State of California
Natural Resources Agency
California Department of Fish and Wildlife

Flow Monitoring and Unimpaired Flow Estimation Report for REDWOOD CREEK, Humboldt County

STREAM EVALUATION REPORT 18-1

December 2018

Cover photo: Upper Redwood Creek, April 12, 2016

California Department of Fish and Wildlife

Report No. 18-1

FLOW MONITORING AND UNIMPAIRED FLOW ESTIMATION REPORT FOR REDWOOD CREEK, HUMBOLDT COUNTY

December 2018

John Laird	Edmund G. Brown Jr.	Charlton H. Bonham
Secretary for Resources	Governor	Director
Natural Resources Agency	State of California	Department of Fish and Wildlife

Flow Monitoring and Unimpaired Flow Estimation Report for Redwood Creek, Humboldt County

By

William Cowan, P.E.
California Department of Fish and Wildlife
Statewide Water Planning
Instream Flow Program

Suggested Citation: Cowan, W. 2018. Flow Monitoring and Unimpaired Flow Estimation Report for Redwood Creek, Humboldt County. Stream Evaluation Report 18-1. California Department of Fish and Wildlife, Water Branch Instream Flow Program. 33 pp.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The dominant variable in determining the form and function of a river is its flow regime (Annear et al. 2004). Hydrology is a key riverine component that influences everything from the shape of a river's channel to the abundance and diversity of fish and other organisms reliant on distinctive flow patterns (Annear et al. 2004). Watershed hydrology is best characterized by examining trends in flow monitoring data, preferably from stream gages with a long continuous record, and where the flows have not been significantly impaired by diversions. A key component of flow regime criteria is the consideration of anticipated seasonal flows (CDFG 2008).

The California Department of Fish and Wildlife (Department) Instream Flow Program conducted a study of Redwood Creek, Humboldt County, a tributary to the South Fork Eel River (SFER). The SFER is priority watershed under the California Water Action Plan (CWAP). This study was part of a suite of actions supporting the CWAP to address instream flow enhancement for anadromous salmonids in California streams and rivers. A hydrologic record is necessary to assess a streams hydrologic function as well as stream components such as habitat change, water quality, channel maintenance, and riparian processes (Annear et al. 2004). Further, streamflow data are needed to develop hydrologic time series and habitat time series, and components necessary for development of flow prescriptions. This report documents the methods, techniques, and analyses used to estimate an unimpaired streamflow time series for Redwood Creek. The results of this study will be used to further evaluate relationships between streamflow and habitat in Redwood Creek.

A long-term, continuous streamflow record is not directly available for Redwood Creek. Fortunately, a long-term stream flow record was available for Bull Creek, a nearby watershed north of Redwood Creek (Figure 1). Bull Creek is believed to have remained relatively unimpaired since 1988, when the United States Geological Survey (USGS) installed a gage to monitor and record water stage. In the Water Year Summary for the Bull Creek stream gage, USGS remarked that there are "minor diversions upstream from the station for domestic and recreational use" (USGS 2016a).

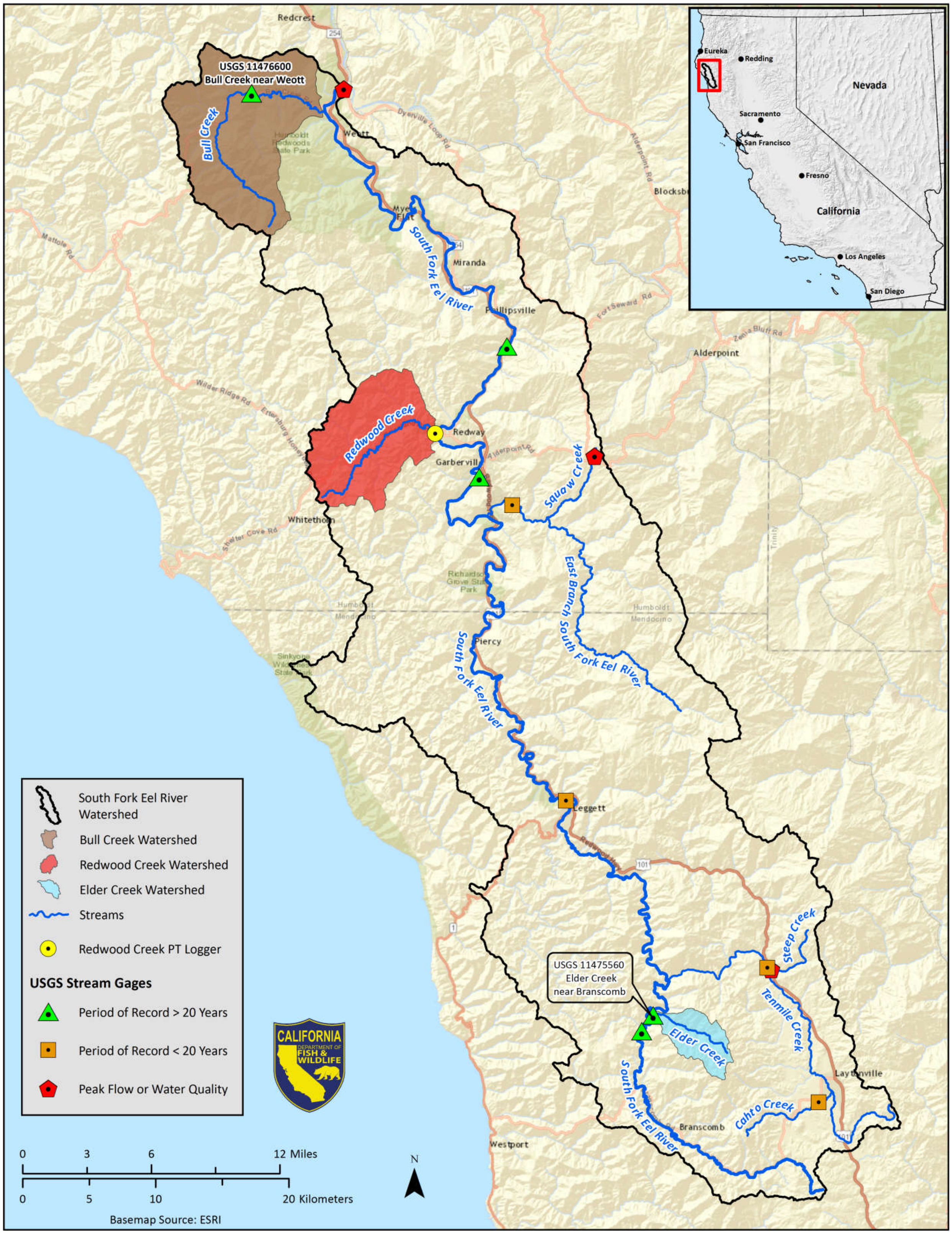

Figure 1. South Fork Eel River watershed map highlighting Bull Creek, Redwood Creek, and Elder Creek watersheds.

2.0 OBJECTIVES

The objectives of this study were to: 1) estimate an unimpaired streamflow time series for Redwood Creek by scaling the Bull Creek streamflow record; 2) develop hydrographs for Redwood Creek and the tributaries to Redwood Creek using monitoring data collected in the Redwood Creek watershed in 2016; and 3) compare the 2016 hydrograph developed for Redwood Creek to the hydrograph for Bull Creek over the same time-period. Water stage monitoring in the Redwood Creek watershed was completed using pressure transducers (PTs) installed near the downstream end of Redwood Creek and each of the five major tributaries. The water stage readings were paired with discharge measurements recorded near the PTs to generate the hydrographs.

3.0 METHODS

Unimpaired flow for Redwood Creek was estimated from the Bull Creek long-term stream flow record using scaling techniques proposed by the State Water Resources Control Board (Water Board; SWRCB 2014). Watershed scaling is a desktop method that simulates the long-term flow record from an existing stream gage to an ungaged watershed by factoring annual precipitation and drainage area. Annual precipitation and drainage area were generated from the internet-based computer program StreamStats (USGS 2016b).

Discharge measurements and water stage data were collected using standard operating procedures (SOPs) from the Department Instream Flow Program (CDFW 2013a) and the State of Utah Division of Water Quality (DWQ 2014), respectively. Department staff installed water stage monitoring equipment at the base of Redwood Creek and its five major tributaries. The stage-discharge rating relationships were developed using standard regression techniques in Microsoft Excel and the empirical hydraulic utility IFG4 (Waddle 2001), commonly known as Log-Log regression.

3.1 Watershed Scaling

The Water Board Division of Water Rights recommends watershed scaling to estimate flow in an ungaged watershed. When direct gage data are not available, the watershed is scaled to another nearby watershed with a long-term hydrologic record. The gaged watershed flow is multiplied by the ratio of the drainage area and mean annual precipitation of the two watersheds.

Drainage area and annual precipitation were generated from the computer program StreamStats (USGS 2016b), a map-based tool that allows users to select a point on a stream and receive back hydrologic and geographic information for the upstream tributary watershed. StreamStats outputs details such as watershed drainage area, annual precipitation, average gradient, longest flow path, and other information described below in Section 4.0.

The Water Board published the following scaling equation in *Appendix B. Guidelines for Preparation of Water Supply Report and Cumulative Diversion Analysis* of their Policy for Maintaining Instream Flows in Northern California Coastal Streams (SWRCB 2014):

$$MDD(ungaged) = MDD(gaged)\left(\frac{DA(ungaged)}{DA(gaged)}\right)\left(\frac{MAP(ungaged)}{MAP(gaged)}\right)$$

where: MDD = mean daily discharge in cubic feet per second (cfs)

DA = drainage area in square miles (mi^2)

MAP = mean annual precipitation in inches (in)

3.2 Water Stage Monitoring

A direct comparison between two watersheds can be made by collecting short-term stream gage data from the subject watershed and comparing that to the gaged stream data for the same time period. The two short-term flow records will likely not match nor overlay directly if the subject watershed is impaired. However, watershed similarities can be assessed by comparing the magnitude of storm peaks, the shapes of each hydrograph, and the slopes of each hydrograph’s receding limbs.

In the spring of 2016, Department staff installed PTs near the downstream confluence of Redwood Creek with the SFER, and in each of its five major tributaries: Seely, Somerville, Miller, Lower China, and Upper Redwood creeks. Upper Redwood Creek is considered a tributary to the mainstem Redwood Creek, commonly referred to here as Lower Redwood Creek. The confluence of Upper Redwood and Lower China creeks are assumed to be the headwaters of mainstem Redwood Creek (Figure 2). The PTs were located in pools near the bottom of each tributary. The PTs were installed in stilling wells to minimize the impact of water turbulence on the depth measurements. The water surface elevation (WSEL) above the PT depth sensor was routinely recorded using an auto level to ensure the PTs remained in a stable position over the course of the monitoring period.

Staff measured discharge near each PT from March through December 2016. Installation and data collection was consistent with the State of Utah Division of Water Quality SOP for Pressure Transducer Installation and Maintenance (DWQ 2014). Discharge was measured consistent with the Department’s SOP for Discharge Measurements in Wadable California Streams (CDFW 2013a). Discharge measurements and PT stage height readings were used to develop stage-discharge ratings for the 2016 spring-summer recession period in Redwood Creek and its tributaries.

