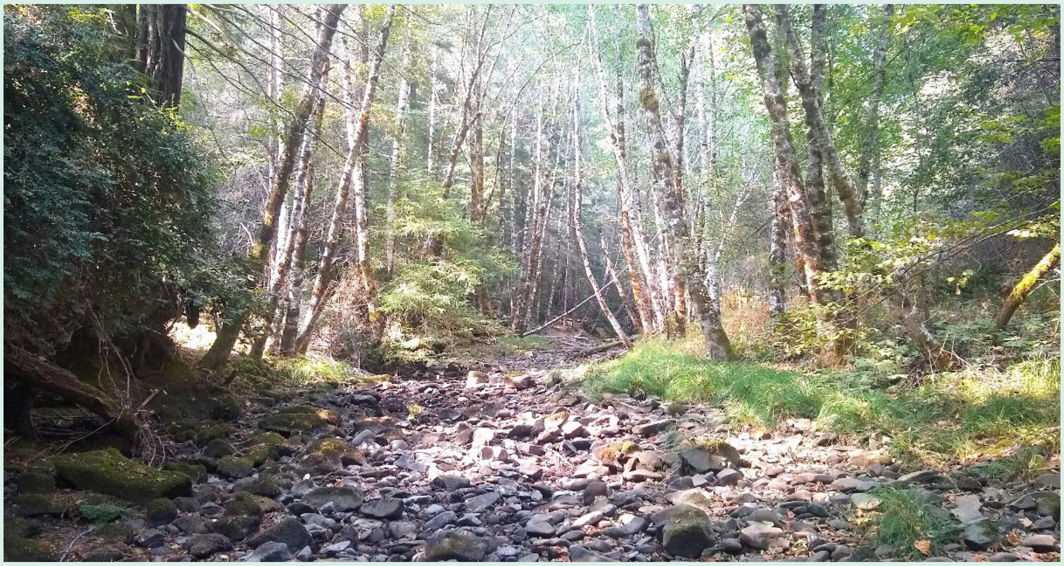
MAY 2023

Sproul Creek Flow Enhancement Implementation Plan



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Cover photos: A dry reach in West Fork Sproul Creek just upstream of the South Fork confluence (top photo). A unique argillite bedrock weir creates a large pool in South Fork Sproul Creek (bottom photo).

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1 INTRODUCTION

This report provides an overview of hydrologic conditions in the Sproul 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 Sproul 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). Sproul 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 Sproul Creek and explores the implications for runoff dynamics and dry-season streamflow enhancement activities. Next, eight years of 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 Sproul Creek.

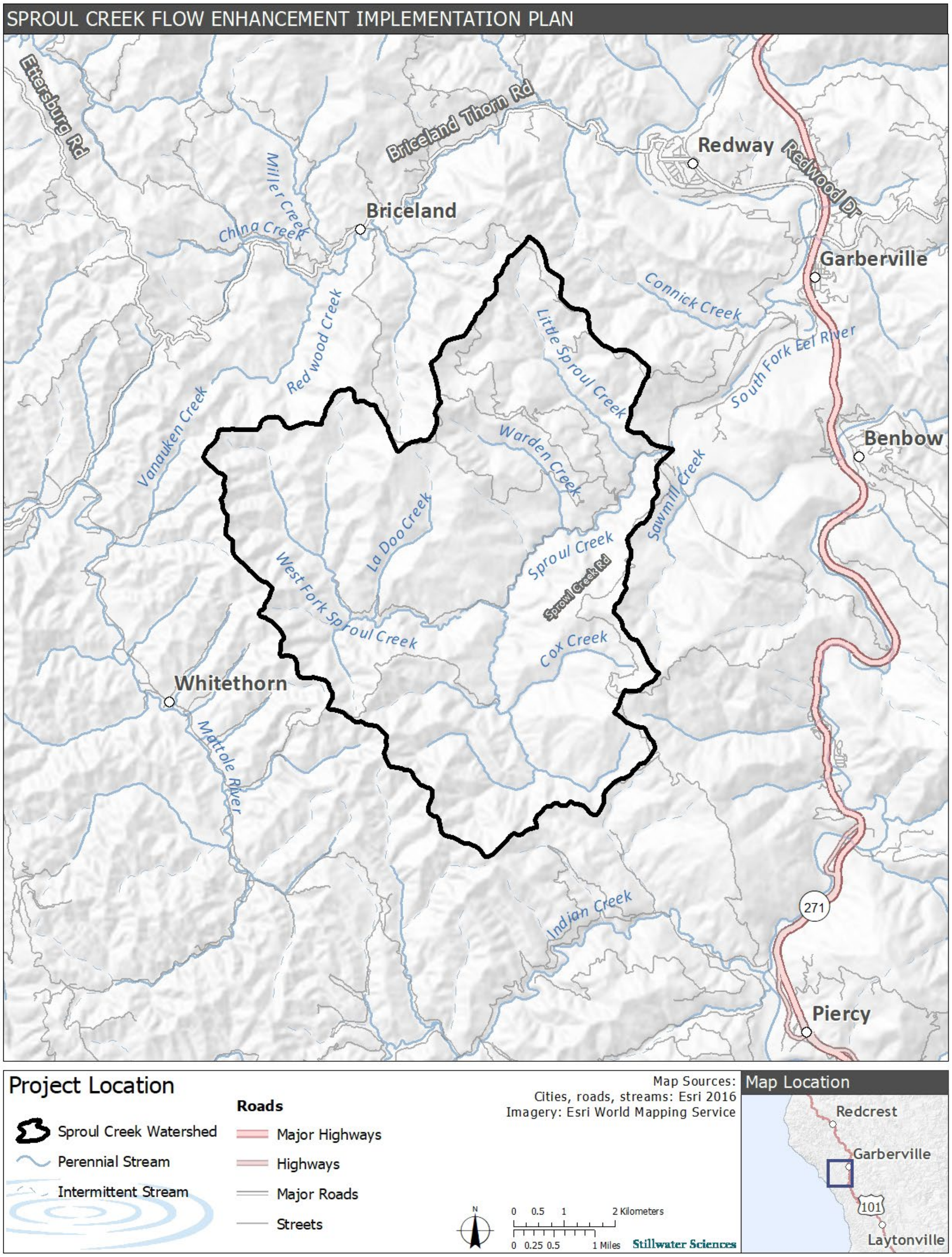


Figure 1-1. Sproul Creek watershed vicinity map.

1.1 Background and Project Overview

Efforts to improve dry-season streamflow in Sproul Creek have been underway since 2015 when CalTrout initiated dry-season flow monitoring with 319(h) funding through the North Coast Regional Water Quality Control Board (NCRWQCB). Then, beginning in 2019, SRF took over the dry season flow monitoring with funding from WCB SEP. In addition to the flow monitoring, the WCB-SEP grant funded development of a flow enhancement assessment and implementation plan for the entire Sproul Creek watershed (this report). The goal of this effort is to prepare a roadmap for flow enhancement actions in Sproul 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 Sproul 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:

- Class I watercourses throughout Sproul Creek with a focus on the mainstem.
- Groups of contiguous parcels under the same ownership.
- 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 in Sproul and nearby Redwood Creek including:

- 8 years of dry-season flow monitoring by CalTrout and SRF;

- Flow Enhancement Feasibility Study for a part of Redwood Creek (Stillwater Sciences 2017);
- 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 Sproul Creek have been synthesized in this report and support the prioritized implementation actions listed in Section 5.

1.2 Conservation Need

Aquatic habitat in Sproul 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 Sproul 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 Sproul 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 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 (S. Bauer, Environmental Scientist, CDFW, pers. comm., February 5, 2015).

This project addresses this key limiting factor by providing a long-term plan to increase dry-season flows in Sproul 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 Sproul 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.

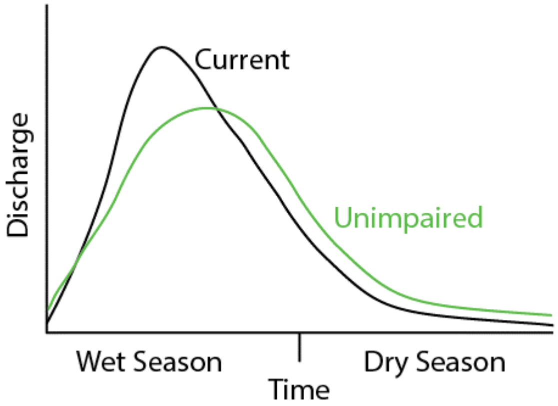


Figure 1-2. Conceptual hydrograph comparing current and unimpaired flow conditions.

2 SPROUL CREEK WATERSHED EXISITNG CONDITIONS

2.1 Watershed Geology and Geomorphology

The Sproul 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.

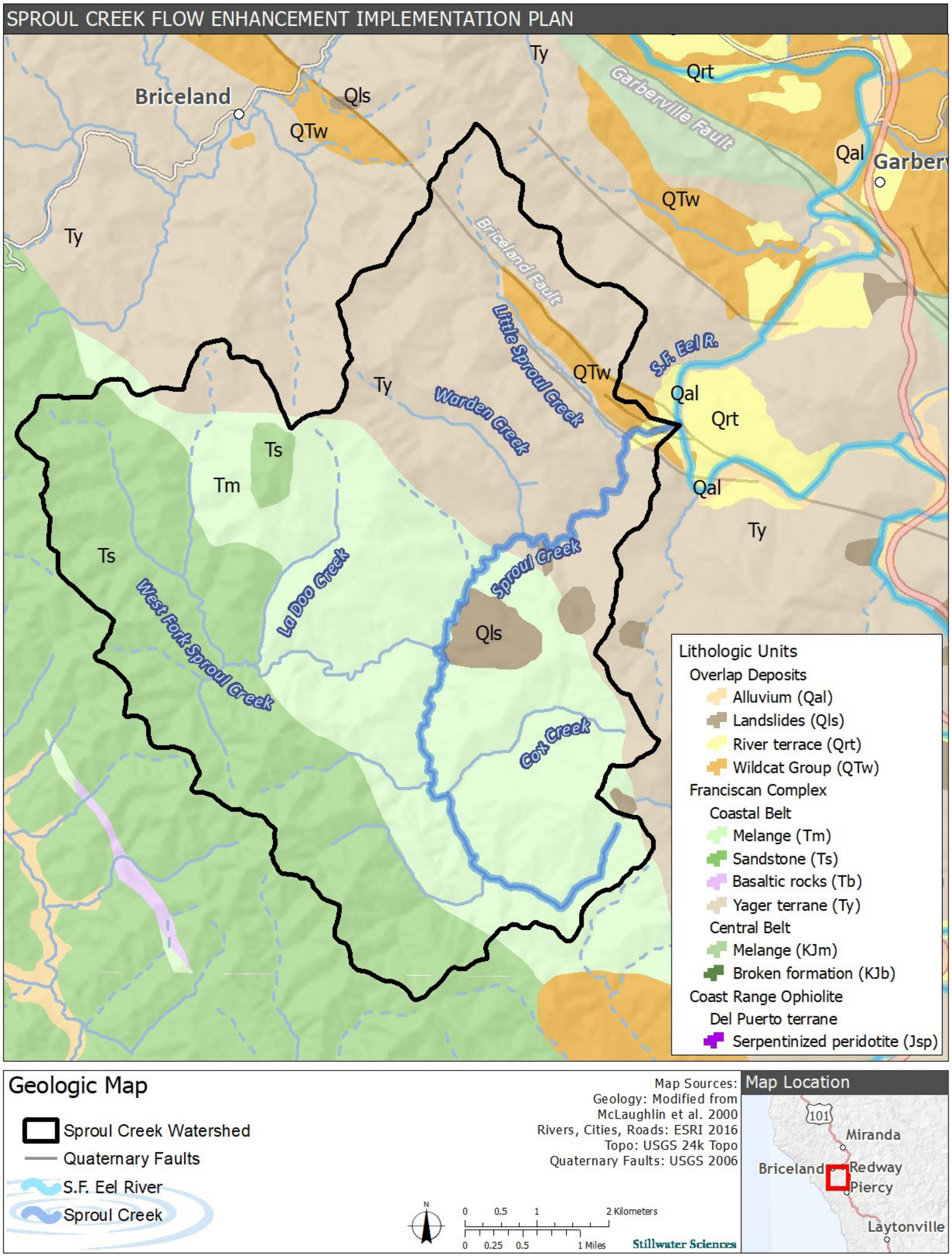


Figure 2-1. Generalized geologic map of the Sproul Creek watershed.

The Sproul Creek watershed is primarily underlain by the Coastal Belt of the Franciscan Complex, with minor amounts (2%) of the younger marine and non-marine overlap deposits of the Wildcat Group (Figure 2-1). Mapping indicates that 29% of the Sproul Creek watershed is underlain by various subunits of the Eocene to Paleocene Yager terrane which primarily consists of sheared and highly folded mudstone interbedded with sandstone and lenses of conglomerate (McLaughlin et al. 2000). Approximately 39% of the watershed is underlain by Coastal Belt mélange, which contains subequal amounts of shattered sandsone and argillite. Both the Yager and Coastal Belt mélange bedrock in the watershed generally exhibit irregular topography lacking a well-incised drainage system. Finally, 28% of the watershed is comprised of the more competent Coastal Belt sandstones of which exhibit sharp crested topography and well incised sidehill drainages.

Runoff and streamflow dynamics vary across the different bedrock geologic units within Sproul Creek. Nearby Central Belt geologic units located to the northeast of the Sproul Creek watershed have higher concentrations of clay and mudstone resulting in 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 and Coastal Belt melange units are positioned between the Central Belt and Coastal Belt Sandstone units. Although both the Yager and Coastal Belt melange are 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 these units in Sproul Creek function more like Central Belt melange terrane from an infiltration, runoff and baseflow perspective.

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 units within the Yager and Coastal Belt Melange terranes mapped by McLaughlin 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 those of "unimpaired" dry-season base flow. It also provides an important basis for the development of a flow enhancement implementation plan.

Figure 2-2 shows Stillwater's subdivision of the Yager and Coastal terranes, where $Y_{central}$ and $Tm_{central}$ units are believed to be composed primarily of clay and mudstone, and from a hillslope runoff perspective, behave more like the Franciscan Central Belt to the east. Meanwhile, $Y_{coastal}$ and $Tm_{coastal}$ are composed primarily of sandstone and behave more like Franciscan Coastal Belt terranes to the west. Based on this refined delineation, approximately 12% of Sproul Creek is composed of geologic units with runoff dynamics that behave like the Central Belt and 88% of Sproul Creek is composed of units that behave more like the Coastal Belt.

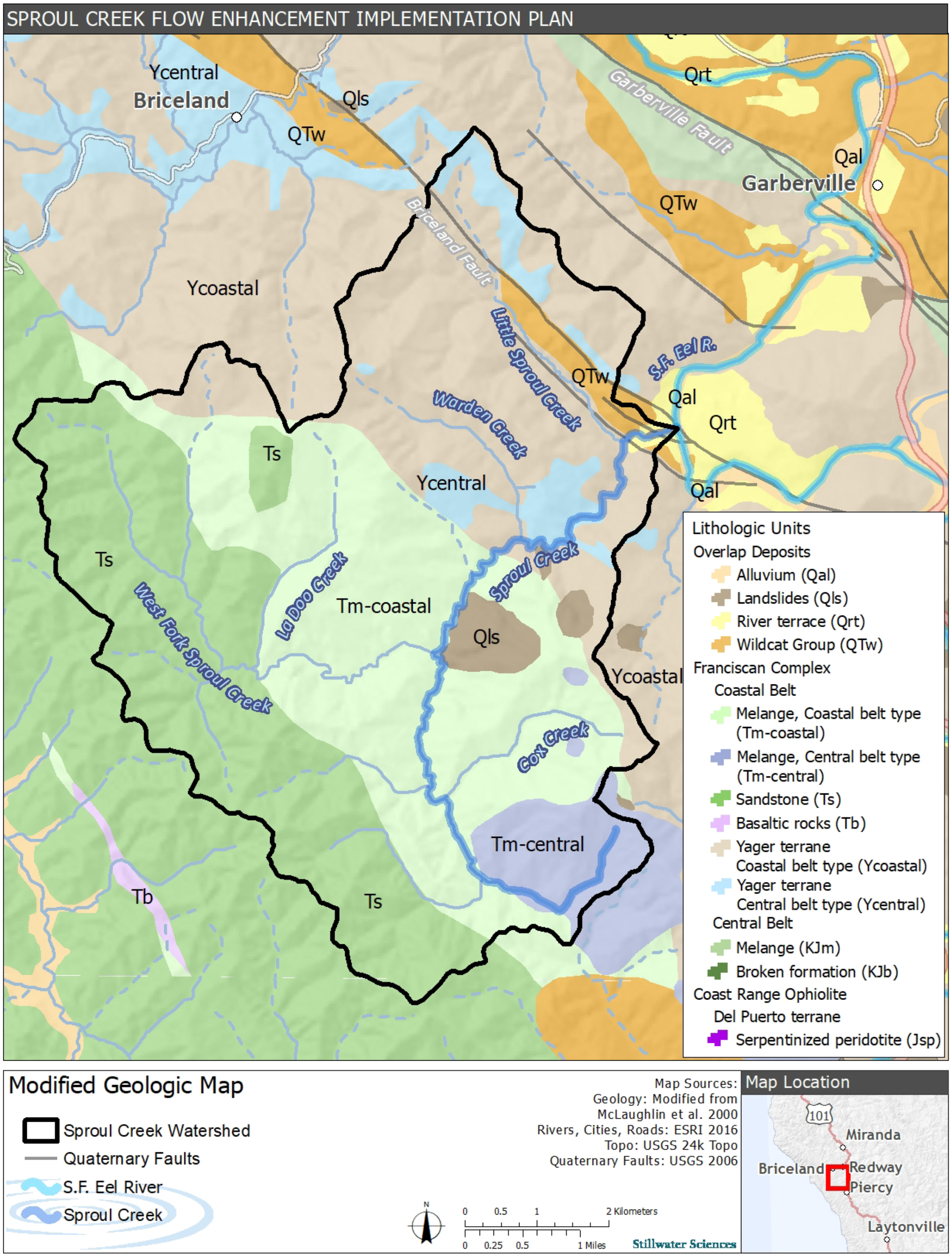


Figure 2-2. Modified geologic map of the Sproul Creek watershed showing Coastal Belt Yager and Melange terrane sub-units.

