Low Flow Stream Discharge Monitoring Report for the Redwood Creek Watershed, 2015-16

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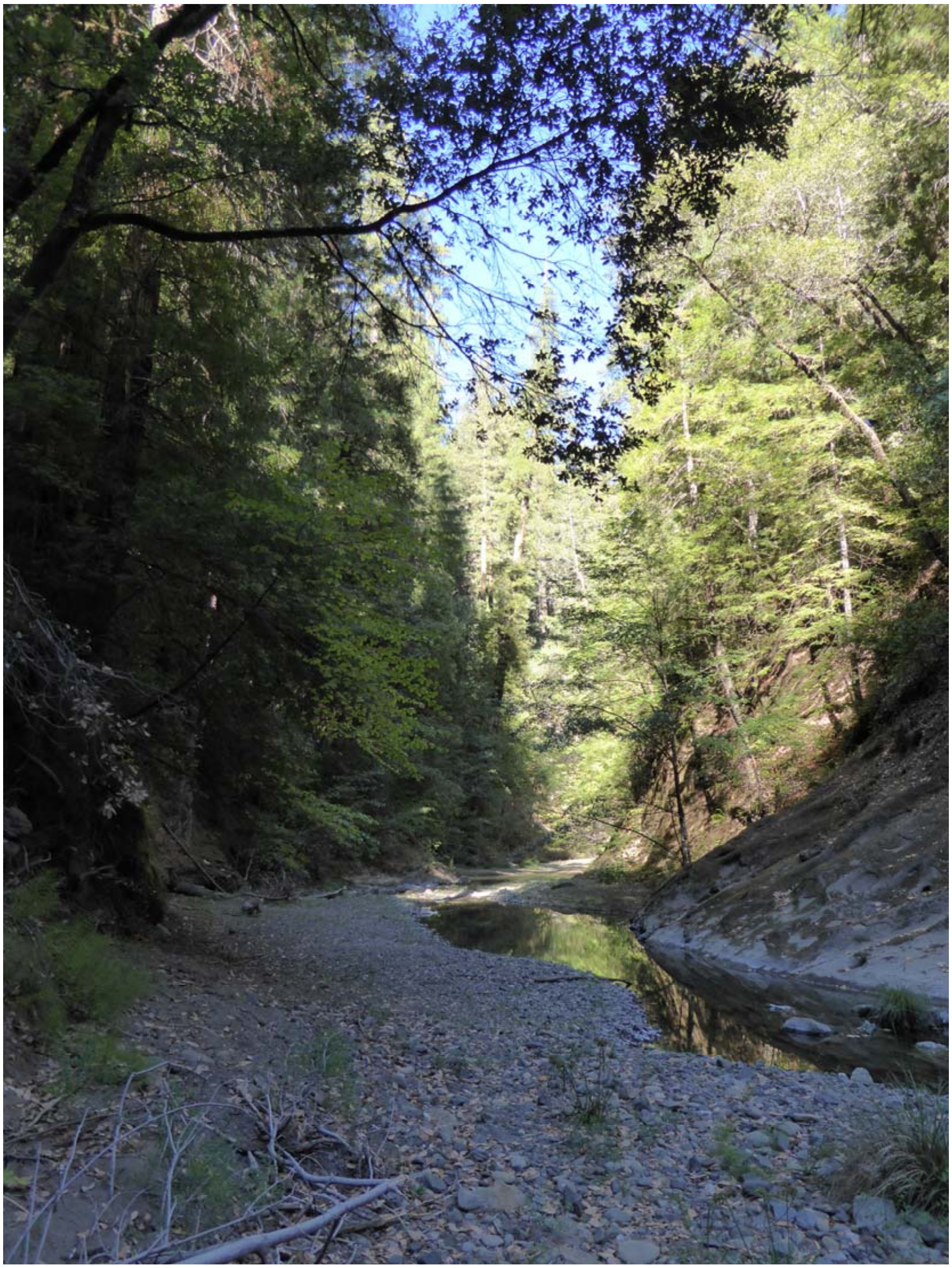
Prepared for the Salmonid Restoration Federation



Isolated pool in lower mainstem Redwood Creek, September 24, 2015. R. Klein

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Introduction

Through grants provided by the State of California, the Salmonid Restoration Federation was able to begin 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 report presents data collected during the two-year study period for this project (summers of 2015 and 2016). Both 'spot' discharge data (single measurements made during site visits) from mainstem and tributary sites and continuous discharge records from three of the six mainstem sites along Redwood Creek are presented in graphical form. Some comparisons between 2015 and 2016 are provided.

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 impaired 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 to optimize benefits to juvenile salmonids.

The low flow monitoring and enhancement program underway in Redwood Creek is modeled, in part, on that pioneered in the Upper Mattole River basin by Sanctuary Forest, a local non-profit. Klein and others (in press) inferred that, after installation of over 5 million gallons worth of tank capacity in the Upper Mattole, low flows had been measurably improved. Most of the increase in storage has been from landowners participating in a forbearance program whereby they agree to cease pumping water from stream channels when notified that a threshold has been reached, thereafter relying on stored water until the low flow season ends. The success of this program, particularly in an era of increasing water demands and drought severity, provides a model for replication elsewhere, and the Salmonid Restoration Federation's Redwood Creek project is poised to replicate such a program.

Factors Affecting Low Flows

A variety of factors influence low flows, such as, climate (rainfall, temperature, fog, relative humidity, wind speed), vegetation species and age distribution, ground disturbance, streambed sediment depth, and water use for domestic and agricultural purposes. Of these, only vegetation, ground disturbance, human water use, and possibly riparian aquifer storage are subject to human influences and therefore might be modified to improve low flows.

Stubblefield and others (2012) measured water use by trees in the nearby Mattole River, finding that although older and larger trees use more water, dense, younger tree stands use more per unit area. They project that as forests are allowed to mature, the declining numbers of young trees will result in less total water use by forested areas. This, of course, assumes forests will be maturing despite ongoing timber harvest and future stand-replacing wildfires, should they occur.

Sawaske and Freyberg (2014) analyzed stream gaging records from Pacific coastal streams, finding that although spring discharge recession rates have remained relatively constant for the past four to eight decades, summer recession rates have increased. Their results agree with those of Asarian and Walker (2016), who found that although precipitation-adjusted streamflow at pristine sites had not declined, September streamflow declined at 73% of un-dammed sites in Northwest California and Southwest Oregon in the latter part of the available record. They attributed this to water withdrawals and vegetation changes rather than precipitation or other climatic changes.

The burgeoning cannabis industry in North coastal California has been well-publicized. Bauer and others (2015) conducted aerial inventories of 'grows' (signified by large greenhouses and outdoor gardens) relying primarily on Google Earth's high-resolution images with some level of verification derived from law enforcement activities on the ground. When their study was done in 2012, Bauer and others (2015) estimated that, for the redwood region, from 23% to 100% of summer flows may be withdrawn for use by this industry, but that deriving more accurate numbers was hampered by grows being typically clandestine operations located on private property. Whatever the true rates of water withdrawals for cannabis growing operations (and they have likely risen since 2012), their proliferation adds to the cumulative effects of the other human-caused decreases in streamflows mentioned above.

Rainfall Patterns of 2013-16

Figure 1 compares rainfall for 2013-15: 2013 and 2015 stand out as the driest years shown going into the low flow season (by June 1), with 2014 twice as wet and 2016 over three time as wet. Near record low rainfall leading up to the 2015 low flow season (14.7 in. by June 1), similar to 2013 (12.2 in. by June 1), 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. In 2015, rainfall essentially stopped in early April, 2015, and didn't resume in earnest until late October, getting off to a relatively slow start. By contrast, 2016 rainfall was far greater, accumulating to 39.7 inches by June 1, and rainfall ended the 2016 wet season by mid-October with a series of intense storms lasting through the end of the year (Fig. 1).

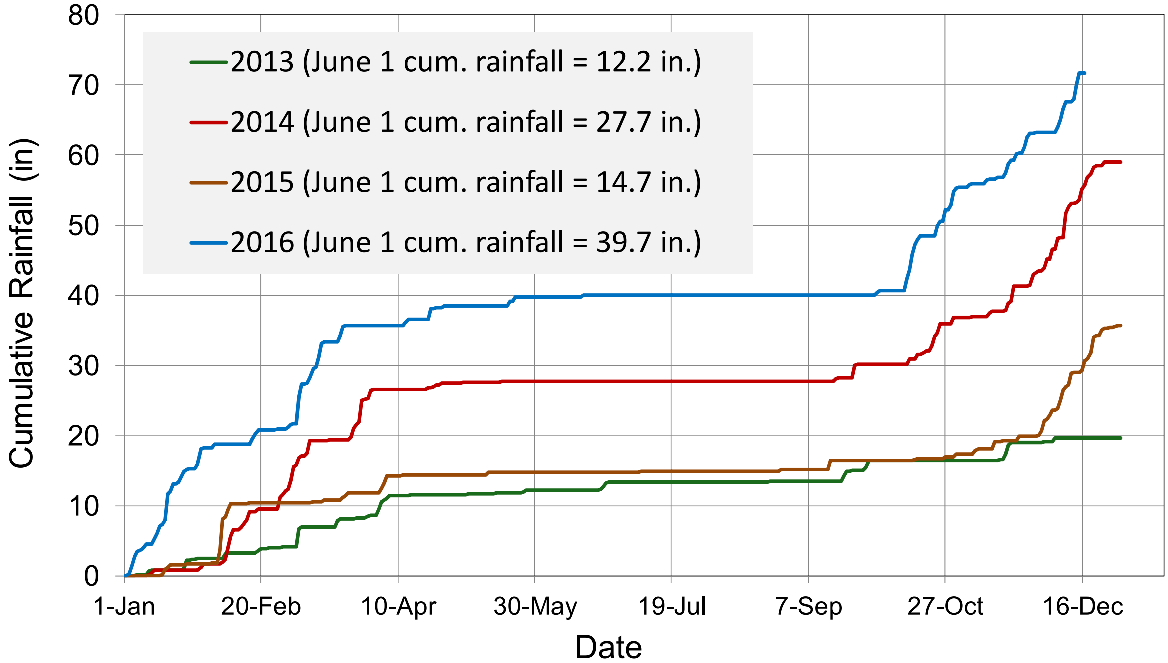

Figure 1. Cumulative calendar year (CY) rainfall from the Calfire station 'ERC' at Redway, CA, for 2013-16.

The extreme droughts of 2013 and 2015 were certainly exacerbated by human water withdrawals, which tended to increase with drier conditions as crop irrigation demands intensified. Although water withdrawals certainly reduced flows in 2014 and 2016 as well, the much larger amount of rainfall that preceded the low flow seasons in those years moderated the impacts, as did the earlier onset of the wet season (Fig. 1).

Redwood Creek Watershed Study Area

Joining with the South Fork Eel River near Redway, CA, Redwood Creek drains a basin area of about 26 square miles of forested steeplands. 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 utilized most of the sites monitored in 2013-14 and added several additional 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 (see Appendix B) shows watershed geography and the locations of hydrologic monitoring in 2015-16.

At present, the factors controlling discharge rates within the watershed are not well understood (see above) and generally cannot be controlled, so a controlled experimental design could not 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; note that site URC-1 served as both a mainstem and a tributary monitoring site).

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

Redwood Creek Monitoring Site	Site Code	River Mile Upstream from Mouth*	Drain-age 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.

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 recorded with electronic data loggers were collected.

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 were 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. The accuracy of estimated discharges varies depending on the strength of the stage-discharge relationship at each site. Variability can be caused by channel complexities at the gaging site, errors in reading stages, and errors in measuring discharge.

Data Treatment and Analyses

Manual field data (discharge, stage height, water and air temperature) were entered into spreadsheets soon after data collection. Data logger downloads were processed to adjust for atmospheric pressure and appended into a single data file for each year. Several additional steps were required to prepare the data for analysis, specifically, adjustment of electronic stages to match manual stages, development of a stage-discharge rating equation specific to each site, and finally, computing continuous discharge. For ease of comparison among sites in Redwood Creek that vary widely in contributing drainage area, the discharge data presented herein is expressed as cubic feet per second per square mile of drainage area (cfs/mi^2), or ‘unit discharge’.

Results

2015 and 2016 Discharge Measurements by Groupings

As discussed above, rainfall was vastly different between 2015 and 2016, affording an opportunity to compare discharges from two hydrologically distinct sets of conditions. The drought of 2015 extended through late October, punctuated by several small rainfall events (see Fig. 1). In 2016 there were no significant rainfall events between May 24 and October 13, but cumulative rainfall leading up to the dry season was much higher in 2016 than in 2015. In addition, the rain persisted further into the spring recession and began again somewhat earlier than in 2015 (Fig. 1).