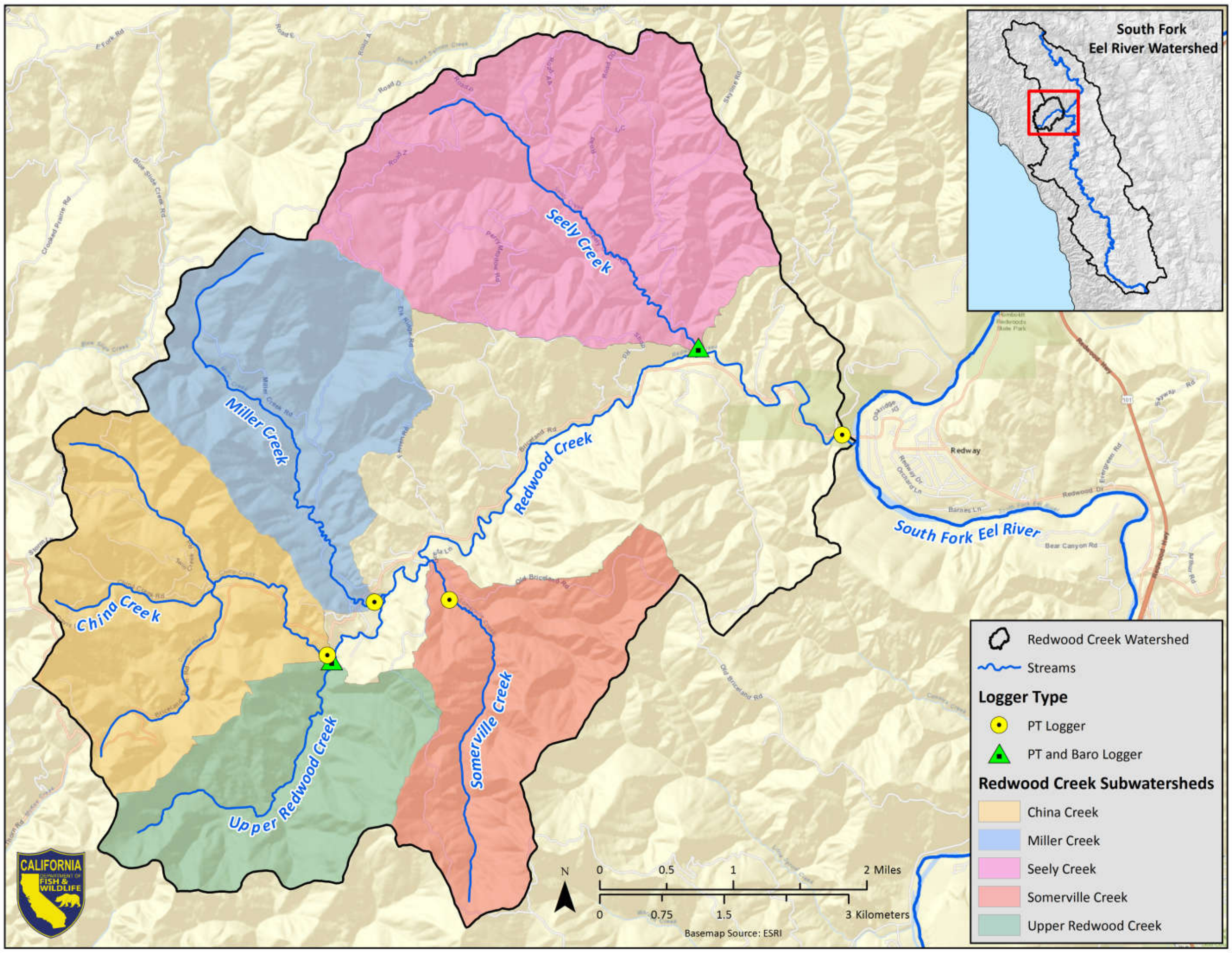

Figure 2. Redwood Creek watershed map indicating mainstem and five major tributaries.

3.3 Rating Curve Development

Stage-discharge rating curves were developed for each site by plotting the field discharge measurements with their corresponding PT depths. Two types of regression relationships were prepared for each rating curve, a power regression and a linear logarithmic regression (Log-Log). Power regression refers to the relationship derived from using discharge (*Q*) as the independent variable and depth (*D*) recorded by the PT at the time of the discharge measurement as the dependent variable (*Equation 1*). Log-Log regression employs the same independent and dependent variable, but incorporates the concept of a downstream hydraulic control into the computation of depth (*Equation 2*). The regression relationship that gave the best correlation was selected for rating curve development. The correlation coefficients (R^2) were compared and the regression with the best R^2 value was selected.

The power regression formula is as follows:

$$D = aQ^b \quad (Equation\ 1)$$

where ‘a’ is a constant variable, ‘Q’ is the discharge, and ‘b’ is the power function variable. The power regression coefficients were generated using a curve fitting tool in Microsoft Excel.

The linear logarithmic regression (Log-Log) method is most useful where the WSEL above the PT is influenced by a downstream hydraulic control point (Figure 3). Log-Log regression uses three or more measured stage and discharge pairs, along with the stage of zero flow (SZF) elevation, to develop a relationship between stage and discharge based on the following equation:

$$WSEL - SZF = aQ^b \quad (Equation\ 2)$$

Equation 2 is converted to log-log format and a log-log linear relationship is fit to the data. In a habitat unit where the slope of the longitudinal water surface is determined by a downstream hydraulic control point, like a pool or deep run, the elevation of that downstream control point is the SZF.

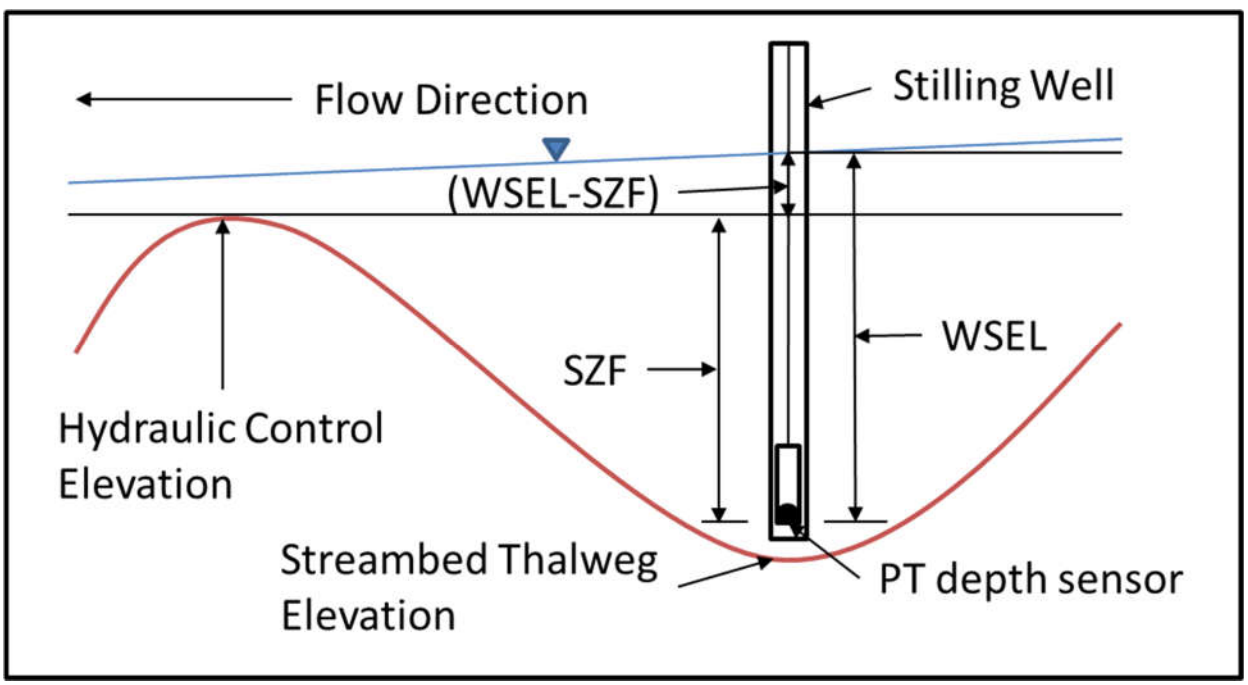

Figure 3. Stage of zero flow diagram.

4.0 WATERSHED SCALING DATA AND RESULTS

The ideal companion watershed for hydrologic scaling should be of similar size, be close in proximity, have a minimal number of diversions, and have a continuous stream flow record of at least 20 years. The 20-year minimum record length is derived from Department guidance (CDFG 2008) that recommends a minimum of 3 representative water years for each of the 6 water year classifications (critically dry, dry, below normal, above normal, wet, and extremely wet). A National Water Information System (USGS 2016a) query listed 12 USGS stream gaging stations in the SFER watershed (Table 1). Half of the gages are located in Humboldt County and half in Mendocino County. Not all the SFER stations measure stage continuously, and some gages have short periods of record (i.e., less than 20 years). USGS gages listed in Table 1 were omitted from analysis if the gaged watershed did not meet the criteria for scaling described above, namely: 1) being of similar size to the Redwood Creek watershed, 2) being in close proximity to Redwood Creek, 3) representing unimpaired flow by having minimal diversions, and 4) having a continuous stream flow record of at least 20 years.

Table 1. Selected USGS stream gages in the South Fork Eel River watershed.

USGS Stream Gage	Period of Record (number of full water years)	Watershed Size (mi^2)
Humboldt County		
SQUAW C NR GARBERVILLE CA (11475900)	01/20/1964 – 01/16/1973 Peak streamflow only, 10 counts	0.26
EB SF EEL R NR GARBERVILLE CA (11475940)	06/01/1966 – 09/29/1972 (5)	74.3
SF EEL R A GARBERVILLE CA (11476000)	10/01/1911 – 09/29/1940 (28)	468
SF EEL R NR MIRANDA CA (11476500)	09/26/1988 – present (29)	537
BULL C NR WEOTTCA (11476600)	08/05/1988 – present (29)	28.1
SF EEL R A DYERVILLE CA (11476620)	No streamflow data, water quality only	689
Mendocino County		
SF EEL R NR BRANSCOMB CA (11475500)	10/01/1946 – 09/29/1970 (23)	43.9
ELDER C NR BRANSCOMB CA (11475560)	09/25/1988 – present (29)	6.50
CAHTO C NR LAYTONVILLE CA (11475610)	10/03/2007 – present (9)	5.09
STEEP C NR LAYTONVILLE CA (11475690)	01/31/1963 – 01/16/1973 Peak streamflow only, 11 counts	2.90
TENMILE C NR LAYTONVILLE (11475700)	10/01/1957 – 09/29/1974 (16)	50.3
SF EEL R A LEGGETT CA (11475800)	09/22/1988 – present (19)	248

Department staff indicated that Bull and Elder creeks represented the least impaired gaged watersheds in the SFER drainage basin. Watershed properties of Redwood, Bull, and Elder creeks were compared (Table 2).

Table 2. Watershed properties of Redwood, Bull, and Elder creeks. Parameters are estimated for the area above the stream gage.

Description	Redwood Creek	Bull Creek	Elder Creek
Drainage Area (mi^2)	26	27.7	6.5
Relief (feet (ft)); max - min elevation)	2079	3090	2806
Max basin elevation (ft)	2371	3366	4202
Min basin elevation (ft)	292	275	1397
Drainage basin perimeter (mi)	31.4	37	15.5
Basin relief divided by basin perimeter (ft per mi)	66.2	83.5	180
Mean basin elevation (ft)	1021	1545	2792
Mean basin slope (%)	32.7	35.7	44.8
Percentage of area covered by forest	63.5	69	62.9
Average percentage of impervious area	0.1	0.1	0.0
Basinwide mean annual precipitation (in)	61.9	65.5	99.9
Percentage of developed (urban) land	2.2	4.1	0.2
Longest length of flow path (mi)	11	10	6

The parameters used in the scaling equation (see Section 3.1 Watershed Scaling) are drainage area and mean annual precipitation. Elder Creek is approximately four times smaller in area than both Redwood and Bull creeks (Table 2). In addition, the mean annual precipitation of Elder Creek is 100 inches, versus Redwood and Bull creeks at 62 inches and 66 inches, respectively (Table 2). Bull Creek is similar to Redwood Creek in mean basin slope and longest flow path length, indicating the lag time for the peak flow to occur at the point of flow measurement will be similar.

