

Preliminary Low Flow Stream Discharge Monitoring Report

for the Redwood Creek Watershed

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Introduction

Through grants provided by the State of California, the Salmonid Restoration Federation was able to conduct watershed-wide monitoring of low flows on Redwood Creek near Redway, California, in 2015, building on previous (2013-14) data collection by Bill Eastwood, long time Redwood Creek resident and watershed restoration practitioner. This preliminary report presents data collected during summer and fall, 2015. Both 'spot' discharge data (single measurements made during site visits) and continuous discharge records from both the main channel and selected tributaries of Redwood Creek are presented in graphical form. Data collection for this project will continue through the 2016 low flow season, followed by final data preparation, analysis and interpretation.

The summer and fall of 2015 brought a continuation of extremely dry conditions to the North Coast of California. Near record low rainfall the prior winter, particularly during the latter part of the wet season, combined with delayed onset of rainfall events in the fall, caused many streams to go dry for a substantial portion of the low flow season. Redwood Creek near Redway, California, was not immune to the causes and effects of the drought. In addition to low rainfall, the problem was certainly exacerbated by human water withdrawals, which tend to increase with drier conditions as crop irrigation demands intensify, and long-term watershed changes brought about by both historical and ongoing logging.

The objectives of hydrologic monitoring are to: 1) quantify low flows at a variety of sites selected to represent potential juvenile salmonid rearing habitat; 2) identify locations within Redwood Creek where low flows appear to be most severely reduced by human uses; 3) identify locations where low flows appear to be relatively unimpaired; and 4) prioritize stream reaches for actions to augment low flows with a goal of optimizing benefits to juvenile salmonids.

Problem Statement

Ideally, a low flow study aimed at improving conditions for fish would be based on known quantities of discharge 'impairment', or human-induced losses from the natural flow regime. Unfortunately, we know from experience that few of those quantities can be known, requiring assumptions that cannot be validated. Complicating matters further, even in unimpaired watersheds low flow characteristics generally do not conform well to a systematic (i.e., predictable) arrangement, with the Upper Mattole River providing an example (Klein, 2015). Despite these potential problems, measuring low flows can provide important information for guiding actions aimed at improving low flow conditions for fish by providing answers for questions such as:

- What are current low flow conditions and where in the watershed are they the worst?
- What reaches have the highest potential for aiding salmonid recovery by augmenting flows?

Answering these questions can help guide flow improvement activities.

Factors Affecting Low Flows

Spring discharge recession begins when spring rainfall ceases. In an unmanaged watershed, flow rate decays very gradually throughout the dry season. Even some reaches with small drainage areas continue to flow all year despite drought conditions. Dry season discharges in comparable managed streams, depending on land use specifics, typically recede faster and often go dry until climatic conditions in the fall promote resumption of surface discharge. These conditions include lowering of air temperatures (reducing evaporative demand), shorter photoperiods and drought-induced dormancy of vegetation (reducing transpiration), overcast skies (reducing evapotranspiration), periods of lowered atmospheric pressure (raising the water table and re-establishing connectivity to effluent streams), and of course, the onset of the rainy season. Dry season climatic events (rain, fog) can temporarily ease drought conditions in small streams and trigger resumption of surface flow, but the benefits are typically short-lived as small streams can go dry again shortly after the rain stops or skies clear (Klein, 2015).

Human water withdrawal from streams is but one disturbance factor that reduces dry season streamflow (Asarian and Walker, 2016). All but a few small watersheds in North coastal California have been, for practical purposes, permanently altered hydrologically by humans, and such alterations can be considered 'legacy' impairments. Old-growth tree harvesting, loss of deep forest floor litter and organic-rich soil, and road and skid trail construction have permanently altered the dispensation of storm rainfall by increasing surface and shallow subsurface runoff ('quickflow', Wemple and others, 1996). A corollary of increased surface runoff during storms is that less water is available for groundwater recharge. Adding to those effects is the change in stand composition from old-growth to mostly young, even-aged forests. Recent research indicates that younger stands use more water for transpiration than larger, older trees (Stubblefield and others, 2012) per unit surface area of land. The combination of these factors causes more winter rainfall to runoff more quickly, leaving less available for seepage into the groundwater table for sustaining dry season flows while increasing evapotranspirative water losses.

Some propose to use timber harvest as a tool for increasing summer low flows. Research into the efficacy of timber harvest as a tool for increasing water yields is voluminous, dating back many decades. Several studies showed increased summer flows after logging, but others found that increased flows were short lived. In a recent review paper, Rhodes and Frissell (2016) compiled and synthesized research into harvesting effects and found numerous flaws with the concept, though their research was focused on the Sierra Nevada Mountains.

Sawaske and Freyberg (2014) attribute reduced dry season flows largely to "*increased evapotranspiration resulting from air temperature increases*", a contributing factor that may be caused by land cover-induced meso-climate changes, global climate change, or both. In a more recent study, Asarian and Walker (2016) state "*The most pristine surface-runoff dominated watersheds within the study area showed no decreases in precipitation-adjusted streamflow during the summer months. These results suggest that streamflow decreases at other sites were likely due to more increased human withdrawals and vegetation changes than to climate factors other than precipitation quantity.*" Their conclusions tend to support the importance of land use as an important driver of low flows.

Combining with watershed hillslope hydrologic conditions that reduce low flows, massive erosion from past land abuse and storms filled (aggraded) channels with sediment. Much of this has since been transported downstream, but locally aggraded reaches persist. The accumulation of sediment on the channel bed causes a shift in the proportion of surface flow to channel bed seepage, reducing flow at the surface.

One form of land use that has recently come to the forefront of controversy is water diversion for marijuana cultivation. Bauer and others (2015) documented a rapid growth of large-scale 'grows' in North coastal California. From aerial surveys, they estimated the number of marijuana plants from inventoried grows and the water irrigation volume needed to bring each plant to maturity. They concluded that: "*Our results indicate that water demand for marijuana cultivation has the potential to divert substantial portions*

of streamflow in the study watersheds, with an estimated flow reduction of up to 23% of the annual seven day low-flow in the least impacted of the study watersheds. Estimates from the other study watersheds indicate that water demand for marijuana cultivation exceeds streamflow during the low-flow period.” Diversion of 23% to 100% of streamflows during the dry season would certainly contribute to lower flows, despite a portion of the diverted water likely returning to streams as irrigation return flow.

Clearly, both watershed legacy effects and ongoing water withdrawals are impacting hydrologic conditions for salmonids, but expecting hydrologic monitoring (or modeling based on the results) to provide a definitive pathway for optimizing restoration actions is unrealistic – as described above there are too many unknowns and confounding factors. Given the complexities involved, the best approach for optimizing restoration actions may be based on field inventories of rearing habitat quality and quantity, i.e., where will summer survival benefit the most from flow augmentation. Despite the limited ability to collect empirical data on instream flows and human water use, any actions taken to reduce those impacts have potential to improve conditions for fish, both locally and cumulatively downstream.