Hydrologic monitoring for this project began in June in both 2015 and 2016 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 in 2015 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. By mid-October of 2015, rainfall events were sufficient to re-establish flows at all monitoring sites.

Manual discharge measurements were compiled and re-formatted for plotting and used to develop discharge rating curves for converting continuous stage (from the data loggers) to discharge. Plots of measured discharge data using discharge per unit area (‘unit discharge’ per square mile of contributing watershed area upstream) from 2015 are shown below in Figures 2-3 for the mainstem and tributary sites, respectively [note that URC-1 serves both groups]. Figures 4 and 5 show unit discharges for 2016.

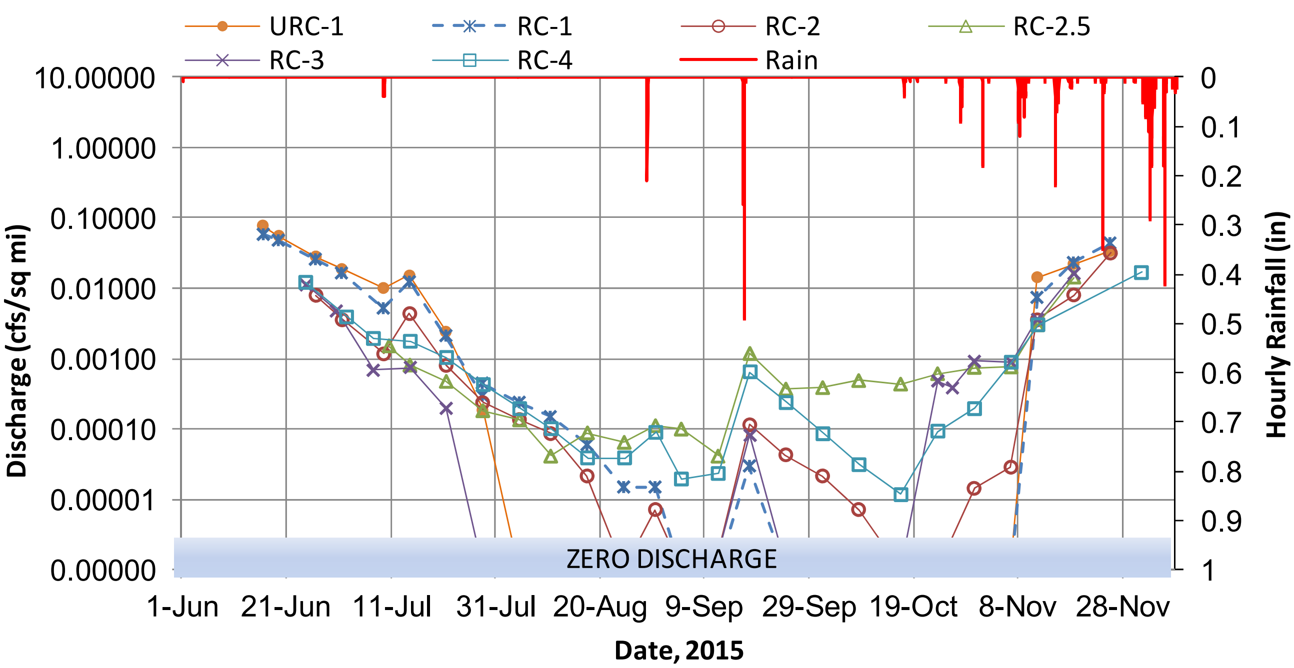

Figure 2. Unit discharge and rainfall at mainstem sites, 2015.

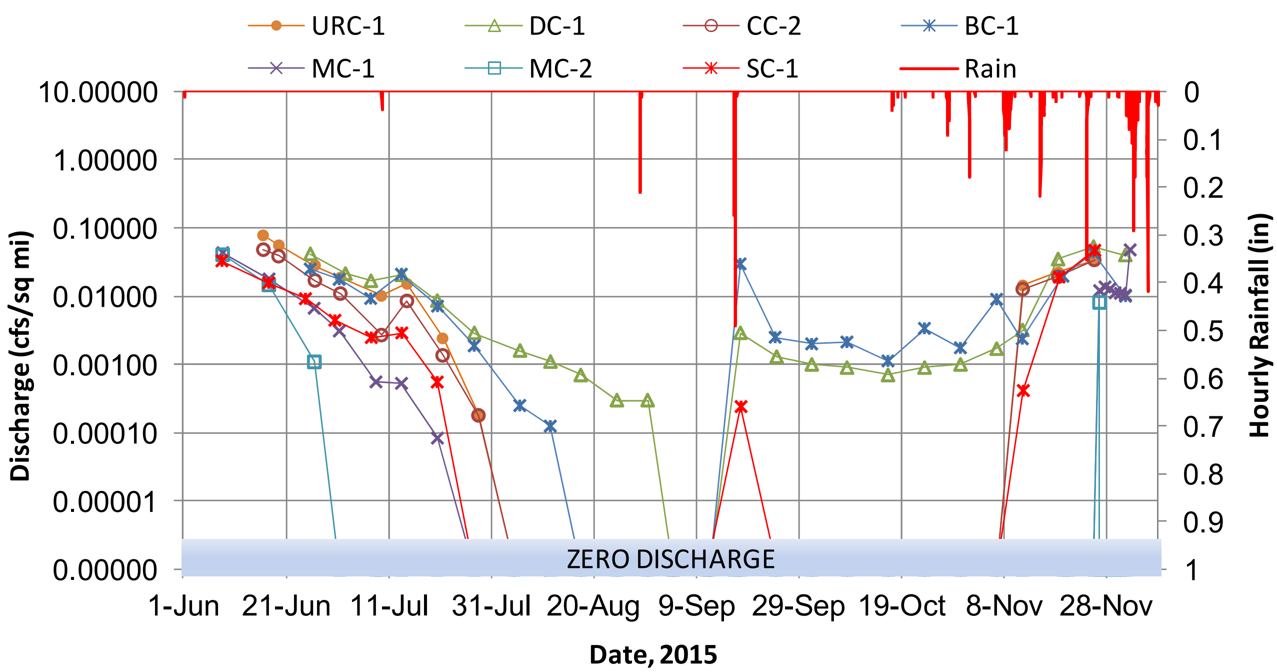

Figure 3. Unit discharge and rainfall at tributary sites, 2015.

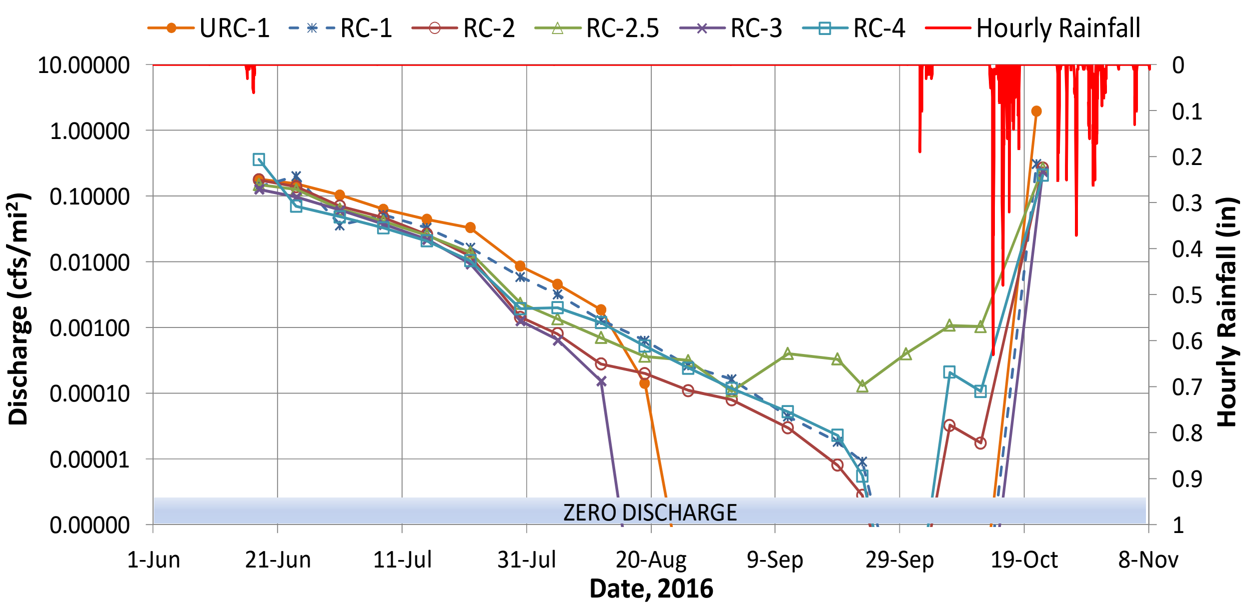

Figure 4. Unit discharge and rainfall at mainstem sites, 2016.

Figures 2-5 illustrate the differences in streamflow between two low flow seasons with differing rainfall. Two rainfall events in mid-summer, 2015, prevented two mainstem sites from going dry (RC-2.5, RC-4, Fig. 2) and caused several tributary sites to rebound after going dry (BC-1, DC-1, and SC-1, Fig. 3). Steady recession of flows in 2016, uninterrupted by rainfall, occurred at all sites from early July through mid-October, when a series of rainfall events ended the dry season (see Figs. 4 and 5). Despite the rainy start to 2016, only two sites had continuous flows throughout the dry season: mainstem site RC-2.5 (Fig. 4) and Buck Creek (BC-1, Fig. 5). Even though the other sites went dry for a part of the low flow season, the periods of zero discharge were much shorter than in 2015.

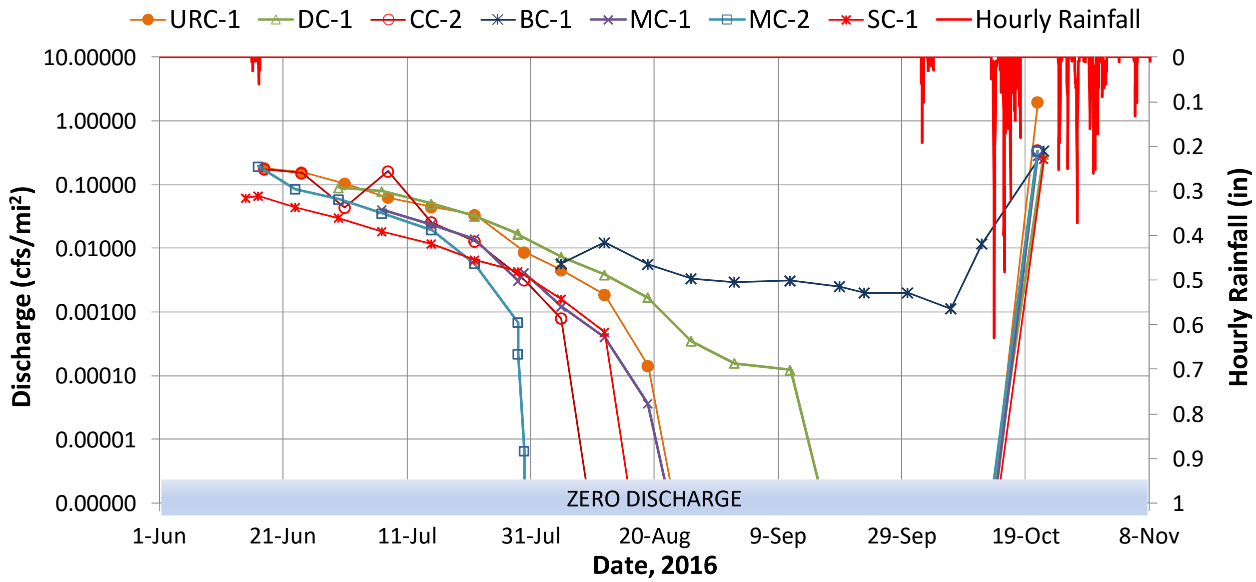

Figure 5. Unit discharge and rainfall at tributary sites, 2016.

Discharge Measurements by Site, 2013-2016

Figures 6 through 17 show unit discharge (cfs/mi^2) for the entire periods of record for mainstem and tributary sites. Six sites had measurements going back as far as 2013, providing a somewhat longer view of annual trends beyond our study period for this project. Of note, in Figure 9, the 2013 data suggest there was continuous flow throughout the dry season at RC-3. This is an artifact of the gap in measuring discharge from mid-August until late September. Field observations indicated that flow had indeed ceased at RC-3 from August 15 through September 23, 2013 (Bill Eastwood, pers. comm. 2017).

