 feet) and by habitat type was greatest in run habitat (178 fish/1,000 feet) (Figure 20).

Brown Trout >125 mm were observed at one of the 18 sites sampled in 2018, site 16-DP in the Holm Powerhouse sub-reach (Table 19). No Brown Trout were observed in the Eleanor Creek Reach in 2018. Brown Trout density at site 16-DP was 9 fish/1,000 feet.

Table 19. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by site in the Cherry Creek and Eleanor Creek reaches in 2018 (95 percent CI).

Site	Habitat type	Trout >125 mm (age-1 and older)		
		Rainbow Trout	Brown Trout	All trout[1]
Upper Cherry sub-reach				
394-SP	shallow pool	11 (±10)	0 (±0)	11 (±10)
392-DP	deep pool	4 (±2)	0 (±0)	4 (±2)
276-SP	shallow pool	6 (±4)	0 (±0)	6 (±4)
Lower Cherry sub-reach				
274-BG	boulder garden	15 (±4)	0 (±0)	15 (±4)
135-DP	deep pool	5 (±4)	0 (±0)	5 (±4)
131-DP	deep pool	24 (±10)	0 (±0)	24 (±10)
127-DP	deep pool	2 (±2)	0 (±0)	2 (±2)
45-SP	shallow pool	32 (±2)	0 (±0)	32 (±2)
40-SP	shallow pool	42 (±29)	0 (±0)	42 (±29)
34-RN	run	16 (±10)	0 (±0)	16 (±10)
Holm Powerhouse sub-reach				
16-DP	deep pool	16 (±12)	2 (±2)	16 (±12)
14-DP	deep pool	5 (±2)	0 (±0)	5 (±2)
Eleanor Creek Reach				
153-RN	run	15 (±8)	0 (±0)	15 (±8)
147-SP	shallow pool	16 (±2)	0 (±0)	16 (±2)
107-DP	deep pool	61 (±27)	0 (±0)	61 (±27)
103-DP	deep pool	28 (±4)	0 (±0)	28 (±4)
5-BG	boulder garden	2 (±2)	0 (±0)	2 (±2)
3-DP	deep pool	2 (±2)	0 (±0)	2 (±2)

[1] Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

Table 20. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by sub-reach in the Cherry Creek and Eleanor Creek reaches in 2018 (95 percent CI).

Sub-reach	Trout >125 mm (age-1 and older)		
	Rainbow Trout	**Brown Trout**	**All trout[1]**
Upper Cherry	21 (±11)	0 (±0)	21 (±11)
Lower Cherry	136 (±33)	0 (±0)	136 (±33)
Holm Powerhouse	21 (±12)	2 (±2)	21 (±12)
Eleanor Creek	124 (±29)	0 (±0)	124 (±29)
Total	**302 (±47)**	**2 (±2)**	**302 (±47)**

[1] Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

Table 21. Abundance estimates for Rainbow Trout and Brown Trout >125 mm by habitat type in the Cherry Creek and Eleanor Creek reaches in 2018 (95 percent CI).

Habitat type	Trout >125 mm (age-1 and older)		
	Rainbow Trout	**Brown Trout**	**All trout[1]**
Shallow pool	107 (±31)	0 (±0)	107 (±31)
Deep pool	147 (±32)	2 (±2)	147 (±32)
Run	31 (±13)	0 (±0)	31 (±13)
Boulder garden	17 (±4)	0 (±0)	17 (±4)
Total	**302 (±47)**	**2 (±2)**	**302 (±47)**

[1] Note that estimates for "all trout" are calculated separately from estimates for Rainbow Trout and Brown Trout and include observations of unidentified trout (if present); therefore, estimates for "all trout" may be different (higher or lower) than the sum of the estimates for Rainbow Trout and Brown Trout.

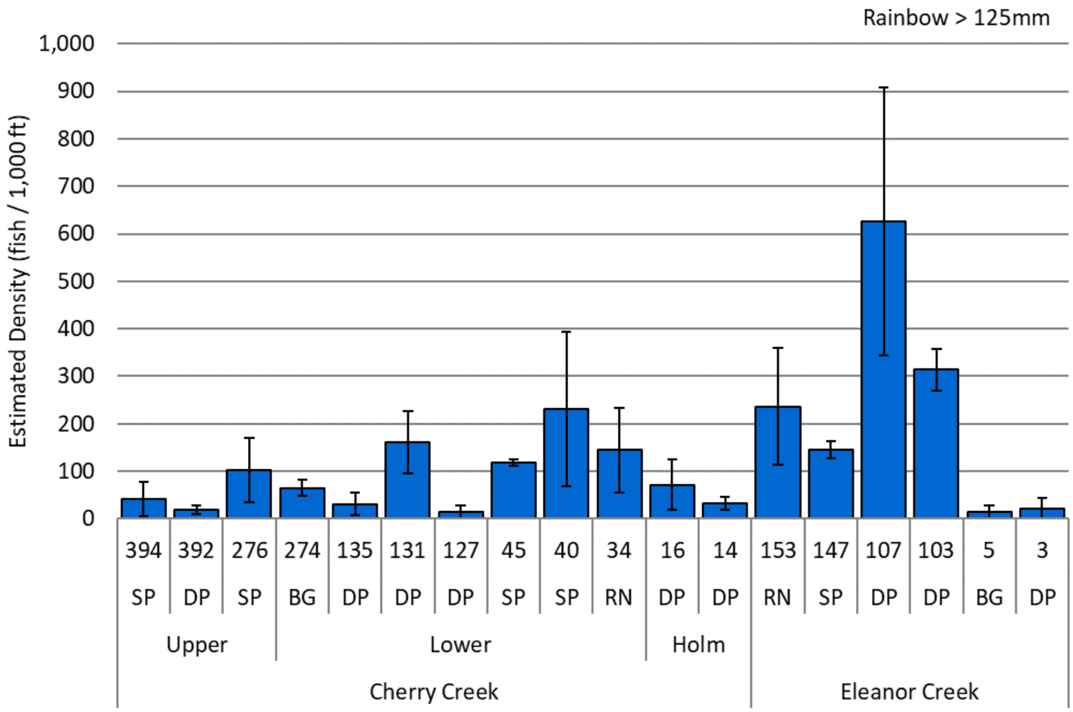

Figure 20. Estimated linear density of Rainbow Trout >125 mm by sub-reach and site in the Cherry Creek and Eleanor Creek reaches in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, BG = boulder garden, RN = run.)

Trout ≤125 mm

The 2018 fish population monitoring results for trout abundance and linear density in the Cherry Creek and Eleanor Creek reaches are presented below for trout ≤125 mm (Tables 22–24, Figure 21). Rainbow Trout ≤125 mm were observed at 12 of 18 monitoring sites surveyed in the Cherry Creek and Eleanor Creek reaches in 2018 (Table 22). No Brown Trout ≤125 mm were observed at monitoring sites surveyed in the Cherry Creek and Eleanor Creek reaches in 2018. In 2018, estimated abundance of Rainbow Trout ≤125 mm at all sites in the Cherry Creek and Eleanor Creek reaches combined was 171 (Table 23). Abundance estimates for Rainbow Trout ≤125 mm ranged from 0 trout at six monitoring sites to 39 trout at site 107-DP (Table 22). Interestingly, no Rainbow Trout were observed at sites 3-DP and 5-BG in lower Eleanor Creek. Furthermore, one deceased Rainbow Trout, approximately 176 to 200 mm in length, was observed at site 3-DP.

Estimated linear density for Rainbow Trout ≤125 mm ranged from 0 fish/1,000 feet at four sites to 400 fish/1,000 feet at site 107-DP (Figure 21). Average density of Rainbow Trout ≤125 mm by sub-reach was greatest in the Eleanor Creek Reach (166 fish/1,000 feet) and lowest in the Holm Powerhouse sub-reach (0 fish/1,000 feet). Average density of Rainbow Trout ≤125 mm by habitat type was greatest in run habitat (126 fish/1,000 feet) and least in deep pool habitat (46 fish/1,000 feet). The three most upstream sites in the Eleanor Creek Reach had greater densities of Rainbow Trout ≤125 mm compared with the other sites surveyed in the Cherry Creek and Eleanor Creek reaches.

Table 22. Abundance estimates for Rainbow Trout ≤125 mm in the Cherry Creek and Eleanor Creek reaches in 2018 (95 percent CI).

Site	Habitat type	Trout ≤125 mm (age-0)
Upper Cherry sub-reach		
394-SP	shallow pool	0 (±0)
392-DP	deep pool	2 (±2)
276-SP	shallow pool	9 (±8)
Lower Cherry sub-reach		
274-BG	boulder garden	25 (±14)
135-DP	deep pool	5 (±4)
131-DP	deep pool	6 (±2)
127-DP	deep pool	0 (±0)
45-SP	shallow pool	7 (±0)
40-SP	shallow pool	15 (±2)
34-RN	run	4 (±4)
Holm Powerhouse sub-reach		
16-DP	deep pool	0 (±0)
14-DP	deep pool	0 (±0)
Eleanor Creek Reach		
153-RN	run	18 (±0)
147-SP	shallow pool	32 (±8)
107-DP	deep pool	39 (±27)
103-DP	deep pool	9 (±2)
5-BG	boulder garden	0 (±0)
3-DP	deep pool	0 (±0)

Table 23. Abundance estimates for Rainbow Trout ≤125 mm by sub-reach in the Cherry Creek and Eleanor Creek reaches in 2018 (95 percent CI).

Sub-reach	Trout ≤125 mm (age-0)
Upper Cherry	11 (±8)
Lower Cherry	62 (±15)
Holm Powerhouse	0 (±0)
Eleanor Creek	98 (±29)
Total	**171 (±33)**

Table 24. Abundance estimates for Rainbow Trout ≤125 mm by habitat type in the Cherry Creek and Eleanor Creek reaches in 2018 (95 percent CI).

Habitat	Trout ≤125 mm (age-0)
Shallow pool	63 (±11)
Deep pool	61 (±28)
Run	22 (±4)
Boulder garden	25 (±14)
Total	**171 (±33)**

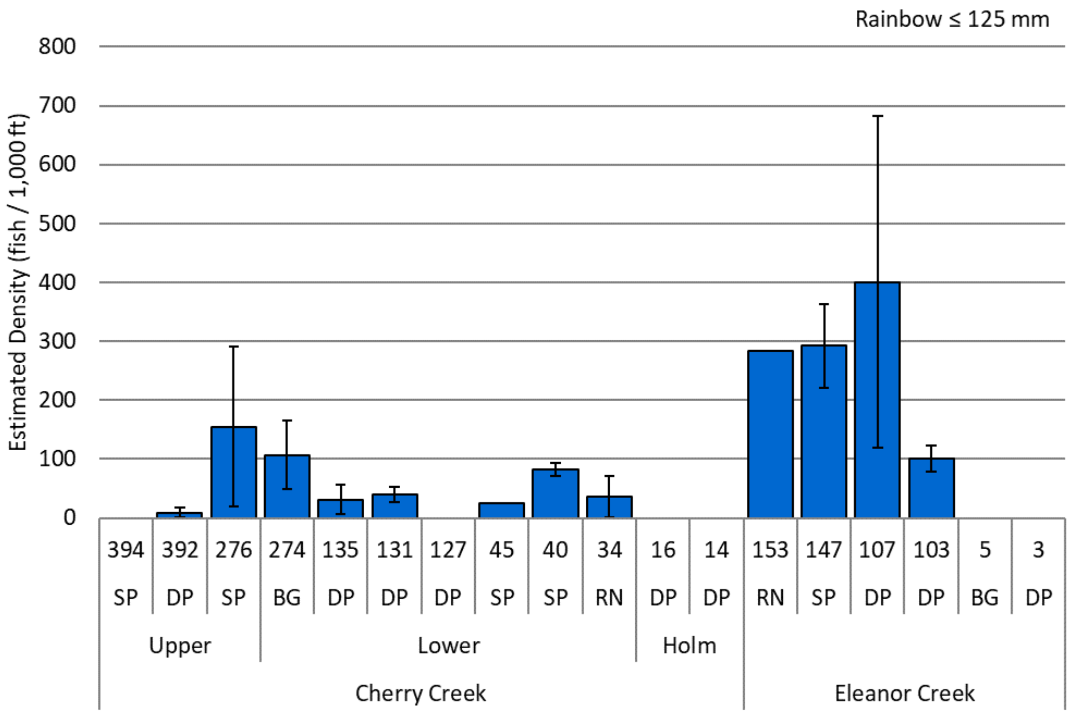

Figure 21. Estimated linear density of Rainbow Trout ≤125 mm by site in the Cherry Creek and Eleanor Creek reaches in 2018. (Error bars indicate 95 percent CI.) (SP = shallow pool, DP = deep pool, BG = boulder garden, RN = run.)

4.2.3.2 Reach-level comparisons of recent monitoring results in Cherry Creek and Eleanor Creek Reaches

Trout >125 mm

Linear densities of Rainbow Trout >125 mm in the Upper Cherry and Lower Cherry sub-reaches show strikingly different (nearly opposite) patterns over the four years of monitoring. For the Upper Cherry sub-reach, linear density of Rainbow Trout >125 mm was slightly higher in 2018 compared with 2017 (Figure 22). For the Lower Cherry sub-reach, linear density of Rainbow Trout >125 mm was lower in 2018 compared with 2017 and similar to densities observed in 2016 (Figure 22). Rainbow Trout densities decreased from 2017 to 2018 in the Lower Cherry, Holm

Powerhouse, and Eleanor Creek sub-reaches. Rainbow Trout densities in the Holm Powerhouse sub-reach show a dramatic decline from 408 fish/1,000 feet in 2017 to 56 fish/1,000 feet in 2018. Rainbow Trout densities in the Eleanor Creek Reach in 2018 were relatively high compared with the other sub-reaches surveyed (Figure 22).

The differing trends observed between the Upper Cherry and Lower Cherry sub-reaches are likely the result of differences in habitat conditions (channel gradient and confinement, habitat complexity) and the influence of flow (magnitude, timing, duration) and water temperature. Flow and water temperature are substantially different between these two sub-reaches, with conditions in the Upper Cherry sub-reach being strongly influenced by regulated flow release from Valley Dam resulting in variable, managed flow conditions and substantially cooler summer water temperatures. The Lower Cherry sub-reach has greater influence from natural tributary accretion flow and water temperature regimes.

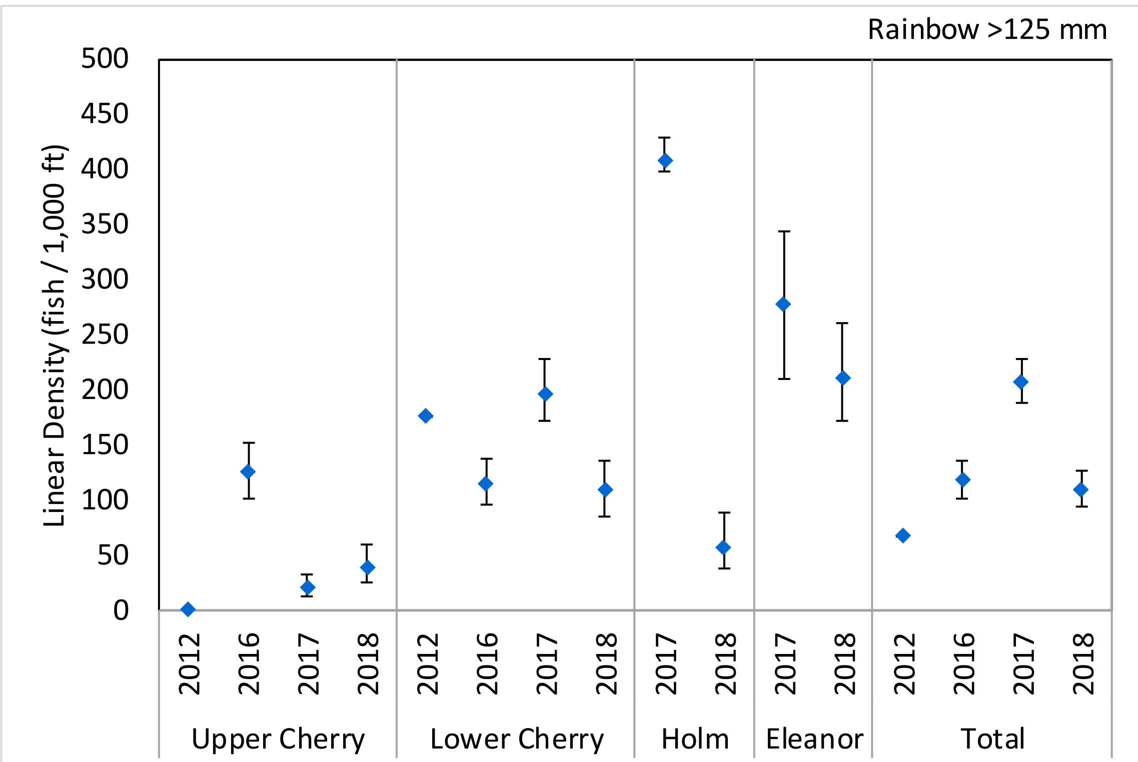

Figure 22. Estimated linear density of Rainbow Trout >125 mm by sub-reach in the Cherry Creek and Eleanor Creek reaches for monitoring years 2012 and 2016-2018. (Error bars indicate 95 percent CI.) Note that total linear density for 2017 and 2018 includes the Holm Powerhouse and Eleanor Creek sub-reaches, which are not included for 2016 or 2012.

