TECHNICAL MEMORANDUM

DATE: March 15, 2016

TO: Dana Stolzman, Salmonid Restoration Federation

FROM: Joel Monschke, Joshua Strange, and Jay Stallman, Stillwater Sciences

SUBJECT: Preliminary Recommendations for Target Late Recessional and Dry Season Streamflows in Redwood Creek

1 INTRODUCTION

The Salmonid Restoration Federation, working under DFW Grant #: D1410509, contracted Stillwater Sciences to identify preliminary recommended flow targets for Redwood Creek (tributary to the South Fork Eel River). Preliminary recommended flow target are intended to inform additional tasks performed under this contract that evaluate the feasibility of improving dry season streamflow in the watershed through site-specific water forbearance, storage, and other conservation practices. This memorandum draws upon the results of recent streamflow monitoring in Redwood Creek (Eastwood 2014; Klein 2015 [Appendix A]), long-term streamflow records in adjacent watersheds, and other related efforts to define instream flow requirements for at-risk anadromous salmonids in north coastal California. The analyses in this memorandum focus on the Feasibility Study Area, including Miller Creek and a portion of mainstem Redwood Creek (Figure 1). The methods presented here can be extended to all of the sites where streamflow monitoring was conducting in Redwood Creek from 2013 to 2015.

Within the Feasibility Study Area shown on Figure 1, three gages were operated in summer 2014 and four stream gages were operated in summer 2015. This memorandum compares the 2014 and 2015 low flow data in Redwood Creek to low flows in other adjacent watersheds to identify a range of preliminary recommended flow targets that will improve salmonid summer rearing habitat conditions. We also summarize the results of a basin-specific hydrologic model that highlights the degree of flow impairment in Redwood Creek and conclude with recommendations for further analyses and flow enhancement activities.