Redwood Creek Watershed

Joining with the South Fork Eel River near Redway, CA, Redwood Creek drains a basin area of about 26 square miles of forested steepplands. Historic land uses were dominated by timber harvest, which continues to the present. Rural residential and small-scale agriculture compose other land and water uses. The town of Briceland is located near the centroid of the watershed and Redway is downstream near the watershed’s outlet. Coho, Chinook, and steelhead have historically thrived in Redwood Creek, and reaches of high quality habitat still exist in the watershed.

Study Design

The 2015-16 study design utilizes most of the sites monitored in 2013-14 and adds several new sites. Table 1 provides watershed information for areas upstream from the monitoring sites, and the types of monitoring at each site (some data acquired from USGS StreamStats, 2015). The accompanying map (separate cover) shows watershed geography and the locations of hydrologic monitoring in 2015.

Table 1. Watershed and channel attributes and monitoring for Redwood Creek monitoring sites.

Redwood Creek Monitoring Site	Site Code	River Mile Upstream from Mouth*	Drainage Area (mi ²)	Max. Elev. (feet)	Min. Elev. (feet)	Relief (feet)	Mean Basin Elev. (feet)	Mean Basin Slope (%)	Monitoring Parameters **
Mainstem Redwood Creek	RC-4	0.4	25.8	2371	292	2079	1023	32.7	Q, WT, AT
Mainstem Redwood Creek	RC-3	2.0	23.5	2371	350	2021	1037	32.3	MS, CS, Q, WT, AT
Mainstem Redwood Creek	RC-2.5	2.7	17.1	2361	434	1927	1065	31.6	MS, CS, Q, WT, AT
Seely Creek*	SC-1	2.1	5.8	2371	350	2021	977	34.0	MS, CS, Q, WT, AT
Mainstem Redwood Creek	RC-2	4.5	14.0	2361	555	1806	1081	31.2	Q, WT, AT
Upper Miller Creek*	MC-1	5.3	3.4	2361	602	1759	1176	29.7	Q, WT, AT
Lower Miller Creek*	MC-2	5.3	3.6	2361	579	1782	1166	29.6	MS, CS, Q, WT, AT
Buck Creek*	BC-1	5.3	0.8	2361	798	1563	1492	34.2	Q, WT, AT
Mainstem Redwood Creek	RC-1	6.2	6.7	1755	589	1166	1041	31.5	MS, CS, Q, WT, AT
Dinner Creek*	DC-1	6.3	1.0	1727	784	943	1122	32.0	Q, WT, AT
China Creek*	CC-2	6.3	3.9	1742	598	1144	1044	31.6	MS, CS, Q, WT, AT
Mainstem Redwood Creek	URC-1	6.4	2.7	1755	595	1160	1042	31.5	MS, CS, Q, WT, AT

* river mile distances are to tributary confluence with mainstem; drainage areas are at site.

** MS = manual stage; CS = continuous stage; Q = discharge; WT = water temperature; AT = air temperature.

At present, the factors controlling discharge rates within the watershed are not well understood (see above) and certainly cannot be controlled, so a controlled experimental design cannot be used. Alternatively, the sites were sorted into two groupings that lend themselves to comparisons: a) six

mainstem sites (URC-1, RC-1, RC-2, RC-2.5, RC-3 and RC-4) that will support longitudinal trend analyses, and b) seven tributary sites (URC-1, CC-2, DC-1, BC-1, MC-2, MC-1, and SC-1), several of which are similar enough in drainage area to fit a paired basin analytical approach (note that site URC-1 will serve as both a mainstem and a tributary monitoring site).

Data Collection and Analysis

Data collection focused on stream discharges and water temperatures collected at both mainstem and tributary sites. Both manually collected data and automated stage data were collected with electronic data loggers.

Stream Stage

Stream stage (the height of the water surface above a datum) was manually measured in relation to a permanent reference marker (a nail in a tree, typically) and recorded continuously at seven of the sites ('CS' sites in Table 1) by means of an electronic stage recorder, which senses water depth and records and stores the data. The stage recorders were deployed into the stream inside a stilling well (a section of perforated pipe). Electronic stage data were downloaded several times during the season.

Discharge

Periodic discharge measurements were made at each monitoring site using methods appropriate to field conditions at the time of each visit. With adequate flow depth, a Parshall Flume was used. When flow dropped too low to use the flume, flow was consolidated into a length of plastic pipe and discharge was measured by timing the filling of a graduated beaker at the pipe's outfall. Manual stage was recorded during each site visit, including when discharge measurements are made. Thus, data pairs of stage and discharge were accumulated for each site and will be used to develop stage-discharge relationships. It is this relationship, usually taking the form of an exponential equation, which allows calculation of both manual and electronic stream discharge from stage observations.

Data Treatment and Analyses

Manual field data (discharge, stage height, water & air temperature) were entered into pre-formatted spreadsheets soon after data collection. Data logger downloads were processed to adjust for atmospheric pressure and appended into a single data file. Several additional steps will be required to condition the data for analysis (adjust electronic stages to match manual stages, compute discharge for each electronic reading using a discharge rating equation specific to each site). This will be a substantial task and could not be completed so soon after data collection ended. Before next spring, discharge rating curves will be finalized and discharge will be computed.

Preliminary Results

The drought of 2015 extended through nearly the end of November, punctuated by several small rainfall events. Hydrologic monitoring began in mid-June and continued through early December, thus including the entire low flow period. Many of the monitoring sites had periods of zero flow, and some pools that had monitoring went completely dry. Throughout the study area, flows at most sites were highly, if temporarily, influenced by small precipitation events. On July 13, 2015 the area received about 0.3 inches of rain, and about 2 inches of rain again on September 16, 2015. Late season rains on October 17 (0.3 inches) and 19 (0.1 inch) brought back flows to RC-3 and RC-2.

Manual discharge measurements have been compiled and re-formatted for plotting and used to develop discharge rating curves. Plots of 'spot' discharge data using both measured discharge and discharge per unit area ('unit discharge' per square mile of contributing watershed area upstream) are shown below in Figure 1-4. Separate plots are provided for the mainstem sites (Figs 1 and 2) and the tributaries (Figs. 3 and 4) [remember that URC-1 serves both groups].