Trout ≤125 mm

Linear density of Rainbow Trout ≤125 mm in the Upper Cherry sub-reach was highest in 2012 and lowest in 2017. In the Lower Cherry sub-reach, linear density of Rainbow Trout ≤125 mm shows a decreasing trend over the four years of monitoring. Rainbow Trout densities in 2018 were lower compared with 2017 in the Lower Cherry, Holm Powerhouse, and Eleanor Creek sub-reaches (Figure 23). In 2018, linear density of Rainbow Trout ≤125 mm was greatest in the Eleanor Creek Reach.

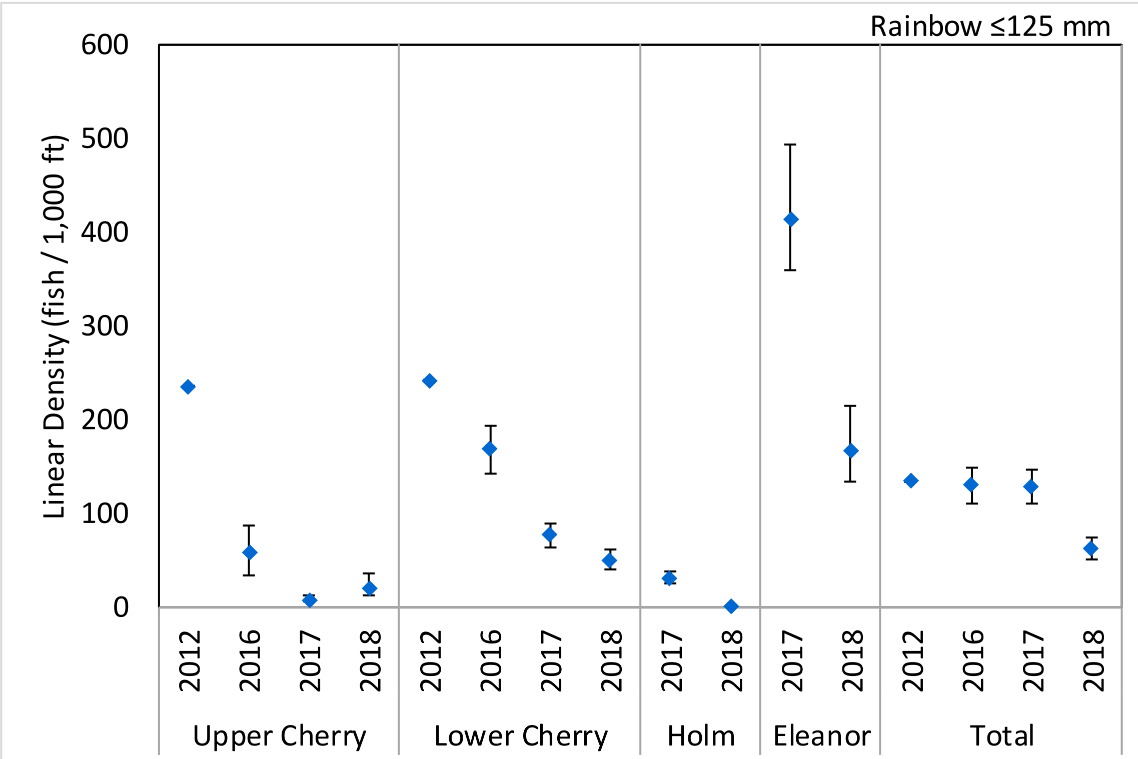

Figure 23. Estimated linear density of Rainbow Trout ≤125 mm by sub-reach in the Cherry Creek and Eleanor Creek reaches for monitoring years 2012 and 2016-2018. (Error bars indicate 95 percent CI.) Note that total linear density for 2017 and 2018 includes the Holm Powerhouse sub-reach and the Eleanor Creek Reach, which are not included for 2016 or 2012.

4.3 Streamflow

4.3.1 Hetch Hetchy Reach

Streamflow in the Hetch Hetchy Reach is derived from (1) required minimum instream baseflow releases from O'Shaughnessy Dam, (2) local accretion from minor tributaries, and (3) snowmelt spill releases from the dam. Two flow monitoring stations in the Hetch Hetchy Reach effectively bracket the survey area: USGS gage 11276500 near Hetch Hetchy at the upstream end of the reach ("Hetch Hetchy gage"), and USGS gage 11276600 above Early Intake at the downstream end of the reach ("Above Early Intake gage") (Figure 24). Hydrographs are presented to illustrate conditions in the reach during WY 2018 relative to conditions during the previous decade (2008–2017) (Figures 25–28). During a typical water year (e.g., WY 2009), flows in the Hetch Hetchy Reach are generally high during the spring and early summer snowmelt runoff period (May–July) and low during the fall and winter (September–February). Short-duration, high-flow events occasionally occur during winter. Minimum baseflow releases are designed to provide optimal temperatures for trout during summer and are higher than typical unimpaired summer inflows in most years. See RMC Water and Environment and McBain & Trush, Inc. (2007) for a summary of existing instream flow requirements and hydrology.

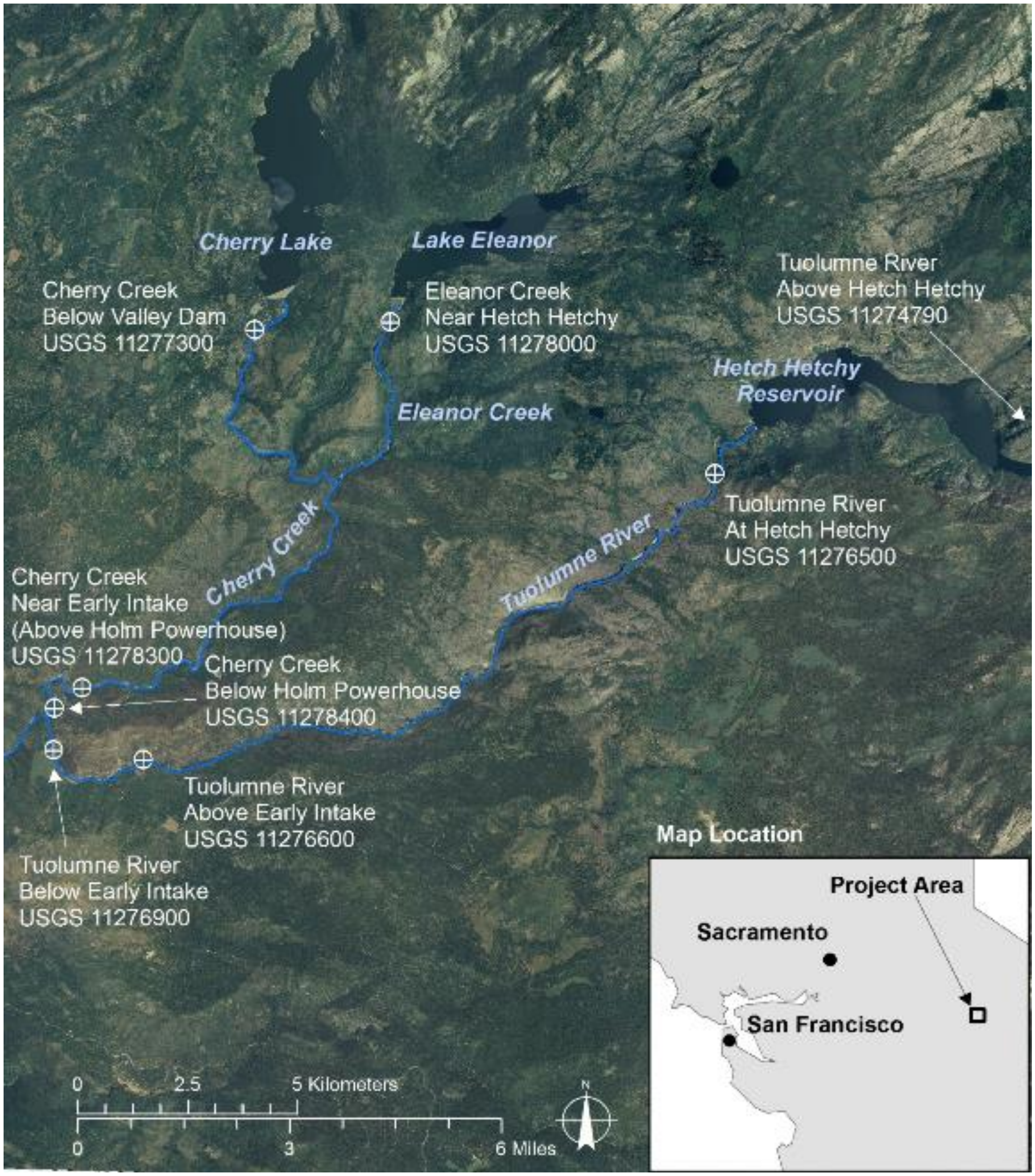

Figure 24. Stream gages in the vicinity of fish monitoring sites in the upper Tuolumne River, Cherry Creek, and Eleanor Creek.

Streamflow conditions during WY 2018 were about average for conditions observed over the past decade, which was a dramatic shift from WY 2017, one of the wettest years on record in recent history (Figures 26 and 28). Mean annual flow and average summer flow (May through mid-September) in WY 2018 were about average at both gages in the reach compared with the past decade (WY 2008–2017). Average daily flow at both gages during October through January was typical of years without significant high-flow events. High-flow events occurring during April were relatively high compared with recent years.

Average daily flow in WY 2018 recorded at Hetch Hetchy gage ranged from 40 cfs in March to 4,152 cfs in April (Figure 26, Table 25). During WY 2018, high-flow events were not observed at Hetch Hetchy gage during October–January and July–September. Low-magnitude high flows occurred during February to mid-March and a series of high-magnitude flow events occurred from late March through early May, transitioning into the spring snowmelt runoff, which created sustained high flows from early May through mid-June. Average daily flows during WY 2018 were highest in April (1,560 cfs mean monthly flow) and May (1,647 cfs mean monthly flow) compared with the rest of the year (47–577 cfs mean monthly flow range) (Figure 26).

Average daily flow in WY 2018 recorded at Above Early Intake gage ranged from 48 cfs in March to 4,394 cfs in April (Figure 28, Table 25). Average daily flows at Above Early Intake gage during April (1,627 cfs mean monthly flow) and May (1,712 cfs mean monthly flow) indicate that average accretion in the Hetch Hetchy Reach was about 66 cfs during this relatively high-flow period in WY 2018.

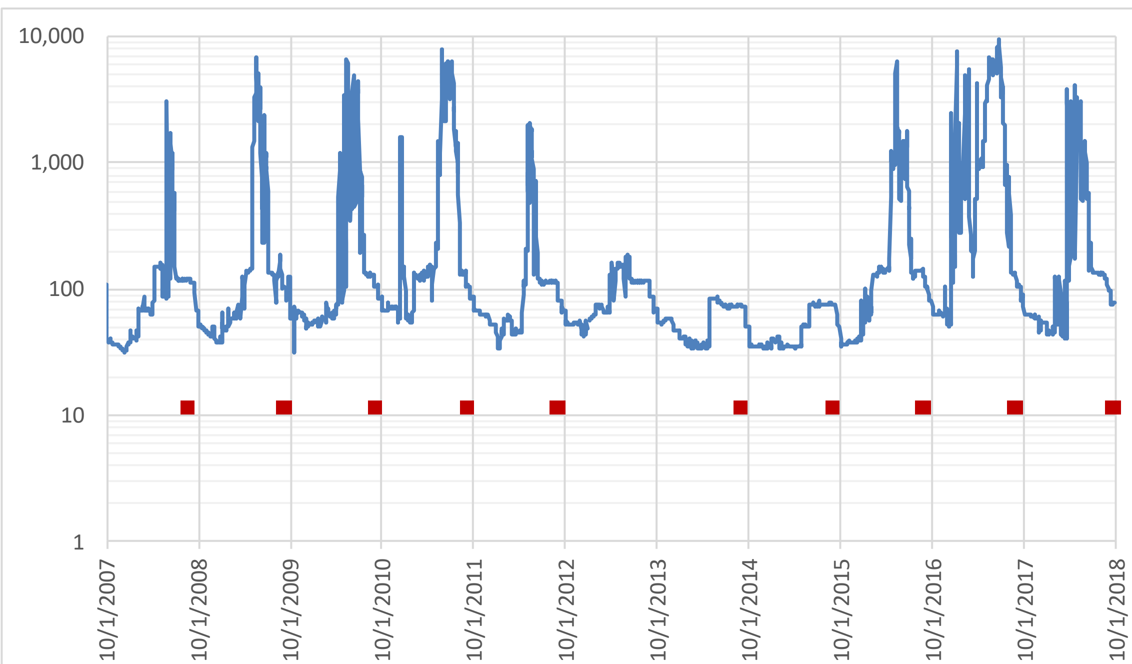

Figure 25. Mean daily streamflow (cfs) in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2008–2018. Snorkel surveys performed by the SFPUC in mid-August through late September 2008–2012 and 2014–2018 are identified by red markers.

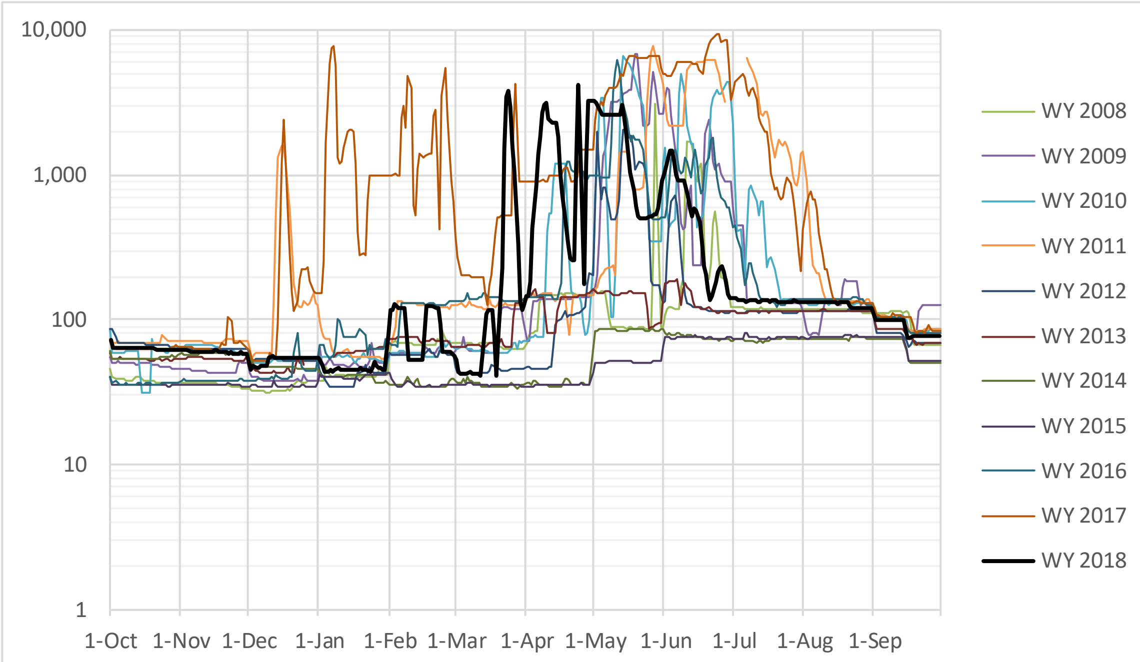

Figure 26. Mean daily streamflow (cfs) in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2008–2018, presented individually.