Another consideration is the proximity of Bull Creek to Redwood Creek (Figure 1). The confluence of Bull Creek with the SFER is approximately 27 miles downstream, north, from the confluence of Redwood Creek with the SFER. The confluence of Elder Creek with the SFER is approximately 98 miles upstream, south, from where Redwood Creek drains into the SFER. Both Bull and Redwood creeks are located on the west side of the basin, while Elder Creek is located on the east side.

Based on the above rationale, the Bull Creek drainage basin was chosen to estimate Redwood Creek unimpaired flows. The existing long-term mean daily discharge record from USGS stream gage BULL C NR WEOTT CA (USGS 11476600) was scaled for Redwood Creek using drainage area and mean annual precipitation. The scaling parameters and computed factors are given in Table 3.

Table 3. Scaling factors for Redwood and Bull creeks.

Basin	Drainage Area (mi^2)	Mean Annual Precipitation (in)
Redwood Creek	26.0	61.9
Bull Creek	27.7	65.5
Scaling Factor	**0.9386**	**0.9450**

The scaling factors (Table 3) were applied to the Bull Creek mean daily discharge hydrograph for the April 5, 2016 through July 13, 2016 period. This period represents the time when stream stage gaging was recorded in Redwood Creek. The Bull Creek hydrograph and scaled hydrograph representing the Redwood Creek synthetic hydrograph are shown in Figure 4.

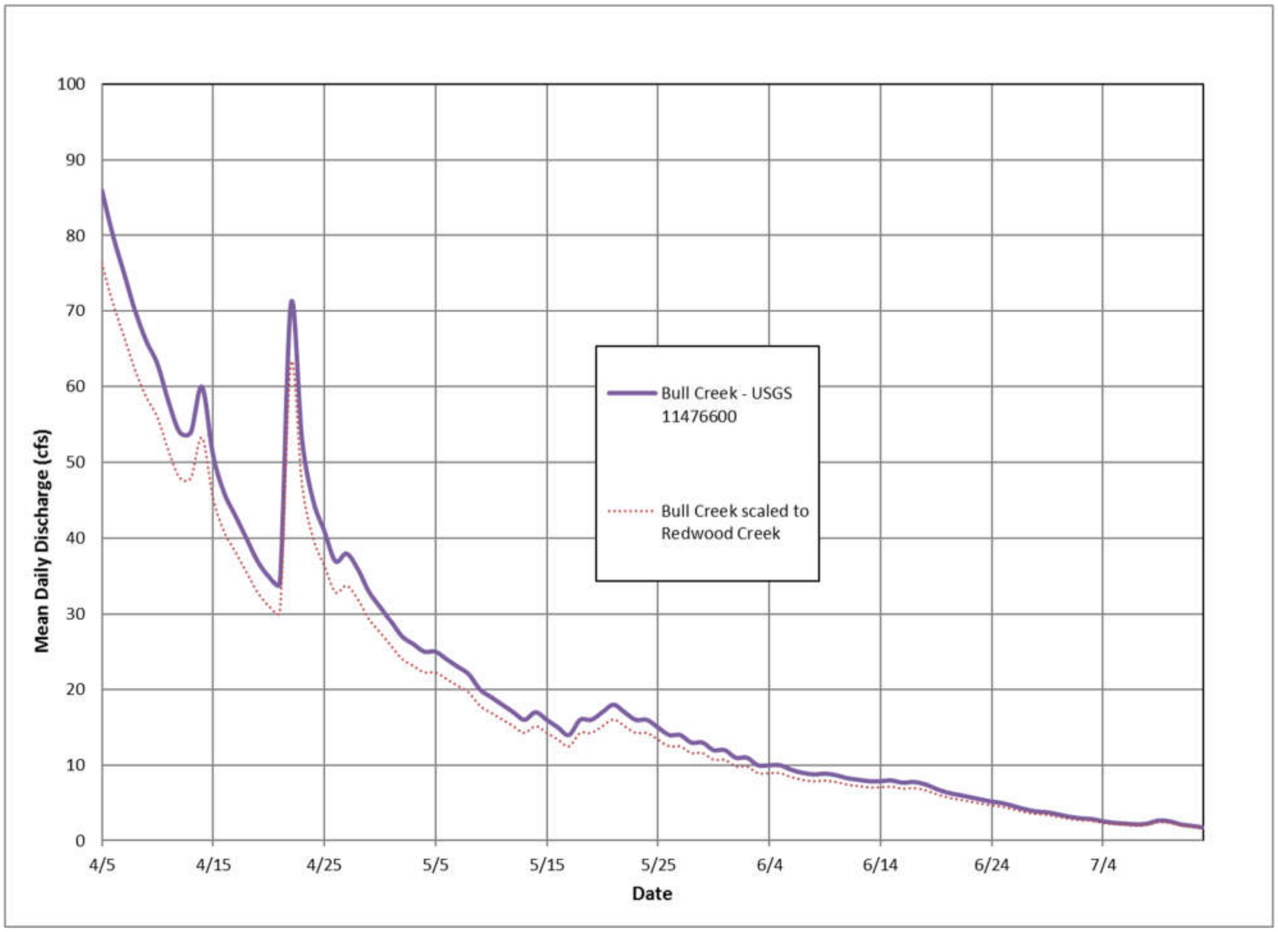

Figure 4. Bull Creek hydrograph and scaled synthetic Redwood Creek hydrograph in spring-summer 2016.

5.0 MONITORING DATA COLLECTION AND RESULTS

Pressure transducers (PT) were installed to monitor the 2016 spring-summer flow recession in the Redwood Creek watershed. The PTs were installed near the downstream boundary of Lower Redwood Creek and in each major tributary stream (Seely, Somerville, Miller, Lower China, and Upper Redwood creeks; Figure 2). The PTs were installed in each tributary in March 2016. The PT near the downstream boundary of Redwood Creek and the confluence with the SFER was not installed until the first week of April 2016, due to unsafe wading conditions caused by high flow levels. The PT's were non-vented sensors that read absolute pressure and measured water depth and temperature at 15-minute intervals. Two barometric pressure loggers were installed to correct the PT data for atmospheric pressure (see Section 5.2 Pressure Transducer Barometric Compensation).

Water stage readings recorded by the PTs were paired with field discharge measurements to develop predictive stage-discharge ratings for each PT location. Five to six distinct flow levels were sampled for discharge over the course of the monitoring period for each PT installation. Ultimately, the rating from each PT location was used to convert the depth recordings to a time series of discharge over the monitoring period.

Storm flows can alter the stream bed profile by displacing particles downstream and allowing materials from upstream to be deposited between the PT and the downstream hydraulic control. The accuracy of a stage-discharge rating relationship relies on a stable longitudinal and lateral stream bed profile between the PT and the downstream hydraulic control (Rantz et al. 1982). Storm flows precluded the use of some PT depth readings and associated discharge measurements recorded near the beginning and end of the monitoring period. The PTs in the tributary creeks were installed during March of 2016, starting in Seely Creek on March 7, 2016. Conditions in the tributaries during March were unstable with several storms occurring. All the PTs, including Lower Redwood, were not collecting PT level data in unison until April 2016.

5.1 Pressure Transducer Stilling Well Installation

Stage-discharge relationships were characterized over the monitoring period by installing PTs in Redwood Creek and each tributary. The PTs were installed in pools where the water surface directly above the PT probe was still, and where the stream bed appeared to be stable. Installation in pools ensured that PTs remained submerged during low flow periods, reduced frequent fluctuations in the depth recorded by each PT, and helped reduce the likelihood of changes to the pool's bed elevation.

A PVC pipe was installed for each PT to act as a stilling well. The PTs were hung inside the stilling wells from the clasp of a padlock using metal cable. Steel fence posts were driven into the substrate to secure the stilling wells, which were lashed to the fence posts using stainless steel hose clamps (Figure 5). The stilling wells were perforated to allow the water surface level inside the stilling well to match the outside stream level (Figure 6), while also protecting the PTs from the wave action of flowing water and from damage. The stilling well construction and deployment of the PTs was consistent with the State of Utah Division of Water Quality SOP (DWQ 2014).

Data collection periods for each monitoring location are listed in Table 4. All six PTs recorded water stage in unison from April 5, 2016 through July 13, 2016. Tributary PTs operated into the fall. However, the water stage sensor in the Lower Redwood Creek PT became clogged with sediment and stopped recording after July 13, 2016. Fortunately, the spring-summer recession occurred within the Lower Redwood Creek monitoring period, April 5, 2016 through July 13, 2016.

Figure 5. Typical pressure transducer stilling well installation.

Figure 6. Perforated stilling well.

Table 4. Levelogger and Barologger installation and removal schedule.

Creek	Levelogger Installation Date	Levelogger Removal Date	Barologger Installation Date	Barologger Removal Date
Lower Redwood	4/5/2016	12/01/2016	-	-
Seely	3/7/2016	11/29/2016	3/07/2016	12/01/2016
Somerville	3/8/2016	11/29/2016	-	-
Miller	3/8/2016	11/29/2016	-	-
Lower China	3/9/2016	11/28/2016	-	-
Upper Redwood	3/22/2016	11/28/2016	3/22/2016	11/28/2016

5.2 Pressure Transducer Barometric Compensation

Department staff installed Solinst Levelogger® Edge Model 3001 PTs at each monitoring location. Two Solinst barometric pressure loggers (Barologgers) were installed near the Seely Creek and Upper Redwood Creek PT sites (Figure 2). The non-vented PTs measure water depth and temperature, and read absolute pressure. Barologgers measure atmospheric pressure. The PT readings must be compensated by subtracting the atmospheric pressure component to resolve the water pressure. The Barologger unit installed in Seely Creek was used to compensate all the PTs except for Upper Redwood Creek. The redundant Barologger in Upper Redwood Creek was installed in the event the Barologger near Seely Creek was damaged or stolen.

5.3 Survey Control

Stage-discharge rating development requires the PT probe elevation to remain constant over the monitoring period. Differential leveling techniques were used to ensure the elevation of each PT sensor was not disturbed by high flow events or storm debris. Vertical control was established at each site by installing a vertical benchmark on the stream bank near the PT stilling well. The WSEL above the PT sensor was routinely surveyed during the monitoring period (Figure 7). The WSEL and SZF (see Section 3.3 Rating Curve Development) were surveyed at each site using a tripod-mounted auto level and a stadia rod. The SZF is the ground elevation of the downstream hydraulic control point. The SZF is found by following the deepest pathway, the thalweg, downstream to a point where the thalweg elevation crests. The SZF level surveys were conducted in accordance with the Department SOP for Streambed and Water Surface Elevation Data Collection in California (CDFW 2013b). The recommended maximum variance in WSEL along a transect in a 1D model is 0.1 ft (USFWS 2011). The 1D standard was applied to the WSEL measurements to confirm the PT probe elevation did not change over the course of the monitoring period (Table 5).

Figure 7. Water surface elevation survey above pressure transducer depth sensor.

Table 5. Level survey results.