While most mainstem and tributary sites had periods of flow cessation, several stand out as more resilient. Mainstem sites RC-1, RC-2, and RC-4 had only brief periods of zero flow over their respective periods of record, and RC-2.5 had continuous flow for all years of monitoring (2015-16).

Buck (BC-1, Fig. 15) and Dinner (DC-1, Fig. 17) creeks had the most persistent flow through the dry seasons monitored among Redwood Creek tributaries. As with RC-3 (see above) in Figure 14, the 2013 data for SC-1 suggest there was continuous flow throughout the dry season, but field observations indicated that SC-1 was not flowing from August 5 through September 23, 2013 (Bill Eastwood, pers. comm. 2017). BC-1 had flow throughout the 2016 dry season, and the periods of flow cessation at DC-1 were relatively brief.

Oddly, summer flow recession in 2013 and 2016 were nearly identical at several mainstem sites (RC-1, Fig. 6; RC-2, Fig. 7; and RC-3, Fig. 9), despite vastly disparate rainfall by June 1 (12.2 in. in 2013 and 39.7 in. in 2016, Fig. 1). This suggests an increase in water withdrawals over the intervening three-year period.

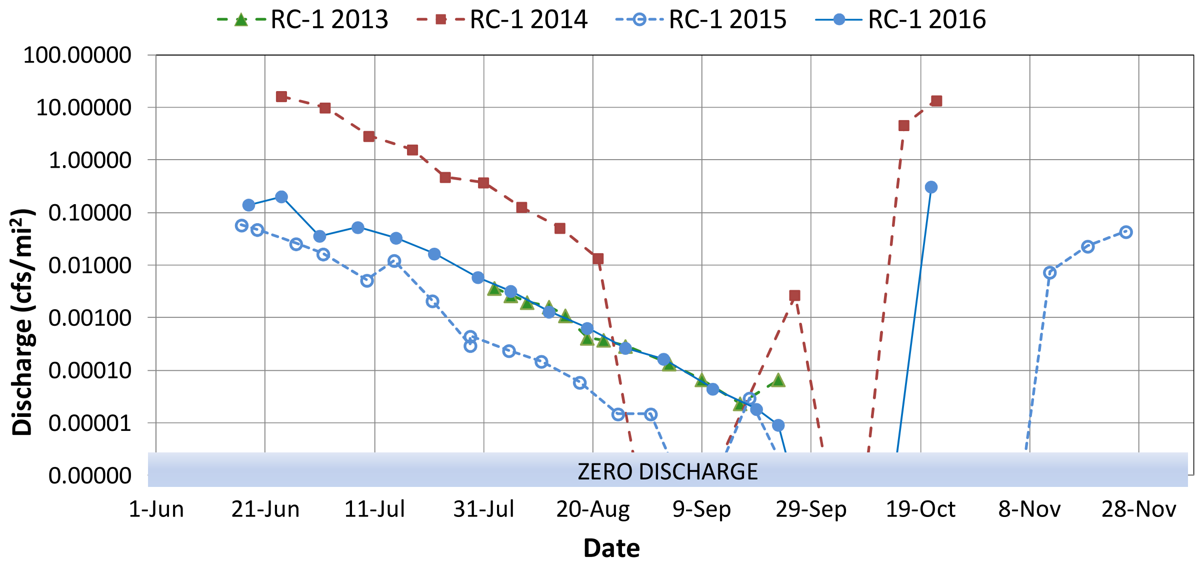

Figure 6. 2013-16 discharge measurements for mainstem site RC-1.

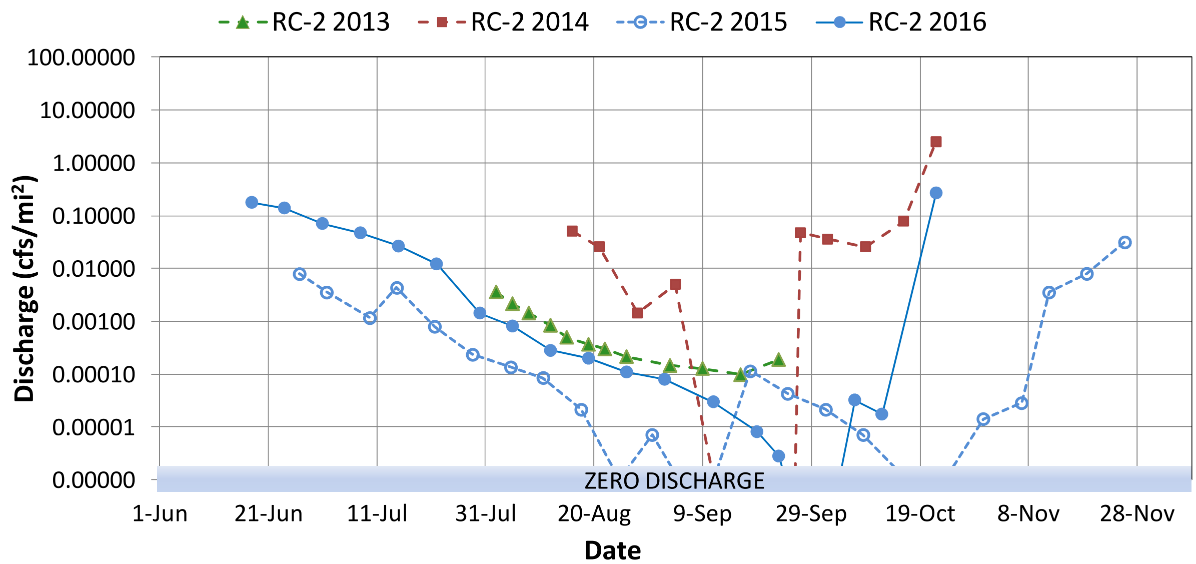

Figure 7. 2013-16 discharge measurements for mainstem site RC-2.

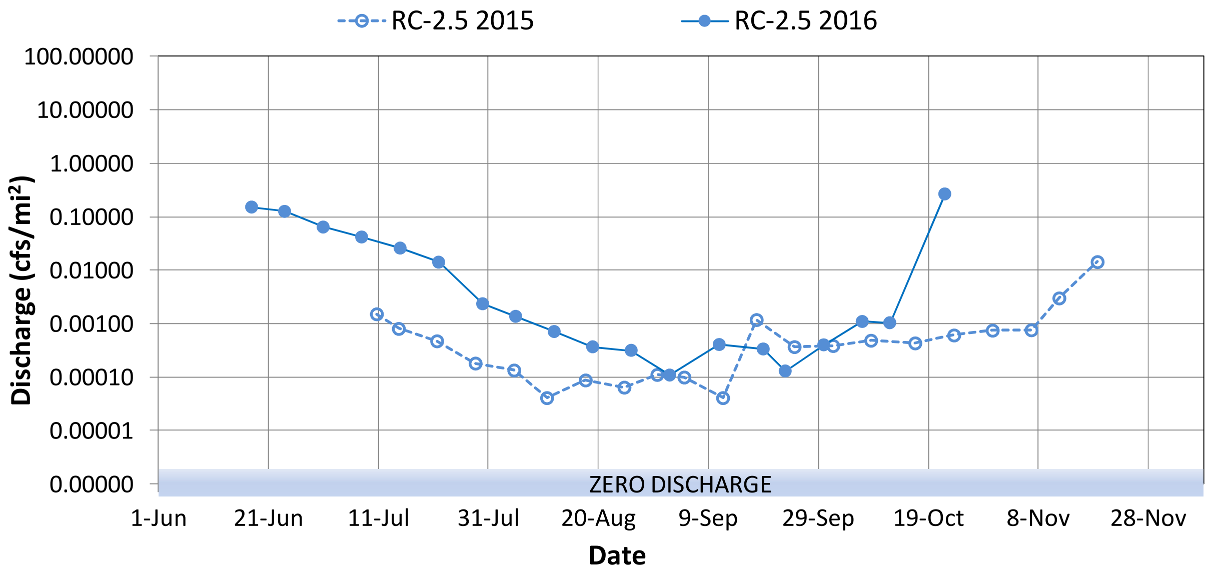

Figure 8. 2015-16 discharge measurements for mainstem site RC-2.5.

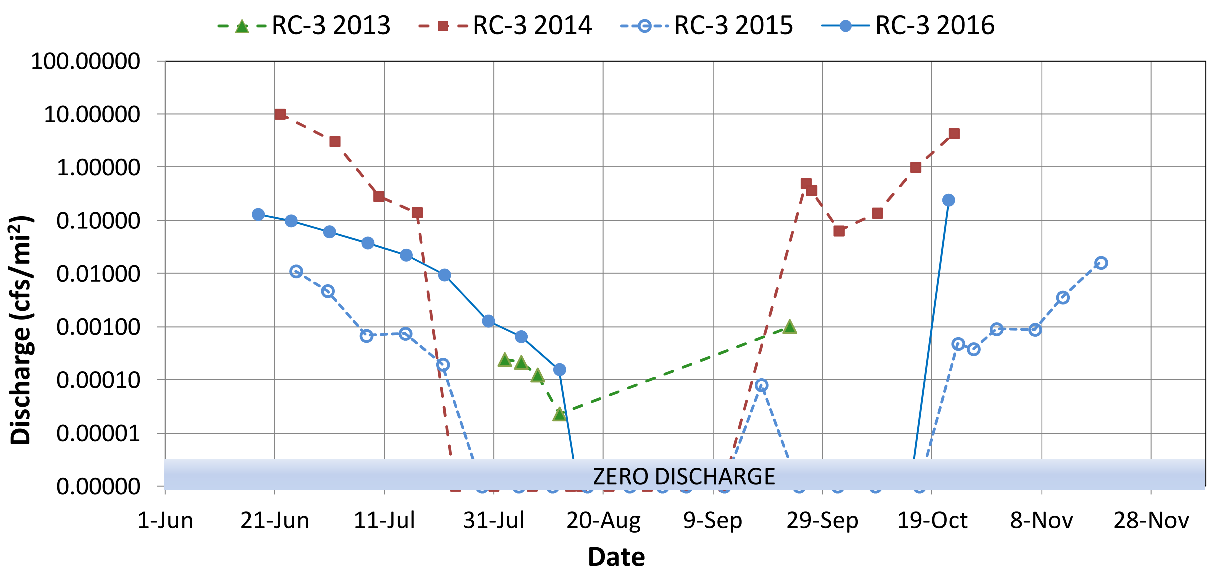

Figure 9. 2013-16 discharge measurements for mainstem site RC-3.

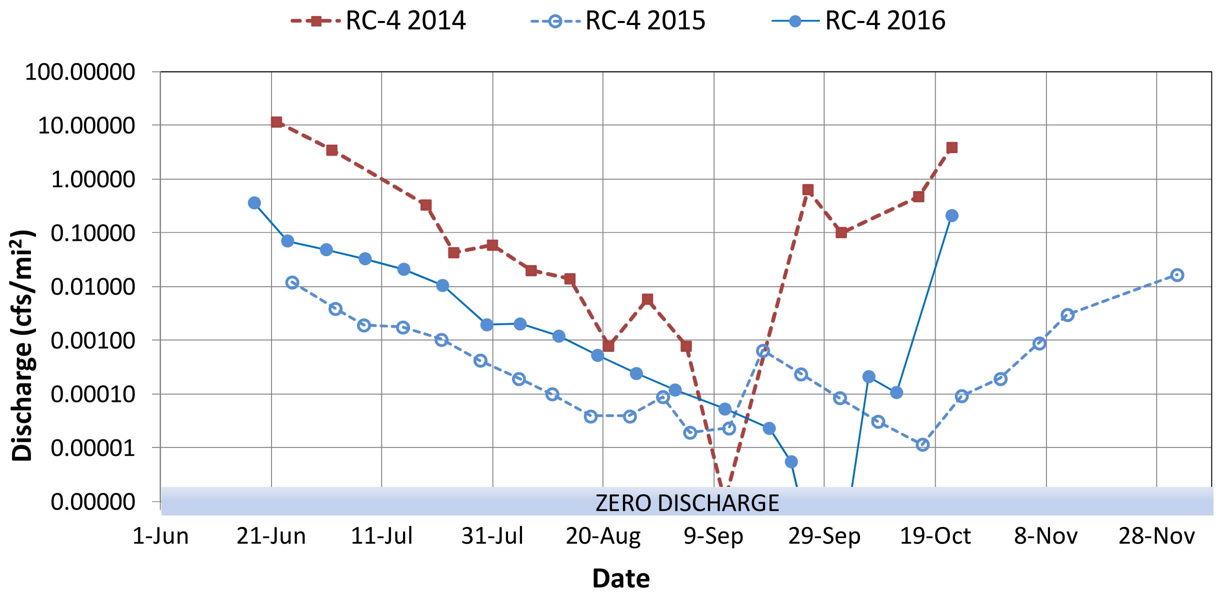

Figure 10. 2014-16 discharge measurements for mainstem site RC-4.