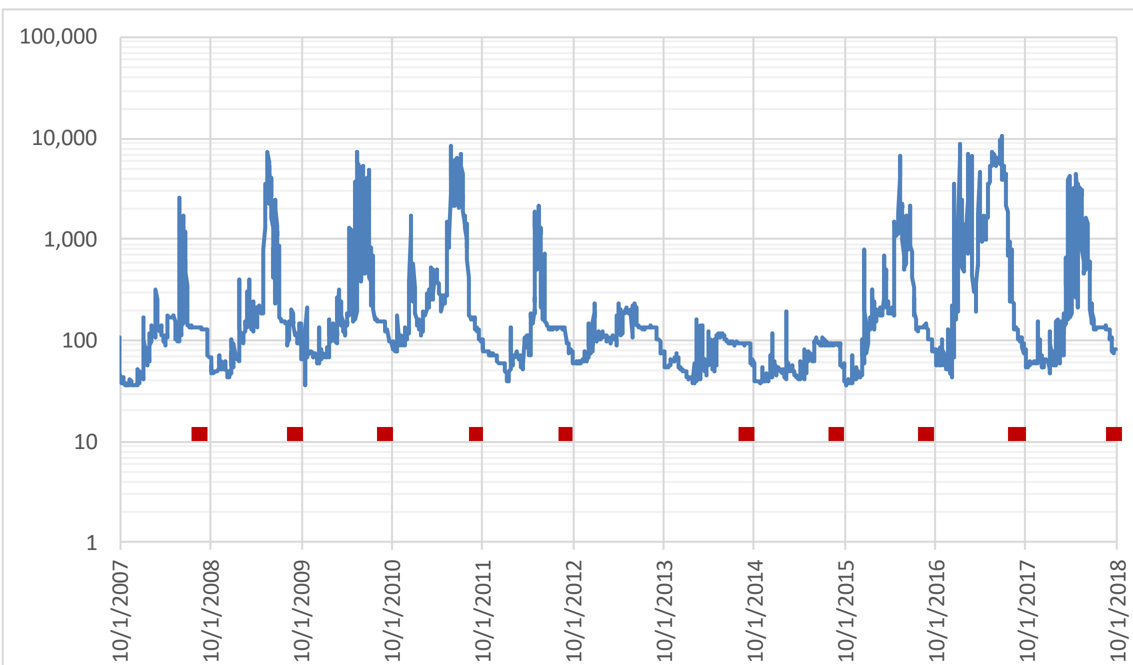

Figure 27. Mean daily streamflow (cfs) in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2008–2018. Snorkel surveys performed by the SFPUC in mid-August through late September 2008–2012 and 2014–2018 are identified by red markers.

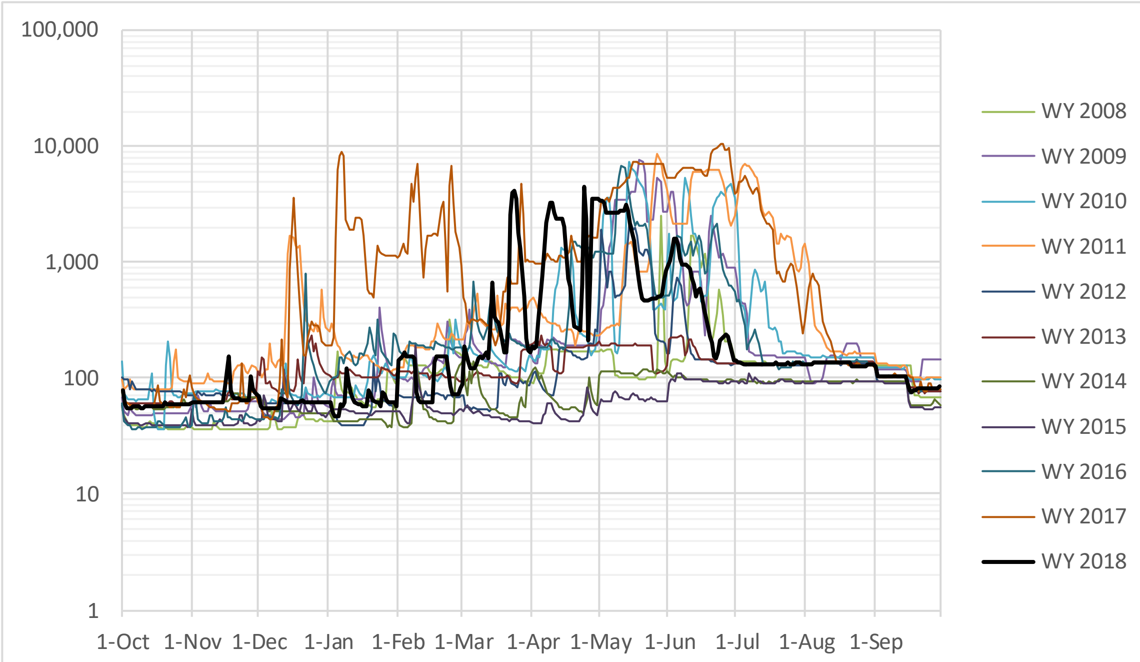

Figure 28. Mean daily streamflow (cfs) in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2008–2018, presented individually.

Table 25. Streamflow metrics (in cfs) for WY 2008–2018 at USGS gages in the Hetch Hetchy Reach.

Flow metric	Water year and year type[1]										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Dry	Nrml	Nrml	ExW	ExD	Dry	ExD	ExD	Nrml	ExW	Nrml
Tuolumne River at Hetch Hetchy gage (USGS 11276500)											
Mean daily average	121	439	499	793	154	92	57	50	359	1,664	417
Median daily average	69	83	75	127	68	75	54	39	131	587	100
Minimum daily average	31	37	31	54	34	43	34	34	35	51	40
Maximum daily average	3,087	6,826	6,725	7,865	2,033	188	87	82	6,273	9,480	4,152
Instantaneous maximum (peak)	6,720	7,010	7,350	8,210	4,340	191	89	91	6,430	9,680	4,870
Tuolumne River at Above Early Intake gage (USGS 11276600)											
Mean daily average	142	494	554	960	178	121	75	64	434	1,874	452
Median daily average	116	146	141	234	91	112	67	54	150	687	132
Minimum daily average	36	44	36	79	39	60	38	38	36	44	48
Maximum daily average	2,571	7,507	7,500	8,508	2,180	234	159	196	6,866	10,663	4,394
Instantaneous maximum (peak)	6,250	7,890	8,270	8,950	4,180	286	235	317	7,260	11,100	4,790

[1] Water year types include: ExD = extremely dry; Dry = dry, Nrml = normal; Wet = wet; ExW = extremely wet

4.3.2 Above Hetch Hetchy Reservoir Reach

Streamflow in the Above Hetch Hetchy Reservoir Reach is unregulated. Flow is monitored at USGS gage 11274790 ("Above Hetch Hetchy gage") located near the downstream end of the reach, immediately upstream of Hetch Hetchy Reservoir. Streamflow in the reach is generally lowest in late September and early October. Flows generally increase from October through May or June, and then decrease from June through October (Figures 29 and 30). Average daily flow in WY 2018 recorded at Above Hetch Hetchy gage ranged from 8 cfs in September to 3,601 cfs in April (Figure 30, Table 26). Flow conditions during WY 2018 were about average compared with the past decade. Mean daily average flow during WY 2018 was 374 cfs, compared with a range of 193 to 922 cfs during WY 2008–2017 (Table 26). Annual peak flow in WY 2018 was 5,620 cfs, the third highest measured during WY 2008–2018.

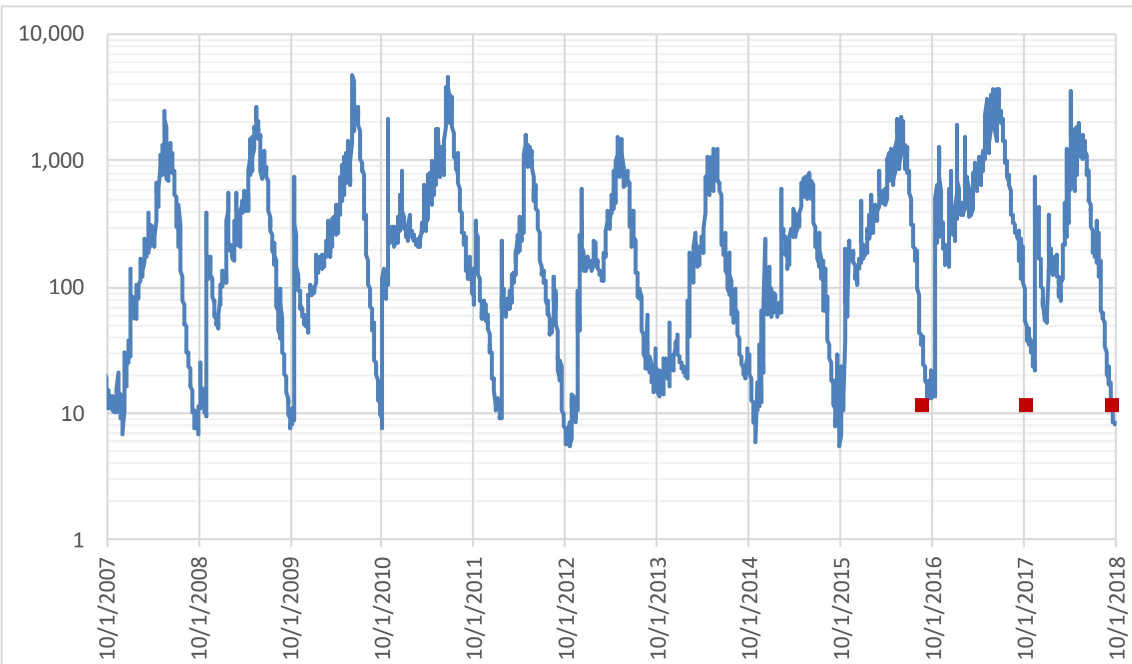

Figure 29. Mean daily streamflow (cfs) in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2008–2018. Snorkel surveys by the SFPUC in August 2016, October 2017, and September 2018 are identified by red markers.

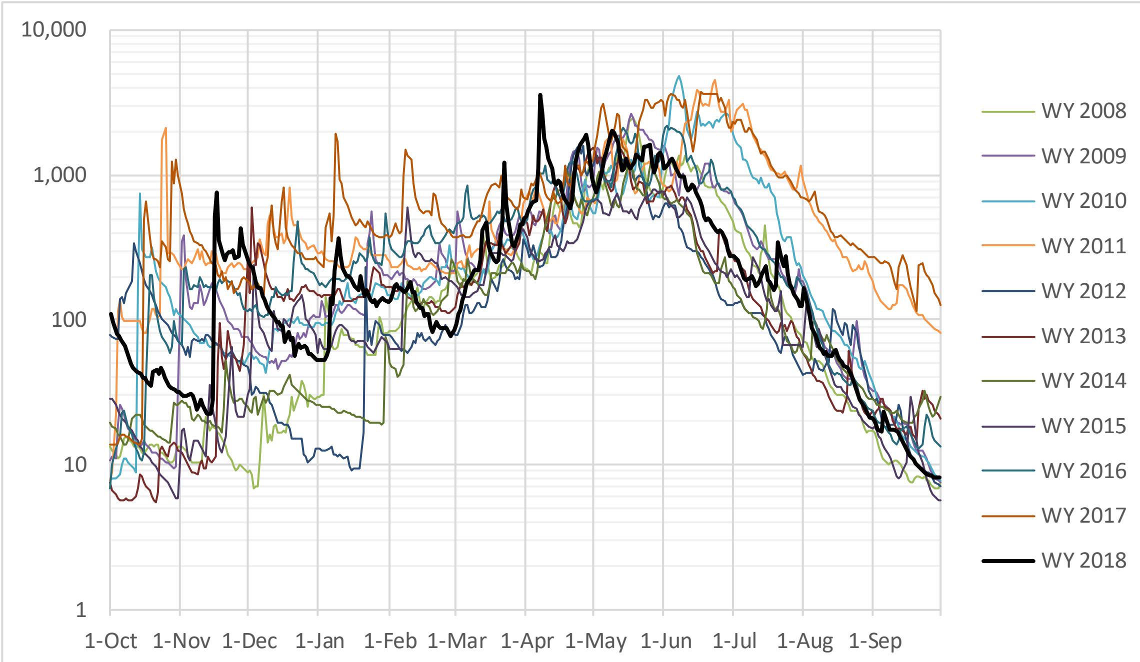

Figure 30. Mean daily streamflow (cfs) in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2008–2018, presented individually.

Table 26. Streamflow metrics (in cfs) for WY 2008–2018 at the USGS gage in the Above Hetch Hetchy Reservoir Reach.

Flow metric	Water year and year type[1]										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Dry	Nrml	Nrml	ExW	ExD	Dry	ExD	ExD	Nrml	ExW	Nrml
Tuolumne River at Above Hetch Hetchy gage (USGS 11274790)											
Mean daily average	292	399	492	682	219	266	204	193	449	922	374
Median daily average	84	181	175	308	80	146	62	98	251	543	163
Minimum daily average	7	8	8	8	7	5	14	6	7	14	8
Maximum daily average	2,512	2,653	4,844	4,522	1,591	1,549	1,243	796	2,195	3,720	3,601
Instantaneous maximum (peak)	3,160	3,330	7,060	6,650	1,840	1,780	1,460	986	2,780	4,660	5,620

[1] Water year types include: ExD = extremely dry; Dry = dry, Nrml = normal; Wet = wet; ExW = extremely wet

4.3.3 Cherry Creek and Eleanor Creek Reaches

Streamflow in the Cherry Creek Reach was analyzed at three flow monitoring stations: USGS gage 11277300 below Valley Dam at the upstream end of the reach ("Below Valley Dam gage"), USGS gage 11278300 above Holm Powerhouse near the downstream end of the Lower Cherry sub-reach ("Above Holm Powerhouse gage"), and USGS gage 11278400 below Holm Powerhouse at the downstream end of the reach ("Below Holm Powerhouse gage"). In addition, streamflow in the Eleanor Creek Reach was analyzed at one flow monitoring station: USGS gage 11278000 in Eleanor Creek near Hetch Hetchy ("Eleanor Creek gage") located near the upstream end of the reach (Figure 24). Flows are presented to illustrate conditions in the reach during WY 2018 relative to conditions during the preceding decade (Figures 31–38).

Streamflow at Below Valley Dam gage is highly variable but generally greatest during the snowmelt runoff period (April–July) and is low during the fall and winter (September–February) (Figure 32). Short-duration, high-flow events occasionally occur outside of the snowmelt runoff period, mostly in winter (e.g., in WY 2011 and WY 2013) (Figures 31 and 32). In all years, minimum baseflow appear to increase from about 5 cfs to 16 cfs on or near July 1. During WY 2018, short-duration high-flow events occurred periodically during the October to early May period and sustained high-magnitude flows occurred from mid-November to mid-December. Flows were relatively low and stable from mid-May through September (Figure 32). Daily average flow at Below Valley Dam gage during WY 2018 ranged from a minimum of 5 cfs in June to a maximum of 936 cfs in December (Figure 32, Table 27). Mean daily average flow for WY 2018 was 39 cfs, which is about average for WY 2008–2018 (not including WY 2017, which was particularly wet) (Figure 32, Table 27).

Streamflow at Above Holm Powerhouse gage is influenced by flow releases at Valley and Eleanor Creek dams in addition to flow accretion from contributing tributaries in the Upper Cherry and Lower Cherry sub-reaches and the Eleanor Creek Reach. Streamflow at Above Holm Powerhouse gage generally peaks during the snowmelt runoff period (April–July), with occasional precipitation-driven high-flow events occurring during fall and winter (September–February) (Figure 34). During WY 2018, high-magnitude flow events occurred from November through January with sustained high flows from mid-November to mid-December. The WY 2018 spring snowmelt runoff period extended from approximately early March to mid-June, and flows were relatively stable from July through September (Figure 34, Table 27). Daily average flow at Above Holm Powerhouse gage during WY 2018 ranged from 19 to 3,074 cfs, both occurring in November (Figure 34, Table 27). Mean daily average flow during WY 2018 was 153 cfs, which is about average for the WY 2008–2018 period (not including WY 2017, which was particularly wet) (Table 27). During WY 2018, the maximum daily average and peak flows were each the third highest recorded during the 2008–2018 period (Figures 33 and 34, Table 27).