2.1.2 Sproul Creek longitudinal profile

2018 USGS Lidar was used to analyze channel gradient and create a longitudinal profile for Sproul 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 slopes between stations 7,500 and 10,000 is likely the result of faulting and a transition to more resistant bedrock that inhibits the geologic incision rate. 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.

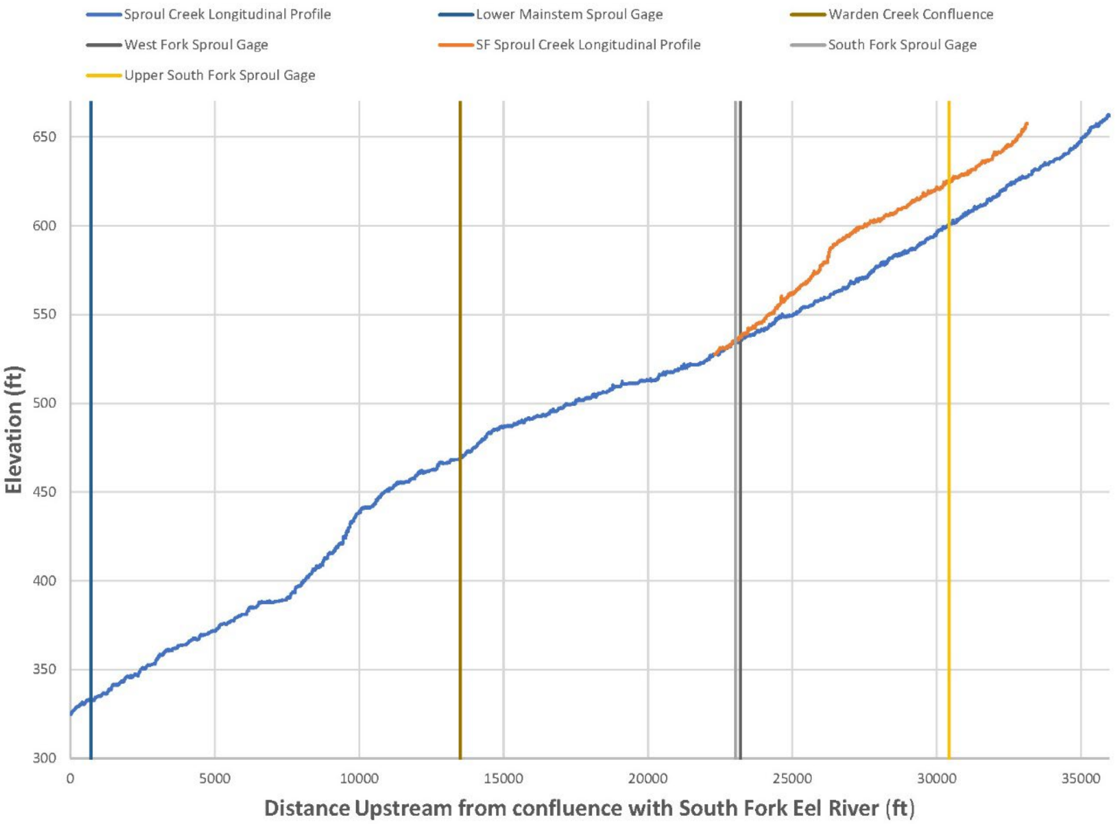


Figure 2-3. Longitudinal profile of Sproul Creek.

2.2 Dry-Season Streamflow

There are no permanent flow gages in Sproul Creek. CalTrout and SRF have been monitoring dry-season streamflows at numerous stations throughout the Sproul Creek watershed since 2015 (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 2015 and 2022 at the Lower Mainstem Sproul Gage, the most downstream monitoring station, are shown in Figure 2-5. Low-flow monitoring results for other monitoring stations are provided in Appendix A.

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

Site description	Station name	River mile upstream from mouth	Drainage area (mi^2)	Years of operation	Status
Lower Mainstem Sproul	LMS	0.15	23.95	2015–2022	Current
South Fork Sproul	SFS	4.23	6.92	2015–2022	Current
Upper South Fork Sproul	USFS	5.72	4.95	2015–2022	Current
West Fork Sproul	WFS	4.24	8.46	2015–2022	Current
Little Sproul	LS	0.52	3.90	2016, 2019–2022	Current
Warden	Warden	2.47	1.58	2021	Past
La Doo	La Doo	6.89	1.44	2021	Current

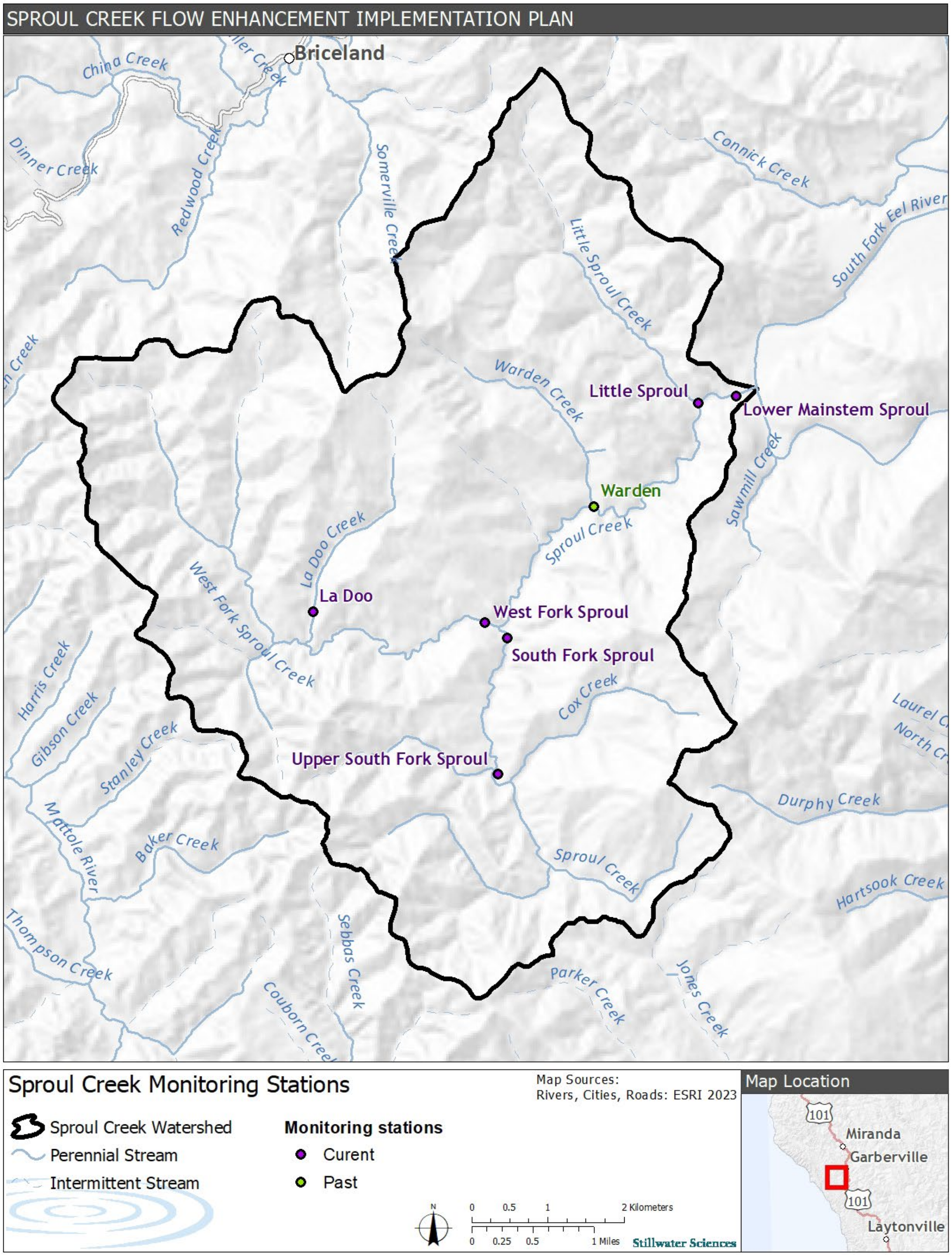


Figure 2-4. Dry-season monitoring stations in Sproul Creek.

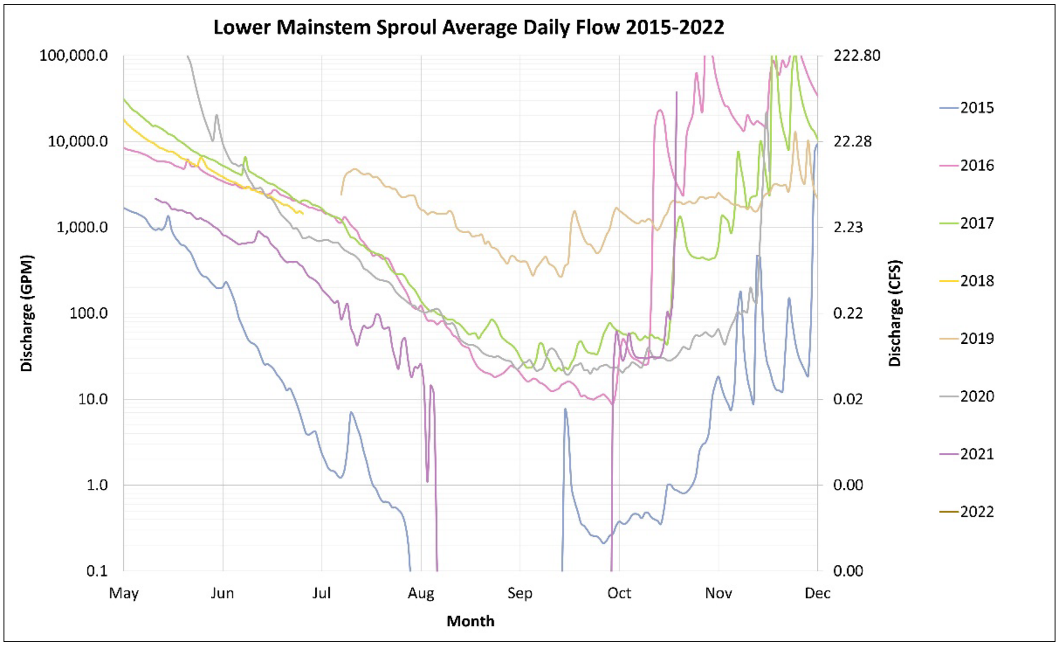


Figure 2-5. Dry-season flow monitoring results for Sproul Creek Mainstem Gage near the confluence with the South Fork Eel River between 2015 and 2022.

The 8 years of dry-season flow monitoring results shown in Figure 2-5 depict a clustering of spring and early summer recession hydrographs with 4 of the 8 years falling within a narrow band. Under these typical decadal recession conditions, flows drop below 100 GPM near the beginning of August. Two of the years (2015 and 2021) are significantly drier, with flows dropping below 100 GPM in early June and early July respectively. One year (2019) was significantly wetter with flows staying above 200 GPM for the entire dry season. The primary driver of the timing of the hydrograph recession is 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 (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 factor into 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 select Sproul Creek 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 200 GPM, the discharge difference between stations narrows: at the beginning of August flows at the South Fork Sproul and Upper South Fork Sproul are nearly the same. Considering that there are no known human diversions within the stream reach between these two stations, the most likely explanation for the variations in discharge comparison is the relative volume of hyporheic flow through the channel bed sediments within each reach. Specifically, the South Fork Sproul station 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, Sproul 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 Sproul Creek reaches assessed sediment deposit variability. As shown in Figures 2-3 and 2-4, the South Fork Sproul station is located just upstream from a major tributary confluence which are often associated with depositional reaches.

Based on a comparison of discharge data from the South Fork Sproul and Upper South Fork Sproul monitoring stations (Figure 2-6), during the dry season, hyporheic flow at South Fork Sproul appears to be approximately 20 GPM higher than Upper south Fork Sproul. This is consistent with findings in Redwood Creek (Stillwater Sciences 2023a) where hyporheic flow was found to vary significantly based on the geometry of coarse sediment deposits within the stream channel. These hyporheic flow assumptions will be further evaluated during Marshall Ranch Flow Enhancement Project post-construction monitoring (Stillwater Sciences 2021).

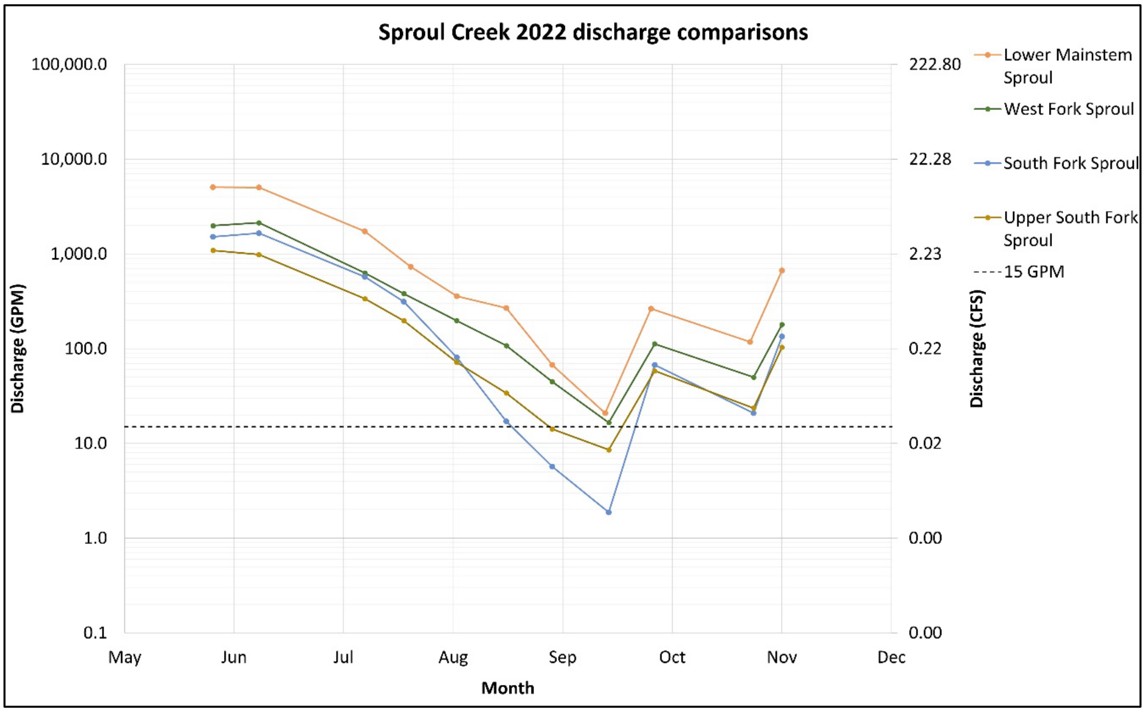


Figure 2-6. 2022 dry-season flow monitoring results for Sproul Creek gages.

2.2.1 Reference watersheds

Considering that there are no permanent flow gages in Sproul Creek, reference watersheds must be used to analyze hydrologic conditions beyond the current dry-season flow data collected by CalTrout and 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 Sproul 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 Sproul Creek.
- Bull Creek provides the best reference watershed for scaling annual hydrographs and water balance calculations for Sproul 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 terrane along the northern and western ridges. Similar to Elder, there is minimal human consumptive use or industrial timberland in the Bull Creek watershed.