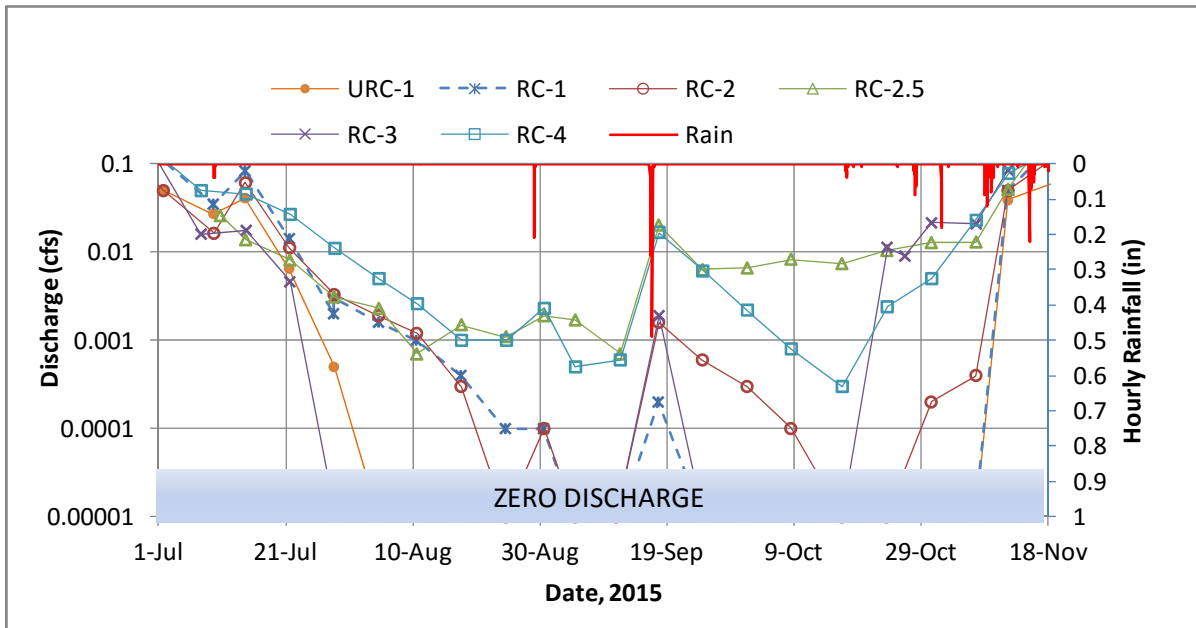


Figure 1. Discharge spot measurements and rainfall at mainstem sites, 2015.

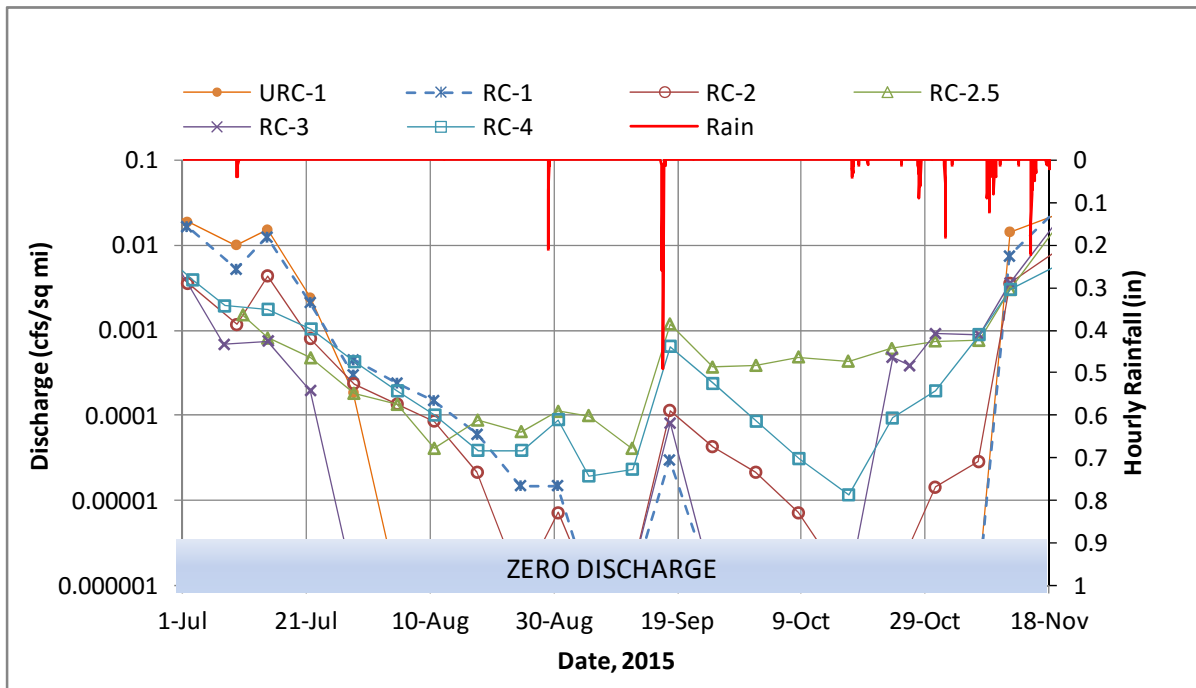


Figure 2. Unit discharge spot measurements and rainfall at mainstem sites, 2015.

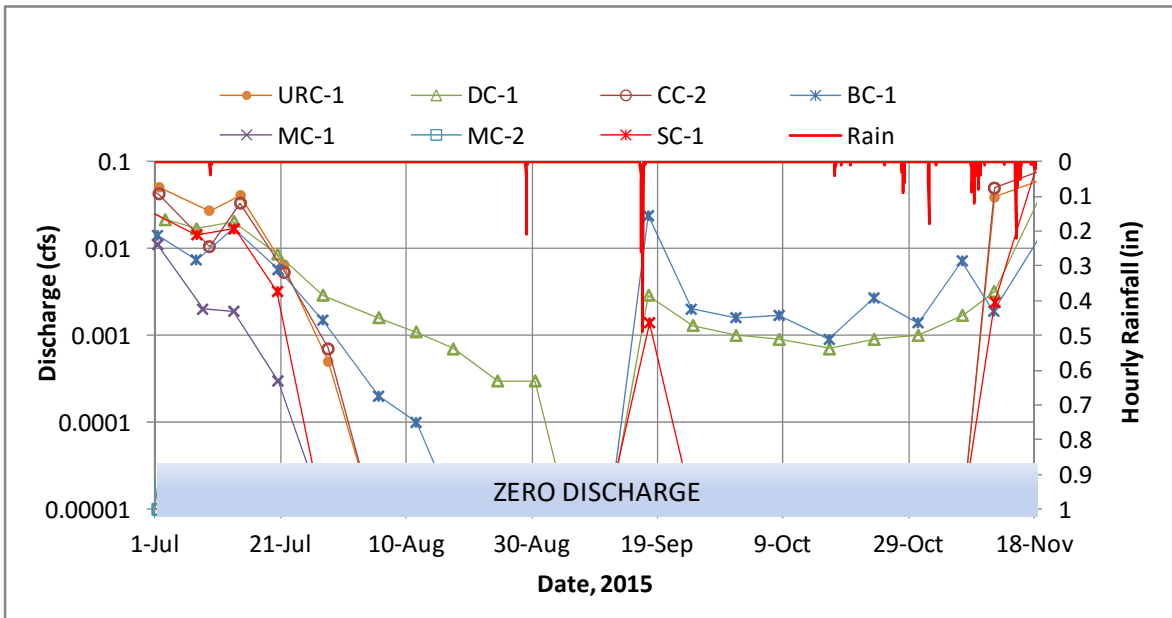


Figure 3. Discharge spot measurements and rainfall at tributary sites, 2015.