Streamflow at Below Holm Powerhouse gage is influenced by releases from Holm Powerhouse in addition to flow from Cherry and Eleanor creeks as measured at Above Holm Powerhouse gage. Highly variable powerhouse flow releases dominate streamflow conditions in the Holm Powerhouse sub-reach. Streamflow at Below Holm Powerhouse gage is generally lowest during October and November, greatest during March through June, and moderate during the rest of the year. Unlike streamflow conditions observed elsewhere during WY 2018, daily average streamflow at Below Holm Powerhouse gage (372 cfs) was below average for WY 2008–2018, with the second lowest daily average flow next to WY 2008 during the period, although flow variability is relatively high at the Below Holm Powerhouse gage (e.g., relatively high flow in November and low flow in September). In WY 2018, average daily streamflow at Below Holm Powerhouse gage ranged from 23 to 3,549 cfs, both occurring in November (Figure 36).

Streamflow at Eleanor Creek gage is influenced by releases from Lake Eleanor Dam, which are dominated by natural runoff patterns into Lake Eleanor. Average daily flow in WY 2018 recorded at Eleanor Creek gage ranged from 6 to 2,454 cfs, both occurring in November (Figure 38, Table 27). During WY 2018, average daily flow at Eleanor Creek gage from October to March was relatively low except for high-magnitude flow events in November and January. Flows remained relatively high during April and May from snowmelt runoff, and were relatively low and stable during June through September (Figure 38).

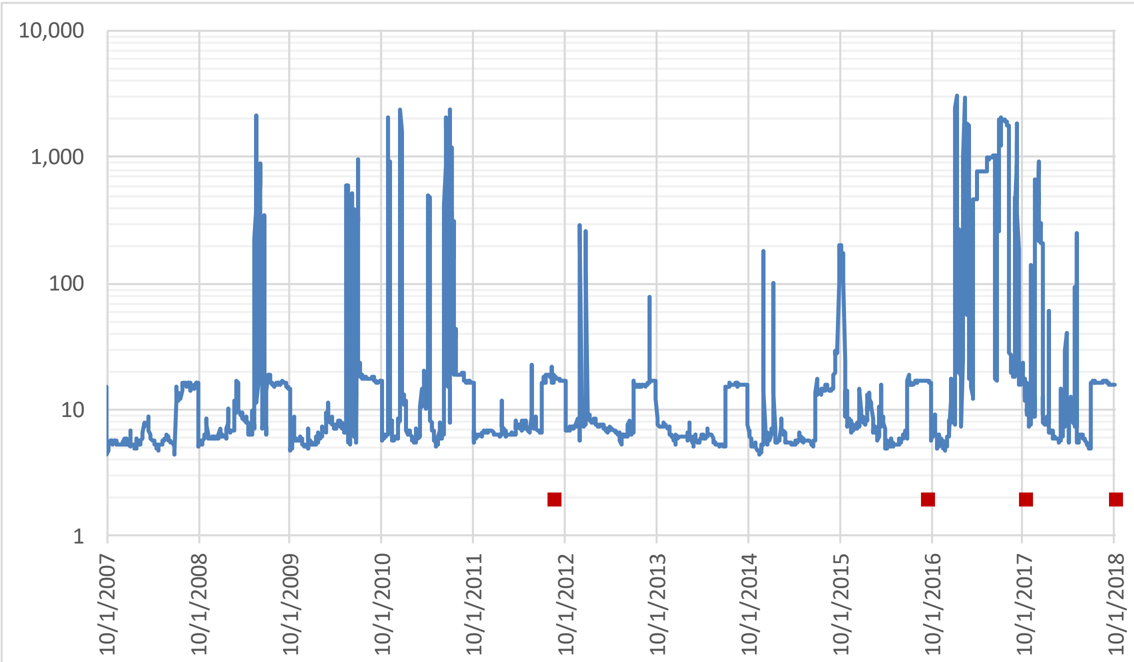

Figure 31. Mean daily streamflow (cfs) in Cherry Creek at Below Valley Dam gage (USGS 11277300) for WY 2008–2018. Snorkel surveys performed in August 2012, September 2016, and October 2017 and 2018 are identified by red markers.

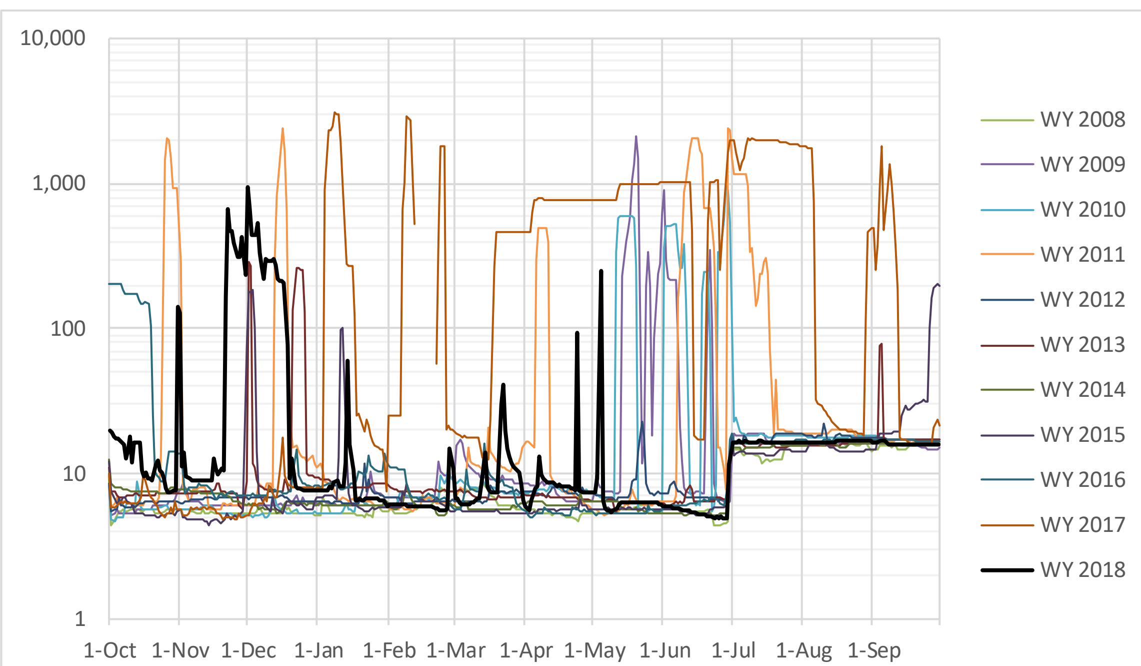

Figure 32. Mean daily streamflow (cfs) in Cherry Creek at Below Valley Dam gage (USGS 11277300) for WY 2008–2018, presented individually.

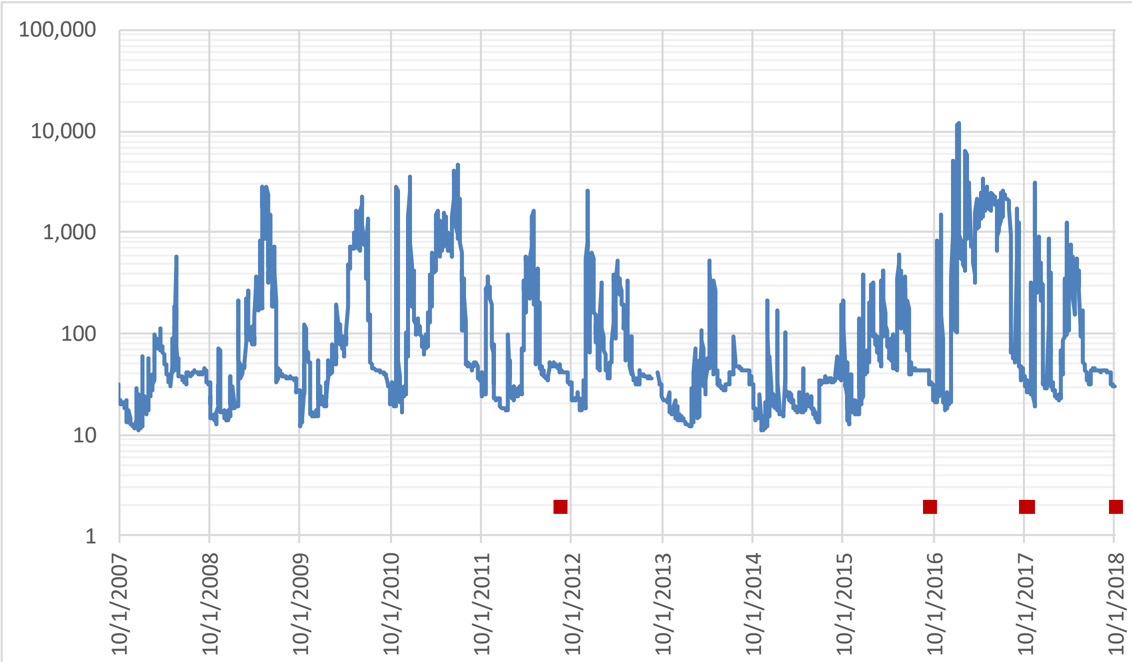

Figure 33. Mean daily streamflow (cfs) in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2008–2018. Snorkel surveys performed in August 2012, September 2016, and October 2017 and 2018 are identified by red markers.

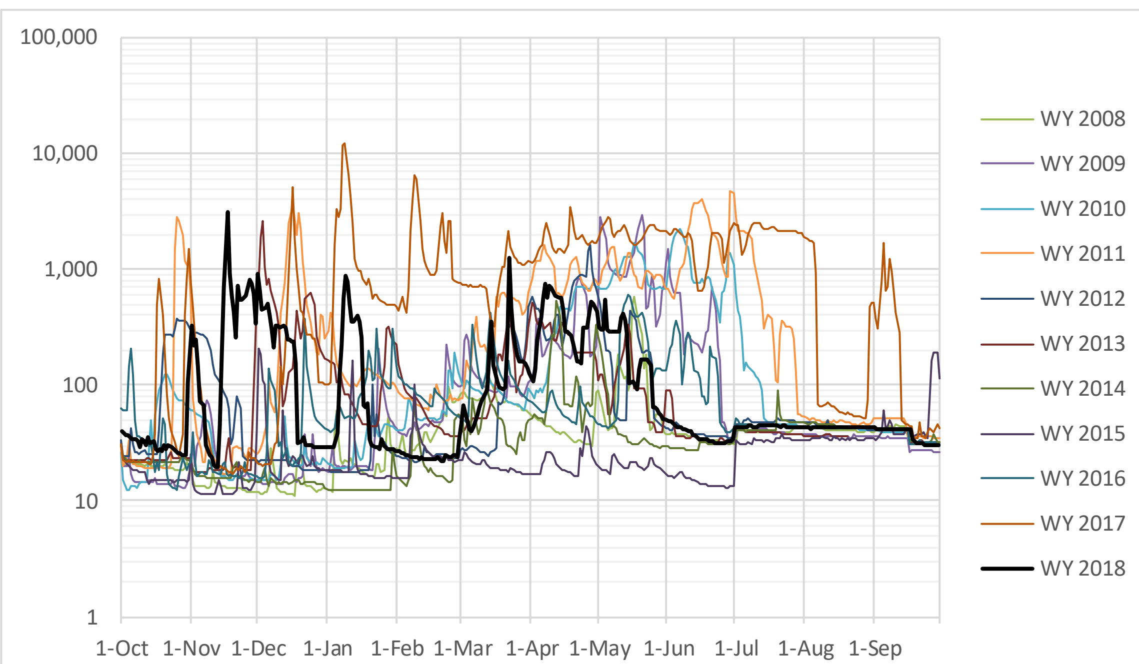

Figure 34. Mean daily streamflow (cfs) in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2008–2018, presented individually.

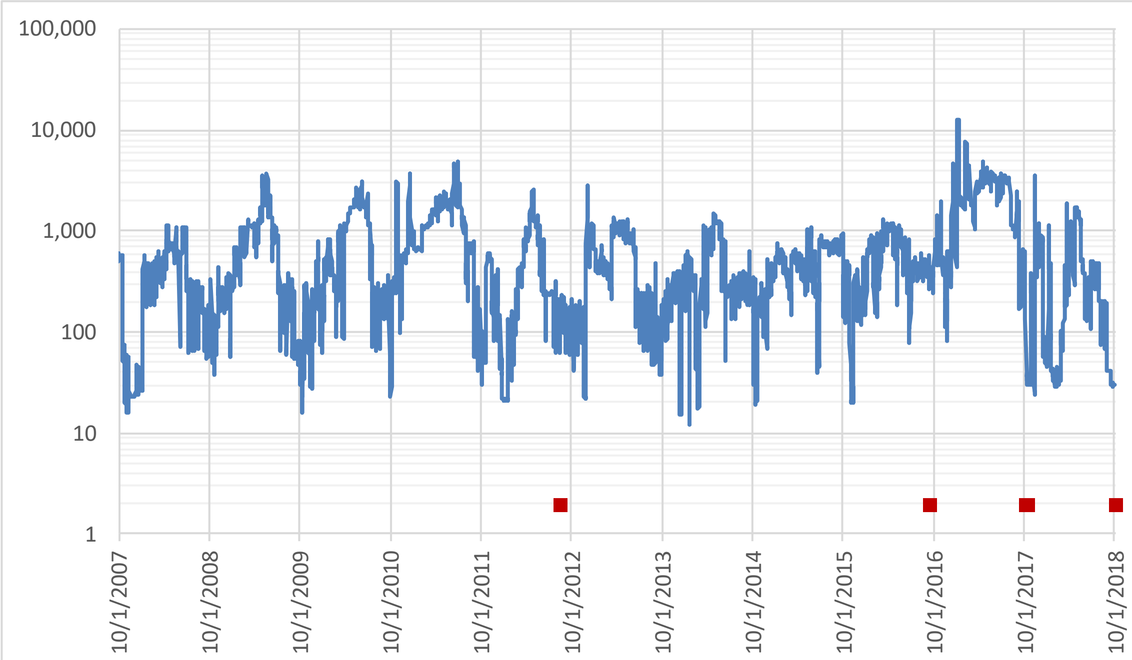

Figure 35. Mean daily streamflow (cfs) in Cherry Creek at Below Holm Powerhouse gage (USGS 11278400) for WY 2008–2018. Snorkel surveys performed in August 2012, September 2016, and October 2017 and 2018 are identified by red markers.

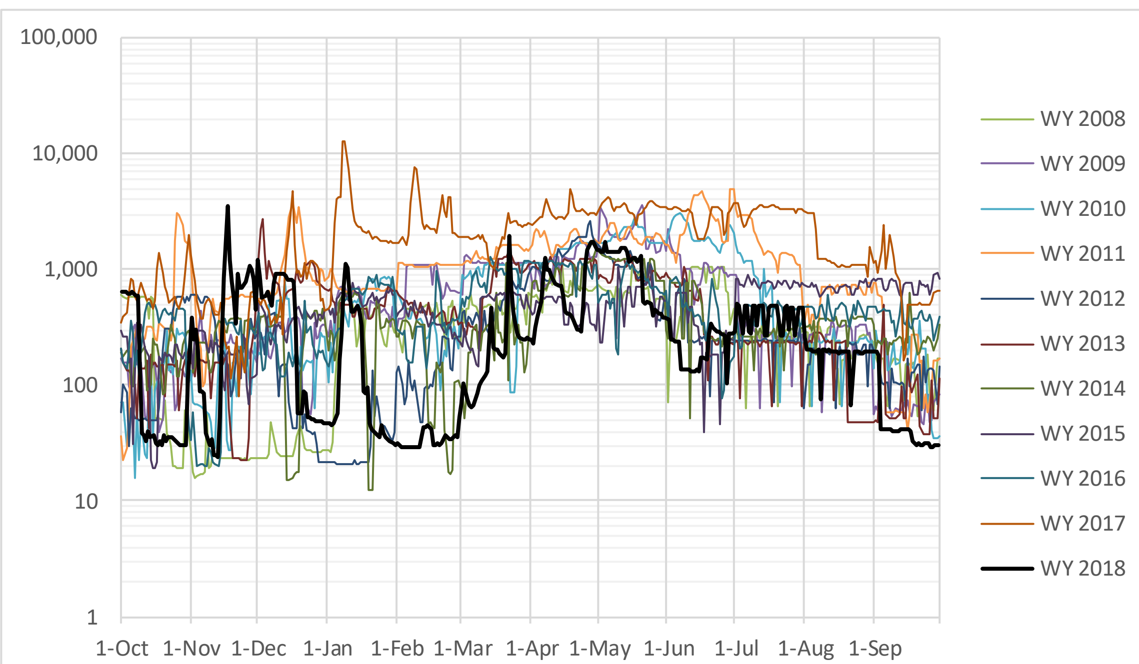

Figure 36. Mean daily streamflow (cfs) in Cherry Creek at Below Holm Powerhouse gage (USGS 11278400) for WY 2008–2018, presented individually.

