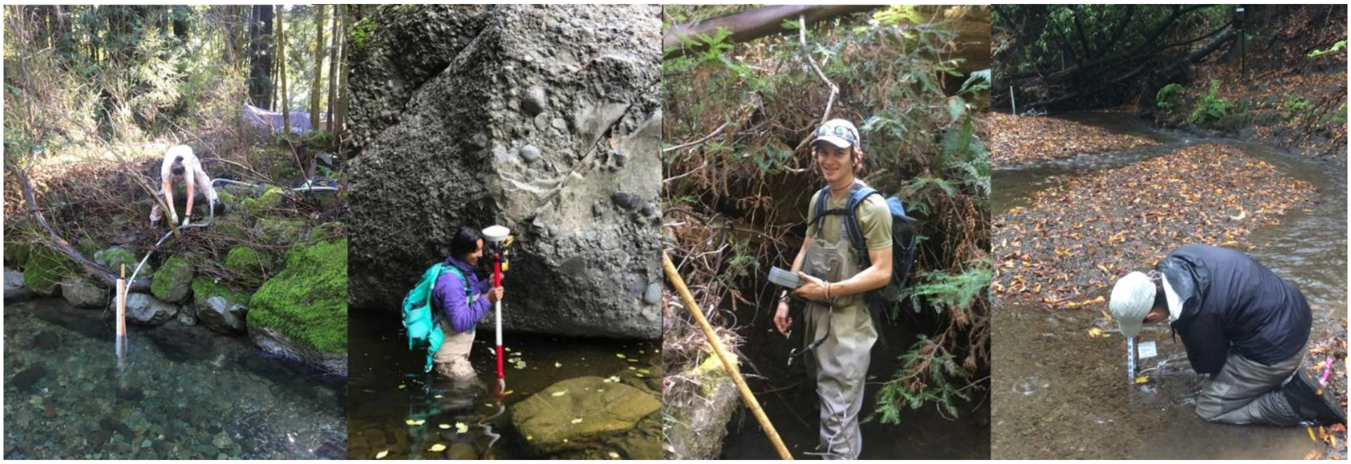
Flow and survival studies to support endangered coho recovery in flow-impaired tributaries to the Russian River



Final report for Wildlife Conservation Board grant WC-1663CR

May 1, 2017 – December 31, 2020

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Contents

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Executive summary

This report presents an overview of the work completed under WCB award WC-1663CR, from 2017-2020. The goal of this project was to support efforts to increase streamflow in tributaries to the lower Russian River that are critical to the recovery of endangered coho salmon populations, by providing recovery partners with information and tools to better understand the flow needs of salmon and limiting factors related to flow and habitat conditions. The work focused on three key tasks: 1) Develop predictive models relating streamflow, environmental metrics, and juvenile coho salmon survival; 2) Document wetted habitat conditions in Dutch Bill, Green Valley, and Mill Creeks in relation to streamflow and fish distribution, and build a predictive model for surface water recession; and 3) Organize annual coordination meetings among the many salmon recovery partners working towards common streamflow improvement goals in the watershed.

To meet the objectives of Task 1, a seven-year dataset was used to develop statistical models relating flow and other environmental metrics to oversummer survival of juvenile coho salmon in study reaches of Dutch Bill, Green Valley, Mill, and Grape creeks. Among eight variables investigated, three showed significant effects on survival; duration of pool disconnection and cropland area both exhibited a negative effect, and minimum pool volume exhibited a positive effect. In drought years, survival was generally lower and variability was higher, though some reaches maintained similar survival during drought and non-drought years. These areas might offer drought refugia critical for juvenile coho salmon survival; however, if duration of pool disconnection increases with projected increases in drought severity, many of these refugial habitats could transform into ecological traps. Research outcomes were published in the journal Global Change Biology (https://onlinelibrary.wiley.com/doi/epdf/10.1111/gcb.15116).