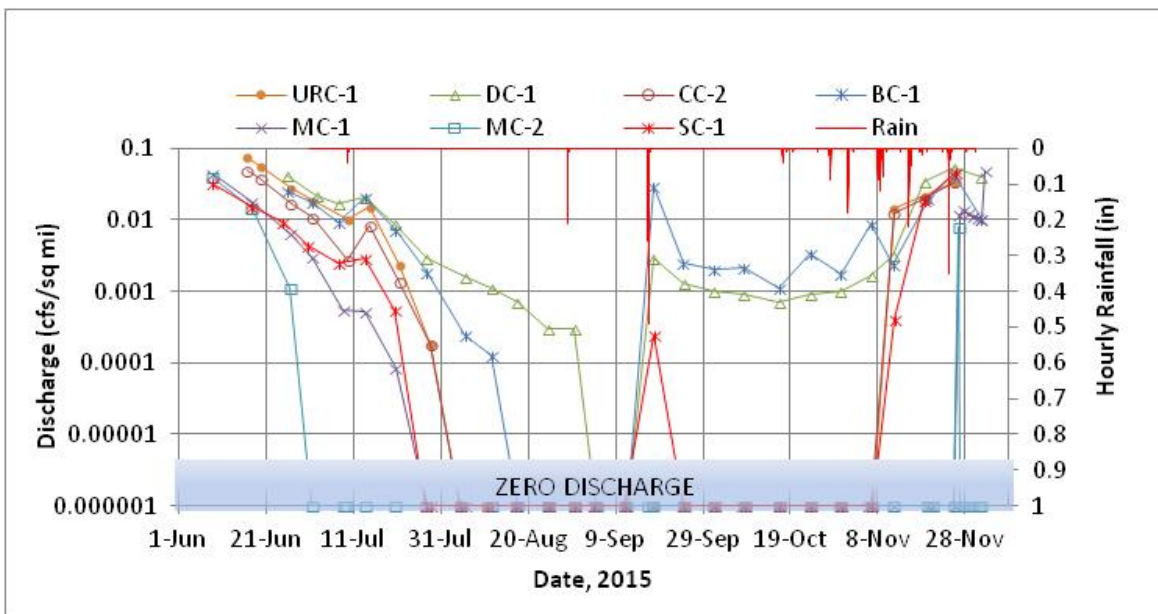


Figure 4. Unit discharge spot measurements and rainfall at tributary sites, 2015.

Figures 1-4 reveal the recession of flows at all sites from early July through late August, when a small rainfall event elevated flows at the mainstem sites (Figs. 1-2) but had little effect on tributary sites (Figs. 3-4). A larger rainfall event on September 16 elevated flows at all sites, followed by a flow recession that varied among the sites. Flows were well-sustained after that rainfall event at RC-2.5, BC-1 and DC-1, while the other sites dropped back to very low flows.

Figure 5 shows continuous discharge data for three mainstem sites (RC-1, RC-2.5, and RC-3) and Figure 6 shows unit discharge for the same sites. As with the spot measurements, flows were elevated by the Sept. 16 rainfall (almost 2 inches) to varying degrees. RC-1 and RC-3 discharges remained very low following the Sept. 16 rainfall until a series of rainfall events beginning in late October brought the summer drought to an end. Of note, RC-2.5, upstream of RC-3 and having smaller drainage area, had

continuous discharge throughout the dry season. Further exploration for the cause of this unexpected phenomenon may provide insights into the role of water withdrawals on mainstem low flows (see 'Field Observations', below).

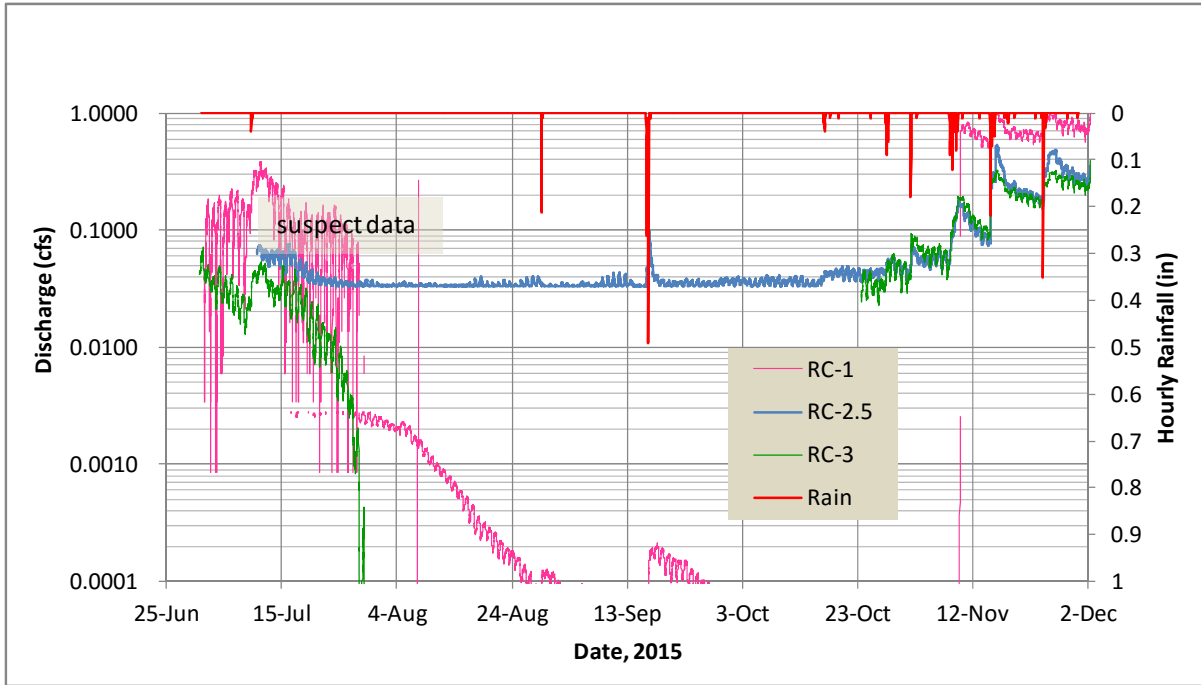


Figure 5. Discharge and rainfall at Mainstem data logger sites.