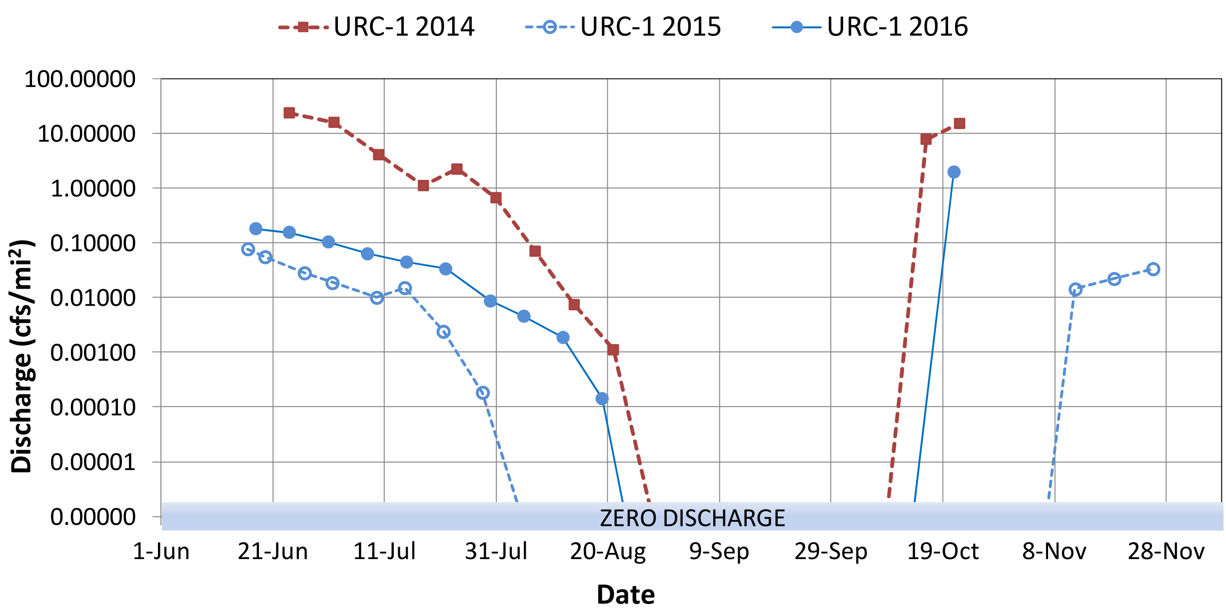

Figure 11. 2014-16 discharge measurements for mainstem/tributary site URC-1.

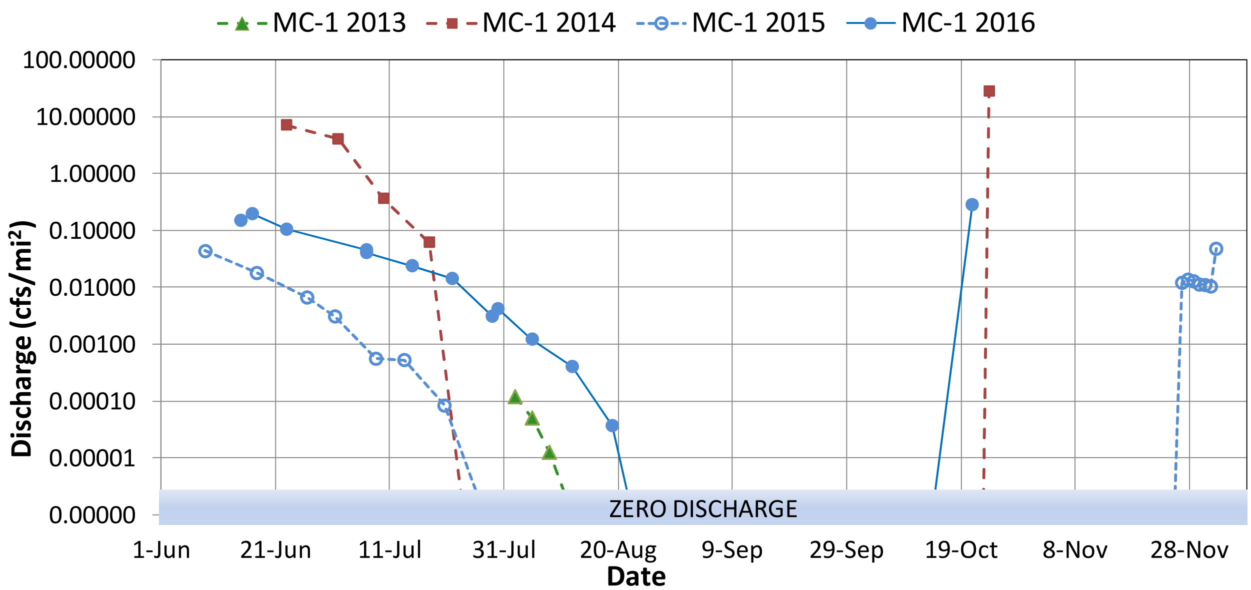

Figure 12. 2013-16 discharge measurements for tributary site MC-1.

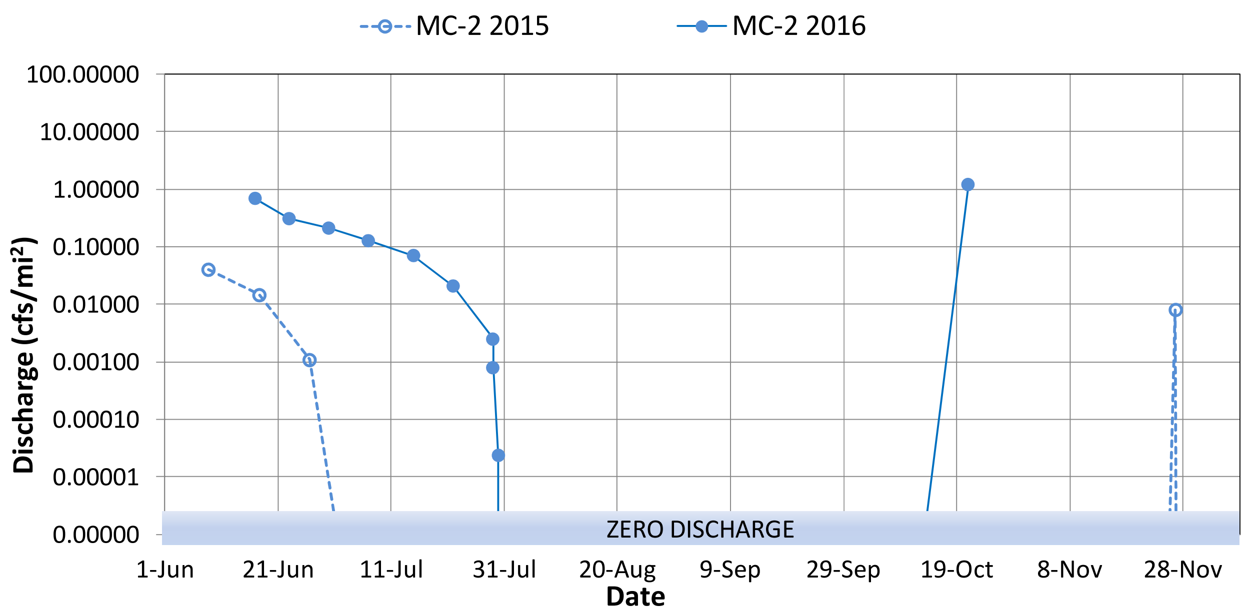

Figure 13. 2015-16 discharge measurements for tributary site MC-2.

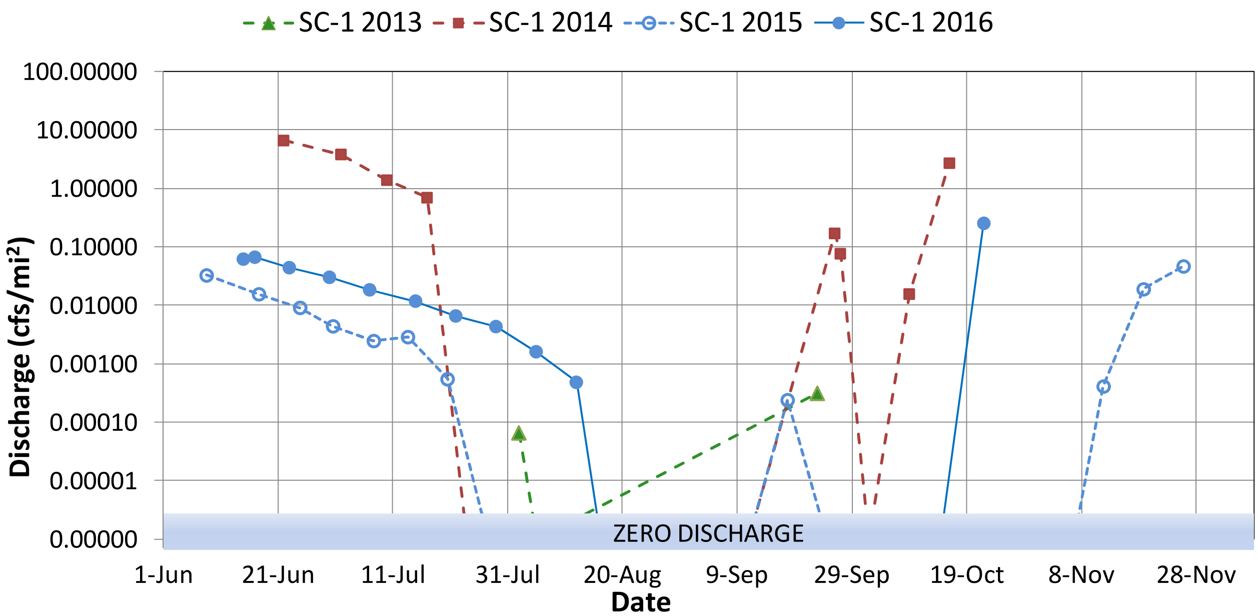

Figure 14. 2013-16 discharge measurements for tributary site SC-2.

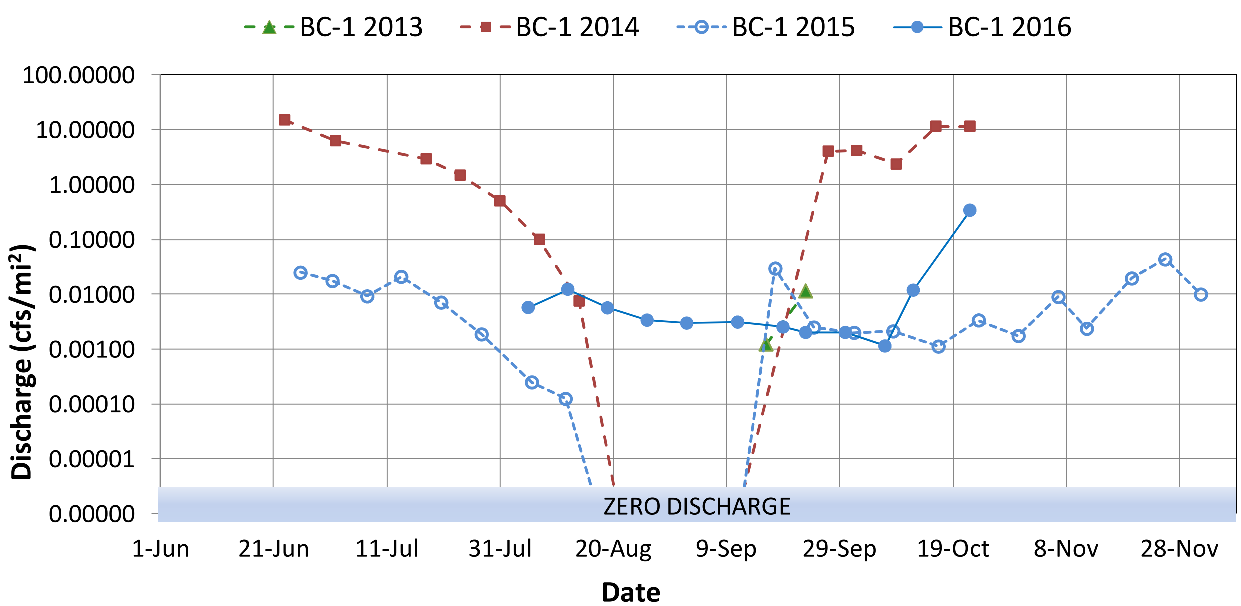

Figure 15. 2013-16 discharge measurements for tributary site BC-2.