For Task 2, we collected field data during the summers of 2017-2019 to assess wetted habitat, water quality, streamflow, surface flow connectivity, and flow release effectiveness. Wet/dry mapping occurred at biweekly intervals in all anadromous reaches of Dutch Bill, Mill, and Felta creeks, and in the upper reaches of Green Valley Creek. Streamflow and water quality were monitored using a network of six stage loggers (including the installation of two online units) and six dissolved oxygen (DO) and water temperature loggers, two each in Dutch Bill, Green Valley and Mill creeks. The environmental data collected through this grant was compared to fish distribution data collected over the same period by statewide and conservation hatchery monitoring programs. Wetted habitat maps and associated water quality data were shared with recovery partners weekly, in-season, and used to organize fish rescues and inform flow release timing. Monitoring outcomes were also used to document the effectiveness of flow releases.

Over the course of the study period, the focus watersheds experienced both wet and dry water year type conditions. WYs 2017 and 2019 received regionally above-average rainfall, and WY2018 below-average rainfall. Despite significantly greater total precipitation in WY2017, WY2019 experienced higher streamflow—the highest in TU's period of record. This was likely influenced by the late-spring storms that occurred in 2019, but data also suggest that the 2012-2016 drought may have had a lingering impact on WY2017 streamflow and associated water quality conditions.

Wetted habitat survey results revealed that Felta Creek consistently experienced the earliest and greatest level of stream drying, with just 42% of the surveyed channel length remaining wet in the driest year of 2018, followed by Dutch Bill Creek with 55%, Mill Creek with 66%, and Green Valley Creek with 69%. In Felta Creek, on average over the 2017-2019 period, only 43% of observed salmonid redds and 40% of observed juveniles were in locations that remained wet the following September. This was followed by Mill Creek, with an average

66% of redds and 70% of juveniles in locations that remained wet, then Green Valley Creek with 73% and 79%, respectively, and finally Dutch Bill Creek, where 90% of both redds and rearing juveniles were observed in habitat that remained wet.

Dutch Bill Creek displayed the lowest interannual variability in stream-scale, end-of-season wetted habitat conditions, suggesting that it is not as sensitive to changes in environmental conditions as the other watersheds. The upper reaches of Dutch Bill Creek (above Tyrone Gulch) and the upper reaches of Mill Creek (above the confluence with Wallace Creek) both remained almost entirely wet and connected through all summers. This indicates that these areas offer reliable summer refugia for rearing fish under the climatic conditions experienced during the study period, though more salmonids appear to be using that habitat in Dutch Bill Creek.

When wet/dry mapping results were averaged across all study streams, 71% of surveyed stream length remained wet through the summer season in 2017, 61% in 2018, and 76% in 2019. For context, the average end-of-season wetted habitat available across the same streams was 39% during the peak of the last drought in 2015. When fish distribution was related to wetted habitat conditions and averaged across streams, we found that between 55% (2018) and 77% (2019) of redds were observed in locations that remained wet throughout the following dry season and between 63% (2018) and 75% (2019) of juveniles were in habitat that remained wet. These percentages are higher than in drought years such as 2015, when on average in these streams only 24% of redds and 28% of juveniles were seen in locations that stayed wet; however, the finding that 25-30% of rearing fish in these systems were threatened by stream drying or disconnection even in wetter-than-average water years like 2017 and 2019—and that this increased to 37% in a below-average water year like 2018—is notable. These results suggest that summer flow impairment is a limiting factor to juvenile salmonid survival, even in non-drought years.

Water quality conditions generally deteriorated with receding streamflow after July of each summer season. Upper Mill and upper Dutch Bill study reaches exhibited near-optimal DO concentrations and temperatures, further indicating their suitability as summer refugia. Substantial, late-summer DO impairment was observed in the lower Dutch Bill Creek study reach and both Green Valley Creek study reaches in 2017 and 2018. Water temperatures were generally suitable in all reaches except for lower Mill Creek, which had the highest temperatures and exceeded 20°C up to 18% of the time in 2017. Water quality was generally best in 2019 and poorest in 2017, despite substantially higher flow conditions in 2017 than 2018 in most reaches.

Wetted habitat and streamflow data were used to estimate connectivity thresholds—the streamflow at which pools begin to disconnect in a given stream reach. A connectivity threshold of 0.20 ft^3/s was identified for each of the upper and lower study reaches in Dutch Bill, Green Valley, and Mill creeks, with the exception of lower Dutch Bill Creek, which had a higher threshold of 0.50 ft^3/s (likely due to channel geometry and substrate). Because days of disconnection has a negative relationship with juvenile salmon survival, connectivity thresholds are useful for understanding impacts and setting targets; however, they should not be confused with the minimum flows needed to support salmonids. Higher flows are almost certainly needed for fish to move, grow, and survive in subsequent life stages.