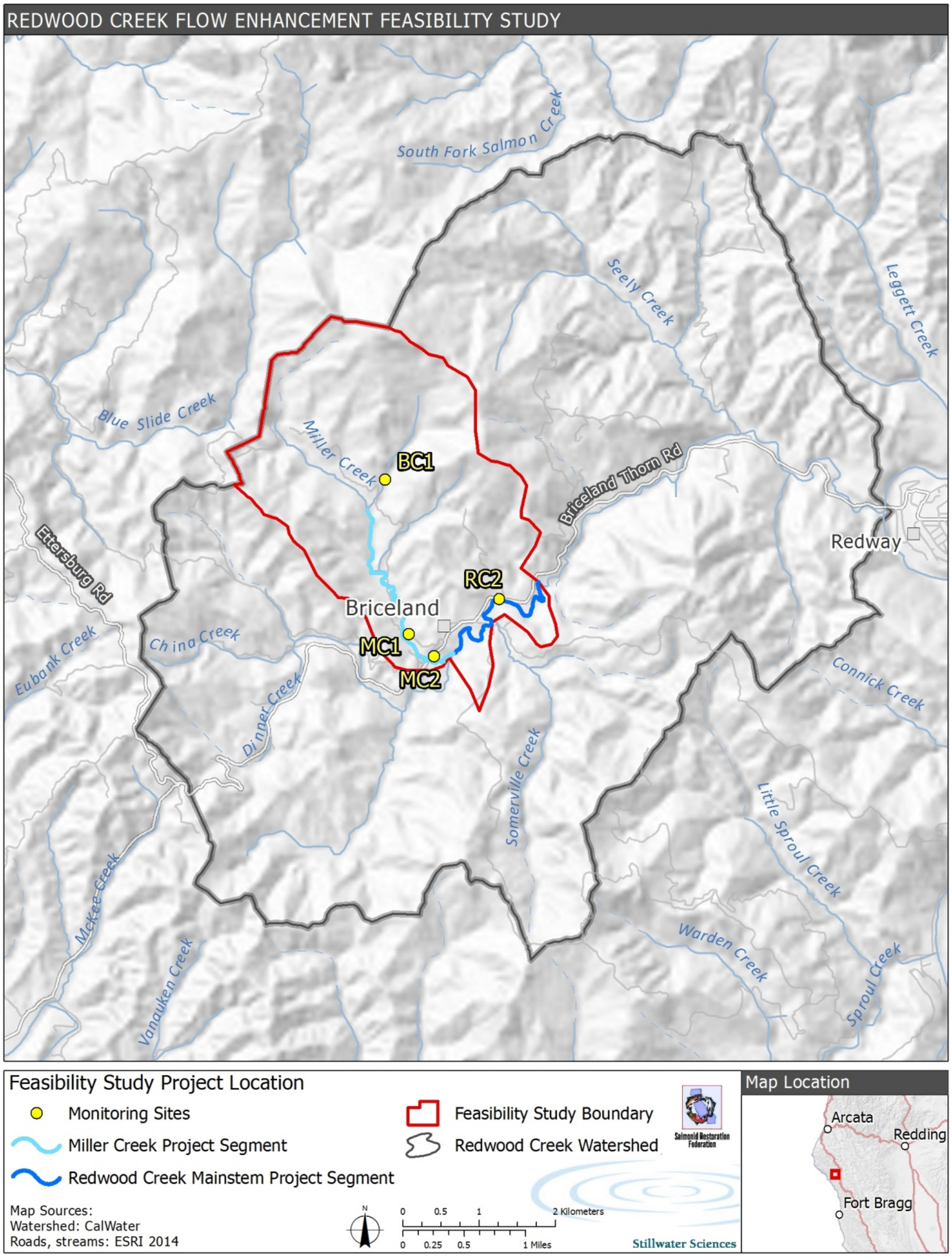

Figure 1. Redwood Creek Feasibility Study Area.

2 SUMMARY OF 2015 MONITORING RESULTS

Extremely dry conditions continued in Redwood Creek and other nearby north coastal California watersheds during the summer and fall of 2015. 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 season. The problem was exacerbated by consumptive water use, which tends to increase with drier conditions. The four gages located within the Feasibility Study Area (RC-2, MC-1, MC-2, and BC-1) all went dry for extended periods of the season as shown on Figure 2 (Klein 2015). The analyses herein use point discharge measurements.

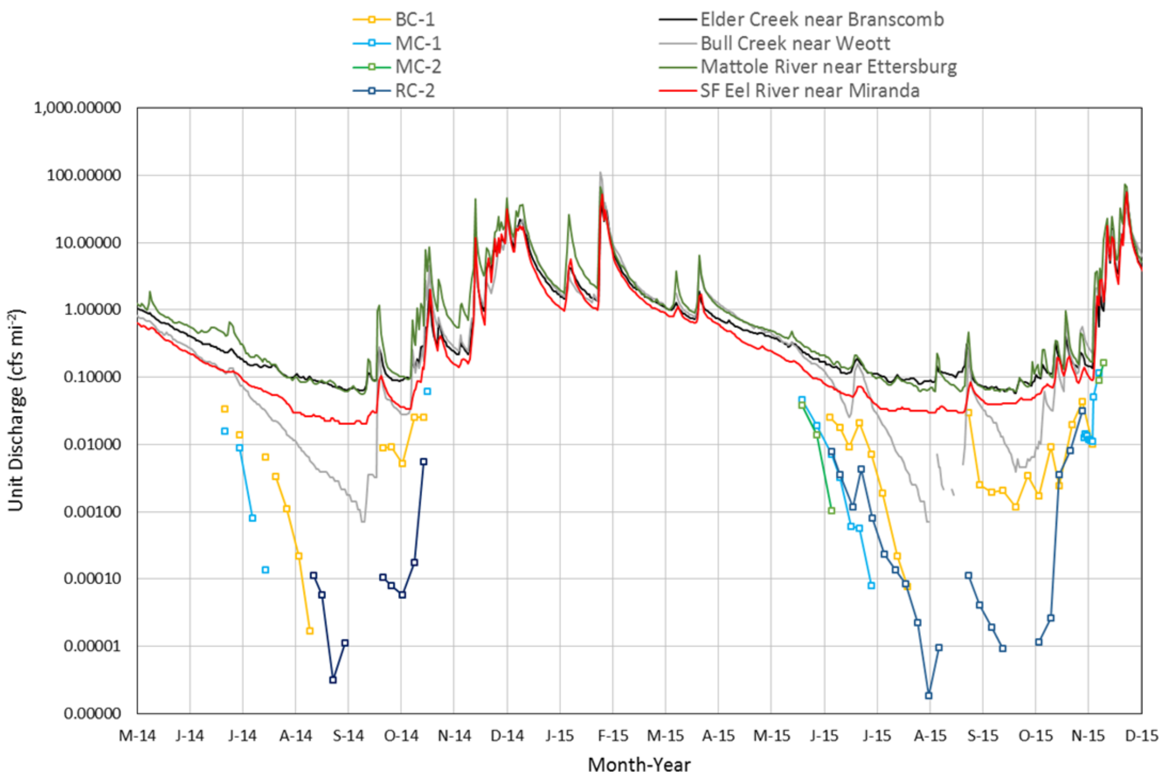

Figure 2. Unit area discharge (cfs mi^{-2}) at streamflow monitoring sites in the Redwood Creek Feasibility Study Area (Klein 2015) and at long-term USGS gaging sites in nearby watersheds. Note that zero flow was observed between the plotted points at the Redwood Creek monitoring sites during each summer and early fall, and that flows at all gages were impacted by drought conditions.