Creek	PT Probe Elevation (ft)		Variance (ft)
	Installation	Removal	
Lower Redwood	93.46	93.44	0.02
Seely	96.46	96.46	0.00
Somerville	96.48	96.43	0.05
Miller	93.96	93.97	0.01
Lower China	95.85	95.82	0.03
Upper Redwood	94.34	94.37	0.03

5.4 Discharge Measurements

Department staff periodically measured discharge during the monitoring period near each PT site. Discharge measurements were performed in accordance with the Department Discharge SOP (CDFW 2013a). Typically, discharge sites were located in glides where the water surface was flat, the depths were generally consistent from bank to bank, and there were no obstacles upstream or downstream that could impact average column velocity (Figure 8).

Figure 8. Discharge measurement location for Lower Redwood Creek.

The State of Utah Division of Water Quality SOP (DWQ 2014) recommends that five to six distinct discharge/water stage pairs be collected to develop the stream stage versus flow ratings. Each site was visited and sampled for discharge at least six times. Some sampled discharge measurements could not be used in the rating development. Excluded discharges were collected outside of the target monitoring period, either earlier in the spring or later in the fall when storm surges had altered the streambed profile, affecting the rating relationship. The discharge measurement data used are provided in Table 6.

Table 6. Pressure transducer discharge summary.

Creek	Date Measured	Discharge (cfs)
Lower Redwood	4/5/2016	38.0
	4/6/2016	35.8
	4/11/2016	26.1
	4/20/2016	17.5
	5/4/2016	13.7
	5/17/2016	8.32
	5/25/2016	7.85
Seely	3/23/2016	41.9
	4/4/2016	5.6
	4/11/2016	3.4
	5/5/2016	1.5
Somerville	3/23/2016	23.33
	4/5/2016	4.51
	4/12/2016	3.23
	5/5/2016	1.37
Miller	3/22/2016	38.73
	4/4/2016	5.29
	4/12/2016	3.58
	5/5/2016	1.97
Lower China	3/22/2016	47.14
	4/4/2016	7.65
	4/11/2016	4.47
	5/4/2016	2.29
Upper Redwood	3/22/2016	31.06
	4/4/2016	5.50
	4/11/2016	3.51
	5/4/2016	2.04

5.5 Rating Curves

The R^2 values using power and Log-Log regression methods were computed for each PT (Table 7). The power regression performed best for Lower Redwood Creek and the Log-Log regression performed best for the tributaries. The best-fit stage-discharge rating relationship for each PT location are provided in Figures 9 through 14.

Table 7. Correlation coefficients (R^2) for pressure transducer gaged creeks. Highest values are in bold.

PT Gaged Creek	Power Regression	Log-Log Regression
Lower Redwood	**0.9933**	0.9807
Seely	0.9869	**0.9888**
Somerville	0.9839	**0.9958**
Miller	0.9916	**0.9974**
Lower China	0.9750	**0.9898**
Upper Redwood	0.9927	**0.9996**

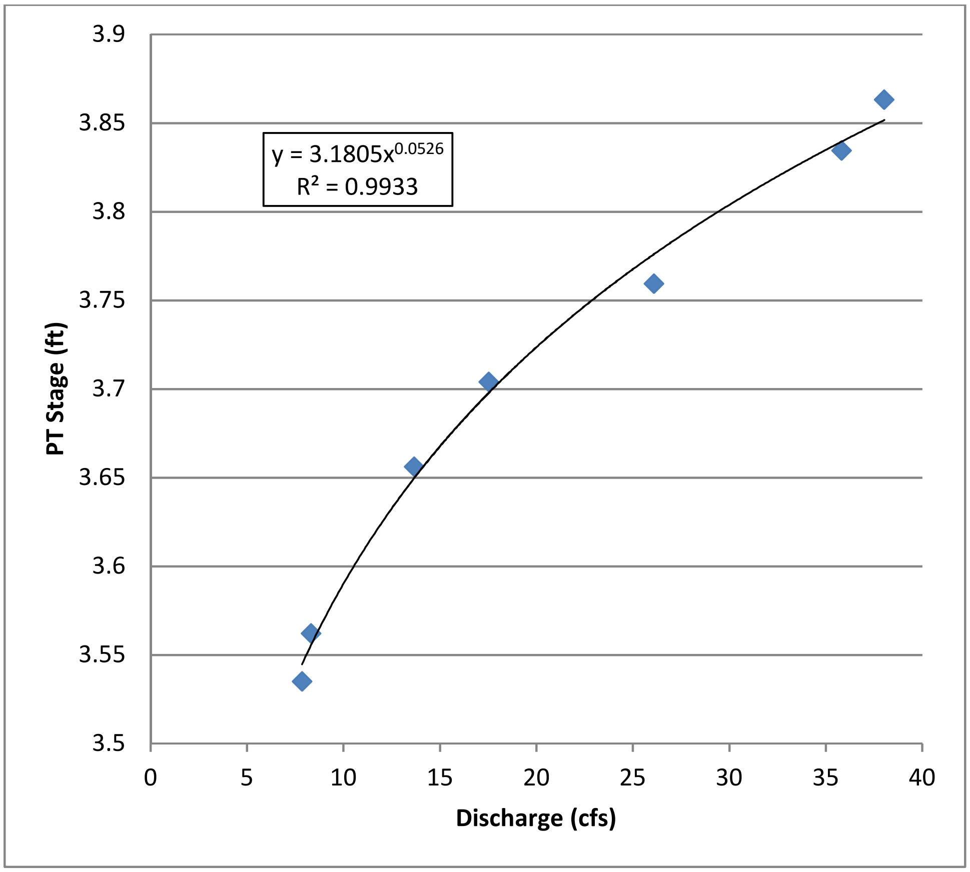

Figure 9. Lower Redwood Creek stage-discharge rating.

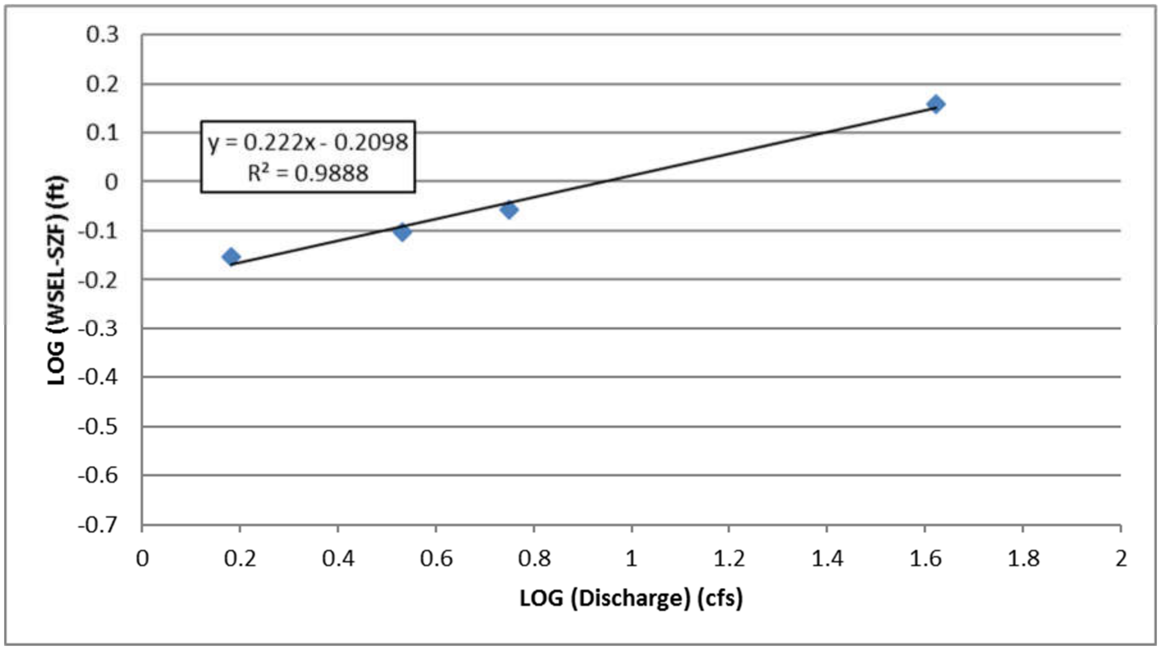

Figure 10. Seely Creek stage-discharge rating.

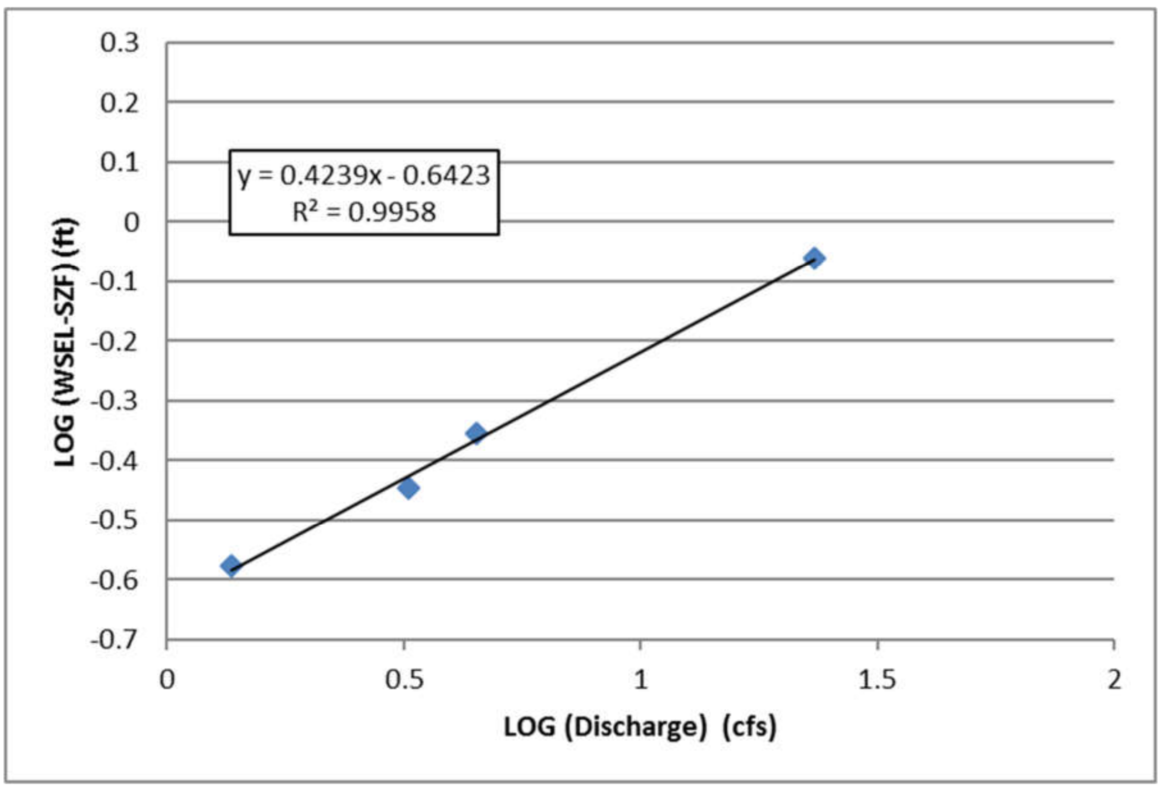

Figure 11. Somerville Creek stage-discharge rating.