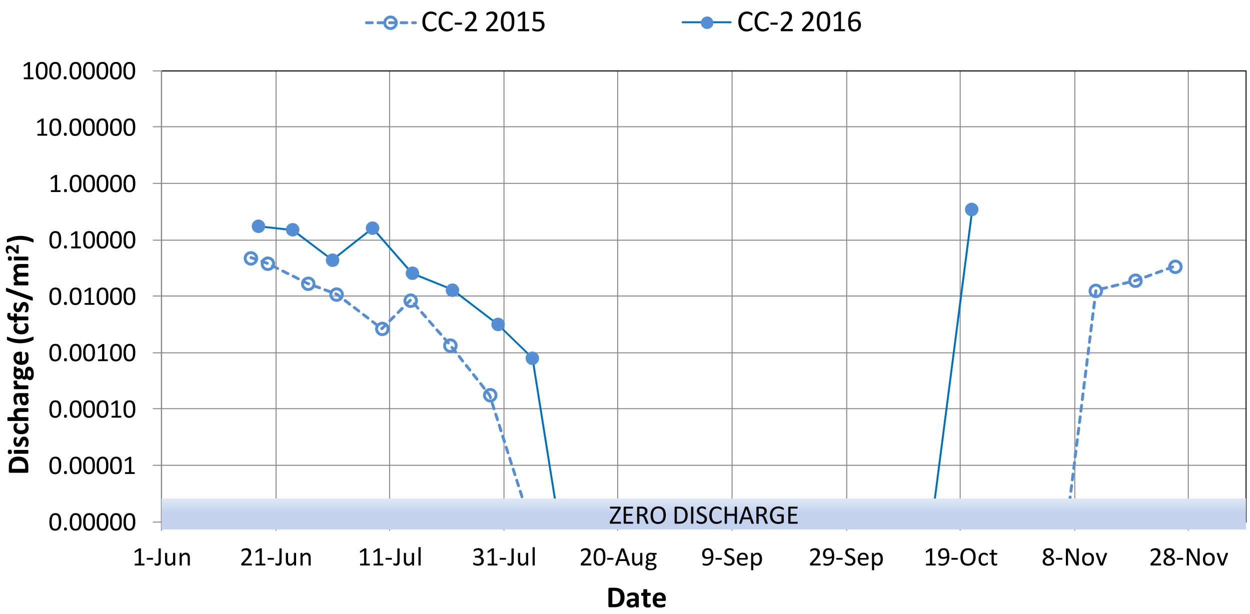

Figure 16. 2015-16 discharge measurements for tributary site CC-2.

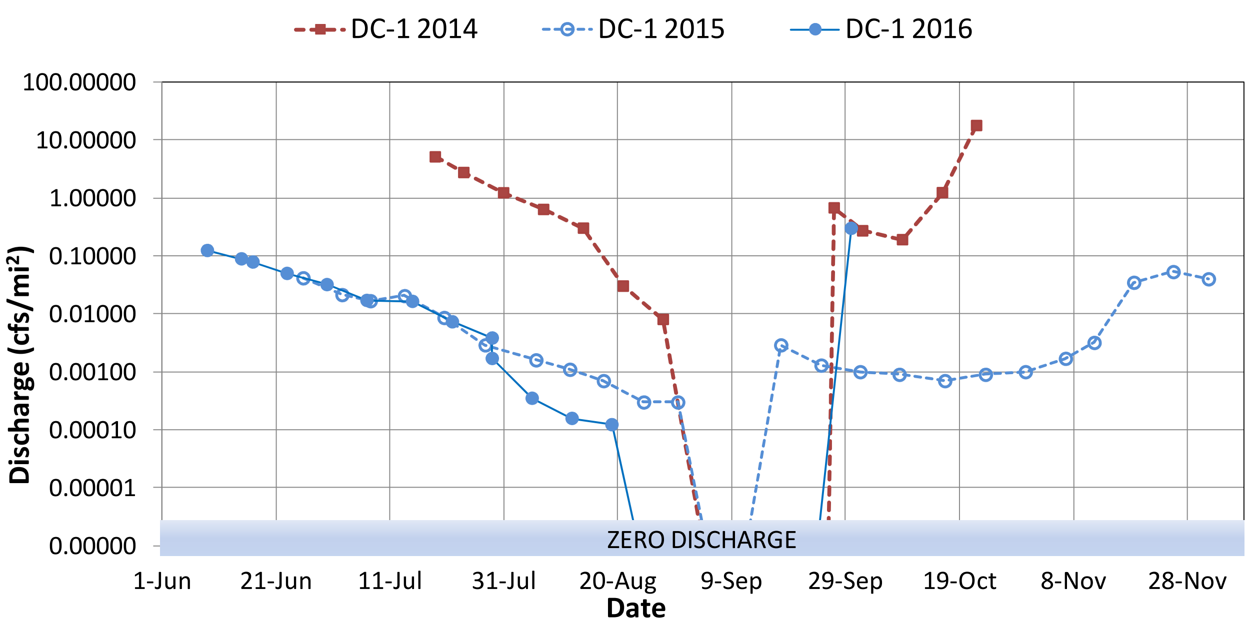

Figure 17. 2014-16 discharge measurements for tributary site DC-1.

Continuous Discharge from Water Level Recorders, 2015-16

Figure 18 shows 2015 continuous discharge data for the four mainstem sites equipped with data loggers (URC-1, RC-1, RC-2.5, and RC-3). Figure 19 shows the 2015 continuous discharge data for the tributaries. Because discharge at the MC-2 site remained at zero for nearly all of the 2015 data collection period, it is not plotted. Hourly rainfall from the nearby Calfire rain gage at Redway is also plotted. The continuous discharge data, although less accurate than the discharge measurement data because of the need for applying an imperfect rating curve to the recorded stage data, allow more precise determinations of the timing of discharge rises and falls.

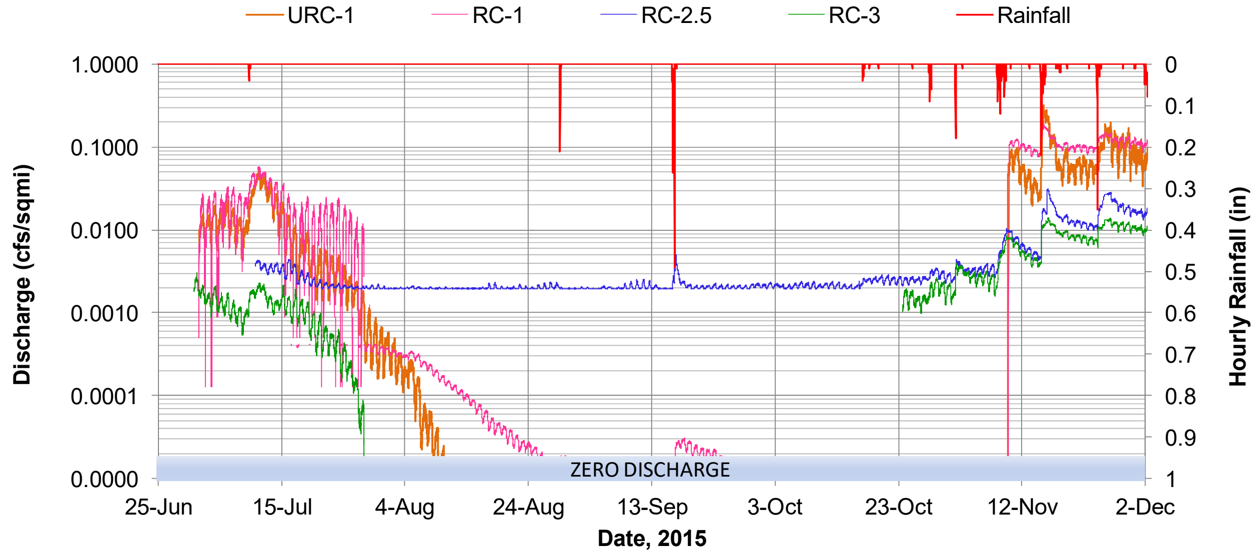

Figure 18. Continuous unit discharge and rainfall at mainstem data logger sites, 2015.

The conspicuous drops in discharge at the beginning of the period at RC-1 from late June through July, 2015, may either be an unexplained artifact of the data logger's recording process or a true depiction of semi-regular periods of discharge fluctuations. Anecdotal knowledge may help explain this phenomenon. If it is the result of periods of instream water extraction, the pumping location would have been very near the data logger site.

All sites except RC-2.5 dropped precipitously beginning in late July, 2015, particularly at RC-3, the downstream-most site. Small rises occurred at RC-1 and RC-2.5 due to a small rainfall event on September 16, 2015. By early November, enough rainfall had accumulated to restore flows at all sites.

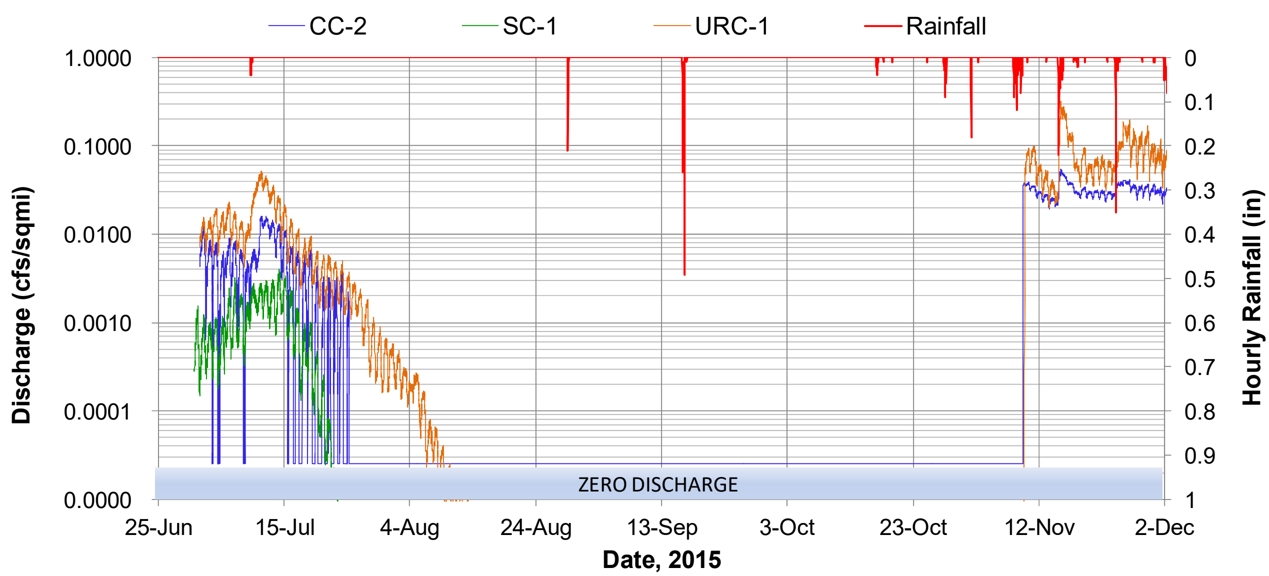

Figure 19. Continuous unit discharge and rainfall at tributary data logger sites, 2015.

Tributary sites behaved similar to the mainstem sites in 2015, dropping precipitously in the summer, but earlier than the mainstem sites. Site CC-2, like the mainstem site RC-1 above, exhibited semi-regular drops through late July, before dropping to zero discharge. As with RC-1, anecdotal information might reveal whether or not these drops are real, and caused by water extraction.