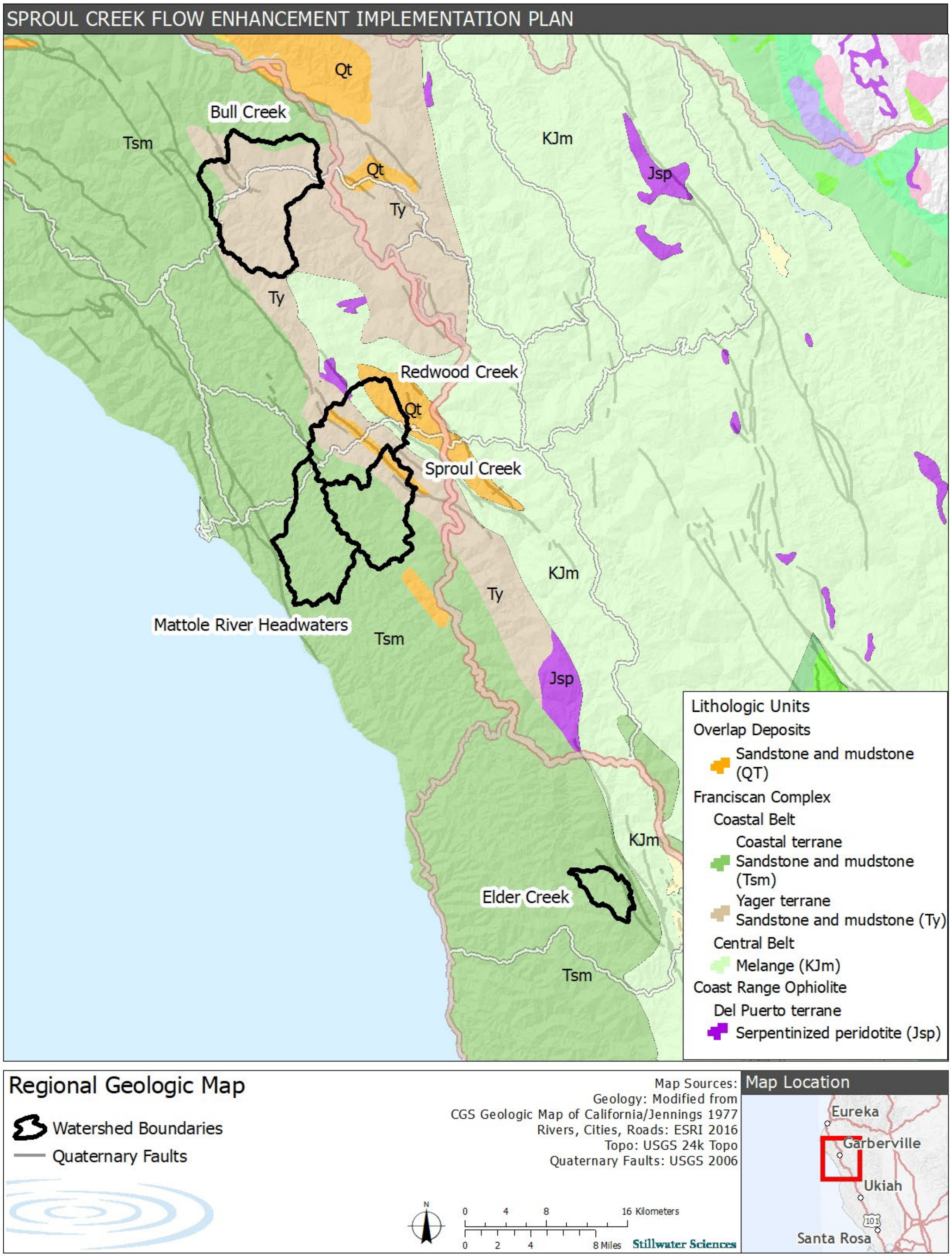


Figure 2-7. Sproul Creek and reference watersheds with regional geology unit underlay.

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 South Fork Eel sub-basin to the north of Sproul 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.

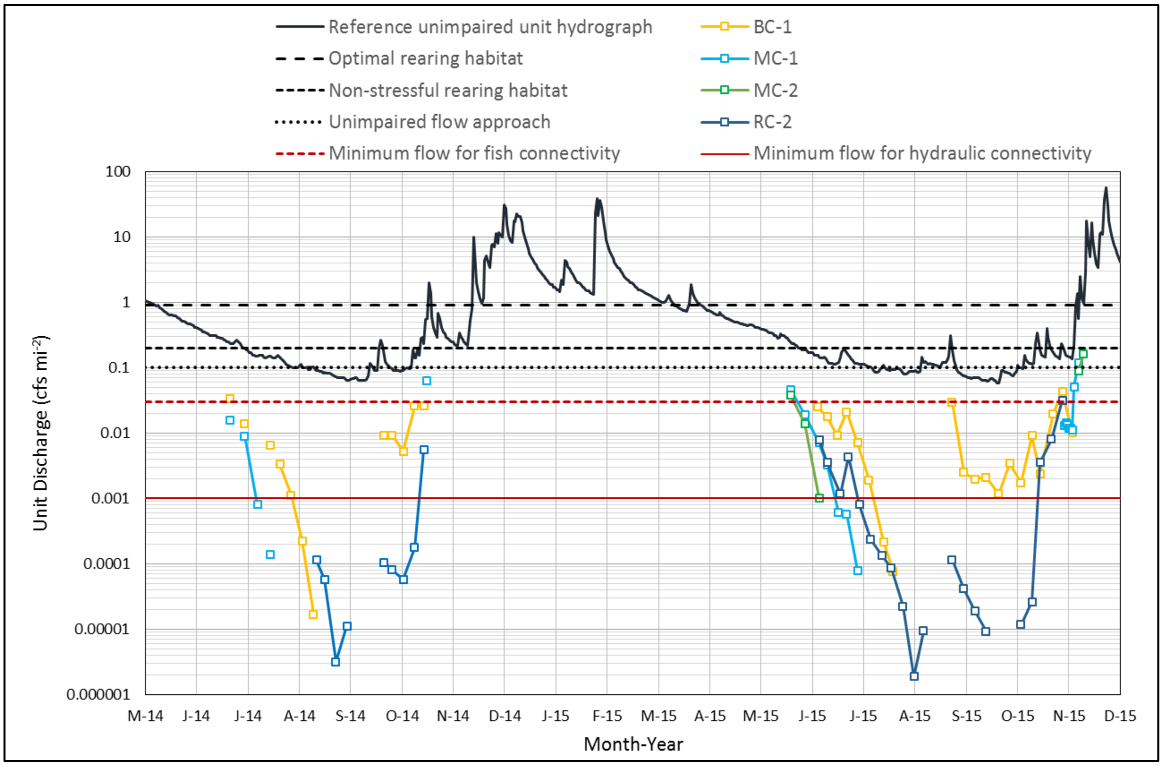


Figure 2-8. Preliminary recommended unit discharges (cfs mi^{-2}) and measured unit discharges from 2014 and 2015 at streamflow monitoring sites in the Redwood Creek Feasibility Study Area. These targets apply to the annual wet season recession and low-flow dry season (Stillwater Sciences 2017).

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. Although these flows were based on analyses of Redwood Creek dry season flow gages, they are relevant for Sproul Creek considering the proximity of the two watersheds (Figure 2-7) These unit discharge targets are presented as flows (in GPM) for the eight subwatersheds including mainstem Sproul Creek in Table 2-2.

Table 2-2. Summary of recommended flows for Sproul Creek Subwatersheds.

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]
Sproul Creek near mouth	9,686	2,152	1,076	646	323	10.8
South Fork Sproul Creek (GPM)	2,253	501	250	150	75	2.5
Lower West Fork Sproul Creek (GPM)	3,427	851	1,322	83	41	1
Upper West Fork Sproul Creek (GPM)	1,648	366	183	110	55	1.8
Little Sproul Creek (GPM)	1,575	350	175	105	52	1.7
Warden Creek (GPM)	639	142	71	43	21	0.7
La Doo Creek (GPM)	603	134	67	40	20	0.7
Cox Creek (GPM)	606	135	67	40	20	0.7
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 Sproul 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 15 GPM, the expected flow augmentation rate generated by the La Doo Meadow project (Stillwater Sciences 2023b) is expected to measurably improve the "average" and "dry" hydrographs (Figure 2-9). Section 5 further explores these simulations to assess specific impacts of different flow enhancement approaches.

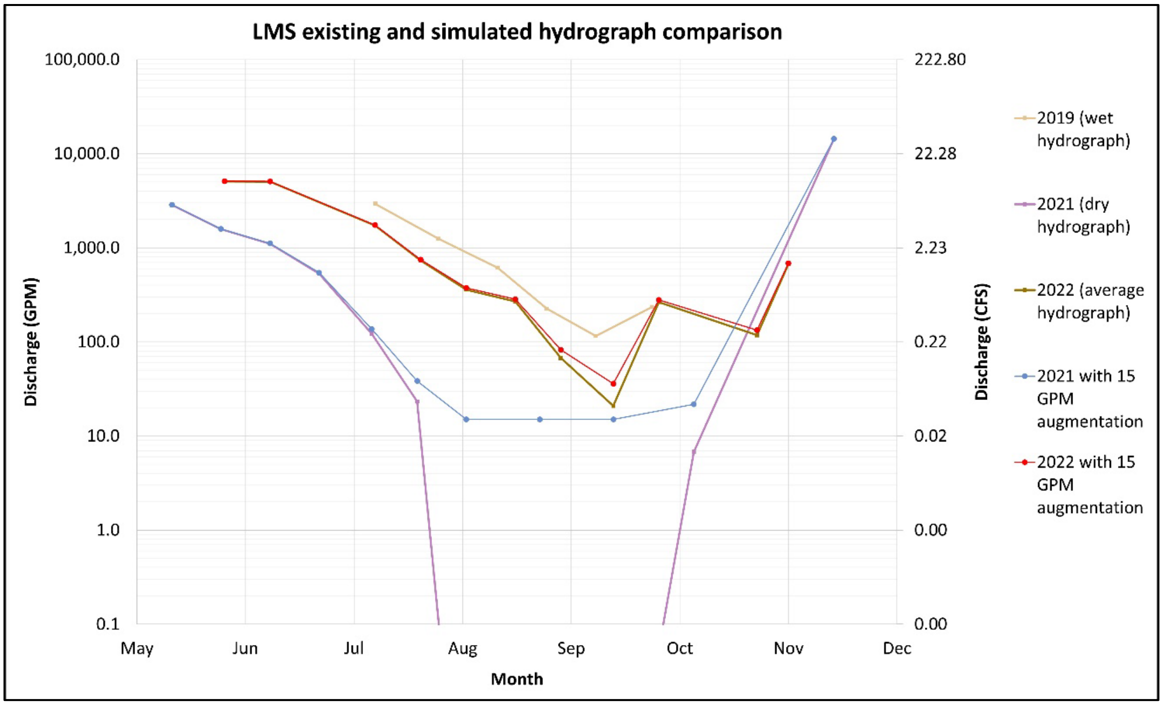


Figure 2-9. Annual dry-season hydrographs for station LMS including dry (2021), average (2022), and wet (2019) years; flow augmentation rates of 15 GPM added to average and dry years for comparison.

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). Prorating these 2 cfs targets to the Sproul Creek watershed area (92% of Redwood) yields 1.84 cfs. This estimate of unimpaired dry season flow falls near 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 Sproul 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 10% is reasonable considering that Sproul Creek is comprised of approximately 12% 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 Sproul Creek of 970 GPM and 580 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 Sproul Creek are closely interrelated. Many stream reaches within the Sproul Creek watershed are shaded by dense alder riparian forests although lack of old growth conifer stands adjacent to the immediate riparian corridor results in more sunlight reaching the riparian corridor than would have occured under unimpaired conditions, especially in the lower reaches of Sproul Creek mainstem. Sproul Creek water temperatures are 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 LMS for the 2021 dry season. Beginning in late June, peak daytime water temperatures begin to exceed 70 degrees Fahrenheit with flows of approximately 200 GPM. However, once surface flows drop below approximately 70 GPM in early July, water temperatures begin to decrease as a higher percentage of the overall flow becomes hyporheic. 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 Sproul Creek.

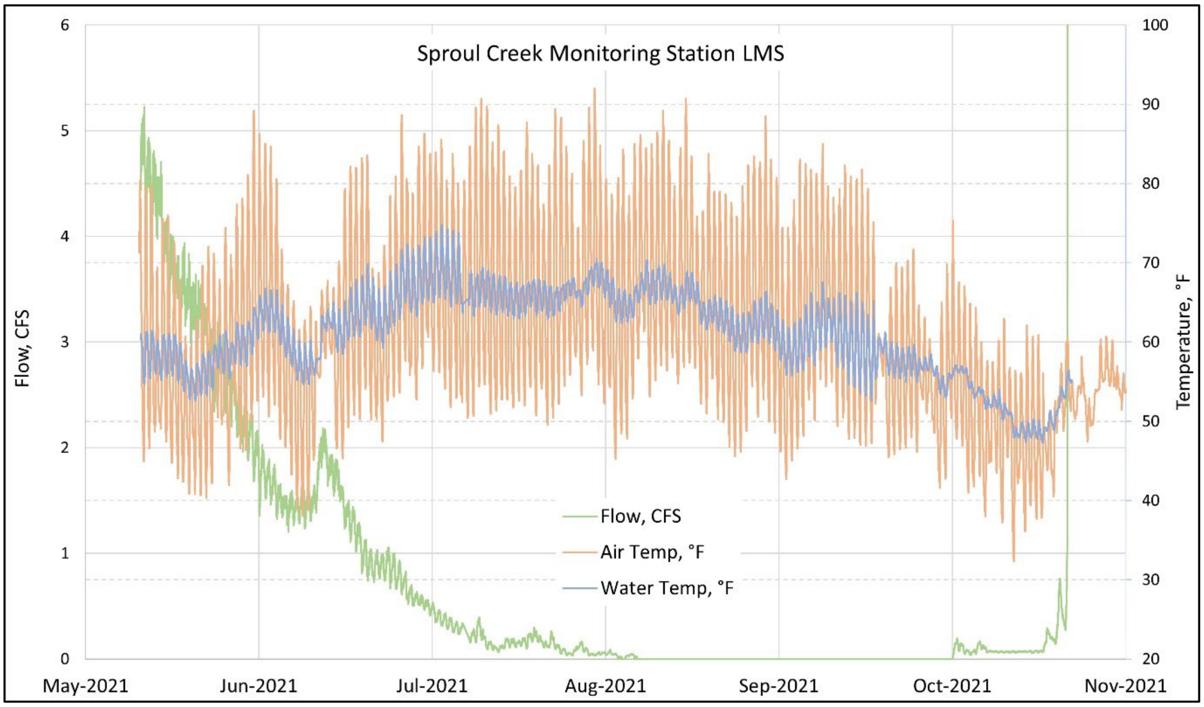


Figure 2-10. Streamflow, air temperature, and water temperature at monitoring station LMS during the 2021 dry season.

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 summarized in Table 2-3. On average, Sproul Creek receives approximately 70.6 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)
Sproul Creek Mainstem	2.9	66.3	10,367
South Fork Sproul Creek	5.6	72.7	21,629
Lower West Fork Sproul Creek	2.9	73.2	11,374
Upper West Fork Sproul Creek	4.1	73.6	16,010
Little Sproul Creek	3.9	64.5	13,402
Warden Creek	1.6	67.2	5,673
La Doo Creek	1.5	72.8	5,803
Cox Creek	1.5	72.5	5,795
Entire Sproul Creek Watershed	24.0	70.6	90,335

2.3.1 Precipitation timing

The Sproul 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 Sproul 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. Over the period of record, December exhibits the highest average precipitation of 14.0 inches, while July the lowest at just 0.07 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.