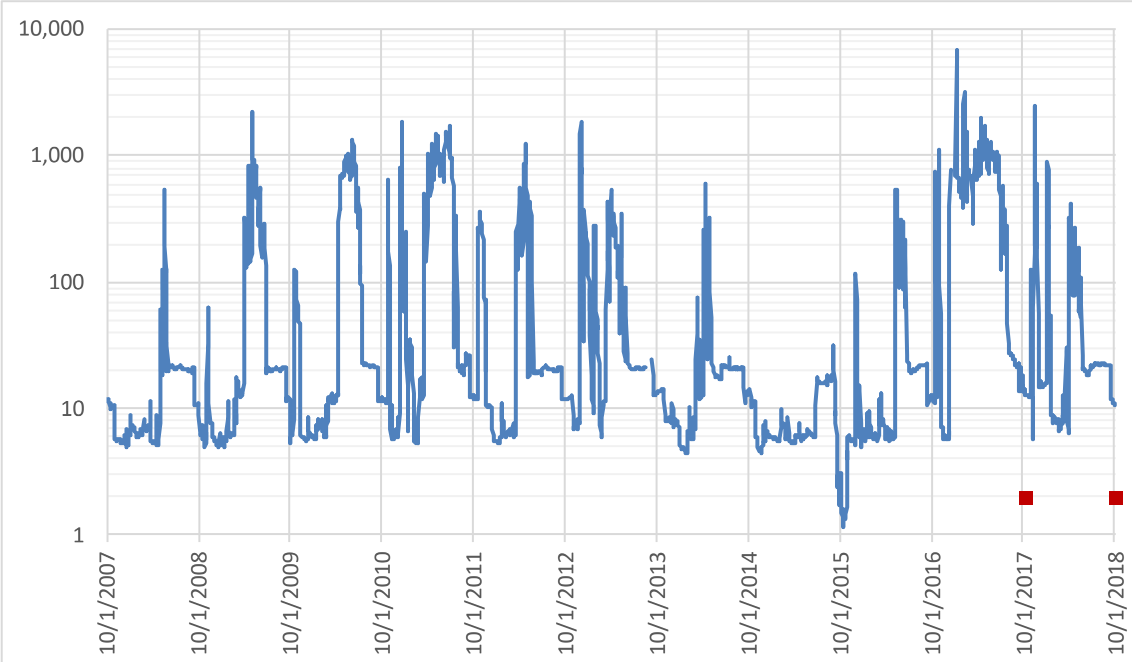

Figure 37. Mean daily streamflow (cfs) in Eleanor Creek at Eleanor Creek gage (USGS 11278000) for WY 2008–2018. Snorkel surveys performed in October 2017 and 2018 are identified by red markers.

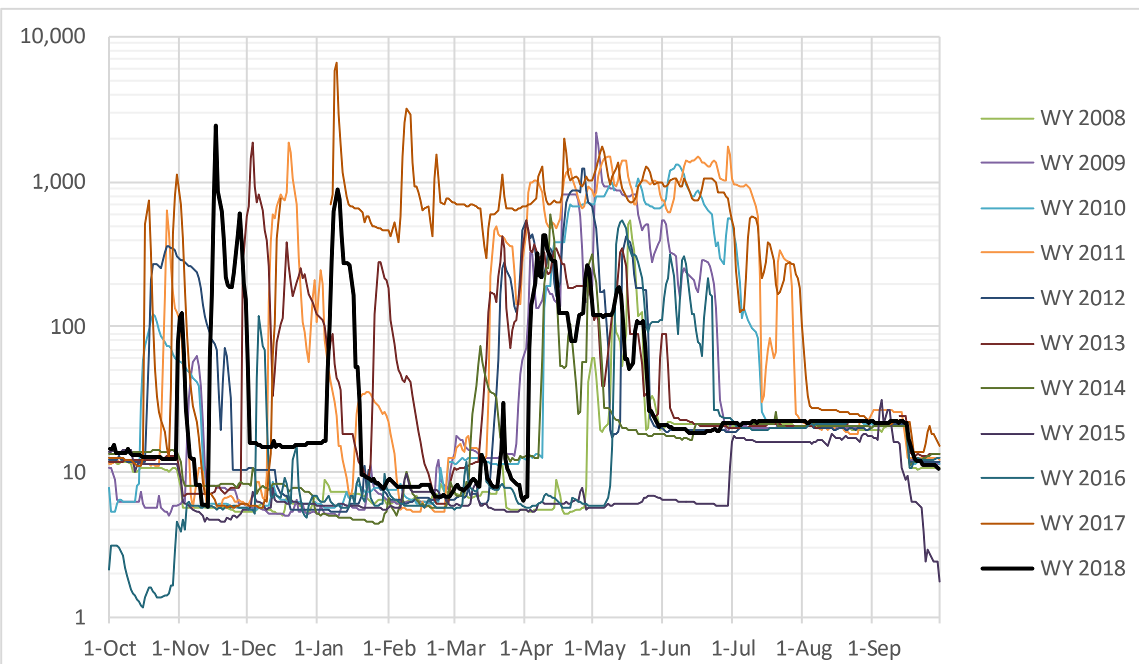

Figure 38. Mean daily streamflow (cfs) in Eleanor Creek at Eleanor Creek gage (USGS 11278000) for WY 2008–2018, presented individually.

Table 27. Streamflow metrics (in cfs) for WY 2008–2018 at USGS gages in the Cherry Creek and Eleanor Creek reaches.

Flow metric	Water year and year type[1]										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Dry	Nrml	Nrml	ExW	ExD	Dry	ExD	ExD	Nrml	ExW	Nrml
Cherry Creek at Below Valley Dam gage (USGS 11277300)											
Mean daily average	8	43	48	162	10	15	9	13	18	549	39
Median daily average	6	8	7	10	7	8	6	6	8	28	9
Minimum daily average	4	5	5	5	6	5	5	4	5	5	5
Maximum daily average	17	2,114	963	2,429	23	288	16	201	202	3,081	936
Instantaneous maximum (peak)	20	2,760	1,230	3,400	44	556	28	205	205	4,520	2,060
Cherry Creek at Above Holm Powerhouse gage (USGS 11278300)											
Mean daily average	44	187	249	575	118	125	41	27	84	1,149	153
Median daily average	37	38	51	133	42	44	31	20	48	826	43
Minimum daily average	11	13	12	17	18	18	12	11	13	17	19
Maximum daily average	585	2,904	2,234	4,770	1,629	2,602	535	211	610	12,167	3,074
Instantaneous maximum (peak)	751	3,640	2,390	6,770	2,310	3,980	931	244	652	18,200	4,770
Cherry Creek at Below Holm Powerhouse gage (USGS 11278400)											
Mean daily average	356	677	746	1,240	392	505	414	481	505	2,106	372
Median daily average	302	372	341	1,081	238	385	310	503	440	1,917	204
Minimum daily average	16	39	16	23	21	22	12	19	20	82	23
Maximum daily average	1,145	3,652	3,048	4,998	2,633	2,782	1,487	1,079	1,307	12,744	3,549
Instantaneous maximum (peak)	1,600	4,390	3,200	6,590	3,190	3,890	1,940	1,220	1,620	20,100	5,270
Eleanor Creek gage (USGS 11278000)											
Mean daily average	20	125	166	354	96	98	26	9	35	545	70
Median daily average	10	16	18	30	20	21	14	6	7	488	21
Minimum daily average	5	5	5	5	5	6	4	2	1	6	6
Maximum daily average	545	2,205	1,336	1,862	1,233	1,882	597	32	543	6,756	2,454
Instantaneous maximum (peak)	777	2,680	1,500	2,580	1,720	3,230	983	83	602	10,300	3,930

[1] Water year types include: ExD = extremely dry; Dry = dry, Nrml = normal; Wet = wet; ExW = extremely wet

4.4 Water Temperature

4.4.1 Hetch Hetchy Reach

Daily average water temperature data for Hetch Hetchy gage and Above Early Intake gage are plotted for WY 2008 through WY 2018, both consecutively (Figures 39 and 41) and individually (Figures 40 and 42) to illustrate annual patterns and compare WY 2018 with conditions during the previous decade. Water temperature metrics based on daily data for WY 2018 are presented in Table 28.

Water temperatures at Hetch Hetchy gage are generally lowest from January through April and highest in June and July, with moderate water temperatures in August through November and transitional periods in December and May (Figure 40). In WY 2018, water temperatures at Hetch Hetchy gage were relatively high from October through February compared with the past decade (2008–2017). The highest water temperatures during WY 2018 at Hetch Hetchy gage occurred in June when two distinct spikes in temperature occurred (Figure 40). Maximum daily average water temperatures in WY 2018 were the second highest in the past decade, with the highest occurring in 2011 (Figures 39 and 40, Table 28). WY 2018 water temperatures in March–April and September were about average compared with the past decade.

Above Early Intake gage follows a slightly different pattern compared with Hetch Hetchy gage, with temperatures at their lowest during December and January, increasing steadily to their highest in late June to early August, and then steadily decreasing from September through November (Figure 42). In WY 2018, water temperatures at Above Early Intake gage were relatively high in November and January and otherwise about average compared with the past decade.

The seasonal range of water temperatures at Hetch Hetchy gage is relatively narrow compared with Above Early Intake gage due to the proximity of Hetch Hetchy gage to O’Shaughnessy Dam. During WY 2008–2018, daily average water temperatures at Hetch Hetchy gage ranged from 45.0 degrees Fahrenheit (°F) to 62.1°F, compared with 42.1°F to 69.6°F at Above Early Intake gage. Instantaneous water temperatures at Hetch Hetchy gage and Above Early Intake gage ranged from 43.9°F to 63.1°F and 40.6°F to 73.4°F, respectively (Table 28).

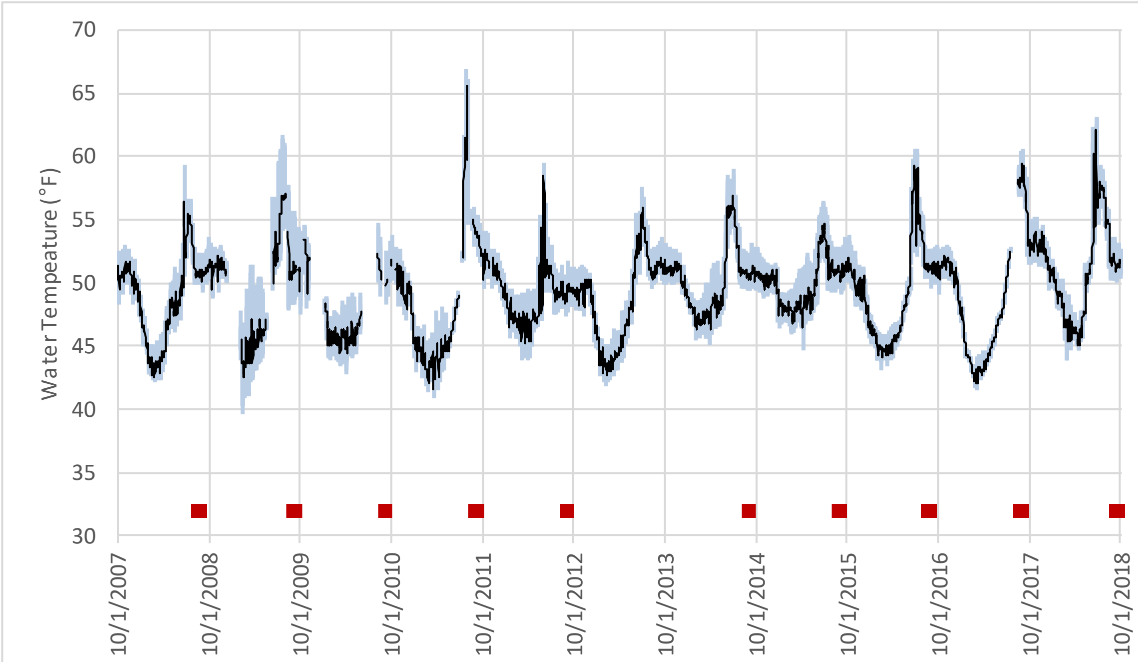

Figure 39. Daily average water temperature (black line) and daily water temperature range (blue lines) in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2008–2018. Snorkel surveys performed by the SFPUC in mid-August through early October 2008–2012 and 2014–2018 are identified by red markers.

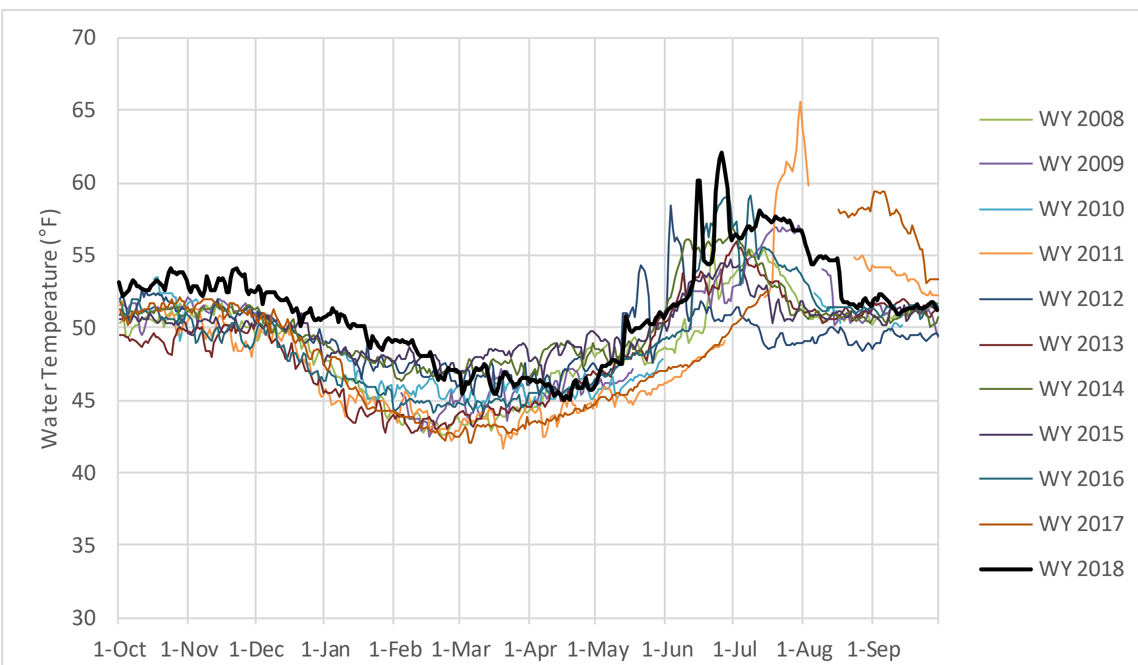

Figure 40. Daily average water temperature in the Tuolumne River at Hetch Hetchy gage (USGS 11276500) for WY 2008–2018, presented individually.

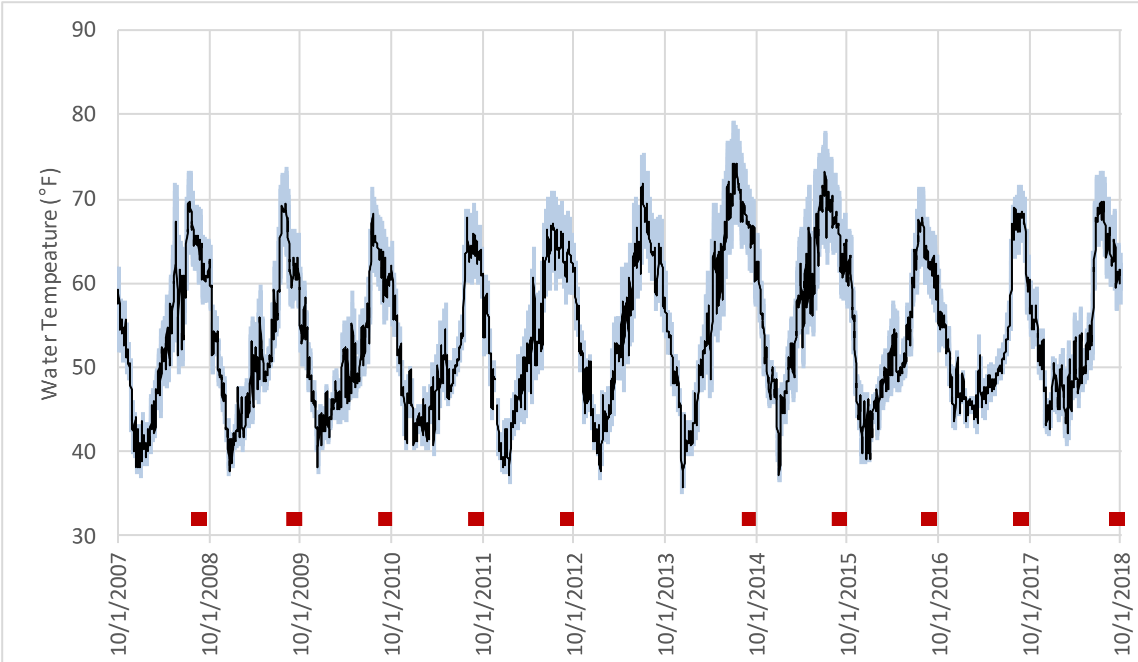

Figure 41. Daily average water temperature (black line) and daily water temperature range (blue lines) in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2008–2018. Snorkel surveys performed by the SFPUC in mid-August through early October 2008–2012 and 2014–2018 are identified by red markers.