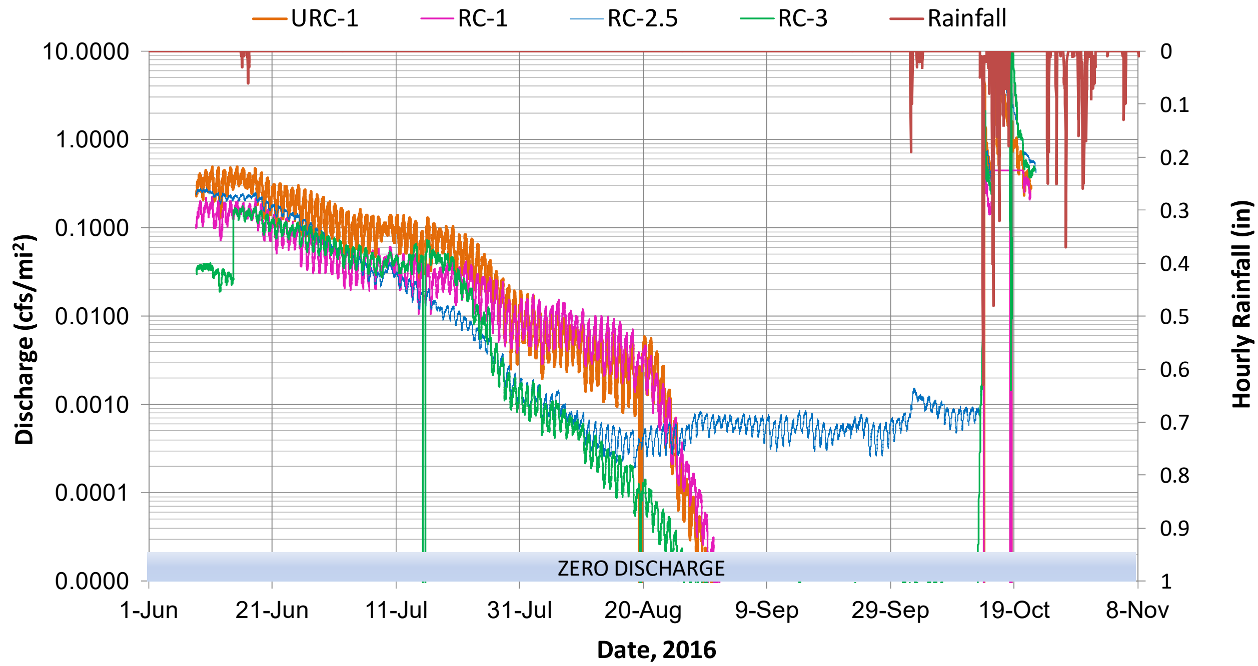

Figure 20. Continuous unit discharge and rainfall at mainstem data logger sites, 2016.

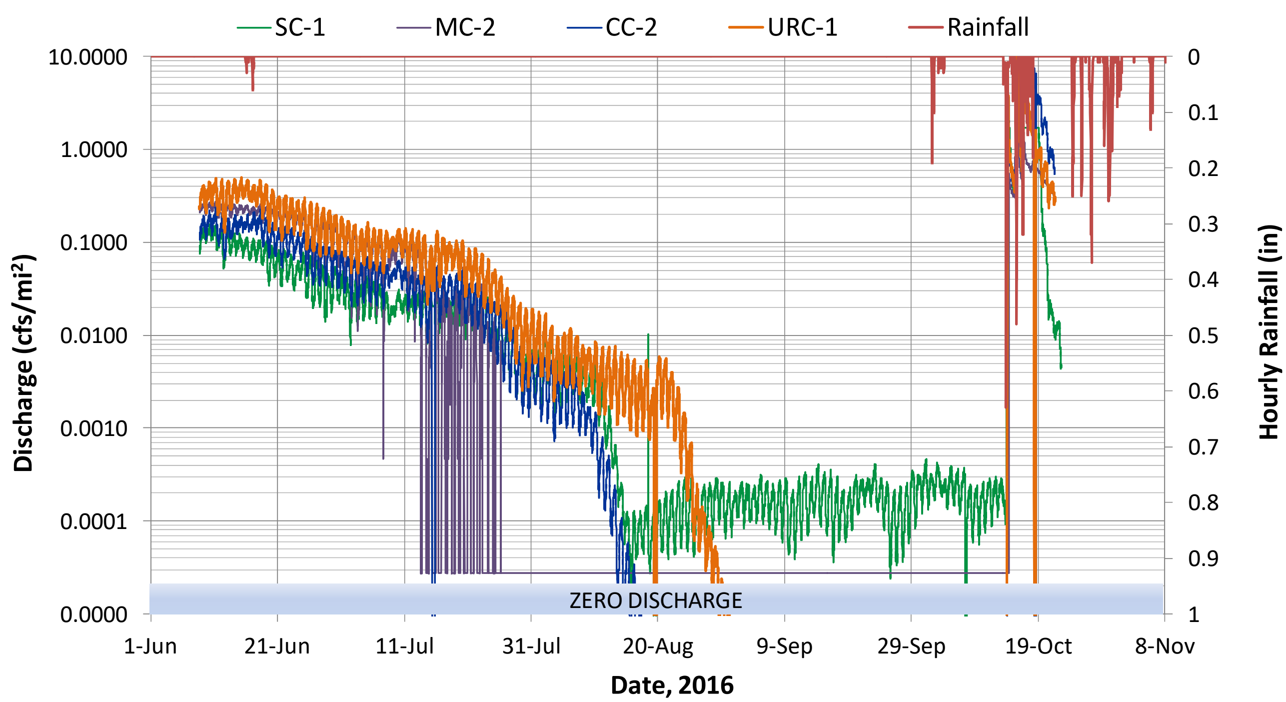

Figure 21. Continuous unit discharge and rainfall at tributary data logger sites, 2016.

Figures 20 and 21 show data logger discharge from 2016 for the mainstem and tributary sites, respectively. As with the spot measurements, flows dropped precipitously at RC-2.5 and RC-3 beginning in July, 2016 (Fig. 20), and resumed with the mid-October rainfall events. Unlike in 2015, the steep decline in flows was delayed at both URC-1 and RC-1 relative to the other two sites, with a rapid decline beginning on August 20. As in 2015, RC-2.5 flows leveled off in early August of 2016 (Fig. 21), after a steep decline, and flowed continuously throughout the season. A small rainfall event October 2, 2016, had little effect on flows, but the larger storm of October 13 brought the dry season to a close.

Longitudinal Discharge Trends

Temporal variations of discharge along the mainstem of Redwood Creek are plotted in Figures 22 and 23 for both years. 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 in both 2015 and 2016 often did not conform well to this model. Site RC-2.5 consistently had higher discharges than both the upstream and downstream sites (RC-2 and RC-3, respectively) throughout the driest part of both 2015 and 2016 (Figs. 22 and 23), dropping steeply downstream to RC-3 before recovering somewhat farther downstream at RC-4. This odd phenomenon began by late July in 2015, and early August, 2016. Beginning in mid-June, 2016, flows were dropping in a relatively consistent manner along the mainstem. However, beginning in late August this pattern was disrupted by a drop in discharge at the RC-3 site, as occurred in 2015. Farther downstream at site RC-4, flow resumed to a level consistent with the upstream sites through the rest of the low flow season. This odd, and as yet unexplained, phenomenon persisted until early November in 2015, and until mid-October, 2016, when flows increased at all mainstem sites in response to fall rainfall events (see Appendix A for a possible explanation).

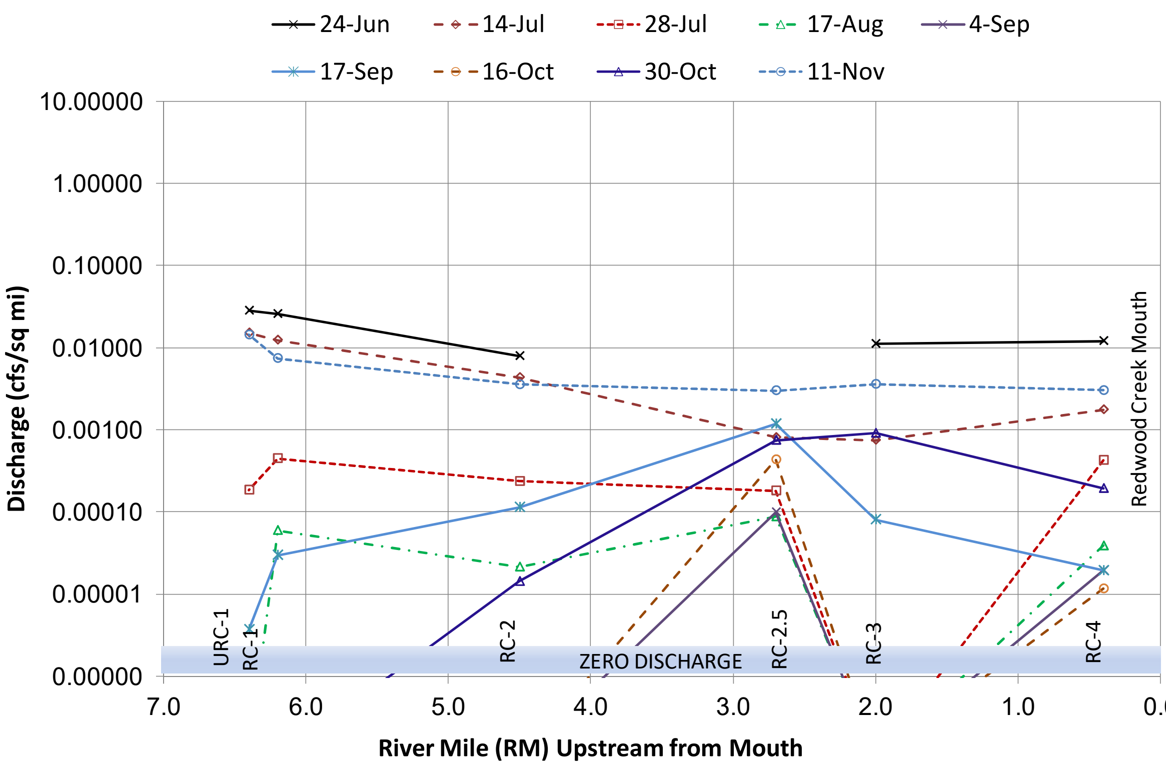

Figure 22. Discharge variations along Redwood Creek at mainstem sites, 2015.

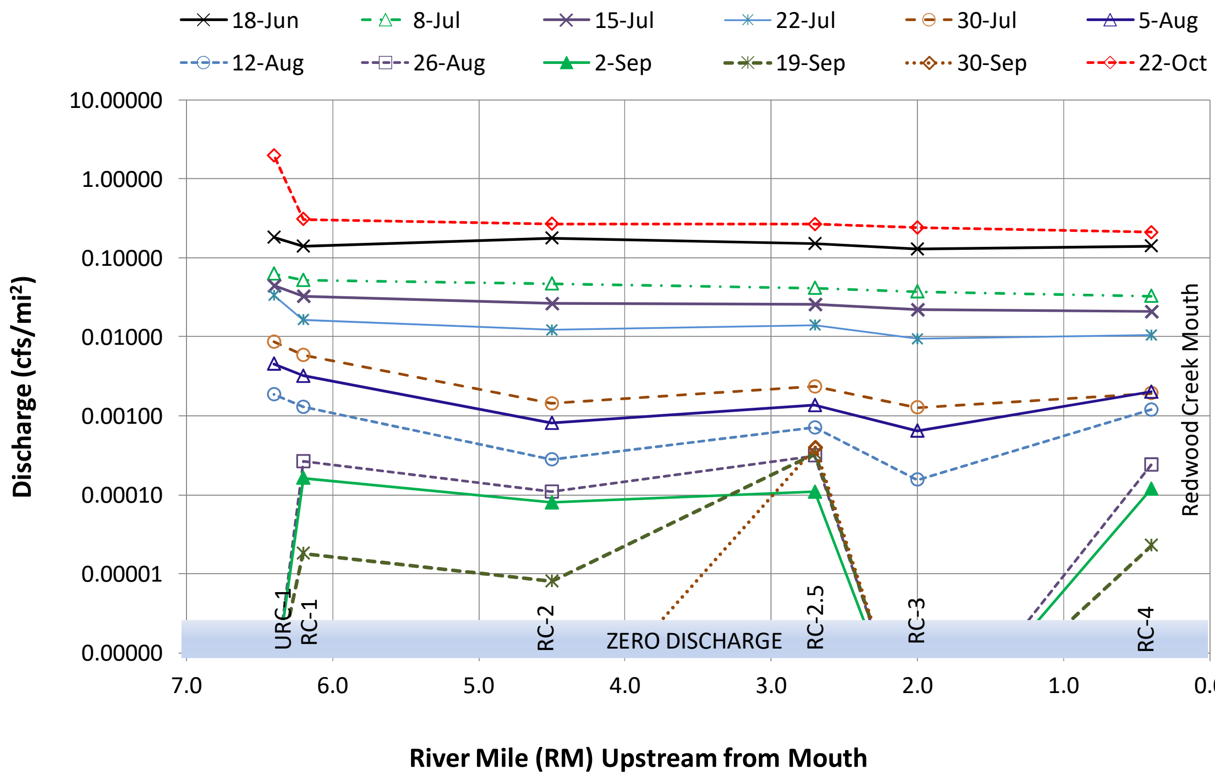

Figure 23. Discharge variations along Redwood Creek at mainstem sites, 2016.

