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Redwood Creek Flow Enhancement Implementation Plan

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Cover photos: A step pool sequence of Redwood Creek downstream of Briceland (top photo) and a dry reach of upper Redwood Creek on the Lost Coast Forestlands property (bottom photo).

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1 INTRODUCTION

This report provides an overview of hydrologic conditions in the Redwood Creek watershed specifically related to dry-season streamflow and recommends implementation actions to enhance these flows. This work is funded through the California Wildlife Conservation Board's Streamflow Enhancement Program (WCB SEP). Salmonid Restoration Federation (SRF) is the project proponent, leading flow monitoring and community outreach, and Stillwater Sciences (Stillwater) is the science and engineering lead for the project.

This effort seeks to improve habitat for Coho salmon (*Oncorhynchus kisutch*) and steelhead (*Oncorhynchus mykiss*) in Redwood Creek (Figure 1-1)—an important salmonid-bearing tributary to the South Fork Eel River—by addressing the limiting factor of low summer streamflows. The South Fork Eel River is one of five priority watersheds selected for flow enhancement projects in California by the State Water Resources Control Board (SWRCB) and the California Department of Fish and Wildlife (CDFW) as part of the California Water Action Plan (SWRCB 2019). Redwood Creek is a critical tributary to the South Fork Eel River that supports Coho and Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead.

Section 2 of this report examines the unique geology of Redwood Creek and explores the implications for runoff dynamics and dry-season streamflow enhancement activities. Next, ten years of SRF's dry-season flow monitoring and other flow studies are analyzed and synthesized. Stillwater assessed watershed conditions including human consumptive water use, general land management, and fish distribution to support a synthesis of watershed conditions, as well as opportunities and constraints for flow enhancement. Following this assessment of existing conditions, Section 3 presents four types of flow enhancement actions and discusses applicability, potential flow benefits, and long-term maintenance considerations. Finally, Sections 4 and 5 define specific recommended actions required to achieve dry-season flow improvements in Redwood Creek.

1.1 Background and Project Overview

Efforts to improve dry-season streamflow in Redwood Creek have been underway since 2013 when SRF initiated dry-season flow monitoring with 319(h) funding through the North Coast Regional Water Quality Control Board (NCRWQCB). Then, beginning in 2015, Stillwater and SRF worked together on a flow enhancement feasibility study for a part of Redwood Creek (Stillwater Sciences 2017) using CDFW drought funding. Following completion of the feasibility study, Stillwater and SRF applied for and secured funding from the WCB SEP for two projects:

1. Design and permitting of the Marshall Ranch Flow Enhancement Project which was the highest priority project based on recommendations from the feasibility study. Currently, the design phase is complete, implementation funding has been secured from the WCB SEP, and construction is planned for 2023.
2. Developing a flow enhancement assessment and implementation plan for the entire Redwood Creek watershed (this report). The goal of this effort is to prepare a roadmap for flow enhancement actions in Redwood Creek over the coming decades.

Throughout the flow enhancement analyses and development of recommendations presented herein, SRF and Stillwater have worked closely with a Technical Advisory Committee (TAC) as well as local community members. TAC members for this project include representatives from CDFW, the National Marine Fisheries Service (NMFS), NCRWQCB, and WCB SEP.

Work on this project conducted to date and described herein includes office- and field-based analyses and assessments to characterize the existing conditions in Redwood Creek with the ultimate goal of developing a prioritized list of flow enhancement actions that will most effectively increase dry-season flows in the future.

Work began reviewing light detection and ranging (Lidar) topography, aerial imagery, geology maps, fish distribution data, and land ownership within the watershed. This office-based GIS analysis provided critical guidance to inform the field assessment priority areas as well as project planning and design. The project team explored opportunities for developing GIS-based algorithms based on multiple datasets that identified and prioritized specific target areas for flow enhancement activities, but it was determined that opportunities and constraints were governed primarily by a combination of considerations that GIS algorithms were not capable of accurately predicting at this time. For example, office-based analysis does not provide the level of site-specific detail that can be obtained from a field assessment of plant types and surface-groundwater dynamics that are critical for determining project feasibility. As the science is further developed and pilot projects are implemented and monitored, GIS-based approaches for project site identification should be further evaluated and developed.

The field assessment focused on supplementing the office-based analyses by gathering site-specific observations from areas within the watershed expected to benefit from flow enhancement projects and/or with a high likelihood for flow enhancement project development. Major considerations that supported the identification of field assessment focus areas included:

1. Class I watercourses throughout Redwood Creek with a focus on the mainstem.
2. Groups of contiguous parcels under the same ownership.
3. Low-gradient landforms.

Following identification of the target areas, landowner outreach was conducted to seek access. For properties where access was granted, hydro-geomorphic field assessments were conducted to document existing conditions and identify opportunities and constraints for flow enhancement activities. Data collection included: mapping wet and dry channel reaches, identification of geomorphic features governing channel conditions, and mapping of water sources and diversions. The hydro-geomorphic assessment approach is discussed further in Sections 2.7 and results are summarized in Sections 4 and 5.

This report also draws information from previous work including:

- 10 years of dry-season flow monitoring by SRF;
- Flow Enhancement Feasibility Study for a part of Redwood Creek (Stillwater Sciences 2017);
- Redwood Creek Water Availability Analysis in Appendix C of Marshall Ranch BOD Report (Stillwater Sciences 2021);
- Instream Flow Evaluation: Juvenile Steelhead and Coho Salmon Rearing in Redwood Creek, Humboldt County (Maher et. al. 2021); and
- Multiple flow enhancement projects underway and completed in the nearby Mattole River headwaters by Sanctuary Forest and Stillwater including work in Baker Creek, Lost River, and other tributaries.

Results, data, and findings that are relevant to flow enhancement actions in Redwood Creek have been synthesized in this report and support the prioritized implementation actions listed in Section 5.

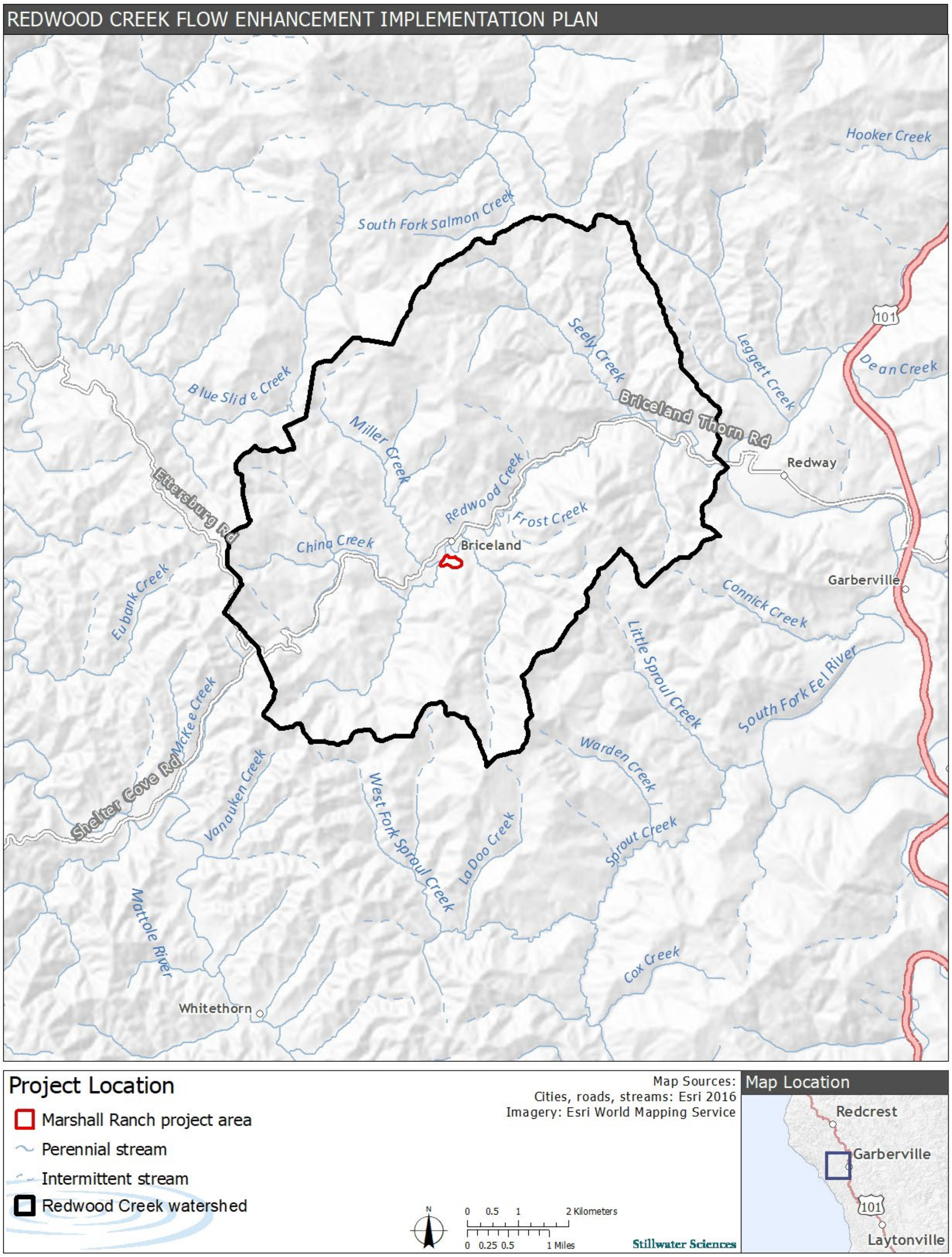

Figure 1-1. Vicinity map.

1.2 Conservation Need

Aquatic habitat in Redwood Creek is impaired due to a variety of factors, including low dry-season flows, high water temperatures, excessive fine sediment, and lack of habitat complexity (CDFW 2014). Dry-season flows (i.e., June–October) in northern coastal California watersheds have decreased over the past half century (Sawaske and Freyberg 2014, Asarian 2014) likely due to a combination of changes in climate, land use and associated consumptive water demand, and vegetative cover.

There are two fish species with threatened status that are expected to benefit from flow enhancement actions in Redwood Creek: (1) the Southern Oregon/Northern California Coast Coho salmon (*O. kisutch*) (SONCC) evolutionarily significant unit (ESU) which is designated as state and federally threatened and (2) the Northern California steelhead (*O. mykiss*) distinct population segment (DPS) which is federally threatened and a CDFW species of special concern. The Redwood Creek watershed is located within the range of the South Fork Eel River population of Coho salmon, which the National Oceanic and Atmospheric Administration (NOAA) identifies as a core population vital to the preservation of the SONCC ESU (NMFS 2014). Coho salmon and steelhead were historically abundant in Redwood Creek; however, loss of juvenile rearing habitat due to habitat simplification and reduced dry-season flow has resulted in substantial declines (NMFS and CDFW 2019). Coho salmon are particularly sensitive to dry-season flows because they often spawn and rear in stream reaches that are lower gradient and more susceptible to drying than steelhead. Coho hatch in the spring and spend a year rearing in the stream before returning to the ocean the following spring. Many stream reaches lack sufficient flow to support suitable juvenile summer rearing habitat despite considerable expenditures in habitat restoration projects (i.e., sediment reduction and placement of large wood habitat structures). In the most impacted watersheds (e.g., by industrial and non-industrial timber harvest, homesteading, and cannabis cultivation), diminished streamflow is having lethal or sub-lethal effects on juvenile salmonids and is also negatively impacting sensitive amphibian species (Bauer et al. 2015).

This project addresses this key limiting factor by providing a long-term plan to increase dry-season flows in Redwood Creek through water storage and retention during the wet season and strategic release of the stored water to enhance flows in critical reaches during the dry season. This primary objective is consistent with the need for "improving flow timing or volume" as identified in the first ten action items of the SONCC Coho Recovery Plan (NMFS 2014).

1.3 Goals and Objectives

The goal of this project is to develop a prioritized list of actions that can be implemented in Redwood Creek over future decades to measurably increase dry-season streamflow and improve associated aquatic habitat conditions.

The hydrographs shown in Figure 1-2 demonstrate the conceptual differences between unimpaired and current flow conditions. The unimpaired landscape resulted in more groundwater recharge and less runoff during the wet season than under current condition due to extensive land disturbance resulting from timber harvest, agriculture and homesteading over the past century. Additionally, there was less water loss during the dry season without human consumptive use and under old growth forest conditions with lower evapotranspiration (ET) (Kobor and O'Connor 2021). Flow enhancement actions are intended to shift the current "impaired" hydrograph toward the unimpaired state. Four generalized flow enhancement approaches for achieving this objective will be introduced in Section 3 of this report.

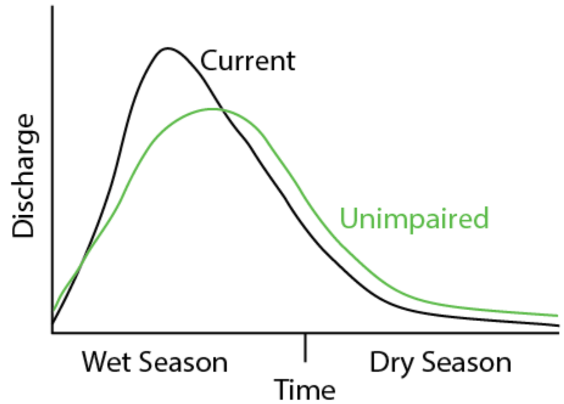

Figure 1-2. Conceptual hydrograph comparing current and unimpaired flow conditions.

2 REDWOOD CREEK WATERSHED EXISITNG CONDITIONS

2.1 Watershed Geology and Geomorphology

The Redwood Creek watershed is located within a tectonically active plate-boundary deformation zone at the northern terminus of the San Andreas Fault Zone at the Mendocino Triple Junction near Cape Mendocino (Kelsey and Carver 1988). A combination of lateral shearing as well as uplift and folding associated with compression creates the dominant NNW-SSE trending topography and structure in the region (Kelsey and Carver 1988). The Quaternary Garberville-Briceland fault zone trends NW-SE across the watershed (Figure 2-1) (McLaughlin et al. 2000). The fault zone consists of multiple named and unnamed fault traces with varying orientations.

The Redwood Creek watershed is primarily underlain by the Coastal and Central belts of the Franciscan Complex, the younger marine and non-marine deposits of the Wildcat Group, and minor amounts of serpentinized peridotite of the Coast Range Ophiolite (Figure 2-1). Much of the Redwood Creek watershed is underlain by various subunits of the Eocene to Paleocene Yager terrane (Franciscan Complex Coastal Belt), which primarily consists of sheared and highly folded mudstone interbedded with sandstone and conglomerate (McLaughlin et al. 2000). This bedrock geology produces irregular topography lacking a well-incised drainage system when compared to other subunits of the Coastal Belt Franciscan Complex.

Runoff and streamflow dynamics vary across the different bedrock geologic units within Redwood Creek. Central Belt geologic units with higher concentrations of clay and mudstone typically have lower infiltration rates and higher runoff during the wet season. Coastal Belt units dominated by sandstone typically have higher infiltration rates, thicker soil layers, and more pervious fractured saprolite resulting in high groundwater storage capacity and subsequently more baseflow during the dry season. In many locations, bedrock geology also creates a strong signature in the dominant vegetation, with claystone and siltstone units typically supporting meadow and oak woodland while sandstone units typically support mixed evergreen forests of conifer and tanoak. The Yager terrane is positioned between the Central and Coastal Belt units in Redwood Creek. Although it is classified as Coastal Belt by McLaughlin et al. (2000), field observations by Stillwater staff and vegetation signatures from aerial photography indicate that runoff dynamics in portions of the Yager unit in Redwood Creek function more like Central Belt terrane.

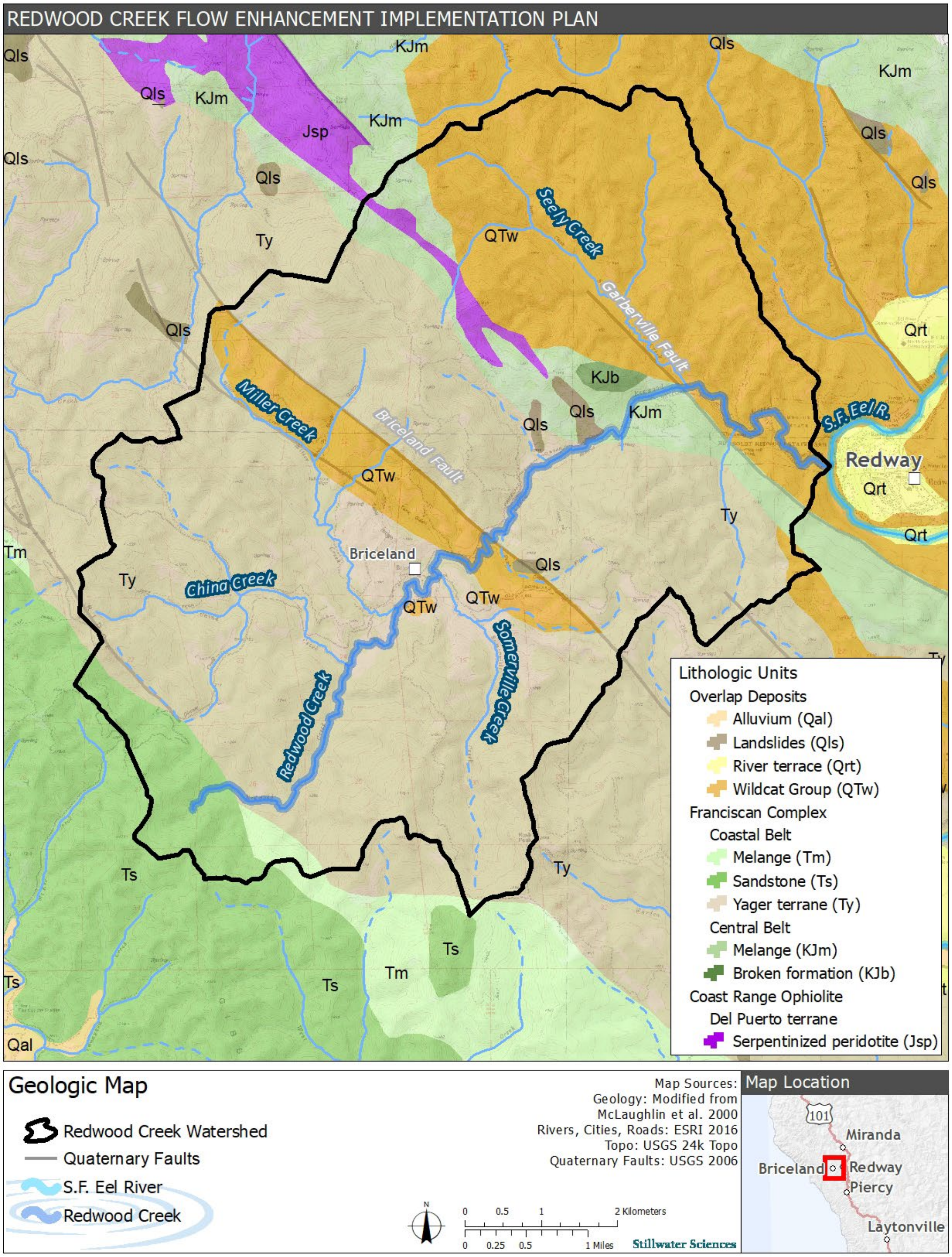

Figure 2-1. Generalized geologic map of the Redwood Creek watershed.

2.1.1 Refinement of bedrock geology mapping

Considering the importance of underlying bedrock type on runoff dynamics and flow enhancement opportunities and constraints, Stillwater refined mapping of the Yager terrane by McLoughlin et al. (2000) based on aerial imagery (Figure 2-2). Because recommended actions are different within areas underlaid by clay and mudstone versus sandstone, this refinement is critical for understanding the infiltration-runoff dynamics in the watershed, including a refinement of “unimpaired” dry-season base flow. It also provides an important basis for development of a flow enhancement implementation plan.

Figure 2-2 shows Stillwater’s subdivision of the Yager terrane, where $Y_{central}$ is comprised primarily of clay and mudstone and behaves more like the Central Belt Franciscan terranes to the east from a hillslope runoff perspective, and $Y_{coastal}$ is comprised of sandstone and behaves more like Coastal Belt Franciscan terranes to the west. Based on this refined delineation, approximately 47% of Redwood Creek is comprised of geologic terranes with runoff dynamics that behave like the Central Belt and 53% of Redwood Creek is comprised of terranes that behave more like Coastal Belt.

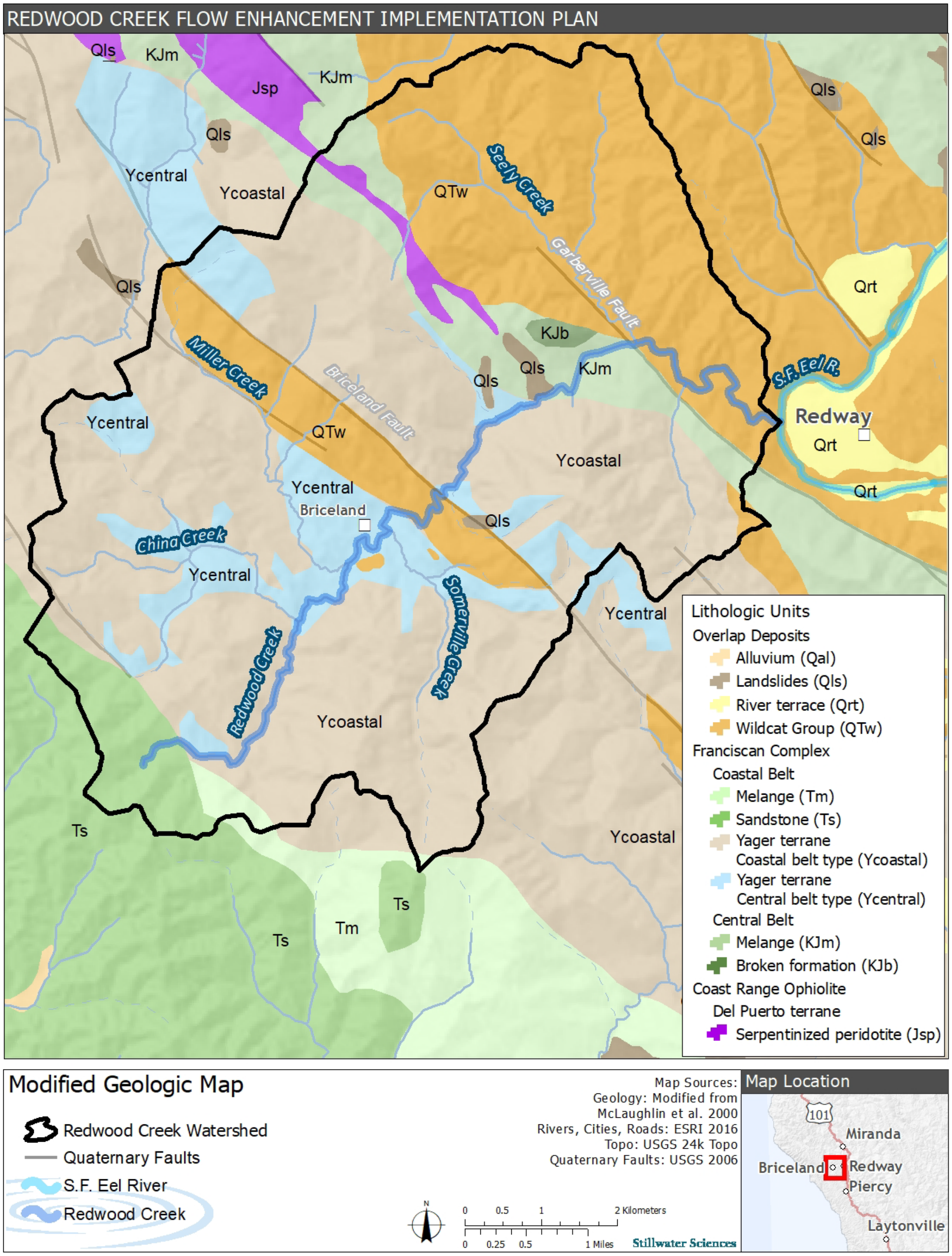

Figure 2-2. Modified geologic map of the Redwood Creek watershed showing Yager terrane sub-units.

2.1.2 Redwood Creek longitudinal profile

2018 USGS Lidar was used to analyze channel gradient and create a longitudinal profile for Redwood Creek (Figure 2-3). Channel slopes vary throughout the watershed, with the upper half of the watershed exhibiting a typical decrease in slope with increased drainage area. A pronounced increase in channel slope between stations 12,000 and 20,000 is likely the result of faulting and a transition to more resistant bedrock that inhibits the geologic incision rate. This steeper reach is primarily underlaid by a strip of Central Belt Melange terrane just to the west of the Garberville Fault. Less sediment deposition is anticipated in this steeper reach due to increased shear stress and channel confinement that result in higher transport capacity. Figure 2.3 also shows the locations of SRF's monitoring stations along the stream profile.

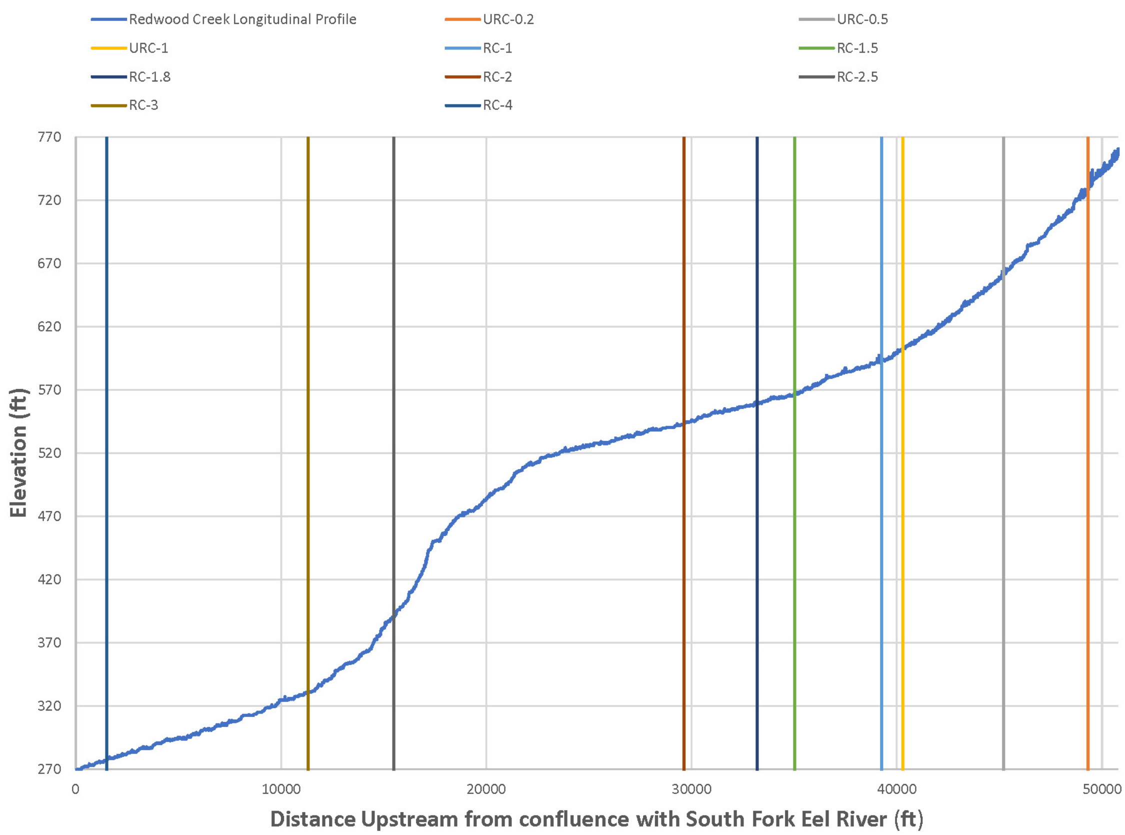

Figure 2-3. Longitudinal profile of Redwood Creek.

2.2 Dry-Season Streamflow

There are no permanent flow gages in Redwood Creek. SRF has been monitoring dry-season streamflows at numerous stations throughout the Redwood Creek watershed since 2013 (Figure 2-4). A summary of these monitoring stations and the years they have been operated is provided in Table 2-1. Dry-season flow measurements taken between 2013 and 2022 at RC-4, the most downstream monitoring station, are shown in Figure 2-5. Flows dropped below 10 gallons per minute (gpm) during August in all years except 2019, often not rebounding above that level until October or even November. In 2014, 2016, 2017, and 2021, periods with surface flow less than 0.1 gpm were recorded beginning in August or September. The Marshall Ranch project proposes to augment 30 gpm from July through November (refer to the dotted line in Figure 2-5 denoting 30 gpm). Low-flow monitoring results for other monitoring stations are provided in Appendix A.

Table 2-1. Redwood Creek Basin flow monitoring summary.

Site description	Station name	River mile upstream from mouth	Drainage area (mi^2)	Years of operation	Status
Mainstem Redwood Creek	RC-4	0.4	25.8	2013 to 2022	Current
Mainstem Redwood Creek	RC-3	2.0	23.5	2013 to 2021	Discontinued
Mainstem Redwood Creek	RC-2.5	2.7	17.1	2015 to 2022	Current
Mainstem Redwood Creek	RC-2	4.5	14.0	2013 to 2017	Discontinued
Mainstem Redwood Creek	RC-1.8	5.0	10.7	2018 & 2022	Current
Mainstem Redwood Creek	RC-1.5	5.3	6.9	2018 & 2022	Current
Mainstem Redwood Creek	RC-1	6.2	6.7	2013 to 2017	Discontinued
Upper Redwood Creek	URC-0.2	8.1	1.0	2021 to 2022	Current
Upper Redwood Creek	URC-0.5	8.8	1.8	2021 to 2022	Current
Seely Creek	SC-1	2.1	5.8	2013 to 2021	Discontinued
Upper Miller Creek	MC-1	5.3	3.4	2013 to 2016	Discontinued
Lower Miller Creek	MC-2	5.3	3.6	2015 to 2022	Current
Buck Creek	BC-1	5.3	0.8	2013 to 2016	Discontinued
Dinner Creek	DC-1	6.3	1.0	2013 to 2021	Discontinued
Upper China Creek	CC-1	6.3	2.2	2013	Discontinued
Lower China Creek	CC-2	6.3	3.9	2014 to 2022	Current
Upper Redwood Creek	URC-1	6.3	2.7	2013 to 2022	Current

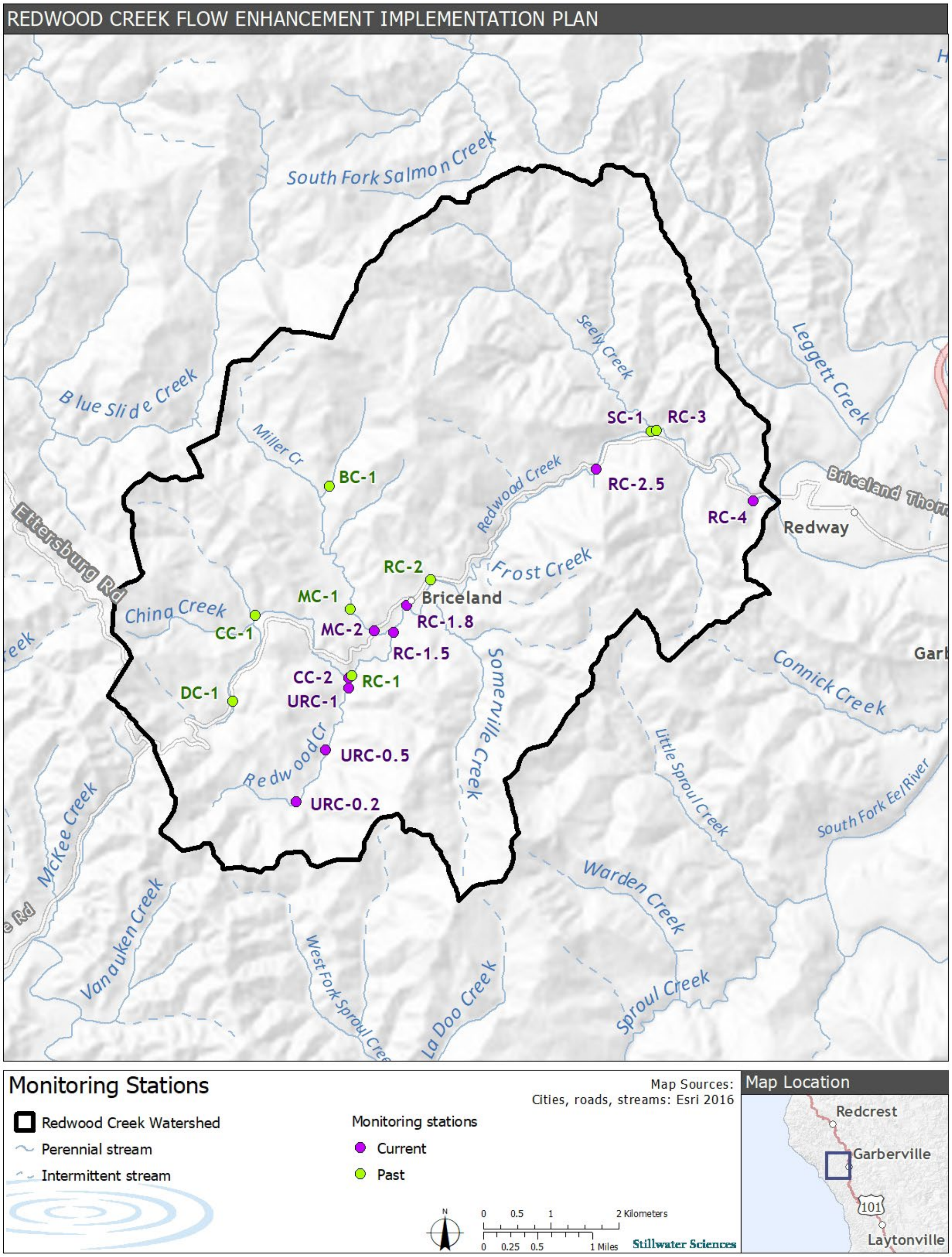

Figure 2-4. Dry-season monitoring stations in Redwood Creek.

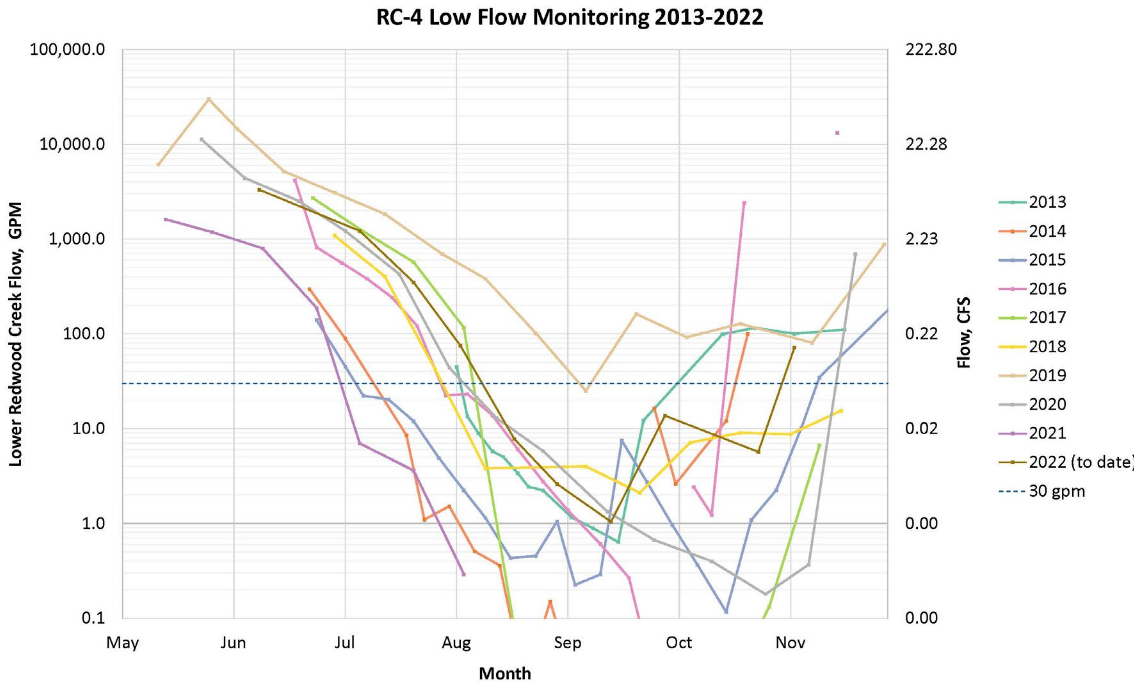

Figure 2-5. Dry-season flow monitoring results for Redwood Creek mainstem near the confluence with the South Fork Eel River (RC-4) between 2013 and 2022.

The 10 years of dry-season flow monitoring results shown in Figure 2-5 depict a clustering of spring and early summer recession hydrographs with 6 of the 10 years falling within a narrow band. Under these typical decadal recession conditions, flows drop below 30 gpm near the beginning of August. Three of the years (2014, 2015, and 2021) are significantly drier, with flows dropping below 30 gpm in early July. One year (2019) was significantly wetter with flows dropping below 30 gpm for a brief period in early September before rebounding back to above 100 gpm. The primary driver of the timing of the hydrograph recession is the timing of winter precipitation which will be discussed further below.

The length of the driest flow period is typically governed by the first significant precipitation event of the year. Several inches of rainfall are necessary to see a measurable increase in flows. It is most common for the first precipitation event to occur in September (2013, 2014, 2015, 2018, 2019, 2022) but in some years precipitation does not arrive until October (2016, 2021) or November (2017, 2020).

Weather patterns, and specifically air temperature. also play a factor in dry-season flow dynamics. Hotter weather increases ET and leads to more rapid declines in flows. Cooler or cloudy weather causes flow to rebound. Typically, flows reach their lowest level in the middle of September, although several years saw a continued decline into October.

Figure 2-6 shows a comparison of flow for the Redwood Creek mainstem gages for 2022 (a typical dry-season hydrograph over the past decade). The recession portion of the hydrographs in Figure 2-6 illustrate the typical pattern in tributary flow accumulation in the downstream direction. However, as flows drop below 50 gpm, the discharge difference between stations narrows: On August 4, flows at RC-2.5 (17.1 mi^2 drainage area) and RC-1.8 (10.7 mi^2 drainage area) are 45 and 38 gpm respectively, and on August 18 flows at RC-4 (25.8 mi^2 drainage area) and RC-2.5 are 8 and 6 gpm respectively. During this period, flow losses from diversion and ET are generally offset by flow inputs from tributaries and groundwater. When flows drop below approximately 20 gpm, variations in measured discharge are strongly impacted by the relative volume of hyporheic flow through the channel bed sediments within each reach. Specifically, RC-1.8 is a localized alluvial reach with a significant volume of hyporheic flow that minimizes surface flow at the gage location.

These monitoring results are consistent with field observations and our understanding of geologic and geomorphic controls on watershed and reach-scale hydrology. In general, Redwood Creek and its tributaries have cut channels into relatively impervious underlying bedrock, resulting in little or no significant surface flow loss to groundwater. However, spatially variable depths of mobile coarse sediment deposited within the underlying channel's bedrock corridor support spatially variable hyporheic flows, with greater hyporheic flows where coarse sediment deposits are thicker.

A comparison of field observations and channel cross sections for monitoring stations within different Redwood Creek reaches assessed sediment deposit variability. As shown in Figure 2-3, monitoring station RC-2.5 is located within a steeper reach of Redwood Creek with a slope of approximately 1.8%, while RC-1.8 and RC-4 are located in reaches with gentler slopes of 0.4% and 0.5% respectively. For each of these monitoring stations, the cross-sectional area of bed sediments was estimated using Lidar topography and field observations. RC-1.8 has the thickest sediment deposit with an estimated cross-sectional area of 80 square feet.