3 RECOMMENDED FLOW TARGETS

3.1 Approach

Varying flow levels during the annual recession of flows during the spring and summer provide a range of functional habitat quantity and quality for rearing juvenile salmonids. These flow-dependent conditions can rapidly transition from relatively expansive and productive rearing habitat during the spring or early summer to very limited and stressful rearing habitat during the summer and early fall. The timing of the transition from productive flow conditions to stressful low flow conditions is important for juvenile salmonid growth and survival and can vary greatly depending on water year types, consumptive water use and other factors. In the Mattole River headwaters, for example, the onset of flows producing stressful salmon rearing conditions occurred from early June to as late as mid-August during 2002–2011 (McBain and Trush 2012). In summary, the date at which flows drop below a given threshold is as important as the degree to which summer low flows drop below these level.

In the absence of long-term empirical information relating habitat to streamflow, a controlled flow study, or sophisticated modeling relating habitat area to flow in Redwood Creek; preliminary recommended flow targets in Redwood Creek discussed herein are based on (1) natural flow regime principles, (2) results of a flow needs study conducted in the adjacent upper Mattole River watershed, and (3) preliminary empirical observations of flow and habitat conditions in Redwood Creek.

As discussed in further detail below, returning Redwood Creek to its natural flow regime is likely impossible through storage and forbearance actions alone. However, we believe that including the natural flow regime as one target, in an array of target flows, is nonetheless important to frame the current low-flow issue within a long-term perspective.

3.1.1 Natural Flow Regime

Natural flow regime principles (Poff et al. 1997) were used to determine preliminary recommended flow targets using long-term gaging records from nearby, relatively unimpaired watersheds. Unimpaired flow estimates represent expected conditions prior to extensive changes in residential land use and consumptive water withdrawal. Recommended flow targets based on unimpaired flow estimates are likely unattainable through forbearance of consumptive water use and other conservation practices alone because unimpaired flows are characterized by conditions without the hydrologic alterations associated with large scale industrial logging, road building, and vegetation change. Old-growth forests with thick, uncompacted soils and without roads allow for more interception and infiltration that replenishes groundwater and eventually contributes to summer low flow. In addition to forbearance of consumptive use, flow augmentation and long-term changes in land management aimed at increasing water yield will likely be required to achieve unimpaired flow levels.

From a fish habitat needs perspective, the unimpaired flow approach provides an important benchmark because unimpaired flows served as the evolutionary template that native fish populations adapted to and, combined with historic habitat conditions, were sufficient to support healthy salmon populations within the Eel River basin. However, in general, unimpaired flows are also subject to natural variability with low flows that cause stressful conditions during dry years. Unimpaired flows also provide a useful benchmark in the absence of, and in combination with, more extensive flow need assessment methods.

The unimpaired flow approach involves normalizing flow into unit discharge (cubic feet per second per unit watershed area [cfs mi^{-2}]). First, we estimate unimpaired unit discharge in Redwood Creek based on flow in Elder Creek, since the Elder Creek watershed is in relatively pristine condition and dry season unit discharge in the Elder Creek watershed appears relatively unaffected compared to Bull Creek near Weott and the South Fork Eel River near Miranda (Figure 2). The Mattole River near Ettersburg initially appears to be unimpaired as it is generally equivalent to Elder Creek in unit discharge. However, we hypothesize that above average unit discharge occurs in the upper Mattole watershed (likely due to relatively high base flow water yield from the King Range), which compensates for flow impairments related to consumptive use and land disturbance in other areas. Therefore, we did not use the Ettersburg gage as part of our unimpaired flow approach considering that the unit discharge would be even higher than Elder Creek without impairments.

Figure 2 suggests that a unit discharge of approximately 0.1 cfs mi^{-2} is an appropriate preliminary summer base flow target based on the unimpaired flow approach. This estimate is less than required for non-stressful rearing habitat conditions (Figure 3) but provides varying levels of habitat functionality to allow for over-summer survival of juvenile salmonids in Redwood Creek. Recommended flow targets for summer base flow based on the unimpaired flow approach are shown in Table 1.

3.1.2 Mattole Flow Study

Second, we draw upon information from a flow needs study for juvenile salmon rearing habitat in the upper Mattole River (McBain and Trush 2012). The upper Mattole River watershed is located directly adjacent to and west of the Redwood Creek watershed and has many of the same physiographic, ecological, and land use characteristics. The study in the upper Mattole River recommended a range of flows that provide varying salmonid rearing habitat quality and quantity (e.g., optimal, non-stressful, and minimum for fish connectivity). We prorated these flows by drainage area to estimate recommended target flows for Redwood Creek (Table 1, Figure 3). Note that optimal rearing conditions for juvenile salmon often occur at flows higher than the unimpaired base flow, while the minimum flow for fish connectivity occurs well below the unimpaired base flow. Differing levels of habitat functionality occur at less than optimal flows, and the timing of onset of stressful rearing habitat conditions is very important for salmonid productivity.