The data collected between 2017 and 2019 were used to evaluate the effects of three small-scale flow releases into Dutch Bill and Green Valley creeks. Overall, we found that flow augmentations as small as 0.05 ft^3/s were successful in improving habitat conditions for rearing salmonids, including streamflow, surface flow connectivity, riffle crest thalweg depth, and DO, with no detrimental impacts to water temperature, in both below- and above-average water years. We recommend that flow release projects be combined with more comprehensive flow enhancement strategies.

Wetted habitat data from the wet/dry mapping and GIS data were incorporated into statistical models to predict the spatial and temporal distribution of wetted habitat in Dutch Bill, Green Valley, and Mill creeks. Antecedent precipitation (from the previous winter and the previous three to five years), drainage area, and soil permeability had the strongest influence on end-of-season wetted habitat conditions. Interannual variability in end-of-season wetted habitat was also modeled in order to better understand which streams are reliably dry, reliably wet, or exhibit high year-to-year variability under different climactic conditions. Interannual variability varied by stream reach and was influenced by watershed lithology, vegetation, and soil conditions. Models were expanded to predict end-of-season wetted habitat conditions and interannual variability in all streams in the lower and middle Russian River watershed. These outcomes can be used by managers to inform habitat recovery strategies and to identify reaches of relative stability and concern in regions where wet/dry mapping has not occurred. A manuscript related to these results is in preparation.

Overall, the environmental and biological data collected, summarized, and analyzed through this project demonstrates that insufficient summer streamflow is negatively impacting oversummer survival of juvenile salmon and steelhead, even in above-average water years. Because the causes of streamflow impairment are complex in the study streams of Dutch Bill, Green Valley, Mill, and Felta creeks (i.e., not just one to two large-scale diversions), a long-term and multifaceted approach to instream flow restoration is necessary to provide adequate late-summer habitat for salmonids. We recommend additional flow enhancement projects as well as efforts to support watershed-scale recharge in all of the study streams, particularly in reaches where high numbers of salmon commonly spawn and summer habitat and water quality are often in the marginal range. We also encourage modeling approaches that allow for testing alternative flow improvement strategies to enable efficient project prioritization and planning, and greater project effectiveness.

Three annual meetings and a session at the Salmonid Restoration Federation’s annual conference were organized to share outcomes from this project and to facilitate the exchange of information related to evaluating and addressing flow impairment in the Russian River watershed and other coastal California watersheds. Project results were also shared at regional technical advisory committee meetings, and disseminated through several presentations at professional meetings. The journal article published through the support of this award was also the subject of multiple news articles.

Data collected through this project has been incorporated into California Sea Grants SQL database which is used to generate web-based mapping tools that allow resource managers and other salmonid recovery partners to investigate specific flow- and fish-related questions in the study streams. Throughout the project period, these tools were used to inform flow releases, fish rescues, and broodstock collection. These data, along with the results from the statistical models, are being used by the Coho Partnership, North Coast Salmon Program, and other conservation efforts to identify flow refuges critical for protection and impaired reaches in the greatest need of improvement. The data will also serve as a baseline for future streamflow enhancement work and for increasing our understanding of the impacts of climate change on coastal California streams.

Introduction

In 2017, California Sea Grant (CSG) and University of California at Berkeley (UC Berkeley) were awarded three years of funding by the Wildlife Conservation Board (WCB) to conduct studies related to streamflow and salmonid survival in Russian River tributaries. This report includes a summary of all tasks completed for WCB award WC-1663CR between 2017 and 2020.

The goal of this project was to support efforts aimed at increasing streamflow in flow-impaired streams critical for the recovery of endangered coho salmon populations. With the assistance of this award, we built upon previous research and an established monitoring infrastructure in the lower Russian River watershed to fill critical knowledge gaps and disseminate the resulting information by performing three key tasks:

- Task 1: Develop predictive models relating streamflow, environmental metrics, and juvenile coho salmon survival in small coastal California streams.
- Task 2: Document wetted habitat conditions in Dutch Bill, Green Valley, and Mill creeks in relation to streamflow and fish distribution, and build a predictive model for surface water recession.
- Task 3: Organize annual coordination meetings among the many salmon recovery partners working towards common goals in the watershed, in order to increase communication, collaboration, and the effectiveness of flow enhancement efforts.