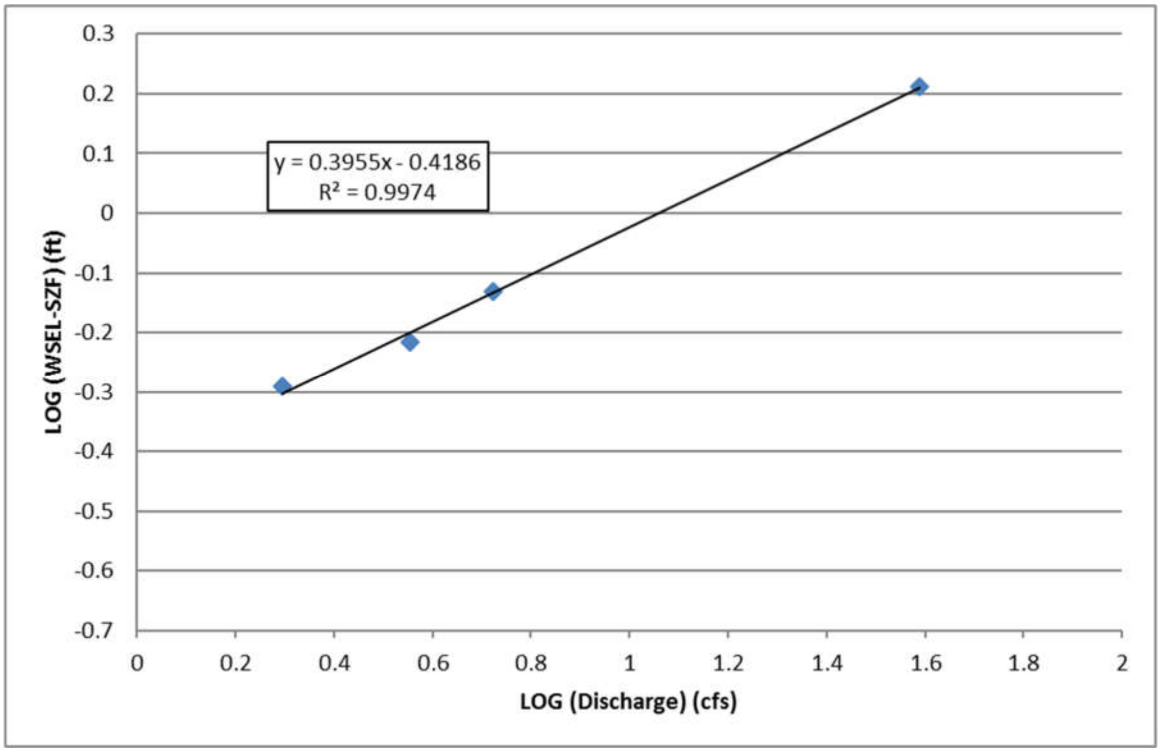

Figure 12. Miller Creek stage-discharge rating.

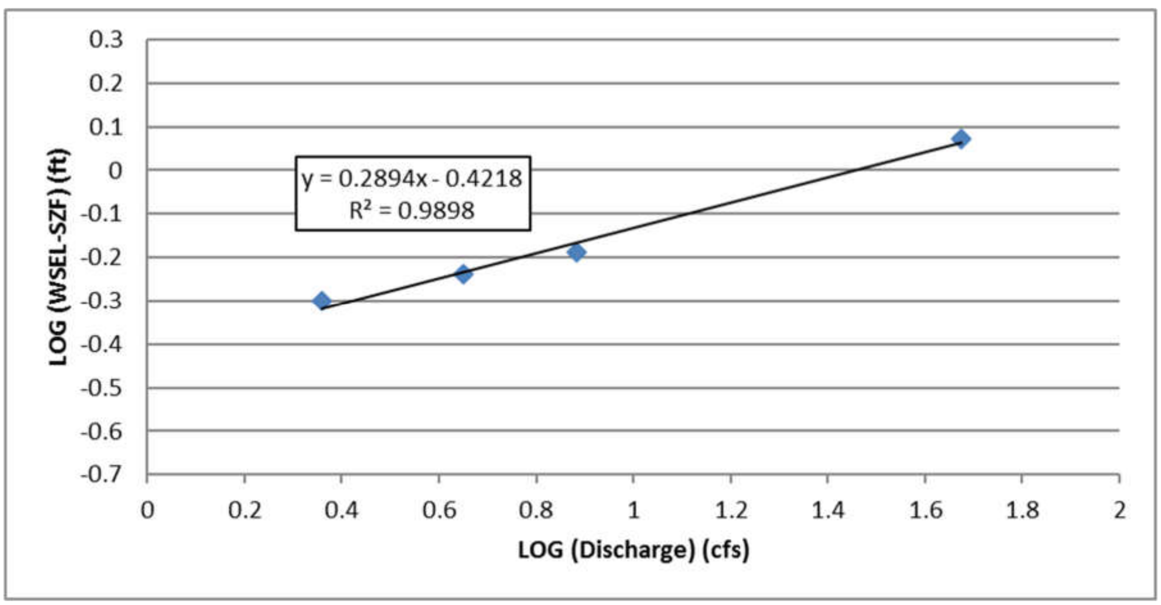

Figure 13. Lower China Creek stage-discharge rating.

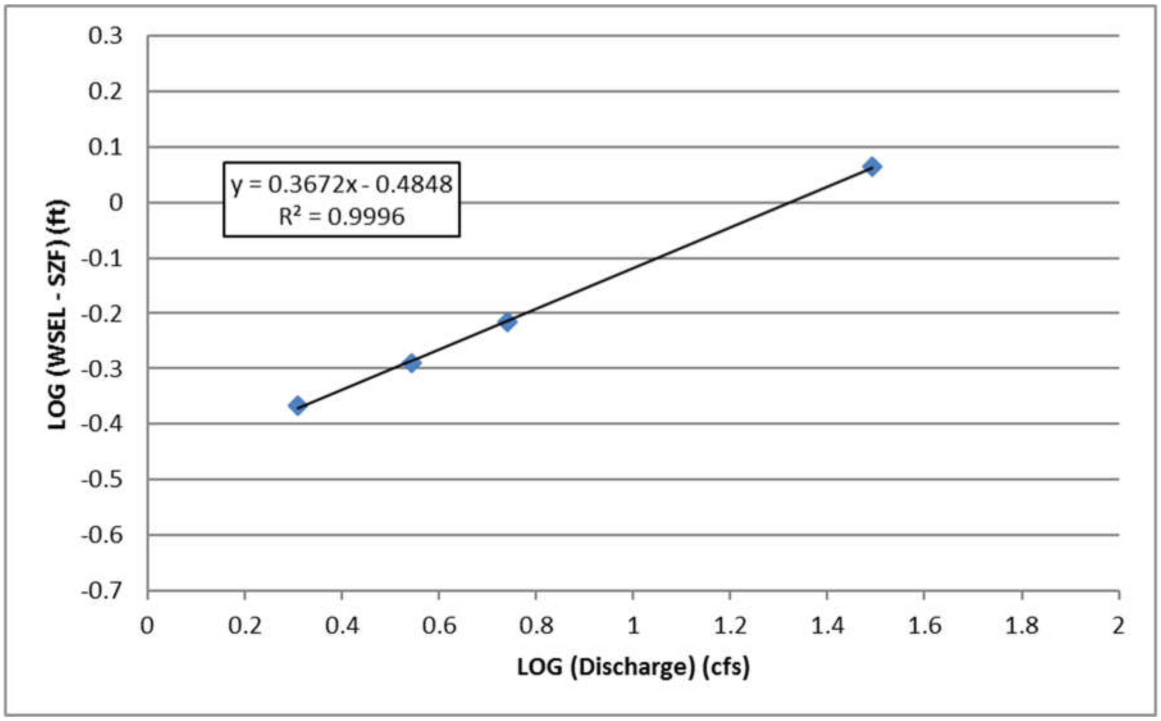

Figure 14. Upper Redwood Creek stage-discharge rating.

5.6 Time Series

Flow and water temperature time series were developed for each PT over the April 5, 2016 through July 13, 2016 monitoring period (Figures 15 through 20). The water stage readings, spaced 15 minutes apart, were converted to flow values using the regression rating curve relationship for each creek (Figures 9 through 14). Water temperature was a default parameter collected by the PT probes and may be used in the future to evaluate conditions in the study area. The timing and magnitude of field discharge measurements collected for each rating curve are indicated by the blue diamond-shaped markers, Q (Field).

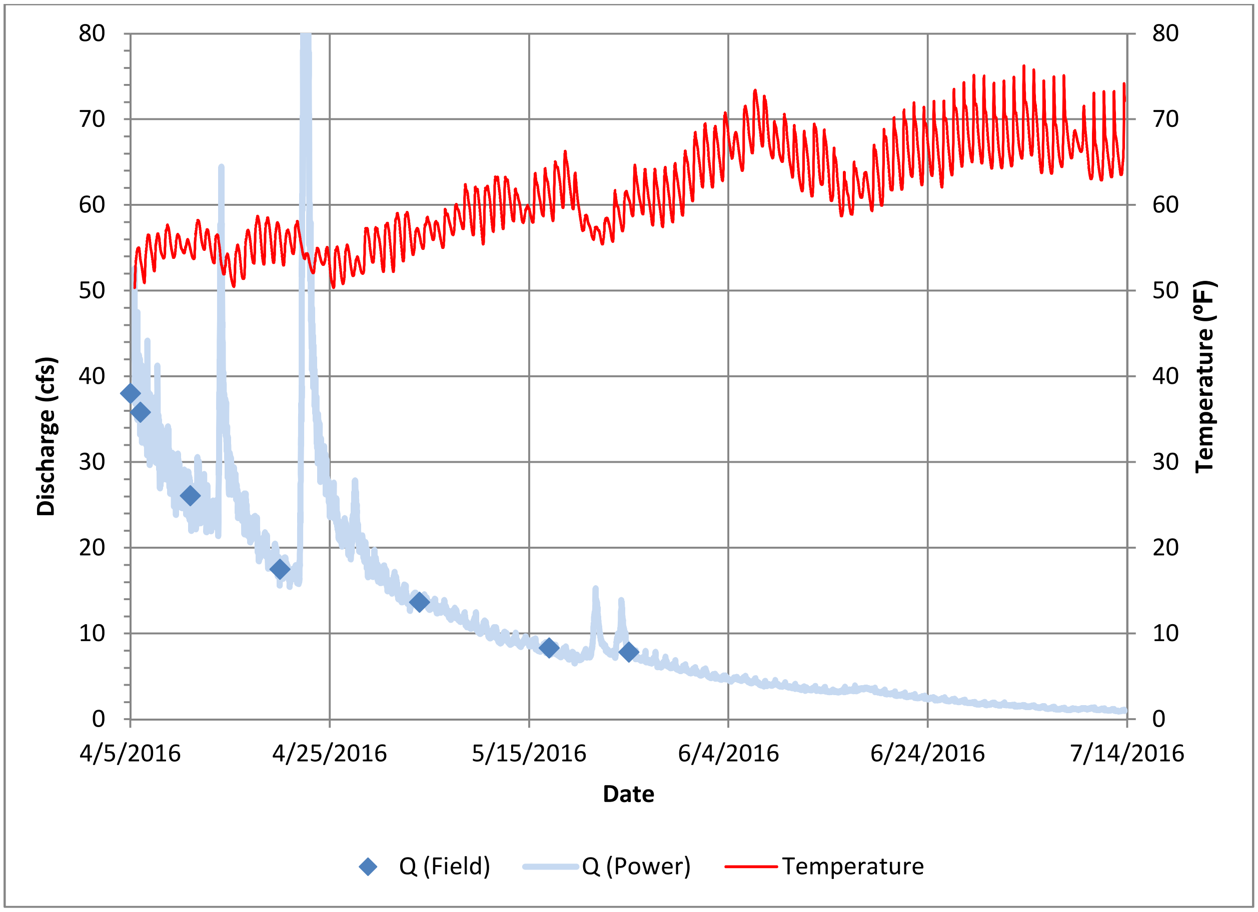

Figure 15. Lower Redwood Creek time series of discharge and water temperature.