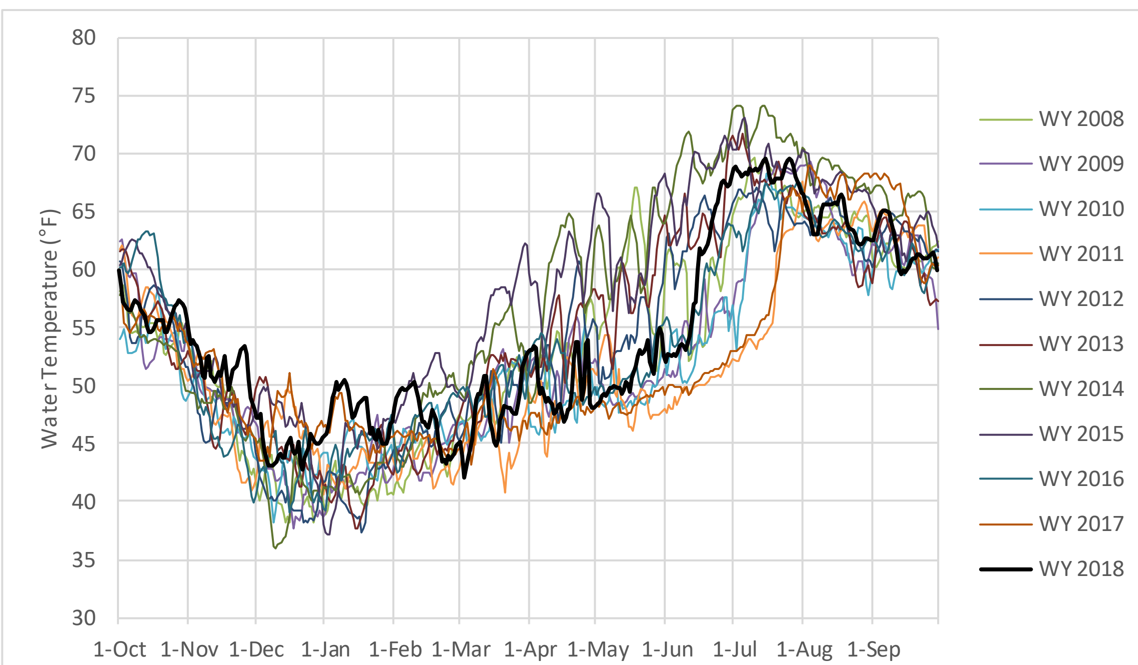

Figure 42. Daily average water temperature in the Tuolumne River at Above Early Intake gage (USGS 11276600) for WY 2008–2018, presented individually.

Table 28. Water temperatures (°F) for WY 2008–2018 at USGS gages in the Hetch Hetchy Reach.

Temperature metric	Water year and type[1]										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Dry	Nrml	Nrml	ExW	ExD	Dry	ExD	ExD	Nrml	ExW	Nrml
Tuolumne River at Hetch Hetchy gage (USGS 11276500)											
Mean daily average	48.8	49.6	47.1	47.9	49.2	48.5	50.2	50.0	49.2	48.5	51.2
Minimum daily average	42.6	42.5	48.2	50.5	45.2	42.8	46.3	46.6	44.1	42.0	45.0
Maximum daily average	56.5	57.0	53.5	65.7	58.4	56.0	56.9	54.7	59.3	59.4	62.1
Minimum daily minimum	42.1	39.6	42.8	40.8	43.9	41.9	45.1	44.6	43.2	41.5	43.9
Maximum daily maximum	59.4	61.7	64.2	66.9	59.5	57.6	59.0	56.5	60.6	60.6	63.1
Tuolumne River at Above Early Intake gage (USGS 11276600)											
Mean daily average	53.5	52.3	51.9	51.3	53.7	54.6	56.7	58.0	53.3	52.4	54.3
Minimum daily average	38.2	37.7	38.2	40.7	37.3	37.6	36.1	37.1	39.1	43.3	42.1
Maximum daily average	69.7	69.4	68.2	67.7	67.1	71.8	73.9	73.1	67.7	69.0	69.6
Minimum daily minimum	36.9	37.0	37.4	39.4	36.1	36.7	35.1	36.3	38.5	42.1	40.6
Maximum daily maximum	73.2	73.8	71.4	69.4	71.1	75.6	79.3	78.1	71.4	71.6	73.4

[1] Water year types include: ExD = extremely dry; Dry = dry, Nrml = normal; Wet = wet; ExW = extremely wet

4.4.2 Above Hetch Hetchy Reservoir Reach

Water temperatures at Above Hetch Hetchy gage are generally lowest in December and January and highest in July and August (Figures 43 and 44). During WY 2008–2018, mean daily average water temperatures at Above Hetch Hetchy gage ranged from 32.1°F to 68.3°F, and instantaneous water temperatures ranged from 31.8°F to 71.8°F (Table 29). Daily average water temperatures at Above Hetch Hetchy gage in WY 2018 were about average compared with water temperatures in the last decade (2008–2017). Minor exceptions include relatively warm daily average water temperatures in early January and relatively cold daily average water temperatures in early March.

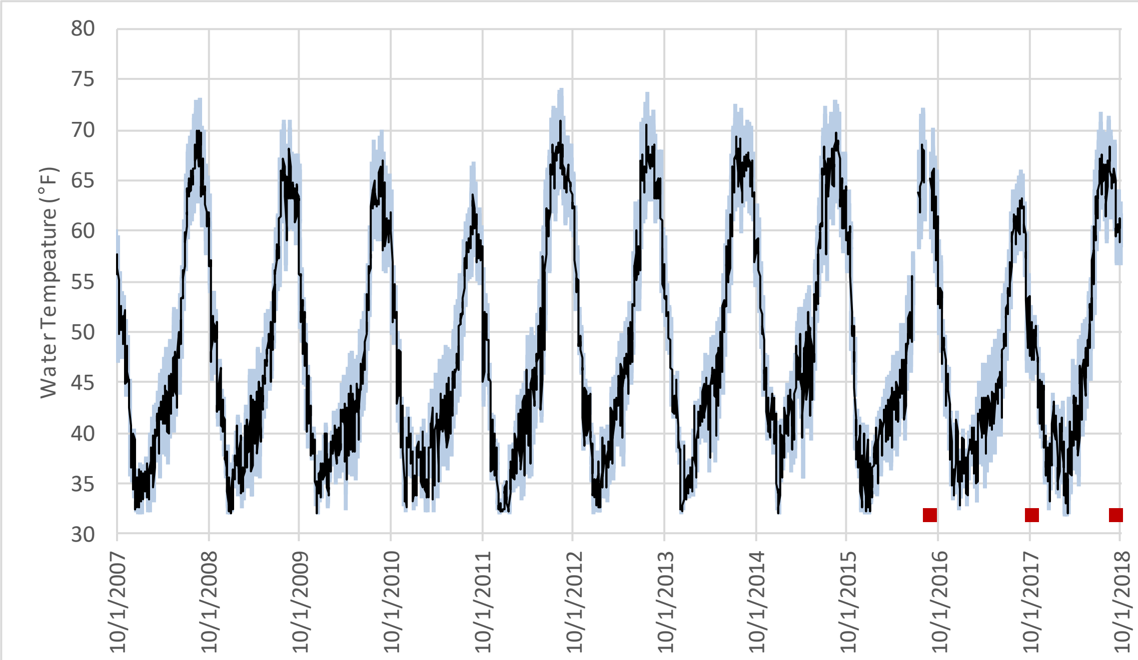

Figure 43. Daily average water temperature (black line) and daily water temperature range (blue lines) in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2008–2018. Snorkel surveys performed by the SFPUC in late August 2016 and October 2017 and 2018 are identified by red markers.

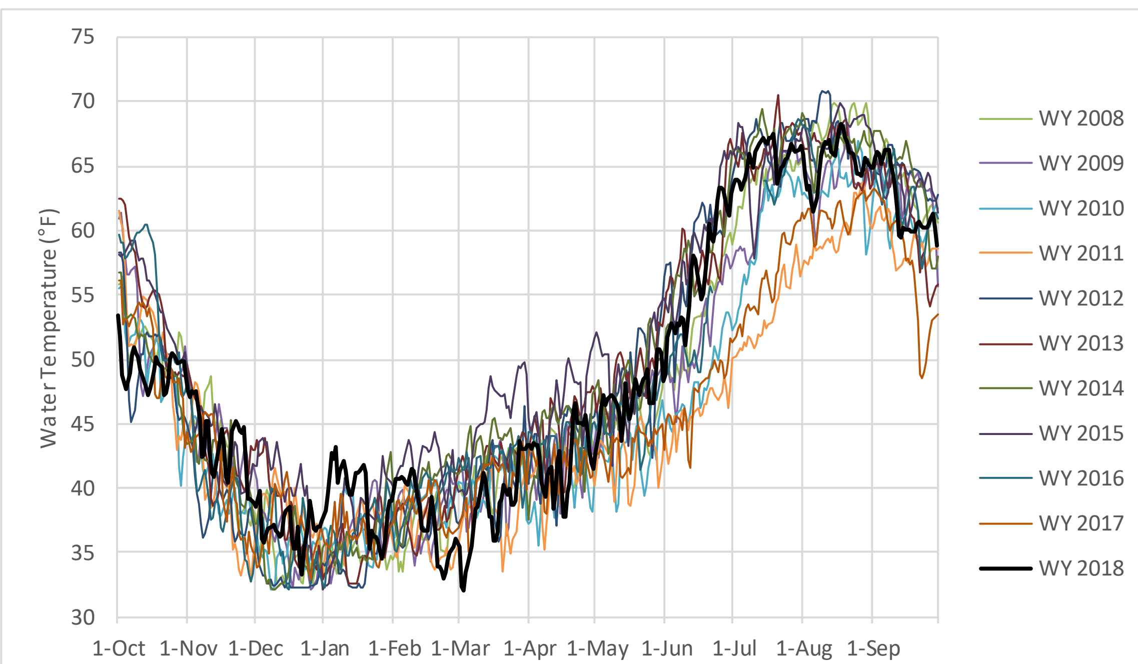

Figure 44. Daily average water temperature in the Tuolumne River at Above Hetch Hetchy gage (USGS 11274790) for WY 2008–2018, presented individually.

Table 29. Water temperatures (°F) for WY 2008–2018 at the USGS gage in the Above Hetch Hetchy Reservoir Reach.

Temperature metric	Water year and year type[1]										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Dry	Nrml	Nrml	ExW	ExD	Dry	ExD	ExD	Nrml	ExW	Nrml
Tuolumne River at Above Hetch Hetchy gage (USGS 11274790)											
Mean daily average	48.3	48.1	46.6	45.2	48.7	49.8	49.5	51.0	46.3	45.9	48.8
Minimum daily average	32.5	32.1	32.1	32.7	32.2	32.6	32.2	32.1	32.2	32.9	32.1
Maximum daily average	70.0	68.1	66.9	63.8	70.9	70.5	69.4	69.9	68.6	63.2	68.3
Minimum daily minimum	32.0	32.0	32.0	32.2	32.0	32.0	32.0	32.0	32.0	32.4	31.8
Maximum daily maximum	73.2	71.1	70.2	66.9	74.1	73.8	72.7	73.0	72.3	66.2	71.8

[1] Water year types include: ExD = extremely dry; Dry = dry, Nrml = normal; Wet = wet; ExW = extremely wet

4.4.3 Cherry Creek and Eleanor Creek Reaches

Daily water temperature data for Below Valley Dam, Above Holm Powerhouse, Below Holm Powerhouse, and Eleanor Creek gages were plotted for WY 2008 through WY 2018, both consecutively (Figures 45, 47, 49, and 51) and individually (Figures 46, 48, 50, and 52), to illustrate annual patterns and compare WY 2018 to conditions during the previous decade (2008–2017). Water temperature metrics based on daily data for the WY 2008 through WY 2018 period are presented in Table 30.

At Below Valley Dam gage during WY 2008 through WY 2018, average daily water temperatures ranged from 37.4°F to 59.1°F, and daily minimum and maximum temperatures ranged from 34.3°F to 61.5°F (Table 30). Water temperatures at Below Valley Dam gage generally decrease from October to December, remain relatively low from December through March, increase from March through June with the highest water temperatures in June, and decrease from July through September (Figure 46). In WY 2018, daily average water temperatures in October and early November were relatively high compared with the past decade (2008–2017) at Below Valley Dam gage. High early-season water temperatures were also experienced in WY 2010. In both WY 2010 and WY 2018, the highest temperatures occurred in October. In WY 2018, water temperatures from December through September were generally about average and within the range observed in recent years (Figure 46, Table 30).

At Above Holm Powerhouse gage during WY 2008 through WY 2018, average daily water temperatures ranged from 36.4 °F to 73.5°F, and daily minimum and maximum temperatures ranged from 35.4°F to 75.9°F (Table 30). The annual pattern of daily average water temperatures at Above Holm Powerhouse gage follows a slightly different pattern compared with Below Valley Dam gage; at Above Holm Powerhouse gage, temperatures are at their lowest during December–January and increase steadily to their highest in late June and July, and then steadily decrease through fall into winter, with no time periods where water temperatures remain stable (Figure 48). Water temperatures for WY 2018 generally followed a similar pattern compared with the past decade (Figure 48). During WY 2018, daily average water temperatures in January and July were relatively high compared with the past decade, with water temperatures in other months within the range observed in recent years.

At Below Holm Powerhouse gage during WY 2008 through WY 2018, average daily water temperatures ranged from 37.0 °F to 67.5°F, and daily minimum and maximum temperatures ranged from 34.9°F to 71.2°F (Table 30). The annual pattern of daily average water temperatures at Below Holm Powerhouse gage follows a slightly different pattern compared with Above Holm

Powerhouse gage; at Below Holm Powerhouse gage, the lowest temperatures occur during December through March and the highest water temperatures occur in June through September (Figure 50). Water temperatures in June through September are particularly variable. Daily average water temperature in WY 2018 generally followed a similar pattern as previous years. Water temperatures during late February and early March were particularly cold compared with conditions in recent years.

At Eleanor Creek gage during WY 2008 through WY 2018, average daily water temperatures ranged from 36.2°F to 71.9°F, and daily minimum and maximum temperatures ranged from 33.3°F to 74.8°F (Table 30). The annual pattern of daily average water temperatures at Eleanor Creek gage is relatively consistent among years, with temperatures at their lowest during December through February and increasing steadily to their highest in late July through early September, and then steadily decreasing again through fall into winter, with no time periods where water temperatures remain stable (Figure 52). Water temperatures for WY 2018 generally followed a similar pattern to the past decade (WY 2008–2017). Water temperatures from November through early February were relatively high compared with recent years, particularly in late December through mid-January.