Based on field observations and flow monitoring data, RC-1.8 is the Redwood Creek mainstem monitoring station with the highest rate of hyporheic flow. Comparing discharge data from different monitoring stations during different years, hyporheic flow at RC-1.8 appears to range between 10 and 30 gpm. Therefore, unit hyporheic flows range from 0.1 to 0.4 gpm per square foot considering the sediment cross-sectional area of 80 square feet. This data can be used to extrapolate estimated hyporheic flows at other locations throughout the watershed. For example, the smaller channel at URC-1 has an estimated sediment cross-sectional area of 15 square feet and would be expected to have hyporheic flows between 1.5 and 6 gpm assuming the same unit discharge. These hyporheic flow assumptions and extrapolation approach will be further evaluated during Marshall Ranch post-project monitoring.

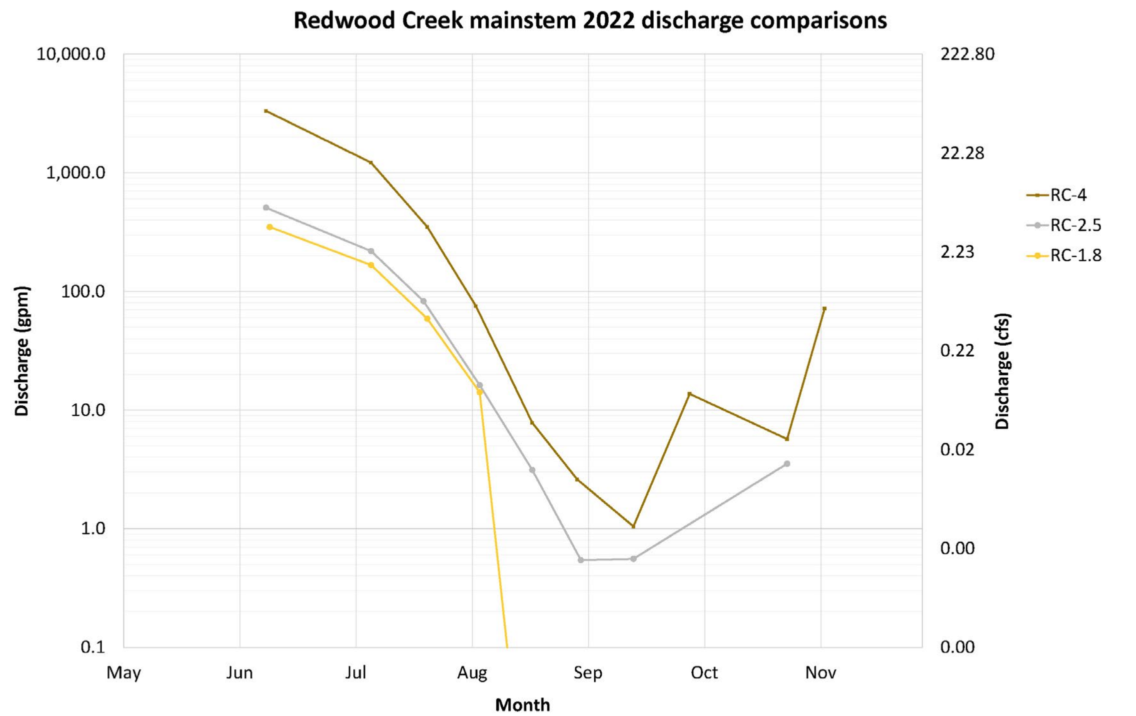

Figure 2-6. 2022 dry-season flow monitoring results for Redwood Creek mainstem gages.

2.2.1 Reference watersheds

Considering that there are no permanent flow gages in Redwood Creek, reference watersheds must be used to analyze hydrologic conditions beyond the current dry-season flow data collected by SRF. Gaged discharge data and other flow studies from nearby watersheds were analyzed including Elder Creek, the Mattole River headwaters, and Bull Creek. Each of these sub-sheds are shown in Figure 2-7 and were used to support development of this implementation plan:

- Elder Creek has a gaged record from 1988 to 2022 for the nearly undisturbed watershed providing data for unimpaired flow considerations (USGS 11475560 Elder Creek near Branscomb CA). The Elder Creek watershed is completely underlain by the Coastal Belt of the Franciscan Complex Bedrock and has no human consumptive use.
- Mattole River headwaters is immediately adjacent to Redwood Creek toward the west and a flow study provides data on salmonid habitat use at different flows. The Mattole headwaters region is almost completely underlain by the Coastal Belt terrane and has similar human consumptive use to Redwood Creek.
- Bull Creek provides the best reference watershed for scaling annual hydrographs and water balance calculations for Redwood Creek. The Bull Creek gage has a 57-year record from 1961 through water year 2018 (USGS 1147660 Bull Creek near Weott CA). The Bull Creek watershed is primarily underlain by Yager terrane with some Coastal Belt along the northern and western ridges. However, Bull Creek land cover is comprised primarily of mixed evergreen forests of conifer and tanoak with small pockets of meadow and oak woodland, as opposed to Redwood Creek which has much more meadow and oak woodland. This signifies that the Yager terrane in Bull Creek is likely more sandstone-dominate than Redwood Creek. McLaughlin et al. (2000) notes that the Yager terrain southwest of Garberville (i.e., Redwood Creek) is highly folded and locally may be

penetratively sheared or broken, which differentiates this portion of the Yager terrane from the rest of the unit. Similar to Elder, there is minimal human consumptive use in Bull Creek watershed.

Runoff and streamflow dynamics vary across the different bedrock geologic units within Redwood Creek. Central Belt geologic units with higher concentrations of clay and mudstone typically have lower infiltration rates and higher runoff during the wet season. Coastal Belt units dominated by sandstone typically have higher infiltration rates, thicker soil layers, and more pervious fractured saprolite resulting in high groundwater storage capacity and subsequently more baseflow during the dry season. In many locations, bedrock geology also creates a strong signature in the dominant vegetation, with claystone and siltstone units typically supporting meadow and oak woodland, while sandstone units typically support mixed evergreen forests of conifer and tanoak. The Yager terrane is positioned between the Central and Coastal Belt units in Redwood Creek. Although it is classified as Coastal Belt by McLaughlin et al., field observations by Stillwater staff and vegetation signatures from aerial photography indicate that runoff dynamics in portions of the Yager unit function more like Central Belt terrane.

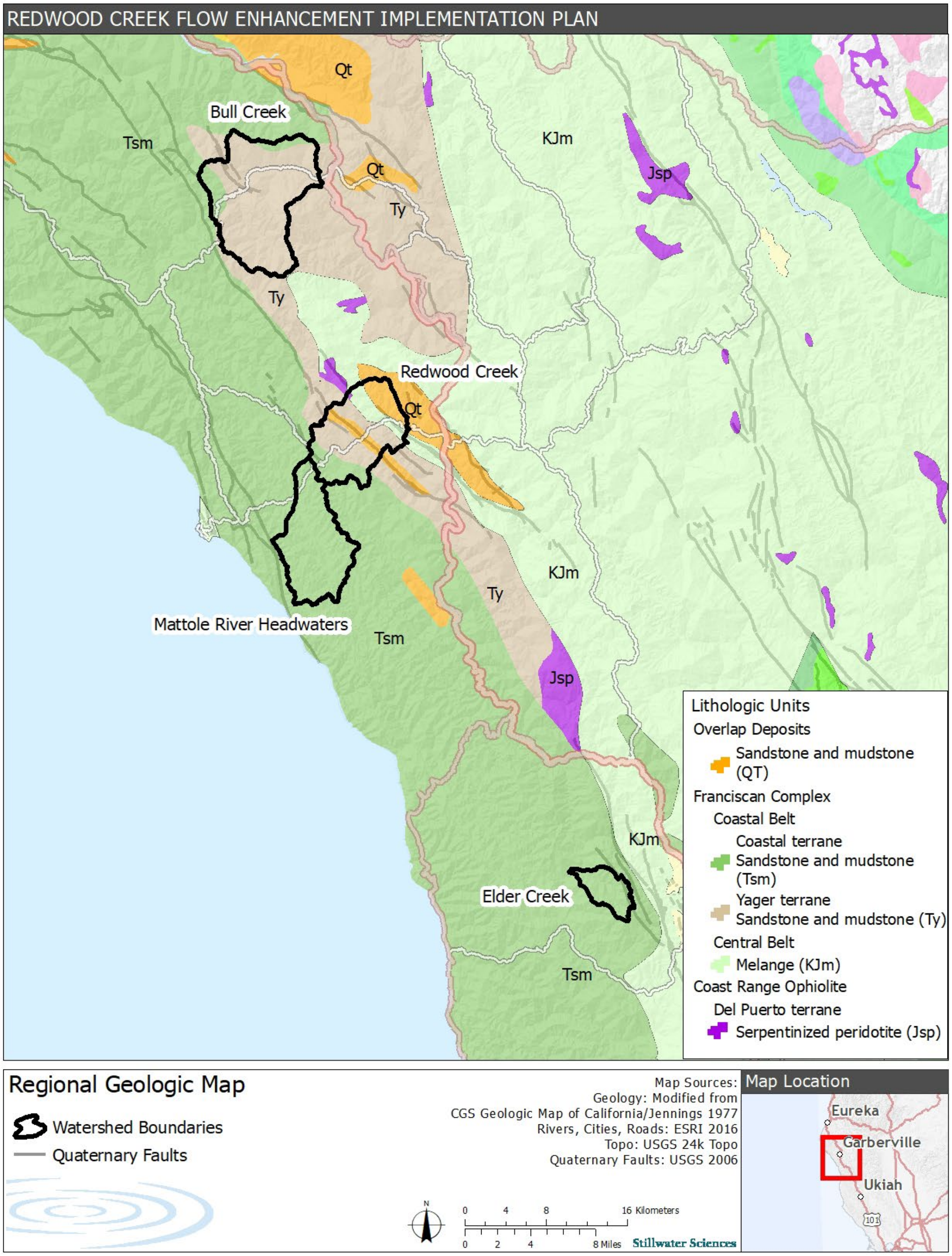

Figure 2-7. Redwood Creek and reference watersheds with regional geology unit underlay.

2.2.2 Dry-season streamflow targets

Annual recession flows during the spring and early summer provide a range of functional habitat quantity and quality for rearing juvenile salmonids. These flow-dependent conditions can rapidly transition from relatively extensive 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 varied from early June to mid-August during 2002–2011 (McBain and Trush 2012).

There have been several studies and analyses conducted to inform dry-season flow targets in Redwood Creek. The preliminary target unit discharges shown in Figure 2-8 were recommended in the Redwood Creek Flow Enhancement Feasibility Study (Stillwater Sciences 2017). This work analyzed hydrologic data from 2014 and 2015, which were two of the three driest years over the past decade (Figure 2-5). These recommended flow targets are based on: (1) natural flow regime principles, (2) results of a flow study conducted in the adjacent upper Mattole River watershed, and (3) preliminary empirical observations of flow and habitat conditions in Redwood Creek.

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 Elder Creek as a reference watershed. The Elder Creek unit hydrograph in cubic feet per second per unit watershed area (cfs mi^{-2}) is shown in Figure 2-8. This suggests that a unit discharge of approximately 0.1 cfs mi^{-2} is an appropriate summer base flow target based on the unimpaired flow approach. Note that during the two drought years shown in Figure 2-8, the unit discharge in Elder Creek actually dropped to near 0.06 cfs mi^{-2} so this lower unit discharge is likely more appropriate for unimpaired conditions during drought years.

Mattole Flow Study
Additional flow targets shown in Figure 2-8 draw from a flow study for 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). These targets were prorated by drainage area to estimate recommended target flows for Redwood Creek (Figure 2-8, Table 2-2). 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.

Redwood Creek Empirical Observations
On-the-ground observations at the Redwood Creek monitoring sites and adjacent stream reaches were used to set a lower bound flow for a recommended target flow. Based on observations by Bill Eastwood (Redwood Creek monitoring coordinator in 2014–2017) hydraulic connectivity was maintained at monitoring station RC-2 at flows between 3 and 7 gpm. This range was averaged and converted into unit discharge of 0.001 cfs mi^2 to provide the lowest target flow in Figure 2-8.

Considering the physical constraints on flow enhancement, realistic flow targets typically fall between the "minimum flow for fish connectivity" and "minimum flow for hydraulic connectivity," shown in Figure 2-8. These unit discharge targets are presented as flows (in gpm) for the six subwatersheds as well as mainstem of Redwood Creek in Table 2-2.

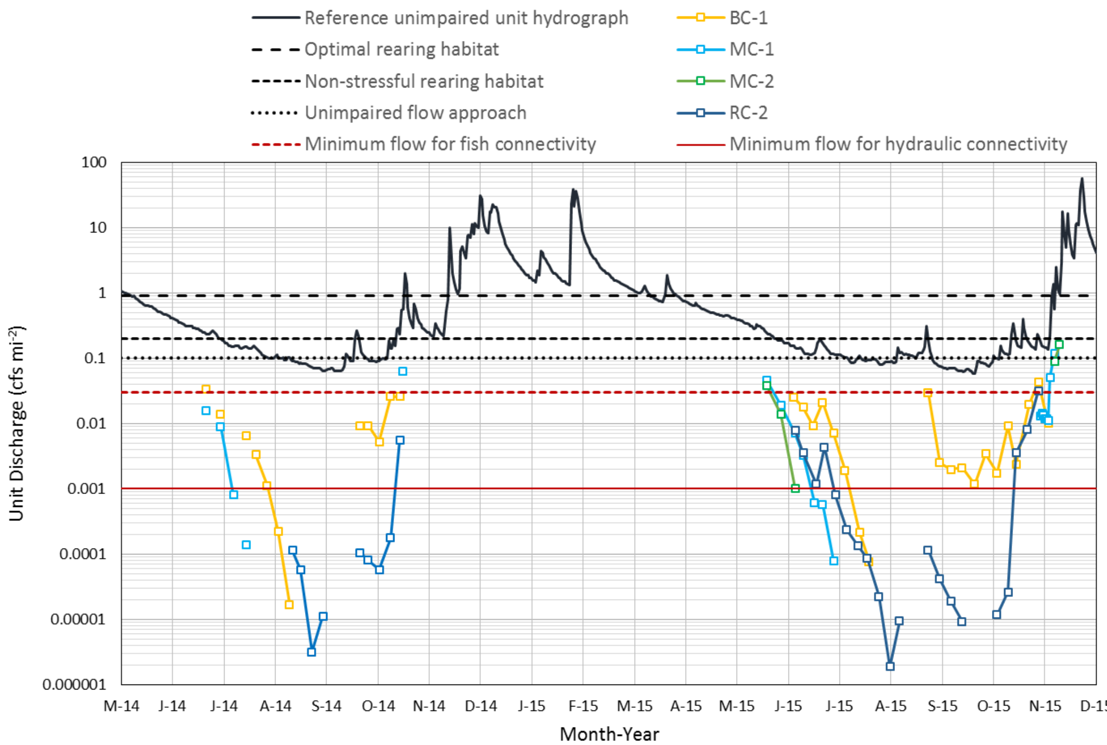

Figure 2-8. Preliminary recommended unit discharges (cfs mi^{-2}) and measured unit discharges from 2014 and 2015 at streamflow monitoring sites in the Redwood Creek Feasibility Study Area. These targets apply to the annual wet season recession and low-flow dry season (Stillwater Sciences 2017).

Table 2-2. Summary of recommended flows for Redwood Creek Sub watersheds.

Subwatershed	Recommended flow (gpm)					
	Optimal rearing habitat[1]	**Non-stressful rearing habitat**[1]	**Unimpaired flow approach (average water year)**[2]	**Unimpaired flow approach (dry water year)**[2]	**Minimum flow for fish connectivity**[1]	**Minimum flow for hydraulic connectivity**[3]
China Creek	1,575	350	175	105	53	1.8
Upper Redwood Creek	1,252	278	139	83	42	1.4
Miller Creek	1,495	332	166	100	50	1.7
Somerville Creek	1,212	269	135	81	40	1.3
Seely Creek	2,343	521	260	156	78	2.6
Redwood Creek near mouth	10,462	2,325	1,162	697	349	11.6
Unit Discharge (gpm/mi^2)	404	90	45	27	13	0.5

[1] Prorated by drainage area from Mattole Flow Study
[2] Prorated by drainage area from Elder Creek, average water year uses unit discharge of 0.1 cfs mi^{-2}, dry water year uses unit discharge of 0.06 cfs mi^{-2}
[3] Redwood Creek empirical observations

The "Minimum flow for hydraulic connectivity" should be considered an absolute minimum flow needed for salmonid survival without considering temperature or dissolved oxygen (DO) implications. Measuring flows at this low level is complicated by the significant amount of hyporheic flow through the channel bed sediments. Based on a comparison of flow data from the different gages, Stillwater estimates that between 10 and 30 gpm flows through the bed material within different reaches of Redwood Creek mainstem. Achieving the "minimum flow for hydraulic connectivity" at most locations throughout the watershed would mainly result in hyporheic flow with minimal surface water expression. Therefore, this "flow target" is not relevant for guiding development of a flow enhancement implementation plan or flow augmentation objectives for individual projects. A more appropriate approach is to compare existing discharge data from different water year types and simulate how the hydrograph in each of those years would benefit from different flow augmentation scenarios. This approach would not use an ecological flow target to evaluate effectiveness but rather relative changes in flow resulting from management activities. The results from this exercise highlight how a flow augmentation of 50 gpm is expected to measurably improve the "average" and "dry" hydrographs (Figure 2-9). Some dry-season flow variability may not be captured in this simple analysis. Section 5 further explores these simulations to assess specific impacts of different flow enhancement approaches.

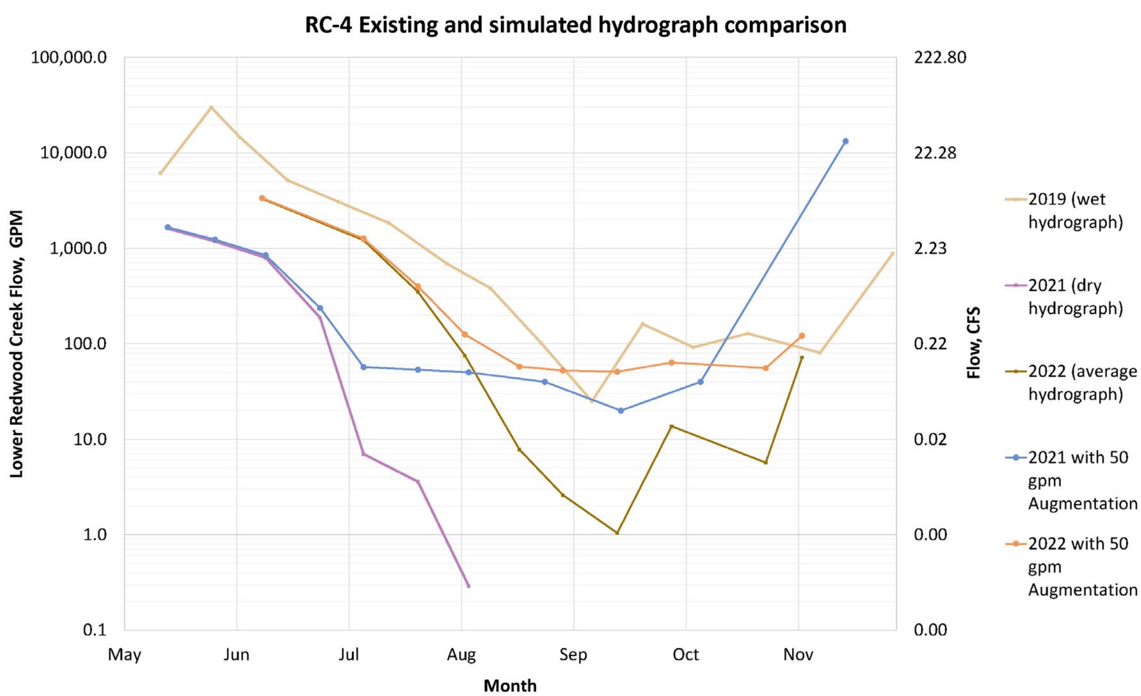

Figure 2-9. Annual dry-season hydrographs for lower Redwood Creek mainstem including dry (2021), average (2022), and wet (2019) years; flow augmentation rates of 50 gpm added to average and dry years for comparison (for dates with zero measured surface flow, augmentation rate has been reduced by 10 to 30 gpm to account for anticipated loss of surface flow to hyporheic flow).

2.2.3 CDFW instream flow evaluation

CDFW has recently published results from an instream flow evaluation of Redwood Creek that presents estimates of unimpaired flows for Redwood Creek and its tributaries, as well as area-weighted suitability projections for juvenile steelhead and Coho salmon (Maher et al. 2021). The CDFW study also provides estimates of protective flows for juvenile steelhead rearing in wet, moderate, and dry years. CDFW's evaluation primarily relied on scaled flow data from Bull Creek gage data (Maher et al. 2021, as described in Cowan 2018). Given that flows at the maximum and median values of the area-weighted suitability curves are higher than the estimates of unimpaired flows for much of the dry season, CDFW defaults to the estimated unimpaired flow rate of 2 cfs (898 gpm) for the moderate and dry year conditions in the driest months (August, September, and October). CDFW's estimate of unimpaired flows fall in the middle of the range of unimpaired flows for Redwood Creek near the mouth shown in Table 2-2.

2.2.4 Revised unimpaired flow targets

Considering Redwood Creek's varying geology as described in Figures 2-1, 2-2, and 2-7 , it is likely to have higher wet-season runoff and lower dry-season base flows than would be expected by simply prorating discharges from Elder and Bull Creeks, which are comprised of a higher percentage of Coastal Belt terrane. Reducing the unimpaired flow targets shown in Table 2-2 by 50% is reasonable considering that Redwood Creek is comprised of approximately 47% of terranes that behave like Central Belt (per Section 2.1.1 above) and that Central Belt terranes typically generate minimal base flow (Dralle et al. 2022). This results in unimpaired flow targets at the mouth of Redwood Creek of 600 gpm and 350 gpm for average and dry years, respectively. Even these reduced unimpaired flow targets will be difficult to achieve through flow enhancement actions over the coming decades. Further, as described in Section 2.2.5 below, water temperature implications may negate the positive benefits of flow enhancement during the hottest period of the summer. Therefore, detailed monitoring and adaptive management of flow enhancement targets will be critical as incremental flow enhancement actions are implemented.

2.2.5 Water temperature implications based on flow enhancement

Streamflow and water temperature dynamics in Redwood Creek are closely interrelated. Although riparian vegetation shades much of the stream channel, land use and geology (i.e., clay- and mudstone-dominated bedrock) limit riparian establishment in many reaches. Redwood Creek water temperature is therefore susceptible to warming during the hottest periods of the summer to a degree that can be detrimental to Coho salmon. Figure 2-10 compares discharge, water temperature, and air temperature at monitoring station RC-1.8 for the 2020 dry season. Beginning in the middle of July, peak daytime water temperatures begin to approach 70 degrees Fahrenheit with flows of approximately 200 gpm. However, once surface flows drop below approximately 30 gpm in early August, water temperatures begin to decrease as a higher percentage of the overall flow becomes hyporheic. Later in the season, there are several spikes in water temperature associated with heat waves (high air temperatures). These are likely due to hyporheic flow dropping to such a low level that it no longer provides a cooling benefit to the disconnected pools. Based on this data, during the hottest period of the year, it is possible that flow enhancement above a certain level could have negative water temperature implications for Coho salmon, and conditions become lethal when hyporheic flows nearly cease. This dynamic is not currently fully understood and will be a focus of monitoring and adaptive management efforts that support future flow enhancement projects. However, this water temperature data strongly supports the need for flow enhancement in Redwood Creek.

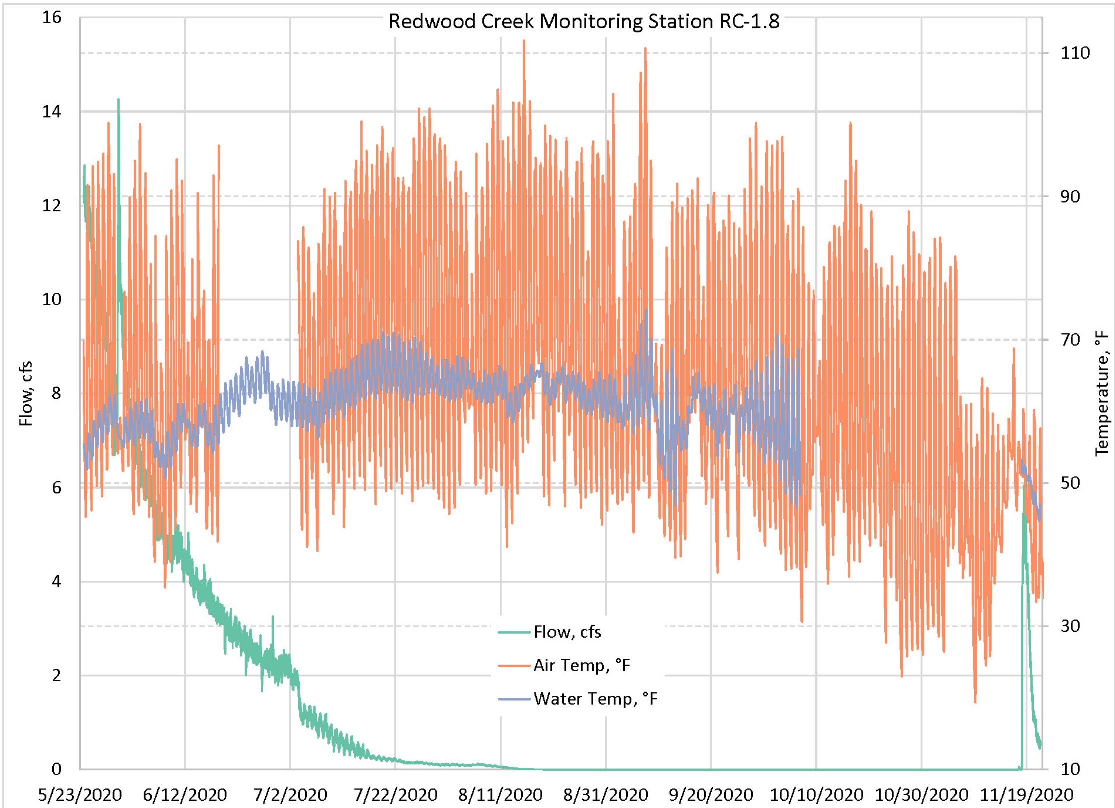

Figure 2-10. Water temperature at monitoring station RC-1.8 during the 2020 dry season.

2.3 Precipitation

Rainfall data for the watershed was acquired from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). The model generates climate datasets using monitoring data and state-of-the-art climate modeling techniques. Average annual precipitation based on the past 30 years of rainfall monitoring data is shown in Figures 2-11 and 2-12, and summarized in Table 2-3. On average, Redwood Creek receives approximately 69.2 inches of precipitation annually.

Table 2-3. Summary of PRISM precipitation data.

Subwatershed	Subwatershed area (mi^2)	Average annual precipitation (inches)	Average annual input volume (ac-ft)
China Creek	3.9	74.9	15,669
Upper Redwood Creek	3.1	72.8	12,174
Miller Creek	3.7	84.1	16,429
Somerville Creek	3.0	67.3	10,846
Seely Creek	5.8	66.3	20,649
Mainstem Redwood Creek	6.4	63.8	21,654
Entire Redwood Creek watershed	25.9	69.2	95,728

2.3.1 Precipitation timing

The Redwood Creek Watershed, as well as much of the north coast of California, are classified by the Koppen-Geiger climate classification system as a Csb, or Mediterranean warm summer climate (Beck 2018). The requisite characteristics for this classification include:

- At least 4 months where average temperatures are greater than 10°C.
- No month where average temperature is equal to or exceeds 22°C.
- At least three times as much precipitation in the wettest month as in the driest.
- The driest month of the summer receives less than 40mm (1.6 inches) of rain.

Typical of the Mediterranean climate, nearly all the precipitation in the Redwood Creek watershed occurs in the form of rainfall during the winter and spring. The watershed does not contain areas of sufficiently high elevation to support significant sustained snowpack development during the winter months. The summer and early fall are characterized as warm and dry with very minimal rainfall. Average monthly precipitation for the town of Briceland between 1991 and 2020 is shown in Figure 2-11. Over this period of record, December exhibits the highest average precipitation of 14.9 inches, while July the lowest at just 0.11 inches. June, August, and September all have average precipitation of 0.8 inches or less.

There is significant annual variation in late winter and spring rainfall timing and volume which has major implications for dry-season flows. Use of antecedent precipitation index (API) has been investigated in the neighboring Mattole River watershed as a means to improve the predictive accuracy of spring recession discharges (Klein 2017). API is a running computation indexing the moisture content (wetness) of the soil mantle and aquifers (Dunne and Leopold 1978). It is computed by taking each day's rainfall starting before the dry season and 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 in the Mattole was derived using a decay factor of 0.98.

However, later analysis in 2015 and 2016 indicate that API alone cannot be used to reliably predict discharges across multiple years with disparate rainfall (Klein 2017). Still, the general concept of API highlights the close connection between precipitation timing and base flow. The 2022 dry season provided a great example of how dry-season flow was sustained by late spring and early summer rainfall, even considering the overall lack of precipitation through the winter and early spring months. Significant rainfall in September then sustained base flow through October.

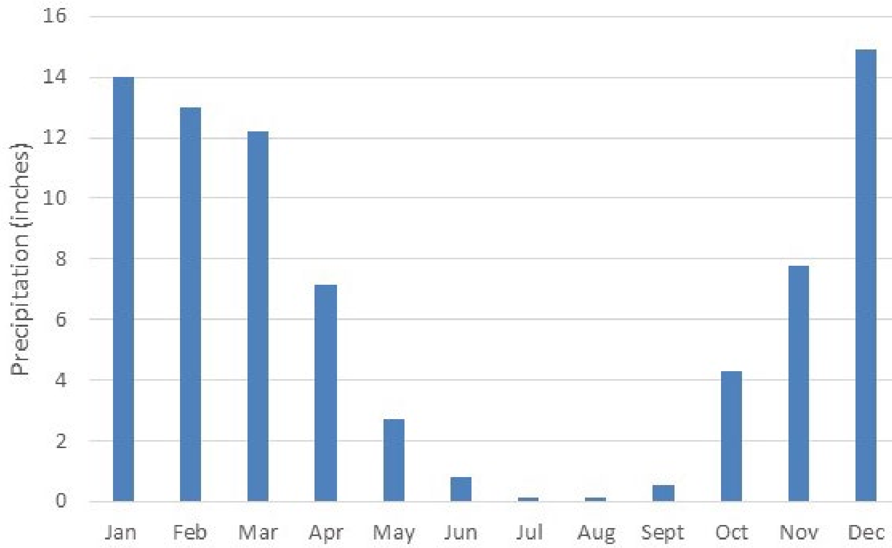

Figure 2-11. Average monthly precipitation in the Redwood Creek Watershed near Briceland from 1991 to 2020. Data from PRISM, OSU.

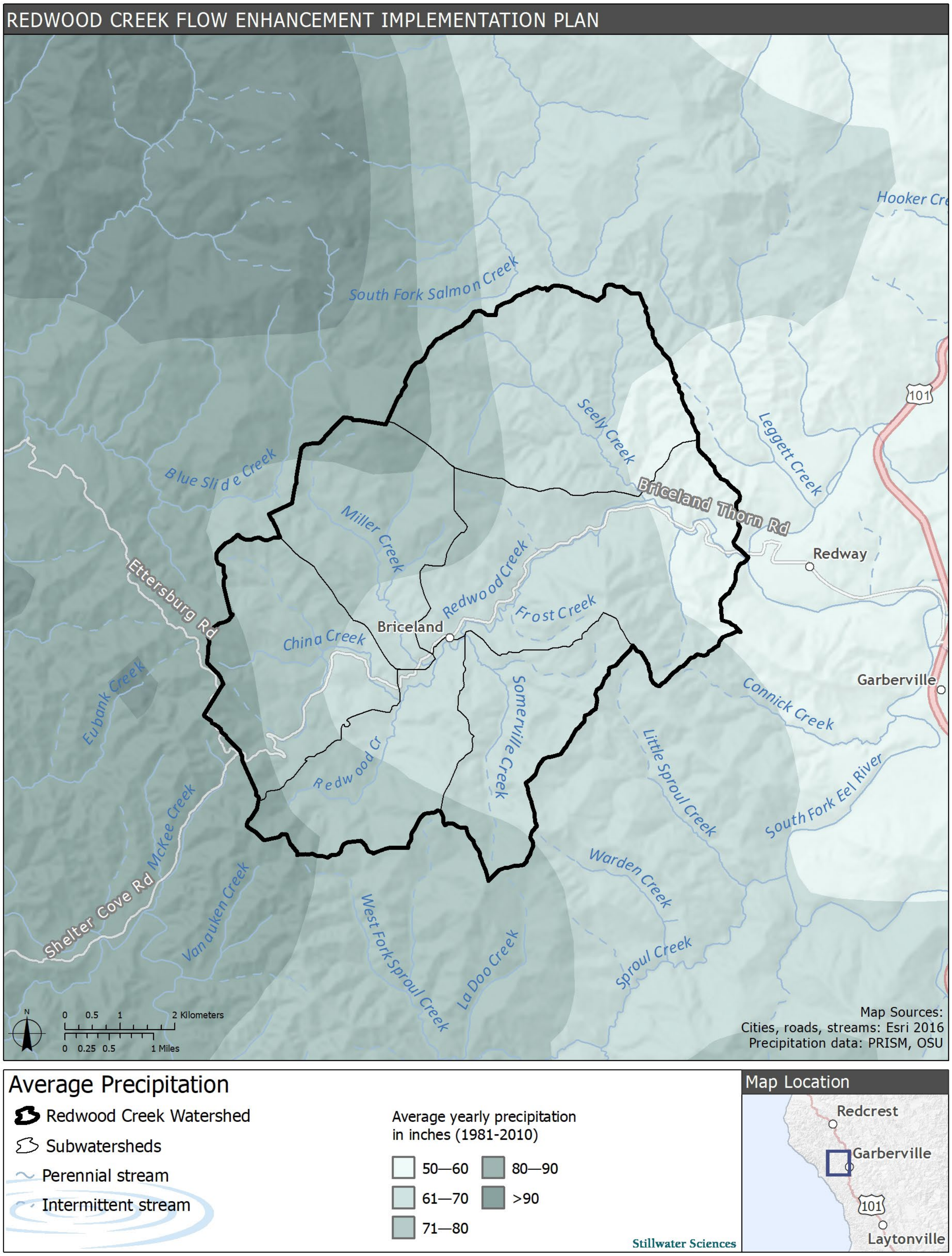

Figure 2-12. Average annual precipitation in the Redwood Creek watershed from PRISM data.

2.4 Seasonal Runoff Dynamics

There are no flow gages that operate year-round on Redwood Creek, so the best way to determine discharge exiting the watershed during the winter is the proration method, as described in the Policy for Maintaining Instream Flows in Northern California Coastal Streams (SWRCB 2014). The USGS Bull Creek gage provides a long-term streamflow record that can be used to estimate unimpaired flow in Redwood Creek, as described in CDFW's Flow Monitoring and Unimpaired Flow Estimation Report for Redwood Creek, Humboldt County (Cowan 2018). Bull Creek is a similar-sized watershed located approximately 15 miles north of Redwood Creek. Average monthly flow in Bull Creek (1960 to 2018) prorated to Redwood Creek results in an estimated annual water yield of approximately 75,067 acre-feet (ac-ft) (Figure 2-13). Considering that there are physical differences between the two watersheds, simple proration may not provide an accurate estimate of individual storm discharge, declining limb hydrograph, or dry-season base flow. However, it does provide a good overview of average monthly discharge characteristics for Redwood Creek. As highlighted in Figure 2-13, there is significant flow in Redwood Creek during the wet season generated by precipitation and runoff.

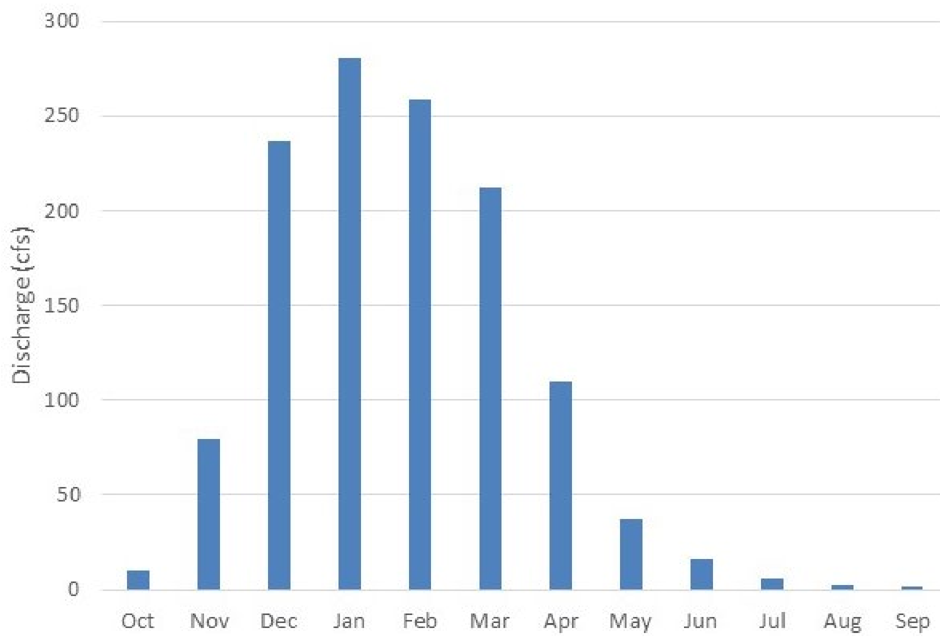

Figure 2-13. Estimated average monthly streamflow in Redwood Creek prorated from Bull Creek gage data.

Table 2-4 drills into the dry-season proration of the Bull Creek discharge and compares it to SRF's flow monitoring data from the last decade. Prorated estimates exceed measurements by an order of magnitude.

Table 2-4. Comparison of measure and prorated monthly average discharges in Redwood Creek during the dry season.

Subwatershed	Area (mi^2)	July (cfs)		August (cfs)		September (cfs)	
		Measured	Prorated[1]	Measured	Prorated[1]	Measured	Prorated[1]
China Creek	3.92	0.20	0.97	0.01	0.44	0.00	0.34
Upper Redwood Creek	3.14	0.29	0.76	0.01	0.34	0.00	0.27
Miller Creek	3.66	0.14	1.02	0.00	0.46	0.00	0.36
Seely Creek	5.84	0.05	1.28	0.01	0.58	0.00	0.45
Entire Redwood Creek watershed	25.94	0.47	5.95	0.03	2.71	0.01	2.10

[1] Flow in Redwood Creek estimated by prorating flow measured in Bull Creek.

Water diversions and other impairments likely play a role in differences between measured and prorated discharge estimates during the summer months. Differences in bedrock geology between the watersheds is also likely an important factor. As described above, Redwood Creek has more claystone and mudstone and less sandstone than occurs in Bull Creek, resulting in typically lower dry-season base flows. Additionally, the measured monthly averages for Redwood Creek are based on only a few measurements and may not accurately represent the monthly average flow, although monitoring results strongly support the overall trend that dry-season flows in Redwood Creek are significantly lower than proration calculations would suggest.