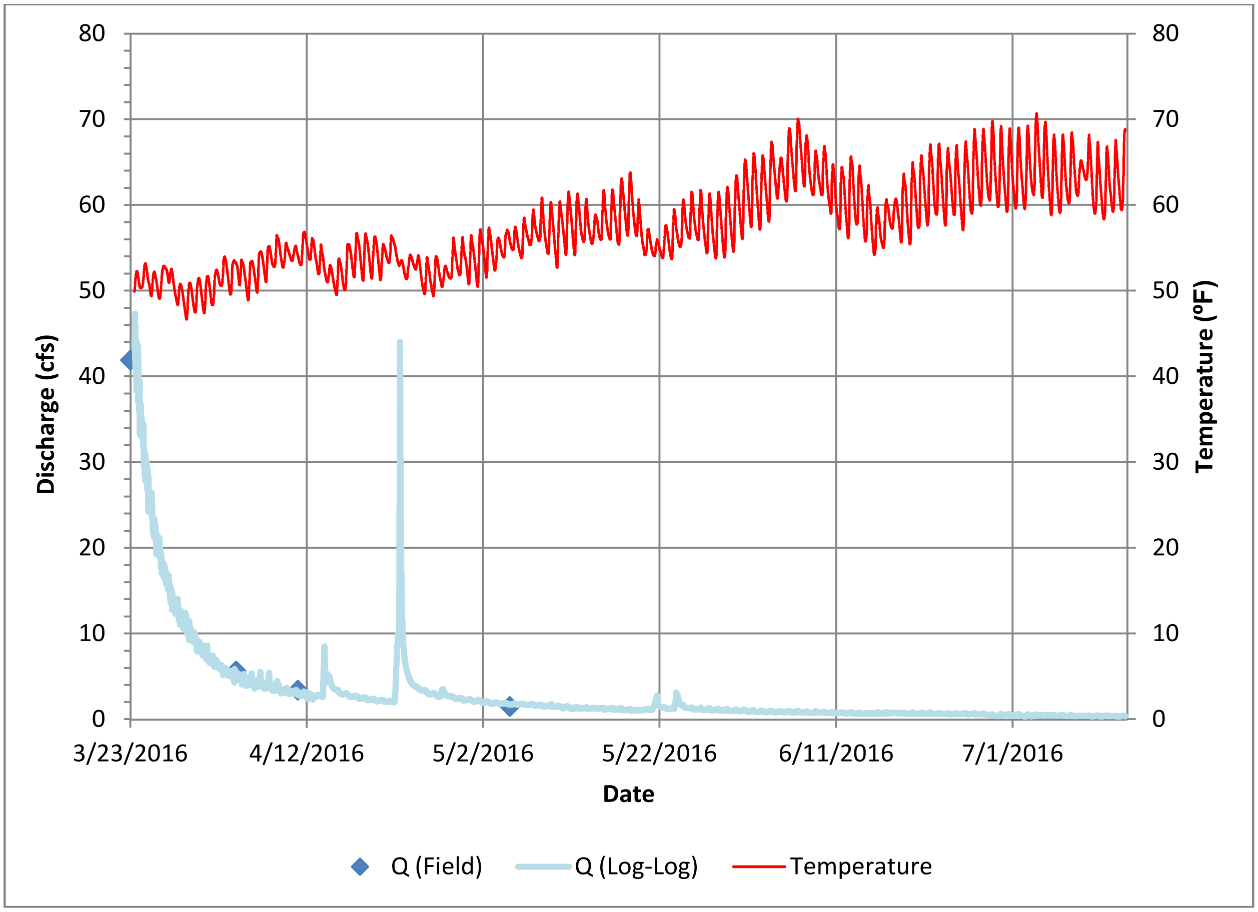

Figure 16. Seely Creek time series of discharge and water temperature.

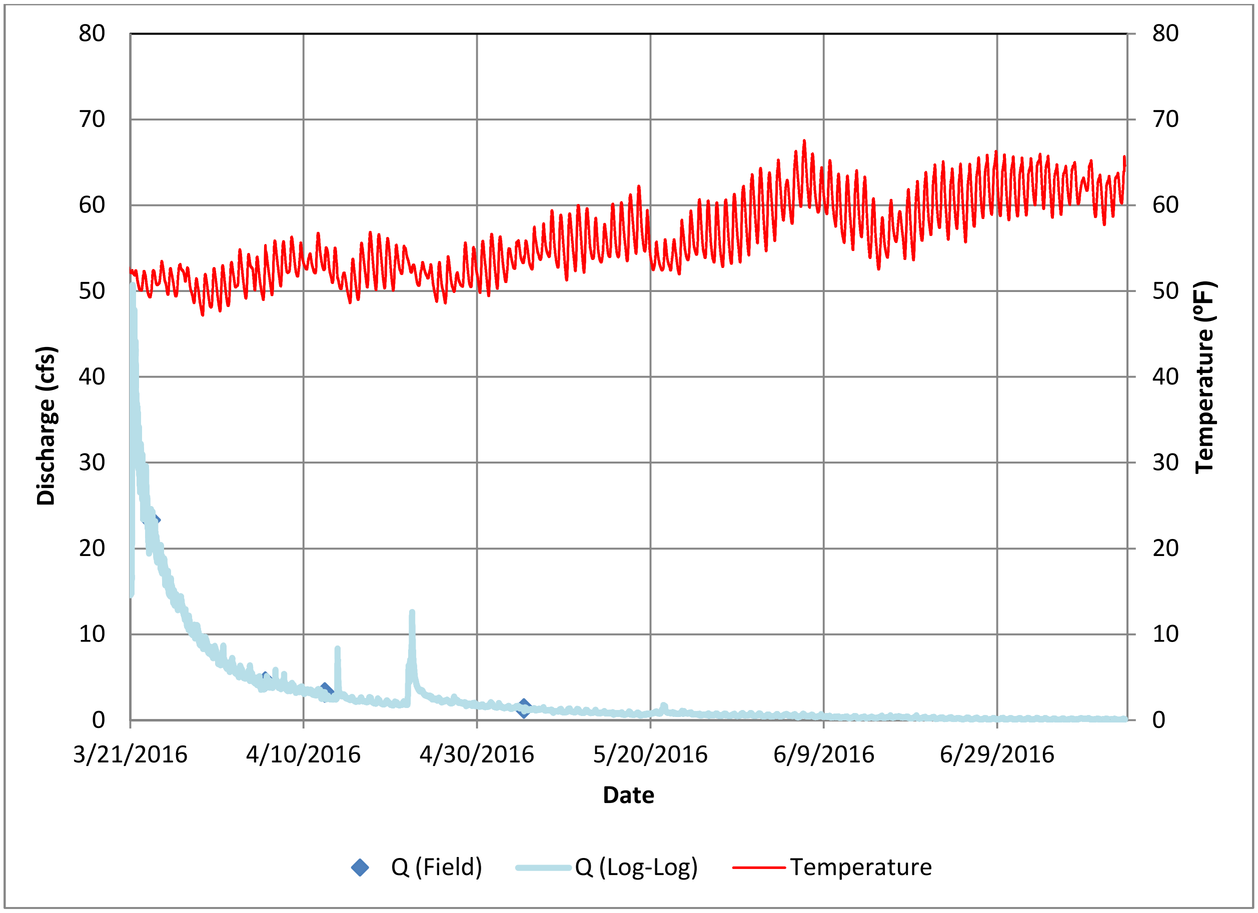

Figure 17. Somerville Creek time series of discharge and water temperature.

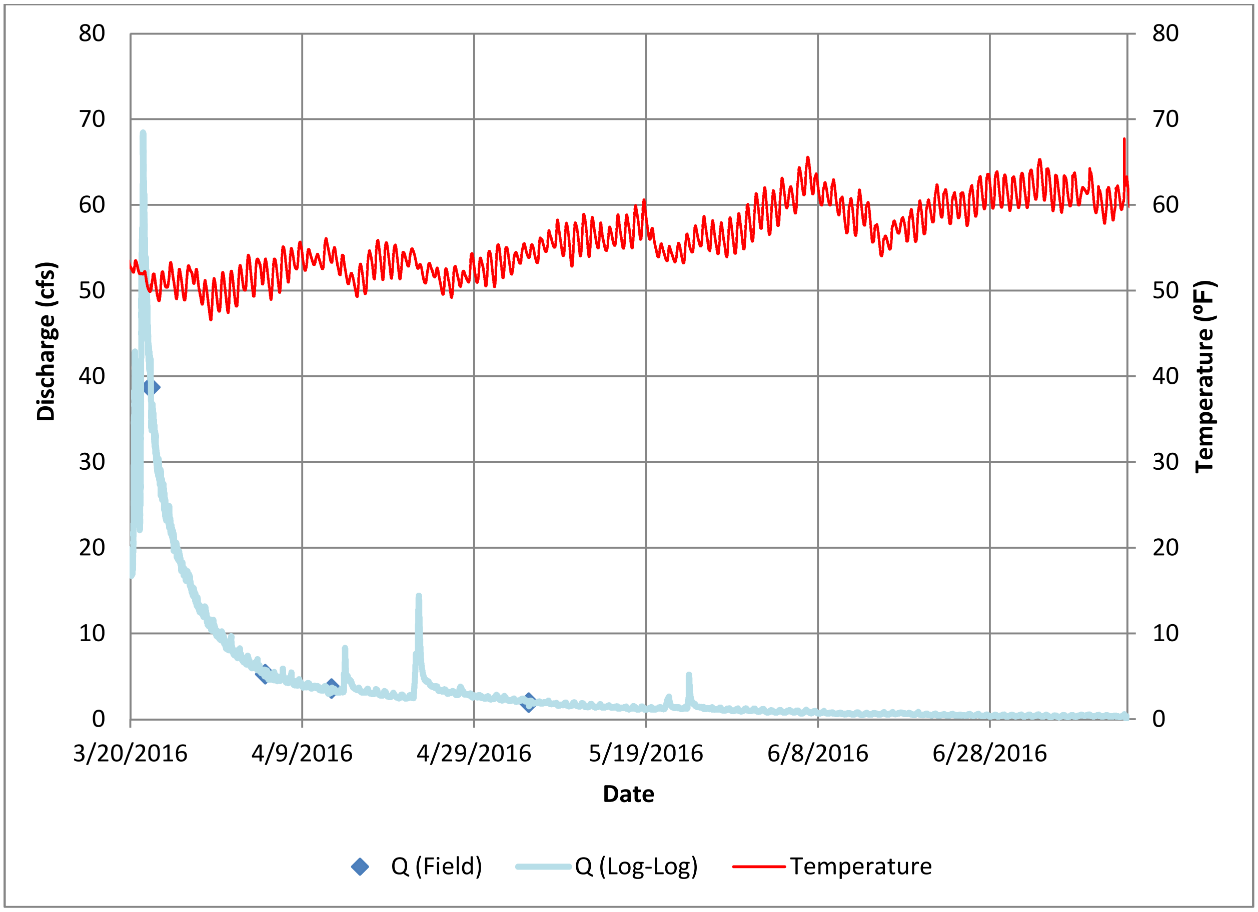

Figure 18. Miller Creek time series of discharge and water temperature.