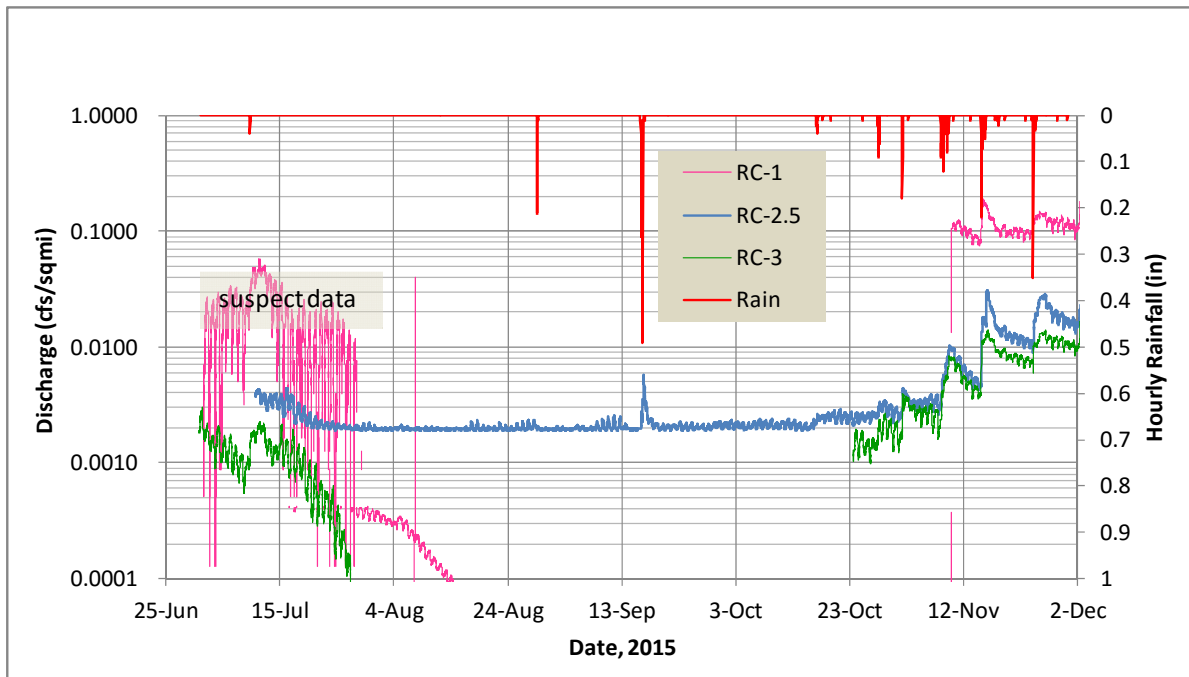


Figure 6. Unit discharge and rainfall at Mainstem data logger sites.

Figure 7 shows continuous discharge data for four tributary sites and Figure 8 shows unit discharge for the same sites. As with the spot measurements, flows dropped precipitously after a small rainfall event in mid-July and, with the exception of a brief rise on Seely Creek (SC-1, Fig. 7), did not recover until significant rains in November.

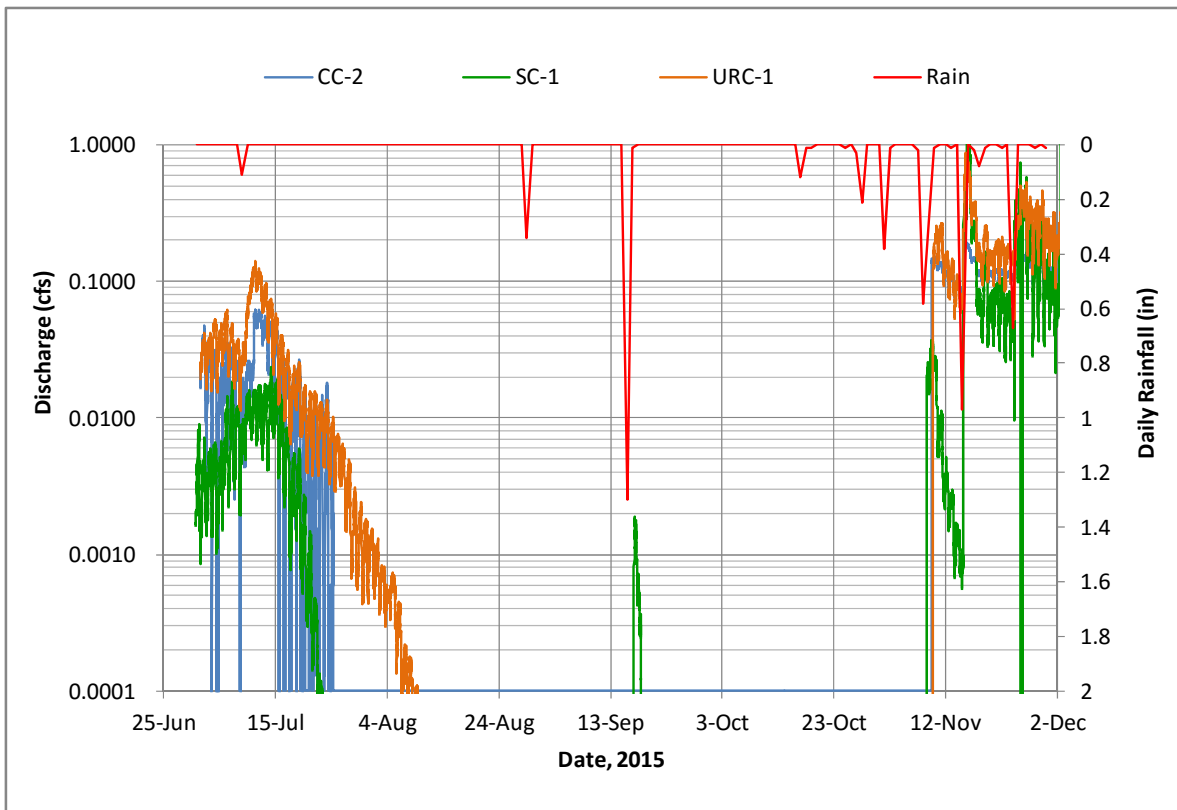


Figure 7. Discharge and rainfall at tributary data logger sites.