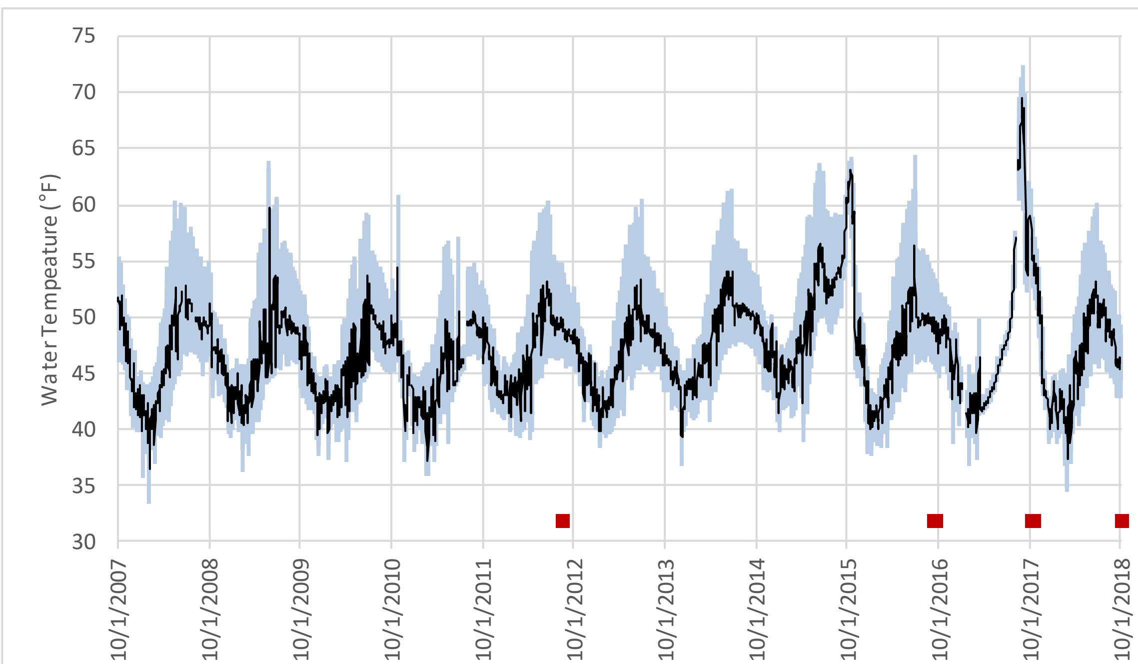

Figure 45. Daily average water temperature (black line) and daily water temperature range (blue lines) in Cherry Creek at Below Valley Dam gage (USGS 11277300) for WY 2008–2018. Snorkel surveys performed in August 2012, September 2016, and October 2017 and 2018 are identified by red markers.

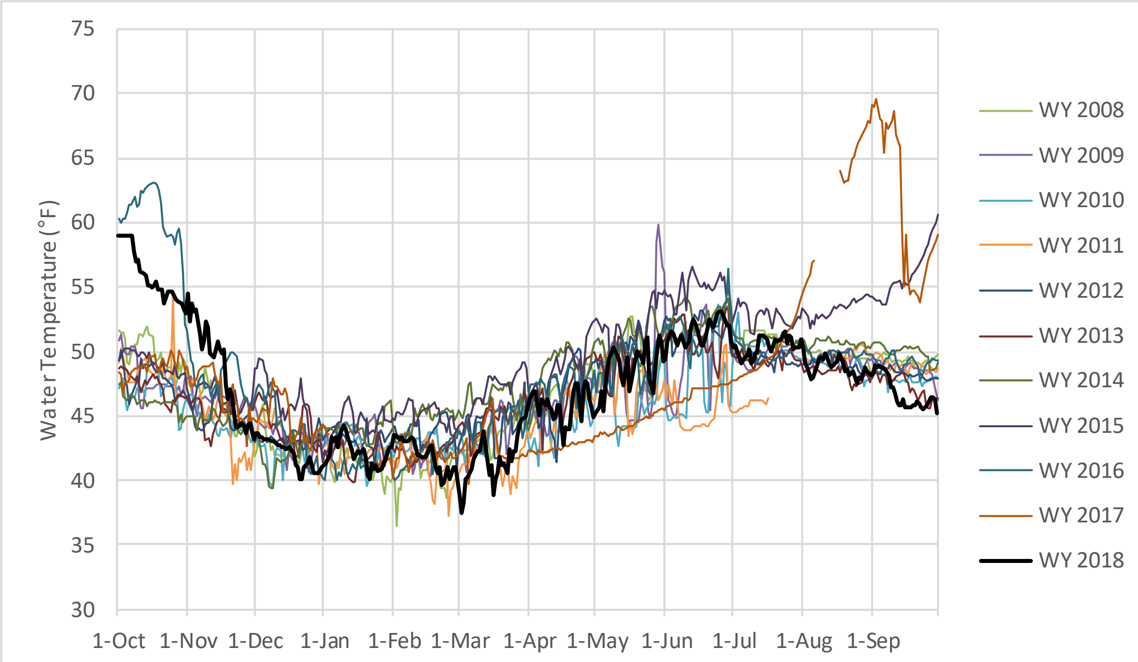

Figure 46. Daily average water temperature in Cherry Creek at Below Valley Dam gage (USGS 11277300) for WY 2008–2018, presented individually.

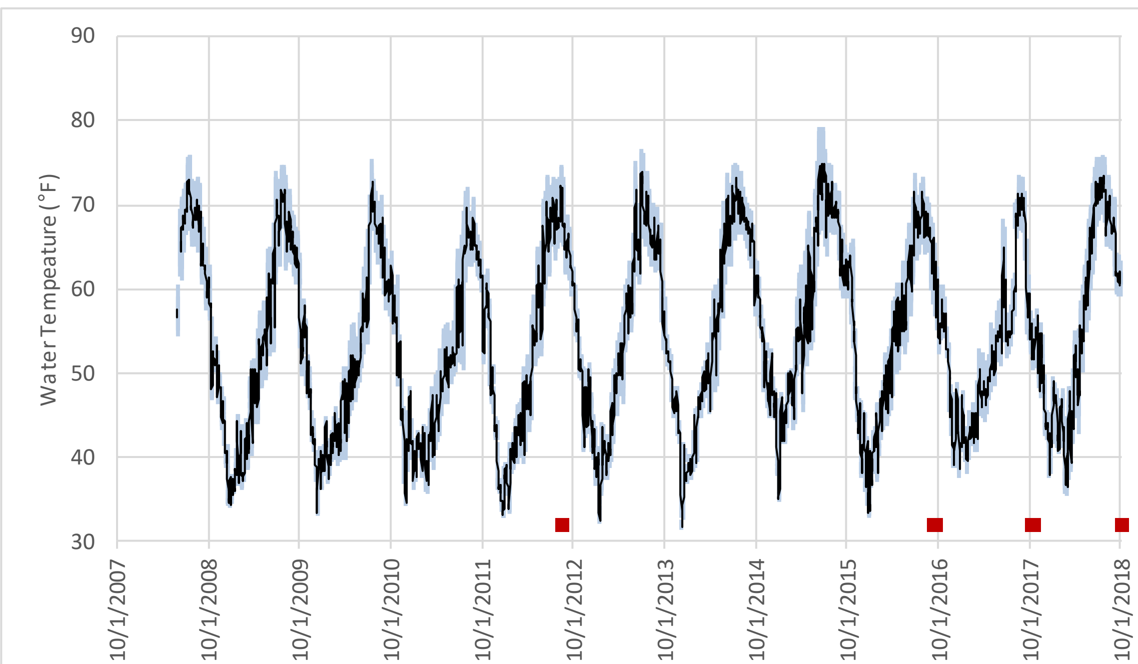

Figure 47. Daily average water temperature (black line) and daily water temperature range (blue lines) in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2008–2018. Snorkel surveys performed in August 2012, September 2016, and October 2017 and 2018 are identified by red markers.

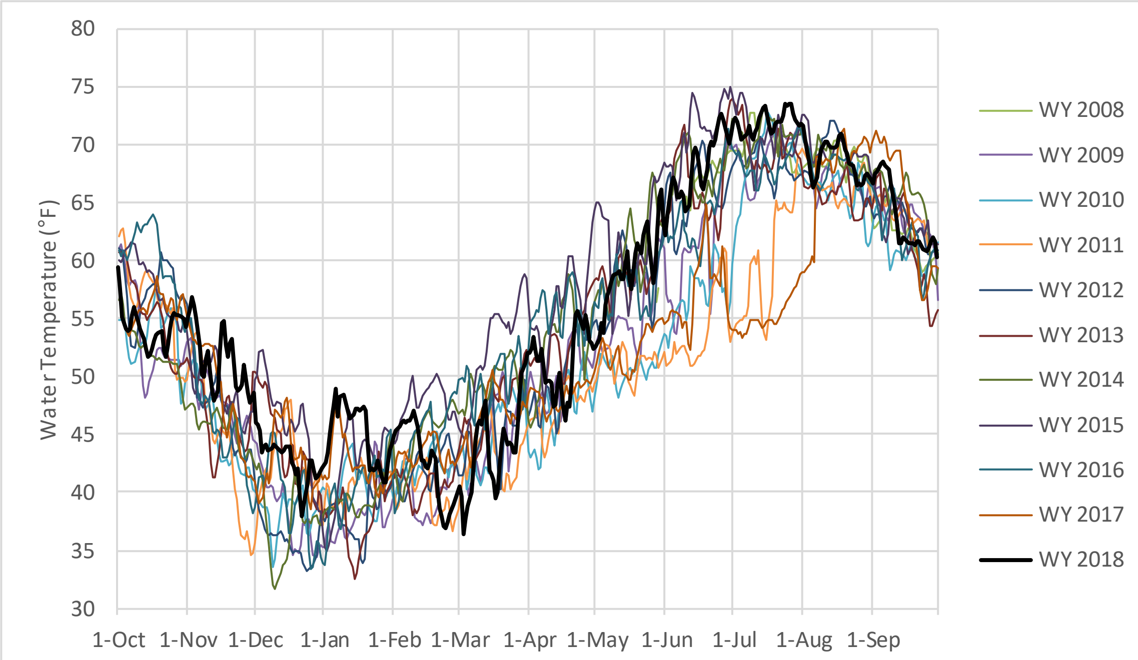

Figure 48. Daily average water temperature in Cherry Creek at Above Holm Powerhouse gage (USGS 11278300) for WY 2008–2018, presented individually.

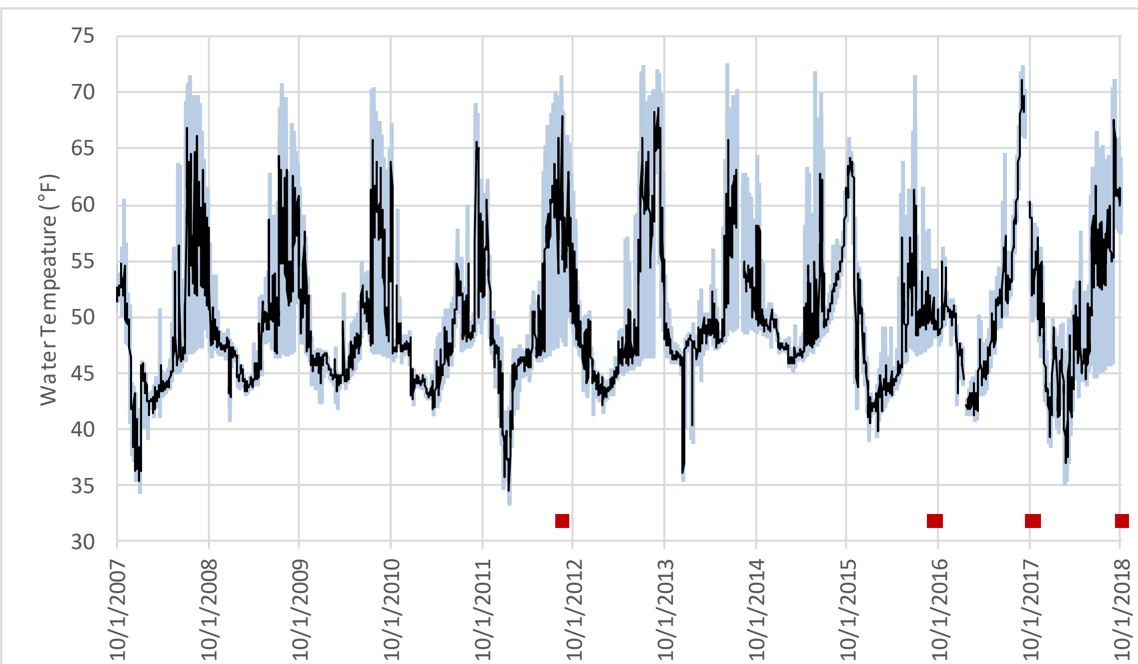

Figure 49. Daily average water temperature (black line) and daily water temperature range (blue lines) in Cherry Creek at Below Holm Powerhouse gage (USGS 11278400) for WY 2008–2018. Snorkel surveys performed in August 2012, September 2016, and October 2017 and 2018 are identified by red markers.

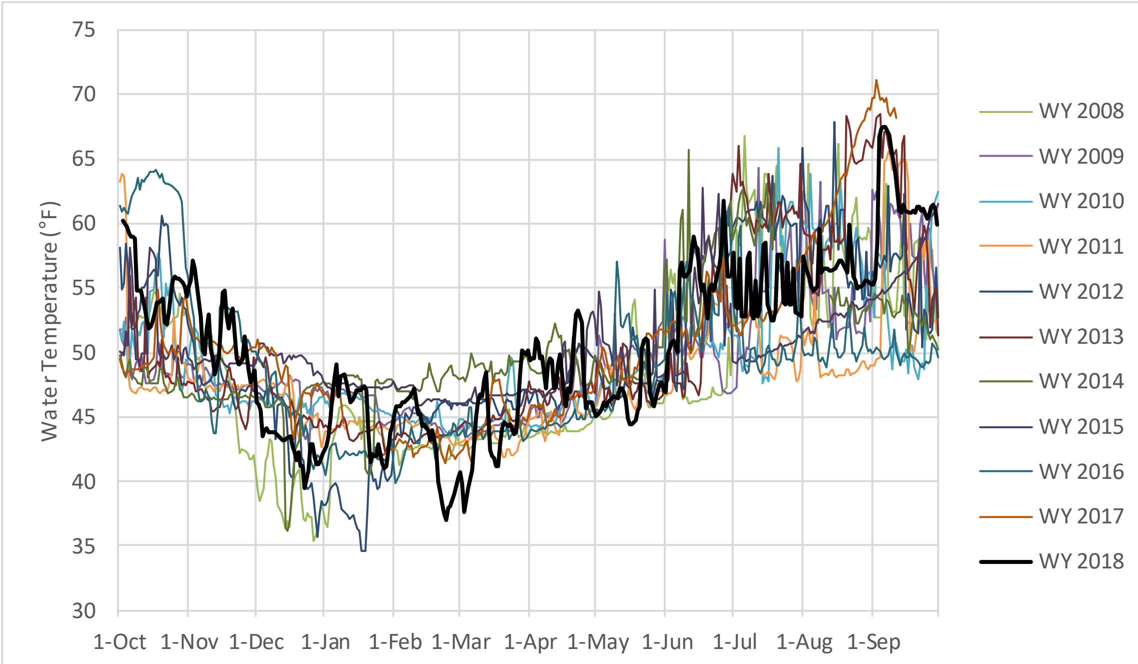

Figure 50. Daily average water temperature in Cherry Creek at Below Holm Powerhouse gage (USGS 11278400) for WY 2008–2018, presented individually.

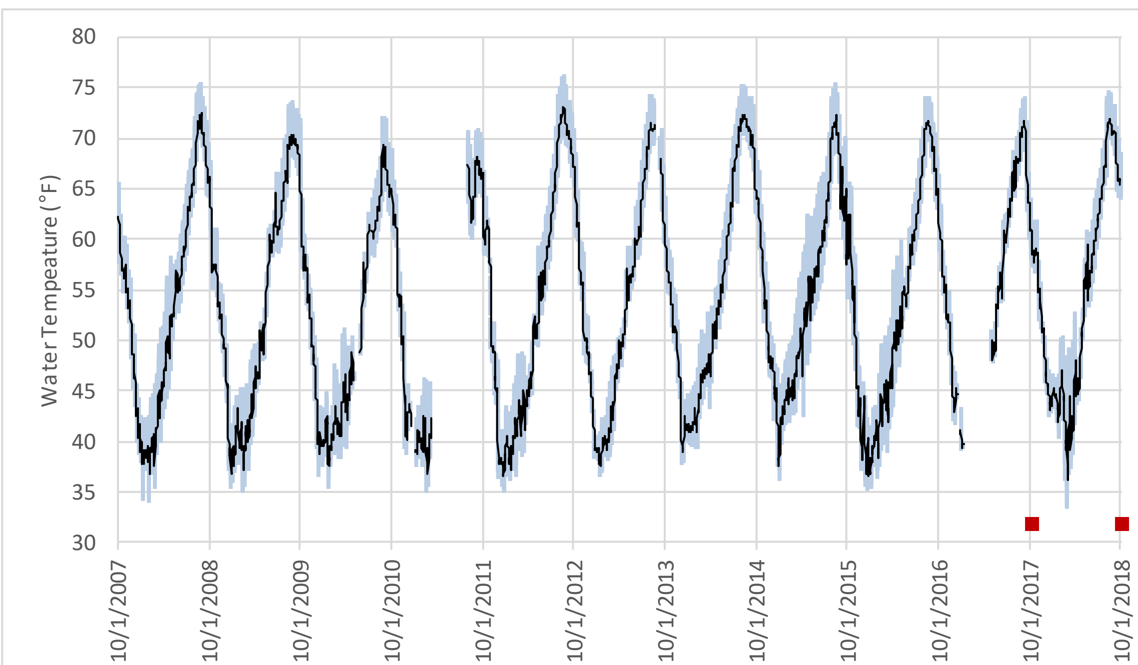

Figure 51. Daily average water temperature (black line) and daily water temperature range (blue lines) in Eleanor Creek at Eleanor Creek gage (USGS 11278000) for WY 2008–2018. Snorkel surveys performed in October 2017 and 2018 are identified by red markers.