The intention behind this work was to provide resource managers and other recovery partners with information regarding both the flow needs of salmon and existing flow conditions in high-priority coho rearing streams in the lower Russian River watershed in order to: aid in the prioritization, design, and evaluation of streamflow enhancement projects; allow optimization of the timing and quantity of water released from upstream storage ponds and wells; inform instream flow recommendations and water policy; and support implementation of emergency actions in times of drought.

The geographic focus of this work was the southwestern portion of the Russian River watershed, in Sonoma County, CA (Figure 1). Task 1, which built on a pre-existing study being conducted through the Russian River Coho Water Resources Partnership (Coho Partnership), focused on Dutch Bill, Green Valley, Mill, and Grape creeks. Task 2, for which the vast majority of field data was collected under this grant, focused on the Dutch Bill, Green Valley, and Mill Creek watersheds.

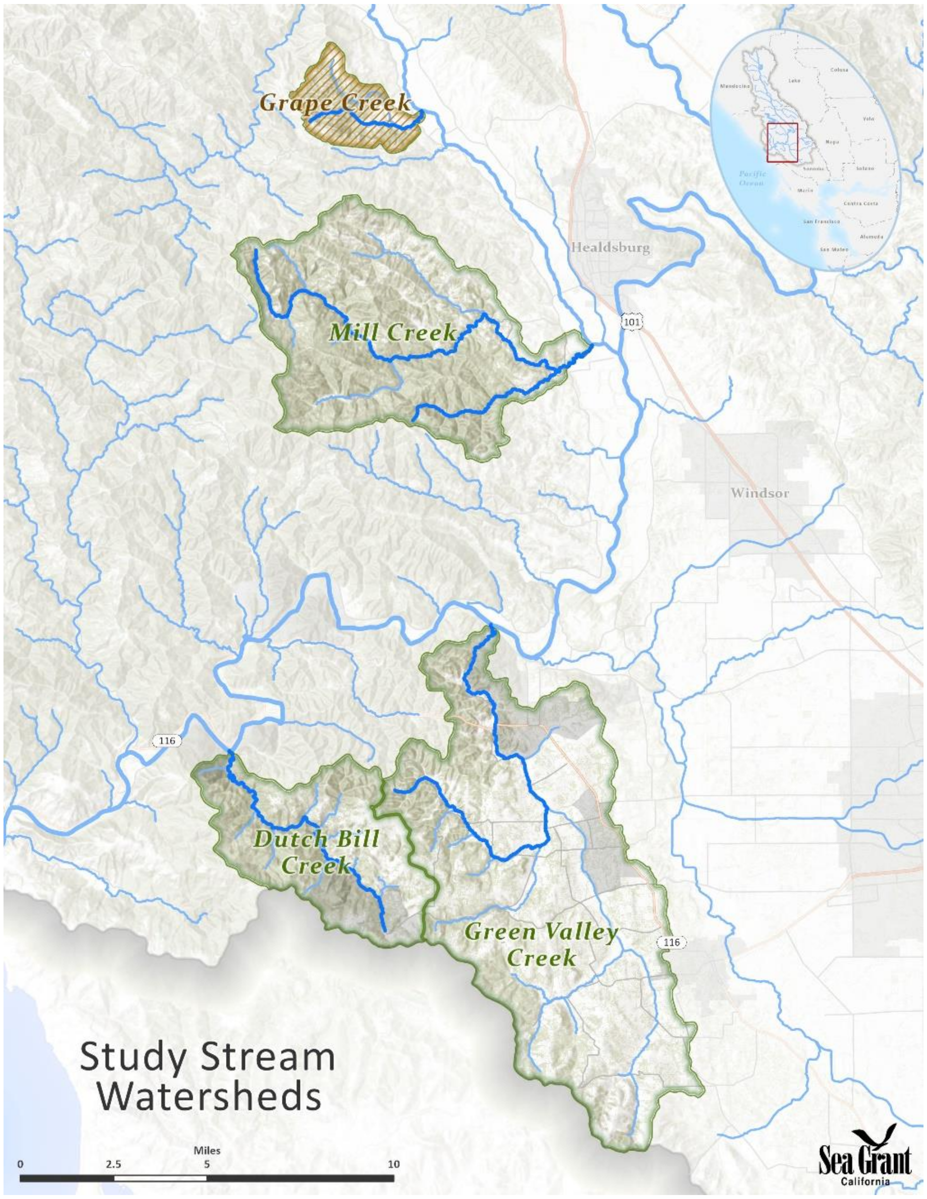

Figure 1. Study streams in the lower Russian River watershed. Dutch Bill, Green Valley, Mill, and Grape creeks were the focus of salmon survival modeling, but Grape Creek was not included in the extensive field data collection efforts supported by this award. Dark blue lines in the Dutch Bill, Green Valley, and Mill watersheds indicate streams that were a focus of environmental and biological data collection and evaluation, and predictive modeling of wetted habitat distribution.

1. Task 1: Develop predictive models relating streamflow, environmental metrics, and juvenile coho salmon survival

1.1. Background

From 2011 through 2017, CSG conducted a study of juvenile salmon oversummer survival in relation to habitat parameters. This work was completed through the Russian River Coho Water Resources Partnership (Coho Partnership), with funding from the National Fish and Wildlife Foundation (NFWF). Between June and October each year, CSG biologists collected juvenile coho salmon survival data in study reaches of Dutch Bill, Green Valley, Mill, and Grape creeks for comparison with environmental metrics such as streamflow, wetted volume, dissolved oxygen, and water temperature. Data collection in 2017, funded through NFWF, served as cost share for this grant and a summary of results can be found in our 2017 annual report (California Sea Grant 2018).