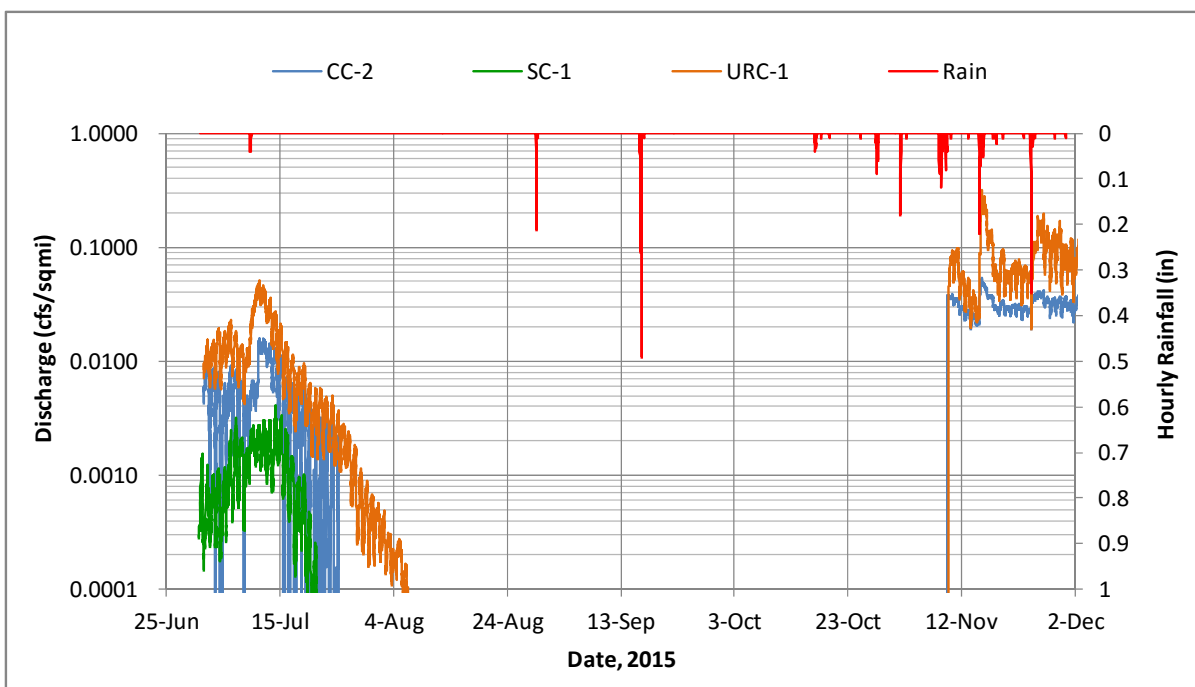


Figure 8. Unit discharge and rainfall at tributary data logger sites.

Longitudinal Discharge Trends

As a rule, stream discharge generally increases with increasing watershed area, and the downstream accretion of streamflow is a basic conceptual model in watershed hydrology. However, low flows in Redwood Creek often did not conform to this model. Spot discharge measurements for selected dates in 2015 are plotted longitudinally in Figures 9 and 10.

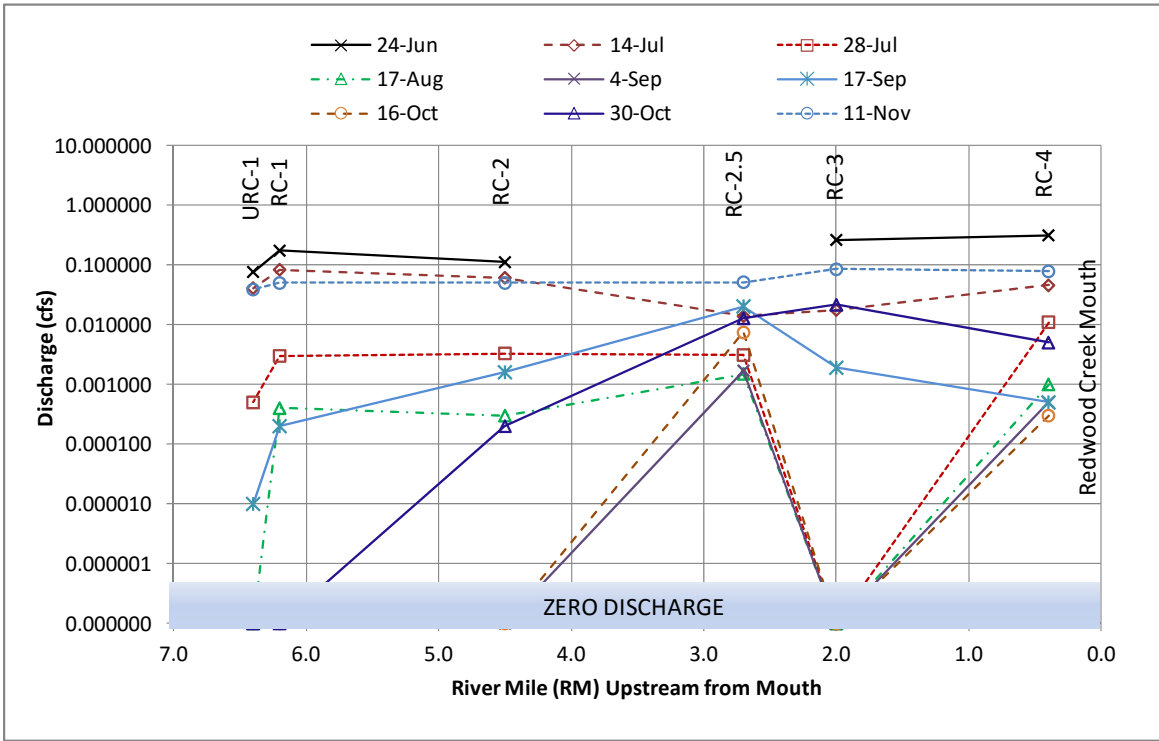


Figure 9. Spot discharges along mainstem Redwood Creek for selected dates in 2015.