Table 1. Preliminary recommended streamflow targets for monitoring sites in the Redwood Creek Feasibility Study Area

Site name	Site number	Drainage area (mi^2)	Preliminary target streamflow (cfs)				
			Optimal rearing habitat*	Non-stressful rearing habitat*	Unimpaired flow approach**	Minimum flow for fish connectivity*	Minimum flow for hydraulic connectivity***
Mattole River at Whitethorn Junction	MS-6	25.6	23	5	2.56	0.7	.018
Mainstem Redwood Creek	RC-2	14	12.58	2.73	1.4	0.38	.011
Upper Miller Creek	MC-1	3.4	3.05	0.66	0.34	0.09	.002
Lower Miller Creek	MC-2	3.6	3.23	0.7	0.36	0.1	.003
Buck Creek	BC-1	0.8	0.72	0.16	0.08	0.02	.0006
Target Unit Discharge (cfs mi^{-2})	--	--	0.9	0.2	0.1	0.03	.001

* Prorated from Mattole Headwaters (McBain & Trush 2012); based on minimum riffle crest flow depth of 0.15 feet allowing fish to swim between pools.

** Prorated from USGS Gage at Elder Creek near Branscomb.

*** Prorated based on flow monitoring and associated field observations at RC-2 (B. Eastwood, pers. comm., 2016; Klein 2015).

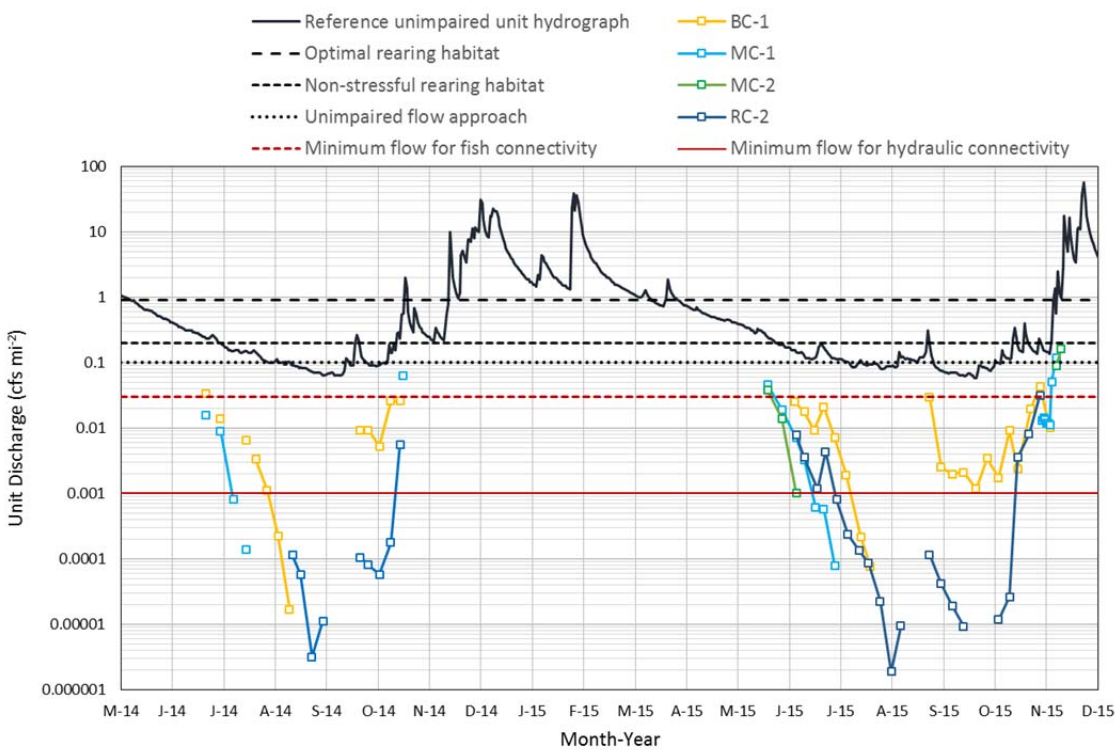

Figure 3. Preliminary recommended unit discharges (cfs mi^{-2}) and measured unit discharges at streamflow monitoring sites in the Redwood Creek Feasibility Study Area in relation to the reference unimpaired unit hydrograph under drought conditions (Elder Creek). These targets apply to the annual wet season recession and low flow dry season.

3.1.3 On-the-ground Observations

Third, we used on-the-ground observations at the Redwood Creek monitoring sites and adjacent stream reaches to set a lower bound flow for a recommended target flow. Based on observations by the project's monitoring coordinator, Bill Eastwood, hydraulic connectivity is maintained at monitoring station RC-2 at flows between 3 and 7 gallons per minute (.007 to .016 cfs). This range has been averaged and prorated by drainage area to define the lower bound target flow recommendations at each monitoring station. These lowest target flows are most likely to be achieved through near-term storage and forbearance activities and maintaining these flows throughout the dry season should improve the level of fish carrying capacity and survival.