Discharge Estimation and Forecasting Tools

Although not an explicit part of the Redwood Creek monitoring project, developing tools to allow estimation and forecasting of stream discharge would be valuable for Redwood Creek in the future. Klein (2017) investigated this in a similar project in the Upper Mattole River. He found that a USGS stream gaging station downstream of the project area (Mattole River at Ettersburg) as a reference gage with online, realtime access was useful for estimating discharge at a key location for the forbearance program. A better tool was ultimately derived using a two-stage estimator, with higher flows based on the reference gage and an exponential recession equation for lower flows. The model assumes no unusual weather phenomena (rain, fog) will interrupt the flow recession during the summer months. The model was provided in the form of a spreadsheet and gave promising results for the dataset examined.

Although Redwood Creek may have no suitable reference gage (although this must first be explored to evaluate the existing candidate gages, such as South Fork Eel River near Miranda and Bull Creek near Weott), other avenues can be explored, such as using daily rainfall data to compute antecedent precipitation index (API). API is a running computation indexing the moisture content of the soil mantle, regolith and aquifers. It is computed by taking each day's rainfall starting before the dry season, adding any new rainfall each day to the previous day's API decayed by a constant. Earlier research (Klein, 2012) indicated the best correlation of API and low flow was derived using a decay factor of 0.98. Figure 24 shows API for 2015 and 2016, again from the Calfire rain gage at Redway, along with discharges measured at DC-1. In 2015, the drier year, API plots almost on top of the DC-1 data, indicating a relatively strong correlation. In 2016, there is similarity in the seasonal trend between API and discharge, but greater variability. Further work, including testing discharge recession coefficients or other parameters, could improve on tools to estimate and forecast discharge at Redwood Creek monitoring sites.

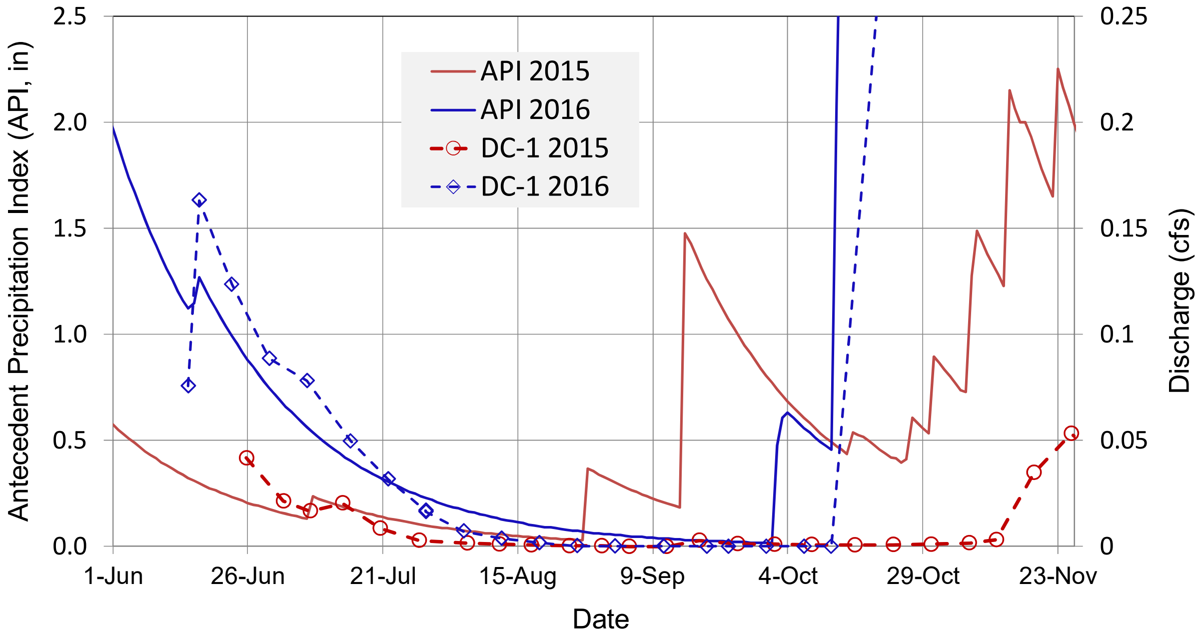

Figure 24. Antecedent precipitation index (API) and discharges at DC-1, 2015-16.

Streamlined Monitoring

There is interest by funding agencies in ‘streamlining’ future monitoring to reduce costs. An appropriate strategy for streamlining will depend on project goals and anticipated flow enhancement projects. Evaluating whether or not to retain other monitoring sites, or to establish new sites to bracket flow enhancement projects in the future, will depend on the available budget and any contributions from cooperators.

With enough prior data, there are several ways to reduce monitoring efforts that may not compromise the utility of monitoring data and thereby fail in providing the necessary minimum information: 1) reduce the number of sites monitored, 2) reduce the frequency of monitoring, and 3) cooperate with partners that could operate complementary monitoring sites (government agencies, volunteer interest groups or individuals). Reducing the number of sites must be done carefully so as to retain sites that are most representative of the overall hydrologic conditions of the watershed (i.e., reference sites that have little or no water extraction) and retain/add sites that focus on one or a cluster of flow enhancement sites to be able to evaluate their performance. Particularly with innovative approaches, post-enhancement project monitoring and evaluation is critical for design refinements and adaptive management. Sites that are most affected by unknown/unknowable sources of variability 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 may be used instead of, or along with, reducing the number of sites, but there is higher risk of missing an important event (e.g., flow cessation) with fewer visits. Monitoring streamflow using data loggers provides a continuous data set that can reduce the need for frequent site visits while providing information on stream conditions when no one is on site. A caveat: there must still be enough discharge measurements taken to develop a good stage-discharge rating curve if the flows estimated from data logger stages are to be used in quantitative analyses. And a caution: if a data logger fails or is vandalized, that will not be known until the next site visit which, with reduced frequency of site visits, may result in a long period of lost data. More importantly, waiting for a data logger download to determine the date at which some target flow threshold was attained, or flow cessation occurs, may result in a missed opportunity to avert harm. Thus, there is inherent risk in relying too heavily on automated data collection. Recent technological advances in real-time data access, using cellular phone services, may provide a viable solution for the conflict between cost and timely knowledge of streamflow conditions.

As partner in this project, Stillwater Sciences has developed conceptual designs for flow enhancement in Redwood Creek, focusing primarily on Miller Creek and a reach of mainstem Redwood Creek downstream of their confluence. Five project areas lie upstream from monitoring sites MC-1 and MC-2. Thus it would be advantageous to retain one or both the sites to evaluate benefits from these projects, particularly because of the advantage of having prior data. Likewise, sites RC-1 and RC-2 could serve for monitoring future enhancement projects in both Miller Creek and along the mainstem. If these four sites were all that were to be included in streamlined monitoring in Redwood Creek, the number of sites would be reduced by two-thirds (from 12 to 4 sites). It cannot be known beforehand whether or not the scale of flow enhancement projects now conceptualized would result in measureable increases in discharge at these sites, but if not monitored, it will surely not be known.

Stillwater's Enhancement Site #1 is conceptualized as a very large infiltration pond, and as such has the greatest likelihood of creating measurable increases in discharge, at least locally. However, the relatively long distance between the existing monitoring sites (RC-1 and RC-2) and the project area reduces the ability to quantify the potential benefits. A better configuration would be to position monitoring sites just upstream and downstream of the project area.

Conclusions

- Substantial amounts of late spring rainfall, such as that occurring in 2016, postpone the date at which minimum low flows are attained, potentially shortening the amount of time low flow conditions persist and maintaining year-round flow at some reaches that might otherwise go dry.
- Despite relatively low rainfall in 2013 (only 12.2 in. by June 1), summer flow recessions at several mainstem monitoring sites were nearly identical to those in 2016, which had much higher spring rainfall (39.7 in. by June 1). This may suggest an increase in water extraction during the intervening years affecting an extensive reach (over 4 miles) of the mainstem Redwood Creek.
- Even small amounts of rainfall (e.g., 0.25") in the driest time of the year can increase discharge and provide temporary relief for fish from drought conditions. Summer fog, a relatively unusual occurrence, can also reduce the recession rate of low flows and perhaps temporarily elevate low flows.
- Longitudinal flow anomalies along the mainstem Redwood Creek were large in the late summer, highlighting the benefits of targeting such areas for more detailed investigations that could lead to relatively rapid and inexpensive fixes.
- Data collected for this project strongly suggest that water withdrawals are impairing streamflow throughout the Redwood Creek watershed, and that the effects are quite serious at some times in some locations.
- Inconsistencies were found across monitoring years as to which sites had more or less discharge. This is most likely due to water extractions differing in timing and location from year to year.
- Periods of highly fluctuating, semi-regular discharge measured with data loggers suggest water extraction effects near the sites exhibiting this behavior. More detailed investigations could reveal if these represent real discharge fluctuations and possible sources.
- Monitoring can be streamlined if done carefully. Future monitoring should include continued monitoring of sites that could help elucidate flow enhancement effects as well as new sites to closely bracket relatively large scale enhancement sites.

Recommendations

- Continue monitoring low flows in Redwood Creek, but reduce the frequency of site visits. Combined with continuous data from water level recorders, fewer site visits than were done in 2015-16, say once every two weeks, could provide sufficient data for evaluating hydrologic conditions and benefits from enhancement projects.
- Network with potential collaborators monitoring flows in Redwood Creek and nearby watersheds. Ensure data collected are complementary and not redundant, and pool data to enable more robust analyses.
- Inventory, to extent feasible, water usage in Redwood Creek, particularly at locations identified as those potentially most impaired by water extraction. Use this information in an outreach program to heighten

awareness of the effects of water extraction and target stream reaches that offer the most benefits of water conservation.

- Establish a water right forbearance program for Redwood Creek, modeled on Sanctuary Forest's program in the Upper Mattole River. Identify 'early adopter' landowners willing to participate in a forbearance program to demonstrate the potential benefits and encourage more participants.
- Implement low flow enhancement projects that are either already proven to be effective (e.g., forbearance, storage tank installation) or are innovative approaches that, with pre- and post-project monitoring, can be tested to determine their effectiveness and formulate design improvements for future projects.

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Appendix A. Field Observations of Low Flow Conditions In the Redwood Creek Watershed

Bill Eastwood

TRIBUTARY STREAMS

James Creek: James Creek has a fish barrier waterfall about ¼ mile upstream from the confluence with Redwood Creek. Any salmonid presence in the lower reach is unknown. The Eel River Salmon Restoration Project (ERSRP) had a salmonid fish rearing facility upstream for about 5 years.

Seely Creek: In late summer of 2016 ERSRP did a low water assessment of 2 1/3 miles of previously inaccessible Seely Creek to determine, water extraction impacts, salmonid presence, and any need for habitat improvement projects. The new owner of this section of the stream is fish minded and enthusiastically gave us access. We were guided by a landowner who was familiar with Seely Creek. We surveyed downstream from a 20 foot high waterfall that is as far as salmonids can travel upstream. Water extractions, likely for agriculture, above the waterfall have dried up the stream except for occasional bedrock pools. Our guide was shocked by the lack of stream flow. This condition persisted for about a half mile downstream until a large landslide with a jumble of trees blocked walking in the stream bed. The slide took us about a half hour to get around. We were pleasantly surprised to find that there was a spring somewhere in the slide that provided enough water to the stream that downstream flow was pretty much continuous and the pools were full. Salmonids, primarily steelhead and possibly Coho, were present in many of the pools. Rains made us cancel a planned dive of this reach to confirm the presence of Coho. Unfortunately our monitoring site SC-1 at the confluence with Redwood Creek was several hundred yards downstream from this long section of continuous flow. This next season ERSRP plans to assess this section of Seely Creek for the presence of Coho and the need for habitat improvement. Water extractions above the water fall also need to be further investigated.

Somerville Creek: in the past was found to have some Chinook spawning and pretty much dried up in the summer.