2.5 Land Use and Human Consumptive Water Use

An overview of land ownership in Redwood Creek is shown in Figure 2-14 delineating large ownership from smaller parcels. Large ownerships include California State Park near the mouth of Redwood Creek and several ranch and timber ownerships in the southern portion of the watershed mostly encompassing Somerville and Upper Redwood Creeks. These large ownerships offer unique opportunities for flow enhancement because they have significantly less consumptive water use and provide broader tracts of land to plan, design and implement flow enhancement actions.

Consumptive water use in a portion of Redwood Creek was estimated from a variety of sources during development of the Redwood Creek Flow Enhancement Feasibility Study (Feasibility Study) (Stillwater Sciences 2017). In this report, the approach and data from Stillwater Sciences (2017) has been extrapolated to the entire Redwood Creek watershed. The period from 2016 to 2017 was the peak of cannabis cultivation in the watershed and a reduction in consumptive water use has likely declined as cannabis cultivation has decreased over the past several years. Further, many cannabis cultivators and other landowners have installed a significant volume of water storage over the past decade to comply with regulations and to meet their water needs during the dry season. Based on these factors, the water use estimates presented here may be an overestimate although they are anticipated to be sufficiently accurate for flow enhancement planning purposes.

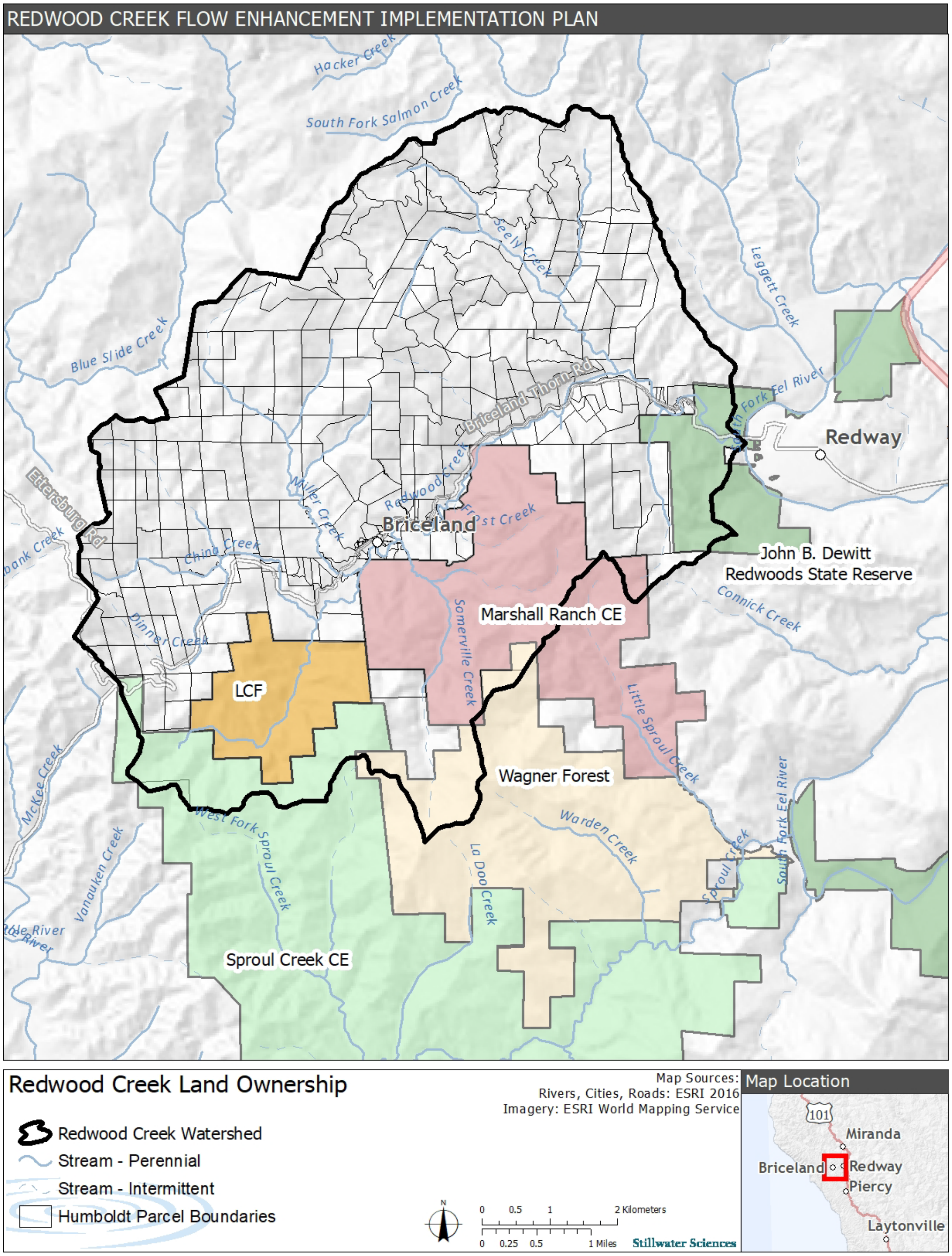

Figure 2-14. Land ownership within the Redwood Creek watershed.

Quantification of consumptive use in Redwood Creek is difficult, as is the case in many rural areas with dispersed water sources and users. The Feasibility Study used several different information sources to estimate water use, including: (1) landowner responses to a water use survey conducted within the study area by SRF, (2) landowner responses from a survey conducted by Sanctuary Forest in the adjacent Mattole River watershed, (3) information reported in Bauer et al. 2015, and (4) new GIS analyses conducted within the study area that estimated water use based on area of agricultural cultivation determined from aerial imagery. Each approach for estimating water use is described below and summarized in Table 2-5.

2.5.1 Landowner responses within the study area

A water use survey was sent to 100 residents within the study area. Response rate was 12%. Based on the 12 responses, average domestic (i.e., household) water use was 102 gallons per day and average irrigation use was 376 gallons per day for a total average water use of 478 gallons per day (Table 2-5). The low response rate and relatively low-resulting estimate of average daily use suggests that many of the larger water users within the study area did not respond, and therefore it may not be appropriate to apply these results more broadly across the entire watershed area. Despite these caveats, the survey provided some interesting findings:

- Half of respondents use a spring as their water source for domestic and irrigation water supply;
- Only 1/3 of the respondents have separate domestic and irrigation water systems;
- Half of respondents are currently forbearing for 3 or 4 months; and
- Water storage capacity varied widely among respondents.

Table 2-5. Consumptive water use estimates.

Water use estimate approach	Estimated water use per parcel (gal/day)	Total water use per parcel during 5-month dry season (gal)
1) Redwood Creek water use survey	478	71,700
2) Upper Mattole water use survey	708	106,200
3) CDFW data for study area (from Bauer et al. 2015, based on 2012 imagery)	725	108,750
4) GIS analyses of study area (based on 2014 imagery)	925	138,750

2.5.2 Landowner responses from adjacent watersheds

A water survey of 40 residents in the upper Mattole River resulted in an average estimated water use of 708 gallons per day during the 6-month dry season (Table 2-5) (Trout Unlimited 2013). Results from this survey are applicable to the Redwood Creek study area, considering that the upper Mattole River is located directly adjacent to and west of the Redwood Creek study area and the Mattole watershed has many of the same physiographic, ecological, and land use characteristics.

2.5.3 Compilation of CDFW data for the Redwood Creek study area

Using the mapping and assumptions of Bauer et al. (2015), Stillwater estimated cannabis-related water use within the Redwood Creek feasibility study area. The approach involved GIS overlay of the study area boundary and mapping from Bauer et al. (2015). Estimates of cannabis irrigation on 77 parcels in the study area averaged 425 gallons per day (excludes parcels serviced with water from the Briceland Community Service District). This included approximately 36,000 ft^2 of greenhouse and 2,200 outdoor cannabis plants. When average domestic use of approximately 300 gallons per day per parcel was added, the average water use determined through this method is 725 gallons per day (Table 2-5). The results of this analysis were generally consistent with results from the upper Mattole River survey.

2.5.4 Updated GIS analysis

Since estimates of water use for cannabis cultivation by Bauer et al. (2015) were based on 2012 aerial imagery, the desktop GIS analysis of water use within the study area was updated based on 2014 aerial imagery. This analysis considered consumptive water use for cannabis cultivation, as well as other land uses (e.g., vegetable gardens and landscaping). Primary results of the analysis include:

- Greenhouse square footage: 53,000 (increase of 17,000 square feet from 2012 to 2014).
- Outdoor cannabis plants: 2,800 (increase of 600 from 2012 to 2014).
- ~5.6 acres of vegetable gardens, orchards, and vineyards that weren't included in the CDFW analysis.

Estimated water use (gallons per day) was then updated using these data and the following assumptions:

- Input from cultivators suggests cannabis plants in greenhouses typically require 3 gallons per day (lower than that estimated by Bauer et al. [2015]).
- Cultivation of outdoor cannabis plants typically requires 6 gallons per day per, a relatively high estimate that accounts for inefficiencies evident in many irrigation systems.
- For other irrigated areas the following formula was used:

(Eto x PF x SF x 0.62) / IE =Gallons of Water per day[1]

Where:

> Eto = ET factor. Taken from http://www.rainmaster.com/historicET.aspx and using zip code 95553 a value of 0.16 is obtained.
>
> **PF** = plant factor. Typically, a value of 1.0 is used for lawn 0.80 for water loving shrubs, 0.5 for average water use shrubs, and 0.3 for low water use shrubs (0.5 was used).
>
> **SF** = irrigated area (square feet).
>
> **0.62** = constant.
>
> **IE** = irrigation efficiency factor. This value compensates for irrigation water that isn't used by the plant. Efficient sprinkler systems with little run-off can have efficiencies of 80%. Drip irrigation systems typically have efficiencies of 90%. (A value of 0.75 was used to account for general leakage and inefficiencies seen in most rural water systems).

Based on these assumptions and calculations, the average water use per parcel was estimated as 625 gallons per day for irrigation. Irrigation for cannabis cultivation accounts for 66% and non-

[1] http://www.irrigationtutorials.com/how-to-estimate-water-useage-required-for-an-irrigation-system/

cannabis irrigation accounts for 34% of total estimated irrigation use. When domestic use of 300 gallons per day is included, the total estimated water use per parcel increases to 925 gallons per day (Table 2-5). Over the 5-month dry season, this equals 93,750 gallons of irrigation water and 45,000 gallons of domestic water.

Given the uncertainties in these calculations, 1,000 gallons per day per parcel was conservatively used as the estimate for total water use within the feasibility study area during the 5-month dry season (Stillwater Sciences 2017). During the seven wetter months of the year, it was assumed that per-parcel water use consisted only of domestic water uses based on estimates above (300 gallons per day). Based on these estimates, total water use in the watershed is shown in Table 2-6. In summary, annual human consumptive use is estimated at 225 ac-ft.

Table 2-6. Consumptive water use estimates by subwatershed.

Subwatershed	Subwatershed area (mi^2)	Number of parcels	Total estimated water use per sub-shed during 5-month dry season (ac-ft)*	Total estimated water use per sub-shed during additional 7 months (ac-ft)**	Total annual water use per sub-shed (ac-ft)
China Creek	3.9	58	26.7	11.5	38.2
Upper Redwood Creek	3.1	24	11.0	4.8	15.8
Miller Creek	3.7	46	21.2	9.1	30.3
Somerville Creek	3	18	8.3	3.6	11.8
Seely Creek	5.8	61	28.1	12.1	40.2
Redwood Creek (lower mainstem)	6.4	134	61.7	26.5	88.2
Entire Redwood Creek Watershed	25.9	341	157.0	67.5	224.5

* Based on estimate of 1000 gal/day/parcel over 5-month dry season
** Based on estimate of 300 gal/day/parcel over 3.5-month diversion season

2.5.5 State Water Board water use reporting data

The State Water Board's EWRIMS website contains records of all water rights and reported water use. Human consumptive use water demand is mainly during the dry season (Riparian Water Rights), with the exception of Appropriative Water Rights users that fill up storage during the wet season. Water users with Riparian Water Rights typically use very small amounts of water in winter for domestic use because they are not legally allowed to divert water during the winter and store it for use in the summer.

A water rights records search of the Redwood Creek watershed was conducted to determine the existing water demand by both appropriative and riparian rights. Diversions covered by appropriative water rights were quantified using their stated annual diversion volume in ac-ft. Since riparian rights do not have a specified annual diversion volume, annual reports submitted between 2011 and 2020 were obtained for all Statements of Diversion and Use. The maximum reported annual diversion volume for that period was then used in determining riparian right diversions within the watershed. The results of this records search are summarized in Table 2-7 and include a total reported annual water use of 87.3 ac-ft. Note that this is approximately 40% of the total water use estimated in Table 2-6 above, accounting for the fact that many landowners in Redwood Creek do not report their water use.

Additional details related to registered diversions are presented in the Marshall Ranch Water Availability Analysis (Stillwater 2022). A map with all registered water users is shown in Figure 2-15.

Table 2-7. Consumptive water use estimates by subwatershed based on State Water Board reporting.

Subwatershed	Subwatershed Area (mi^2)	# Appropriative water rights	# Riparian water rights	Demand Volume of Appropriative Water Right Diversions (ac-ft/yr)	Annual Riparian Diversion Volume (max reported 2011–2020 ac-ft/yr)
China Creek	3.9	13	22	13.1	5.4
Upper Redwood Creek	3.1	1	2	0.2	0.6
Miller Creek	3.7	7	21	7.3	17.6
Somerville Creek	3.0	2	3	0.5	1.4
Seely Creek	5.8	14	19	8.8	5.6
Lower Redwood Creek	6.4	15	22	21.7	5.1
Entire Redwood Creek Watershed	25.9	52	88	51.6	35.7

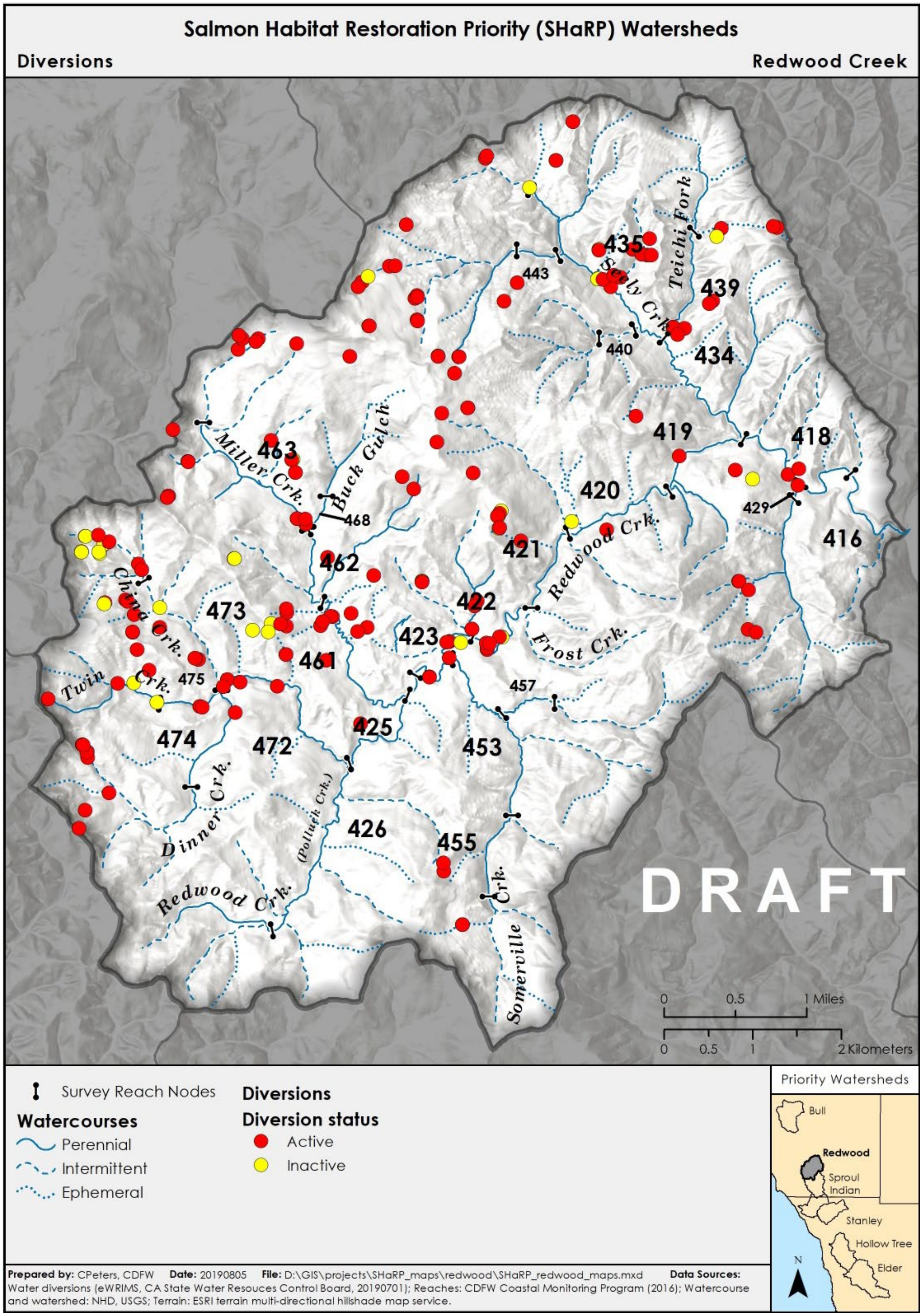

Figure 2-15. Registered Points of Diversion within the Redwood Creek Watershed (figure courtesy of CDFW).

2.6 Evapotranspiration

A significant portion of basin precipitation returns to the atmosphere through evaporation and transpiration from vegetation. It is difficult to quantify the actual ET rates at the watershed scale, but the ET potential has been estimated by the California Irrigation Management Information System (CIMIS) developed by Department of Water Resources and UC Davis[2]. The reference ET rate is the rate at which water evaporates and transpires from a well-watered reference grass crop. According to CIMIS, the Redwood Creek watershed has an average annual reference ET of 46.3 inches per year. However, the actual ET rate in the Redwood Creek watershed is substantially less because the watershed does not have unlimited soil moisture during the dry season and the vegetation is comprised of conifer forest, oak woodlands, shrublands, grassland and some agriculture all of which use less water than the reference grass crop.

ET can be estimated by calculating the annual water balance for a watershed and assuming that ET is the difference between inputs (precipitation) and outflow (discharge out of the watershed and human consumptive use). Based on this analysis, annual ET for the watershed is estimated to be approximately 20,437 ac-ft or approximately 15 inches per year across the entire Redwood Creek watershed.

2.7 Water Balance

Figure 2-16 depicts the water balance in Redwood Creek based on the analyses and data presented in Sections 2.4 to 2.6 above. The estimated ET and runoff are approximately 100 and 300 times greater respectively than the human consumptive use. This comparison of ET and human consumptive use is consistent with recent studies in Russian River tributaries that found ET to be 15 to 160 times greater than human consumptive use (Kobor and O'Connor 2021). This comparison highlights the need to explore opportunities for flow enhancement activities that retain runoff and reduce ET. However, during the peak of the dry season when flows are lowest, human consumptive use certainly has measurable impact on streamflow, even though it constitutes approximately 0.2% of the overall water balance.

[2] https://cimis.water.ca.gov/Default.aspx

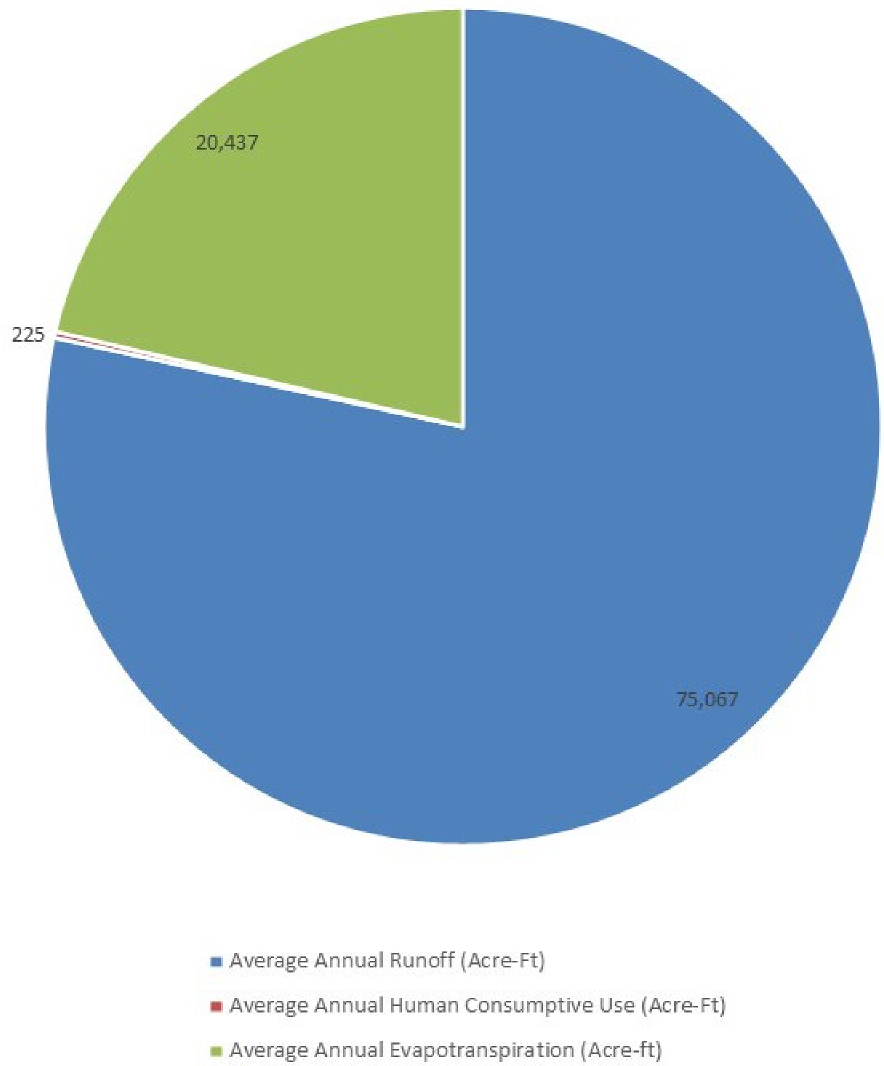

Figure 2-16. Approximate water balance for Redwood Creek, assuming 95,726 ac-ft of average annual precipitation.

2.8 Fish Distribution

The primary goal of flow enhancement actions is to improve conditions for Coho salmon and steelhead, so understanding their distribution throughout the watershed is critical. CDFW summarized salmonid species distribution within the Redwood Creek watershed (Figure 2-17) (NMFS and CDFW 2017). Coho and Chinook are generally limited to similar extents throughout the watershed, while steelhead occupy more upstream, headwater habitats due to their superior ability to migrate through channels with steeper gradient and higher flow velocities. This disparity is most pronounced in the headwaters of Seely, Somerville, Miller, and Redwood Creeks, where steelhead distribution extends 0.75 to 1.5 miles upstream of Coho and/or Chinook distribution. While steelhead and Coho juveniles over-summer in the watershed, juvenile Chinook typically out-migrate by June, and so are unlikely to benefit from dry-season flow enhancement in most years.

The effects of individual flow enhancement projects will likely have a finite range of influence within the watershed, with benefits attenuating with distance downstream from the project site due to ET losses. As such, project location with respect to fish distribution is an important consideration. For example, projects situated farther upstream in the watershed are likely to realize greater habitat benefits for steelhead. Continued monitoring of salmonid distribution throughout the watershed will help inform if and how populations respond to flow enhancement projects.

In the summer of 2022, Stillwater conducted snorkel surveys within approximately one mile of mainstem Redwood Creek near Briceland with the primary goal of characterizing pre-project fish distribution and abundance associated with the Marshall Ranch project (Table 2-8). The survey showed Coho and steelhead within the surveyed reach, with minimal mortality between the August and September survey dates. Additional surveys are planned over the next five years to further develop an understanding of salmonid population dynamics. In addition to fish abundance surveys, an assessment of trends in fish growth and health would be a valuable metric to better understand how dry-season flows and associated water quality impact fish and to optimize the benefits of flow enhancement projects.

Table 2-8. 2022 Redwood Creek mainstem snorkel survey results. Italicized numbers represent estimated ranges based on counting fish in poor visibility.

Reach	Pool type	Coho (age-0)		Steelhead (age-0)		Steelhead (age-1+)		Pikeminnow/Roach (juv)	
		2-Aug	13-Sep	2-Aug	13-Sep	2-Aug	13-Sep	2-Aug	13-Sep
Lower	Flatwater	0	0	2	2	0	0	1	0
Lower	Scour	25	44	24	20	0	1	75	70
Lower	Flatwater	2	2	2	4	0	2	25	0
Lower	Scour	203	158	65	48	2	2	250	220
Lower	Scour	22	23	17	14	0	0	100	40
Lower	Flatwater	12	6	20	4	1	0	40	10
Middle	Scour	70	*10–100*	30	*10–100*	2	*unk*	400	*100–500*
Middle	Scour	22	*1–10*	18	*1–10*	0	*unk*	150	*10–100*
Middle	Flatwater	3	2	8	9	0	0	25	20
Middle	Scour	60	*100–250*	25	*10–100*	3	*unk*	600	*500–1,000*
Middle	Flatwater	3	0	2	3	0	0	20	0
Middle	Mid-Channel	70	*100–200*	26	*10–100*	3	*unk*	800	*500–1,000*
Upper	Flatwater	2	0	6	0	0	0	1	1
Upper	Scour	6	3	11	12	0	0	15	30
Upper	Scour	13	14	2	6	0	0	40	20
Upper	Flatwater	0	0	0	0	0	0	0	0
Upper	Scour	26	35	8	4	0	0	350	350
Upper	Mid-Channel	46	48	19	28	1	2	120	120
Upper	Mid-Channel	18	11	5	3	0	0	75	75

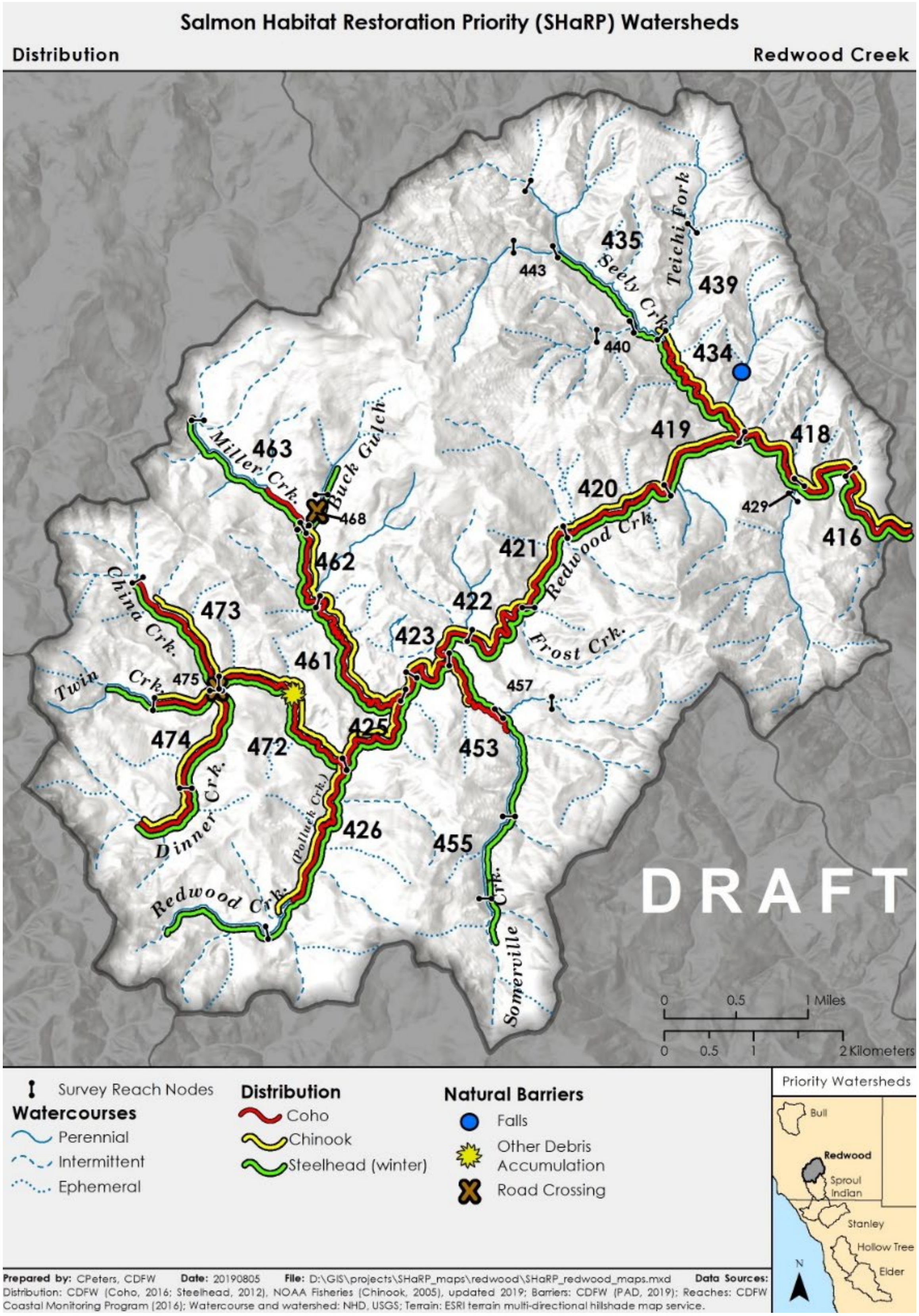

Figure 2-17. Fish distribution within the Redwood Creek Watershed (figure courtesy of CDFW).

2.9 Summary of Hydro-Geomorphic Field Assessment

A preliminary assessment of select stream reaches within the Redwood Creek watershed was conducted in late September 2019 and early November 2020. The assessment was aimed at providing a broad overview of flow conditions, including mapping dry reaches, general channel morphology and substrate type, aquatic habitat condition, and restoration potential within the accessed reaches. In both years, the assessment was scheduled to observe mainstem Redwood Creek and key tributaries during the lowest flow conditions of the season. Assessments were primarily conducted on private property where access permission was gained through landowner outreach, except for a portion of the Redwood Creek mainstem within the John B. Dewitt Redwoods State Natural Reserve.

The weather station closest to the Redwood Creek watershed is approximately three miles to the east of Briceland, near Redway. Identified as Eel River Camp, it recorded a total of 64.6 inches of rain in the 2019 water year, and 30.1 inches in 2020. PRISM estimates of these same water years near Briceland are 96.4 inches and 44.7 inches, respectively. The PRISM estimate of the 30-year average rainfall for the Briceland area is 77.7 inches. The large difference in annual precipitation between the 2019 and 2020 water years is likely to have accounted for the significantly drier conditions observed in Upper Redwood Creek during the 2020 surveys, as compared to those observed in similar reaches during the 2019 surveys.

In 2019, a total of 3.24 miles of the Redwood Creek mainstem were surveyed in eight different segments between the confluence of China Creek on the upstream end, and downstream to the mouth of Redwood Creek at the South Fork Eel River. Segments of four tributaries were also surveyed, totaling 4.6 miles. The tributaries included Dinner Creek, China Creek, Somerville Creek, and Seely Creek. The field effort was completed between September 30th and October 4th. A map of all surveyed reaches is shown in Figure 2-18. Dry stream channel segments observed during the effort were recorded using GPS and are indicated on the map. Observed dry reaches were limited to Dinner Creek and one of its tributaries, whereas all other streams were found to be continuously wetted. As described in Section 1.2.1 above, 2019 had the highest dry-season flows of the last decade, so the dry-season reach mapping does not accurately describe conditions in typical or dry years which constitute nine of the last ten years.

In 2020, additional access was gained to a large tract of timberland owned by Lost Coast Forestlands, LLC (LCF), which encompasses much of the Upper Redwood Creek watershed. A total of 2.1 miles of Redwood Creek and 1.6 miles of five different tributaries were surveyed within this tract during the 2020 effort. The assessment began at the downstream LCF property boundary, approximately 900 feet upstream from the confluence with China Creek and the upstream end of the 2019 assessment. A map of all surveyed reaches is shown in Figure 2-19. Flows during the 2020 dry season followed the "decadal average" declining limb of the hydrograph but there was no measurable precipitation in September or October (Figure 2-5) ensuring that flows in Upper Redwood Creek were extremely low between November 9 and 11 when the survey was conducted. All surveyed stream reaches were either completely dry or had intermittent disconnected pools.

During the field assessment, few dry-season water sources such as springs, seeps, or small tributary inputs were identified within the surveyed reaches, although there are likely some minor groundwater inputs scattered throughout the watershed that were not visible during the dry season. For most reaches, base flow sources were coming from headwater springs beyond the extent of the survey. These headwater springs typically daylight along the hillslopes of steep and forested Coastal Belt terrane with the ridgetops acting as a water tank that captures winter precipitation and meters it out slowly during the dry season. These source areas have been generally identified in Figure 2-20 and should be one of the early targets for forest thinning and headwaters storage and forbearance.

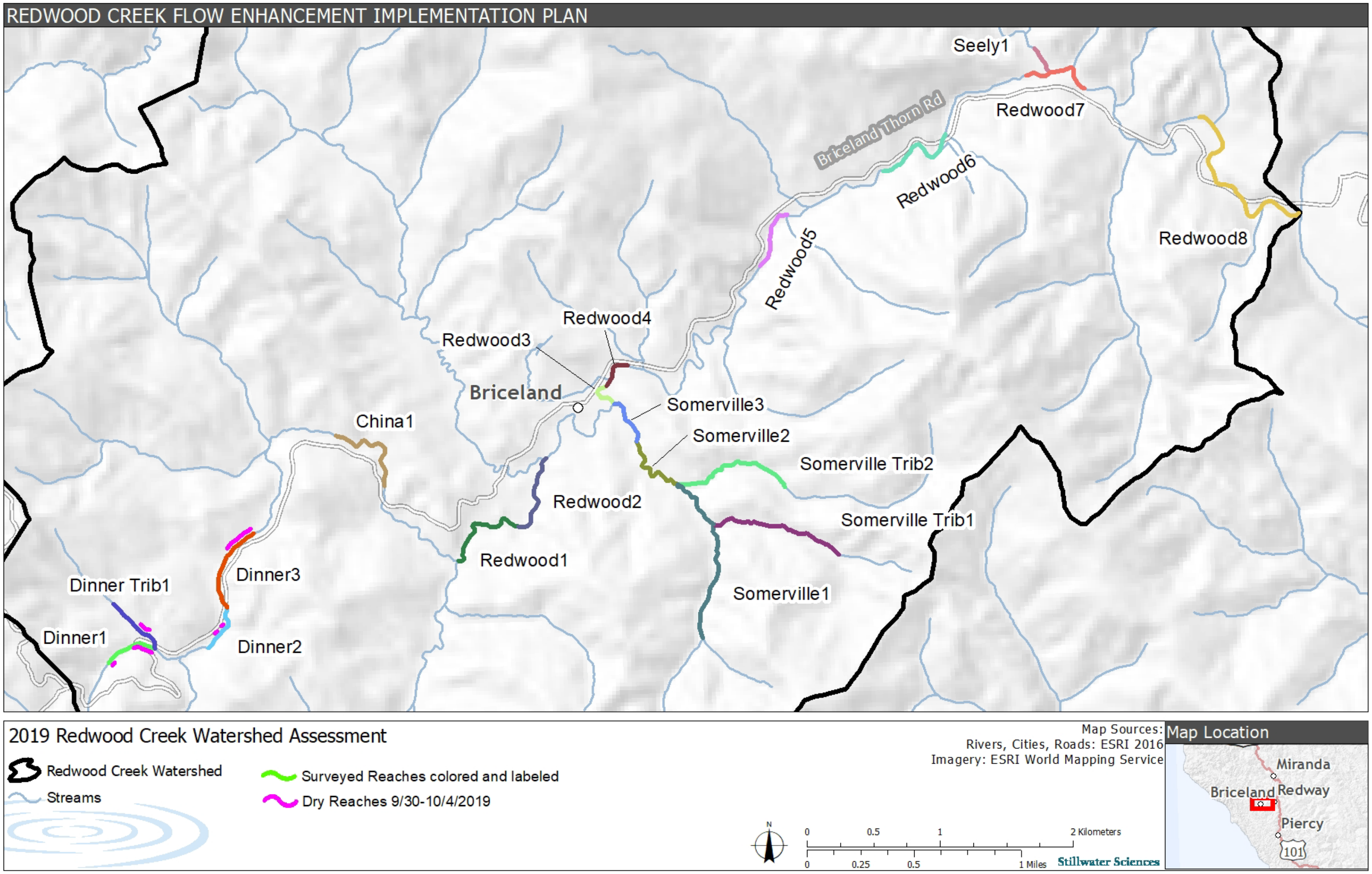

Figure 2-18. Map showing stream reaches surveyed in the 2019 watershed assessment. Dry reaches are indicated by a pink color.

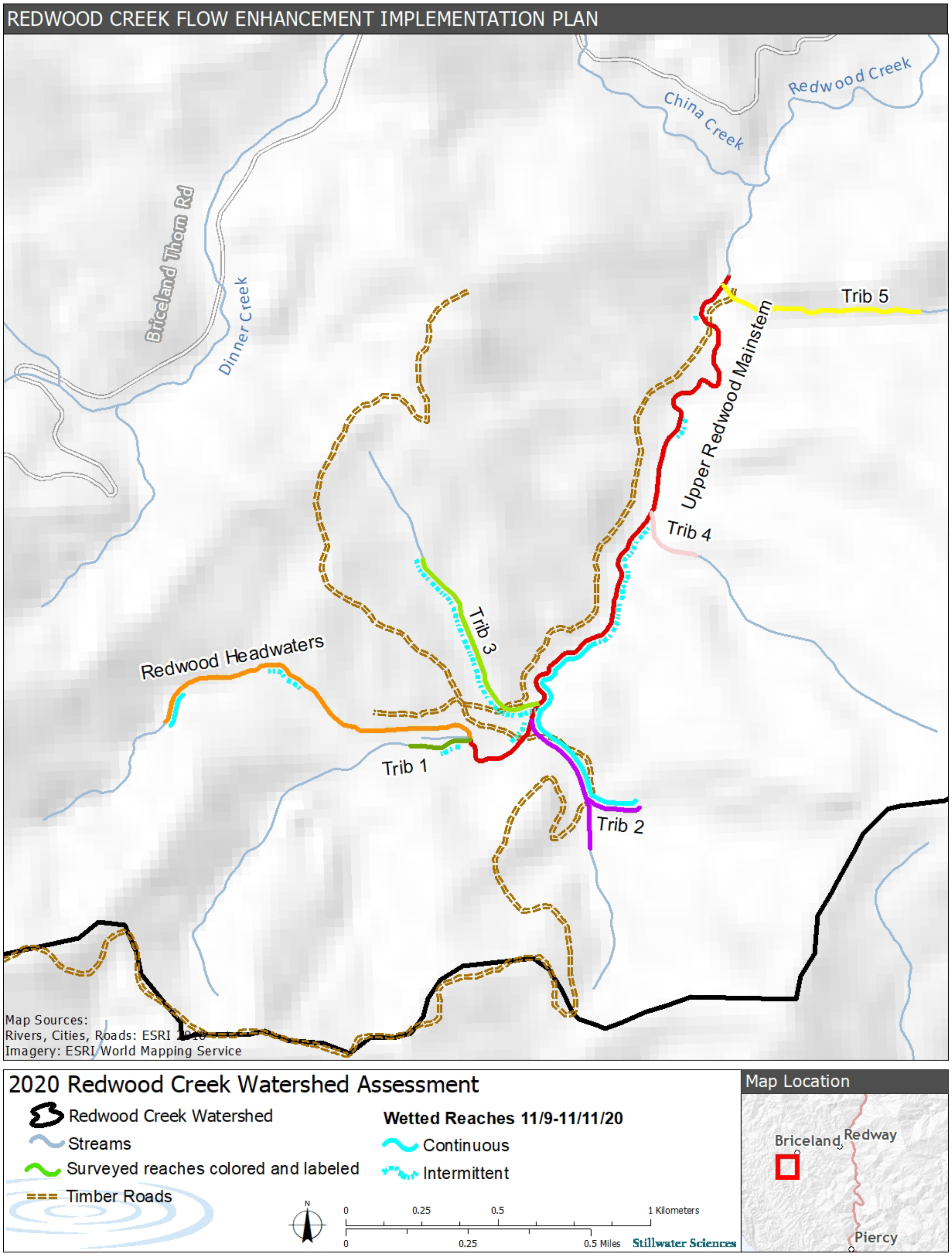

Figure 2-19. Map showing stream reaches surveyed in the 2020 watershed assessment. Wetted reaches are delineated by solid or dashed, light blue lines, indicating continuous and intermittent wetted reaches respectively. All other surveyed reaches were dry.