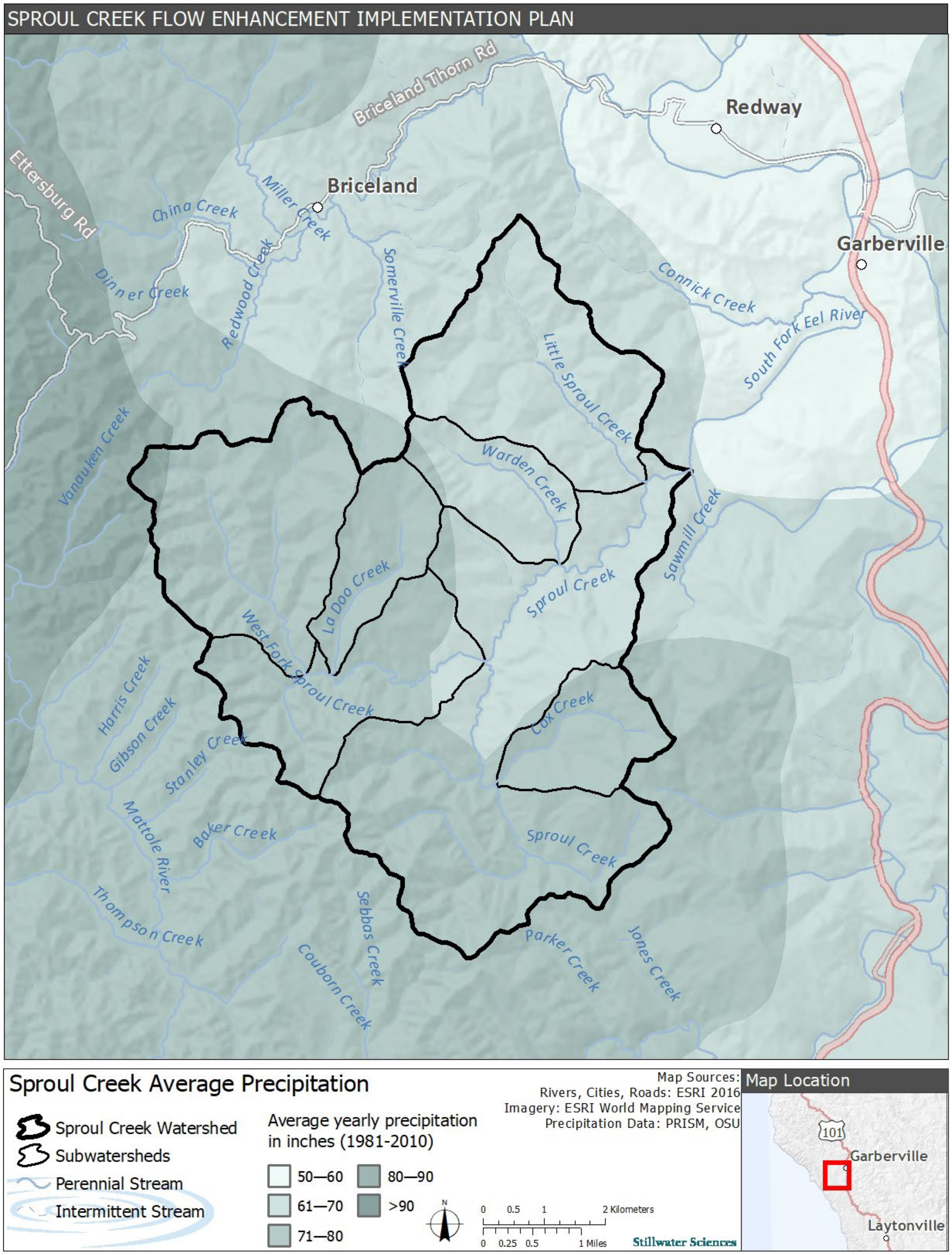


Figure 2-11. Average annual precipitation in the Sproul Creek watershed from PRISM data.

2.4 Seasonal Runoff Dynamics

There are no flow gages that operate year-round on Sproul 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 Sproul 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 20 miles north of Sproul Creek. Average monthly flow in Bull Creek (1960 to 2018) prorated to Sproul Creek results in an estimated annual water yield of approximately 70,838 acre-feet (ac-ft) (Figure 2-12). 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 Sproul Creek. As highlighted in Figure 2-12, there is significant flow in Sproul Creek during the wet season generated by precipitation and runoff.

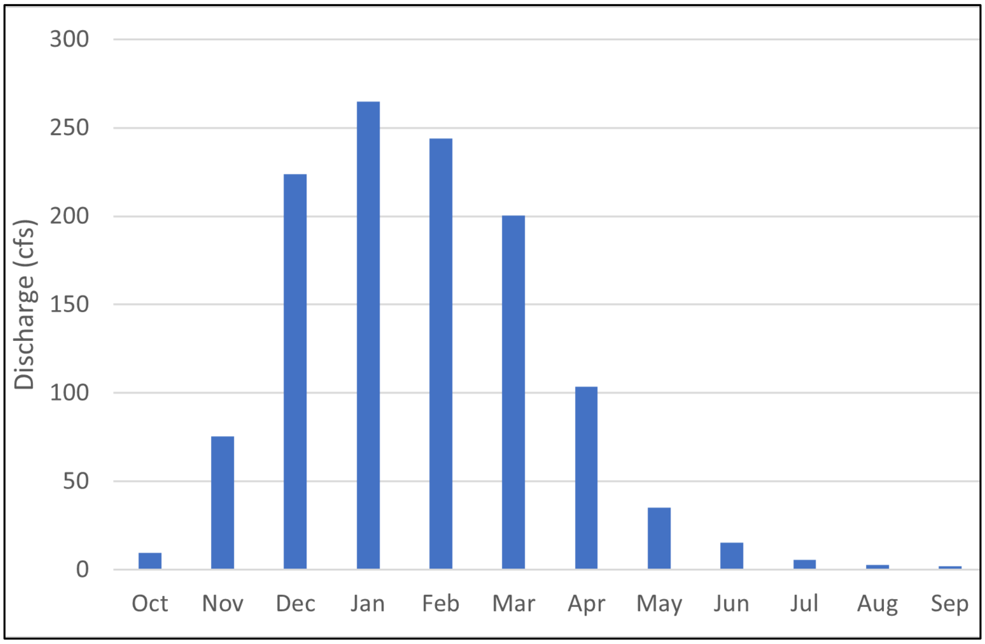


Figure 2-12. Estimated average monthly streamflow in Sproul Creek prorated from Bull Creek gage data.

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 measured and prorated monthly average discharges in Sproul Creek during the dry season.

Subwatershed	Area (mi^2)	July (cfs)		August (cfs)		September (cfs)	
		Measured	Prorated[1]	Measured	Prorated[1]	Measured	Prorated[1]
South Fork Sproul Creek	5.6	0.53	1.34	0.06	0.61	0.04	0.48
West Fork Sproul Creek	2.9	0.91	1.70	0.17	0.77	0.10	0.60
Little Sproul Creek	3.9	0.26	0.83	0.07	0.38	0.06	0.29
Warden Creek	1.6	0.01	0.35	0.00	0.16	0.00	0.12
La Doo Creek	1.5	0.17	0.36	0.04	0.16	0.02	0.13
Entire Sproul Creek Watershed	24.0	2.07	0.36	0.33	0.16	0.22	0.13

[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, Sproul 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 Sproul 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 Sproul Creek are significantly lower than proration calculations would suggest.

2.5 Land Use and Human Consumptive Water Use

An overview of land ownership in Sproul Creek is shown in Figure 2-13 delineating large ownership from smaller parcels. Large ownerships include three primary ranch and timber ownerships that cover the majority of the watershed. 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.

Considering the large ownerships, consumptive water use has a less of an impact on dry season flows in Sproul Creek than nearby subwatersheds with more inhabitants such as Redwood Creek and the Mattole River headwaters. However, consumptive water use still negatively impacts dry season flows in Sproul Creek during drought conditions. Consumptive water use in Sproul Creek has been estimated based on the approach described in the Redwood Creek Flow Enhancement Feasibility Study (Stillwater Sciences 2017).

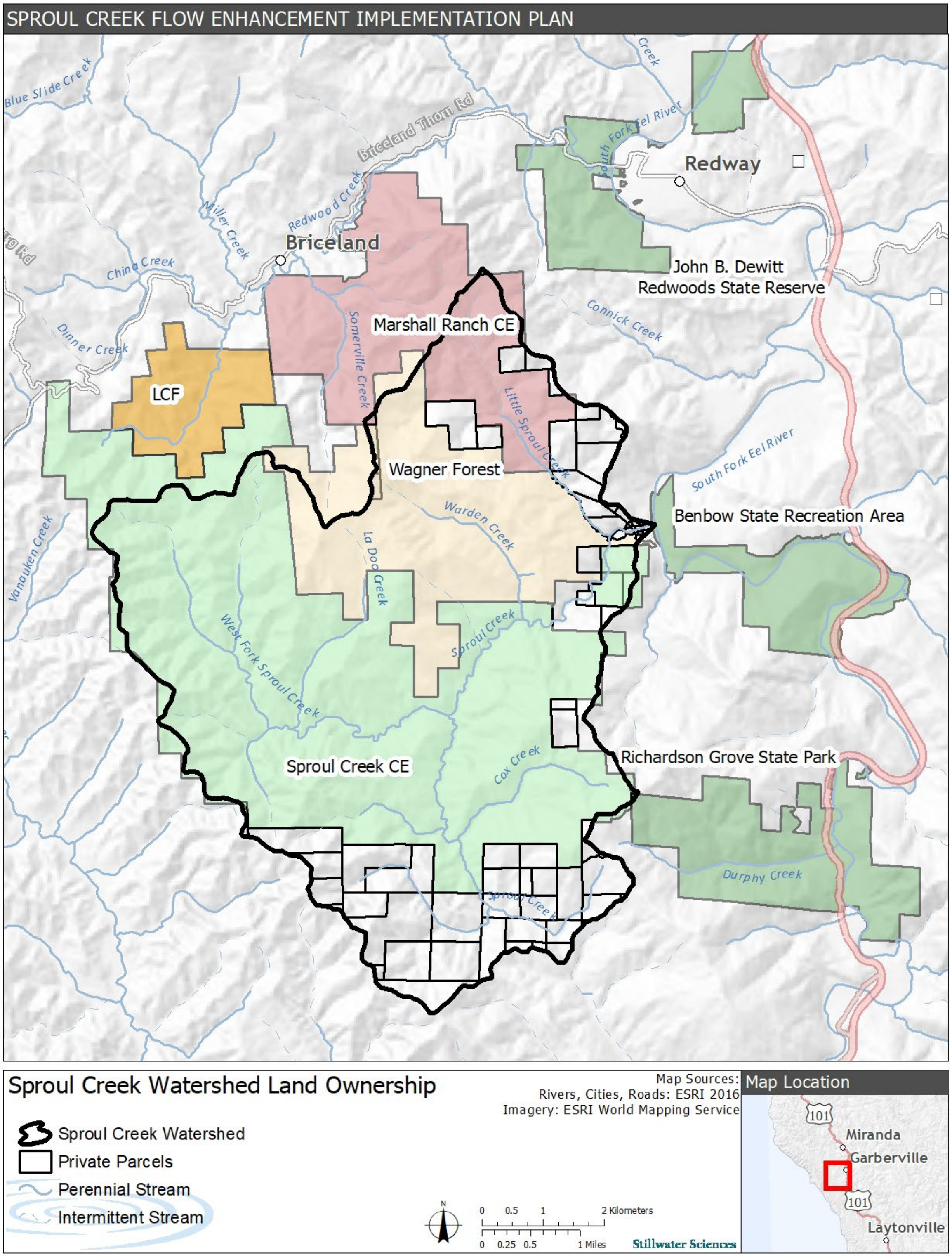


Figure 2-13. Land ownership within the Sproul Creek watershed. LCF is an acronym for Lost Coast Forestlands, LLC. The Sproul Creek CE (conservation easement) is owned by Green Diamond Resource Company.

Quantification of consumptive use in Sproul Creek is difficult, as is the case in many rural areas with dispersed water sources and users. Data gathered for neighboring Redwood Creek and the Mattole headwaters was used to estimate consumptive water use in Sproul Creek. This data was generated from landowner responses to water use surveys and GIS analyses conducted by CDFW and Stillwater Sciences. A compilation of the data provided conservative estimates of domestic and irrigation water use of 300 and 700 gallons per parcel day respectively for the 5-month dry season. 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 24.8 ac-ft.

Table 2-5. Consumptive water use estimates by subwatershed.

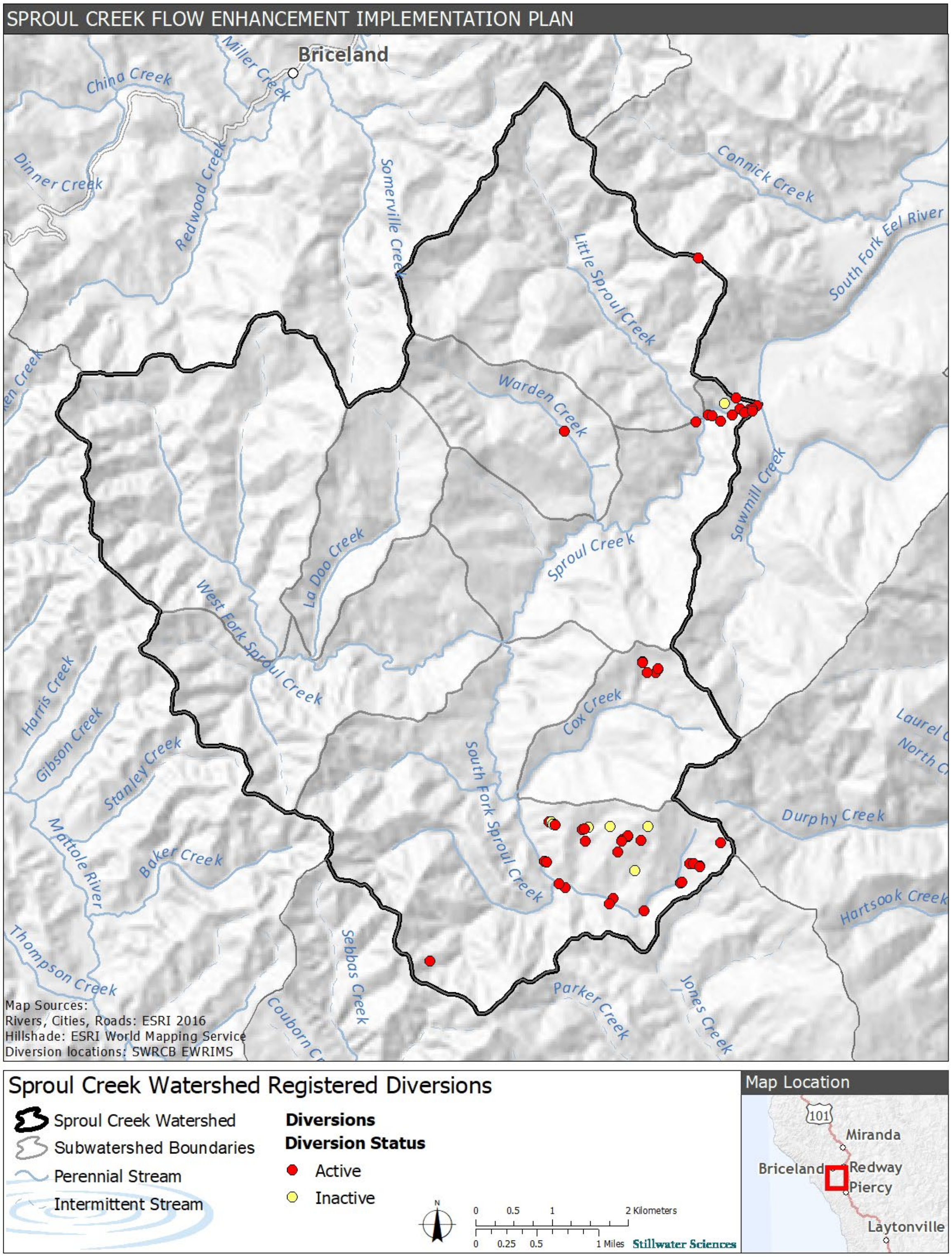
Subwatershed	Subwatershed area (mi^2)	Number of parcels with residence	Total estimated water use per sub-shed during 5-month dry season (ac-ft)*	Total estimated water use per sub-shed during additional 7 months (ac-ft)**	Total annual water use per sub-shed (ac-ft)
Sproul Creek Mainstem	2.9	15	6.9	2.9	9.8
South Fork Sproul Creek	5.6	18	8.3	3.5	11.8
Lower West Fork Sproul Creek	2.9	0	0.0	0.0	0.0
Upper West Fork Sproul Creek	4.1	0	0.0	0.0	0.0
Little Sproul Creek	3.9	4	1.8	0.8	2.6
Warden Creek	1.6	0	0.0	0.0	0.0
La Doo Creek	1.5	0	0.0	0.0	0.0
Cox Creek	1.5	1	0.5	0.2	0.7
Entire Sproul Creek Watershed	24.0	38	17.5	7.3	24.8

* 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

2.5.1 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. Based on Stillwater Sciences analysis for Redwood Creek, it was found that reported water use significantly underestimates actual water use, so a full analyses of reported water use in Sproul Creek was not conducted. However, the map of registered water users in Sproul Creek shown on Figure 2-14 does provide a spatial representation of where consumptive water use is focused within the watershed.