Miller Creek: has a long history of steelhead, Coho, and Chinook presence. Flow gets quite low in the summer time but somehow over-summering Coho and steelhead juveniles have always hung on. Tributary Buck Creek usually continues to flow all summer, providing a salmonid refuge when Miller Creek has dried up in the lower reaches. Pumping by several landowners in lower Miller Creek has dried up the lower section for at least the last few years. When the effects of this pumping were pointed out in the summer of 2016 the landowner became concerned and promised to solve this problem before next summer. We'll see. It should be noted that the Briceland Water District gets its water from a good spring on a Miller Creek tributary about half way upstream from the confluence with Redwood Creek. Minimal storage capacity precludes the possibility of dry season forbearance.

China Creek: also has a long history of steelhead, Coho, and Chinook presence. Water extractions are probably greater than in the past.

Dinner Creek: A fish habitat structure that the ERSRP put in upper Dinner Creek more than 15 years ago has inspired a promising future project to increase the number of over-summering Coho salmon. The structure is near the highway culvert where it is easy to check on. The pool is 2 to 3 feet deep and has a lot of wood. Every year we have seen a significant number of Coho in this pool! Flow sometimes stops in the creek but the pool formed by the structure always stays full. In 2015 we walked the upper reaches of Dinner Creek after flow had stopped to see where there were any other residual pools. We found about 15 shallow pools which were photographed and locations taken with a

GPS. Several of these pools even had a few Coho. Most were very shallow - just a few inches deep. We reasoned that, given access for equipment, some of these pools would be very good prospects for boulder/log scour structures similar to the one we have been watching for many years. Placement in locations where there is known water during the driest conditions would guard against the all too common practice of choosing "good" locations when the stream is flowing only to find that many of the structures ended up in dry locations when the water stopped flowing.

This year we repeated the Dinner Creek stream walk to see how consistent our data was. We found all the pools from last year plus a few more. It was decided that we would use the locations from 2015 for proposed pool habitat improvements because 2016 was slightly wetter than 2015. Now we need to figure out which sites have decent equipment access and write up a proposal to the California Department of Fish and Wildlife. This project stands an excellent chance of getting funded. Little is known about the level of water extraction in this watershed although it appears to be fairly low.

Mainstem Redwood Creek: Over-summering Salmonid presence is in general confined to the cooler upper reaches of Redwood Creek downstream as far as the Briceland area. Steelhead juveniles are also found in pools downstream to about monitoring site R-2.5.

Upper Redwood Creek above the confluence with China Creek is entirely on timber-company and undeveloped private land. There are no residents in this area and, as confirmed by an overflight, there is no observable marijuana growing activity. So it is likely that this watershed has no water extractions for human use. It is interesting that this watershed shows similar low flow declines as populated tributary watersheds where we know there is a large amount of water withdrawal.

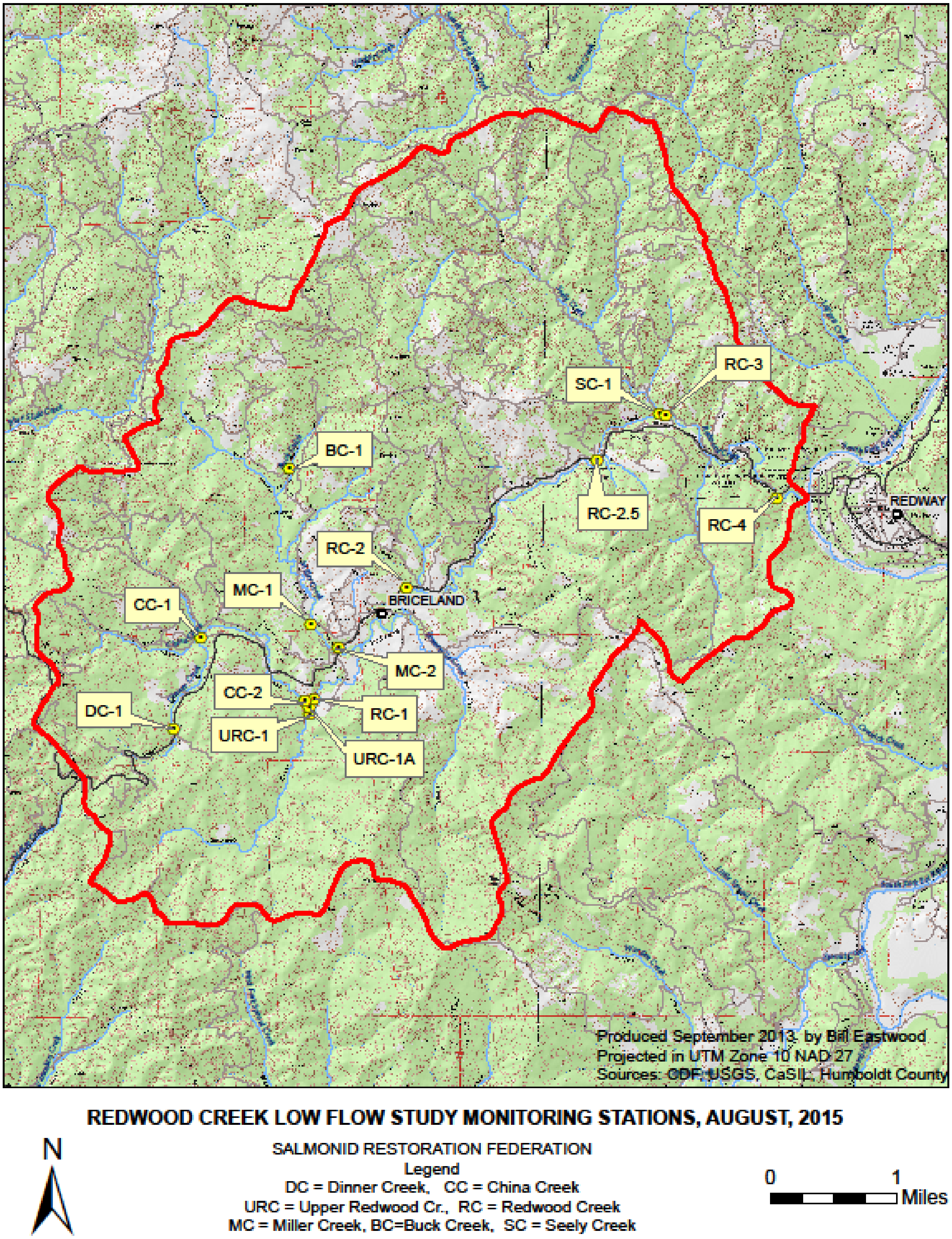
There is a dry season flow anomaly between Redwood Creek monitoring sites RC- 2.5 and RC-3. There has always been good low water flow at RC- 2.5 but by the time Redwood Creek reaches RC-3 it is usually dry. Where did all the water go? A stream walk of this half mile reach confirmed that there is one residence that pumps water from the creek and is possibly responsible for the impaired flow. Another possibility is that the water flowing past RC 2.5 has a single source upstream that is diminished downstream by vegetation and evaporation. The land owner that pumps from the stream has been made aware of the problem and has been increasing his water storage to decrease pumping during the dry period. He is cooperative and we hope to monitor this situation next season.

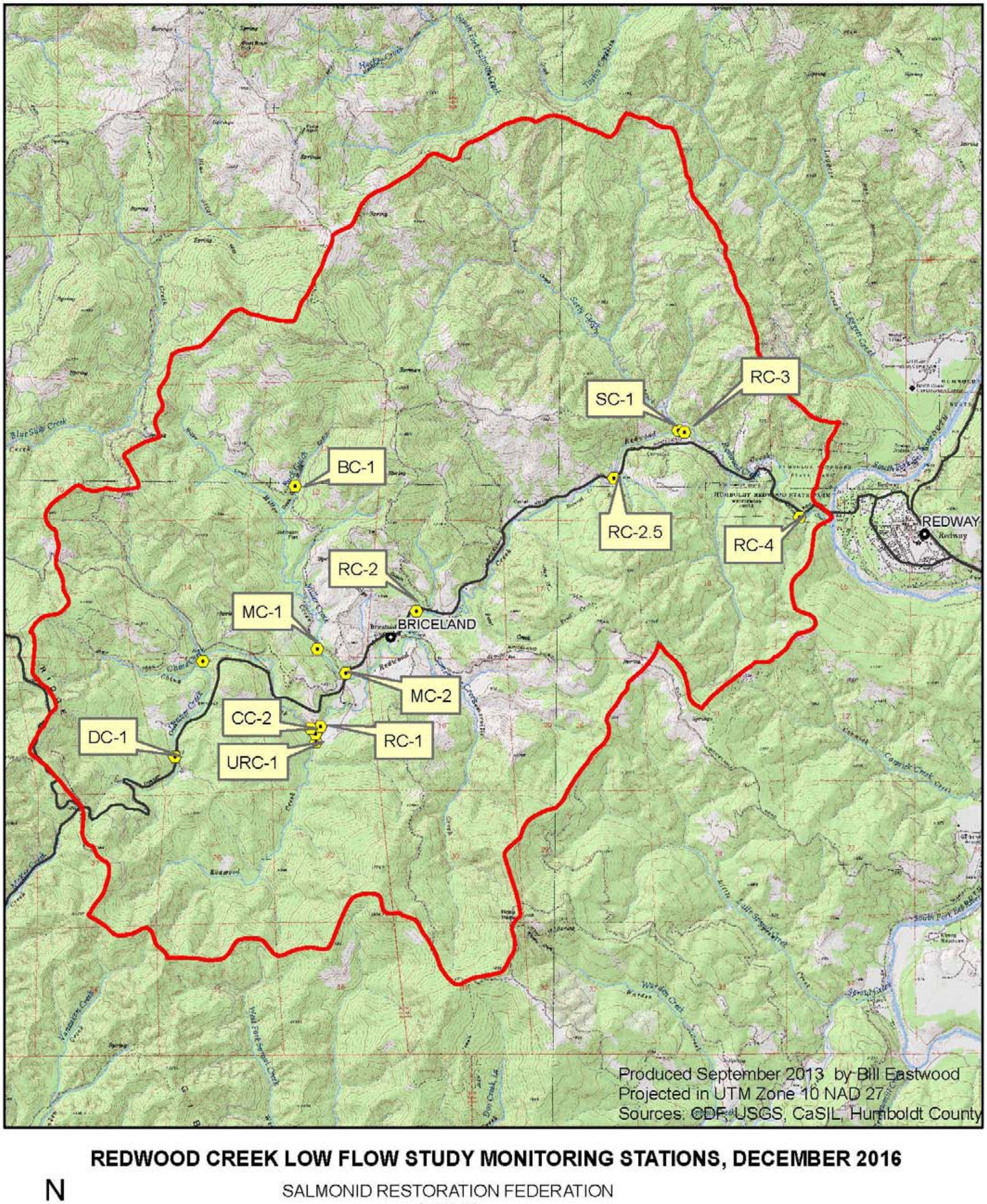
General Observations: In general, observations at the monitoring sites, indicated that there was a decline in the number of salmonid young-of-the-year from 2013 to 2016. There is no question that the human population of the watershed is increasing and that marijuana production is a major economic activity that has expanded substantially. The resulting increased water demand has to have had a negative effect on summer time low flows. The move to legalize marijuana production has resulted in the sale of a very large number of water tanks. The effect of this increase in water storage on summer stream flow is unknown. The water situation is so bad that some landowners are resorting to buying water from sources outside the watershed. There is also a substantial increase in the number of wells that are being drilled, again with unknown effects on stream flow.

Another factor that may very well be reducing dry season stream flow is a likely increase in water intake by our growing forests, especially due to region-wide Douglas fir encroachment.
In addition to low flow problems, the increase in population and marijuana activity has markedly increased the traffic on the watershed's unpaved rural roads, greatly increasing the amount of harmful sediment being delivered to fish bearing streams. This sediment problem has been especially bad this winter with the near record rainfall. Road maintenance of many major rural roads has gotten so far behind that two wheel drive vehicles often have major problems negotiating the muddy messes that many of these roads have turned into.

Conditions for salmon survival in the Redwood Creek Watershed are not looking good. It seems unlikely that the residents of the watershed will be able or willing to forbear enough water use during the low flow period to increase the flow significantly. Perhaps, as has been proposed, we could resort to the supplementation of stream flow with water from specially designed large ponds that are filled during the winter.

Appendix B. Maps of monitoring sites in the Redwood Creek Watershed (B. Eastwood, 2015 & 2016)





REDWOOD CREEK LOW FLOW STUDY MONITORING STATIONS, DECEMBER 2016

SALMONID RESTORATION FEDERATION
Legend
DC = Dinner Creek, CC = China Creek
URC = Upper Redwood Cr., RC = Redwood Creek
MC = Miller Creek, BC=Buck Creek, SC = Seely Creek