Through this WCB grant, the Carlson and Grantham labs at UC Berkeley worked with CSG to develop models to identify which environmental factors and streamflow metrics best predict coho salmon survival in small coastal California streams. Data used to build the models include the seven-year coho salmon survival and environmental data set collected by CSG through the Coho Partnership, and hydrogeological and watershed-level data available in GIS. The goal of the modeling was to quantify general relationships across streams to aid in identifying flow thresholds for juvenile salmonid persistence throughout the summer season in coastal California streams.

1.2. Development of survival models

Through the support of this grant, CSG and UC Berkeley compiled a long-term survival, flow, and habitat dataset, to allow for analyses and model development to determine which flow and other environmental metrics best predict summer survival of juvenile coho salmon rearing in small coastal California streams.

In November of 2017, CSG and UC Berkeley hired a postdoctoral scholar, Dr. Ross Vander Vorste, to assist with data analyses, modeling, and dissemination of project results. Working with colleagues, Dr. Vander Vorste developed models and drafted a manuscript examining the effects of environmental variables on oversummer survival of juvenile coho salmon. It was submitted to the journal Global Change Biology (impact factor 8.997) on May 1, 2019 and accepted for publication on March 27, 2020. The article can be viewed at https://onlinelibrary.wiley.com/doi/epdf/10.1111/gcb.15116 and is posted on CSG's and UC Berkeley's websites.

As described in (Vander Vorste et al. 2020), we estimated spatial and temporal variability of oversummer coho salmon survival using mark-recapture of nearly 20,000 tagged fish in intermittent stream pools during a seven-year period encompassing drought and non-drought conditions. We then determined the relative importance of physical habitat, streamflow, precipitation, landscape, and biological characteristics that may limit survival during the dry season (Figure 2). Days of pool disconnection and cropland area exhibited a significant negative effect on cumulative survival, with increases in these variables leading to reduced estimates of survival, while minimum pool volume had a significant positive effect, with increases in volume leading to higher estimated survival (Figure 3). These models can be used by resource managers to develop thresholds and conservation goals. For example, if a particular agency had a goal of ensuring that 50% of juveniles survive the summer, the conservation goals would be to prevent pools from disconnecting for more than 10 days, reduce cropland area to less than 5%, and implement measures that promote pools with volumes of 50 m^3 or greater.