3.2 Summary and Next Steps

The combination of the three approaches described above provides a range of preliminary recommended flow targets for each monitoring site within the Redwood Creek Feasibility Study Area as shown on Table 1 and Figure 3. It is important to note these approaches do not account for flow variability caused by natural site-specific, reach level, or sub-basin hydrologic factors including processes influencing runoff, infiltration, and groundwater flow; influence of shallow bedrock on surface and groundwater interaction; subsurface flow through porous alluvium (e.g. gravel) in the channel and adjacent floodplains; and evapotranspiration.

During the spring/early summer of 2016, project team members will inspect instream habitat conditions in Redwood Creek when flows are within the target range to verify that these flows are achieving the desired fish habitat objectives. These functional habitat objectives will include suitable to optimal conditions for rearing of juvenile coho and Chinook salmon and steelhead related to:

- Flow depths and velocities
- Water quality/temperature
- Connectivity/passage
- Pool volume and habitat quantity
- Benthic macroinvertebrate productivity

The flows described above provide a preliminary range within which recommended target flows can evolve over time, taking into consideration general flow recession characteristics of the natural hydrograph, results from fish life cycle modeling, and additional observations and studies.

4 WATER TEMPERATURES

Summer water temperatures in Redwood Creek generally appear suitable to marginally suitable for salmonid rearing (Figure 4). Reaches with excessively high summer water temperatures may reduce or preclude the benefits of flow enhancement for salmonids. Generally, increased flows will improve water quality through higher levels of dissolved oxygen and lower water temperatures. However, considering that many portions of Redwood Creek have gone dry over the past two summers (sub-surface flow only), it is possible that small flow increases in certain stream reaches could actually lead to increased water temperatures (in cases where the flow increases are sufficient to bring flows to the surface and the stream reach is not sufficiently shaded). This concept should be considered when identifying key focus areas for landowner outreach and storage and forbearance actions.

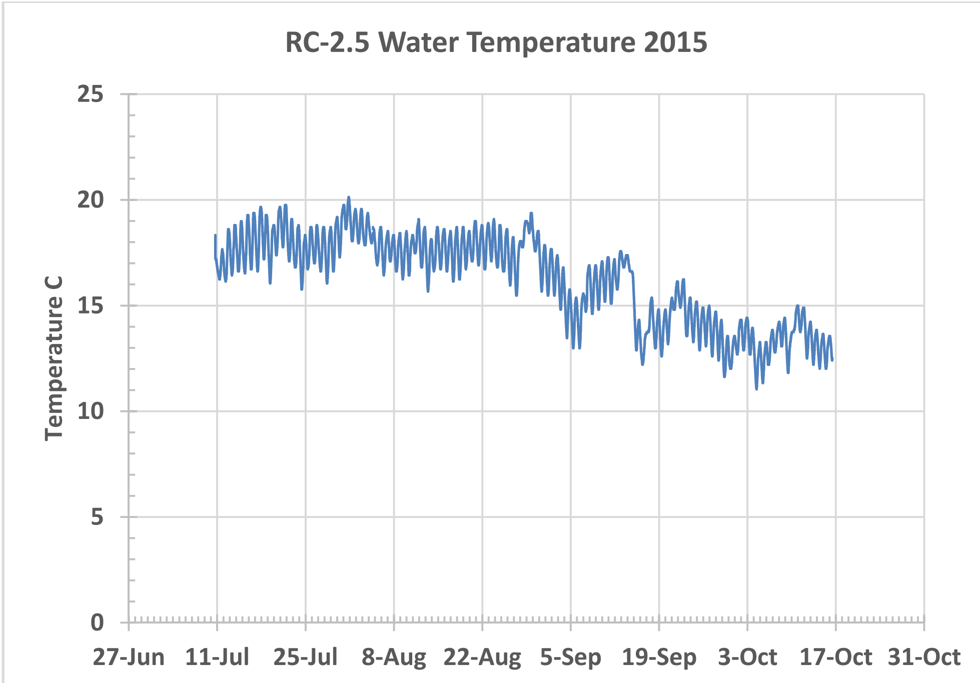

Figure 4. Water temperature during the summer low flow period at the RC-2.5 monitoring site in Redwood Creek.

5 HYDROLOGIC MODELING

Simple hydrologic modeling was conducted to explore the relative extent and intensity of management activities required to achieve the range of preliminary recommended flow targets described in Table 1.

5.1 Hydrologic Model Setup

A simplified hydrologic model was developed in the US Army Corps of Engineers' HEC-HMS (Hydrologic Engineering Center's Hydrologic Modeling System) covering the Feasibility Study area. The model includes nine sub-basins and five stream segments as shown on Figure 5 and Table 2. Modeling focused on the spring to early summer flow recession in an effort to better quantify the steep decline in flows that occur in Redwood Creek (as compared to the long-term USGS gage sites) prior to the commencement of low flow monitoring.