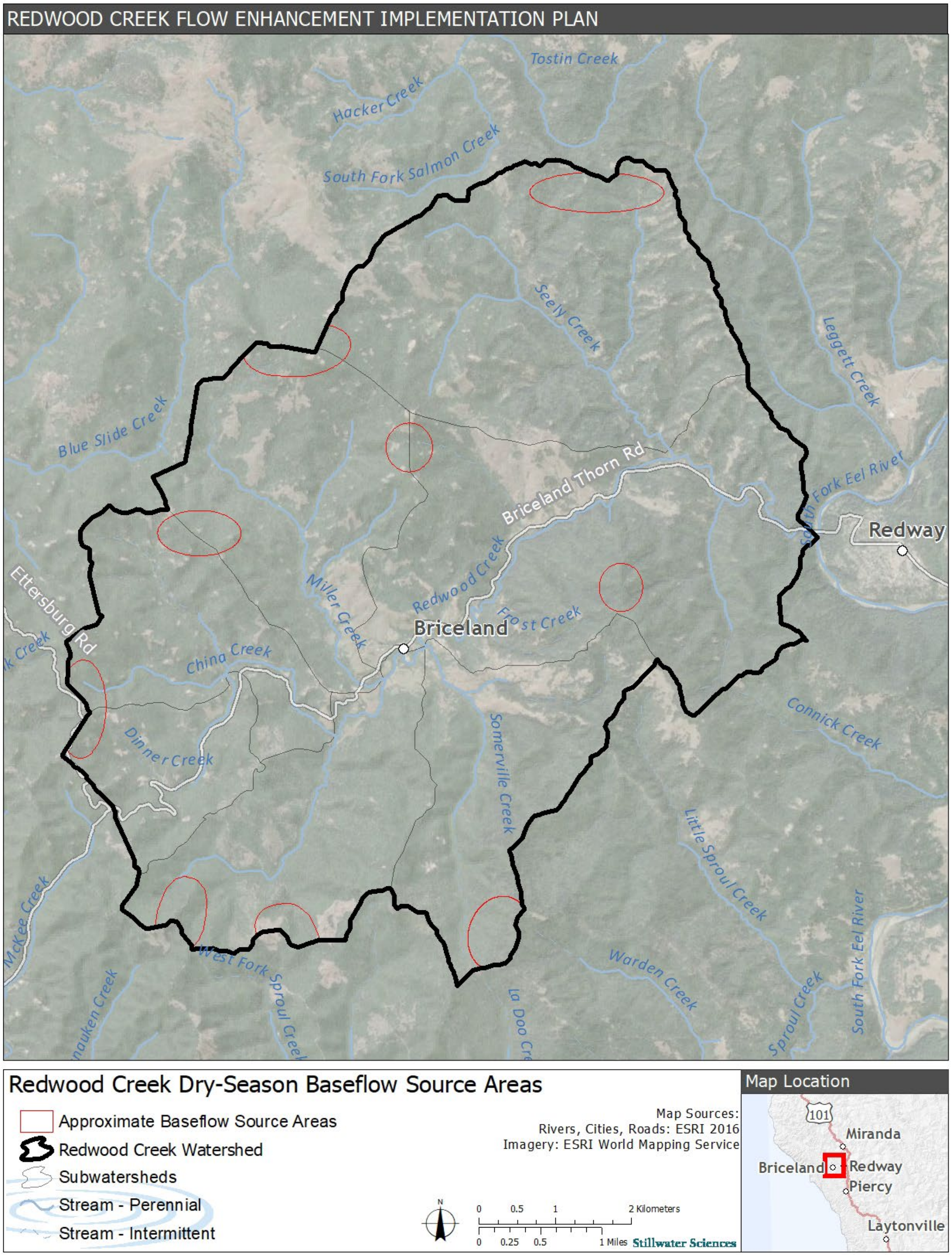

Figure 2-20. Generalized map showing primary dry-season base flow source areas comprised of steep forested ridgetops underlain by sandstone bedrock terrane.

3 IMPLEMENTATION APPROACHES TO ENHANCE DRY-SEASON FLOW

Based on dry-season conditions, flow enhancement objectives, and watershed characteristics described above, there are multiple approaches to enhance dry-season flows in Redwood Creek. To achieve flow enhancement benefits, specific actions must be taken to change the dynamics of groundwater and surface water flow out of the watershed, thereby changing the hydrograph.

3.1 Flow Enhancement Conceptual Model

Four types of flow enhancement approaches are explored in this report, each of which are described in detail in Sections 3.2–3.5:

1. Storage and forbearance;
2. Direct flow augmentation;
3. Runoff detention and passive release; and
4. ET reduction through forest management.

To maximize flow enhancement benefit, the application of each approach should consider the interaction with hillslope hydrologic processes. Eel River Critical Zone Observatory (ERCZO) studies have illuminated connections between hillslope hydrology and aquatic ecosystem functions within California's north coast region (Dralle et al. 2022). The generalized cross section in Figure 3-1 depicts a conceptual model of hillslope hydrologic processes developed by Rempe and Dietrich (2018). The four flow enhancement approaches have been added to the ERCZO cross section to conceptualize how each approach fits within the watershed hydrologic process.

Each of these flow enhancement approaches is expected to alter the current hydrograph in different ways as shown in Figure 3-2, moving the "enhanced" hydrograph toward unimpaired condition. Storage and forbearance and direct flow augmentation projects impact the hydrograph similarly by storing water during the wettest period of the year and enhance flow during the driest period, albeit with varying magnitudes. Forest thinning and runoff detention with passive release are expected to primarily provide flow enhancement benefit during the declining limb of the hydrograph. A combination of multiple flow enhancement activities distributed throughout the watershed will be needed to achieve measurable and meaningful flow enhancement benefits throughout Redwood Creek. A conceptual example of how these actions would be distributed throughout a subwatershed is demonstrated in Figure 3-3.

Typically, forest management treatments are located in upslope and upstream areas, flow augmentation ponds are sited on flat terrain in the upstream portions of the watershed to maximize downstream aquatic habitat benefit, and storage and forbearance infrastructure targets areas with human consumptive use adjacent to stream reaches hosting critical aquatic habitat. Runoff detention approaches can be more widely disbursed throughout the watershed. Upslope road, gully and retention pond treatments reduce runoff rates and increase infiltration and groundwater recharge within the hillslopes. Channel grading, weirs, and clay barriers in small watercourses can slow water down and increase available aquatic habitat. Similarly, wood structures in mainstem reaches provide habitat diversity, increase flow onto floodplains during storms, and can also raise the local groundwater level.

A site-specific, long-term flow enhancement implementation plan for Redwood Creek incorporating many of these approaches is described in Sections 4 and 5. It is anticipated that multiple stacked flow enhancement projects will collectively slow the flow of water out of the watershed through detention and storage. Many of the techniques proposed herein are new and innovative, with pilot projects underway or beginning in Redwood Creek and the Mattole River watersheds that will inform future flow enhancement planning, design and implementation actions.

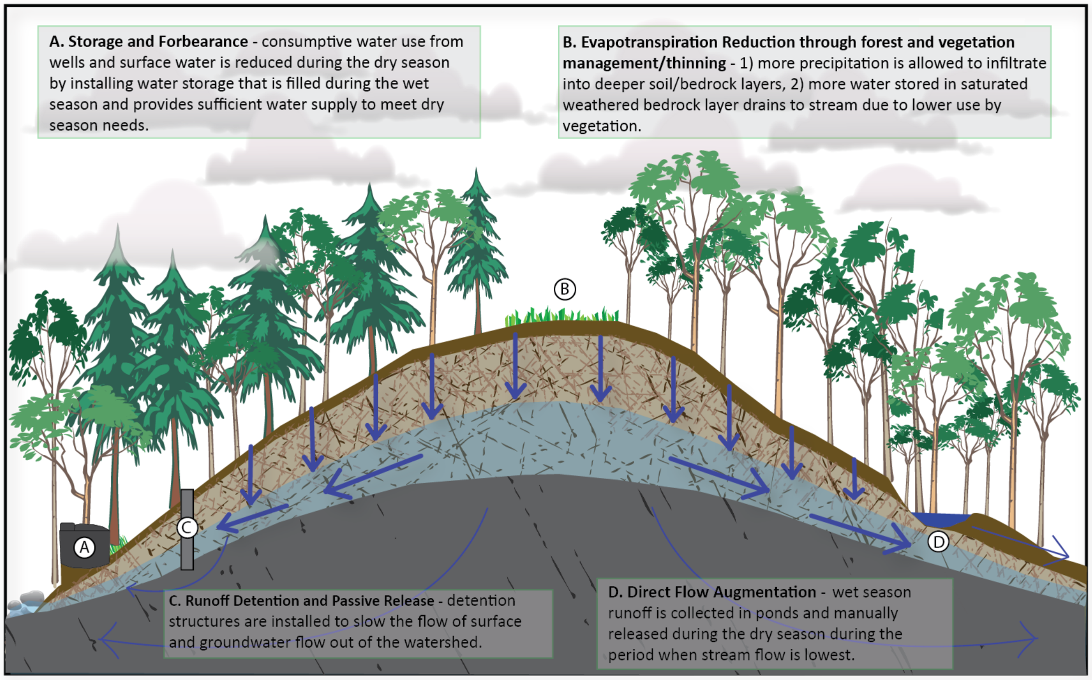

Figure 3-1. Flow Enhancement Conceptual Model adapted from the Eel River Critical Zone Observatory, presented by Rempe and Dietrich (2018).

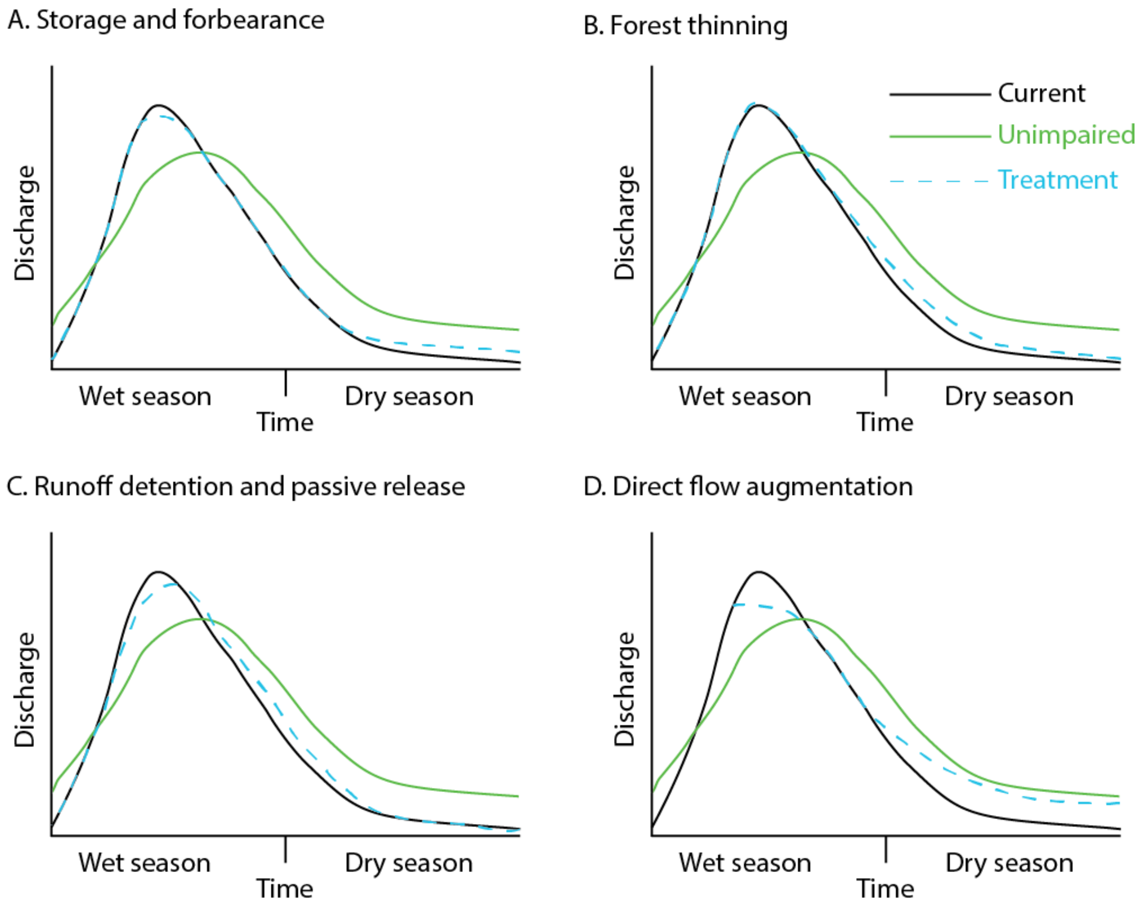

Figure 3-2. Conceptual hydrograph impacts from flow enhancement approaches.

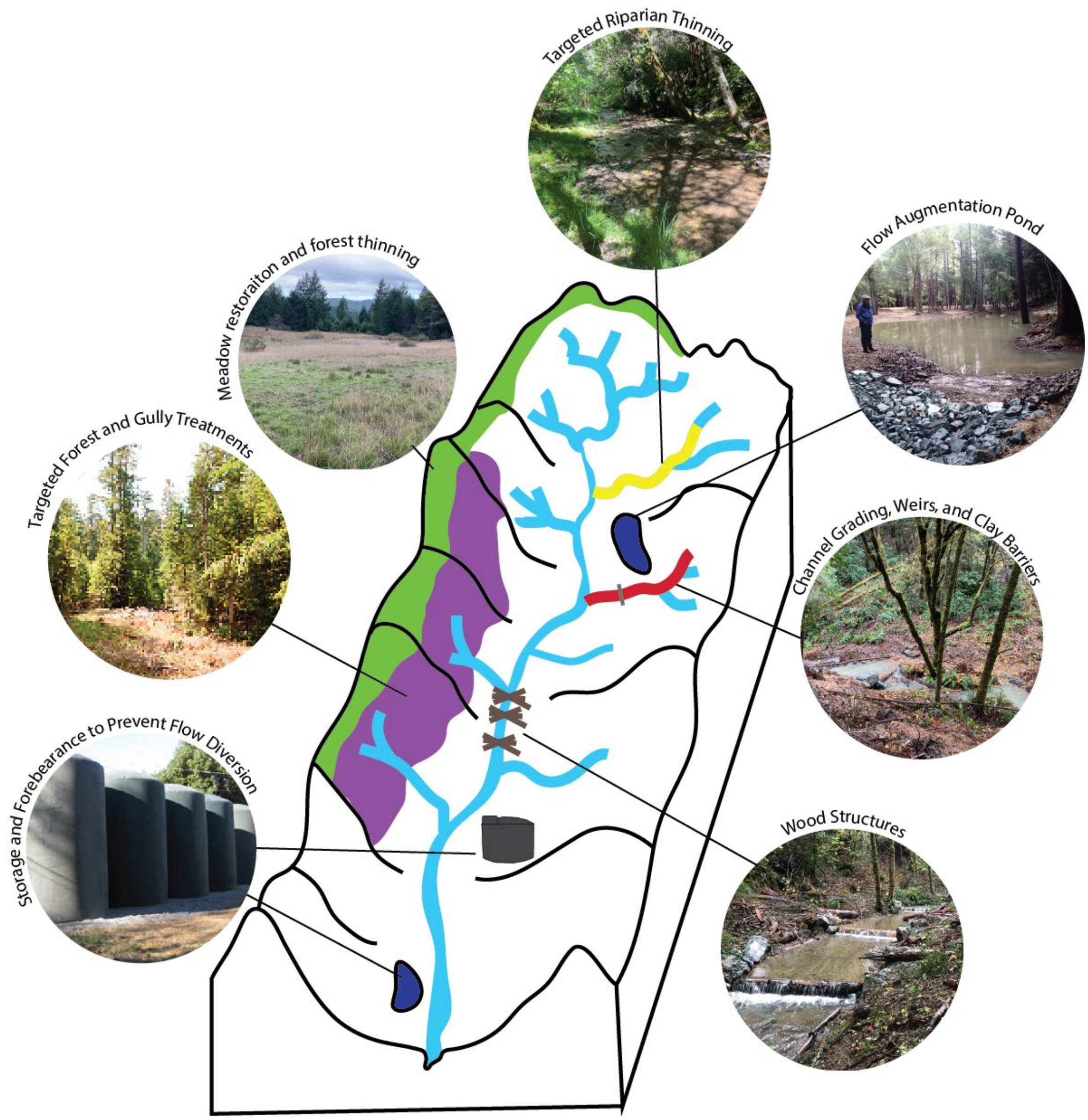

Figure 3-3. Flow Enhancement approaches within the watershed context.

3.2 Storage and Forbearance

Storage and forbearance projects enable landowners to forbear from diverting water during the dry season by providing them with a water storage system that has sufficient capacity to supply their needs during the dry season. Each landowner is educated on how to operate the water storage system, including water use reductions through conservation and leak proofing, along with guidelines for habitat protection while filling and topping off their tanks. Each landowner signs a legally enforceable forbearance agreement with restrictions that protect aquatic habitat, including the following: (1) minimum streamflows below which no pumping is allowed, (2) maximum pumping rates and bypass flows, (3) assigned pumping days to minimize cumulative impacts, and (4) pump intake screens that comply with CDFW and NMFS criteria.

Typically, storage and forbearance programs focus on reducing direct diversion from mainstem creeks. However, to be effective in parts of Redwood Creek, storage and forbearance actions will need to reduce dry-season human consumptive use from spring diversions and wells. There are no mapped groundwater basins in the vicinity of Redwood Creek (California Department of Water Resources 2019). Groundwater dynamics in Redwood Creek are like those throughout much of the north coast region—shallow groundwater tables perched on top of shallow bedrock that are filled seasonally with precipitation during the wet season and drain during the dry season as demonstrated in Figure 3-1. At some locations, groundwater persists through the dry season along the bedrock-soil interface or within bedrock fractures. However, in this setting it is likely that most groundwater withdrawals during the dry season impact nearby surface water, considering the interconnectivity of the hillslope hydrologic process shown in Figure 3-1. Therefore, storage and forbearance in Redwood Creek should address direct diversions from creeks, springs, and groundwater wells.

Sanctuary Forest and the community in the Mattole River headwaters have pioneered a storage and forbearance program with funding from CDFW and other agencies. By 2014, 32 households and institutions were participating in seasonal forbearance along the Mattole mainstem, resulting in measurable improvements in streamflow (Klein 2017). More recently, Sanctuary Forest has expanded the storage and forbearance program to Mattole River tributaries that are also experiencing low flows during the dry season.

Sanctuary Forest has developed a relatively streamlined permitting and compliance approach for their storage and forbearance program that consists of three agreement and permits:

1. Forbearance agreement;
2. Small Domestic Use Registration with SWRCB; and
3. LSAA Agreement with CDFW.

The forbearance agreement is recorded on the landowners' property title and results in legally binding and enforceable restrictions for 15 years in which direct diversion riparian rights are limited to seasons with adequate flows. The landowners' existing or new Small Domestic Use Registration allows for storage of longer than 30 days. Additionally, CDFW terms and conditions to protect bypass flows and instream habitat are incorporated in the modified water right. Finally, the landowner enters into an LSAA agreement with CDFW that incorporates all of the protections and restrictions of the forbearance agreement and the water right.

Planning and design work includes community outreach to achieve landowner participation, development of a Water Management Plan for each property including type, size, and location of water storage features; trench layout (requiring archaeology and botany site clearance first); system components needed to connect storage to existing system; leak safety and controls; and participant cost share tasks and responsibilities. After the project is designed, permitting is completed through the pathway listed above.

Next, the plumbing and water storage system is constructed including site preparation; tank and/or pond installation; trenching and piping from storage to house; pressure pump and small pressure tank installation if needed; plumbing and electrical hook-ups; meter installation; CDFW/NOAA-compliant fish screen installation; and filtration system installation. The filtration system prevents deterioration of stored water.

As built drawings along with operating instructions are prepared upon completion of each system. System review with the landowners including a site walk through to explain all parts of the water system including operational controls, leak safety controls, and winterizing tasks.

SRF and Stillwater currently have funding to begin a storage and forbearance program in Redwood Creek modeled after Sanctuary Forest's program. The program will be initiated in early 2023 with planning, design, and construction for five properties near the town of Briceland (described in more detail in Sections 4 and 5 below).

3.2.1 Operations and maintenance considerations

The storage systems are designed and constructed with high quality materials with the goal of being as maintenance-free as possible for the first 25 years of operations. However, the landowner will be responsible for standard operations and maintenance (O&M) which includes filling the tanks during the wet season and performing standard yearly maintenance.

As part of the Redwood Creek Storage and Forbearance Program, SRF and Stillwater will develop instream flow thresholds that trigger both the restricted pumping season and the no-pump season. SRF will continue to monitor streamflow in Redwood Creek and inform storage and forbearance participants by email and phone regarding the diversion schedule and restrictions.

Compliance monitoring by SRF will include a minimum of one site visit and one phone contact per year. Spring monitoring will occur by phone and ensure that water system maintenance has occurred, all conservation systems are in place for the low-flow months, and that tanks are properly topped off prior to the dry season. Fall monitoring will include a site visit to determine if objectives are being met by reviewing water meter records. Spot monitoring during the dry season will also be an option.

Anticipated emergencies include leaks or other equipment failures. All systems will be outfitted with leak safety devices; however, emergencies could still occur. Leaks will be handled by providing replacement water or managing a safe refilling plan. Adaptive management will help refine the seasonal water management program for maximum compliance and workability.

3.3 Direct Flow Augmentation

Direct flow augmentation is achieved by capturing runoff in ponds during the wet season and releasing the water during the late spring recession and dry season via pipes and valves to supplement flow. These types of projects require gently sloped and stable terrain to achieve significant storage volumes. Ideally, direct flow augmentation projects would be located just upstream from reaches expected to have abundant steelhead and Coho salmon rearing in the summer. Recent flow enhancement initiatives in lower Russian River tributaries have demonstrated that direct augment can be highly successful at enhancing dry-season streamflow. Flow releases from agricultural ponds in Green Valley Creek and Porter Creek began in 2015 have resulted in significant instream benefits (Grantham et.al. 2018, RRCWRP 2019). Data shows that flow augmentations in all years from 2015–2018 were able to appreciably increase wetted channel habitat, increase dissolved oxygen in the stream, and decrease water temperature downstream from the flow augmentation release points Ruiz (2019). For example, releases into Dutch Bill Creek averaging 36 gpm beginning in late August of 2015 were able to cumulatively re-wet more than 2,300 feet of stream channel, with effects measurable up to 1.8 miles downstream. While modest compared to winter flows, these augmentations have the potential to increase pool connectivity and water quality. A foundational hypothesis—that increased pool connectivity will bolster over summer survival of juvenile salmonids—is strongly supported by the work of Obedzinski et al. (2018). Their study found that days of disconnected surface flow showed a strong negative correlation with juvenile Coho salmon survival rate in four tributaries to the Russian River.

In Redwood Creek, direct flow augmentation projects are being considered in two settings: (1) repurposing of existing on-stream ponds and (2) newly constructed off-stream ponds. On-stream ponds are located directly on the stream and affect flow velocity and sediment transport, while off-stream ponds are located away from streams and are filled by rainfall and diverted flow. Ponds used for direct flow augmentation typically need to have significant water storage capacity to offset the impacts of evaporation loss, high water temperatures, and nutrient loading that can occur in small ponds. Typically, a minimum pond volume of one million gallons is considered appropriate for direct flow augmentation although ponds can be smaller depending on their setting and the size of watercourse that the flow augmentation is targeting. There are several on-stream ponds within the Redwood Creek watershed where repurposing for direct flow augmentation is underway or proposed. These are discussed further in Sections 4 and 5 below. Direct flow augmentation projects require a water right if surface water is diverted or detained from a watercourse. A Small Domestic Use Registration may be used if the total diversion is less than 10 ac-ft and there is a human residence or dwelling within the vicinity of the project. Otherwise, a full Appropriative Water Right is needed.

Suitable locations for new off-stream ponds in Redwood Creek are limited based on topographic, geologic, and infrastructure constraints—much of the Redwood Creek watershed is comprised of steep terrain and the flatter locations are inhabited or bisected by roadways. Stillwater has assessed many pond locations throughout the watershed. Currently, the highest priority target areas for off-stream ponds are located on terraces near existing watercourses. These sites have several advantages compared to upslope sites:

1. Low-lying terraces are the largest low-gradient areas within the watershed thus requiring the least amount of earthwork to construct ponds;
2. Terrace ponds can be filled with rainfall and gravity fed diversions from nearby watercourses; and
3. Flow releases are delivered directly to a watercourse where benefits are immediately realized.

Upslope or ridgetop pond sites have also been considered and several suitable locations have been identified, as described in Sections 4 and 5. However, due to the three considerations described above, ponds on near-stream terraces are considered a higher priority for Redwood Creek at this time.

Pond construction requires extensive excavation and placement of an earthen berm. The berm will then be raised in one-foot lifts and compacted with a vibratory sheepsfoot roller. The ponds are sealed either with a High-Density Polyethylene (HDPE) liner, naturally occurring clay soils, or imported bentonite clay. In general, the naturally occurring soils in Redwood Creek are porous and do not hold water on their own, although there are some locations within the watershed that do have a high clay content. The use of bentonite clay to construct an impervious restrictive barrier or keyway within and underneath the pond berm is an approach that is currently being piloted in the Mattole River headwaters. This method has been used in other settings for levee and dam repairs. The keyway approach works well at locations where the native soil already has some clay and the proposed pond site is located in naturally concave topography allowing for the keyway to tie into bedrock on both extents of the pond berm. This technique is described further in Section 3.3.3 below. HDPE liners are the best approach to seal ponds at locations with highly porous underlying soils and/or on terraces where the pond berms do not tie into the hillslope. All ponds will have spillways engineered to withstand 100-year storm events, armored with small rock, and located on native ground (rather than within the berm). All disturbed soil is mulched and seeded with native grass.

At this time, new onstream ponds are not proposed within Redwood Creek. Onstream ponds have several issues that make them a lower priority including: 1) sediment supply capture/disruption, 2) higher risk of failure during storm events, 3) permanent habitat conversion, and 4) permitting difficulty. However, depending on the results of the flow enhancement actions proposed herein and ongoing climatic trends toward longer dry seasons, new onstream ponds may need to be considered in the future to provide sufficient flows for aquatic habitat.

3.3.1 Operations and maintenance considerations

Direct flow augmentation projects require significant long-term O&M. Flow conditions within the watershed need to be closely monitored to inform diversion during the wet season and flow augmentation during the dry season. Similar to storage and forbearance, direct flow augmentation projects require yearly maintenance to ensure that all systems are functioning as designed. Each direct flow augmentation project will have an O&M plan developed specifically for that project with a list of operations, monitoring, maintenance, and adaptive management tasks and activities. The O&M plan typically describes operations for a minimum of 20 years post-construction.

Unlike the storage and forbearance projects that provide domestic water for individual landowners who thereby take ownership in the O&M, direct flow augmentation projects are designed with the primary objective of improving aquatic habitat conditions and therefore typically require management by a non-profit organization and some type of long-term funding mechanism. For the Marshall Ranch Flow Enhancement Project, SRF and the Marshall Ranch have secured a funding commitment from a private foundation to cover long-term O&M costs.

Although O&M requirements are significant, direct flow augmentation is likely the best approach for guaranteeing measurable flow enhancement benefits in August and September during drought conditions. The other approaches described in this report have not proven to result in measurable flow enhancement benefits during the driest conditions.

3.4 Runoff Detention and Passive Release

Runoff detention and passive release is achieved by slowing the rate of wet-season runoff which results in increased groundwater recharge. This additional groundwater storage is then released to watercourses during the spring recession and dry season.

A variety of approaches in different settings throughout the watershed can be used to achieve this objective:

1. Log and rock weirs
2. Beaver dam analogues
3. Subsurface clay restrictive barriers
4. Floodplain reconnection and stage zero channel grading
5. Large wood structures

6. Detention basins

These six approaches are described in more detail below and are often used in tandem to complement each other. The relatively small scale of these approaches requires stacking of project features to achieve measurable flow enhancement benefits. Also, because these features rely on passive groundwater release, their flow releases typically mimic the natural hydrograph with extensive flow augmentation during the spring when groundwater is high and decreasing significantly throughout the summer as groundwater levels lower.

3.4.1 Log and rock weirs

Instream log and rock weirs can be constructed as described in CDFW's Stream Habitat Restoration Manual (Flosi et al. 2010) to raise the channel bed, resulting in additional groundwater recharge in the upstream channel, banks, and floodplain. These structures can also increase surface flow because they are typically keyed into the bedrock or impervious clay under the streambed, thereby pushing the subsurface flow to the surface at each weir. In addition to the flow benefits, weirs also help store and sort spawning gravels, increase pool depth and area, and generally increase instream habitat complexity.

Weir construction begins with a trench in the channel and banks to prevent undercutting and flanking around the weir. Logs or boulders are placed in the trench and gravel and clay material excavated from onsite is used to backfill against the weirs. Fish passage is provided for by creating a structure with maximum one-foot jump heights. Subsurface clay restrictive barriers can also be constructed in association with the weirs as discussed below.

Proof of concept for increasing water availability and floodplain habitat with weirs has been demonstrated in Baker Creek, a tributary to the Mattole River, where an instream project completed between 2012 and 2017 installed approximately 20 instream log weirs along approximately 1,800 linear feet of Class I channel and has raised water levels by approximately 1.5 feet along a portion of the project reach. The instream structures have significantly increased water availability within the project vicinity during the period of mid-June through mid-August. Pool depth and area has greatly increased and the pools persist much later into the dry season as compared with pre-project conditions mainly due to the downstream log weirs slowing the down-valley flow of groundwater.

Increased water availability was also observed in McKee Creek, a tributary to the Mattole River, following construction of 16 weirs in 2018 and 2019. Long-duration high storm discharges during the 2018–2019 wet season transported approximately 540 CY of gravel and fine sediment into the project reach transforming the habitat. The project also appears to have increased water availability within the reach. The summer of 2019 was the first summer in 20 years with surface flow all summer (although it was also the wettest summer in the last decade).

3.4.2 Beaver dam analogue (BDA) structures

Like weirs, beaver dam analog (BDA) structures can be used in small watercourses to increase gravel storage, groundwater storage in the streambed and banks, pool depth and area, and generally habitat complexity. BDA structures are not effective for bringing subsurface flow to the surface because they are by nature more porous than weirs and do not include trenching.

BDAs consist of posts installed by hand or with an excavator attachment to form one or two rows across the channel. Willow stems or other locally sourced brush or tree branches are woven into the post line to create a semipermeable structure. Cobble, gravel, straw, and clay are placed at the upstream base of the structure to reinforce the posts, reduce permeability, and retain surface water. Scour on the downstream side of the BDA could lead to tipping of the structures and can be mitigated by placement of cobble and a small diameter log pinned with additional posts on the downstream side of the structure. The weirs are backfilled with gravel/clay excavated on site from strategically selected high points in the existing floodplain.

Some concern has been expressed about the application of BDAs because the historic presence of beavers in the Mattole headwaters or Redwood Creek has not been documented. However, the abundance of large and small wood in the creek channels provided a similar function as beaver dams, and the large-scale removal of that wood in the 1980s has significantly contributed to channel incision, disconnected floodplains, and a lower water table. In addition, the heavily logged forests in the region will not be contributing large wood for many decades and therefore BDAs aim to utilize small wood to build instream structures that are designed to restore the functions that were lost using local materials. Similar projects utilizing channel spanning post-assisted check dams have been implemented in other western states with well-documented outcomes showing benefits to anadromous fish (Bouwes et al. 2016). BDAs are envisioned to serve as small log jam analogs with a comparison shown in Figures 3-4 and 3-5.

Figure 3-4. Photo of a beaver dam analog with post line and willow weave (photo from Dr. Michael Pollock).

Figure 3-4 and Figure 3-5 illustrate the similarities between these structures, with Figure 3-4 showing a beaver dam analog from Oregon and Figure 3-3 showing a small debris jam in North Fork Lost River (Mattole River tributary). Both structures raise the streambed and water elevation upstream of the structure, connecting the floodplain for improved winter habitat and increasing groundwater storage in the streambed material and adjacent banks and floodplains. In addition, both structures create a scour pool downstream of the structure, thereby improving summer pool habitat and gravel sorting.

Figure 3-3. Photo of small wood jam in a Mattole River tributary (photo from Sanctuary Forest).

Sanctuary Forest implemented their first BDA installation project in the South Fork Lost River, tributary to the Mattole River in 2019. Although monitoring of that project is just underway, some important lessons have already been learned. In terms of construction, large scale BDAs are time-consuming and expensive to construct by hand. If equipment access is possible, BDAs are likely less expensive (and less back-breaking) using heavy equipment for installation of the posts and hauling/placement of gravel, with hand labor limited to weaving the willow. Initial results from the 2019/2020 wet season suggest that the BDAs may be highly effective at retention of wet-season runoff for sites where weir heights are greater than 3 feet and streambed sediments are sufficiently thick/deep for post installation (i.e., 4 feet minimum depth to bedrock). As previously discussed, because BDAs are built on top of the streambed, subsurface clay restrictive barriers are needed to keep the streambed saturated and bring water to the surface, but BDAs are not effective at slowing groundwater flow. Because they are imbedded into the subsurface, log weirs are more effective for slowing subsurface flow than BDAs and are likely the best fit for projects seeking to increase summer flows where logs are readily available. However, Sanctuary Forest has not had good results with log weirs greater than 3 feet in height and at that size they are more difficult to modify and maintain than BDAs. It is relatively easy to adjust weir height, add an additional weir for jump heights, and other maintenance activities where hand labor is feasible once the posts are set in place.

One key site selection consideration for design of instream features is the degree of channel incision. When channels are incised more than 6 feet below their floodplain, and particularly where streams have incised down into the bedrock, groundwater storage in the bed and streambank is limited and gravel adjacent to the channel is well above the groundwater base level. Therefore, large weirs and BDAs are typically only proposed along stream reaches where the channel is less than 6 feet below its floodplain (optimally 3–4 feet).

Within the reaches that are suitable for weirs and BDAs additional design measures are applied to provide stability and achieve objectives:

1. The structures are strategically located such that high flows will overflow onto adjacent floodplains reducing the hydraulic forces on the structures and minimizing undercutting and/or flanking. Gravel to be used as backfill against the weirs will be excavated on site from strategically selected high points in the existing floodplain, where excavation will facilitate increased floodplain access. These strategies also achieve the project objectives of reconnecting floodplains and inundating a larger extent of floodplains during high flows.
2. Weirs and/or BDAs are also installed as a series of structures. Each structure is designed to support the function and stability of the other structures to achieve desired objectives. Additionally, a series of structures are used to form step pools or side channels for fish passage.

3.4.3 Subsurface clay restrictive barriers

Subsurface clay restrictive barriers are intended to slow the flow of shallow groundwater. These features consist of trenches dug perpendicular to groundwater flow down to an impervious layer (bedrock or clay) and then backfilled with compacted clay to create a barrier to subsurface groundwater flow. Depending on local conditions, clay can be derived from on-site or off-site sources or native soil mixed with bentonite can be used.

Instream subsurface barriers are typically installed in tandem with weirs or BDAs. The intent of the subsurface barriers is to greatly reduce the rate of subsurface flow within alluvial sediments along and below the channel. While grade control structures typically are tied into the bed and banks to reduce undercutting and flanking during high flow events, the intent of the restrictive barrier is to go a step farther and reduce underflow and flanking by groundwater. Therefore, native clay or bentonite will be used to fully seal the upstream side of the log weirs with the bedrock and/or clay in the bed and banks through the alluvium to the bedrock-alluvium boundary. Subsurface clay restrictive barriers can also be used in association with off-stream ponds to increase groundwater storage potential and reduce the rate of seepage loss.

3.4.4 Floodplain reconnection and Stage Zero channel grading

Many stream reaches in Redwood Creek experienced significant disturbance from legacy timber harvest activities resulting in incised channels and disconnected floodplains. In some reaches, remnant logging roads in the creek channel are still evident and actively eroding. These sites can be treated with grading to elevate the channel and reconnect the floodplain. In some cases, a modified Stage Zero channel restoration approach (Cluer and Thorne 2013) is the best approach, while in other cases more targeted channel grading can help connect the floodplains. The channel grading differs from the Stage Zero approach utilized in the Pacific Northwest where entire valleys have been reshaped. Instead, this work proposes reshaping of narrower valleys (generally 20–100 feet in width) extending from hillslope to hillslope. For this grading approach, the existing incised channel is filled and a combination of grade control and roughness is used to direct flows along a more sinuous path. Due to the Mediterranean climate and absence of snowmelt, extreme dry-season water scarcity exists in this region and aggrading the streams without the inclusion of subsurface clay restrictive layers would result in increased subsurface flow (and decreased surface flow) during the dry season.

Combining Stage Zero and targeted floodplain grading with weirs also eliminates the problems of sediment starving the downstream reaches because it eliminates the sediment sinks that can be created by weirs or BDAs that are not fully backfilled.

3.4.5 Large wood structures

Large wood structures as described in CDFW's Stream Habitat Restoration Manual (Flosi et al. 2010) can provide some flow enhancement benefit if they are sufficiently large-scale to result in geomorphic and hydraulic change. Structures can be anchored or unanchored depending on the size of wood and stream setting. These structures are typically intended to provide sufficient roughness to support channel aggradation or at least reduce the incision rate. These structures can also back up high flows to push water onto the floodplain and increase groundwater recharge. However, the timing of flow benefits resulting from these types of structures is not aligned with the dry season. Increased groundwater storage resulting from these types of structures is typically released in the spring.

The large wood structures have multiple habitat enhancement objectives including enhancing summer and winter habitat as well as sorting/retaining gravel. Also, they can often be used in parallel with other features described herein to result in a holistic restoration project that benefits aquatic habitat for a range of flow conditions. However, as a stand-alone flow enhancement action, they are unlikely to result in measurable benefit.

3.4.6 Detention basins

Detention basins or ponds capture runoff during the wet season and passively release the water through seepage back into the groundwater and downslope watercourses. A relatively large-scale example of this approach is the Baker Creek String of Pearls project constructed by Sanctuary Forest in the Mattole headwaters. This project is comprised of three ponds with a total surface water storage volume of approximately three million gallons. Rainfall and shallow groundwater flow fill the ponds during the wet season and they drain during the spring and early summer. Based on a hydrologic analysis of the site, the ponds have effectively increased streamflow during the late spring and early summer, but have not resulted in a measurable flow benefit during the peak of the dry season (McKee 2022).

