Low Flow Stream Discharge Monitoring Plan
for the Redwood Creek Watershed

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Introduction

Human demands on water are increasing, and most rural landowners withdraw water for agricultural and personal use from flowing streams. A negative cumulative effect of water withdrawals occurs when the sum of all water withdrawals is of sufficient quantity to impact riparian and aquatic ecosystems. Effects include shrinking the wetted channel surface area, drying up of backwater habitat, hydraulically disconnecting pools and complete loss of surface flows. Aquatic organisms, including juvenile salmonids, can suffer from lack of dissolved oxygen, excessive water temperatures, increased predation, and desiccation.

To address the low flow problem in Redwood Creek, a study will commence in 2015 with these objectives:

1. Quantify summer/fall stream discharges at a suite of main channel and tributary sites;
2. Evaluate possible causes of unexpected flow variations (e.g., decreasing discharge with increasing drainage area);
3. Identify and rank sub-watersheds that may be impacted by water diversions and therefore benefit from forbearance agreements;
4. Recommend means to streamline future monitoring.

This document provides a study design and methodologies for quantifying potential water withdrawal effects on the physical stream environment in Redwood Creek near Redway, California. It will contribute to directing future efforts for water conservation aimed at sustaining dry season discharges through a forbearance program similar to that implemented in the Upper Mattole River by Sanctuary Forest. Understanding of Redwood Creek's low flow hydrology is in the early stages. Beginning in 2013 and continuing through 2014, stream discharge monitoring of sites along the mainstem and selected tributaries in Redwood Creek showed differences among sites that varied from the typical model of discharge increasing with drainage area. Several factors could explain such variations, including channel bed slope, channel width, bedrock presence, gravel thickness and texture, and other geomorphic and hydraulic attributes as well as water withdrawals by riparian water users.

This plan builds upon prior monitoring with several modifications to strengthen the ability to distinguish between water extraction and other factors mentioned above. It guides data collection for 2015 and 2016 to help ensure project objectives can be met by collecting data that will provide the best return on effort. This study design attempts to estimate the effects of water extraction on Redwood Creek's low flow hydrology, provide a reliable basis for allocating scarce water conservation resources, and guide efforts to streamline future monitoring.

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 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 there is extensive, high quality habitat in the watershed.

Data collected in 2013 and 2014 provided a good basis for a general understanding of stream discharge variations in time and space. The accompanying map shows the locations of hydrologic monitoring in 2013-14. 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).

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

Redwood Creek Location	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*	3.6	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.

Study Design

This plan utilizes most of the sites monitored in 2013-14. At present, the factors controlling discharge rates within the watershed are not well understood, so a controlled experimental design cannot be used. Alternatively, two suites of sites were selected to provide 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). Table 1 (above) shows the types of monitoring for each group.

As indicated in Table 1, two tiers of monitoring intensity will be used to assign the greatest effort to those sites offering the greatest ability for data analysis to provide insights, while other sites will have more basic data collection(Q, WT, AT) that minimizes costs. The sites with continuous stage data collection (CS, Table 1) will likely provide the best opportunity for comparisons among areas in the watershed. T~~, t~~hey will be outfitted with stage data loggers to provide continuous datasets. The advantage of continuous data is that stage and discharge variations between site visits will be quantified. Diurnal stage oscillations are common in North Coast streams and rivers, and can only be detected with continuous data. In addition, upstream pumping events causing sudden drops or rises in stage would not likely be detected without continuous data.

Spatial and temporal trends may reveal discharge variations from the normal condition of increasing discharge with drainage area. Data from 2013 and 2014 show this occurs in Redwood Creek. Mainstem trends will be evaluated using URC-1, RC-1, RC-2.5, and RC-3 fitted with data loggers. For tributary analyses, URC-1, CC-2, MC-2, and SC-1 are similarly-sized tributary watersheds thus appropriate for comparing and contrasting. Because of its size and location, URC-1 will serve both the tributary and mainstem analyses.

Of importance, results of this study cannot provide conclusive guidance for prioritizing areas in need of water conservation efforts without quantitative information on the locations, timing, and volumes of water extraction. Simply quantifying differences in discharge among the study sites can only suggest potential human effects on instream flows. Thus, an important part of the conservation efforts in Redwood Creek is watershed outreach, a program that is in its early stages and will hopefully provide the information needed for prioritizing areas in most need of forbearance agreements.

Data Collection and Analysis

Data collection will be very similar to that of 2013-14, focusing on stream discharges and water temperatures collected at five mainstem and four tributary sites. The main difference going forward will be a minor reallocation of efforts and supplementing manually collected data with automated stage data collected with electronic data loggers.

Stream Stage

Stream stage (the height of the water surface above a datum) can be read visually from a staff gage or reference marker (manual stages) and recorded continuously by means of an electronic stage recorder, which senses water depth and records and stores the data. The stage recorder is deployed into the stream inside a stilling well (a section of perforated pipe).