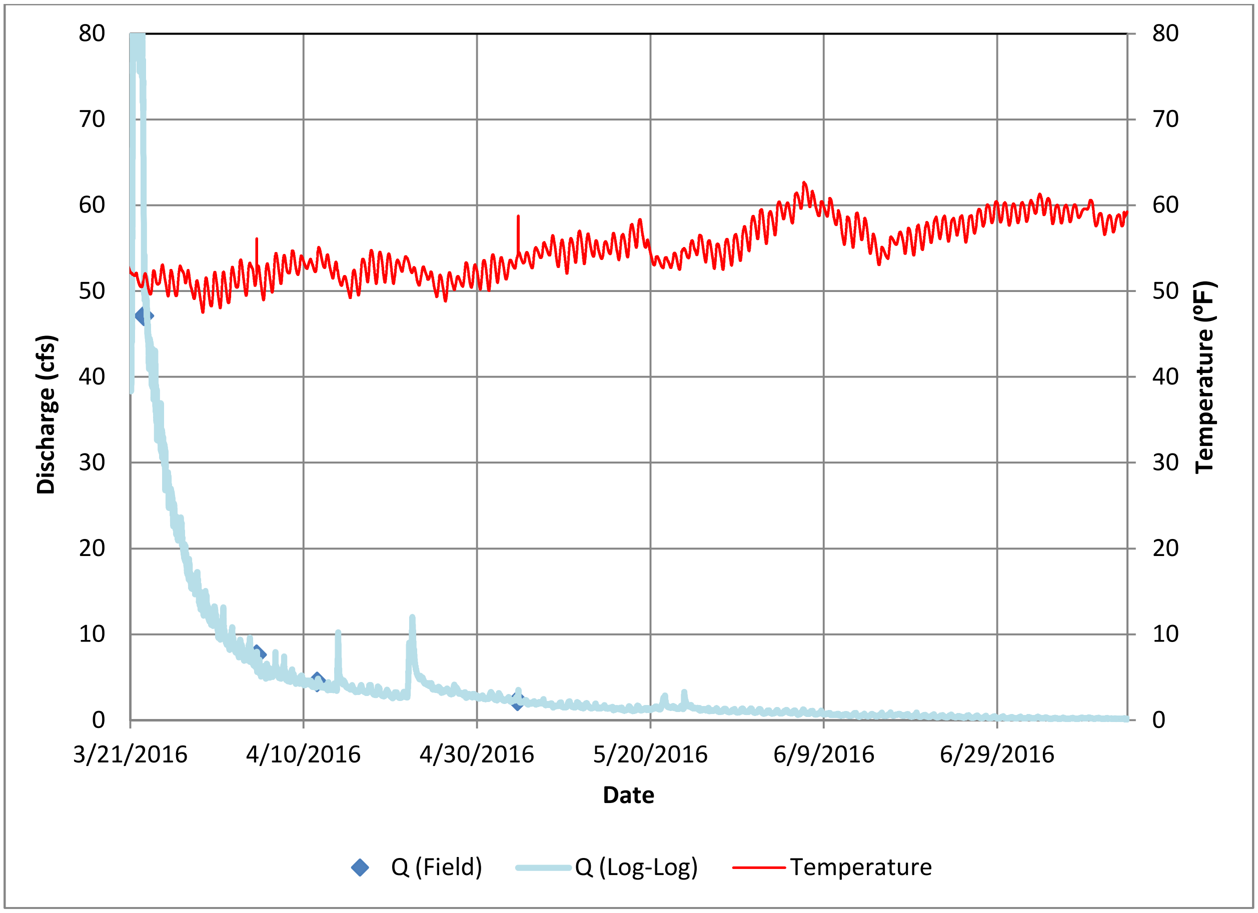

Figure 19. Lower China Creek time series of discharge and water temperature.

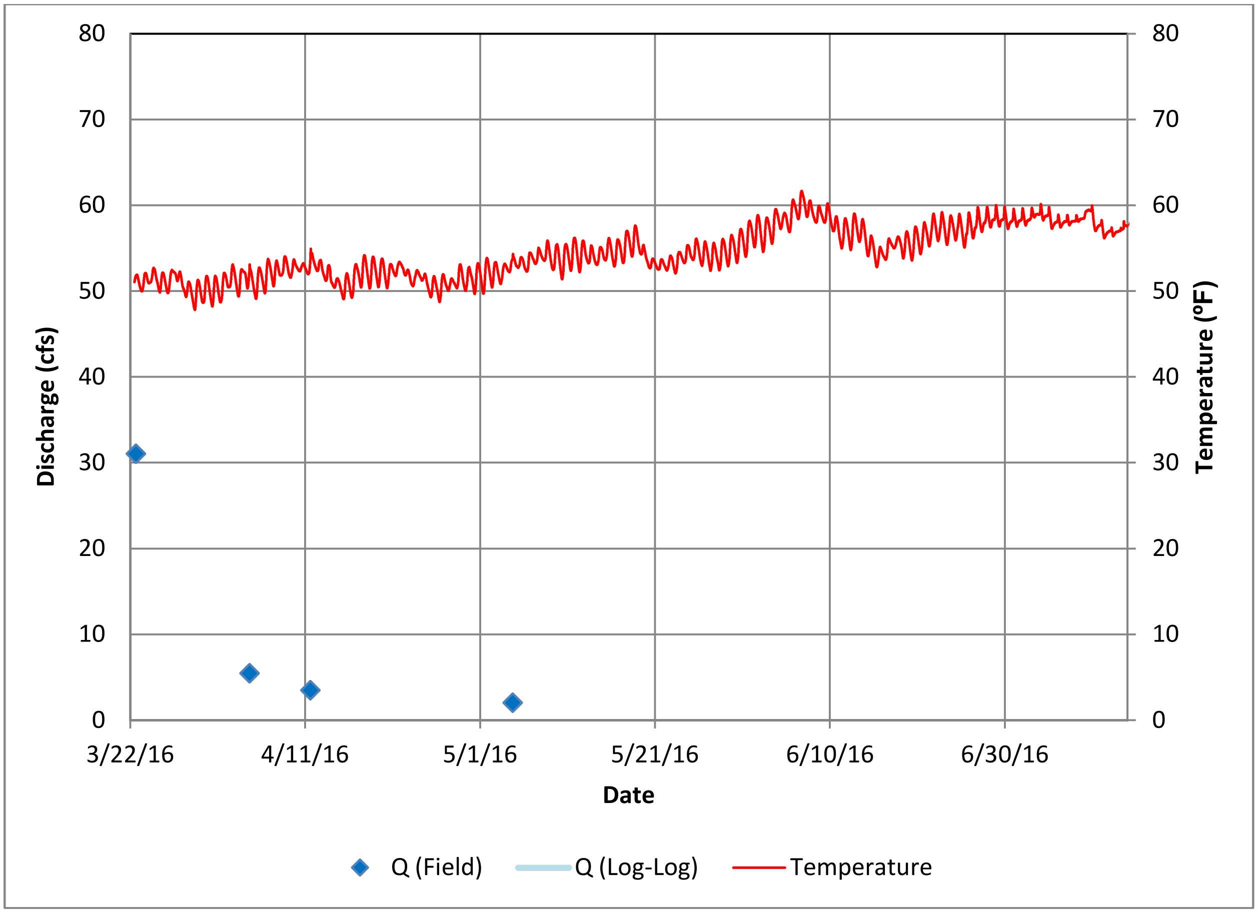

Figure 20. Upper Redwood Creek time series of discharge and water temperature.

6.0 DISCUSSION

Stream flows recommended for aquatic resources should consider intra- and inter-annual variability in instream flows (Annear et al. 2004; CDFG 2008). The Department recommends instream flow regimes for fish and wildlife be developed using unimpaired flow conditions. Unimpaired conditions are assumed to be the natural flow, without projects that divert water from the stream. Flows in Redwood Creek have not been gaged until recent efforts by Department staff documented in this report. Redwood Creek flows are believed to be impaired by diversions, primarily for cannabis cultivation. Even if a long-term gage record existed for Redwood Creek, the data would not meet criteria for estimating unimpaired conditions. A long-term stream gage record exists for Bull Creek, a nearby watershed of similar size and considered relatively unimpaired. Scaling techniques proposed by the SWRCB (2014) were used to estimate a long-term unimpaired flow time series for Redwood Creek by scaling data from Bull Creek. Water stage was monitored in Redwood Creek to: 1) compare the spring-summer recession of Redwood Creek with Bull Creek; and 2) measure the contribution of each major tributary to the total outflow of Redwood Creek.

6.1 Redwood and Bull Creek Mean Daily Flow Comparison

For comparison purposes, the PT flow time series and Bull Creek (USGS 11476600) data were converted from 15-minute to mean daily flow. The PT readings and discharge measurements recorded in lower Redwood Creek during 2016 were limited to a shorter time period than the tributaries. The PT stilling well in lower Redwood Creek was silted in, causing data logging to cease on July 13, 2016. The Redwood Creek outflow can only be compared with Bull Creek and its tributaries from April 4, 2016 through July 13, 2016.

Mean daily flow hydrographs were developed for Redwood Creek, Bull Creek, and Bull Creek scaled to Redwood Creek (Figure 21). The total flow volume measured for Redwood and Bull creeks, as indicated by the area under each hydrograph, was different. The volume measured at the Bull Creek stream gage was 4,269 acre-feet from April 5, 2016 through July 13, 2016. Department staff measured 2,155 acre-feet in Redwood Creek during the same period. This indicated Redwood Creek had approximately half of the volume measured for Bull Creek during the same period. Five storm events appeared in each hydrograph on the same days in 2016. Two distinct storm peaks appeared on April 14 and April 22. Three more minor peaks occurred on April 27, May 21, and May 24. The April 22 Redwood Creek storm peak resulted in a 74 cfs average daily flow. The same storm registered a 71 cfs average daily flow in Bull Creek.

The slopes of the recession curves were compared using visual techniques developed by Willems (2003). The Willems method assumes the recession curve is composed of three parts: 1) quick flow, the steep slope immediately after the peak; 2) interflow, the transition between the quick flow and the base flow; and 3) base flow. The Willems method is not quantitative with rigorous pass/fail type criteria but is a qualitative way to describe the temporary transition of stream flow from peak to base flow. There are two peak storm events shown in Figure 21. The magnitudes of the April 14 peak event differed between Redwood and Bull creeks, 37 and 60 cfs, respectively, but the slopes of both the quick flow and interflow recession curves appeared similar. The April 22 peak event occurred before either hydrograph appeared to reach base flow. The peak magnitudes were much closer, 74 and 71 cfs, respectively. Again, the quick flow and interflow recession slopes appeared to be similar. There is no data-supported evidence to explain the difference in volume between Redwood Creek and Bull Creek hydrographs.