We found that survival was generally lower in drought years and that variability in survival was high across the study region (Figure 4), although several study sites maintained similar survival during drought and non-drought years. Habitats where survival is strongly reduced by drought are concerning because they may represent ecological traps, meaning that their ability to support oversummer survival is reduced during extreme drought. Whereas, our finding that many pool habitats maintained high survival even during extreme drought helps identify drought refugia that are important for juvenile coho salmon survival. Among the environmental variables associated with drought, we found duration of pool disconnection was most strongly correlated with reduced survival (Figure 2). With this in mind, we used wet/dry mapping in specific streams and modeling approaches (see ***Task 2: Document environmental conditions in relation to fish distribution and build a predictive model for surface water recession***) to identify stream reaches that maintain pool connectivity during drought, as well as reaches that are impaired, to help guide conservation efforts.

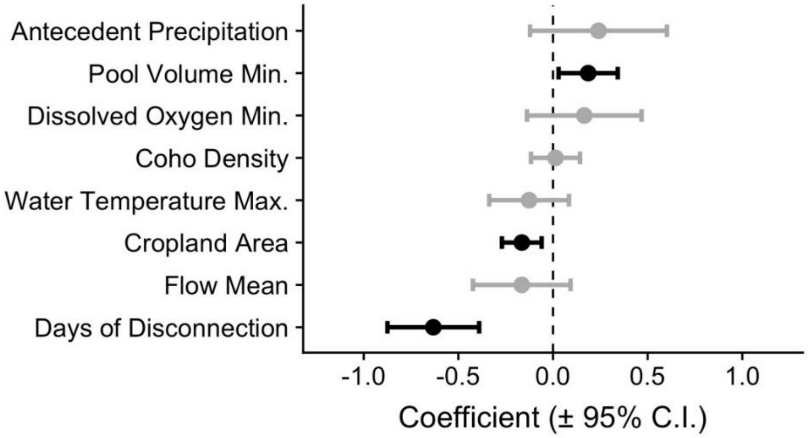

Figure 2. Effect sizes (± 95% confidence limits) for eight explanatory variables on cumulative juvenile salmon survival during 2011–2017. Effects sizes estimates are the model coefficients from generalized linear mixed effects models. Black points and confidence bars are statistically significant, whereas grey coloring indicates non-significant variables (p > 0.05).

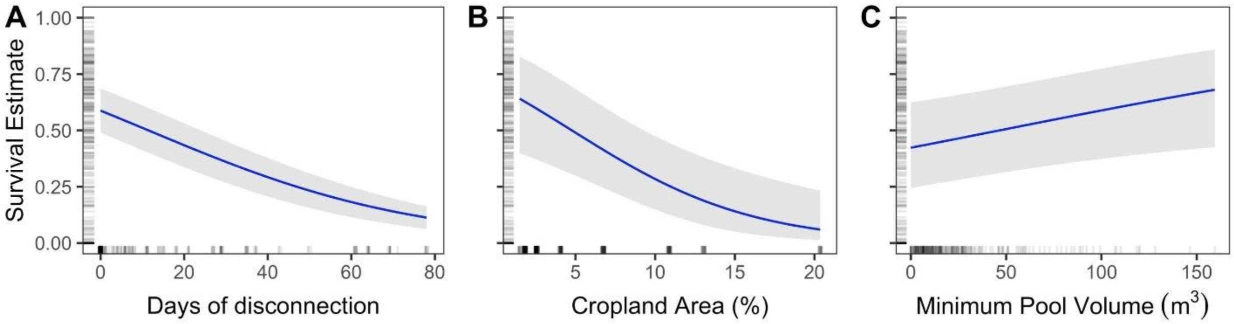

Figure 3. Juvenile coho salmon survival in relation to statistically significant explanatory variables (partial dependence from generalized linear mixed models). Model estimates (solid lines) and 95% confidence intervals (shading) for (A) days of disconnection, (B) cropland area, and (C) minimum pool volume.