At 'CS' sites, both manual and electronic stage data will be collected, and the stage data loggers will also record water temp. Data will be downloaded periodically for processing, typically on a monthly basis. At 'B' sites a simple HOBO water temperature loggers will be installed and maintained throughout the low flow season. Manual stages will be obtained at ‘MS’ sites (Table 1) using staff gages or stage reference markers appropriate for each site.

Discharge

Periodic discharge measurements will be made at each monitoring site using a method appropriate to site conditions at the time of each visit. With adequate flow depth, a spinning cup-type current meter or electromagnetic device will be used to take velocity measurements across the gaging cross section. Using this method discharge will be computed as the product of velocity and flow area. When depths are too shallow to use a velocity meter, either a Parshall Flume or the bucket-and-stopwatch method will be used. When properly installed into the channelbed, the flume discharge is computed from the depth of flow using a rating formula. With the bucket-and-stopwatch method, flow is concentrated so it pours into a bucket, the filling of which is timed. Manual stage is visually read during each site visit, including when discharge measurements are made. Thus, data pairs of stage and discharge will be accumulated for each site and will then be used to develop and periodically update stage-discharge relationships. It is this relationship, usually taking the form of an exponential equation, that allows calculation of stream discharge from stage observations, both manual and electronic.

Discharge measurements will be taken often enough to develop and maintain accurate rating curves. Minor changes in the configuration of the channel cross section at the gages, which occur virtually every high flow season, can alter stage-discharge relationships at low flows, while very high flows can alter the entire stage-discharge relationship over the full range. Consequently, rating curves will be continually updated by incorporating new stage and discharge measurement pairs.

Stage data logger sites will provide the most important data and are thus prioritized for discharge measurements for development of stage-discharge rating equations. An important goal of taking discharge measurements is to strive to get all sites on the same day or within two consecutive days. Without meeting this goal the ability for comparisons among sites will be more limited. Consequently, fieldwork will strive to measure discharges at all the mainstem sites (URC-1, RC-1, RC-2, and RC-3) on a single day and all tributary sites (URC-1, CC-12, DC-1, BC-1, MC-2, and MC-1) on a single day. Ideally, there will be some days when discharge will be measured at all sites.

Data Treatment and Analyses

Manual field data (discharge, stage height, water & air temperature) will be entered into a pre-formatted spreadsheet soon after data collection. Data logger downloads will occur once every month and processing (to adjust for atmospheric pressure) will occur soon thereafter to help identify any errors or drift.

Part way through each low flow season, all hydrologic data will be provided to the project hydrologist for preliminary analysis and a quality control check. Discharge rating curves will be developed, and any sites lacking adequate stage-discharge pairs for reliable use will be identified and targeted for additional measurements.

At the end of the low flow season, the data collected will be prepared for presentation in an annual report. Discharge rating curves will be finalized and discharge will be computed for every manual stage data point. Plots of these ‘spot’ measurements will be created using both discharge and discharge per unit area (‘unit discharge’).

All data logger files for each site will be appended into one continuous file for plotting. As with manual stages, continuous discharges will be computed from data logger stage data and both discharge and discharge per unit area (‘unit discharge’) will be plotted. Total water volume passing by each site during the low flow season will be computed for comparison.

Along-stream trends will be examined using the mainstem sites. The data 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.

Several additional data sources will be used to place the Redwood Creek dataset in a broader hydrologic context: 1) South Fork Eel River USGS gaging station, 2) Bull Creek USGS gaging station, and 3) rainfall records from a nearby station. The USGS stream gage on South Fork Eel River provides data from a larger watershed to which Redwood Creek is a tributary. Another, potentially better correlation~~e~~ would be the USGS Bull Creek gaging station because it has similar drainage area to Redwood Creek. Both gages will be evaluated to see if there is a strong enough correlation in discharges to be of use as a surrogate 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. Should the forbearance program go forward in Redwood Creek, having a readily available estimate of Redwood Creek discharges could assist in forecasting when forbearance should be invoked in the Redwood Creek watershed. It could also serve for estimating flows at 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.

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. Several tributaries in the lower watershed are forested with a mix of old growth redwood and maturing cutover lands incorporated into the park after harvesting decades ago. 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). 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 necessary equipment and staff to monitor flows in several Bull Creek tributaries (D. Manthorne, pers. comm., 2015).

Table 3. Possible control sites in Bull Creek.

Bull Creek Location	Basin Side	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 (%)
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

Assuming control data become available from Bull Creek, the Redwood Creek dataset will be compared and contrasted with data from control sites.

Literature Cited

Klein, R.D. 2015. Hydrologic analysis of low flows in the Mattole River Basin, 2004-2014. A report to Sanctuary Forest. 18 p.

USGS. 2015. StreamStats online mapping tool: http://water.usgs.gov/osw/streamstats/california.html.