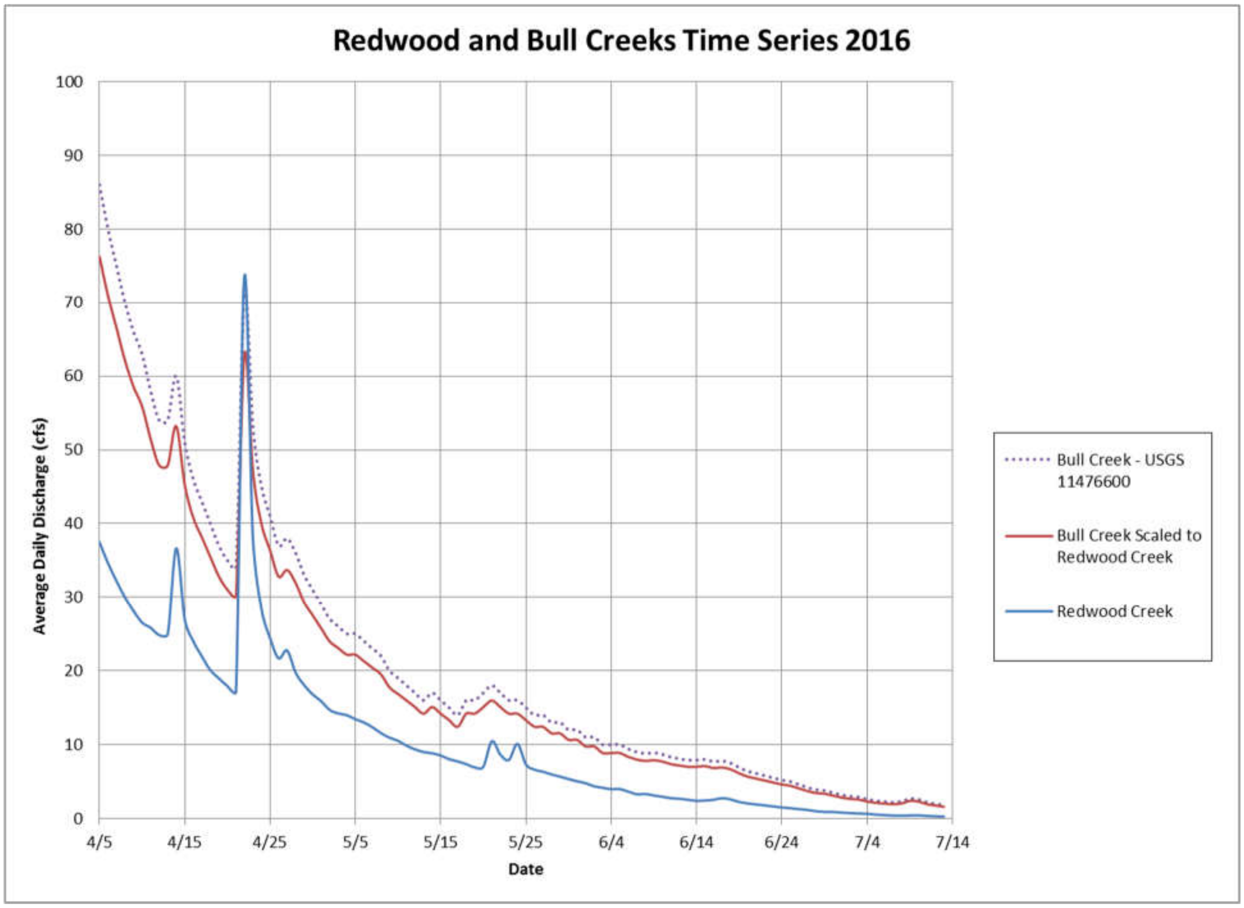

Figure 21. Hydrographs for Bull Creek, Redwood Creek, and Bull Creek scaled to Redwood Creek in 2016.

6.2 Redwood Creek Tributary Contribution

The contributions of the five major tributaries to Redwood Creek's overall flow was compared. The headwaters of Redwood Creek were assumed to be the confluence of Upper Redwood Creek with Lower China Creek (Figure 2). Redwood Creek flows downstream approximately seven-tenths of a mile before reaching its confluence with Miller Creek. Somerville Creek flows into Redwood Creek next, approximately seven-tenths of mile downstream of Miller Creek. Finally, Seely Creek enters Redwood Creek approximately 3.8 miles downstream from Somerville Creek.

Figure 22 depicts a series of spring-summer flow recession hydrographs from the Redwood Creek watershed. The time series from each tributary PT was normalized to average daily discharge (cfs). The contributions of each tributary were added together starting with Upper Redwood Creek to illustrate the gradual increase in flow volume moving downstream.

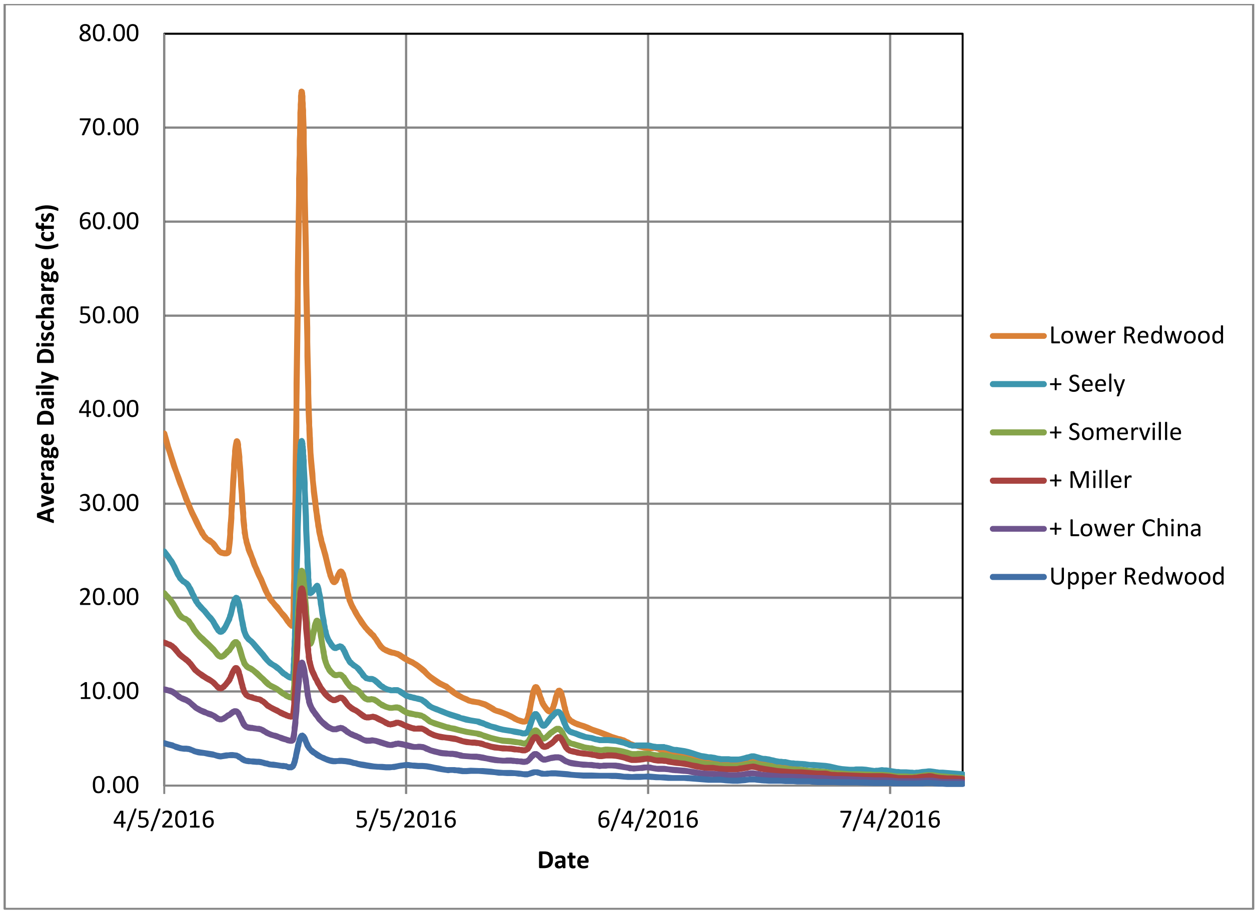

Figure 22. Redwood Creek tributary contribution.

The hydrograph builds in volume as flow moves downstream towards Lower Redwood Creek and the confluence with the SFER (Figure 22). The graph starts on the bottom with the hydrograph recorded at the base of Upper Redwood Creek. The flow recorded at the base of Lower China Creek was then added to Upper Redwood Creek to create the next hydrograph in the series, (+) Lower China, and so on with the additions of the other tributary contributions moving downstream. Figure 22 indicates that the spring-summer recession shape is similar among the five major tributaries and Lower Redwood Creek. The graph area between the addition of Seely Creek and Lower Redwood Creek hydrographs represents the direct drainage into the Redwood Creek mainstem and from other minor stream tributaries. An evaluation of Figure 22 shows that the storm response pattern of the five major tributaries was consistent with mainstem Redwood Creek.

7.0 CONCLUSION

An unimpaired flow record is needed to understand a river's natural, unaltered, flow regime. Redwood Creek unimpaired flows were estimated by evaluating the flow record from Bull Creek, a nearby watershed. Bull Creek is of similar size to Redwood Creek, has similar annual precipitation and gradient, and is located along the same western slope of the SFER watershed. Bull Creek and Redwood Creek watershed flow dynamics were compared using monitoring data collected from Redwood Creek during the 2016 spring-summer recession and found to share similar aspects of their hydrographs (Figure 21). An unimpaired flow record was estimated for Redwood Creek by scaling the Bull Creek flow record using a method documented by the SWRCB (2014). The relative contribution of each of the five major tributaries to Redwood Creek was characterized using the water stage data collected at the base of each drainage (Figure 22).

REFERENCES

Annear, T., I. Chisholm, H. Beecher, A. Locke, and 12 other authors. 2004. Instream Flows for Riverine Resource Stewardship, Revised Edition. Instream Flow Council, Cheyenne, Wyoming.

CDFG. 2008. Guidelines to the Application and Use of the Physical Habitat Simulation System. California Department of Fish and Game (CDFG). Sacramento, CA

CDFW. 2013a. Standard operating procedure for discharge measurements in wadeable streams in California. California Department of Fish and Wildlife, Water Branch, Instream Flow Program (CDFW), Sacramento, CA. CDFW-IFP-002. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=74169. Accessed: December 9, 2015.

CDFW. 2013b. Standard operating procedure for streambed and water surface elevation data collection in California. California Department of Fish and Wildlife, Water Branch, Instream Flow Program (CDFW), Sacramento, CA. CDFW-IFP-003. Available: https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=74173. Accessed: December 10, 2015.

DWQ. 2014. Standard Operating Procedure for Pressure Transducer Installation and Maintenance. State of Utah, Department of Environmental Quality, Division of Water Quality (DWQ), SOP Pressure Transducers. Available: https://deq.utah.gov/legacy/monitoring/water-quality/docs/2014/05May/SOP_PressureTransducers_5.1.14_Rev0.pdf. Accessed: May 2, 2017.

Rantz, S., and others. 1982. Measurement and computation of streamflow: Volume 1 measurement of stage and discharge. United States Geological Service, Geological Survey Water-supply Paper 2175. United States Government Printing Office, Washington.

SWRCB. 2014. Policy for Maintaining Instream Flows in Northern California Coastal Streams Appendix B. State Water Resource Control Board (SWRCB), Sacramento, CA. Available: http://www.waterboards.ca.gov/waterrights/water_issues/programs/instream_flows/docs/adopted_policy.pdf. Accessed: May 4, 2017.

USFWS. 2011. Sacramento Fish and Wildlife Office Standards For Physical Habitat Simulation Studies. U.S. Fish and Wildlife Service (USFWS), Sacramento Fish and Wildlife Office, Sacramento, CA.

USGS. 2016a. National Water Information System data available on the World Wide Web (USGS Water Data for the Nation). United States Geological Survey (USGS). Available: http://waterdata.usgs.gov/nwis/. Accessed: July 21, 2017.

USGS. 2016b. The StreamStats Program for California. United States Geological Survey (USGS). Available: https://water.usgs.gov/osw/streamstats/california.html. Accessed: June 1, 2017.

Waddle, T.J. (ed.). 2001. PHABSIM for Windows: User's Manual and Exercises: Fort Collins, CO, U.S. Geological Survey, 288 p

Willems P. 2003: WETSPRO: Water Engineering Time Series PROcessing Tool, Reference Manual and User's Manual, Hydraulics Laboratory K.U. Leuven, Leuven, Belgium.

State of California
Natural Resources Agency
Department of Fish and Wildlife
Water Branch, Instream Flow Program
830 S Street
Sacramento, CA. 95811