Another consideration is the placement of these features within the watershed context. Small scale features higher on the hillslope that capture and infiltrate road runoff could potentially be more effective at providing flow enhancement benefit during the driest months due to longer groundwater flow paths than detention features constructed on low-lying terraces, which deliver their benefit in the late spring/early summer. However, there is much uncertainty associated with the hillslope hydrologic processes which makes it difficult to design and monitor upslope projects of this type. In addition to the challenge of finding topographically and geologically suitable locations (relatively flat and stable) for these types of upslope retention features, there is also uncertainty regarding the recharged groundwater flow timing and pathways in these settings. Because upslope groundwater flow patterns in faulted regions like the Redwood Creek watershed can be complex, the flow could take years to reach the stream, emerge in a different watershed, or emerge mid-slope and increase the risk for landslides.

Large scale upslope infiltration projects have not been implemented in our region to date. However, there could be strong synergy with several of the other approaches described herein, including BDA-type check-dam structures in small upslope gullies and forest management activities described below in Section 3.4. A combination of these approaches could result in measurable flow benefits.

3.4.7 Operations and maintenance considerations

Flow detention features typically have minimal operations and maintenance requirements.

3.5 Evapotranspiration Reduction through Forest Management

One approach to increasing streamflow to support fish is reducing ET through forest thinning. Theoretically, if ET is reduced, other components of the water balance (including storage and runoff) would increase. The effects of forest management on baseflow have been investigated using numerous paired watershed studies and hydrologic models that track changes and predicted discharge before and after forest management. Paired watershed studies, however, show that the effect of forest thinning or logging on the baseflow varies (Harr 1980, Hicks et al. 1991) and tends to be short-lived (e.g., Keppeler and Ziemer 1990), with the length of the effect dependent on local conditions (Hicks et al. 1991, Lane and MacKay 2001, Dan Moore and Wondzell 2005). Goeking and Tarboton (2020) reviewed 78 studies of the hydrologic response to drought, fire, insects, and harvest to changes in forest stand density from 2000–2019. These studies showed that the ET could increase, decrease, or remain unchanged, although ET was more likely to decrease (and streamflow increase) in studies where forests were only partially impacted than studies where the entire stand was replaced by high-intensity fire or harvest. Most of the studies in Goeking and Tarboton (2020) were in snow-dominated watersheds. A further study suggests that the effects of thinning are more persistent in wetter and colder areas (i.e., Washington State and Montana) than drier ones (Goeking and Tarboton 2022).

A paired watershed study at the Caspar Creek Experimental Forest, about 60 miles south of Redwood Creek, tracked hydrologic change due to harvesting approximately 67% of the stand volume from a Douglas-fir and redwood forest (Keppler and Ziemer 1990). At the Caspar Creek site, reduced ET led to increased flows in general for about 10 years, but the summer low-flow increases only persisted for about 5 years. Most of the increased discharge flowed during the wet season, but relative flow increase was greater during summer low flows. The effects of logging on flow are short-lived because thinned areas become revegetated as available water and sunlight promotes plant growth. Forest thinning (and associated roads) may also change rainfall-runoff relationships, causing an increasing portion of the rainfall to runoff directly to channels rather than enter the groundwater system, thereby further reducing summer baseflow. Decreases in evapotranspiration following forest thinning are likely to be short-lived and may largely contribute to changing flows during wetter times of the year, rather than summer baseflows where aquatic organisms can be most affected by water withdrawal.

Kobor and O'Connor (2021) summarized research on stand age and forest ET to assess the potential effects of forest management on Coho habitat in the Northern California Coast Range. Their literature review found that ET was related to stand age, with intermediate age forests (15–50 years) use more water than younger and older forests, and managing these intermediate-age trees could lead to increased baseflows.

A recent group of papers exploring the effects of a change in fire management in a watershed in Yosemite National Park shows the effects of returning to natural fire regime in a snow-dominated environment (e.g., Boisrame et al. 2017, 2019). Starting in 1972, fire suppression ceased in the watershed. The forest has subsequently had lower intensity fires about every 10 years. The constant fires have helped to limit understory growth causing an increase in soil moisture and transforming parts of the watershed from forest to dry and wet meadow. Hydrological modeling suggested that overall water discharge has increased while ET has decreased, but baseflow was relatively constant following the change in fire regime.

These studies did not explore the importance of vegetation management. Vegetation closer to streams may have a larger effect on summer flows than upslope vegetation, but shading and other benefits provided by streamside vegetation are crucial for maintaining habitat and stream temperatures.

Taken together, these studies suggest that forest thinning and meadow restoration could lead to increased summer baseflow, but baseflow increases are likely to be short-lived following treatment, therefore requiring frequent maintenance. Changes to baseflow are also highly dependent on local geology and composition of the critical zone (e.g., Dralle et al. 2022) with better results expected in Coastal Belt terranes rather than Central Belt terranes. There is considerable uncertainty in the potential effects of forest management on summer baseflows, but because local conditions (including subsurface architecture, the type of precipitation, forest age, etc.) are a crucial determinant of forest response to vegetation management, a pilot study managing intermediate-age forests may provide fire protection on fire-prone upslope areas while also providing increased summer flow, particularly if vegetation is continually managed.

Another vegetation management approach that could be tested is prairie restoration or conversion of ridgetop forests to meadow and shrub vegetation. Again, this would mainly provide flow benefit in Coastal Belt terranes by promoting increased groundwater recharge during spring-time precipitation events that would then result in more dry-season baseflow. A pilot study could be used to explore whether the lack of trees might increase wind-driven evaporation, how the amount of ET would depend on the composition of the meadowy vegetation, and whether it could negatively impact fog drip depending on the setting. This treatment would certainly require maintenance by frequent low-intensity fires.

3.5.1 Operations and maintenance considerations

Significant work is necessary to maintain flow enhancement benefits achieved through forest thinning. After a thinning project is complete, smaller trees and shrubs begin to grow back immediately and maintenance of this regrowth is necessary. Forest management using controlled burning techniques is likely the most cost-effective approach, although there are many issues associated with risk and liability. Some controlled burning pilot projects are underway within the watershed. Expanding controlled burning activities will be greatly supported by more overall water storage within the watershed, both through storage and forbearance and direct flow augmentation projects.

3.6 Impacts Assessment

Based on observations within the project area and elsewhere throughout the region, flow enhancement activities can result in potential negative impacts: increased erosion, reduction in flows during the diversion season, poor water quality, and introduction of invasive species. In all cases, these potential impacts can be avoided and/or mitigated through appropriate planning, design, and maintenance.

3.6.1 Erosion potential

Flow enhancement projects should be constructed with strong consideration for local geologic and geomorphic constraints to reduce instabilities and erosion potential. Similarly, the site designs should incorporate strong erosion control features to reduce erosion.

Projects not constructed at suitable locations or engineered properly have the potential to cause significant negative impacts, including increased surface erosion and/or mass wasting. In the worst-case scenario, failed ponds and/or cut/fill slopes can cause significant gullying or landslides. It is recommended that experienced licensed professionals should design all significant flow enhancement projects, and experienced licensed contractors should perform all construction work. Long-term monitoring, maintenance, and adaptive management is also critical to ensure that all project components are functioning as designed.

3.6.2 Reduction in wet-season streamflows

If water is diverted to off-stream storage and detained in basins and ponds during the wet season, it has the potential to reduce streamflows during this period. Typically, the most critical periods to minimize diversions (in addition to the dry season) are: 1) the late fall and early winter when streamflows first rise and fish begin to move into and within the system, 2) winter baseflow between storm events during dry years, and 3) the spring and early summer when flows recede and fish require suitable flow and temperature to avoid stressful low-flow conditions.

Storage and forbearance and off-stream direct flow augmentation projects can avoid risks to aquatic resources during the wet season by diverting during periods with high flow. Sufficient water is available in Redwood Creek to divert for at least several months during a typical winter. The diversion management considerations described in Sections 3.1 and 3.2 above will greatly reduce the potential for wet-season runoff impacts caused by storage and forbearance and direct flow augmentation projects.

It is critically important to reduce the degree to which storage is "topped-off" late in the spring, especially higher in the watershed at spring diversions because this diverted water has a greater potential to support dry-season flow in downstream channels.

Flow enhancement projects that utilize runoff detention and passive release approaches have the potential to impact wet-season flows during the first precipitation events of the year as the groundwater recharge-associated features fill with runoff. For small scale projects, this impact is likely immeasurable; however, for larger projects implemented over a broader scale, the potential impacts to the early wet-season hydrograph should be considered and monitored to inform adaptive management and future project planning and design.

Overall, a broad variety of projects spread throughout the watershed that divert or detain water during different periods and within multiple sub-sheds within the watershed is a good approach for flow enhancement, and by focusing larger scale projects where dry-season flows are greatest impaired.

3.6.3 Draining of Groundwater

A concern with ponds is the interception of shallow groundwater from pond excavation and loss of the intercepted water to evaporation. However, groundwater is very flashy in Redwood Creek, with peak water tables elevations of approximately four feet below ground surface and dropping by up to two feet per week after heavy rains stop in some places. Therefore, if some of this peak groundwater flow can be captured and held for several months, it can augment flows in the spring and early summer. Evaporation during the months water is stored is relatively low, so the benefits of the detention typically outweigh the evaporation loss from the ponds in an overall water balance. In months with high evaporation rates (June through October) the pre-project groundwater table is generally lower than the maximum excavation depth. Since none of the deeper groundwater will be intercepted during this period, none of it will be lost to evaporation. Therefore, evaporative losses from ponds were confined to water that was retained during the wet season and would have otherwise discharged from the system. Typically, these features should not be constructed downslope from year-round springs because that would lead to net water loss in the pond that captures dry-season runoff and increases evaporative losses of water that would otherwise provide streamflow benefit.

3.6.4 Water quality

Water quality is a significant concern for direct flow enhancement projects. The primary water quality issues are high temperature and/or low dissolved oxygen (DO). High water temperature can be mitigated by releasing water from the bottom of the pond and ensuring sufficient water depth in the pond during the peak of the dry season to maintain stratification. This approach is discussed in the Marshall Ranch Basis of Design Report Appendices H & I (Stillwater Sciences 2021). SRF has been monitoring dry-season water temperatures in an existing 2.8-million-gallon pond on the Kulchin property in Miller Creek. Temperature stratification is evident as shown on the figures in Appendix B, which summarize three years of dry-season temperature monitoring data. Low DO can be mitigated by releasing flow through a nozzle providing significant DO increases just before it gets delivered to a watercourse.

Further, these concerns can be mitigated by running flow through subsurface soil and gravel. The SWRCB conducted experimental projects exploring this treatment in Sonoma County in the summer of 2015. Agricultural pond water was used for direct flow enhancement in critical fish-bearing streams that were going dry. Initially, the quality of the stored water was not suitable for flow enhancement. However, when it was allowed to flow through substrate and mix with groundwater, the resulting input to streamflow was suitable for aquatic habitat and the methodology proved effective for increasing streamflow (Schultz 2016).

The Marshall Ranch project also proposes a pilot cooling/filtration gallery that will further test this approach of running flows through a constructed sand and gravel gallery. Another approach is to let aggraded reaches in existing downstream watercourses naturally cool the water through hyporheic flow.

All direct flow augmentation projects need to consider water quality, although depending on the aquatic conditions at the point of release, the water quality targets may vary.

Water quality is also a consideration for flow retention projects where groundwater levels are increased in floodplain terraces with high organic material content. Poor water quality at some sites has been observed and should be further monitored to further understand the longevity and spatial extent of the water quality impacts. Forest thinning projects also have the potential to negatively impact water quality based on the disturbance footprint, although negative impacts should be minimized if California forest practice rules are followed.

3.6.5 Invasive species and inhabitation by native species

The potential to introduce and propagate invasive species (e.g., bullfrogs, canary reed grass, bass, and other Centrarchids) should be avoided to the greatest extent feasible when planning and designing flow enhancement projects. An invasive species monitoring and management plan should be developed for any project involving a pond. At a minimum, periodically monitoring, and if needed, draining of the pond for bullfrog management, is required.

There are many ways to drastically minimize the amount of mosquito activity in ponds. One of the easiest ways is to keep the water from remaining stagnant by adding a pond aeration system capable of disrupting the surface of the water. Native tadpoles can reduce larvae populations also, and when they become frogs they will consume large amounts of adult mosquitoes. Altering the environment and structure of the pond is another method to minimize mosquitoes. Managing vegetation and aquatic weeds in and around the pond is crucial because they can create pockets of calm and shady water even if the pond is aerated and agitating most of the surface. Overhanging bushes and trees also support shady locations that are ideal for mosquitoes, and should be clipped to reduce shade. Larger trees that provide shade for the pond and reduce solar radiation should be left in place.

Draining and cleaning ponds to suppress bullfrogs or improve water quality can negatively impact native species (newts, frogs) if they are present. Therefore, it is important to have a relocation plan either to a nearby pond or other appropriate location.

3.7 Climate Change

In north coastal California, climate change is likely to bring more severe droughts and longer/hotter dry seasons. Beck (2018) used analyses of climate change modeling to generate a predictive climate classification map of the US for the years 2071–2100 at a 1 km grid scale. This mapping suggests that the Redwood Creek watershed, as well as large areas of the North Coast, will transition from a Csb to a Csa, or Mediterranean hot summer climate, in which at least one month experiences average temperatures of greater than or equal to 22°C (72°F).

Micheli et al. (2018) estimated that summer season temperatures in the North Coast region will increase 3–5 °F by mid-century (2040–2069) and 6–9 °F by end-century (2070–2099). Winter season temperatures are expected to increase by a greater magnitude: 5–7 °F by mid-century and 8–11 °F by end-century. Climate model projections suggest trends of reduced dry-season streamflows will continue. Cayan et al. (2018) predict a higher frequency of extreme dry years in California, with severe droughts that now occur once in 20 years, occurring once every 10 years by the end of the century, and once-in-a-century droughts, occurring once every 20 years. As a result, the lowest streamflow occurring each decade is expected to be 30–40% lower by end of century, relative to average historical conditions (1950–2005).

The flow enhancement projects described herein are intended to make Redwood Creek more resilient to these conditions by storing wet-season precipitation and runoff, and metering it out during the dry months to provide increased streamflow. These projects, however, must be designed with consideration for future expected drought conditions, so that they will still function with less precipitation and a longer dry season. Projects with more adjustable systems (and thereby more O&M) may be more resilient to climate change rather than projects that are completely passive.

3.8 Cost-Benefit Analysis

The costs of different flow enhancement projects are summarized in Table 3-1. These cost estimates are based costs from a range of projects at various phases—completed, under construction, and planned. Project costs vary site by site, so the specific project costs or unit costs listed in Table 3-1 should be considered approximate. However, the results highlight findings that are key to watershed flow enhancement planning:

1. Storage and forbearance projects are up to four times as expensive as direct flow augmentation on a price per gallon basis.
2. Detention and passive release projects have the potential to be the most cost-effective, but the timing of the flow enhancement does not coincide with the aquatic habitat need.
3. There is too much uncertainty about the flow-related benefits of forest thinning to make any estimate at this time.

Although the cost benefit analysis is a useful tool to guide watershed planning, it is one of many considerations. Even though it is the most expensive approach, there are locations within Redwood Creek where storage and forbearance is critical to prevent flow diversion from a stream reach that supports critical aquatic habitat.

Table 3-1. Costs for planning, design and construction of flow enhancement projects.

	Site assessment engineering, and permitting	Earthwork, forest thinning	Water storage supplies liners/ tanks	Plumbing	Total cost	Flow enhancement benefit (gal)[3]	Cost per gallon	Typical period of benefit
Storage and Forbearance (100,000 gallon system)								
Tank system only	$40,000	$20,000	$120,000	$30,000	$210,000	100,000	$2.10	July–Nov
Tanks & Small Pond	$40,000	$40,000	$70,000	$40,000	$190,000	100,000	$1.90	July–Nov
Direct Flow Augmentation								
Marshall Ranch (9,500,000 gal HDPE lined ponds)	$800,000	$1,500,000	$500,000	$500,000	$3,300,000	7,000,000	$0.47	July–Nov
NFLR (1,500,000 gal unlined ponds with bentonite keyway)	$150,000	$400,000	$150,000	$20,000	$720,000	1,000,000	$0.72	July–Nov
Runoff Detention and Passive Release								
Baker Creek Instream (weirs)	$75,000	$400,000	$0	$0	$475,000	1,000,000	$0.48	May–July
McKee Creek Instream (weirs)	$100,000	$250,000	$0	$0	$350,000	500,000	$0.70	May–July
NFLR Instream (weirs, LW placement, channel grading, BDAs)	$125,000	$750,000	$0	$0	$875,000	1,650,000	$0.53	May–July
South Fork Lost River (BDAs)	$75,000	$100,000	$0	$0	$175,000	200,000	$0.88	May–July
Baker Creek String of Pearls (unlined detention ponds)	$75,000	$750,000	$0	$0	$825,000	4,000,000	$0.21	May–July
Evapotranspiration Reduction through Forest Thinning								
40 acres of forest thinning	$200,000	$200,000	$0	$0	$400,000	Unknown	Unknown	Unknown

[3] Flow enhancement benefit is less than the total storage volume due to evaporation losses.

4 SUBWATERSHED CONDITIONS AND RECOMMENDATIONS

Considering the diverse range of geologic, geomorphic, land use, and flow dynamics observed throughout the watershed, it is helpful to divide Redwood Creek into subwatersheds for individual analysis. Figure 4-1 below shows the subwatershed delineations. A discussion of existing conditions, as well as opportunities and constraints for flow enhancement projects, are presented below for each subwatershed. Tables containing more detailed information gathered during the assessments are included in Appendix C.

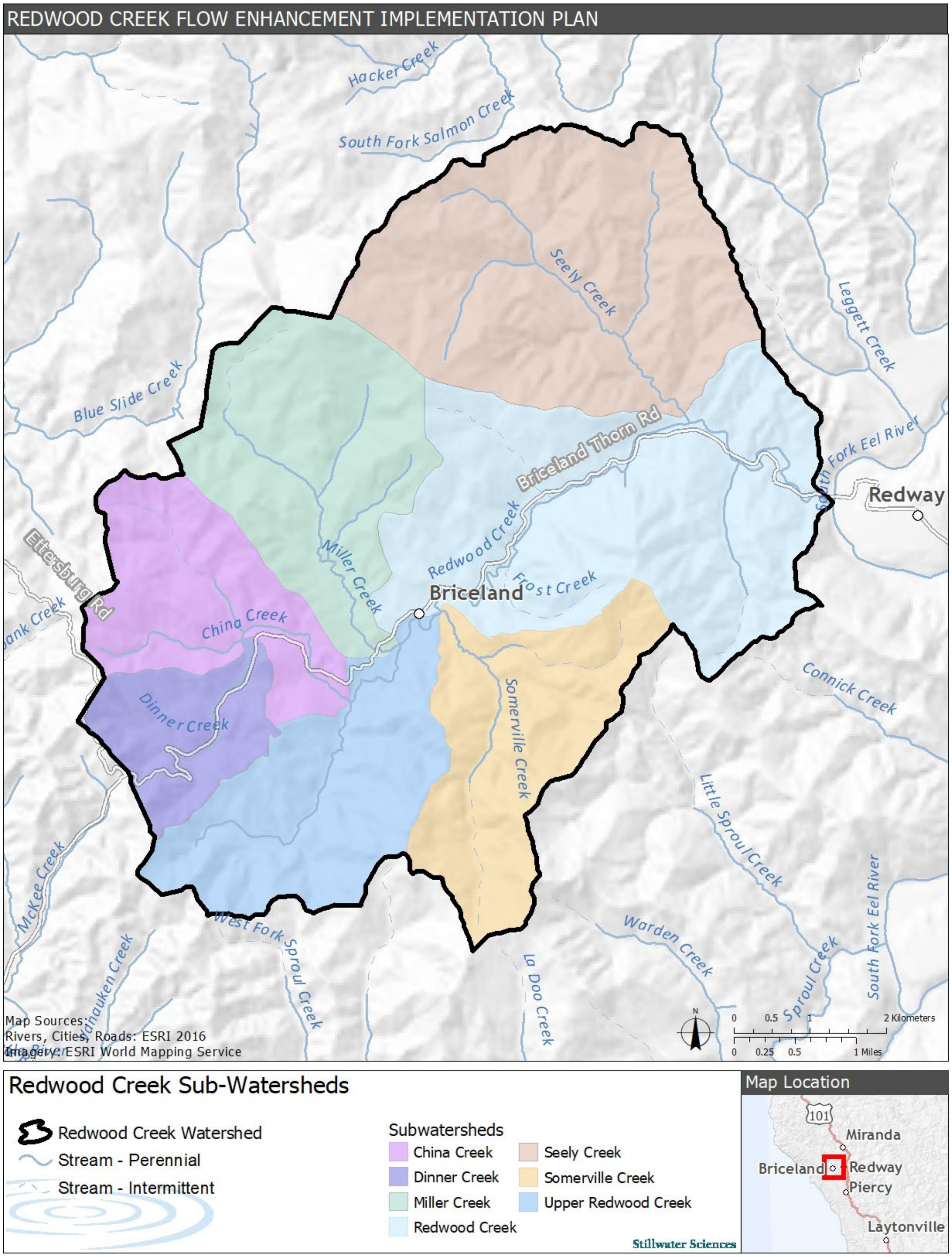

Figure 4-1. Subwatershed delineations within the Redwood Creek watershed.

4.1 Dinner Creek

4.1.1 Existing conditions

Dinner Creek is a tributary to China Creek, lying in the far western extent of the Redwood Creek watershed. It extends approximately 2 miles generally south and west from its confluence with China Creek. The creek forks approximately 0.5 miles from its head, and a tributary (though larger than the mainstem) labeled "Dinner Trib 1' (see Figure 2-19) extends to the north and west. A small instream pond lies on the "Dinner 1" section of the mainstem shortly upstream. While the Dinner 1 section is generally narrow, steep, and confined with low habitat potential, Dinner Trib 1 has approximately 1/3 mile of moderate slope, 6- to 10-foot-wide channel in which young-of-year (YOY) steelhead were observed in small pools during the 2019 assessment. Downstream, segments Dinner 2 and Dinner 3 broaden to 10–20 foot in width and have a slope of approximately 2%. YOY steelhead were observed in pools throughout. The lower portion of Dinner 3, about 530 feet in length, was dry during the assessment and is confined along the right bank by the Briceland Road prism. This dry section is part of a large depositional zone likely caused by a historic landslide just upstream from the Dinner-China Creek confluence.

Briceland Road closely follows the Dinner Creek channel for much of its length, crossing the stream in two different locations. The road also crosses Dinner Trib 1 just upstream of its confluence with the mainstem. This crossing and a crossing at the downstream end of Dinner 2 were upgraded by Humboldt County within the last 5 years. Aggradation of substrate upstream of the crossings resulted in a streambed elevation difference on either side of the road, and headcuts are migrating upstream from both crossings. The headcut on Trib 1 is 2–3 feet high and the headcut on Dinner 2 is 4–5 feet high. While channel incision and lack of floodplain connectivity appears to be an issue throughout much of the creek, it is particularly pronounced upstream of the Dinner 2 crossing where the creek bed was observed to be about 8 feet below the floodplain. The majority of the observed fish-bearing reaches would likely benefit from the addition of large wood to stabilize incision as well as increase pool development and cover.

4.1.2 Project opportunities and constraints in the Dinner Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~15 landowners, would likely have measurable impact	Critical landowners not interested	Landowner funded (Casali)	High priority to expand storage and forbearance program
Direct Flow Augmentation	One site identified to repurpose existing onstream pond	Mostly steep withfew sites for off-channel storage, significant infrastructure, residence within floodplain	Conceptual design for upsizing existing onstream pond on Dinner 1 reach. (See concept design in Appendix C)	Few additional opportunities due to constraints listed
Runoff Detention and Passive Release	Low gradient incised upper reach	Landowner access	None	Casali property (Dinner 1 and Dinner Trib 1), Upstream of County culvert (Dinner 2)
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	Forest thinning on Casali property (applied for CDFW CRGP funds in 2022, see concept scope in Appendix C)	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	Several undersized culverts on private driveways likely partial fish passage barriers; opportunities for LWD placement	High cost-benefit on fish passage sites; landowner access constraints	None	None yet planned

4.2 China Creek

4.2.1 Existing conditions

Access to China Creek during the 2019 assessment was limited to one parcel and 0.47 miles of stream. This reach begins 0.57 miles upstream from the mouth at Redwood Creek on the western edge of Briceland. Although the surveyed China Creek channel is confined by steep valley walls, the channel is generally broad (~30 feet) and low gradient (~1%). Moderate amounts of large wood and frequent bedrock outcrops support relatively consistent pool development with good woody cover. Flow in China Creek was observed to be continuous and water quality in pools appeared to be good. High densities of YOY as well as some age 1 and older steelhead were observed throughout.

4.2.2 Project opportunities and constraints in the China Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~30 landowners, would likely have measurable impact	Generally difficult community to gain access	None	Moderate priority to expand storage and forbearance program
Direct Flow Augmentation	None currently identified	Watershed hillslopes are steep, valley generally narrow	None	Opportunities limited due to constraints
Runoff Detention and Passive Release	None currently identified	Confined channel with few terrace features, shallow bedrock	None	Opportunities limited due to constraints
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout sub-shed
Other Restoration Opportunities	LWD placement	Landowner access, existing LWD load is fair	None	Opportunities to combine with forest thinning project.

4.3 Upper Redwood Creek Subwatershed

4.3.1 Existing conditions

The Upper Redwood Creek subwatershed is the watershed upstream of the Sommerville Creek confluence in Briceland, not including the other subwatersheds identified in Figure 4-1. There are approximately 4.24 miles of stream channel from this confluence to the upstream extent of the USGS blue line for Redwood Creek. Access to one property and 0.87 miles of channel in the Upper Redwood Creek watershed was gained in 2019. This section was divided into the Redwood 1 and Redwood 2 reaches shown in Figure 2-8. Redwood 1 generally appeared to be in good condition, exhibiting both confined and more open channel types, with more extensive side channel and floodplain habitat in Redwood 2. A combination of natural LWD, installed LWD, and boulder weirs provide pools and shelter. The installations were completed around 2010 by ERWIG. High densities of YOY as well age 1 and older salmonids were observed throughout Redwood 1. Redwood 2 is a largely confined reach and has considerably less channel complexity. Fill from a legacy mill site likely has impinged on the left bank of the channel. As it is no longer in use, the large flat and adjacent channel presents the opportunity for a large-scale instream, off-channel, and floodplain restoration project at the confluence of Redwood and Miller Creeks.

In 2020, Lost Coast Forestlands (LCF) purchased 880 acres in Upper Redwood Creek and granted access assessment to an additional 2.1 miles of Upper Redwood Creek upstream from the confluence with China Creek. This section of Upper Redwood Creek was divided into two reaches, with the lower half labeled as Upper Redwood Mainstem and the upper half labeled Upper Redwood Headwaters in Figure 2-19. Flows observed throughout the assessment reaches were significantly lower than those in 2019, which was unsurprising given the pronounced differences in water year precipitation. Estimates by PRISM indicate that the 2019 water year precipitation was 124% of the 30-year average, while the 2020 total was 58% of average.

The channel in the Upper Redwood Mainstem reach is generally between 10–15 feet wide, is primarily confined, and has an average slope of 2%. A mix of dry, intermittent, and continuous flow conditions were observed in the channel and with flow generally decreasing upstream (Figure 2-9). Water in the continuously flowing portion of the channel seemed to be of good quality, though the isolated pools in the intermittent areas were often quite cloudy or dark with tannins, indicating stagnation. Summer base flow in this reach appears to come predominantly from Trib 2. Some high-quality salmonid rearing pools were observed, though were more common in the upper portion of the reach. Many pools containing YOY appeared to be on the verge of drying out. Periodic large wood occurs throughout the reach at low densities and is rarely embedded sufficiently to alter channel morphology. As a result, channel grade and substrate type are often very homogenous. Lack of complexity and pool development and low baseflows limit salmonid rearing habitat. Figure 4-2 exemplifies the lengthy stretches of dry, plane bed morphology commonly observed here.

Figure 4-2. Subwatershed delineations within the Redwood Creek watershed.

The Upper Redwood Headwaters reach extends from the LCF western property boundary at the upstream end to the confluence of Trib 1 downstream. The channel through this reach is significantly narrower than in the Upper Redwood Mainstem, averaging between 4–6 feet wide with slope increasing in the upstream direction from 2.5% to 6.5%. Channel incision is active and pronounced here, with frequent 6–10 foot high vertical or undercut banks in the lower portions of the reach. At the upper end of the reach, incision ranges from 3–5 feet. While the reach was dry at its base, infrequent pools were observed upstream and there was a small and shallow but continuous flow at the upstream boundary. Portions of the reach contain some LWD and occasional pools, but the reach lacks geomorphic complexity. Based on observed flow and habitat quantity, summer fish survival is unlikely in many years. Deep incision likely hinders groundwater storage in the large terrace feature to the south of the lower reach. Restoration of much of this reach is being considered as part of the LCF Flow Enhancement Project.

Both the Marshall Ranch and LCF Flow Enhancement Projects are proposed in the Upper Redwood Creek subwatershed. Combined, the projects would constitute 16 million gallons of off-channel storage for direct flow augmentation. The LCF and the Marshall Ranch projects propose to add LWD structures to enhance instream habitat. Channel grading and several subsurface clay barriers are additionally proposed for the LCF project to encourage flood plain connection and groundwater recharge.

4.3.2 Project opportunities and constraints in the Upper Redwood Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	2 landowners that have consumptive water use	Minimal impacts due to the small number of diverters	Marshall Ranch project providing domestic supply to one of these landowners	None
Direct Flow Augmentation	Several additional pond sites have been identified, others on LCF, Shroeder property.	Watershed generally steep. Landowner outreach	Marshall Ranch Project to be constructed in 2023; LCF Project in design and permitting phase.	Depending on results of Marshall and LCF, consider additional flow augmentation on Shroeder property (dependent on change in ownership)
Runoff Detention and Passive Release	Many opportunities in upper extent of mainstem and tributaries	Equipment access	Groundwater recharge proposed as part of LCF Project	None
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements. Significant opportunities on LCF timberlands	None	None	High priority to conduct forest management pilot on LCF property
Other Restoration Opportunities	Large habitat gains to be achieved by LWD placement. Off-channel habitat creation. Regrading of impinging historic mill site on Shroeder property	Landowner buy-in	Some LWD structures proposed as part of LCF project. LWD and boulder weir structures installed by ERWIG in Redwood 1 reach.	High priority to combine forest thinning pilot with large wood placement on LCF

4.4 Miller Creek Subwatershed

4.4.1 Existing conditions discussion

Miller Creek flows into Redwood Creek at Briceland and extends upstream approximately 4.3 miles with a drainage area of 3.7 square miles. Miller Creek Rd follows the creek valley and there are two stream crossings of the mainstem and one crossing of a large steelhead-bearing tributary named Buck Gulch. Miller Creek was assessed as part of the Flow Enhancement Feasibility Study for a portion of Redwood Creek (Stillwater Sciences 2017). While not included in the 2019 assessment, Stillwater has recently worked on two projects within the watershed. The first was the crossing upgrade of Buck Gulch, which previously had an undersized and perched culvert that constituted a fish passage barrier. This culvert was replaced with a railcar bridge in 2021. A roughened channel with several grade control and large wood structures was constructed through the reach to ensure channel stability and fish passage.

SRF's flow monitoring station in lower Miller Creek is one of the first to go dry each year. Based on this data and channel observations from 2016, lower Miller Creek has been identified as one of the few losing reaches in the Redwood Creek watershed and projects to improve baseflow in Miller Creek are unlikely to be successful.

4.4.2 Project opportunities and constraints in the Miller Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~40 landowners, would likely have measurable impact; Spring that feeds Briceland is located in the Miller Creek watershed	Landowner outreach; Losing reach in lower Miller Creek	Briceland municipal water district working on multiple projects to increase storage and improve efficiency	Moderate priority to expand storage and forbearance program
Direct Flow Augmentation	Several potential pond sites within watershed	Landowner outreach/ willingness; Permitting challenges associated with current instream ponds; Losing reach in lower Miller Creek	Kulchin with approximately 1 million gallons annual flow release.	None
Runoff Detention and Passive Release	Areas of Miller Creek and tributaries have suitably broad, low gradient valley bottoms with overbank storage potential	Landowner access; Losing reach in lower Miller Creek	None	None
ET Reduction	Sandstone bedrock supports summer base flow sources, though with high potential for improvements. High percentage of meadows in the watershed. Potential for encroachment thinning.	Landowner access	Funding recently awarded from CDFW CRGP program to design forest thinning pilot project on Stein property.	None
Other Restoration Opportunities	LWD placement, meadow and wetland restoration	Driest tributary in subwatershed	None	None

4.5 Sommerville Creek Subwatershed

4.5.1 Existing conditions

Sommerville Creek has 3.0 miles of blueline stream channel that joins Redwood Creek in the center of Briceland and extends south to the divide with the Sproul Creek watershed. The creek drains 3.02 square miles, the majority of which lies on the Marshall Ranch conservation easement. Approximately 1.5 miles of the mainstem and 1.3 miles of tributary were assessed in 2019. Much of the upper and middle watershed is densely forested, though significant areas of open meadow can be found on the somewhat shallower slopes of the lower watershed, predominately below the mouth of the tributary labeled as Sommerville Trib 2 in Figure 2-8.

The assessed reaches of the Sommerville Creek channel are generally between 15–20 feet wide with a 5% slope in the Sommerville 1 reach, and a 3% slope in Sommerville 2 and 3. The steeper Sommerville 1 was observed to have substantial flow and likely stays wetted throughout most dry seasons. The channel is mostly confined in this reach and contains good steelhead habitat, with high densities of YOY observed throughout. Areas of low complexity and plane bed channel were observed that would benefit from LWD placement. While the Sommerville 2 and 3 reaches were wetted during the 2019 assessment, they likely run dry during most years. YOY densities appeared to decrease in the downstream direction, with few sightings in Sommerville 3. Sections of two tributaries, labeled Sommerville Trib 1 and Sommerville Trib 2 in Figure 2-8, were also assessed in 2019. Both tributaries were generally narrow and high gradient (~8%), and confined by steep hillslopes. Observed flows were very low, and the reaches are likely to be mostly dry during average summer months. The surrounding meadows appear to be underlain by an erosive and unstable shale (likely Wildcat Group) and many active inner gorge failures were observed in the tributaries. Grazing and hoof punch by cattle is likely exacerbating the instabilities and erosion.

4.5.2 Project opportunities and constraints in the Sommerville Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~5 landowners	Difficult to measure impact from few landowners	None	None
Direct Flow Augmentation	Several potential pond sites identified on the Marshall Ranch	Watershed hillslopes are steep, valley generally narrow. Meadows generally unstable.	None	Preliminary assessment has identified several potential pond sites on Marshall Ranch
Runoff Detention and Passive Release	May be potential in Sommerville 2 where side channels and terraces occur.	Shallow and unstable bedrock	ERWIG conducted large wood project in 2020/2021	None
ET Reduction	Significant potential in upper reaches of watershed	Meadow areas and shale geology in lower watershed likely have low unit runoff	None	Potential for forest management in headwaters of Somerville Creek tributaries
Other Restoration Opportunities	LWD placement in mainstem, especially Sommerville 2 and 3. Cattle fencing of tributaries.	Some unstable geology	None currently	None currently

4.6 Seely Creek Subwatershed

4.6.1 Existing conditions

Seely Creek enters Redwood Creek east of Briceland and extends approximately 3.4 miles to the northwest, with a drainage area of 5.84 square miles. Due to very limited landowner-granted access, only 750 feet of channel was assessed in 2019. The channel was observed to be about 20 feet wide, generally confined, and with a gentle slope of 1%. Continuous flow was observed in the reach, with some shallow pools and YOY salmonids observed throughout. These pools may be discontinuous or dry up completely in drier years. No significant large wood was observed in the reach.

In general, because of Seely Creek's position lower in the Redwood Creek watershed and high concentration of rural homestead properties, it is generally considered a lower priority for flow enhancement activities than more upstream subwatersheds.

4.6.2 Project opportunities and constraints in the Seely Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~60 landowners, would likely have measurable impact	Undetermined	None yet	Moderate priority to expand storage and forbearance program
Direct Flow Augmentation	None currently identified	Watershed hillslopes are steep, valley generally narrow.	None	Few opportunities due to constraints listed
Runoff Detention and Passive Release	Potentially in upper watershed but currently no landowner access	Confined channel with few terrace features, shallow bedrock	None	None yet planned
ET Reduction	Significant portion of the watershed is densely forested	Landowner access. Summer baseflows may be limited by predominately shale bedrock (Wildcat Group).	None	None yet planned
Other Restoration Opportunities	LWD placement. From small reach observed, could be highly beneficial.	Landowner access	None	None yet planned

4.7 Lower Redwood Creek Subwatershed

4.7.1 Existing conditions

During the 2019 assessment, access was gained to five discrete sections of lower Redwood Creek within the 5.8 miles of Redwood Creek (from the Sommerville Creek to the South Fork Eel). The uppermost section was subdivided into Redwood 3 through Redwood 8 (Figure 2-8). These reaches comprise 2.4 miles of the 5.8-mile-long extent of lower Redwood Creek. Channel widths throughout are often in the range of 50–60 feet, with average channel slope around 1%, except for the considerably steeper and coarser Redwood 6 at 3% slope, and the broader and gentler Redwood 8 which has a slope of 0.8% slope near the confluence with the South Fork Eel (Figure 4-3).

Figure 4-3. Redwood Creek near the confluence with South Fork Eel on July 17, 2020.

In Redwood 3 and Redwood 4, a combination of existing LWD placements and natural recruitment provides relatively consistent structure, though flows were observed to be lower and more stagnant than in other reaches. While Redwood 4 is relatively confined, Redwood 3 has a broader valley with some opportunities for side channel and floodplain enhancement. Redwood 5 and 6 are generally steeper and coarser with dominant substrates of cobble and boulder. Continuous flows were observed throughout both reaches, and water quality appeared to be good. Large wood densities were low, through these reaches and LWD enhancement is likely the primary restoration opportunity. The exception to this would be the upper half of Redwood 6, which is quite steep and coarse, and boulder step pools provide good habitat complexity and pool depth. Redwood 7 has a low gradient and finer substrates than the other reaches. Several very long (>100 foot) pools were observed in this reach. While the channel was generally confined to the south, a large floodplain along the northern bank would be suitable for floodplain habitat enhancement.

Redwood 8, which includes the Redwood Creek mouth, flows through the old growth redwood groves of the John B. Dewitt Redwoods State Natural Reserve. The channel becomes considerably broader here to an average width of about 80 feet, and large lateral and point gravel bars are common. Several large and deep pools were observed, apparently formed by scour adjacent to bedrock outcrops. Large wood density was fairly low, though several large redwood logs were present that were of sufficient size to alter flows. While LWD enhancement here would likely be beneficial for pool formation and especially for cover, local trees are protected old growth and wood would need to be imported from elsewhere.