Map Sources:
Rivers, Cities, Roads: ESRI 2016
Hillshade: ESRI World Mapping Service
Diversion locations: SWRCB EWRIMS

Figure 2-14. Registered Points of Diversion within the Sproul Creek Watershed. Data from the SWRCB's eWRIMS database.

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[1]. The reference ET rate is the rate at which water evaporates and transpires from a well-watered reference grass crop. According to CIMIS, the Sproul Creek watershed has an average annual reference ET of 46.3 inches per year. However, the actual ET rate in the Sproul 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 also 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 19,472 ac-ft or approximately 15 inches per year across the entire Sproul Creek watershed.

2.7 Water Balance

Figure 2-15 depicts the water balance in Sproul Creek based on the analyses and data presented in Sections 2.4 to 2.6 above. The estimated ET and runoff are approximately 800 and 2,800 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 0.03% of the overall water balance.

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

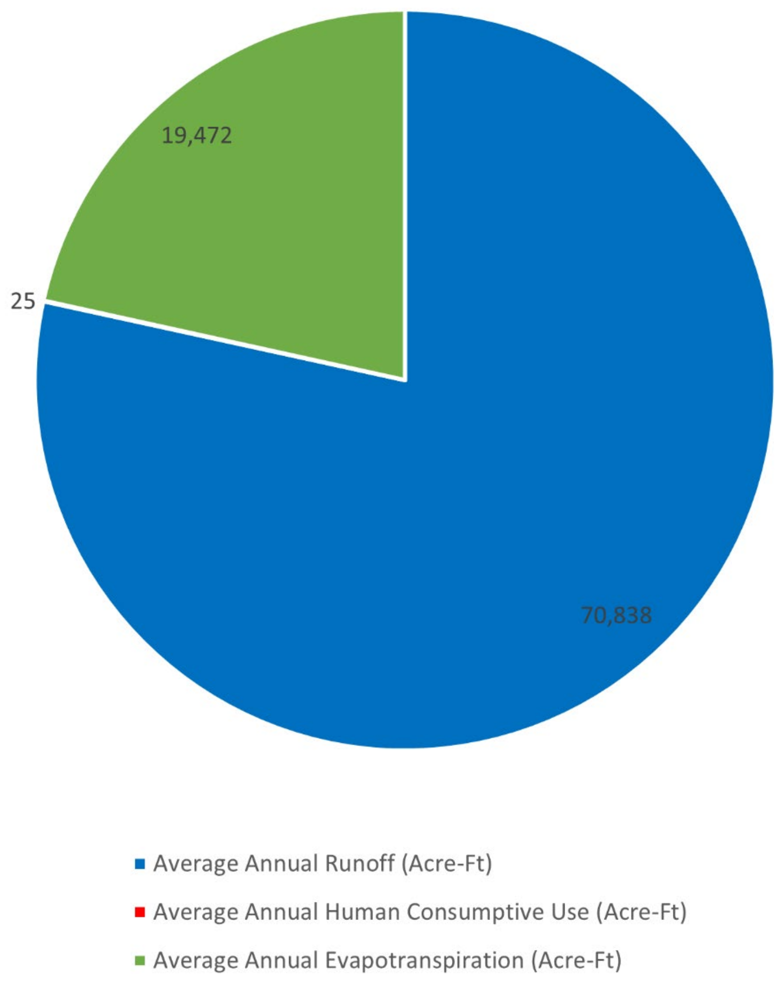
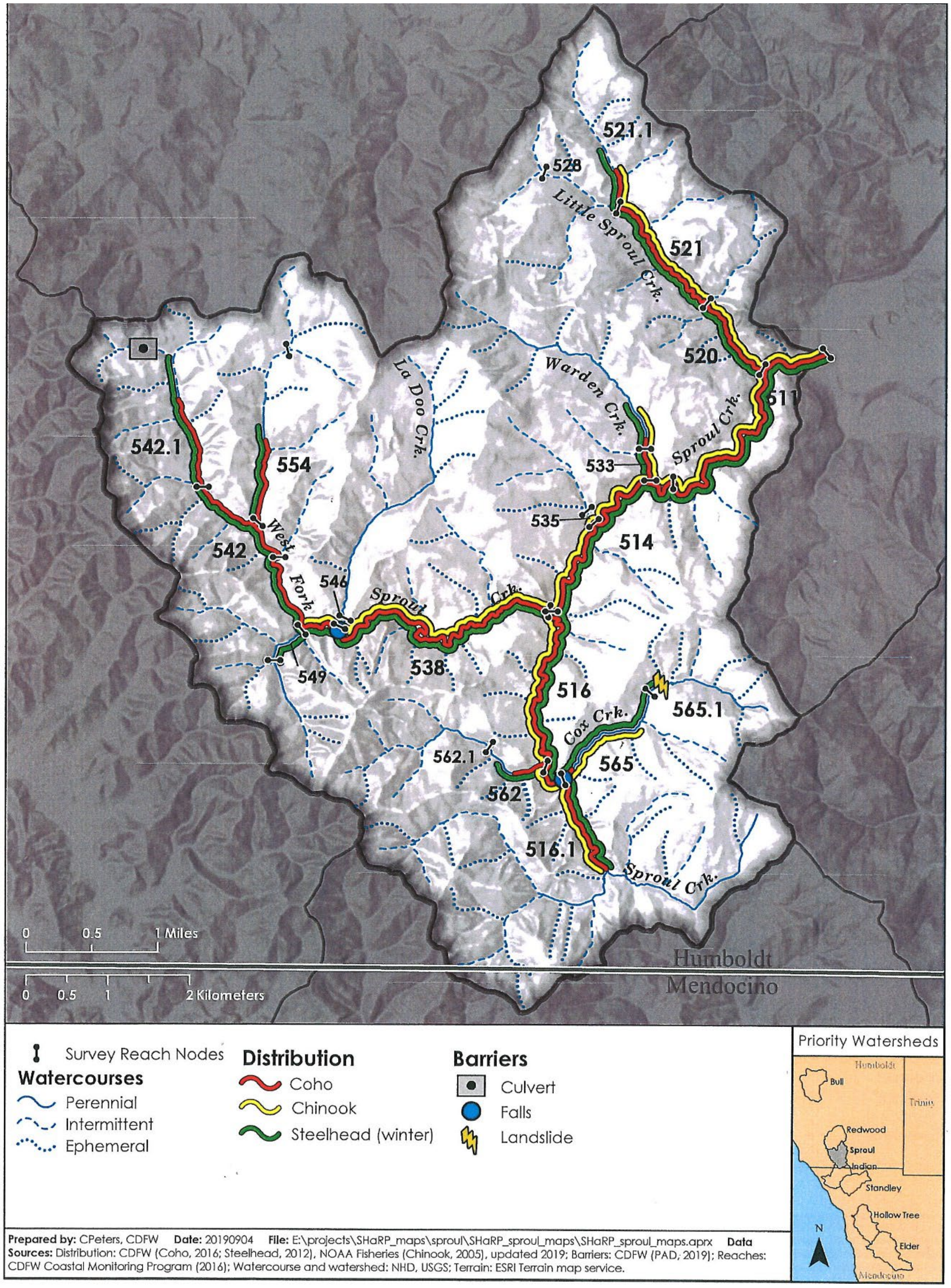


Figure 2-15. Approximate water balance for Sproul Creek, assuming 90,335 ac-ft of average annual precipitation.

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 Sproul Creek watershed (Figure 2-16). 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.



Prepared by: CPeters, CDFW **Date:** 20190904 **File:** E:\projects\SHaRP_maps\sproul\SHaRP_sproul_maps\SHaRP_sproul_maps.aprx **Data Sources:** Distribution: CDFW (Coho, 2016; Steelhead, 2012), NOAA Fisheries (Chinook, 2005), updated 2019; Barriers: CDFW (PAD, 2019); Reaches: CDFW Coastal Monitoring Program (2016); Watercourse and watershed: NHD, USGS; Terrain: ESRI Terrain map service.

Figure 2-16. Fish distribution within the Sproul Creek Watershed (figure courtesy of CDFW).

2.9 Summary of Hydro-Geomorphic Field Assessment

A preliminary assessment of select stream reaches within the Sproul Creek watershed was conducted over the course of three weeks in late September and early October of 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. The assessment was scheduled to observe mainstem Sproul Creek and key tributaries during the lowest flow conditions of the season. Assessments were entirely conducted on private property where access permission was gained through landowner outreach. A significant majority of the reaches assessed are located on land owned by the Green Diamond Resource Company and the Wagner Land Company.

A total of 11.3 contiguous miles of the Sproul Creek mainstem, West Fork, and South Fork were surveyed, beginning at the Little Sproul Creek confluence on the downstream end. An additional 11 miles of tributary, including Little Sproul, Warden, La Doo, and Cox Creeks, as well as portions of 6 unnamed streams were surveyed. The field effort was completed between September 24th and October 9th. A map of all surveyed reaches is shown on Figure 2-17. Dry stream channel segments observed during the effort were recorded using GPS and are indicated on the map. While at least some small dry channel segments were observed in all subwatersheds, significant dry reaches were mapped in lower South Fork Sproul, lower Cox Creek, and throughout West Fork trib 1. The longest uninterrupted wetted reaches were observed in Little Sproul Creek, lower West Fork Sproul, and upper South Fork Sproul.

The 2020 flow monitoring data series displayed on Figure 2-5 indicates that the survey was in fact coincident with the lowest measured flows in lower mainstem Sproul of 2020. Of the 8 years monitored, 2020 was the fourth driest after 2015, 2016, and 2021 (approximately average). The weather station closest to the Sproul Creek watershed is approximately 5 miles to the north, near the town of Redway. Identified as Eel River Camp, it recorded a total of 30.1 inches of rain in the 2020 water year. The PRISM estimate of the same water year in the Sproul Creek watershed is 42.2 inches. The PRISM estimate of the 30-year average rainfall for the watershed is 70.6 inches. Therefore, the 2020 water year was approximately 60% of the 30-year average representative of dry year low flow conditions over this longer historic period. However, as previously discussed, 2020 represents an average year low flow conditions when considering only the past decade.

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 2-18 and should be one of the early targets for forest thinning and headwaters storage and forbearance.

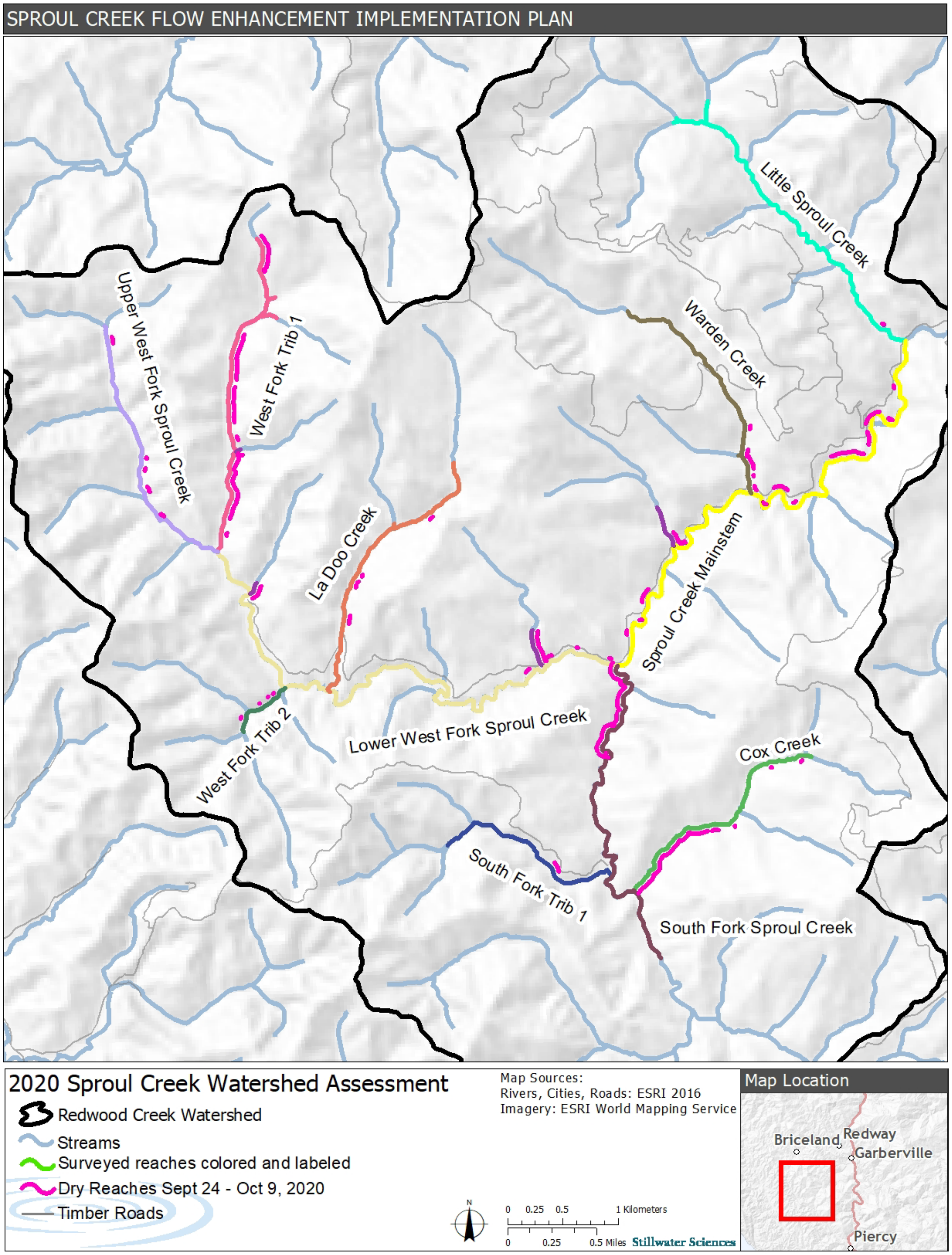


Figure 2-17. Map showing stream reaches surveyed in the 2020 watershed assessment. Dry reaches are delineated by pink lines. All other surveyed reaches were wetted.

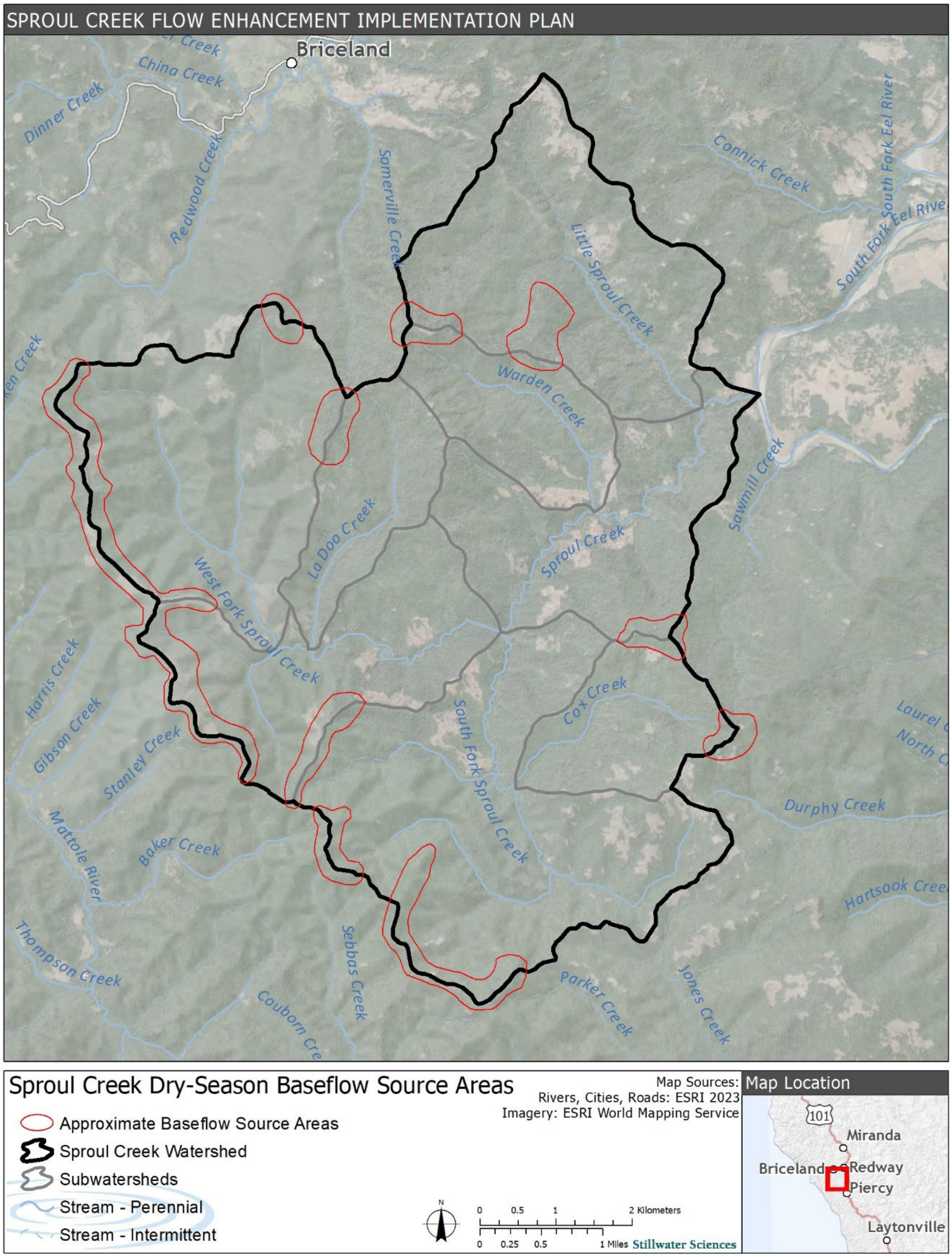


Figure 2-18. Generalized map showing primary dry-season base flow source areas comprised of steep forested ridgetops underlain by sandstone bedrock terrane.