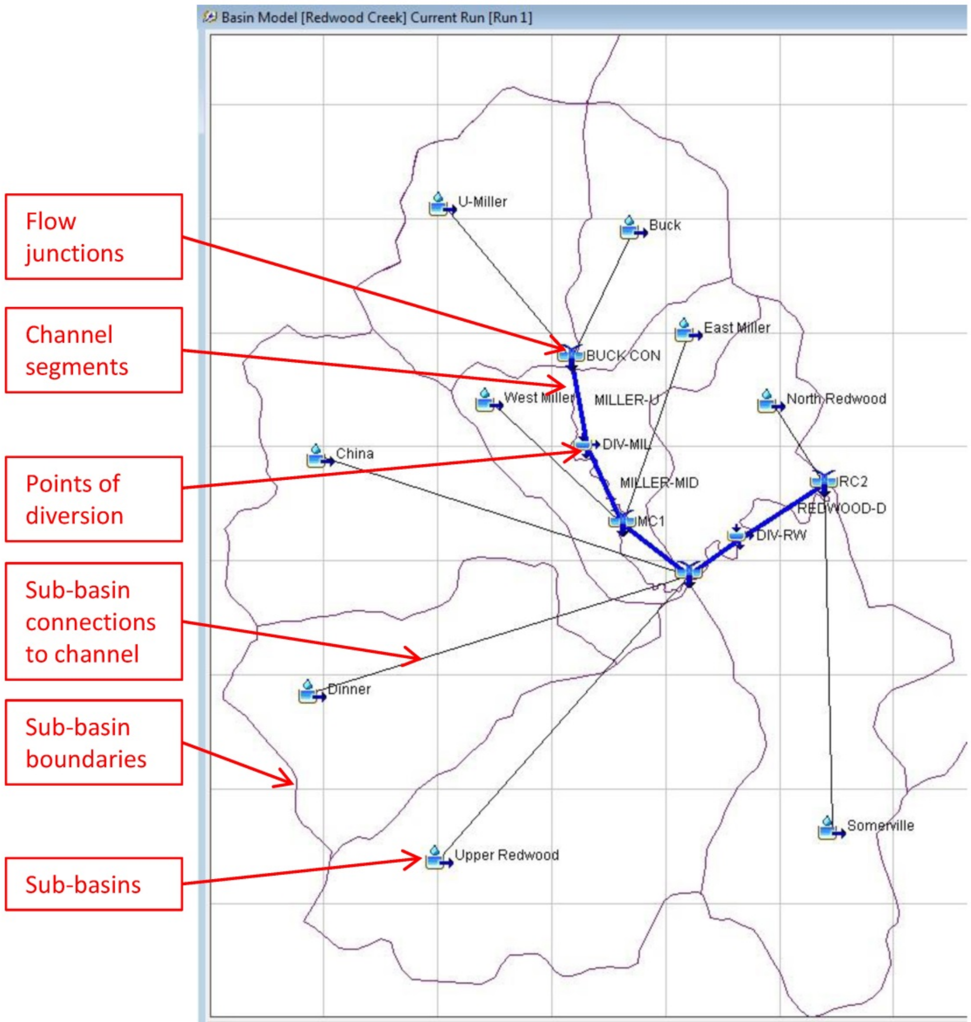

Figure 5. Redwood Creek Feasibility Study Area Hydrologic Model Schematic

Primary input parameters for the model included initial discharge and recession coefficients for each of the nine sub-basins. Rather than using the “unimpaired” recessional limb of the Elder Creek gage to calibrate the model, we chose to use flows from the USGS gage on the SF Eel near Miranda which has the steepest spring/early summer recession and is therefore the gage that we believe most closely matches the heavily impaired conditions within our study area. SF Eel flows were prorated by drainage area to the RC-2 monitoring station and are shown on Figure 6. The HEC-HMS model was then calibrated to nearly match the prorated SF Eel flows with a total initial discharge of 13.8 cfs on March 25, 2015 and recession coefficient of 0.97 as shown on Table 2.