4.7.2 Project opportunities and constraints in the Lower Redwood Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~100 landowners, would likely have measurable impact	Landowner outreach	None to date	High priority to expand storage and forbearance program especially focused on landowners that divert water from Redwood Creek in upstream portion of this sub-area
Direct Flow Augmentation	None currently identified	Watershed hillslopes are steep	None, Marshall Ranch and LCF flow enhancement project in Upper Redwood Creek sub-sheds expected to provide extensive flow benefit to this reach.	None
Runoff Detention and Passive Release	None currently identified	System likely too large to be feasible in mainstem	None	Few opportunities due to constraints listed
ET Reduction	Sandstone bedrock in some areas supports summer base flow sources in some areas, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout sub-shed
Other Restoration Opportunities	LWD placement. Floodplain and side channel habitat enhancement.	Landowner access, high energy system and proximity of Briceland Rd requires careful engineering. Would likely require old growth trees in lowest reaches.	Large wood habitat projects constructed by ERWIG in the Redwood 3 and 4 reaches during the past decades	None

5 IMPLEMENTATION PLAN

The flow enhancement projects and activities discussed above in Section 4 are summarized in Table 5-1. The project list and prioritization ranking represent opportunities based on the current state of flow enhancement science as of December 2022. However, because flow enhancement is a relatively new scientific and engineering field, it is likely that new understanding resulting from pilot project monitoring over the coming years will change the recommendations presented herein. New projects should also be considered for this list based on changes to ownership or access that may provide opportunities throughout the watershed or strategic integration of different project types—i.e., forest thinning projects combined with instream habitat enhancement.

5.1 Prioritization Approach

Five factors were used to prioritize the flow enhancement actions listed in Table 5-1 with each factor given a rating between 1 and 3, as described below:

1. **Flow increase rating**: 1-5 gpm = 1; 5-10 gpm = 2; >10 gpm = 3
2. **Timing of flow enhancement**: Increase to natural recession = 1; Constant throughout dry season = 2; Augmentation during lowest flow period = 3.
3. **Instream Habitat Value: <3** miles of downstream Class I habitat = 1; 3-6 miles of downstream Class I habitat = 2; >6 miles of downstream Class I habitat = 3
4. **Construction Cost Effectiveness Value**: >$2/gal = 1; <$2/gal and >$1/gal = 2; <$1/gal = 3
5. **Project Environmental Impacts Value**: Significant conversion of native habitat = 1; Moderate disturbance/disruption of native habitat = 2; Minimal impacts to native habitats = 3

This prioritization approach is intended to be used as a general guide, but should not be considered as a strict directive. Lower priority project activities could begin in parallel with some of the higher priority projects to test pilot approaches in different settings. Further, as described previously, multiple project approaches enacted in a coordination throughout the watershed will be needed to achieve meaningful flow enhancement.

The five highest-priority projects are described below in Section 5.2 followed by more generalized discussion of storage and forbearance, forest thinning, and groundwater recharge actions described more generally in Section 5.3.

Table 5-1. Prioritization flow enhancement actions.

Site-specific action	Subwatershed	Landowner	Flow increase rating	Timing of flow enhancement	Instream habitat value of receiving waters	Cost effectiveness	Project Impacts	Total priority rating
Marshall Ranch Flow Enhancement	Upper Redwood	Marshall Ranch	3	3	2	3	2	13
LCF Flow Enhancement	Upper Redwood	Lost Coast Forestlands	3	3	3	3	1	13
Briceland Municipal Storage	Miller	Briceland Municipal	3	3	3	1	3	13
Kulchin Pond Repurposing	Miller	Kulchin	2	3	2	3	3	13
Casali Pond Repurposing	Dinner	Casali	2	3	3	3	2	13
Dinner Storage and Forbearance	Dinner	Multi	1	3	3	1	3	11
China Storage and Forbearance	China	Multi	1	3	3	1	3	11
Somerville Flow Augmentation Ponds	Somerville	Marshall Ranch	2	3	2	3	1	11
Lower Redwood Storage and Forbearance	Lower Redwood	Multi	2	3	2	1	3	11
Miller Storage and Forbearance	Miller	Multi	1	3	2	1	3	10
Upper Dinner Instream Habitat Enhancement and Groundwater Recharge	Dinner	Multi	1	1	3	2	2	9
Seely Storage and Forbearance	Seely	Multi	1	3	1	1	3	9
Dinner Forest Management	Dinner	Multi	1	1	3	1	2	8
China Forest Management	China	Multi	1	1	3	1	2	8

Site-specific action	Subwatershed	Landowner	Flow increase rating	Timing of flow enhancement	Instream habitat value of receiving waters	Cost effectiveness	Project Impacts	Total priority rating
Upper Redwood Forest Management	Upper Redwood	Lost Coast Forestlands	1	1	3	1	2	8
Miller Forest Management	Miller	Multi	1	1	2	1	2	7
Somerville Forest Management	Somerville	Marshall Ranch and others	1	1	2	1	2	7
Seely Forest Management	Seely	Multi	1	1	1	1	2	6
Lower Redwood Forest Management	Lower Redwood	Multi	1	1	1	1	2	6

5.2 Site-specific High-priority Flow Enhancement Projects

Each of the top five priority projects within the watershed are described below and shown in Figure 5-1 along with general forest thinning, storage, and forbearance treatment areas throughout the watershed.

5.2.1 Marshall Ranch flow enhancement project

The Marshall Ranch project is currently in the final permitting phase and construction is scheduled for 2023. The project is located near Briceland optimally positioned near the epicenter of consumptive human water use within the watershed. The project will construct 10 million gallons of off-stream water storage with the objective of providing approximately 30 gpm of flow augmentation to Redwood Creek mainstem during the 5-month dry season.

5.2.2 Lost Coast Forestlands flow enhancement project

The Lost Coast Forestlands project is currently in the preliminary design phase. The project site is in the only location within the upper portion of the Redwood Creek watershed with a supportive landowner and sufficient gentle terrain to host pond storage of significant scale. The site is optimally positioned near the upstream extent of anadromy. However, one drawback to the project is the necessity to convert several acres of forestland to make space for off-stream storage. The objective of the project is to construct ponds and groundwater recharge features that provide approximately 20 gpm of flow augmentation to Upper Redwood Creek and Redwood Creek mainstem during the 5-month dry season.

5.2.3 Briceland Community Services District (BCSD) water system upgrade

BCSD is currently the largest single water user within the Redwood Creek watershed and supplies domestic use water to approximately 26 residences (~75 residents), a community center and fire station. Planning and design work has been underway to upgrade the system to improve efficiency and install additional storage with the initial phase of construction scheduled to begin in 2023. This work is being conducted by the BCSD with a separate consultant team, so the exact details, timing, and extent of the system upgrades are unknown at this time. However, continued progress to reduce dry season diversion for residents of Briceland remains a high priority and ongoing support of these efforts should be prioritized by funding agencies.

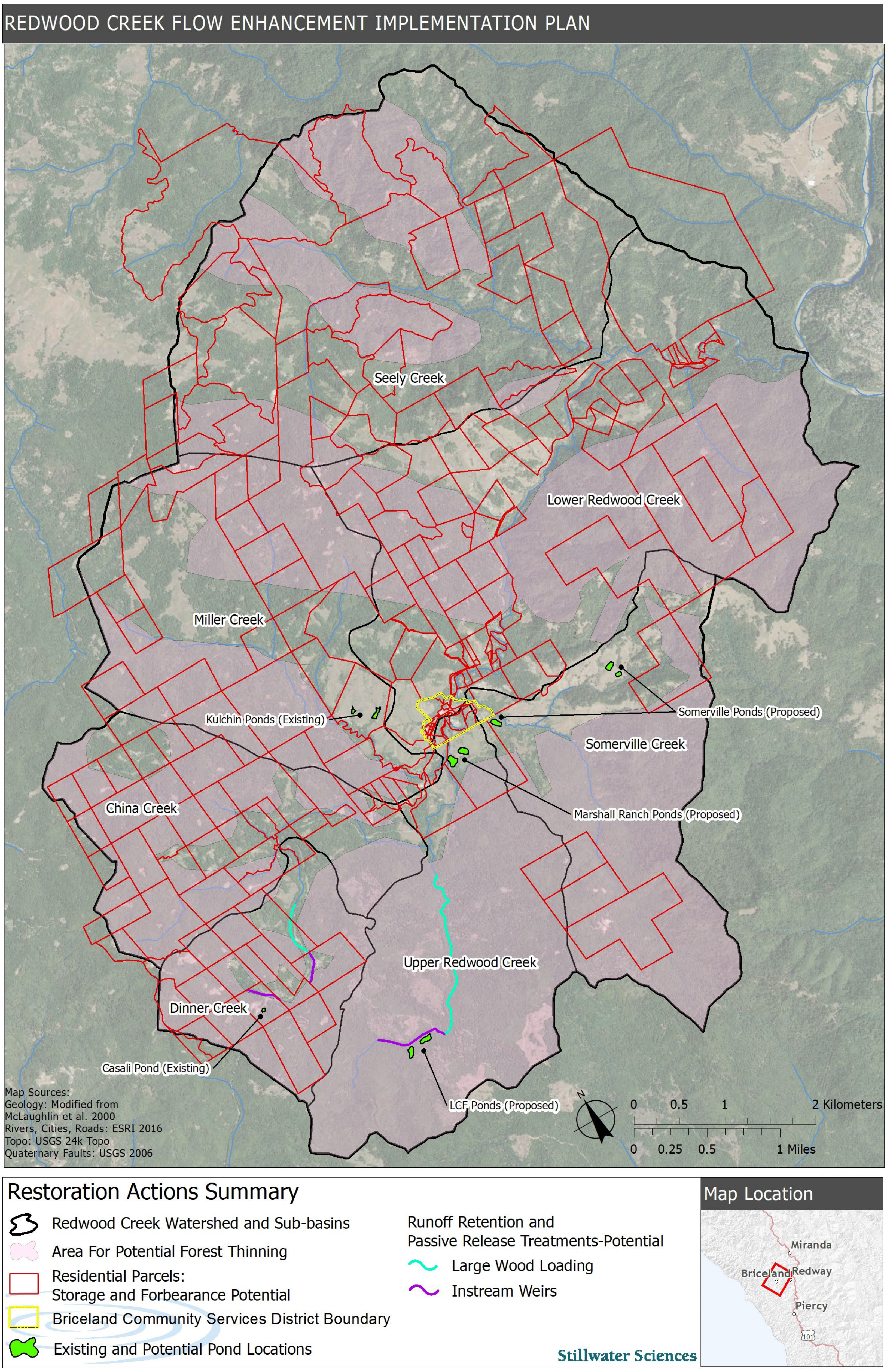

Figure 5-1. Redwood Creek flow enhancement implementation plan recommended actions.

5.2.4 Kulchin pond repurposing

Within the Miller Creek watershed, two instream ponds have existed on private property for at least 30 years. The ponds impound two small tributaries and have a combined capacity of 3.59 million gallons. Stillwater is working with the landowners (Daniel Kulchin) as well as CDFW, NCRWQCB, and the SWRCB to find a permittable arrangement which allows the use of 1/3 of the pond volumes annually for direct flow augmentation, fire suppression, and for landowner domestic use and cannabis irrigation, respectively. A total of 988,000 gallons was released between August and October of 2022 at a rate of roughly 8 gpm. It is recommended that ongoing support is provided to the landowner to facilitate this ongoing flow release in the future.

5.2.5 Casali pond repurposing

An instream pond has existed on private property on a small tributary of Dinner Creek for at least 40 years. The pond does not hold water in the summer due to high percolation rates and passively releases flow downstream. Consequently, the pond starts draining as soon as measurable precipitation stops, causing a complete drying of the pond by mid-summer. Stillwater has approached the landowner about repurposing the pond for flow augmentation purposes. This would include sealing the pond to reduce infiltration rates, increasing the pond's capacity, and adding a valved outflow line so water could be released into Dinner Creek during the height of the dry season.

5.3 General Flow Enhancement Activities

In addition to the site-specific projects described above, additional general flow enhancement actions are recommended throughout the watershed.

5.3.1 Storage and forbearance

Storage and forbearance projects are typically the least cost-effective, but they are also the only projects that directly address human consumptive use and also have a low environmental impact. Many landowners in the watershed have already installed some water storage to meet domestic and agricultural needs, and these landowners could be brought into storage and forbearance program at a lower cost considering that some of their storage is already constructed. Through a storage and forbearance program, diversion schedules throughout Redwood Creek could be better coordinated, encouraging water users to divert during higher runoff periods as opposed to the spring recession. Although difficult to quantify, this coordination could have measurable flow benefits, so it is strongly recommended that SRF's Redwood Creek storage and forbearance program expands quickly beyond the few initial participants to provide a watershed-wide resource for diversion coordination.

In general, it is recommended that storage and forbearance efforts focus initially along mainstem channels that have direct pump diversions. Therefore, lower Redwood Creek mainstem is the recommended initiation location and SRF has secured funding to begin a storage and forbearance program beginning in 2023 focused on five landowners within this reach. However, the program should quickly expand into the upper watershed (Dinner/China Creeks) and then progressively move downstream. Note that due to the complexity of working with multiple landowners and cost for individual systems, storage and forbearance activities could be installed at the rate of several systems per year for the foreseeable future. Therefore, although this project type is a critical to increasing dry-season flows, it's difficult to achieve rapid measurable benefits with the storage and forbearance approach alone.

5.3.2 Forest management

As described above in Section 3.4, forest management activities have the potential to result in dry-season flow benefits. However, there is significant uncertainty and no proven studies, so it is considered a lower priority at this time. However, considering the multi-benefits of wildfire safety associated with forest thinning, it is certainly an approach that should be further explored. To maximize the likelihood of achieving flow enhancement benefits, forest thinning projects should be located on Coastal Belt geologic terrane upslope and/or downslope from springs where there is a strong likelihood that the vegetation is tapping into groundwater and if transpiration is reduced surface flows will increase. SRF and Stillwater recently received funding from CDFW to design forest thinning pilot projects in the Miller and Dinner Creek watersheds to test approaches and treatments. Additionally, Upper Redwood Creek would also be an excellent candidate for forest thinning pilot projects.

5.3.3 Direct flow augmentation

At this time, the only additional flow augmentation projects beyond those described above in Section 5.2 are located in Somerville Creek. No other suitable sites with landowner access have been identified for ponds with volume greater than 1 million gallons, which is the lowest desirable volume for flow augmentation ponds. Direct flow augmentation projects can be located either on Coastal or Central Belt terranes, each having advantages and disadvantages—Coastal Belt terranes are more stable, but the pond almost always need to be lined, while Central Belt terranes may not require a liner, but the underlying geology is inherently less stable.

One property that has significant potential for direct flow augmentation and other restoration activities is the Shroeder ownership located just west of Briceland. The current landowner has allowed small instream restoration projects in the past but is not supportive of large restoration projects. The property also has significant additional complications considering that it was the site of a historic mill and has old infrastructure in varying degrees of decay scattered throughout, resulting in unknown environmental hazards. The property would certainly be a strong target for conservation acquisition if the current owner sells.

5.4 Implementation Timing and Anticipated Flow Benefits

Table 5-2 shows estimates of implementation timing and flow benefits for the different activities described in Sections 5.1–5.3. The dates and flow benefits are approximate best estimates, and although they are presented as constant average flow augmentation rates, through implementation and adaptive management of these actions, the flow benefits are likely to vary and generally conform with the shape of the natural hydrograph. Considering that the forest management activities are still in the pilot phase, no flow estimates have been included on the table. A combination of all direct flow augmentation, storage, and forbearance efforts are estimated to provide a dry-season flow benefit of just under 100 gpm, with the one groundwater recharge project (see Section 5.2.2) providing a small additional benefit.

In summary, this table shows that feasible opportunities for large-scale flow enhancement are limited in Redwood Creek, considering the multiple constraints associated with topography, stability, ownership, and infrastructure. However, based on current watershed characteristics and water temperature dynamics, this scale of flow enhancement (50–100 gpm) may be optimal for Coho salmon, allowing for a significant percentage of total flow to be hyporheic through many of the alluvial reaches and thereby maintaining suitable water temperatures during the hottest portion of the summer. In the long term, through forest management and a return to a more old-growth dominated forest, perhaps the unimpaired flow targets of 350–600 gpm described in Section 2.2.4 can be achieved.

Table 5-2. Implementation timing and flow benefits.

Site-specific action	Subwatershed	Landowner	Estimated flow benefit start date (year)	Flow benefit (GPM, averaged over 5-month dry season)	Cumulative flow benefit (GPM, averaged over 5-month dry season)
Instream Pond Repurposing	Miller	Kulchin	2022	5	5
Marshall Ranch Flow Enhancement	Upper Redwood	Marshall Ranch	2024	30	35
Storage and forbearance (equivalent 650,000 storage)	Miller	Briceland Municipal	2023	3	38
LCF Flow Enhancement	Upper Redwood	Lost Coast Forestlands	~2026	20	58
Instream Pond Repurposing	Dinner	Casali	~2027	5	63
Storage and forbearance (20 participants)	Redwood Mainstem	Multi	~2025-2030	5	68
Storage and forbearance (40 participants)	Dinner/ China	Multi	2030-2040?	10	78
New Flow Augmentation Ponds (2 Mil gallons)	Somerville	Marshall Ranch	2030?	10	88
Upper Dinner Instream Habitat Enhancement	Dinner	Multi	2030?	2	90
Storage and forbearance (40 participants)	Miller/ Lower Redwood/ Seely	Multi	2035-2045?	10	100

5.5 Land Acquisition and Conservation Easements

An additional important action that can facilitate flow enhancement within the watershed is land acquisition and conservation easements. This effort is already underway on the Marshall Ranch and Green Diamond property, where conservation easements have been put in place to ensure that the properties are not subdivided and remain in ranch and timber production. Not only do these large ownerships limit human consumptive water use, they also provide strong partnerships to support other types of flow enhancement activities.

It is strongly recommended that CA state agencies continue to support these efforts, including placing the Lost Coast Forestlands property in Upper Redwood Creek into a conservation easement and promoting the expansion of these sustainable ranch and timber properties. Specifically, it is recommended that these conservation actions focus first on Upper Redwood Creek and Dinner Creek to move additional properties toward conservation rather than rural residential and agricultural development when properties come up for sale.

5.6 Monitoring and Adaptive Management

A critical component of ongoing flow enhancement efforts is detailed monitoring and adaptive management. Specifically, multiple components of direct flow augmentation, groundwater recharge, and forest management activities are experimental with pilot projects just getting underway. Therefore, a key objective is learning from the outcomes of projects to inform future flow enhancement project management, planning, and design.

Primary monitoring components are discharge and water quality monitoring (flow augmentation) and discharge and groundwater well monitoring (groundwater recharge and forest thinning). As funding allows, annual monitoring to document Coho salmon and steelhead abundance should also be completed. Specifically, monitoring data will be compared to pre-project data to define project benefits and identify areas where assumptions described earlier in this report, or in individual projects' Basis of Design Reports, are incorrect or need to be refined.

Because water quality and the timing and magnitude of flow releases can be adjusted, direct flow augmentation projects have many opportunities for adaptive management. Post-construction, groundwater recharge projects have lower potential for adaptive management, but design approaches for future projects can be modified based on lessons learned from previously constructed projects.

Storage and forbearance is the least experimental, so monitoring and adaptive management would mainly focus on optimizing the water system to improve functionality and reduce maintenance for the landowner.

The nexus between forest management activities and flow enhancement is the most experimental, with initial pilot projects just recently being granted funding but have yet to begin. Monitoring and adaptive management at all levels will be required for these complex project types.

Work in Redwood Creek incorporates knowledge gained from ongoing projects within the Mattole watershed and also relies on literature from leading practitioners from around the world. Still, it is recognized that every site is unique and there are additional lessons to be learned. Adaptive management strategies will be developed in close coordination with the Technical Advisory Committee (TAC) convened by SRF. Representatives from the TAC have participated in planning design tours of several Redwood Creek flow enhancement projects and input from agency meetings and discussion continues to be incorporated into flow enhancement planning and design efforts.

A typical monitoring approach for most projects is described below. However, direct flow augmentation projects do require a significant long-term management commitment with associated monitoring and adaptive management that is different from other restoration projects, and therefore specific operations and management plans are needed for those projects that provide a detailed, site-specific monitoring and adaptive management plan.

5.6.1 Years 1 and 2 Monitoring

Monitoring in the first two years post-construction will be robust and designed to determine if the project objectives are being met, and if the features are functioning as intended. Typically, two years of post-project monitoring will include at a minimum: photo documentation, groundwater and dry-season streamflow measurements, instream habitat assessment, and surveys of the extent of dry stream length.

If it is determined that the project objectives are not being met, SRF and Stillwater will develop adaptive management measures with TAC collaboration. The TAC will review the monitoring outcomes and recommend action based on the best available science, and also assist with re-evaluation following implementation of corrective measures.

5.6.2 Years 3 to 5 Monitoring

Monitoring in the post-construction years 3–5 will typically focus on continuing to assess the flow enhancement benefit and potential need for adaptive management through continued dry-season discharge monitoring by SRF. If further adaptive management needs are identified, the TAC will be convened to determine modifications and/or maintenance of the structures.

5.6.3 Years 6 to 20 Monitoring

Long-term monitoring and adaptive management are necessary for larger flow enhancement projects, both as a requirement listed by the funder and to ensure functionality of these pilot projects. During this period, monitoring efforts will be reduced to the minimal extent necessary to inform project function and adaptive management needs but reduce cost. The specific monitoring approach for this period will be based on the monitoring and adaptive management efforts during the first 5 years of post-project monitoring and site conditions.

It is very difficult to secure funding to cover long-term operations, maintenance, and monitoring for restoration projects. Standard instream habitat restoration projects do not typically need a significant amount of long-term funding, but flow enhancement is different. To achieve long-term flow benefits from direct flow augmentation and forest thinning, long-term monitoring and operations or maintenance will be required. For the Marshall Ranch project, SRF has secured a long-term funding commitment from a private foundation to cover a portion of this cost. Forest management projects in particular are likely to require periodic thinning or vegetation management through controlled burning.

If flow enhancement efforts are to be successful in Redwood Creek over the long term, prolonged and concerted effort will be needed to both implement the actions listed in Table 5-2 and develop funding mechanisms for ongoing operations and maintenance. In parallel, developing projects that are as maintenance-free as possible is also ideal, but as described throughout this document, some level of long-term support is needed for most effective flow enhancement actions.

A combination of community/landowner involvement, private donors, and government grants will be needed to maintain these projects. Working toward multi-benefit outcomes such as wildfire safety and water security brings more landowner resources to the table to sustain projects for the long-term.

6 CONCLUSION AND IMPLICATIONS FOR OTHER WATERSHEDS

Section 5 of this report defines a roadmap for flow enhancement in Redwood Creek. Specific direct flow augmentation, storage, and forbearance projects have been identified that are expected to result in 100 gpm of flow augmentation. Still, this falls well below the unimpaired flow targets for Redwood Creek of 350–600 gpm as defined in Section 2.2.4. However, based on current watershed conditions, this scale of flow enhancement is expected to provide meaningful benefits to Coho salmon and steelhead. In the long term, vegetation management with a return to a more old-growth dominated forest, combined with passive runoff retention and release, is likely to result in additional progress toward the unimpaired flow target goals.

Flow enhancement is a highly challenging restoration field that is still in its infancy in terms of supporting science and identifying projects that achieve results. Pilot projects that are currently underway should be closely analyzed to understand how different approaches can be implemented to achieve the desired outcomes. The flow enhancement implementation plan presented herein should be adaptively managed based on project outcomes.

The general project planning approach described in Sections 1 and 2 of this report are replicable for flow enhancement planning efforts in watersheds experiencing similar dry-season conditions. Special attention should be paid to spatial variations in hillslope hydrologic processes throughout the target watershed to understand general dynamics, to identify potential project sites, and to inform design and future management activities.

There is a strong benefit to incorporating a variety of project types into flow enhancement efforts, both to provide increased flows during different periods of the dry season and engage different sectors of the community through projects with multi-benefits. Considering the relative innovation of these restoration goals, it is important to try a variety of approaches and use lessons learned from those approaches to further evolve the field.

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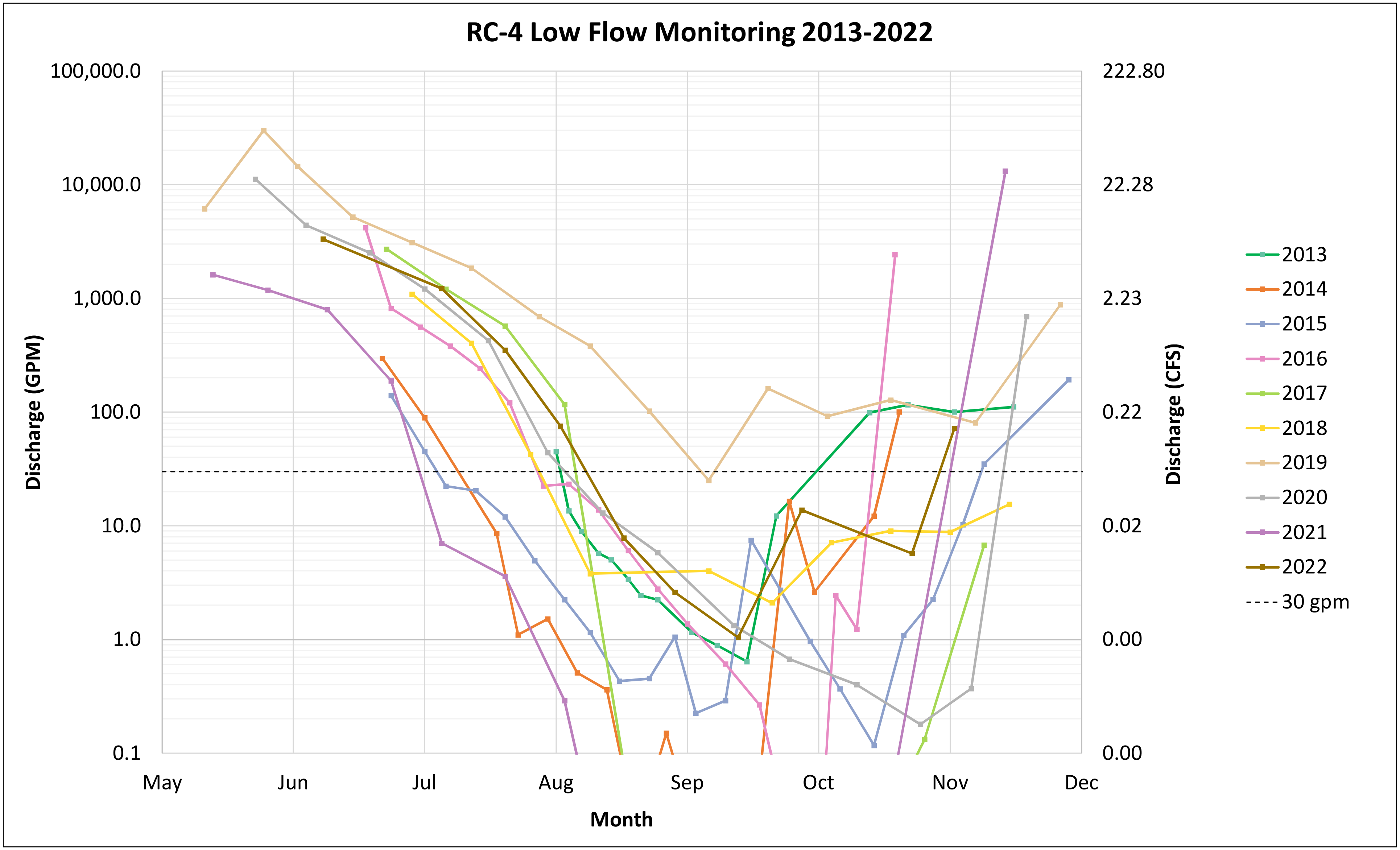
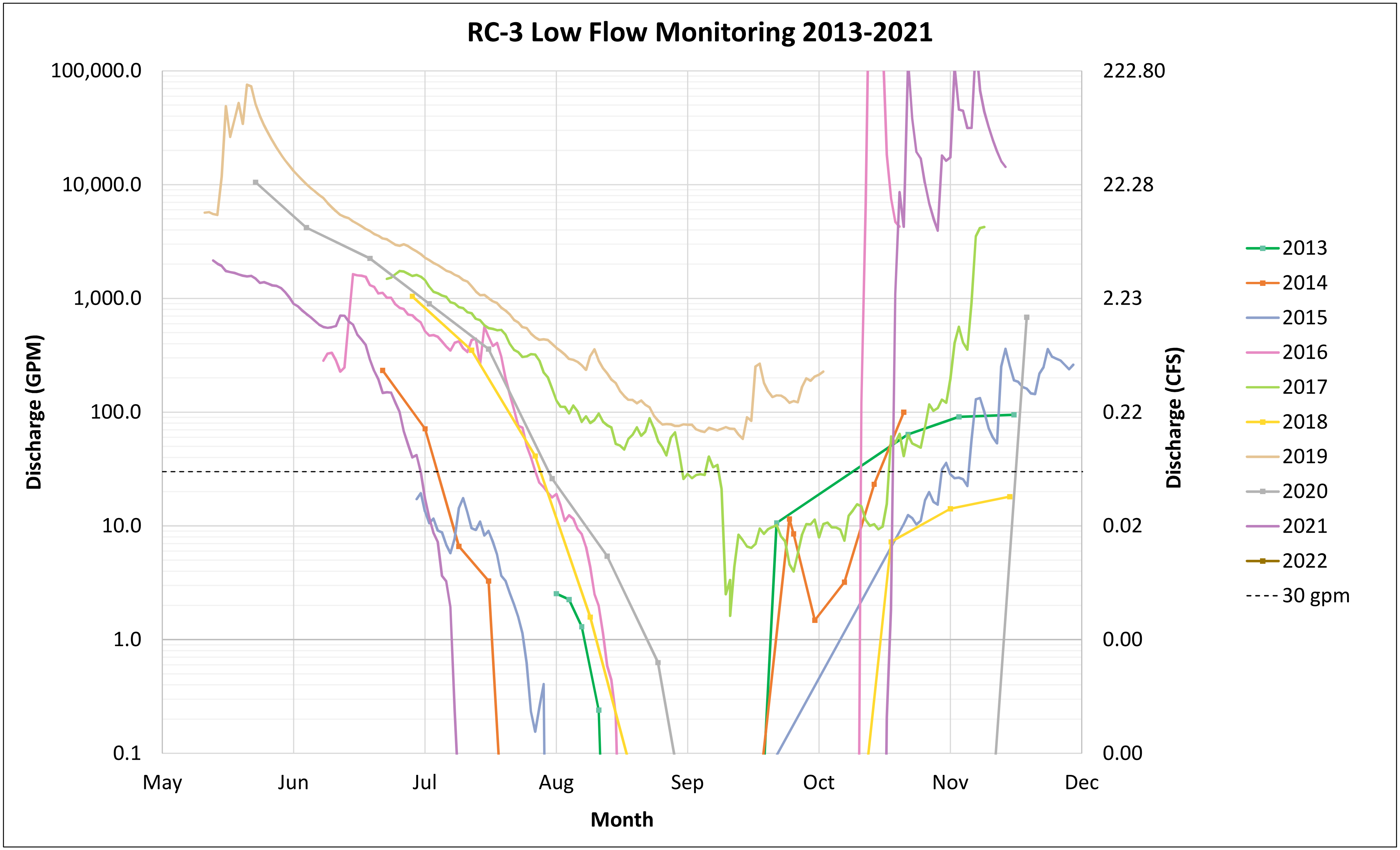
Appendices

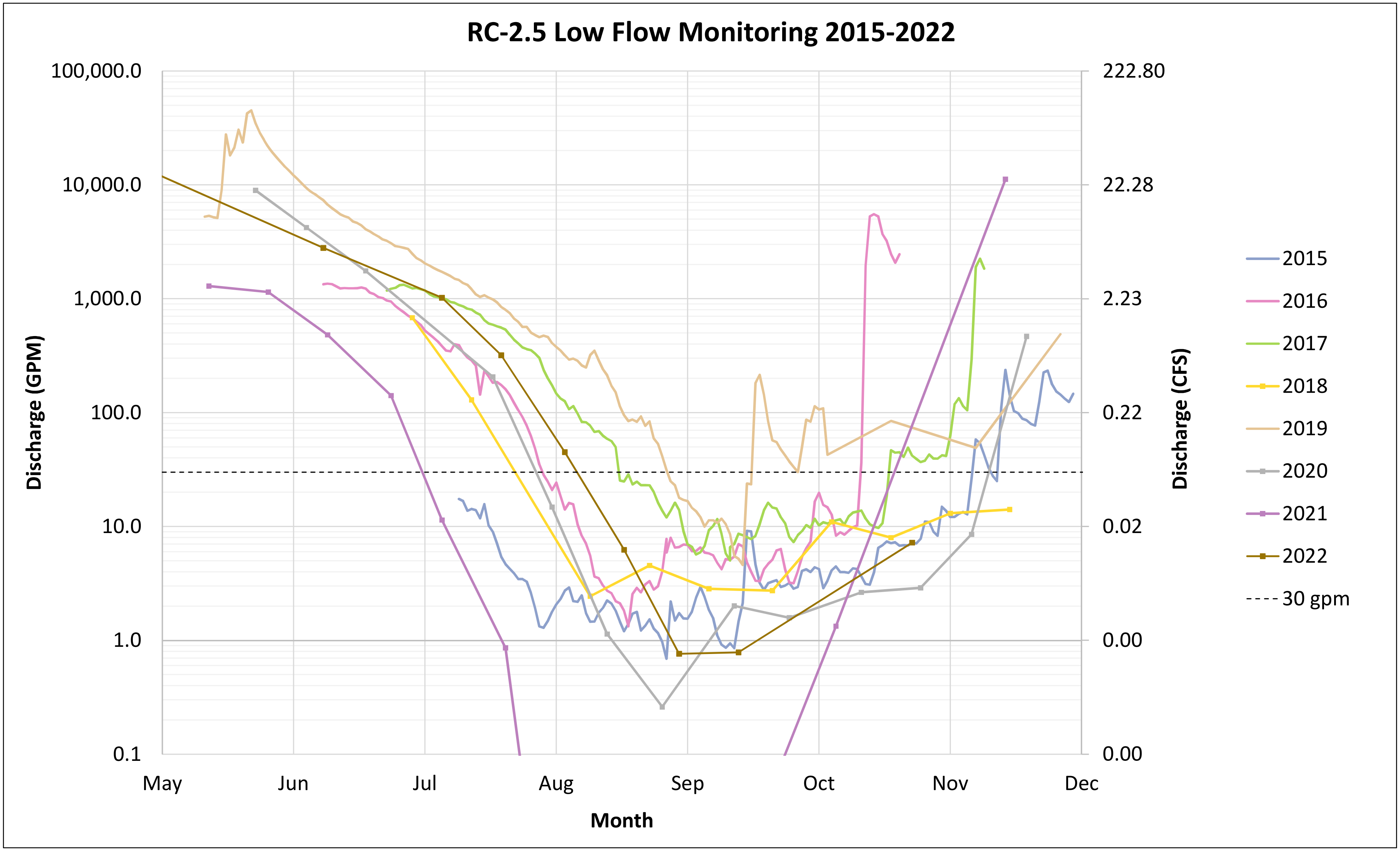
Appendix A

Dry-season Flow Monitoring Results for 2013 to 2022

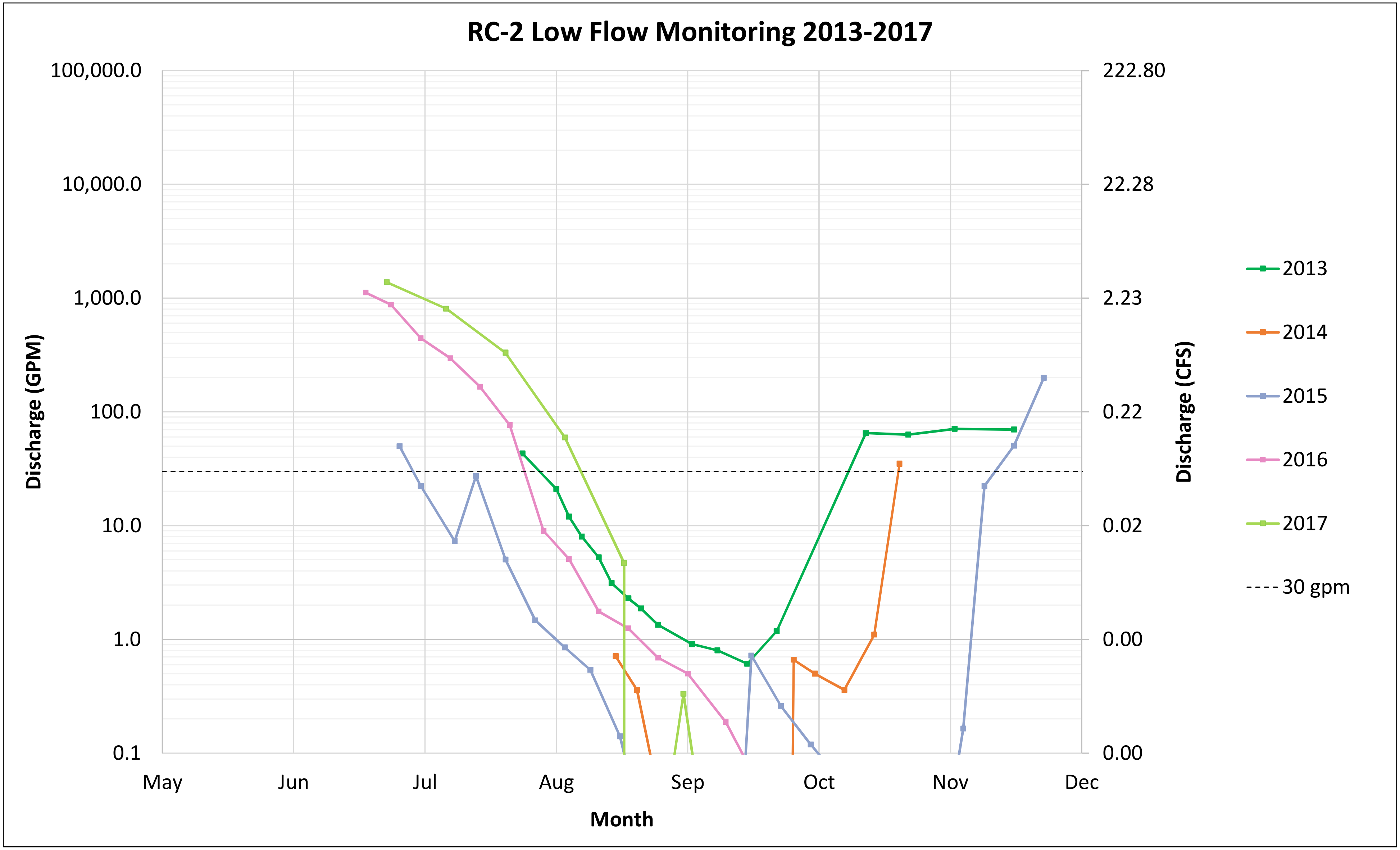


RC-4 Low Flow Monitoring 2013-2022
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
30 gpm