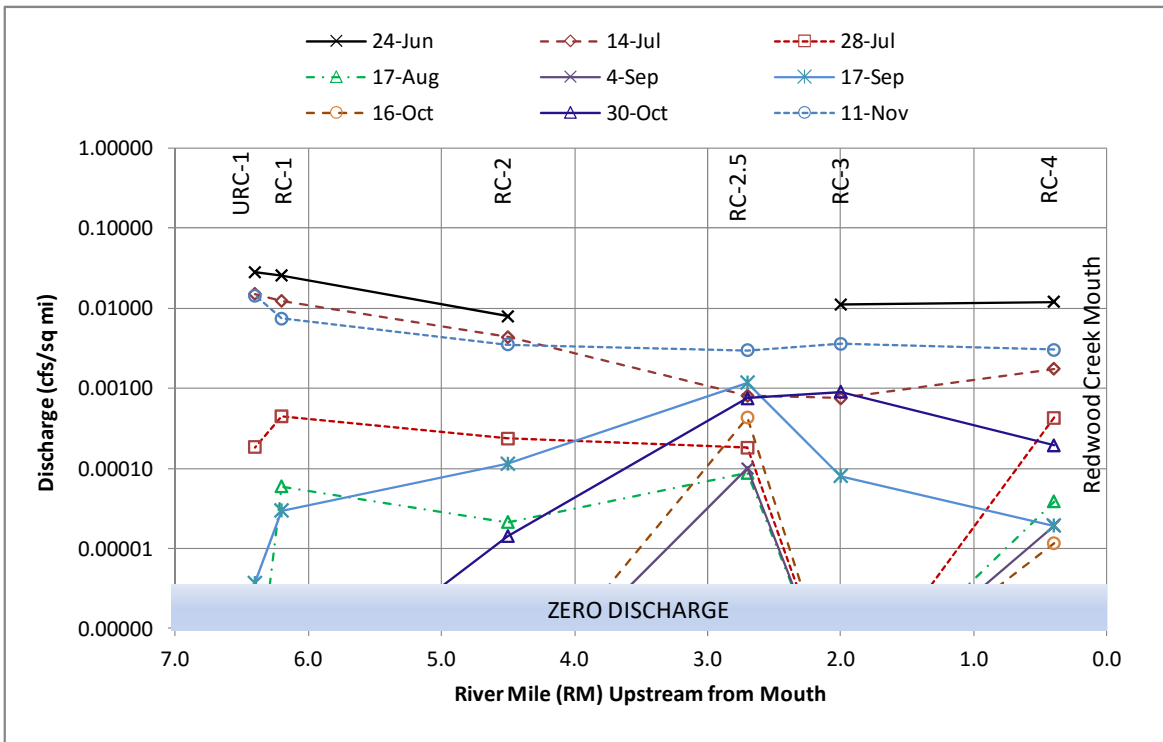


Figure 10. Normalized spot discharges along mainstem Redwood Creek for selected dates, 2015.

In terms of simple discharge (Fig. 9), along-channel discharges were near constant early and late in the season late June through mid-August from RC-1 to RC 2.5, then increased from upstream to downstream from early September through late October, the only period conforming to expectations.

From RC-2.5 downstream to RC-3, discharge dropped precipitously from late July through mid-October, despite inflows from Seely Creek (SC-1) just upstream of RC3 during and briefly following a rainfall September 16. A possible explanation for this is the large number cannabis growing facilities between these two sites, both in the Seely Creek watershed and along the mainstem on both sides of the channel. Figure 11 shows the locations and relative sizes of cannabis facilities mapped by the California Department of Fish and Wildlife (CDFW) using 2012 satellite imagery and the locations of the SRF monitoring sites.

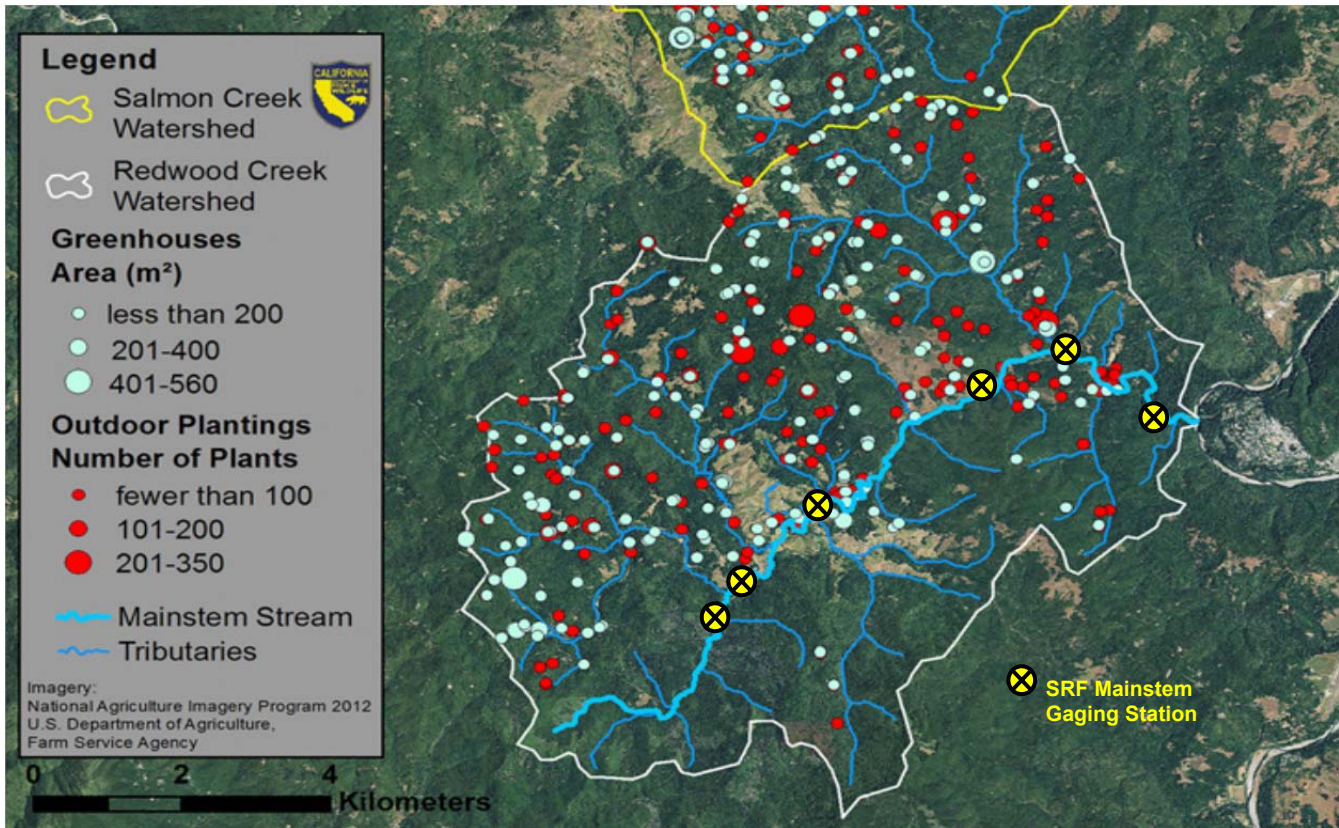


Figure 11. Cannabis growing facilities in Redwood Creek as of 2012 (reproduced with permission from CDFW, 2015).

Between RC-2 and RC-2.5, the right bank of the main channel (to the southeast) is nearly devoid of cannabis grows and, as is apparent in Figures 9 and 10, this reach of Redwood Creek was the only one in 2015 that conformed to the downstream flow accretion model. Thus there appears to be an association between the behaviors of flows longitudinally and the densities of cannabis grows. It should be noted that this may be a coincidence (i.e., no causal relationship), and there are surely other human influences on flows that have not been inventoried or quantified.