Table 2. HEC-HMS primary input parameters

	Area (mi^2)	Initial Discharge (cfs)	Recession Constant
Upper Miller Creek	1.5	1.5	0.97
Buck Creek	0.9	0.9	0.97
East Miller Creek	0.7	0.7	0.97
West Miller Creek	0.6	0.6	0.97
Upper Redwood Creek	3.0	3.0	0.97
China Creek	2.2	2.2	0.97
Dinner Creek	1.8	1.8	0.97
Somerville Creek	2.4	2.4	0.97
North Redwood Creek	0.9	0.9	0.97
Total	13.8	13.8	

Next, using HEC-HMS we explored two different flow diversion scenarios that resulted in reduced flow rates at RC-2. As a very preliminary approximation of human use, we summed the number of assessors parcels within the study area and assumed that the maximum consumptive use for each parcel was 1,000 gallons per day. This estimate was based on information from the Mattole headwaters where a water survey of 40 residents resulted in an average estimated water use of 708 gallons per day during the 6-month dry season (Trout Unlimited, 2013). We then increased the estimate from the Mattole by 40% to add conservatism to this preliminary modeling exercise (resulting in ~1,000 gallons per day). The total estimated maximum consumptive use is shown on Table 3. The HEC-HMS model inputs for the two diversion points are shown on the bottom row.

Table 3. Maximum Consumptive Use Estimates

	Area (acres)	Area (mi^2)	Number of Parcels	Diversion rate per parcel (gpd)	Total Diversion Rate (cfs)	Diversion from Redwood Creek mainstem (cfs)	Diversion from Miller Creek (cfs)	Notes
Upper Miller Creek	941.55	1.47	16	1000	0.025		0.025	
Buck Creek	557.33	0.87	12	1000	0.019		0.019	
West Miller Creek	374.27	0.58	9	1000	0.014		0.014	
East Miller Creek	432.32	0.68	8	1000	0.012		0.012	
North Redwood Creek	569.19	0.89	32	1000	0.050	0.050		Does not include ~26 small parcels
China Creek	1406.35	2.20	27	1000	0.042	0.042		
Dinner Creek	1124.53	1.76	25	1000	0.039	0.039		
Upper Redwood Creek	1899.38	2.97	9	1000				All timber land, no direct diversion
Somerville Creek	1512.92	2.36	24	1000	0.037	0.037		
Briceland municipal							0.012	8,000 gallons per day
Total						**0.17**	**0.08**	

Model results indicate that even with the estimated consumptive use shown on Table 3, modeled flows are still considerably higher than the spot measurements collected at RC-2 (Figure 6). A final model run was conducted with an additional diversion of 0.5 cfs which appears to better corroborate to the RC-2 spot measurements (Figure 6). However, as discussed below, it is unlikely that consumptive use is responsible for this continuous 0.5 cfs flow “deficiency.”

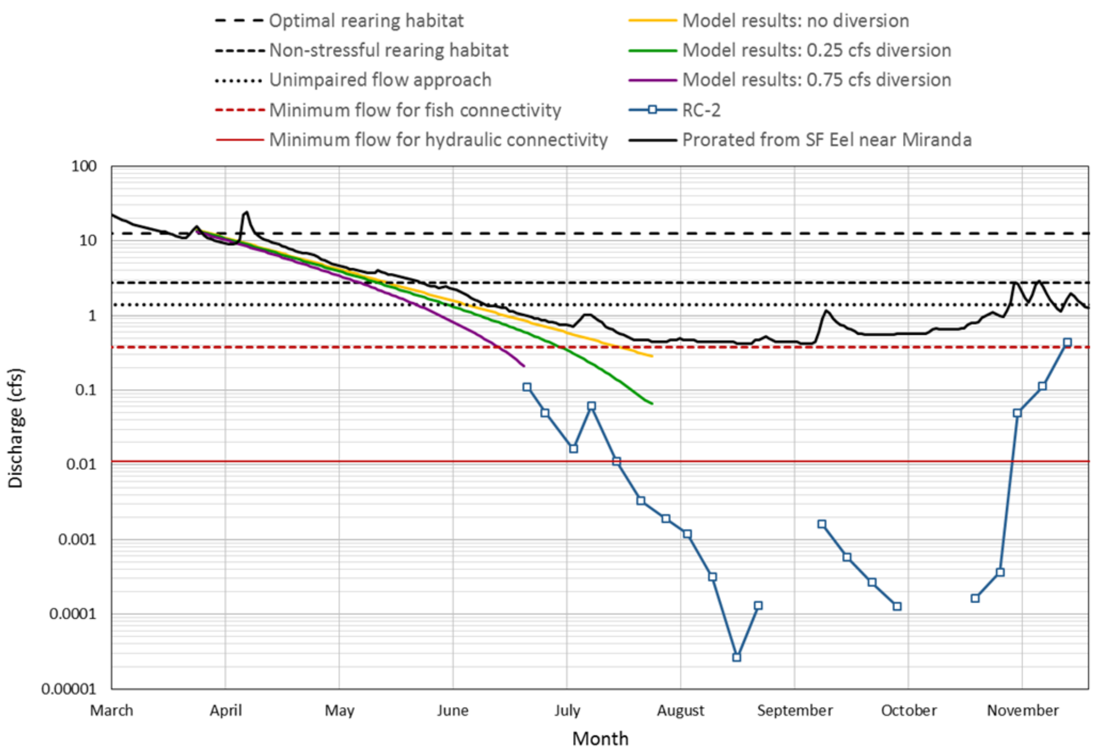

Figure 6. Hydrologic modeling results for the 2015 spring to summer recession at RC-2.