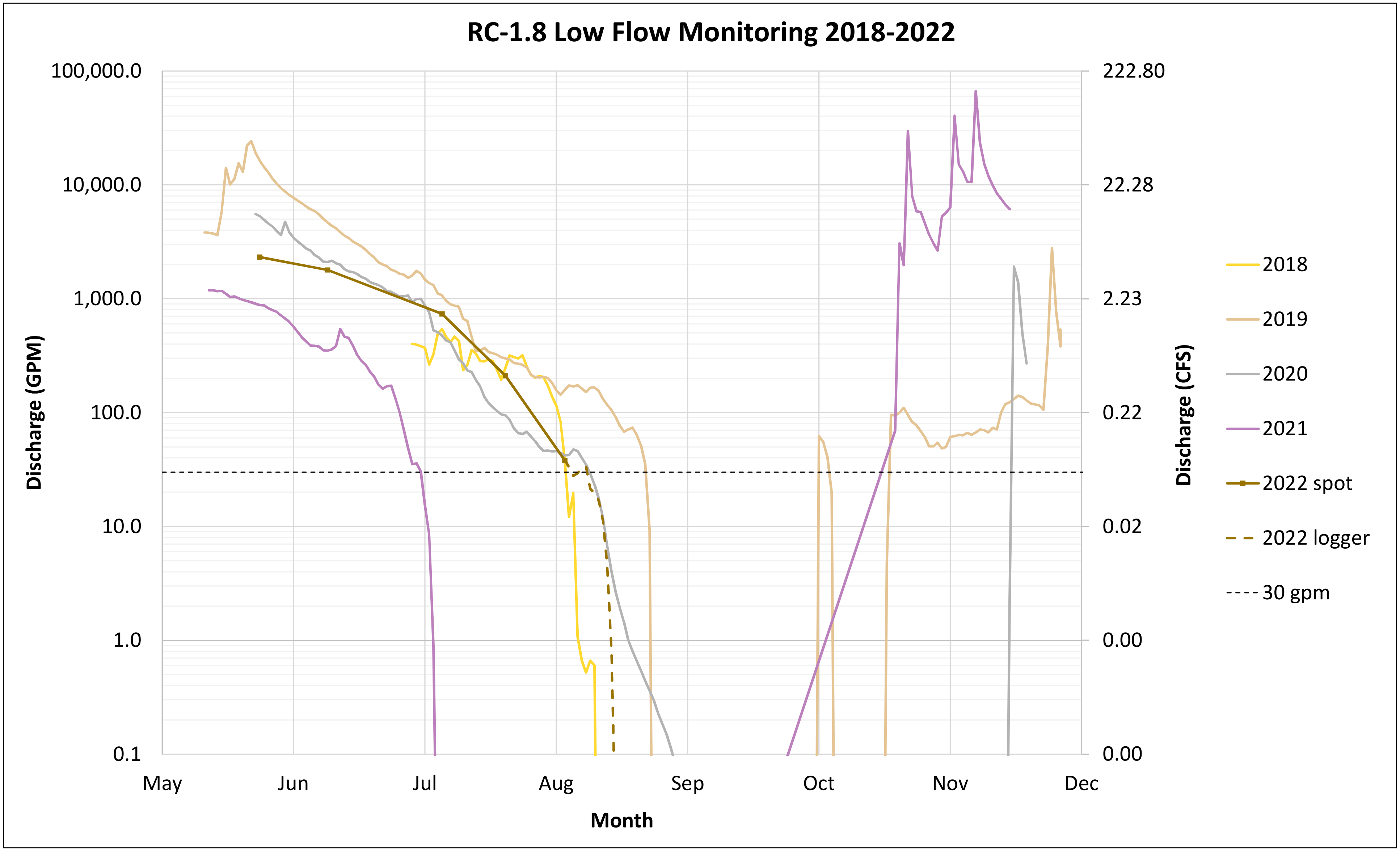

RC-3 Low Flow Monitoring 2013-2021
Discharge (GPM)
Discharge (CFS)
Month
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
30 gpm



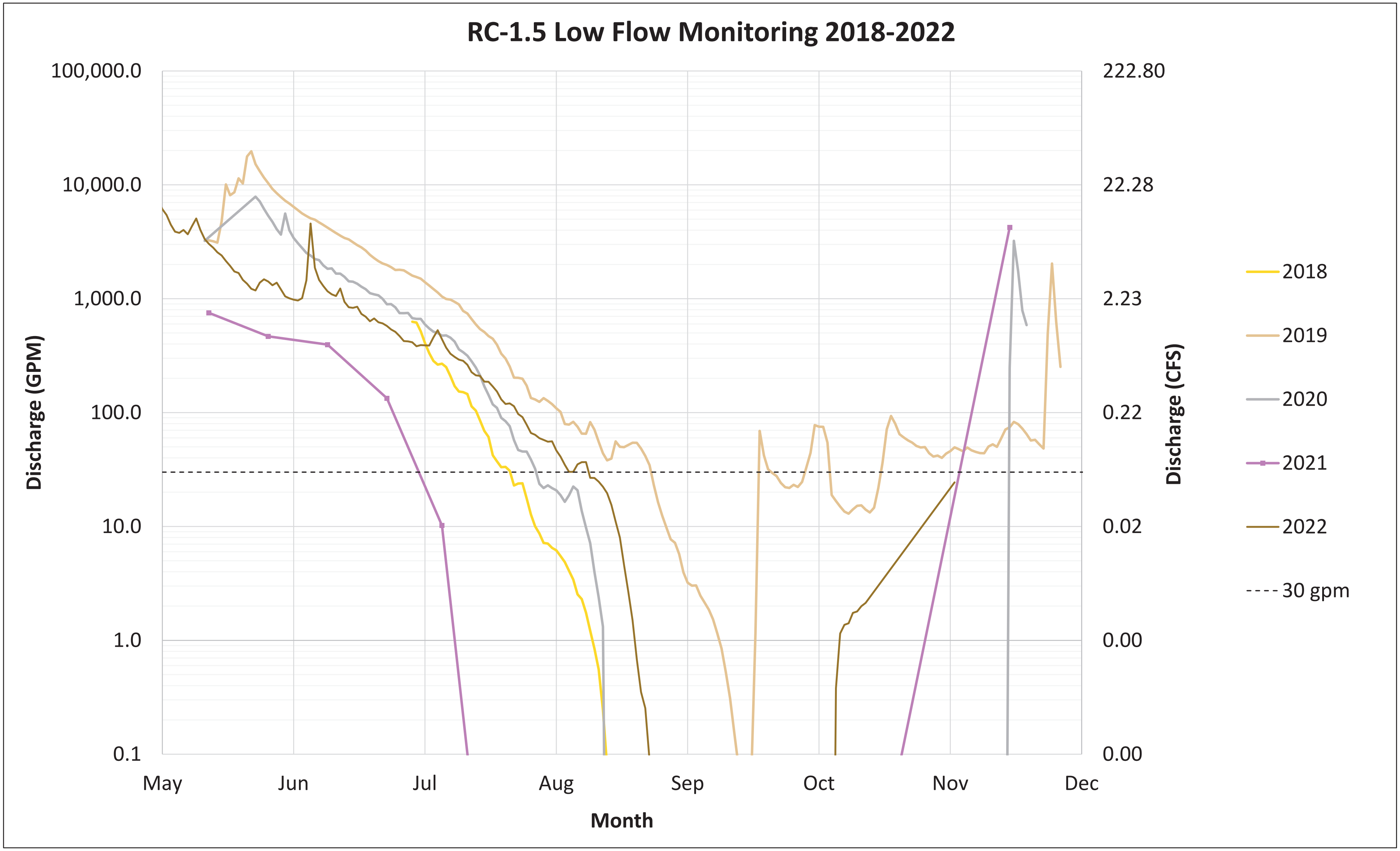
RC-2.5 Low Flow Monitoring 2015-2022
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2015
2016
2017
2018
2019
2020
2021
2022
30 gpm

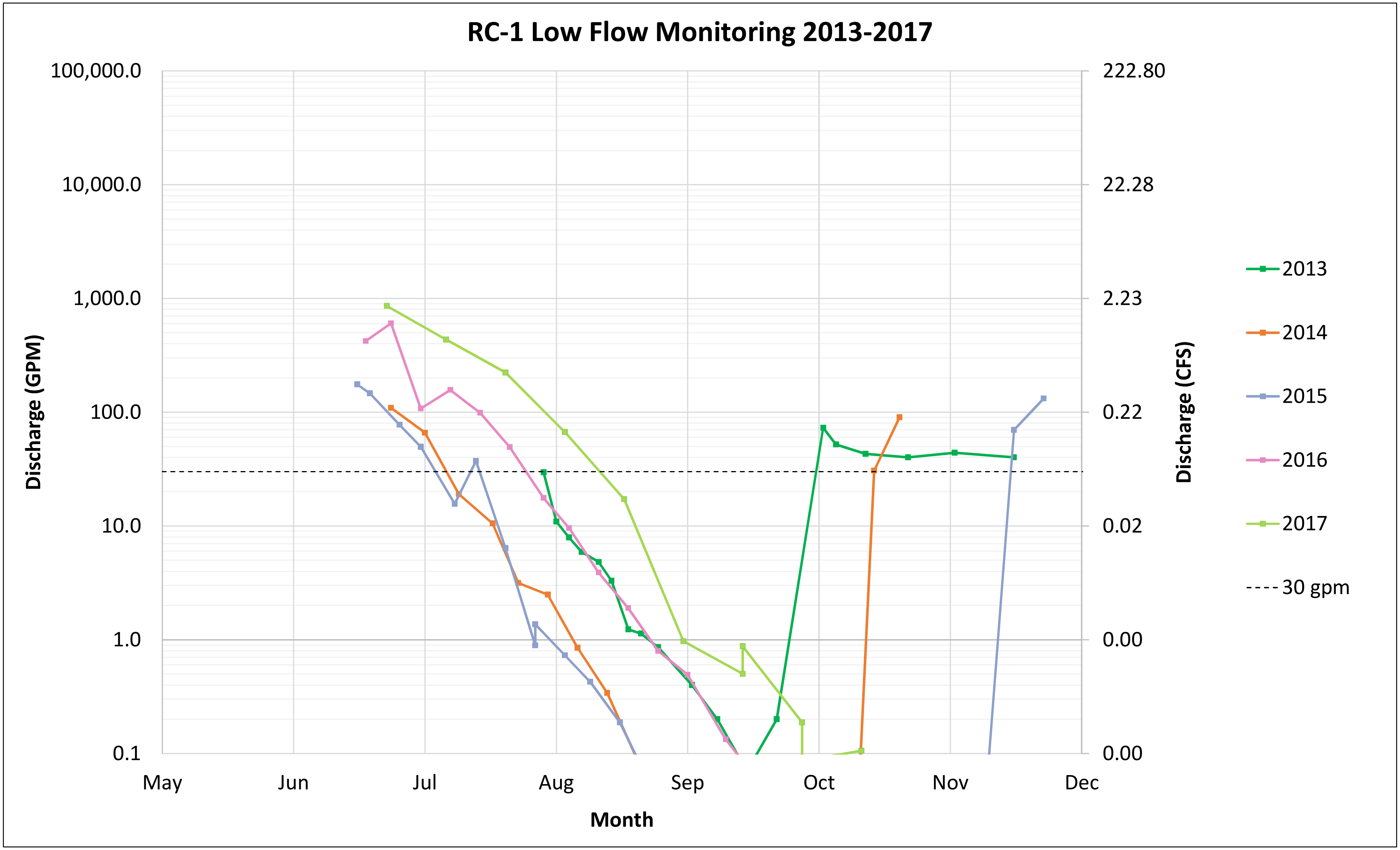


RC-2 Low Flow Monitoring 2013-2017
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
2017
30 gpm

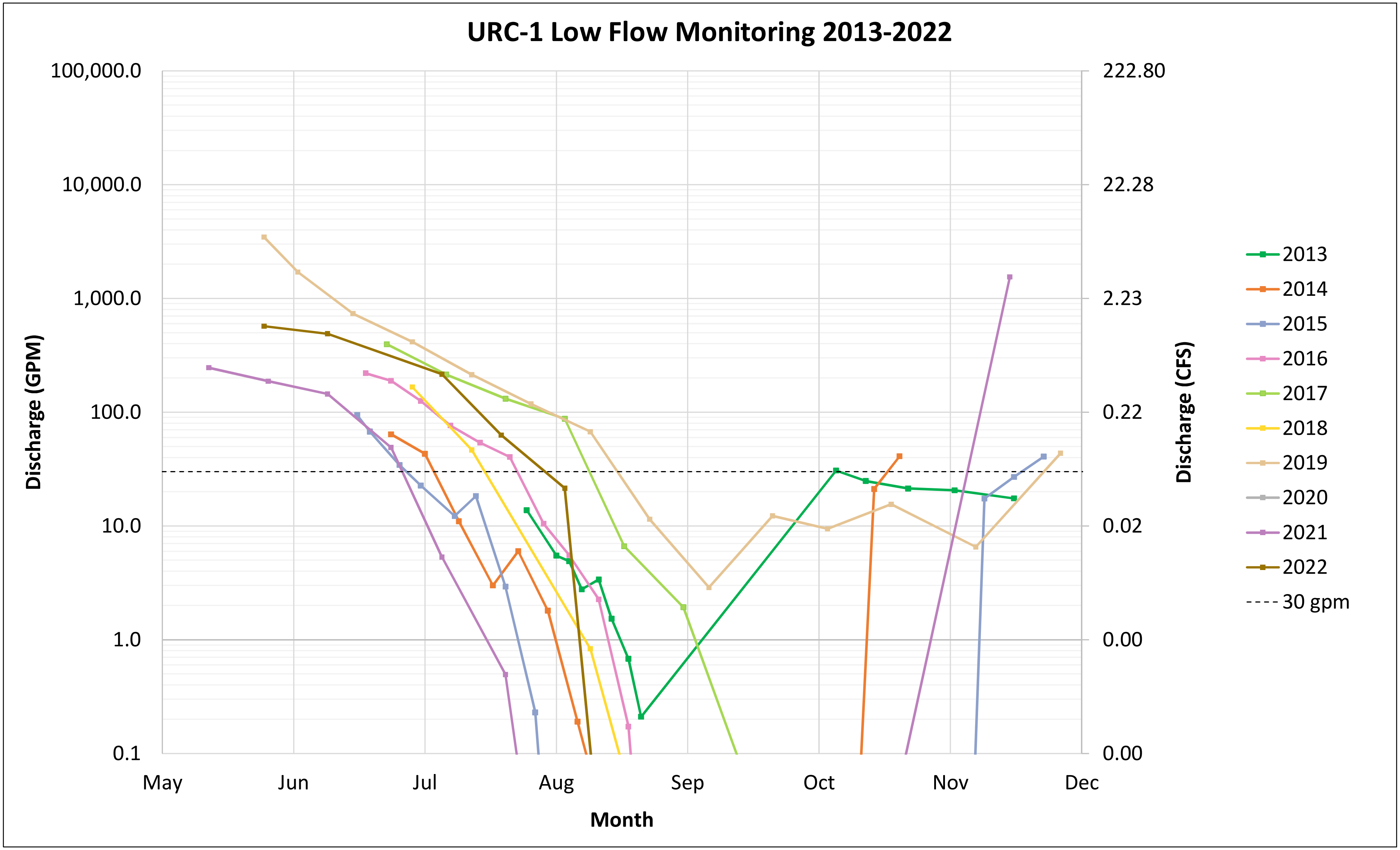


RC-1.8 Low Flow Monitoring 2018-2022
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (GPM)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
Discharge (CFS)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2018
2019
2020
2021
2022 spot
2022 logger
30 gpm


RC-1.5 Low Flow Monitoring 2018-2022
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2018
2019
2020
2021
2022
30 gpm



RC-1 Low Flow Monitoring 2013-2017
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
2017
30 gpm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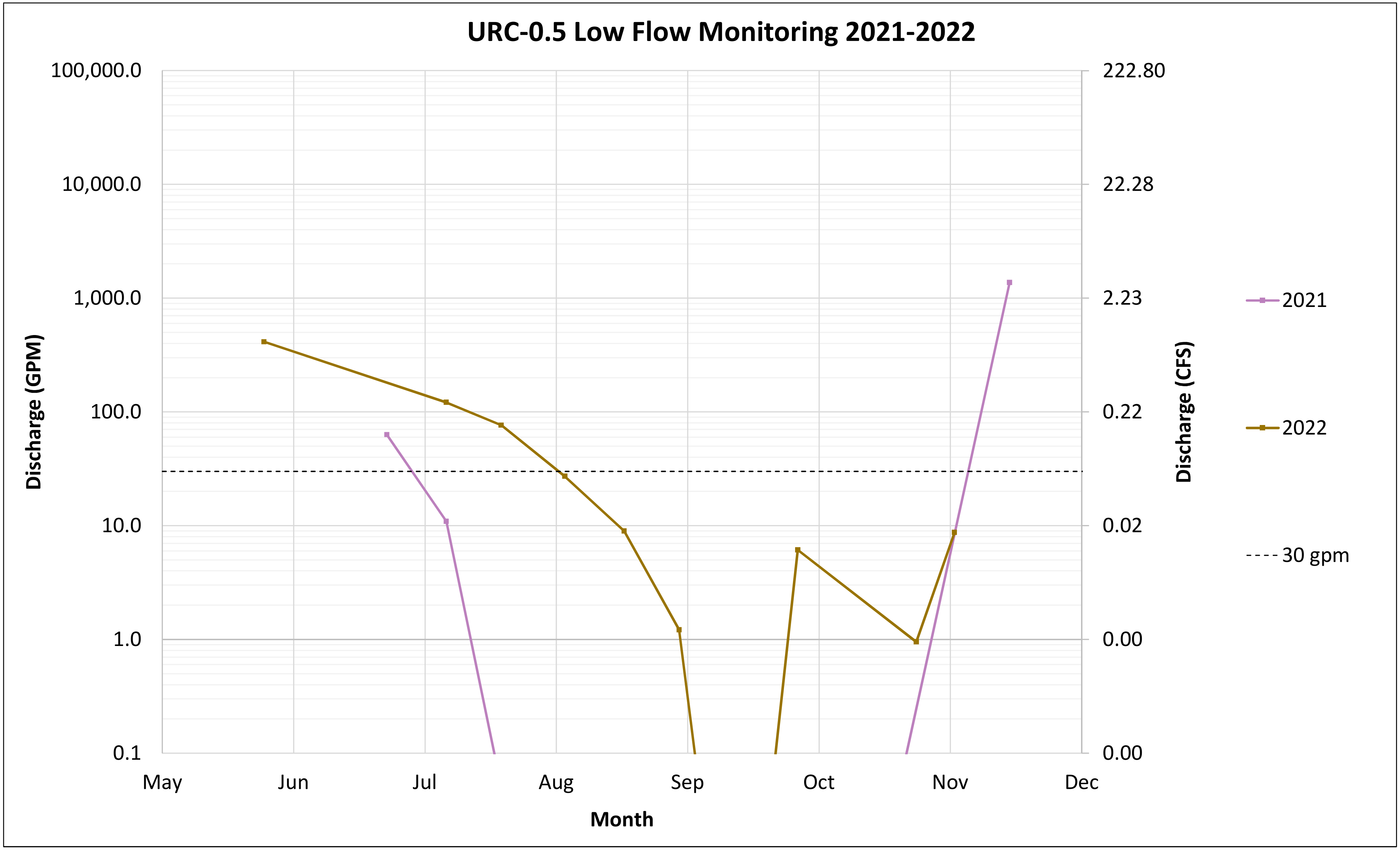
1,000.0
100.0
10.0
1.0
0.1
Discharge (GPM)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
Discharge (CFS)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
30 gpm



URC-0.5 Low Flow Monitoring 2021-2022
Discharge (GPM)
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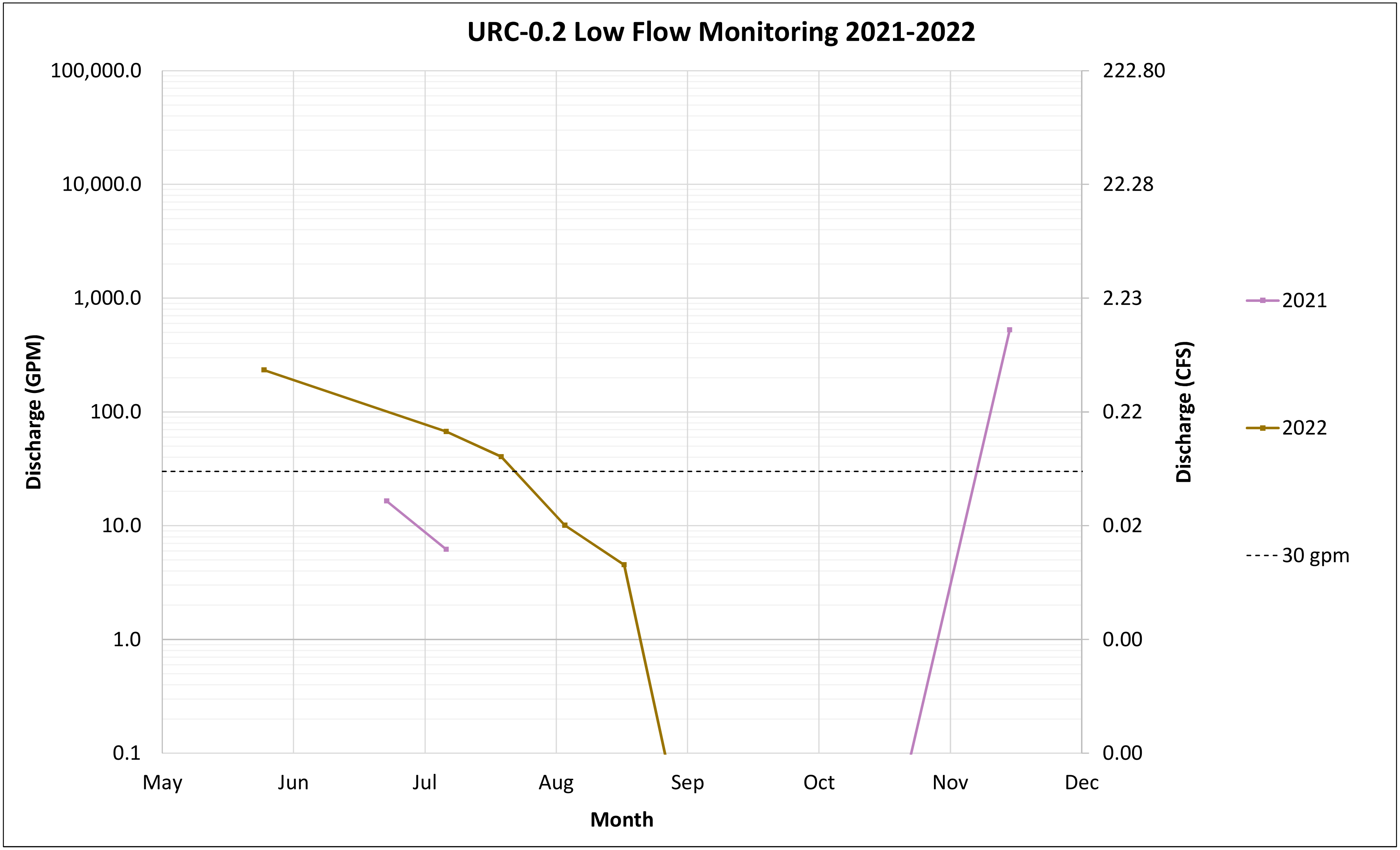
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2021
2022
30 gpm


URC-0.2 Low Flow Monitoring 2021-2022
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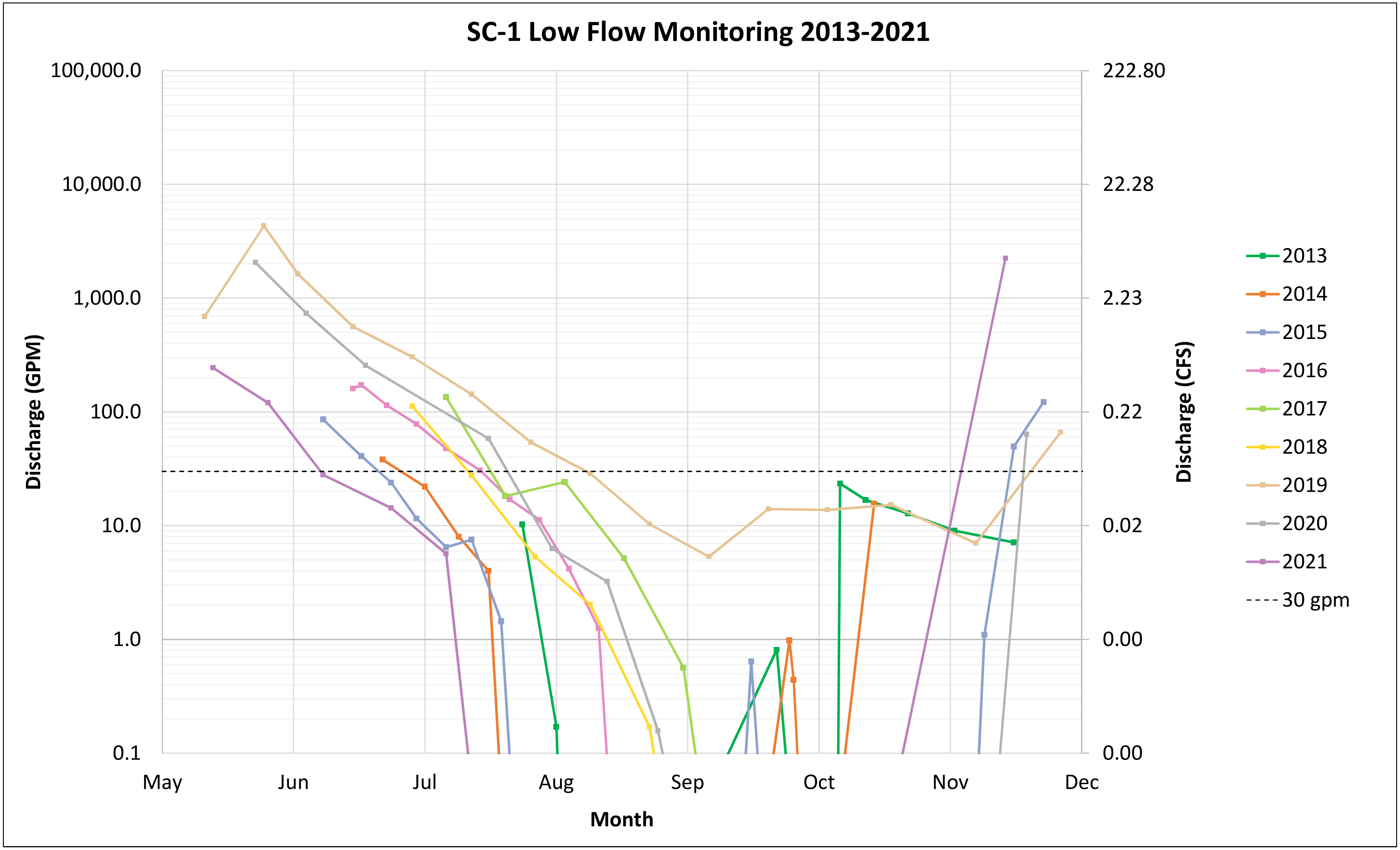
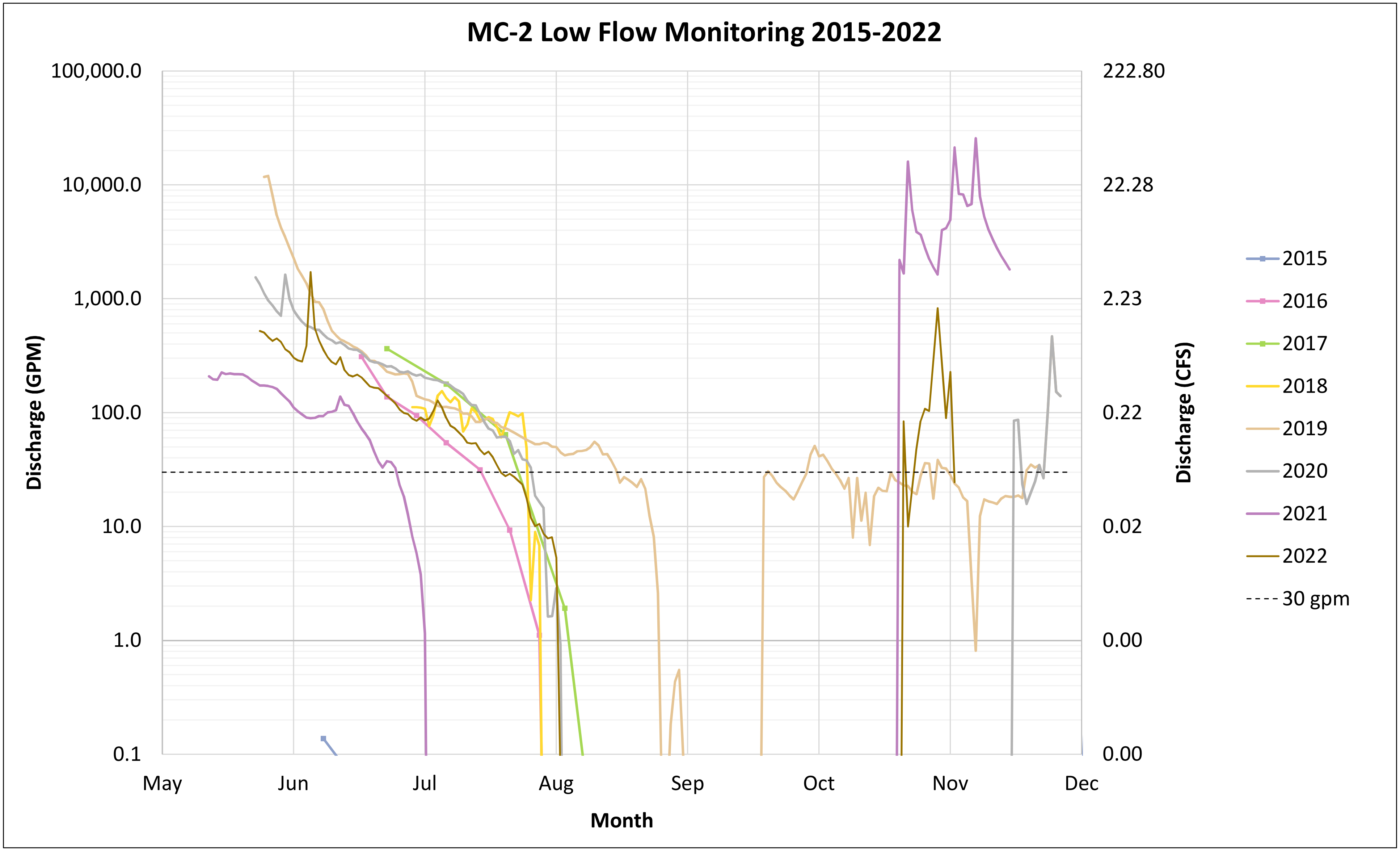
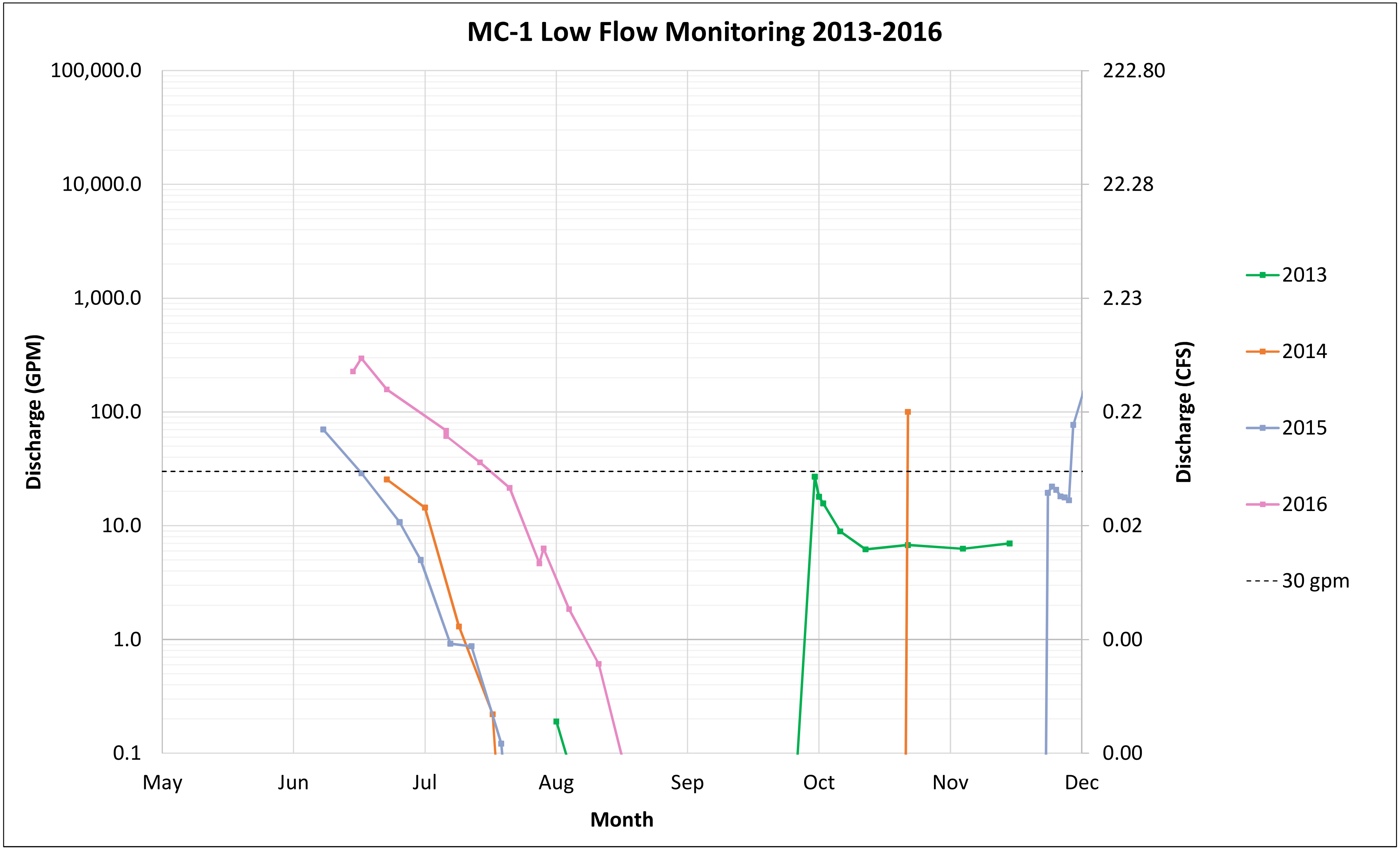
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (GPM)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
Discharge (CFS)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2021
2022
30 gpm



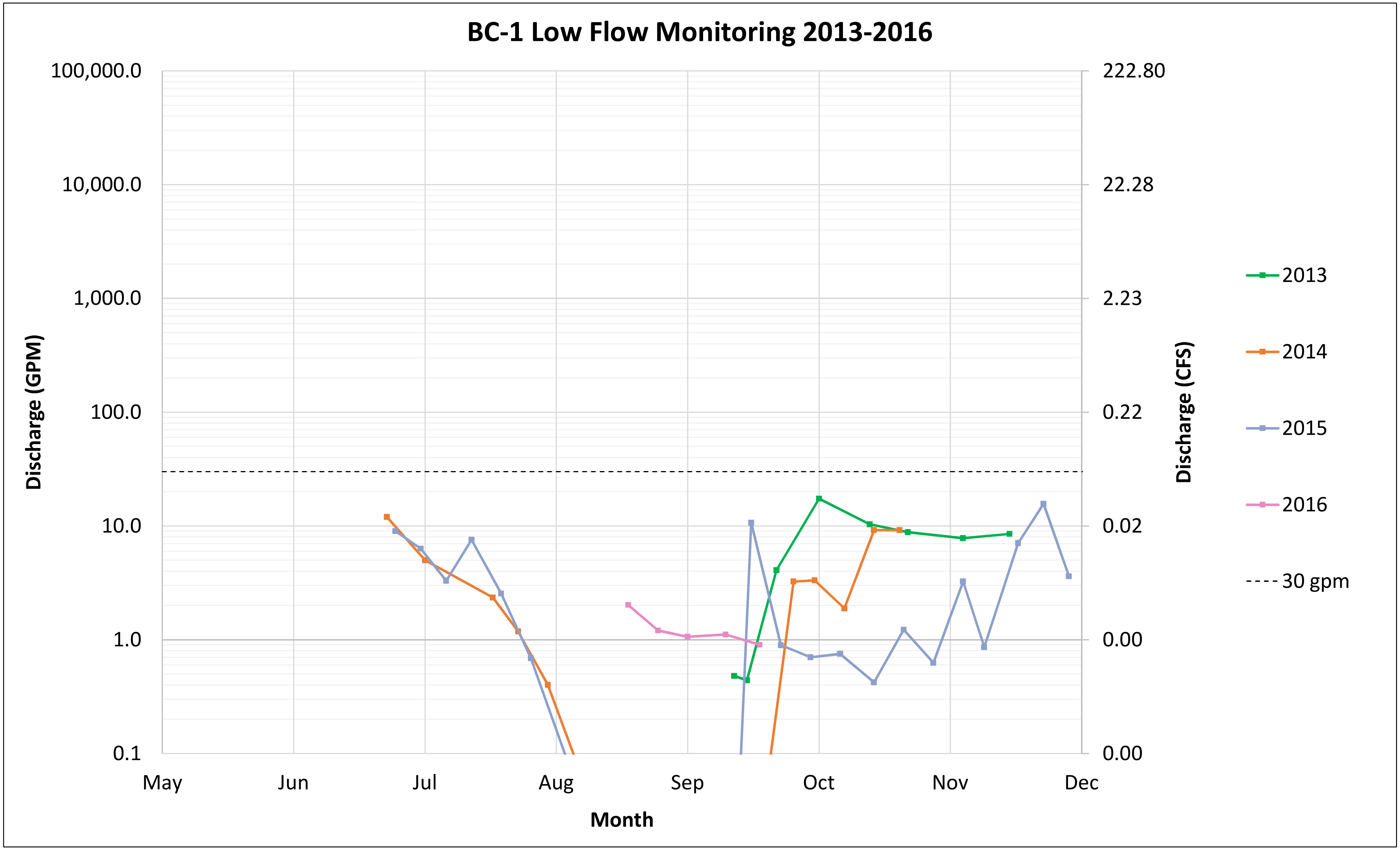
SC-1 Low Flow Monitoring 2013-2021
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
2017
2018
2019
2020
2021
30 gpm

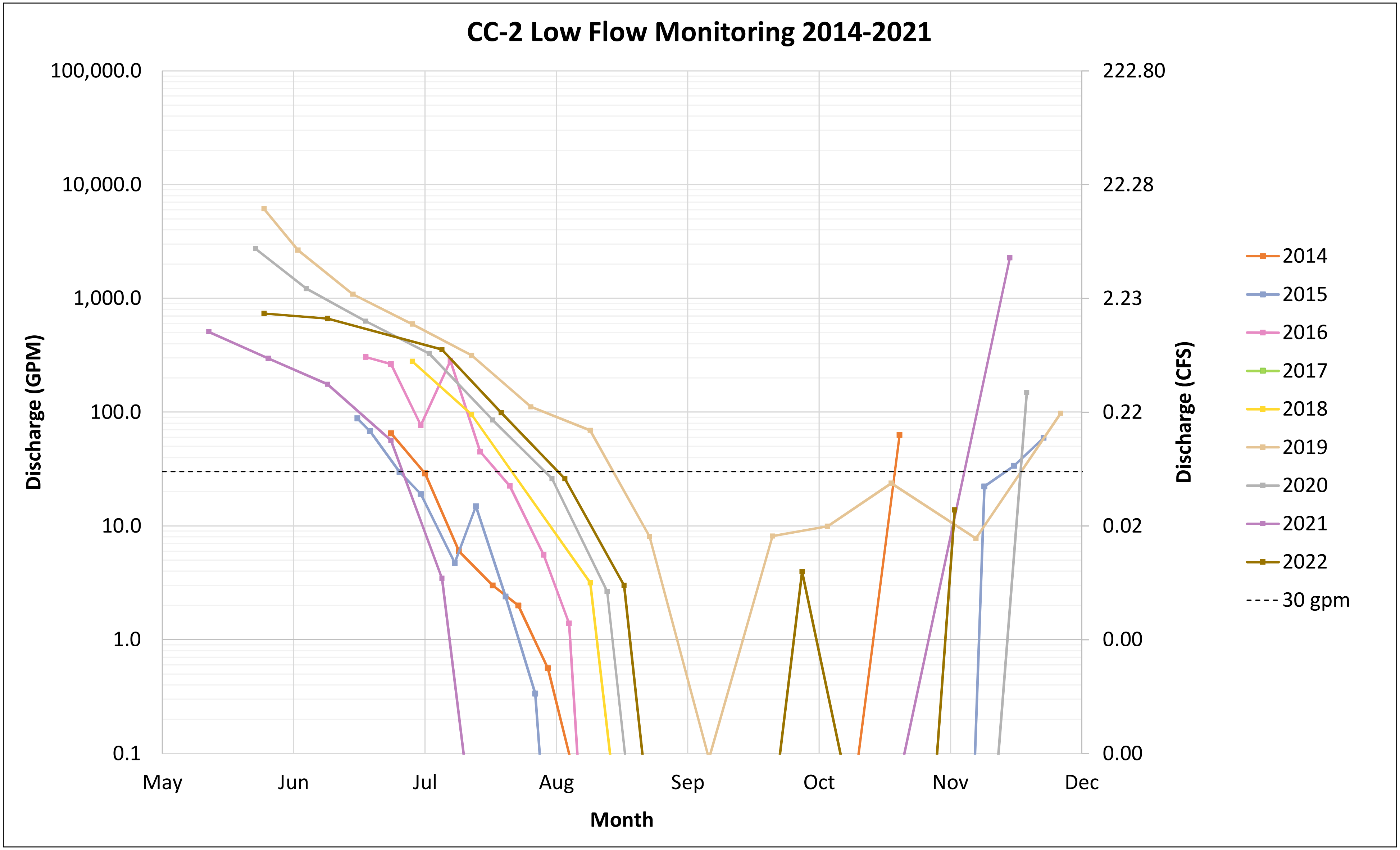


MC-2 Low Flow Monitoring 2015-2022
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2015
2016
2017
2018
2019
2020
2021
2022
30 gpm