3 IMPLEMENTATION APPROACHES TO ENHANCE DRY-SEASON FLOW

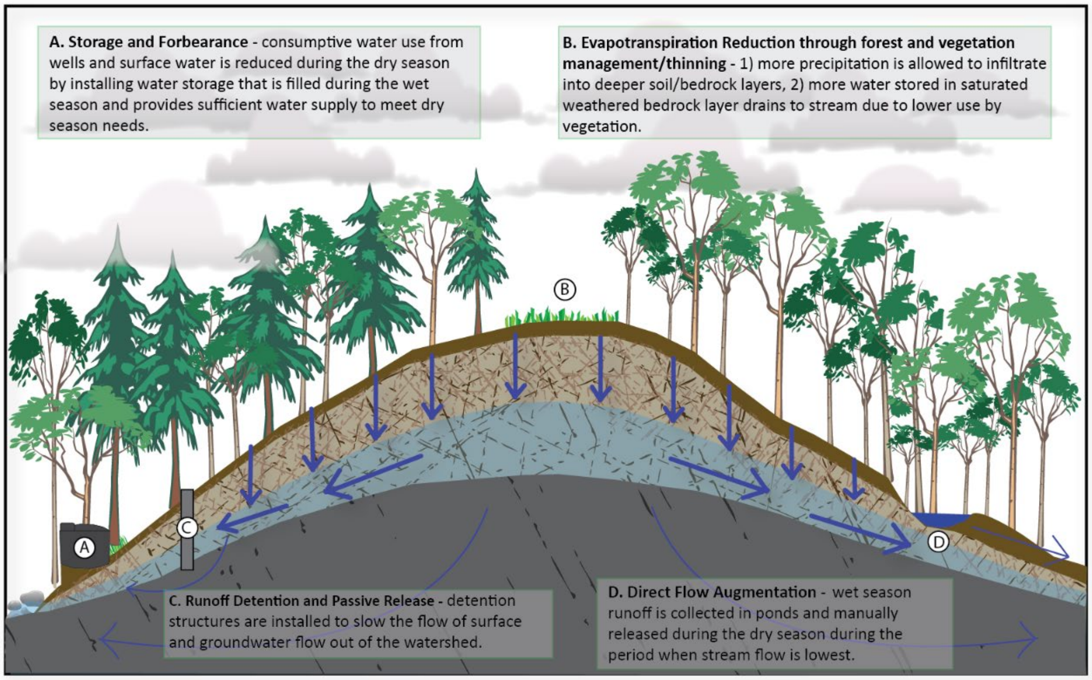
Based on dry-season conditions, flow enhancement objectives, and watershed characteristics described above, there are multiple approaches to enhance dry-season flows in Sproul Creek. To achieve flow enhancement benefits, specific actions must be taken to change the dynamics of groundwater and surface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



A. Storage and Forbearance - consumptive water use from wells and surface water is reduced during the dry season by installing water storage that is filled during the wet season and provides sufficient water supply to meet dry season needs.

B. Evapotranspiration Reduction through forest and vegetation management/thinning - 1) more precipitation is allowed to infiltrate into deeper soil/bedrock layers, 2) more water stored in saturated weathered bedrock layer drains to stream due to lower use by vegetation.

C. Runoff Detention and Passive Release - detention structures are installed to slow the flow of surface and groundwater flow out of the watershed.

D. Direct Flow Augmentation - wet season runoff is collected in ponds and manually released during the dry season during the period when stream flow is lowest.

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

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 Sproul Creek. A conceptual example of how these actions would be distributed throughout a subwatershed is demonstrated in Figure 3-3.

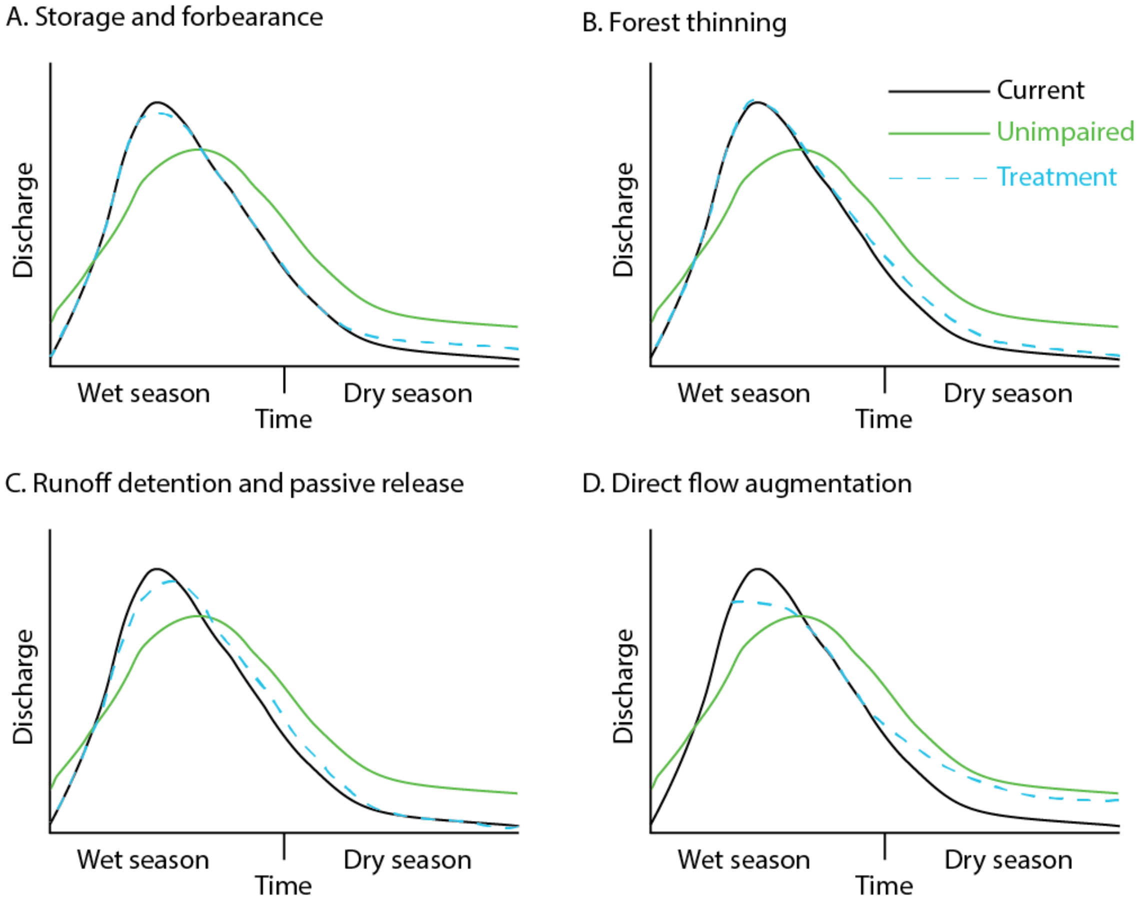


Figure 3-2. Conceptual hydrograph impacts from flow enhancement approaches.

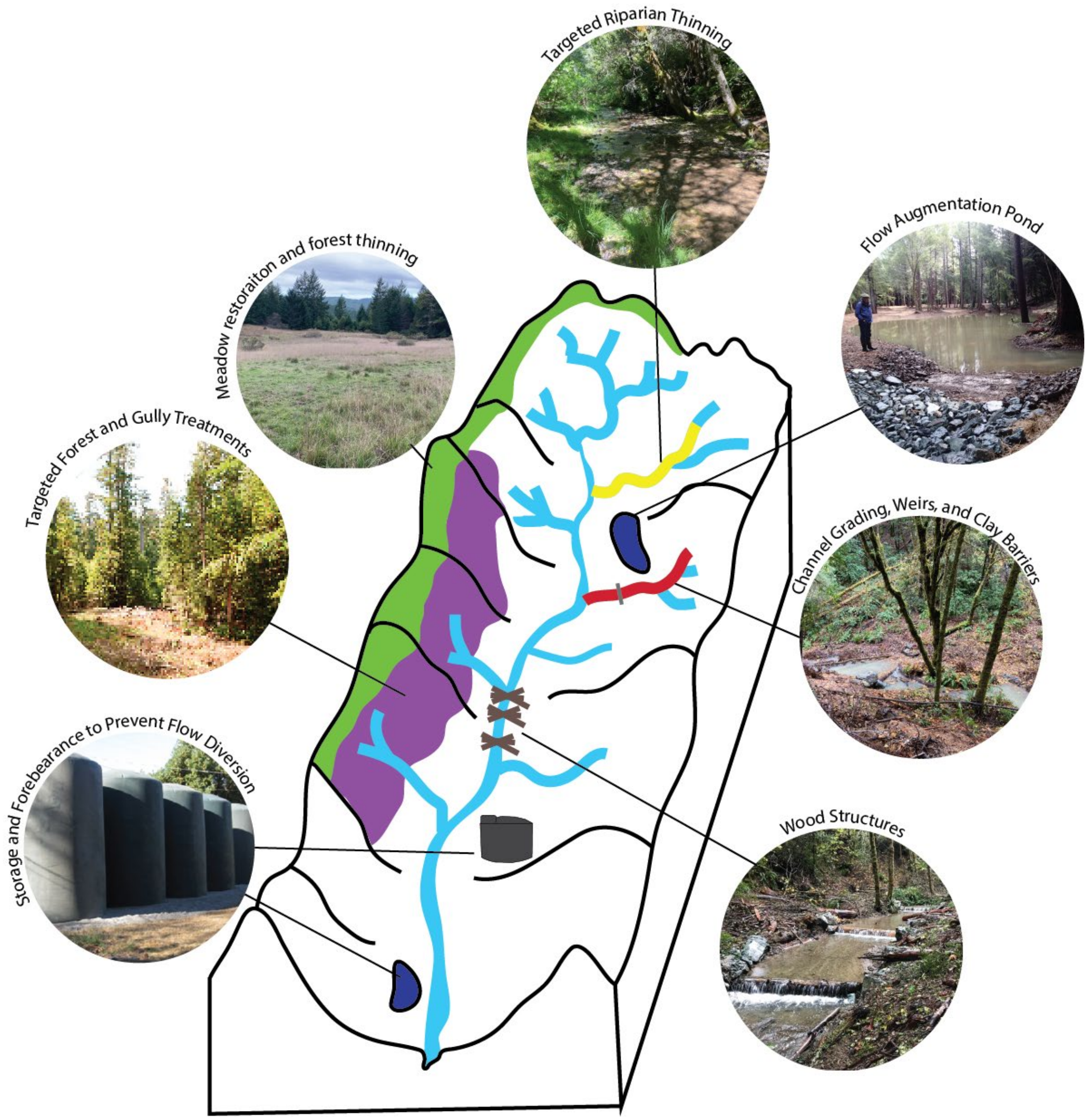


Figure 3-3. Flow Enhancement approaches within the watershed context.

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 Sproul 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.

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 Sproul 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 Sproul Creek (California Department of Water Resources 2019). Groundwater dynamics in Sproul 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 Sproul 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.

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 a future Sproul 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 Sproul 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 (ft) 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.

The Sproul Creek watershed is generally steep with few opportunities for large ponds based on topographic constraints. During the assessment, six potential sites for direct flow augmentation were identified including on- and 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. 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.

Based on topographic constraints, the identified direct flow augmentation project sites in Sproul Creek are either located upslope near ridgetops and/or onstream. These types of sites pose challenges in terms of filling the ponds during the wet season (i.e., the need to pump long distances to ridgetop sites) and permitting (i.e. impacts of onstream ponds). It is anticipated that many of the sites identified during the assessment and described later in this report would face extreme hurdles in the current regulatory environment. Before advancing these projects the outcomes from other local direct flow augmentation projects such as the Marshall Ranch Project will need to be well documented and provide strong scientific evidence that the benefits of direct flow augmentation well outweigh the impacts.

Impacts related to onstream ponds that need to be considered during the planning and design process include: (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 projects 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.

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 Sproul 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.

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 ft 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 Sproul 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 3-5. Photo of small wood jam in a Mattole River tributary (photo from Sanctuary Forest).

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.

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 ft and streambed sediments are sufficiently thick/deep for post installation (i.e., 4 ft 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 ft 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 ft 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 ft below its floodplain (optimally 3–4 ft).

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 Sproul 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 ft 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 (T., McKee, Water Program Director, Sanctuary Forest, pers. comm., 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 Sproul 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 Sproul 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 Sproul 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 Sproul Creek, with peak water tables elevations of approximately 4 ft below ground surface and dropping by up to 2 ft 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 Sproul 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 of the summer 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 Sproul 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 Sproul 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)[1]	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

[1] 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 Sproul 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.

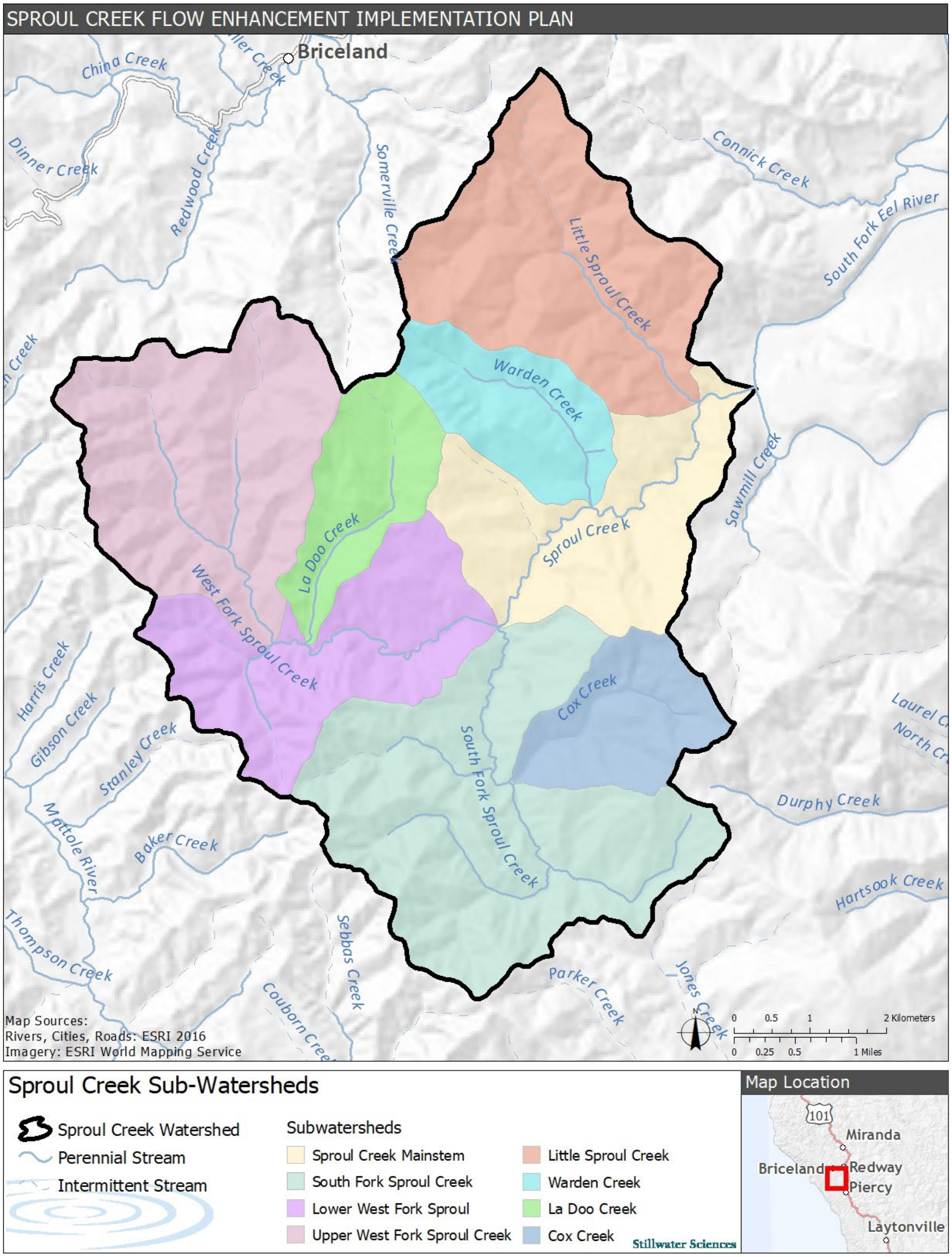


Figure 4-1. Subwatershed delineations within the Sproul Creek watershed.