5.2 Discussion of Model Results

The primary conclusion from this modeling exercise is that even compared to the heavily impaired flows of the South Fork Eel near Miranda, Redwood Creek has a much steeper spring to summer hydrograph recession that cannot be entirely attributed to consumptive use. A similar discrepancy in flow recession is seen in the upper Mattole between the MS6 gage (operated by Sanctuary Forest) and the USGS gage near Ettersberg (Trout Unlimited 2013). Therefore, the recessional flow "deficiency" of approximately 0.5 cfs is more likely due to variation in local hydrogeomorphic characteristics (e.g., geology, topography, and climate) and/or due to the fact that runoff and infiltration dynamics have been more heavily impacted by anthropogenic disturbance within these study areas as compared to the Eel or Mattole River watersheds as a whole.

Preliminary modeling analyses strongly suggest that storage and forbearance actions alone are unlikely to achieve "Unimpaired" target flows. Results suggest that during dry years, even 100% forbearance may not achieve the "Minimum flow for fish connectivity." In the near term, projects should focus on meeting the "Minimum flow for hydraulic connectivity" in areas where flows are already close to this threshold and coho are known to be present. Storage, forbearance, recharge, and other water conservation practices would then be implemented incrementally over time with the goal of cumulatively achieving higher target flows.

These results also highlight the need to consider larger scale projects in terms of groundwater recharge or direct flow enhancement (in association with storage and forbearance) if recommended flow targets beyond the "minimum for hydraulic connectivity" are ever to be achieved. Large-scale groundwater recharge projects are currently in the design and planning phase in the upper Mattole.

6 CONCLUSION AND RECOMMENDATIONS

The next steps for this project involve conducting a feasibility analysis to inform specific recommendations for meeting preliminary target flow objectives. Although this analysis was originally envisioned only within the Feasibility Study area (one of the most highly impaired areas of the watershed), preliminary results discussed herein indicate that near-term actions should focus on increasing hydraulic connectivity in channel reaches with the least flow impairment and/or most suitable existing habitat. Working in these reaches will provide the most benefit to salmonid carrying capacity in the watershed. After hydraulic connectivity has been restored and/or enhanced in the stream reaches with the most suitable existing habitat, longer-term actions should focus on spatially expanding flow enhancement activities and meeting the higher recommended flow targets.

Specific recommendations at this early phase of the project include the following:

- Prioritize water storage for users in most upstream areas and work downstream in order to match the longitudinal profile of stream temperatures, which are typically coldest and most suitable in the most upstream reaches accessible to salmon (Dinner Creek);
- Prioritize other areas where flows are continuous and temperatures are suitable (mainstem near RC-2.5)
- Prioritize storage for the largest users (Briceland Municipal);
- Prioritize actions that prolong non-stressful and more functional rearing conditions into the dry season (work with landowners to insure that they are not diverting excess amounts of water to "top off" their tanks in the late spring early summer); and
- Consider large-scale groundwater recharge and/or direct flow releases that will likely be necessary to achieve flows higher than "minimum for hydraulic connectivity."

6.1 Additional analyses and monitoring

Significant data gaps exist in our understanding of the relationships between hydrology, streamflow, and salmonid rearing habitat conditions in Redwood Creek. The project team is actively seeking additional funding to continue monitoring low flow conditions, and the following additional analyses should be considered as budget allows (input from Klein and Stillwater):

- Compare Elder Creek flows with additional Redwood Creek monitoring stations, including RC-1 (which has a similar drainage area to Elder Creek) and RC-2.5 (which had continuous flow monitoring in 2015);

- Conduct additional flow monitoring during the period of spring flow recession to better define the nature and timing of the rapid annual flow recession in Redwood Creek compared to the all nearby USGS gages;
- Monitor summer flows in one or more Bull Creek tributaries to better understand the relative importance of direct human consumptive use versus deviations in unimpaired flow related to legacy timber harvest activities and associated vegetation change;
- Evaluate the utility of precipitation adjusted streamflow (Asarian and Walker, 2016) for establishing recommended flow targets;
- Compare total discharge volumes (water yield) at continuous sites within Redwood Creek and at reference sites in a water balance framework (this approach would require year-round gage data in Redwood Creek); and
- Include flow measurements in Whitmore Creek, a tributary in lower Redwood Creek draining State Park ownership that would serve as a "within-basin" references site.

Note that the project team submitted a proposal to the California Wildlife Conservation Board's Proposition 1 Flow Enhancement Program that included funding for all of the analyses listed above (along with additional items). The proposal was not recommended for funding by the Selection Panel in 2016, but we will be seeking funding in upcoming cycles.

7 REFERENCES

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