MC-1 Low Flow Monitoring 2013-2016
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (GPM)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
Discharge (CFS)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
30 gpm


BC-1 Low Flow Monitoring 2013-2016
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
30 gpm



CC-2 Low Flow Monitoring 2014-2021
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
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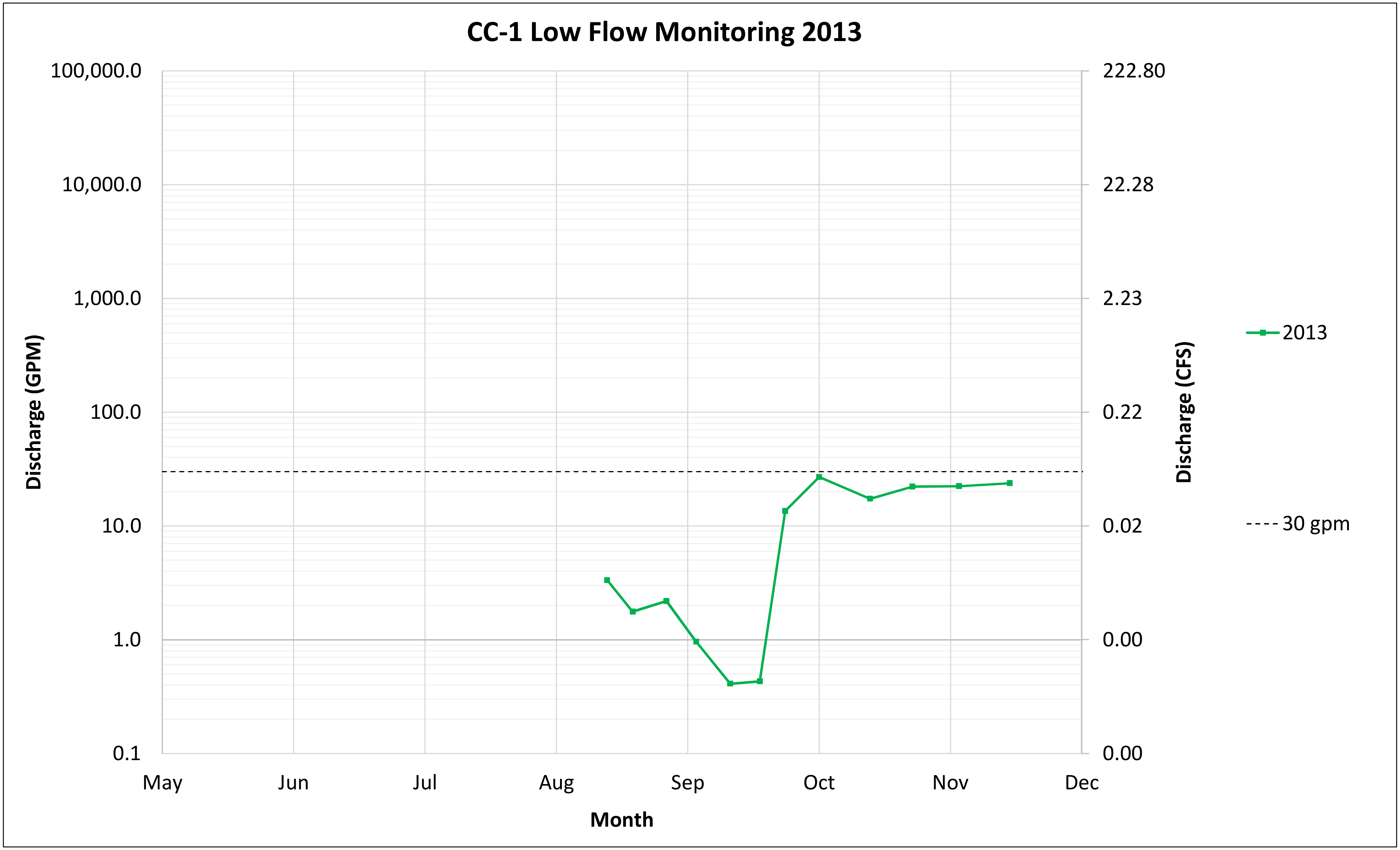
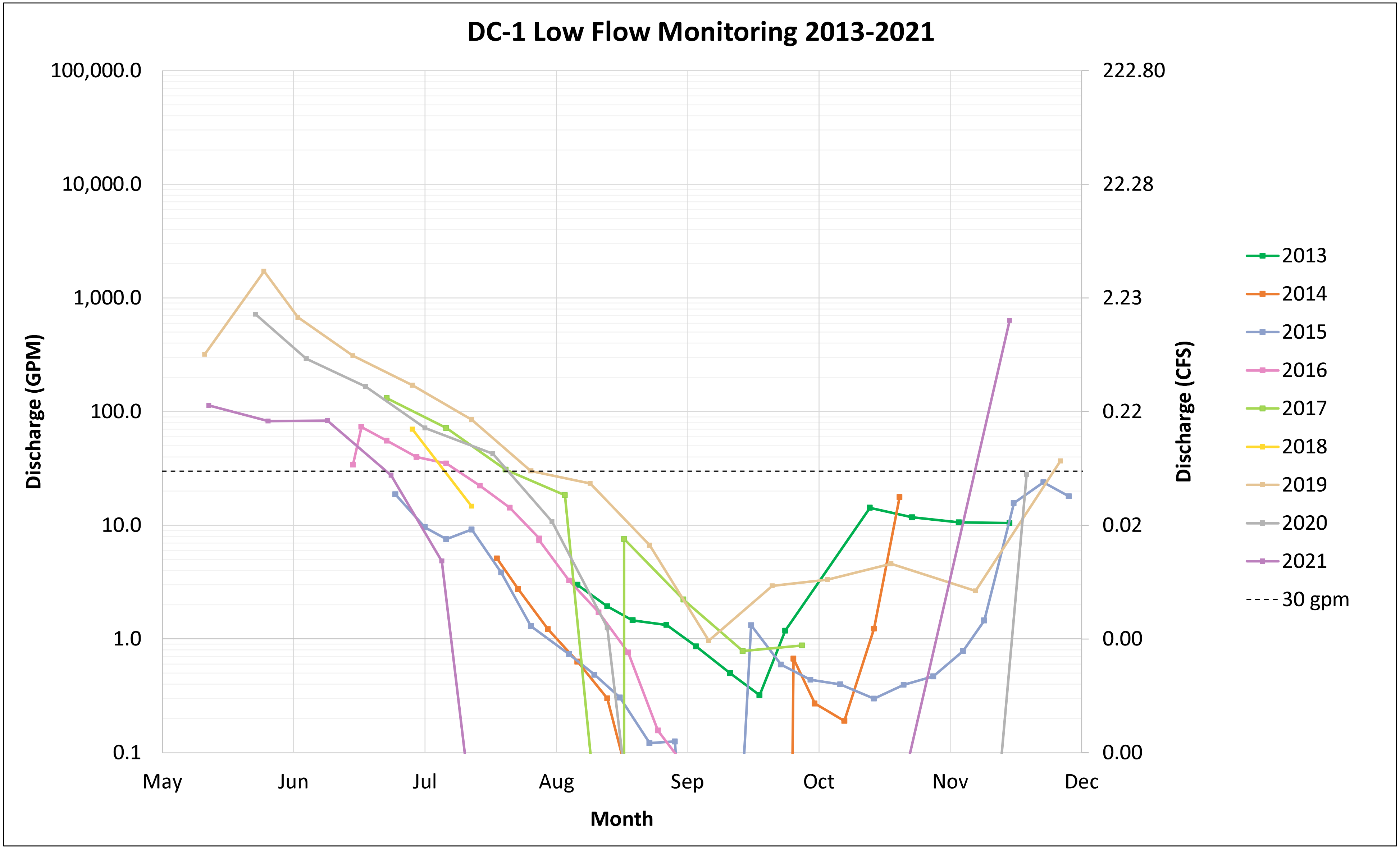
Sep
Oct
Nov
Dec
Month
2014
2015
2016
2017
2018
2019
2020
2021
2022
30 gpm



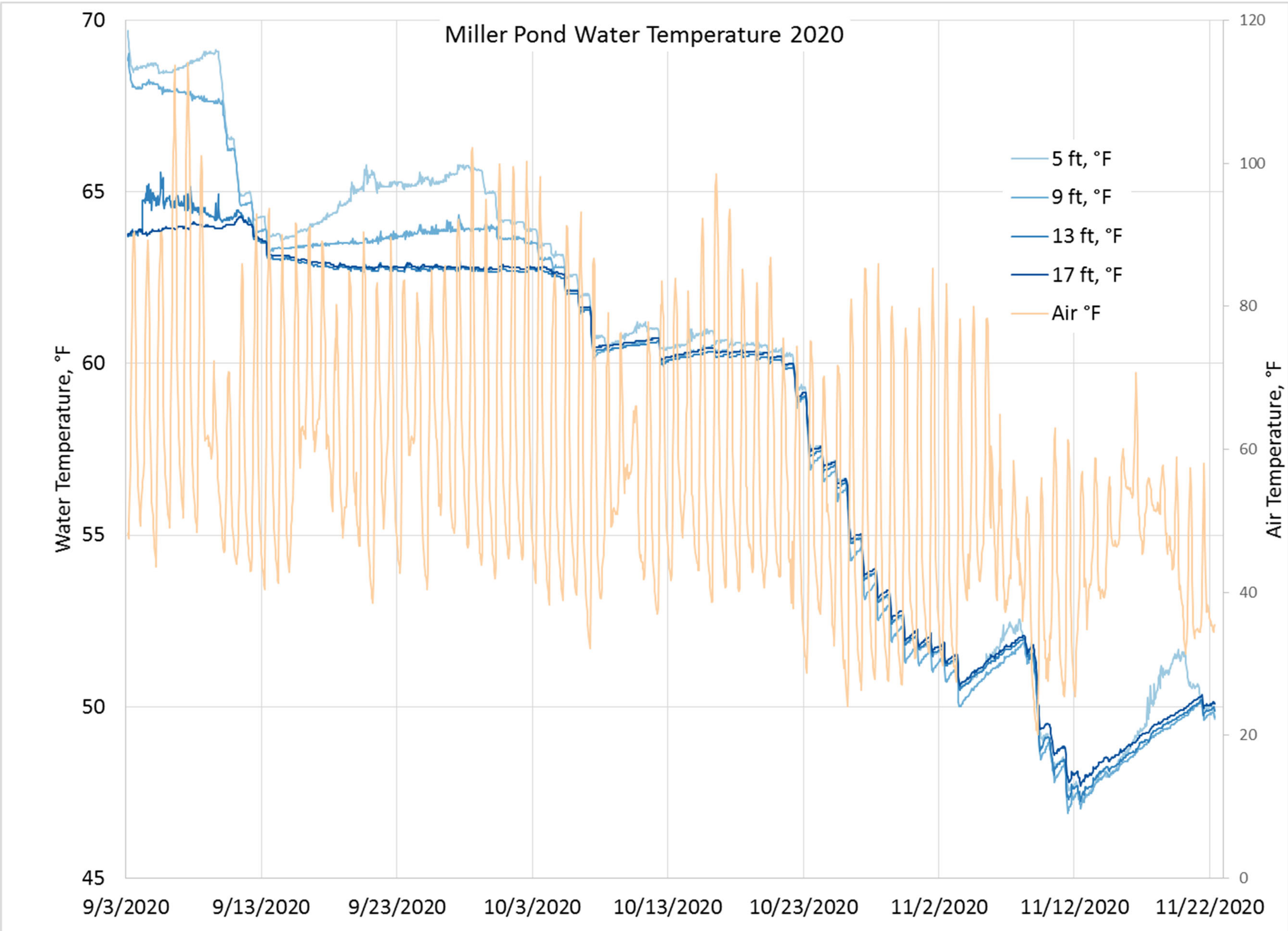
CC-1 Low Flow Monitoring 2013
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (GPM)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
Discharge (CFS)
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
30 gpm

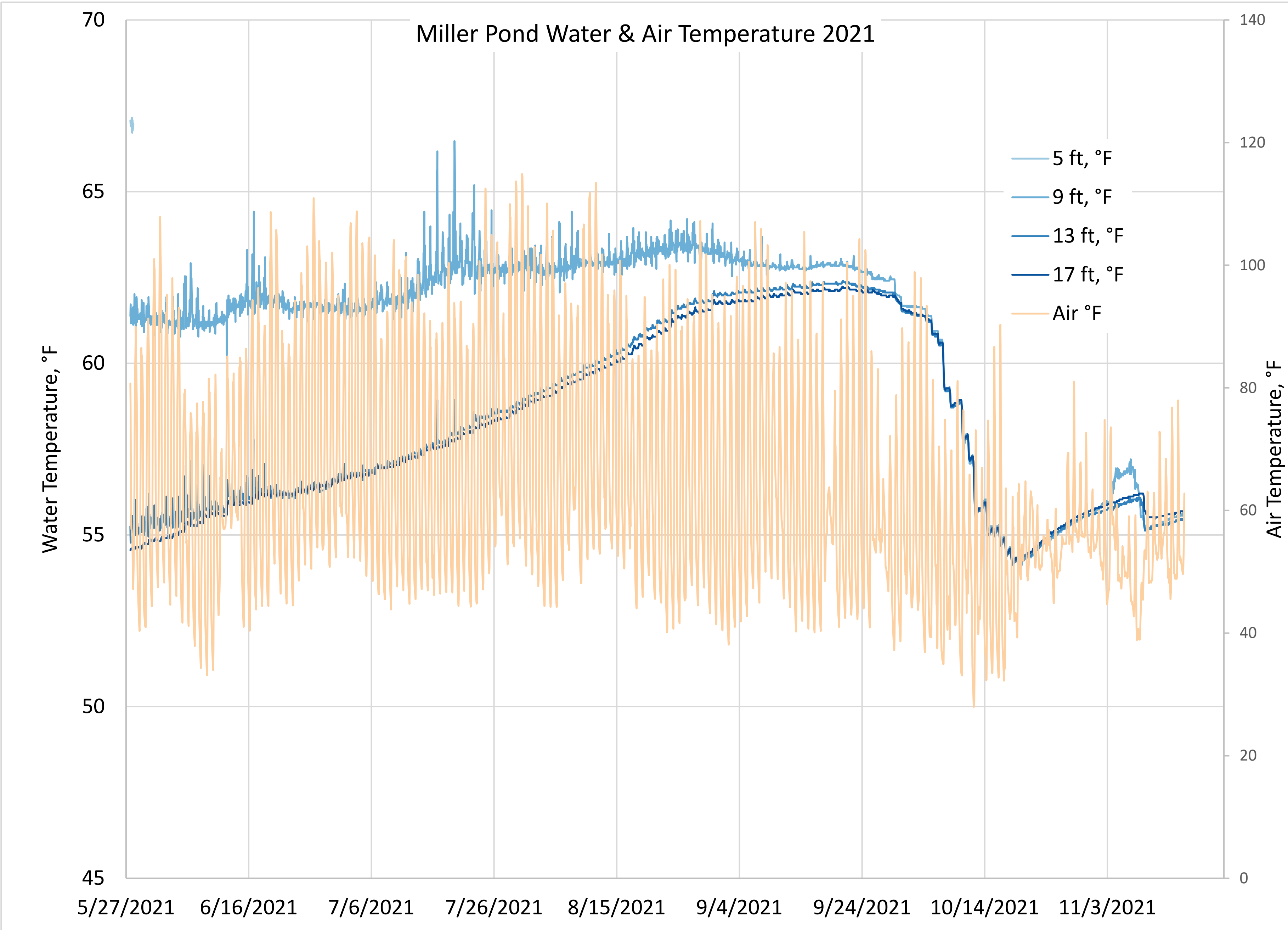


DC-1 Low Flow Monitoring 2013-2021
Discharge (GPM)
100,000.0
10,000.0
1,000.0
100.0
10.0
1.0
0.1
Discharge (CFS)
222.80
22.28
2.23
0.22
0.02
0.00
0.00
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
2013
2014
2015
2016
2017
2018
2019
2020
2021
30 gpm

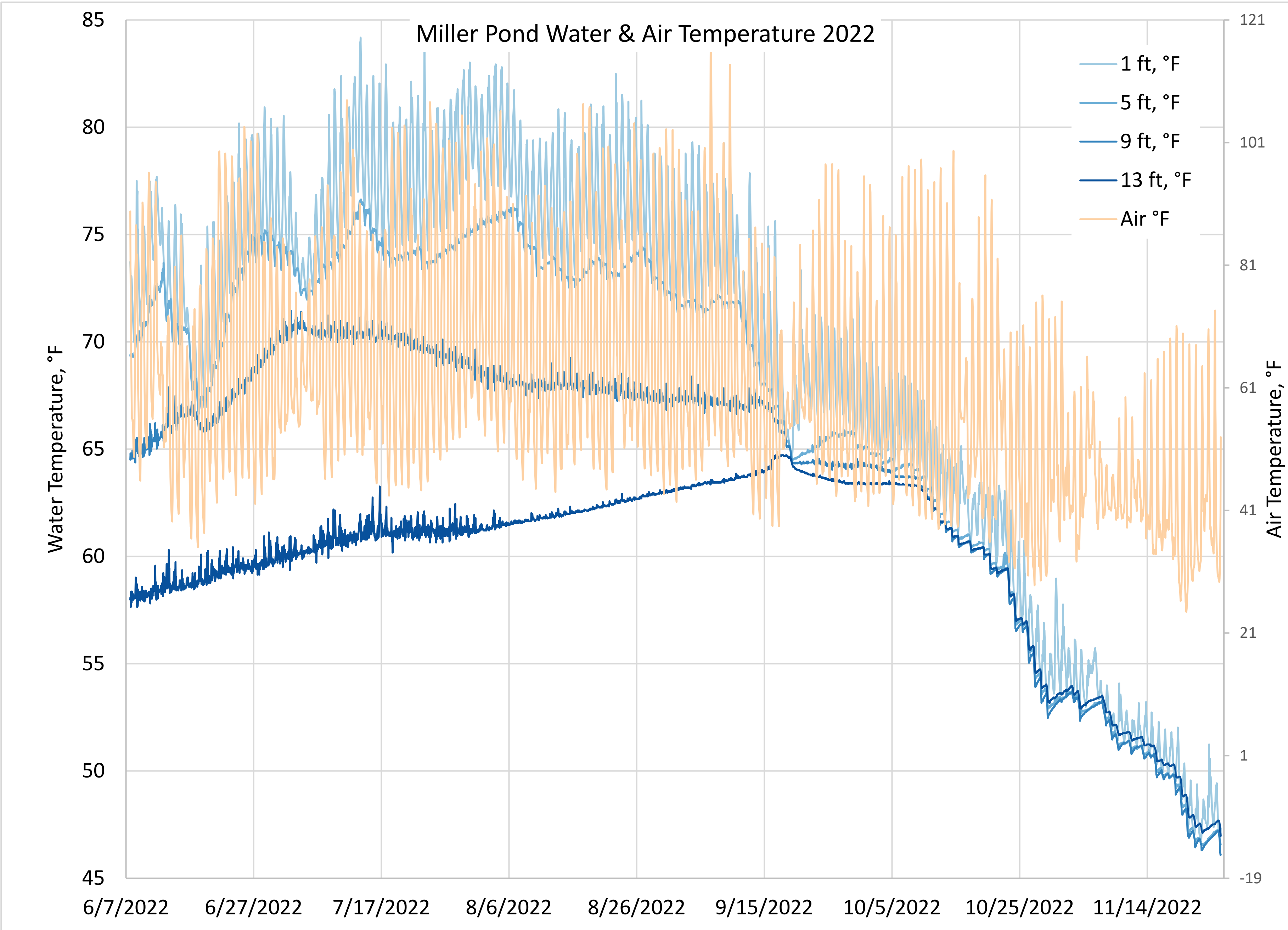
Appendix B

Dry-season Pond Water Temperature Monitoring Results for 2020 to 2022


Miller Pond Water Temperature 2020
Water Temperature, °F
Air Temperature, °F
70
65
60
55
50
45
120
100
80
60
40
20
0
9/3/2020
9/13/2020
9/23/2020
10/3/2020
10/13/2020
10/23/2020
11/2/2020
11/12/2020
11/22/2020
5 ft, °F
9 ft, °F
13 ft, °F
17 ft, °F
Air °F



Miller Pond Water & Air Temperature 2021
Water Temperature, °F
Air Temperature, °F
70
65
60
55
50
45
140
120
100
80
60
40
20
0
5/27/2021
6/16/2021
7/6/2021
7/26/2021
8/15/2021
9/4/2021
9/24/2021
10/14/2021
11/3/2021
5 ft, °F
9 ft, °F
13 ft, °F
17 ft, °F
Air °F


Miller Pond Water & Air Temperature 2022
Water Temperature, °F
Air Temperature, °F
1 ft, °F
5 ft, °F
9 ft, °F
13 ft, °F
Air °F
85
80
75
70
65
60
55
50
45
121
101
81
61
41
21
1
-19
6/7/2022
6/27/2022
7/17/2022
8/6/2022
8/26/2022
9/15/2022
10/5/2022
10/25/2022
11/14/2022

Appendix C

Hydro-geomorphic Field Assessment Summary Data

Redwood Creek Watershed Assessment 2019

All surveys conducted between Sept 30 and Nov 4, 2019

Stream Reach Name	APN	Landowner	Sub-Reach	Dry Reach?	Flow and Water Quality Observations	Reach Length (ft)	Average Slope (%)	Average Channel Width (ft)	Dominant Channel Substrate	Legacy Channel Disturbance	Recent Channel Disturbance/Restoration activities	General Morphology	Fish Observations	Aquatic Habitat Conditions	Restoration Potential
Dinner Trib 1	220091025	John Casali	Lower	No	Trickle	360	4	10	Small cobble and gravel	Culverts on Briceland/Thorn Road and private driveway agraded channel	Replaced two culverts for fish passage, ~2-3' of incision migrating upstream	Channel incised ~6 to 8' below floodplains	YOY Steelhead in small pools	Likely goes dry in most years; minimal complexity	Flow enhancement potential exists, revisit as reach-scale approaches are developed; Instream habitat enhancement adjacent to and upstream from recent culvert upgrades
			Mid	Yes	N/A	430	5	8	Small cobble and gravel	Culverts on Briceland/Thorn Road and private driveway agraded channel	Replaced two culverts for fish passage, ~2-3' of incision migrating upstream	Channel incised ~6 to 8' below floodplains	N/A	N/A	Flow enhancement potential exists, revisit as reach-scale approaches are developed.
			Upper	No	Good flow and water quality for size of channel, appears to be a major source for Dinner Creek	860	6	6	Small cobble and gravel	Remnants of blown out instream pond (culvert/spillway infrastructure); near channel logging roads	None	Channel incised ~6 to 8' below floodplains	YOY Steelhead in small pools	Fairly typical small Class I watercourse, could use more complexity	BDAs/Large Wood/Trench Walls
Dinner 1	220091026	John Casali	Lower	Yes	N/A	460	5	8	Cobble	Gravel has been cut off by instream pond	None	Varies	N/A	N/A	Large Wood/Trench Walls
			Mid	No	Instream pond, with minor inflow	300	N/A	N/A	N/A	Instream Pond	Cleaning/repair of instream pond	N/A	N/A	N/A	Rebuild dike, manage pond for flow enhancement
			Upper	Yes	Trickle	560	10	4	Gravel and small cobble	Signfiicant disturbance from legacy logging road crossing	None	Confined valley	N/A	Amphibians only	Retrofit failing legacy crossing and manage for flow enhancement
Dinner 2	220092007	Irene Randall	Lower	No	Minimal flow though relatively continuous pools with clear water.	350	2	12	Small cobble and gravel	Culverts on Briceland Thorn Road aggraded channel	Replaced culvert for fish passage, ~4-5' of incision migrating upstream	Channel incised ~8 feet below floodplain	YOY Steelhead in pools	Incision causing LWD recruitment.	Good opportunity for instream habitat enhancement in reach directly upstream from recent culvert upgrade: weirs and LW placement
			Upper	Yes	Two short dry patches totalling 160',one 100' intermittent reach. Wide pools wih clear water otherwise.	1,260	2	10	Small cobble and gravel	Culverts on Briceland Thorn Road aggraded channel	Not yet affected by headcut. Large log providing grade control demarcates upper from lower reach. Series of 3 wood weirs installed in upper portion of suveyed reach	Both confined and unconfined. Some floodplain areas to the south side of the channel begin ~4-5' above channel bed.	YOY Steelhead in pools	Good pools, gravel, could likely benefit from more complexity	BDAs/Large Wood/Trench Walls, however landowner likely not interested in experimental work
Dinner 3	220092013	Patricia Hopper and Barbara Rasband	Lower	Yes	Dry	530	2	20	small cobble to sand	Undersized crossing and confinement by Briceland Thorn Rd at bottom of surveyed reach	Nothing significant	Generally unconfined with floodplains 2-4' above channel bed.	N/A	Likely goes dry most years	Trench walls, really need to look at this reach as a whole, but don't currently have access from downstream landowner.
			Upper	No	Little flow but fairly contiguous pools of high quality water	1,430	2	20	small cobble to sand	Excess coarse sediment from upstream culvert replacement has filled pools in upper portion of this reach	Upstream culvert replaced (same culvert as affecting Dinner 2), minimal increase in incision downstream.	Generally unconfined with floodplains 2-4' above channel bed until confinement by Briceland Thorn Rd at end of surveyed reach.	YOY Steelhead in pools	High quality pools wth good shelter provided by undercut banks and tree roots. Moderate amounts of LWD	Could add BDA/LW structures, but currently has fairly good habitat for small stream
China 1	220061001,220061002,220061003	Robin Downing,William Jackson IV and Briceland Company, Briceland Corporation		No	Relatively good flow and high water quality	2,480	1	30	range from sand to bedrock	Bridge, but not much other local disturbance	Nothing significant	Confined valley	Lots of YOY steelhead, and some larger	High quality pools wth good shelter provided by undercut banks and tree roots. Moderate amounts of LWD	Could add LW structures, but currently has fairly good habitat for small stream

Stream Reach Name	APN	Landowner	Sub-Reach	Dry Reach?	Flow and Water Quality Observations	Reach Length (ft)	Average Slope (%)	Average Channel Width (ft)	Dominant Channel Substrate	Legacy Channel Disturbance	Recent Channel Disturbance/Restoration activities	General Morphology	Fish Observations	Aquatic Habitat Conditions	Restoration Potential
Redwood 1	220061013	Freia Shroeder	Upper	No	Relatively good flow and high water quality	2,450	1	50	Mostly gravel with some cobble	Appears mostly natural, unstable bridge and historic small dam site toward downstream end of reach	Numerous large wood structures installed, rock weir grade control structures adjacent to bridge (ERWIG)	Combination of confined valley and reaches with floodplain and side channels	Lots of YOY steelhead, and some age 1+	High quality pools wth good shelter provided by LWD	Creek looks pretty good, Opportunity for large off-channel pond on old airstrip to southeast of reach.
Redwood 2	220061013	Freia Shroeder	Lower	No	Noticeably lower water quality than upper reach on Shroeder property	2,160	1	40	Mostly cobble, with some gravel	Old mill site appears to pinch channel in multiple locations, need to conduct historic air photo analyses	Nothing significant	Generally confined channel against shale bedrock on east streambank	Not many fish	Generally poor quality habitat	Great opportunity for large scale instream, off-channel, and floodplain restoration
Redwood 3	220251034	Rama Boyd		No	Relatively poor flow and water quality	840	1	60	Gravel with cobble	Nothing significant	Large wood structures (ERWIG)	Broader valley with some side channels and floodplain habitat	Not many fish, a few steelhead and Roach (?)	Adequate amount of instream large wood	Opportunity for floodplain enhancement, off-channel pond on higher terrace didn't present any obvious opportunity but should be investigated further
Redwood 4	220231027	Michael La Bonte		No	Relatively poor flow and water quality	850	1	50	Large gravel/cobble, bedrock reach at downstream extent	Nothing significant	Large wood structures (ERWIG)	Relatively confined	Not many fish, a few steelhead and Roach (?)	Adequate amount of instream large wood	Relatively confined reach, not much opportunity
Redwood 5	215062007	The Marshall Ranch LLC		No	Deep and contiguous pools of clear cold water.	1,610	1	50	Boulder and cobble	Nothing significant	None Known	Mostly confined, some point bar and side channel development	YOY steelhead throughout	Good pools throughout, lacking LWD	LWD enhancement
Redwood 6	220261012	Derik Veenhuis and Dorly Mueller		No	Deep and contiguous pools of clear cold water	2,350	3	50	Boulder and cobble	Nothing significant	None Known	Mostly confined, some point bar and frequent side channel development in the lower portions	YOY steelhead throughout	Good pools throughout, lacking LWD	LWD enhancement
Redwood 7	220261020	Wallace and Carol West		No	Deep and contiguous pools of clear cold water	1,850	1	50	Boulder and cobble, sandy reaches	Nothing significant	None Known	Generally confined to the south, large floodplain area to the north in lower portion of reach	YOY steelhead throughout	Good pools throughout, lacking LWD	LWD enhancement
Redwood 8	222221005	State of California, John B. Dewitt Redwoods State Natural Reserve		No	Deep and contiguous pools of clear cold water	5,000	0.8	80	Boulder and cobble, sandy reaches	Nothing significant	None Known	Generally confined to the north, bed ~10' below terrace to the south adjacent to Briceland Thorn Rd.	YOY steelhead throughout	Good pools throughout, lacking LWD	LWD enhancement
Somerville 1	215064005	The Marshall Ranch LLC		No	Good flow, likely always maintains wetted channel	4,550	5	16	Cobble, boulders	Evidence of legacy logging disturbances, but generally healing well	None	Mostly confined channel, steep pool morphology	Lots of YOY steelhead	Good steelhead habitat not a lot of complexity	No recommendations at this time
Somerville 2	215064004, 215064005	The Marshall Ranch LLC		No	Fairly good flow, however, reach likely goes dry during most dry seasons	1,970	3	20	Cobble	Cattle, legacy logging	Evidence of active incision below floodplains	Unique channel reach, actively incising, numerous floodplains, side channels and terraces at different elevations, fairly unstable underlying shale	Some YOY steelhead	Moderate to poor	Opportunties for large wood placement with variety of objectives; Assess at reach scale with Somerville 3; Need to consider unstable underlying geology

Stream Reach Name	APN	Landowner	Sub-Reach	Dry Reach?	Flow and Water Quality Observations	Reach Length (ft)	Average Slope (%)	Average Channel Width (ft)	Dominant Channel Substrate	Legacy Channel Disturbance	Recent Channel Disturbance/Restoration activities	General Morphology	Fish Observations	Aquatic Habitat Conditions	Restoration Potential
Somerville 3	220252037, 220251034	Chestine Anderson, Rama Boyd		No	Fairly good flow, however, reach likely goes dry during most dry seasons	1,260	3	16	Cobble	May have been chanelized historically	Riprap bank stabilization at some locations (ERWIG)	Incised ~8' below terrace	Not many fish, a few steelhead and Roach (?)	Some pockets of good habitat, but mostly moderate to poor due to lack of complexity	Opportunties for various instream and off-channel treatements; Assess at reach scale with Somerville 2
Somerville Trib 1	215063007, 215064005	The Marshall Ranch LLC		No	Trickle, drains from mostly shale geology	3,500	8	10	Cobble and bedrock	Logging and cattle	cattle	Channel flows along geologic contact between sandstone and shale bedrock, actively eroding shale on north extent	None	Generally poor salmonid habitat	Cattle exclusion fencing
Somerville Trib 2	215063007, 215064005	The Marshall Ranch LLC		No	Trickle, drains from mostly shale geology	3,250	8	10	Cobble and bedrock	Logging and cattle	cattle	Confined with fairly erosive banks	One 6" steelhead (likely resident) in small pool	Generally poor salmonid habitat	Cattle exclusion fencing
Seely 1	220261020	Wallace and Carol West		No	Contiguous pools, clear water	750	1	20	Small cobble and gravel	None Known	None Known	Generally Confined	YOY steelhead throughout	Pools but lacking complexity	LWD enhancement

Redwood Creek Watershed Assessment 2020				All surveys conducted on Lost Coast Forestlands property between Nov 9 and Nov 11, 2020.								
Stream Reach Name	**Sub-Reach**	**Dry Reach?**	**Flow and Water Quality Observations**	**Reach Length (ft)**	**Average Slope (%)**	**Average Channel Width (ft)**	**Dominant Channel Substrate**	**Legacy Channel Disturbance**	**Recent Channel Disturbance/Restoration activities**	**General Morphology**	**Fish Observations**	**Aquatic Habitat Conditions**	**Restoration Potential**
Redwood Creek Headwaters	Upper	No	Mostly continuous surface water but very shallow/little flow. Occasional pools, many with poor water quality	440	7	4-5	Cobble with some gravel	Bank erosion associated with incision. Less severe than lower reaches. Approximately 50% of the upper watershed heavily logged sometime between 1993 and 2005 (as visible in Google imagery)	Some active bank erosion	~3-5' channel incision, mostly confined valley	None	Some LWD and occasional pools. Incision may be hindering groundwater recharge/storage. Observed flow and habitat likely insufficent for summer fish survival many years	LWD and flow enhancement. Measures to encourage channel aggradation and floodplain connectivity
	Middle	No	Infrequent pools, generally of poor water quality	1,350	3	4-5	Cobble with some gravel	Same as above	Same as above	Both confined and unconfined. Frequently incised 4-6'	None	Little LWD in the channel and few pools. Unlikely to support salmonids	LWD and flow enhancement. Measures to encourage channel aggradation and floodplain connectivity
	Lower	Yes	Dry	2,100	3	5-6	Cobble with some gravel	Bank erosion and severe incision	Significant active erosion in upper portion of sub-reach, banks frequently vertical	Valley largely unconfined but channel frequently incised 6-10' in upper portion of sub-reach	None	Some LWD and pool habitat but completely dry	LWD and flow enhancement. Measures to encourage channel aggradation and floodplain connectivity
Upper Redwood Mainstem		No	A mix of dry, intermittent, and continuous flow conditions. Water in the continuous reach generally seemed to be of good quality though some pools in the intermittent areas were quite cloudy or dark with tannins. Summer base flow in this reach appears to come predominatly from Trib 2	7,300	2	10-15	Cobble/gravel	One bridge near downstream end	nothing significant	Mostly confined, generally not incised	Steelhead YOY in pools	Some quality rearing pools, more common in the upper portion of the reach. Many pools containing YOY salmonids observed to be on the verge of drying out. Some large wood observed but in low density and rarely embedded sufficiently to alter channel morphology. As a result, channel grade and substrate type is often very homogenous. Lack of complexity and pool development, in tandem with low baseflows, appear to be severely limiting salmonid rearing habitat	LWD, boulder weirs, and flow enhancement
Trib 1		No	Infrequent pools, mix of water quality	670	4	4	Cobble/gravel	Some incision and bank erosion	Some active bank erosion	Unconfined though incised 2'-4' in places	None	Some large wood and occasional pools. Good woody cover provided by dense huckleberry. Insufficient water in 2020, still likely borderline on an average year	LWD and flow enhancement. Broad unconfined valley and apparent lack of rearing habitat could allow for instream pond or trenchwall construction

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Trib 2	Lower (up to second crossing)	No	Good continuous flow of clear water	1,200	2	6-8	Cobble with some gravel	Arch culvert crossing shortly upstream of the mainstem confluence. Appears to be low impact	Some active incision/bank erosion, more pronounced near the mainstem confluence	Generally confined, incised 2-4' in places.	None, though observed a high density of caddisfly larvae	Fair amount of large wood and smaller woody cover. Good pool development	Perhaps a few LWD structures but generally in good shape
	Upper W Fork	Yes	Dry	550	5	4	Gravel	Outlet of undersized CMP culvert at beginning of reach is perched ~3'. Channel immediately upstream of culvert aggraded, then severely incised	active erosion at culvert outlet and areas of vertical, failing banks upstream	confined, incised 4-6' in places	None	Few pools, little complexity, lots of downed wood but generally spanning incised banks and rarely in the channel. Likely non fish-bearing	Cuvert replacement, grade control structures, LWD
	Upper E Fork	No	Good continuous flow of clear water	625	8	4	Gravel to boulder	Undersized CMP culvert, outlet perched ~2'	nothing significant	unconfined in lower reach, confined in upper	None	Great flow, good complexity and LWD density. Many Pools. Likely non fish-bearing due to slope	No recommendations at this time
Trib 3	Lower (up to crossing)	No	Mostly dry with occasional pools, varying water quality	160	16	3	Gravel and cobble	Undersized CMP culvert	nothing significant	Confined until fan at confluence	None	Short, steep, section from crossing down to mainstem confluence. Approximately 10' bedrock chute directly downstream of crossing presents natural barrier to fish passage	Culvert replacement
	Upper	No	Occasional pools of varying water quality	2,120	3	3	Sand and gravel	Channel seems in good shape, surrounding forest appears to have been heavily logged.	Nothing significant	Mostly unconfined, channel generally shallow	None	Lots of woody debris, though mostly smaller. Dense growth of huckleberry on both banks. Wetland plants observed near some pools suggesting perenially flow, if only in isolated locations	Broad low angle reach upstream of the culvert may be a good candidate for trench walls or ponds. Potential pond locations noted in meadow to the east which could outlet to this watercourse
Trib 4		Yes	Dry	785	8	4-5	Cobble to boulder	Nothing significant	Nothing significant	Confined, generally not incised	None	Likely goes dry most years, fair to good complexity. Likely non fish-bearing	No recommendations at this time
Trib 5		Yes	Dry	2,260	5	6	Gravel and cobble	Culvert crossing ~100' upstream from Redwood Creek confluence.	Culvert outlet is perched and eroding adajcent banks. Fill prism is failing.	Confined, steep but seems relatively stable with only occasional incised areas.	None	All dry except one very small pool at the base of a bedrock chute. Fair to good complexity, likely goes dry most years. Likely non fish-bearing	No recommendations at this time