4.1 Sproul Creek Mainstem Subwatershed

4.1.1 Existing conditions

The Sproul Creek Mainstem is defined here as extending from the confluence of Sproul Creek with the South Fork Eel River, upstream to the confluence of the West Fork and South Fork of Sproul Creek. The total length of this reach is 4.13 miles, though the lowest portion from the mouth to the confluence of Little Sproul Creek was not surveyed. Flowing largely north and east, the mainstem has an average slope of 0.95% and an active channel width which generally ranges from 25–35 ft. Channel substrates are dominated by cobble and gravel. The stream valley throughout this reach is broader with lower angled walls in comparison to upstream reaches, and the creek is often has floodplain terraces along one side. Cobble dominant lateral bars are relatively common and typically colonized by mature stands of alder which provide medium density canopy cover. Several split-channel reaches were observed. Nearly all of the Sproul Creek watershed has been historically logged, and a narrow band of alder and sometimes bigleaf maple trees along the banks of the mainstem quickly give way to a mixed coniferous-hardwood forest dominated by second to third growth redwood, tanoak, and douglas fir.

Naturally recruited large wood is relatively rare in the mainstem and the majority of significant structural diversity in the channel is driven by the presence of bedrock outcrops (Figure 4-2) and large boulders which result in scour pool formation. Frequent landslides, particularly along the outside of channel bends are also evident and likely deliver large boulders to the channel. Occasional long reaches of homogenous, plane-bed morphology were observed (Figure 4-3), and these were frequently dry. Throughout the 1.44 miles of channel surveyed, 43% by length was mapped as dry. A spot check of the Lower Mainstem Sproul flow monitoring station two days after the assessment (September 27) yielded a flow of 8.03 GPM.

With the exception of bedrock scour pools, riffle and pool depths were generally shallow. Riffle depths often appeared to be too shallow to be navigable by fish. Water in pools frequently appeared to be stagnant and highly tannic, and sometimes supported significant growth of green algae. Constructed large wood and boulder weir structures observed in the reach appear to be functioning well, often having created substantial pool habitat. While salmonid young-of-year (YOY) were observed throughout the reach they appeared to be outnumbered by invasive pikeminnow and/or roach, particularly in the lowest portions of the reach.

Figure 4-2. A bedrock scour pool in mainstem Sproul Creek.

Figure 4-3. A dry plane bed reach of mainstem Sproul Creek.

4.1.2 Project opportunities and constraints in the Sproul Creek mainstem subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	~15 landowners, would likely have measurable impact	landowners are concentrated on lowest 0.5 miles of creek, limiting habitat benefit	None	Medium priority to expand storage and forbearance program
Direct Flow Augmentation	One location identified for potential development of two ponds (Old Mill site ponds)	Mostly steep with few sites for off-channel storage	None	Old Mill site ponds
Runoff Detention and Passive Release	None currently identified	Mainstem system likely too large to be feasible, maybe some potential in smaller tributaries	None	Few opportunities due to constraints listed
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	LWD and boulder instream features. Floodplain and side channel habitat enhancement	High energy system and proximity of timberland access road. Relatively small amount of floodplain area.	LWD and boulder instream habitat enhancement projects implemented by ERWIG and Green Diamond	None yet planned

4.2 South Fork Sproul Creek Subwatershed

4.2.1 Existing conditions

South Fork Sproul Creek drains an area of 5.6 square miles and flows generally from south to north. Active channel widths in the reach are frequently between 20-25 ft and the average channel slope is 1.2%. The channel is primarily confined within a steep-walled valley with the exception of the reach between South Fork Trib 1 and Cox Creek (Figure 2-17). Occasional split channel morphologies were observed, mostly in the lower reach. As with the mainstem, complexity and pool formation are primarily driven by bedrock outcrops, which are more prevalent in the upper reaches.

The channel was observed to be dry at the West Fork confluence with only intermittent pools and long dry stretches for approximately 4,000 ft upstream (Figure 4-4). Most pools in this lower reach were observed to be shallow, stagnant, tannic, and supporting dense algal growth. This lack of pools is driven in part by a relatively low density of large wood, with many long runs of homogenous grade and substrate. Surface flow quantity and water quality gradually increase in the upstream direction, with continuous flows at the southern terminus of the surveyed reach (Figure 4-5). Of the 2.31 total miles of channel surveyed, 29% was dry. Spot checks of flow monitoring stations on South Fork Sproul Creek measured no flow at station SFS (downstream) and 4.12 GPM at station USFS (upstream) on September 27th, 5 days prior to the assessment.

Salmonid YOY were seen throughout the reach in densities comparable to the mainstem or somewhat higher. A sighting of what was likely pikeminnow or roach was made in the lower reach. One pacific lamprey ammocoete was observed desiccating on the edge of a shrinking pool. LWD and boulder habitat enhancement features could help to increase deep pool formation and the persistence of wetted dry season habitat.

Figure 4-4. An extended dry reach of lower South Fork Sproul Creek.

Figure 4-5. Continuous surface flow and pool formation facilitated by shallow bedrock near the upper end of the surveyed reach.

4.2.2 Project opportunities and constraints in the South Fork Sproul Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	18 residences, 29 registered diversions	Landowner outreach	None	Medium priority for storage and forbearance program
Direct Flow Augmentation	Cox Meadow Pond would provide flow benefit to this reach (see section 4.8); Otherwise limited	Steep watershed, numerous smaller landowners	None	None yet planned
Runoff Detention and Passive Release	None currently identified	Confined channel with few terrace features	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 much of the subwatershed
Other Restoration Opportunities	LWD and boulder instream features, especially in downstream reaches	Equipment access	None	None yet planned

4.3 Lower West Fork Sproul Creek Subwatershed

4.3.1 Existing conditions

In many ways, lower West Fork Sproul Creek bears a strong resemblance to the lower mainstem though narrower and somewhat steeper. Channel widths are commonly in the vicinity of 20 ft, and average slope is 1.1%. As with the mainstem, bedrock outcrops are the primary drivers of pool formation, and active landslides were frequently observed along outside bends. However, only 2% of the 3.78 miles of channel surveyed were dry. These elevated surface flows, in tandem with greater quantities of in channel large wood, result in a higher density and greater depth of pools (Figure 4-6). A spot check measurement of the WFS monitoring station in lower West Fork Sproul on September 27th, 8 days before the assessment, measured a flow of 1.98 GPM. Water quality generally appeared to be good, with only some pools appearing stagnant. While much of the large wood observed is not of sufficient size to drive pool formation, it offers a greater degree of cover habitat throughout the reach. As with the mainstem however, some long stretches of homogenous grade and substrate were observed (Figure 4-7). Placement of large wood and boulder features to increase habitat complexity and cover would likely be beneficial.

Figure 4-6. An example of excellent pool habitat in West Fork Sproul Creek.

Figure 4-7. A plane bed reach with very shallow surface flow that is likely impassible to fish.

4.3.2 Project opportunities and constraints in the lower West Fork Sproul Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	No residences or permitted diversions	N/A	None	None needed
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	System likely too large to be feasible	None	Few opportunities due to constraints listed
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	LWD and boulder instream features. Floodplain and side channel habitat enhancement	Relatively small amount of floodplain and side channel area	None	None yet planned

4.4 Upper West Fork Sproul Creek Subwatershed

4.4.1 Existing conditions

Upper West Fork Sproul is divided from lower at the prominent confluence with "West Fork Trib 1" (Figure 2-17) and drains the western half of the West Fork Sproul headwaters. The channel is narrower and significantly steeper than lower West Fork Sproul with active channel widths in the vicinity of 10-15 ft and an average channel slope of 2.3%. Observed flows were mostly continuous and clear though quite low, in the range of several GPM, and trending towards intermittent in the uppermost reaches. There, many pools were dark with tannins or densely colonized by iron bacteria (Figure 4-8). Approximately 8% of the 1.6 miles surveyed were mapped as dry. Channel morphology is steeper and more complex than the lower West Fork Sproul, and predominately confined within steep valley walls. A relatively high density of large wood drives frequent pool formation (Figure 4-9) and thick riparian vegetation provides good shading. Much of the large wood is likely to be debris from legacy logging operations, as evidenced by cut ends (Figure 4-9). One of the more complex reaches in the watershed, the upper West Fork generally contains good quality habitat throughout, though lack of surface flow in the uppermost reaches leads to a significant decrease in habitat availability.

Figure 4-8. An example of very low flows and high concentrations of iron bacteria in the upper reach of upper West Fork Sproul Creek.

Figure 4-9. An example of the high densities of woody debris in upper West Fork Sproul Creek.

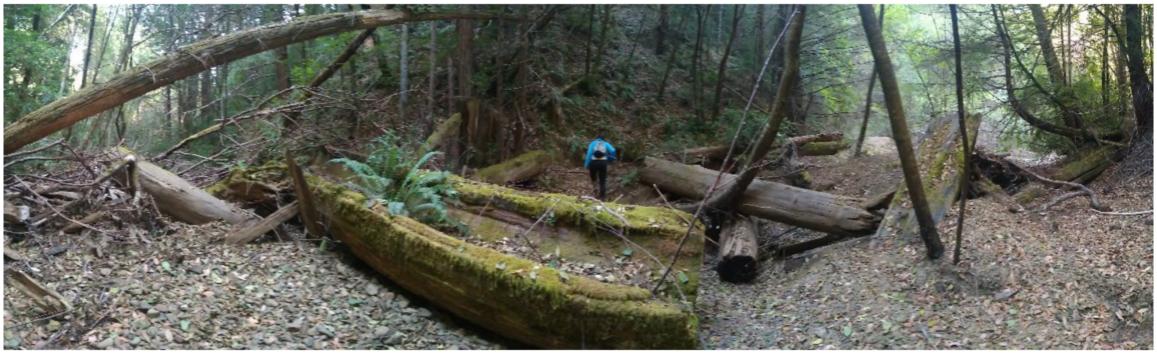


Figure 4-10. A significant amount of the large wood observed is from legacy logging.

4.4.2 Project opportunities and constraints in the upper West Fork Sproul Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	No residences or permitted diversions in subwatershed	N/A	None	None needed
Direct Flow Augmentation	One potential onstream pond site identified (discussed further in Section 5)	Watershed hillslopes are steep and densely forested, valley generally narrow	None	West Fork Sproul onstream pond
Runoff Detention and Passive Release	Some opportunities in upper extent as well as in small tributaries	Equipment access at some locations	None	None yet planned
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	LWD and boulder instream features	Equipment access at some locations	None	Low priority, existing densities high. Some short reaches could benefit, particularly around bridge crossing

4.5 Little Sproul Creek Subwatershed

4.5.1 Existing conditions discussion

Little Sproul Creek is a tributary to mainstem Sproul Creek and its mouth is approximately 0.53 miles upstream from the confluence with the South Fork Eel River. This tributary runs generally from NW to SE and drains a watershed area of 3.9 square miles. Similar to upper West Fork Sproul, active channel widths are in the vicinity of 15 ft, and average slope is 2.2%. The channel is largely confined by steep slopes and occasional mudstone bedrock outcroppings can be observed along the banks or underlying the channel. Landslide activity along valley walls is prevalent, especially in the upper reaches. A relatively high density of woody cover is provided by frequent landslide activity recruiting small diameter trees to the channel (Figure 4-11). However, woody debris is only occasionally of sufficient size to influence channel morphology. Channel grade is therefore somewhat homogenous, and deep pools are somewhat rare (Figure 4-12).

Flow was observed to be clear and continuous throughout the 2.04-mile survey extent with the exception of one 100 ft long section approximately 800 ft upstream from the outlet. Flows measured at the monitoring site three days after the assessment on September 27th were 5.9 GPM. These relatively good baseflows, and perhaps the presence of shallow bedrock, provide sufficient habitat to support a robust steelhead population even during a dry year. Construction of large wood and boulder habitat structures could help to improve habitat complexity, and deep pool formation that could increase resiliency in drought years.

Figure 4-11. An example of one of the many landslide features contributing woody debris to Little Sproul Creek.

Figure 4-12. A typical stretch of Little Sproul Creek with homogenous channel and only shallow pool development.

4.5.2 Project opportunities and constraints in the Little Sproul Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	5 residences, 2 water rights on record; may not have measurable impact	Landowner outreach	None	Low priority to expand storage and forbearance program
Direct Flow Augmentation	Several potential offstream ponds sites identified on Marshall Ranch	Watershed hillslopes are steep	None	Little Sproul offstream ponds
Runoff Detention and Passive Release	Some opportunities in upper extent as well as in small tributaries	Equipment access	None	None yet planned
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	LWD and boulder instream features	Equipment access	ERWIG has completed a wood loading project over the past several years	None yet planned

4.6 Warden Creek Subwatershed

4.6.1 Existing conditions

Warden Creek is a tributary to Sproul Creek mainstem which has a watershed abutting and parallel to Little Sproul Creek, though less than half as large with an area of 1.6 square miles. The active channel width in the reach surveyed is approximately 6 to 8 ft and channel slopes were quite steep. In the downstream half of the survey, channel slope averages 6.9%, while it is 4.2% in the upstream half. One approximately 850-ft-long reach in the downstream half is composed of a boulder cascade that has a slope of 18%. Of the 1.4 miles of channel surveyed, 13% was dry, all in the downstream third. Above those dry portions, flows were continuous and water was clear, though very shallow in riffles. Young of year salmonids were observed throughout the survey, though in low densities upstream of the boulder cascade. The cascade is likely to be at least a partial barrier to anadromy, if not a complete barrier with a landlocked population upstream. Overall channel morphology of Warden Creek is very similar to Little Sproul, though with a greater degree of woody debris and boulder recruitment through land sliding and bank failure (Figure 4-13) particularly in the upper portions of the reach. Additionally, wood appears to be incorporated into the channel bed more frequently, resulting in more scour pool development. A small legacy dam exists approximately halfway through the surveyed reach, composed of concrete with a 5 ft wide sluiceway. Under observed flow conditions, the sluice was perched about 2 ft above the downstream pool and about 4 ft above the channel bed. Some minor bank erosion has occurred downstream of the sluice while channel aggradation and widening has occurred upstream of the dam (Figure 4-14). With minor upgrades, there is potential to operate this existing dam as a small flow enhancement pond.

Figure 4-13. An example of woody debris and boulder inputs from landslide activity in upper Warden Creek

Figure 4-14. The broad, aggraded reach upstream of the small dam

4.6.2 Project opportunities and constraints in the Warden Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	No residences, 1 registered diversion associated with the historic small dam	N/A	None	None
Direct Flow Augmentation	Potential to re-purpose existing dam; build new small off-stream pond in nearby meadow	Watershed hillslopes are steep, valley generally narrow; meadows generally unstable.	None	Warden Creek onstream pond repurposing (low priority)
Runoff Detention and Passive Release	Several opportunities for trench wall construction in unconfined reaches	Equipment access	None	None yet planned
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	LWD and boulder instream features in some downstream reaches	Equipment access; potentially limited extent of anadromy	None	None yet planned

4.7 La Doo Creek Subwatershed

4.7.1 Existing conditions

La Doo Creek is a tributary to lower West Fork Sproul Creek and drains a watershed area of 1.5 square miles. Channel slope in the assessed reach averages 4.0% and active channel widths average approximately 8 ft. Just above its confluence with the West Fork Sproul, the La Doo flows through a large bedrock outcrop and forms a vertical 14 ft waterfall to the pool below. This waterfall is a barrier to anadromy, and no fish were observed in the assessed reach. Upstream of the waterfall, the channel is predominantly confined, with fair complexity and pool development, and bares many similarities to upper Warden Creek (Figure 4-15). Flows were mostly continuous and water quality appeared to be good. 7% of the 1.6 miles assessed were mapped as dry.

The proposed La Doo Creek Meadow Flow Enhancement Project seeks to build a 5 million gallon off-channel flow enhancement pond on a ridgetop meadow at the northeast watershed boundary. Flows would be released into a small headwater tributary to La Doo Creek approximately 2.5 miles upstream from West Fork Sproul Creek. The project plans to provide 15 GPM of streamflow enhancement throughout 5-months of the summer dry season.