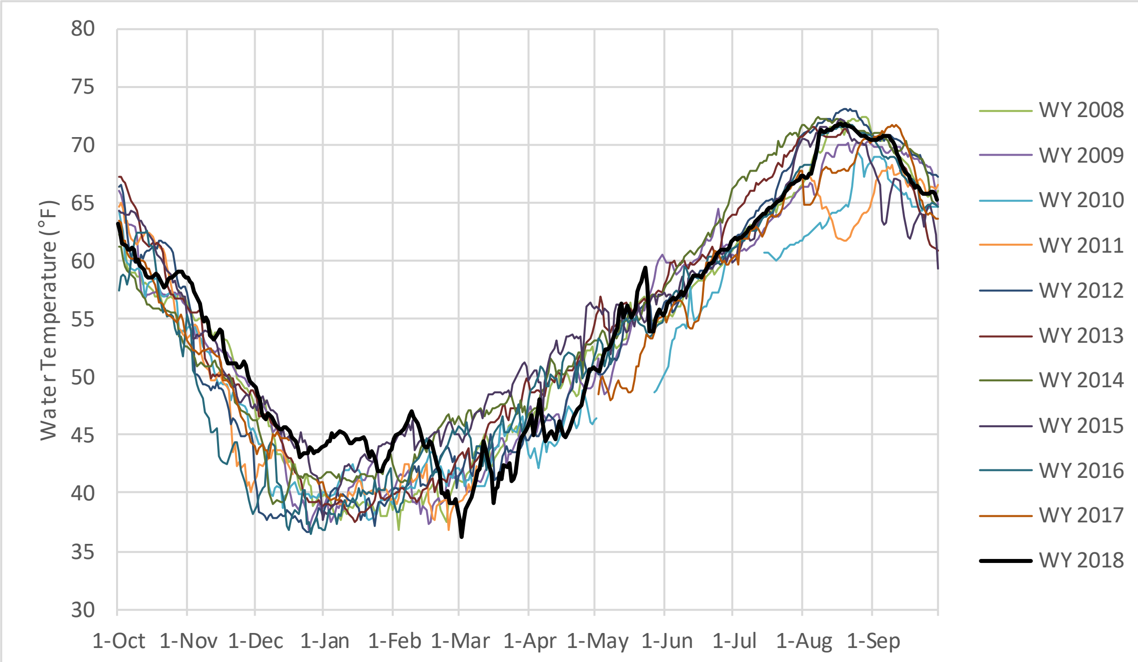

Figure 52. Daily average water temperature in Eleanor Creek at Eleanor Creek gage (USGS 11278000) for WY 2008–2018, presented individually.

Table 30. Water temperatures (°F) for WY 2008–2018 at USGS gages in the Cherry Creek and Eleanor Creek reaches.

Temperature metric	Water year and year type[a]										
	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
	Dry	Nrml	Nrml	ExW	ExD	Dry	ExD	ExD	Nrml	ExW	Nrml
Below Valley Dam gage (USGS 11277300)											
Mean daily average	46.4	46.7	45.8	45.3	46.9	46.6	47.7	49.6	48.1	47.8	47.0
Minimum daily average	36.4	40.3	39.4	37.2	40.8	39.9	39.3	41.4	40.0	39.6	37.4
Maximum daily average	52.8	59.8	53.7	54.4	53.2	53.4	54.1	60.6	63.2	69.6	59.1
Minimum daily minimum	33.4	36.1	37.0	35.8	39.0	38.3	36.7	38.8	37.6	36.7	34.3
Maximum daily maximum	60.4	63.9	59.4	61.0	60.4	60.6	61.5	63.7	64.4	72.5	61.5
Above Holm Powerhouse gage (USGS 11278300)											
Mean daily average	--[b]	52.6	51.3	50.9	53.5	54.1	54.7	57.4	54.7	52.2	55.3
Minimum daily average	--[b]	34.4	33.5	34.5	33.2	32.5	31.7	35.0	33.4	38.5	36.4
Maximum daily average	--[b]	71.8	72.8	69.7	72.2	74.0	73.3	74.9	71.5	71.3	73.5
Minimum daily minimum	--[b]	34.0	33.1	34.2	32.7	32.2	31.5	34.7	32.9	37.6	35.4
Maximum daily maximum	--[b]	74.7	75.6	72.1	74.7	76.6	75.0	79.3	73.8	73.6	75.9
Below Holm Powerhouse gage (USGS 11278400)											
Mean daily average	48.3	49.4	49.4	48.0	50.2	50.3	49.9	50.2	48.9	50.5	50.4
Minimum daily average	35.3	42.9	43.3	41.9	34.5	42.1	36.2	45.8	39.8	41.4	37.0
Maximum daily average	66.8	64.3	65.8	65.6	68.0	68.6	65.7	62.8	64.2	71.2	67.5
Minimum daily minimum	34.2	40.6	41.7	41.2	33.3	41.2	35.2	45.1	38.8	40.6	34.9
Maximum daily maximum	71.6	70.9	70.5	69.1	71.6	72.5	72.7	72.0	71.6	72.5	71.2
Eleanor Creek gage (USGS 11278000)											
Mean daily average	53.4	53.4	51.3	52.1[c]	53.3	53.5	54.8	55.0	52.9	57.5[d]	54.3
Minimum daily average	36.9	36.9	37.7	36.8[c]	36.6	37.6	39.0	37.7	36.5	39.4[d]	36.2
Maximum daily average	72.5	70.3	69.4	68.3[c]	73.2	71.6	72.4	72.4	71.8	71.7[d]	71.9
Minimum daily minimum	34.0	34.9	35.2	34.9[c]	34.9	36.5	37.8	36.1	35.1	39.0[d]	33.3
Maximum daily maximum	75.6	73.8	72.3	71.1[c]	76.5	74.5	75.4	75.6	74.3	74.1[d]	74.8

[a] Water year types include: ExD = extremely dry; Dry = dry, Nrml = normal; Wet = wet; ExW = extremely wet
[b] Water temperature metrics are not reported for water years with particularly large data gaps (>50% of data missing).
[c] Water temperature metrics are based on an incomplete data set. Data gaps during WY 2011 occurred in March through July.
[d] Water temperature metrics are based on an incomplete data set. Data gaps during WY 2017 occurred in December and January through early May.

5 CONCLUSIONS

5.1 Hetch Hetchy Reach

WY 2018 exhibited moderate flow conditions compared with the past decade. Average stream flow was substantially lower in WY 2018 compared with WY 2017, which was one of the wettest on record, and higher compared with WY 2013–2015 when drought conditions persisted in the region. The 2013 Rim Fire affected habitat conditions in the reach, evidenced by substantial coarse sediment (i.e., sand and small gravel) deposition in pools. This deposition was reduced in WY 2017 as the result of frequent high flows that scoured substantial amounts of sediment remaining stored in the channel during WY 2016. During 2018 fish monitoring surveys, no appreciable pool filling was observed at monitoring sites where substantial deposition of sand and gravel were observed in the past (i.e., sites 44-PW, 46-DP, and 49-SP).

In 2018, total density of Rainbow Trout >125 mm was lower compared with 2014–2017, and generally showed a decreasing trend over the 2014–2018 monitoring period. However, trends in Rainbow Trout density over the 2014–2018 monitoring period are variable by sub-reach. Similarly, total density of Brown Trout >125 mm in 2018 was lower compared with 2014–2017, with variable trends by sub-reach over the 2014–2018 monitoring period. Rainbow Trout densities have remained consistently higher compared with Brown Trout densities overall and by sub-reach.

The densities of Rainbow Trout and Brown Trout >125 mm in the Early Intake and O'Shaughnessy sub-reaches generally show a similar pattern compared with each other for the 2014–2018 period, indicating that similar environmental pressures were likely influencing these populations. It is unclear why Rainbow Trout and Brown Trout >125 mm densities in the Preston Falls sub-reach show different patterns compared with the Early Intake and O'Shaughnessy sub-reaches, but habitat conditions are likely an important factor. The Preston Falls sub-reach has unique habitat characteristics compared with the other sub-reaches (e.g., long, sand-bedded pools and runs with low channel gradient and complexity). Since water temperature and flow conditions in the Preston Falls sub-reach are expected to be intermediate to those in the Early Intake and O'Shaughnessy sub-reaches, these factors are not likely influencing trout populations differently in the Preston Falls sub-reach. Therefore, differences in density patterns in the Preston Falls sub-reach are more likely influenced by habitat conditions specific to the sub-reach.

For trout ≤125 mm, total densities of Rainbow Trout and Brown Trout in 2018 increased compared with 2017, which had the lowest observed densities during the 2014–2018 monitoring period. Densities of Rainbow Trout and Brown Trout ≤125 mm in the Early Intake, Preston Falls, and O'Shaughnessy sub-reaches were within the range observed during 2014–2017.

Densities of Rainbow Trout and Brown Trout ≤125 mm show similar patterns of year-to-year relative density overall and within each sub-reach during the 2014–2018 monitoring period, suggesting that age-0 Rainbow Trout and Brown Trout are responding similarly to environmental pressures within each sub-reach. However, the fact that these patterns of relative density are different for each sub-reach suggests that there are important differences in habitat quality and/or quantity between the sub-reaches.

Poor recruitment of Rainbow Trout and Brown Trout ≤125 mm in 2017 likely contributed to relatively low densities of trout >125 mm in 2018. Fortunately, the densities of Rainbow Trout >125 mm observed in 2018 were likely sufficient to improve age-0 recruitment in 2019, assuming favorable habitat conditions for spawning, incubation, and early rearing in 2019. Brown Trout populations may also increase in response to favorable conditions, but densities of both >125 mm and ≤125 mm were relatively low in 2018.

The fish population monitoring approach and sampling framework developed in 2014 and implemented in 2014–2018 continue to detect statistically significant differences in trout population abundance and linear density from one year to the next in key sub-reaches of the Hetch Hetchy Reach of the Tuolumne River.

5.2 Above Hetch Hetchy Reservoir Reach

Monitoring of the Above Hetch Hetchy Reservoir Reach was initiated in 2016 and continued through 2018. Rainbow Trout densities in the Above Hetch Hetchy Reservoir Reach in 2018 were higher on average compared with densities observed in the Hetch Hetchy Reach for trout >125 mm during 2017, but lower than observed in 2016. In 2018, Rainbow Trout ≤125 mm were observed at three of the five sites, whereas no Rainbow Trout ≤125 mm were observed in 2017. No Brown Trout were observed at the five monitoring sites surveyed in the Above Hetch Hetchy Reservoir Reach in 2018.

The extent to which trout from Hetch Hetchy Reservoir have access to monitoring sites in the Above Hetch Hetchy Reservoir Reach is unknown. A potential barrier to upstream movement near the downstream end of the Above Hetch Hetchy Reservoir Reach may inhibit trout from moving upstream from the reservoir into the study reach. Due to the close proximity of the reservoir to monitoring sites, unimpeded or periodic access to monitoring sites by trout from the reservoir could affect seasonal abundance estimates, as well as how and when trout use habitats in the Above Hetch Hetchy Reservoir Reach. In addition, if high flows displace substantial numbers of trout (of all age classes) downstream to the reservoir and a barrier then restricts access to habitat upstream of the reservoir, the reservoir could potentially be a “sink” to the trout population in the monitoring reach, assuming recruitment from upstream is insufficient to seed available habitat. Therefore, the potential effect of the reservoir on trout populations at these monitoring sites is currently unknown.

Streamflow and water temperature at Above Hetch Hetchy gage are not affected by management and represent natural flow and water temperature regimes. The WY 2018 annual hydrograph generally showed a typical pattern compared with other water years during 2008–2017. Mean daily streamflow in WY 2018 was similar compared with WY 2016 and lower than in WY 2017. Water temperatures during WY 2018 were generally within the range of conditions observed in the past decade.

5.3 Cherry Creek and Eleanor Creek Reaches

Flow conditions in Cherry and Eleanor creeks during WY 2018 were generally about average compared with conditions experienced over the past decade, with the exception of WY 2017, which was particularly wet (even for extremely wet water year types). Results from 2018 monitoring in Cherry Creek indicate that linear densities of Rainbow Trout >125 mm increased in the Upper Cherry sub-reach and decreased in the Lower Cherry sub-reach compared with 2017. The largest difference between years occurred in the Holm Powerhouse sub-reach, which saw a large decrease in the density of Rainbow Trout >125 mm from 2017 to 2018. Although the causes are uncertain, these differing population responses may have resulted from a combination of factors related to differences in habitat conditions between sub-reaches and the effects of a high-flow event that occurred during the survey in 2018. Water temperature may also influence trout density, with relatively low trout density at sites located near Valley Dam where water temperatures typically remain below 55°F throughout the year. Linear densities of Rainbow Trout >125 mm in the Eleanor Creek Reach decreased moderately from 2017 to 2018.

In 2018, densities of Rainbow Trout ≤125 mm were greatest in the Eleanor Creek Reach and lowest in the Holm Powerhouse sub-reach. Densities of Rainbow Trout ≤125 mm declined in the Lower Cherry and Holm Powerhouse sub-reaches and Eleanor Creek Reach from 2017 to 2018 and increased in the Upper Cherry sub-reach. It is uncertain why age-0 recruitment was lower in three of four sub-reaches in 2018 compared with 2017, but the same relative changes are observed with Rainbow Trout >125 mm.

The fish population monitoring approach and sampling framework for Cherry Creek appear to be effective for efficiently surveying trout populations in key habitat units and for detecting changes in trout population abundance from year to year and trends over longer periods.

6 RECOMMENDATIONS

6.1 Hetch Hetchy Reach

For 2019, monitoring in the Hetch Hetchy Reach should continue in the same monitoring sites that were sampled in 2017 and 2018.

6.2 Above Hetch Hetchy Reservoir Reach

Monitoring sites in the Above Hetch Hetchy Reservoir Reach were added to annual fisheries monitoring surveys in 2016 to include an independent "control" reach to help understand the effects of managed flows on long-term population trends in the Hetch Hetchy Reach. Surveys in the Above Hetch Hetchy Reservoir Reach continued in 2017 and 2018 with minor modifications to the suite of monitoring sites sampled each year. Additional adjustments may be necessary in 2019 to refine the combination of monitoring sites to best represent habitat conditions in the reach and consider the site selection criteria developed for the Hetch Hetchy Reach. To the extent possible, it is recommended that the suite of monitoring sites becomes consistent as soon as possible to reduce year-to-year variability in trout abundance and linear density estimates associated with surveying a different composition of habitats.

Consideration should be given to evaluating whether a barrier to trout passage is present near the downstream end of the reach. This evaluation would help determine whether there is direct access from the reservoir to monitoring sites. This factor could moderate or affect trout abundance at monitoring sites in the Above Hetch Hetchy Reservoir Reach.

6.3 Cherry Creek and Eleanor Creek Reaches

For 2019, monitoring in the Cherry Creek and Eleanor Creek reaches should continue in the same monitoring sites that were sampled in 2017 and 2018.

6.4 Future Analysis

Snorkel survey data have been collected in a similar manner since 2007 in the Hetch Hetchy Reach. Current analysis has been focused on the comparisons and trends among years, especially those since 2014. However, one of the goals of the UTREP snorkel program is to determine the effects of interannual variation in streamflow and water temperature on trout populations. Identifying these effects requires an evaluation of the mechanisms that might be affecting trout populations. For example, how does the frequency, magnitude, duration, and timing of winter flood events affect Brown Trout age-0 abundance? A detailed analysis using the trout snorkel survey, hydrology, and water temperature data that has been collected to date would help develop a mechanistic understanding of these relationships.

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