Field Observations

As seen in previous monitoring years (2013 and 2014) for Redwood Creek and its tributaries, streams started losing connectivity late July, and remaining, isolated pools of water began to dry. The only two monitored locations to maintain flows throughout the season were mainstem sites RC-2.5 and RC-4. Mainstem site RC-2.5 maintained flows throughout the season and often had higher flows than anywhere else in the watershed. DC-1 and BC-1 are the farthest upstream sites, and sustained flows later into the season than all other tributary sites, as well as some mainstream sites. RC-3, located between RC-2.5

and RC-4, was often dry. Monitoring Coordinator, Bill Eastwood, surveyed from RC-3 upstream to RC-2.5 in an attempt determine where the water stopped. He observed a pumping point and crossed a major geologic boundary, which likely explain why flows disappeared between RC-2.5 and RC-3. Located directly downstream of Briceland township, RC-2 flows fluctuated throughout the season for unknown reasons. SC-1, CC-2, and RC-1 flows also fluctuated throughout the season in similar patterns to each other. URC-1, a good coho-bearing watershed, appeared to have similarly low flows as other tributaries in the Redwood Creek Watershed.

The lower end of Miller Creek was already dried up at the beginning of 2015 monitoring, therefore monitoring site MC-1 was established further upstream where flow was present. MC-2 was later established downstream, nearer the mouth of Miller Creek. A continuous water level logger was placed at MC-2 because of the site's proximity to a streamside well, which was observed running about three times throughout the season. After 1.65 inches of rain on November 7 and 8, 2015, all of the Redwood Creek monitored streams began to flow except for Miller Creek. A similar lag in Miller Creek flow resumption was noted in fall, 2014. The first flow resumption in Miller Creek was observed upstream of MC-1 on November 19, 2015. Flow resumption at MC-2 was not observed until December 2, progressing about 200 to 400 feet downstream each day leading up to that. On December 1, when MC-2 was still dry, formerly dry Miller Creek downstream (at the highway culvert and below) contained full pools, but only a very small amount of flow, which didn't increase until after December 2 when flow reached it from upstream. It is unclear how far upstream the zone of depletion extended. Gravel substrates there are thin, underlain by mudstone bedrock sills that likely form impermeable barriers to subsurface flow.

Future Data Collection and Analyses

Several additional analyses are anticipated as time and data allow. Along with manual observations, longitudinal stream discharge trends will be examined to identify any 'losing reaches' (stream reaches exhibiting discharge losses in a downstream direction) indicative of water withdrawal effects. The simple existence of a losing reach may or may not be due to water withdrawal effects, but is useful for identifying areas for closer examination. In addition, total water volume passing by each site during the low flow season will be computed for comparison.

The USGS stream gages on South Fork Eel River and Elder Creek provide data from larger watersheds that will be evaluated to see if there is a strong enough correlation in discharges to be of use as surrogates for Redwood Creek. Based on prior experience in the Upper Mattole (Klein, 2015), a stream gage with online access to realtime data such as the South Fork can serve as an indicator of flow elsewhere. As the forbearance program is implemented in Redwood Creek, having a readily available estimate of Redwood Creek discharges would assist in forecasting when forbearance should be invoked or relaxed in the Redwood Creek watershed. It could also serve for estimating flows at other monitoring sites where a strong enough correlation exists.

A third data source proved to be useful in the Upper Mattole is antecedent precipitation index, or API, which uses a decay function applied to daily rainfall data to provide an index of the watershed's wetness. It is often well-correlated with streamflow. Both South Fork Eel River flow and API will be tested to evaluate their utility for estimating and forecasting low flows in Redwood Creek. Similarly, a weather station in Redway maintained by CalFire records data potentially relevant to this study. Continuous data sets are available through the State on relative humidity and air temperature for Redway. Such data has helped explain low flow anomalies observed in the Upper Mattole studies (Klein, 2015). Although not presently monitored, several tributaries to Bull Creek have the potential to provide relatively unimpaired flows for comparison with Redwood Creek sites. Much of the Bull Creek watershed is located within Humboldt Redwoods State Park. Assuming there is little water extraction in some of these tributaries, they could serve as control sites. They have several key features similar to Redwood Creek, including drainage areas, climate, aspect, geology, and basin geomorphology. Table 3 lists the possible tributaries in Bull Creek and relevant parameters (note that Cabin Creek is not within Bull Creek, but just to the north).

Table 3. Possible control sites in Bull Creek.

Bull Creek Location	Basin Side	River Mile Upstream from Mouth*	Drainage Area (mi ²)	Max. Elev. (feet)	Min. Elev. (feet)	Relief (feet)	Mean Basin Elev. (feet)	Mean Basin Slope (%)
Tepee Creek	South	0.9	0.7	2855	179	2676	968	30.9
Cow Creek	North	1.9	2.4	2413	199	2214	1213	28.2
Connick Creek	South	2.2	0.5	2962	222	2740	1116	33.1
Miller Creek	South	2.8	0.6	2011	208	1804	807	29.3
Calf Creek	North	3.0	0.5	2157	239	1918	1139	27.3
Harper Creek	North	3.5	1.5	2462	255	2207	1313	32.4
Squaw Creek	South	3.8	4.7	3343	242	3101	1367	35.5
USGS Gage #11476600	Main	4.8	28.1	3343	230	3113		
Albee Creek	North	5.0	1.4	2467	363	2105	1443	31.1
Cabin Creek (SF Eel trib)	n/a	n/a	0.7	2010	138	1872	1141	39.4

* river mile distances are to tributary confluence with mainstem

More research is needed to select the most suitable control sites among those in Table 3. Adding Bull Creek sites to the monitoring tasks for Redwood Creek described here is not feasible, but discussions with the CDFW indicate they may have the ability to monitor flows in several Bull Creek tributaries (D. Manthorne, pers. comm., 2015). Assuming control data become available from Bull Creek or elsewhere, the Redwood Creek dataset will be compared and contrasted with data from suitable control sites.

‘Streamlined’ Monitoring

There is interest by funding agencies in ‘streamlining’ future monitoring to reduce costs while still providing sufficient information for attaining project goals. An appropriate strategy for streamlining will, of course, be specifically designed to be compatible with project goals. With enough prior data, there are several ways to reduce the monitoring task that may not compromise the validity of monitoring and thereby fail in providing the necessary minimum information: 1) reduce the number of sites monitored, 2) reduce the frequency of monitoring, and 3) bring in partners that could take over some sites (government agencies, volunteer interest groups or individuals). Reducing the number of sites must be done carefully so as to retain sites that are best representative of the overall hydrologic conditions of the watershed (i.e., ‘index’ sites). Sites that are most subject to unknown sources of variability, unless part of a specific cause and effect study, are the least informative to the broader goals of the study and thus the most likely candidates for omitting.

Reducing the frequency of monitoring site visits might be the better alternative over reducing the number of sites if dry season flow recessions were always linear, in which case linear interpolation could fill in periods of missing measurements. However, we know that is not the case at many sites: flow can recede linearly for some period early in the dry season, then drop precipitously later on (see Figs. 1-4). The more frequent the monitoring visits, the better hydrologic conditions will be characterized and the more precisely will be known the date at which some target flow threshold is attained or flow cessation occurs. For the Redwood Creek study, we can evaluate the best ways that the project could be streamlined so that the impacts to the projects are minimized following data analysis from the 2016 monitoring season.

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