Figure 4-15. A representative photo of upper La Doo Creek

4.7.2 Project opportunities and constraints in the La Doo Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	No residences or registered diversions	N/A	None	None
Direct Flow Augmentation	La Doo Meadow Pond, ~15 GPM. No others identified	Aside from the identified site, the watershed is steep and densely forested	La Doo Meadow	None
Runoff Detention and Passive Release	Few opportunities	Confined channel with few terrace features, shallow bedrock	None	None yet planned
ET Reduction	Sandstone bedrock supports summer base flow sources, high potential for improvements	Landowner access	None	Many opportunities for forest thinning throughout subwatershed
Other Restoration Opportunities	None identified	N/A	None	None

4.8 Cox Creek Subwatershed

4.8.1 Existing conditions

Cox Creek, tributary to South Fork Sproul, drains a watershed area of 1.5 square miles and flows generally from northeast to southwest. The creek is crossed by a timber road 1.2 miles from its mouth where it is conveyed by an undersized arch culvert. In the upper reach above the culvert, a continuous flow of clear water was observed visually estimated to be approximately 5 GPM. The Cox Creek channel is narrow with an active channel width of 4-6 ft and average slope of 5.4%. One large active landslide along the left bank was observed. Habitat has moderate woody cover but little large wood incorporated into the channel. Pools are frequently shallow but steady baseflow provided good water quality throughout much of the surveyed reach. No fish were observed in the upper reach. It is possible that the culvert is a velocity barrier during high flows.

The channel downstream from the culvert is wider with an active channel width of approximately 8 ft and 4% slope. Moderate amounts of woody cover and geomorphic complexity driven by large wood and boulders were observed, though pools were generally shallow. In the downstream direction, continuous flows of clear water transition to intermittent, with increasingly poor water quality before going primarily dry for the lowest 3,000 ft of channel (Figure 4-16). Salmonid YOY were observed in the lower wetted reaches where pools were intermittent. Many pools with fish were drying out and had poor quality, with several containing dense growth of iron bacteria (Figure 4-17).

In addition to the low flows observed in the lower reach, long stretches of plane bed channel with few pools severely limits available rearing habitat. This may in part be a reflection of aggradation of sediments from several active landslides observed upstream. Of the 1.44 miles of channel surveyed, 43% was dry. Promoting deep pool development through installation of large wood and boulder habitat features appears to be critical to achieve viable fish habitat in dry years. Additionally, a direct flow augmentation pond conceptual design has been developed for a meadow in the upper watershed, as discussed in Section 5.2.2.

Figure 4-16. A dry and plane bed reach of lower Cox Creek.

Figure 4-17. An isolated pool in lower Cox Creek with dense growth of iron bacteria.

4.8.2 Project opportunities and constraints in the Cox Creek subwatershed

Treatment	Opportunities	Constraints	Current projects	Future projects
Storage and Forbearance	1 residence, 4 registered diversions	May not have measurable impact	None	None planned
Direct Flow Augmentation	Cox Meadow Pond, ~20 GPM	Minimizing impacts to wetlands and native grasslands habitat	None	Cox Meadow still in concept stages
Runoff Detention and Passive Release	None currently identified	Confined channel with few terrace features	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 subwatershed
Other Restoration Opportunities	LWD and boulder instream features especially in downstream reaches	Equipment access	None	None yet planned

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 May 2023. 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.

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
La Doo Meadow Pond	La Doo Creek	Wagner Land Company	3	3	3	3	3	15
Cox Meadow Pond	Cox Creek	Green Diamond	3	3	3	3	1	13
Old Mill Site Ponds	Sproul Creek Mainstem	Green Diamond	3	3	2	3	2	13
West Fork Sproul Onstream Pond	Upper West Fork Sproul	Green Diamond	3	3	2	3	1	12
Little Sproul Ponds	Little Sproul Creek	Marshall Ranch	2	3	2	2	3	12
South Fork Sproul Storage and Forbearance	South Fork Sproul Creek	Multi	1	3	3	1	3	11
Sproul Creek Mainstem Storage and Forbearance	Sproul Creek Mainstem	Multi	1	3	2	1	3	10
Warden Creek onstream pond repurposing	Warden Creek	Wagner Land Company	1	3	2	2	2	10
Forest Thinning	All	Multi	1	1	3	1	3	9

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 generalized discussions of storage and forbearance, forest thinning, and groundwater recharge actions in Section 5.3.

In addition to the site prioritization presented on Table 5-1, additional comparison of opportunities and constraints associated with the top three priority projects was conducted (Table 5-2). This additional comparison was conducted to determine which of the three highest priority project should be advanced to the 65% design phase as a separate task under the WCB contract that has funded development of this Flow Enhancement Implementation Plan.

Table 5-2. Opportunities and constraints for three highest priority projects.

Site	Cox Meadow	Old Mill	La Doo Meadow
Flow Enhancement Volume	7 million gallons	4 million gallons	4.9 million gallons
Flow Enhancement Benefit Location	Optimal – upstream from critical habitat on Cox Creek and Upper mainstem Sproul	Low – Lower reaches of Sproul mainstem where temperatures above optimal	High – headwaters of La Doo Creek with no anadromy but drains into West Fork Sproul
Pond Fill Approach	Optimal - Rainwater and gravity flow from upslope drainages	Good - Rainwater and gravity pipe from upslope spring	Moderate - Rainwater and pump
Geologic/ geomorphic stability	Optimal - Stable site, some potential for pond sedimentation from upslope gullying	Tributary with high sediment yield to north of site needs to be re-aligned, some risk of future debris torrent impacts to site	Optimal - Stable site near ridgetop

Site	Cox Meadow	Old Mill	La Doo Meadow
Cut-Fill Balance	~15,000 CY excess cut material, likely to be rocky; no clear storage location identified	Mostly balanced	~10,000 CY excess cut, material likely to be rocky; good fill storage locations nearby
Water Rights	Will require Appropriative Water Rights	Likely to require Appropriative Water Right	May be able to utilize SDUR (10 ac-ft for fish and wildlife)
Adjacent projects/land use	Adjacent active THP upslope? Potential to complicate cumulative effects	Large wood habitat enhancement project in Sproul Creek; Near GDR property entrance with multiple management-related uses (materials storage, etc.)	Fire break and oak woodlands/meadow restoration along ridgetop generally consistent with project
Wildlife Impacts	Reduction in general wildlife use at site (no specific sensitive species)	Spotted Owl nesting directly adjacent to site	Minimal considering adjacent meadow habitat
Habitat Impacts	Displacement of significant native grassland and wetland habitat	Some displacement of watercourses and low-quality wetland vegetation, heavily disturbed environment	Displacement of some native grassland habitat
Mitigation Opportunities	Some opportunities for native grassland, oak woodland and wetland habitat enhancement	Seasonal tributary and wetland habitat enhancement opportunities; Invasive weed removal (French broom)	Extensive opportunities for meadow and oak woodland restoration on ridgetop adjacent to project site
Forest Impacts	Removal of multiple small diameter fir trees and one live oak	Removal of several Pine and Redwood trees	Minimal
Fire Suppression Benefits	Optimal location for protection of Nielson Ranch community	Optimal location for protection of Green Diamond ownership	Optimal location for helicopter access for all of Sproul Creek watershed
Other Benefits		Optimal location to supply water for road dust abatement	
Long Term Operations	Passive filling, management required for water quality and augmentation rate	Management required for filling of pond, water quality and augmentation rate	Pumping required for filling, management for water quality and augmentation rate
Planning-level cost estimate	$1,700,000	$1,000,000	$1,350,000
Cost/gal of Flow Augmentation	$0.25/gal	$0.25/gal	$0.30/gal

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. As scientific evidence is further developed to support forest thinning with a flow enhancement objective, there are expected to be many locations throughout the watershed where such treatments may be viable. However, at this time they are not included on Figure 5-1.

5.2.1 La Doo Meadow Pond flow enhancement project

The La Doo Meadow Pond project is currently at the 65% design level and CEQA review phase. The project will construct 4.9 million gallons of off-stream water storage with the objective of providing approximately 15 GPM of flow augmentation to West Fork Sproul Creek during the 5-month dry season.

5.2.2 Cox Meadow Pond flow enhancement project

The Cox Meadow Pond project is currently in the preliminary design phase as shown in Appendix D. The project site is one of only several locations on Green Diamond property that are not forested and is optimally positioned to provide flow augmentation to Cox Creek, South Fork Sproul Creek, and Sproul Creek mainstem. However, the project would result in biological impacts to native grasslands, and a class II watercourse/wetland area. The objective of the project is to construct a pond that provides approximately 20 GPM of flow augmentation to downslope watercourses during the 5-month dry season.

5.2.3 Old Mill Pond flow enhancement project

The Old Mill Pond project is currently in the preliminary design phase as shown in Appendix D. The project site is one of only several locations on Green Diamond property that are not forested and is optimally positioned to provide dry season water storage supply for road watering to Green Diamond with the potential secondary benefit of flow augmentation. There is potential spotted owl nesting nearby and also concern regarding buried detritus associated with the old mill located at this site in the 1940s. There are also several heavily impacted watercourses that flow through the vicinity.

5.2.4 Upper West Fork Sproul flow enhancement project

One potential onstream pond location has been identified on Green Diamond property in Upper West Fork Sproul Creek. This site is near the upstream extent of anadromy and is located in a heavily disturbed, relatively wide and low gradient setting that could generate significant water storage. However, as described earlier in this report, direct flow augmentation projects must demonstrate clear success before onstream water storage sites will be considered as a feasible approach.

5.2.5 Little Sproul flow enhancement project

Several offstream pond sites were identified on the Marshall Ranch in the Little Sproul Creek subwatershed. Due to topographic relief, the maximum feasible pond sizes are in the range of 1 million gallons, which is smaller than optimal for direct flow augmentation projects.

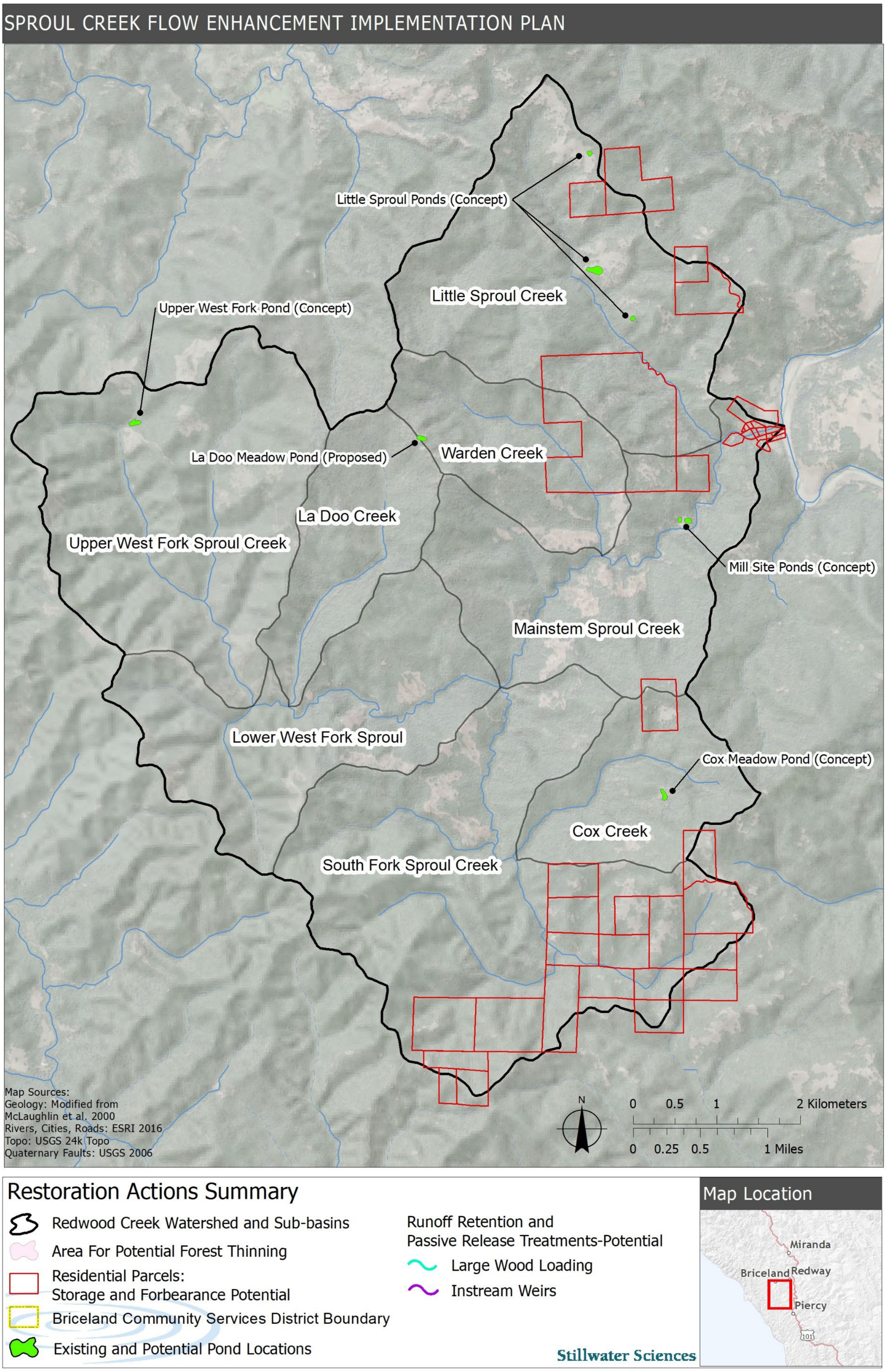


Figure 5-1. Redwood Creek flow enhancement implementation plan recommended actions.

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 Sproul 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 develops a Sproul Creek storage and forbearance program to provide a watershed-wide resource for diversion coordination.

Storage and forbearance activities within Sproul Creek should target the two areas with higher concentration of residents as shown on Figure 5-1 including the lower mainstem Sproul Creek and South Fork Sproul Creek. 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 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, especially in the Sproul Creek watershed where so much of the area is managed for timber. 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. With funding from CDFW, SRF and Stillwater have recently commenced development of a forest thinning pilot projects in the neighboring Redwood Creek watershed to test approaches and treatments.

Based on the outcomes of pilot projects, all subwatersheds in Sproul Creek could be excellent candidates for forest thinning pilot projects.

5.3.3 Direct flow augmentation

Five potential direct flow augmentation projects are described in Section 5.2. At this time, no additional suitable flow augmentation project sites have been identified due to the generally steep terrain within Sproul Creek.

5.4 Implementation Timing and Anticipated Flow Benefits

Table 5-3 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 80 GPM.

In summary, this table shows that feasible opportunities for large-scale flow enhancement are limited in Sproul 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 (40–80 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 through parts of the watershed, additional flow enhancement may be achieved.

Table 5-3. 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)
La Doo Meadow Pond	La Doo Creek	Wagner Land Company	2025	15	15
Cox Meadow Pond	Cox Creek	Green Diamond	~2028	20	35
Old Mill Site Ponds	Sproul Creek Mainstem	Green Diamond	~2028	10	45
West Fork Sproul Onstream Pond	Upper West Fork Sproul	Green Diamond	~2035	15	60
Little Sproul Ponds	Little Sproul Creek	Marshall Ranch	~2030	5	65
Storage and Forbearance (20 participants)	South Fork Sproul Creek	Multi	~2025–2030	5	70
Storage and Forbearance (20 participants)	Sproul Creek Mainstem	Multi	~2025–2030	5	75
Warden Creek onstream pond repurposing	Warden Creek	Wagner Land Company	~2030	5	80

5.5 Land Acquisition and Conservation Easements

An additional important action that can facilitate flow enhancement within the watershed is continued land acquisition and conservation easements. Most of the Sproul Creek watershed is already held in conservation easements including the Marshall Ranch, Wagner Land Company, and Green Diamond ownerships. These conservation easements ensure that these properties will not be subdivided and remain in ranch and timber production. Not only do these large ownerships limit human consumptive water use, but they also provide strong partnerships to support other types of flow enhancement activities.

To support future flow enhancement goals in the watershed, opportunities to expand conserved ownerships within the Sproul Creek watershed should continue.

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 in a neighboring watershed but have yet to begin. Monitoring and adaptive management at all levels will be required for these complex project types.

Work in Sproul 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 Sproul Creek flow enhancement planning meetings 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 Sproul Creek. Specific direct flow augmentation, as well as storage and forbearance projects have been identified that are expected to result in 80 GPM of flow augmentation. Still, this falls well below the unimpaired flow targets for Sproul Creek of 580–970 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, forest management 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 2015 to 2022

Appendix B

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

Appendix C

Hydro-geomorphic Field Assessment Summary Data

Appendix D

Schematic Designs for Cox Meadow and Old Mill Project Sites