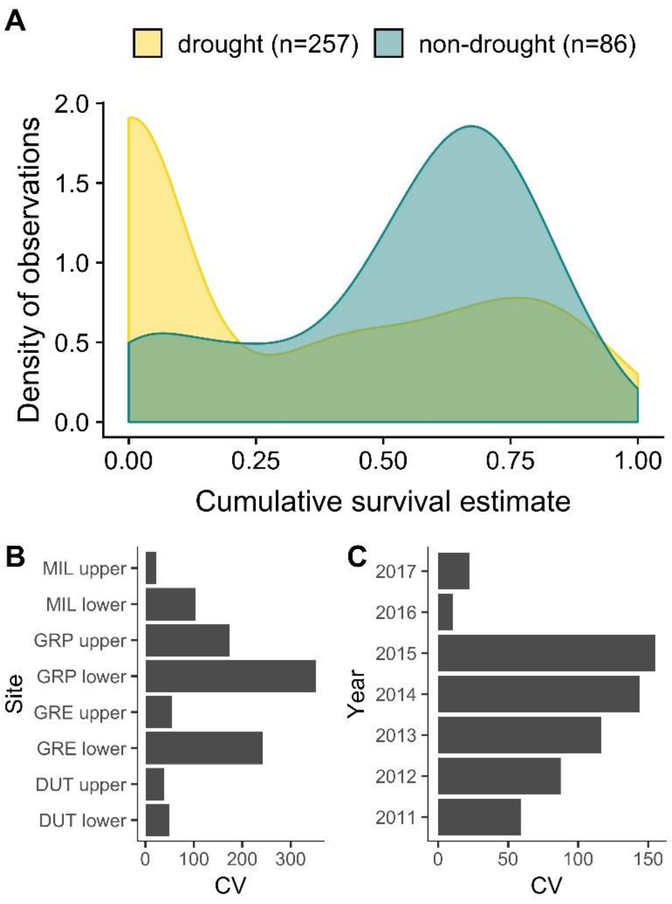

Figure 4. (A) Probability density function illustrating distribution of cumulative salmon survival estimates in stream pools during drought (2012-2016, yellow) and non-drought (2011 & 2017, blue) years. (B) Spatial variability in cumulative survival estimates at eight study reaches within the Russian River catchment. (C) Temporal variability in cumulative survival estimates across study reaches. Presumed survival estimates of zero in dry stream reaches that are removed from subsequent models are added for visual assessment.

2. Task 2: Document environmental conditions in relation to fish distribution and build a predictive model for surface water recession

2.1. Background

Insufficient summer streamflow is a bottleneck to salmonid recovery in many intermittent tributaries to the lower Russian River (Obedzinski et al. 2018; RRCWRP 2015). The Dutch Bill, Green Valley, and Mill Creek watersheds were selected as focal study areas for this project because they have been identified by National Marine Fisheries Service (NMFS) as core, high-priority streams critical to the recovery of Russian River coho salmon (NMFS 2012). Low streamflow is a limiting factor to juvenile salmonid survival in each of these systems, yet opportunities exist for flow improvements. Due to these criteria, they were also selected as focus steams by the Coho Partnership, which has been working to improve streamflow in these watersheds for over a decade.

The mainstem reaches of Dutch Bill, Green Valley, and Mill creeks—along with Felta Creek, a primary tributary to Mill Creek—were surveyed in this study. CSG has been monitoring salmonid populations in these streams since 2004. After several summer periods of observing wide-scale drying and fish mortality in salmonid rearing reaches, it became clear that more information was needed about the existing environmental conditions and resulting impacts to salmonids in order to help identify and address factors limiting juvenile fish survival in these streams.

TU has been monitoring streamflow in Dutch Bill, Green Valley, and Mill creeks for over a decade. The resulting data has built a critical foundation for understanding flow dynamics in these systems; however, flow data from limited points in a watershed cannot adequately reflect habitat conditions in each salmonid-rearing pool or even reach. In 2013, CSG adopted the practice of mapping wetted habitat conditions in late summer (a.k.a. wet/dry mapping). The data collected during these efforts are used to generate maps that show the lengths of each stream channel that are wet, dry, or intermittent in order to display the distribution of wetted habitat available to rearing salmonids at the driest time of the year. In Russian River streams, where surface flows frequently drop to levels hovering at or just above zero (levels that are within the measurement error of most current meters), these wetted habitat maps provide an alternative approach to informing and evaluating patterns in stream drying and oversummer surface water conditions.

In addition, wet/dry mapping allows us to document stream connectivity—the connection of pools to adjacent habitat through continuous surface flow. Surface flow disconnection generally signifies the onset of deteriorating habitat and water quality conditions for rearing fish. CSG studies in these same stream systems have documented a negative correlation between the number of days that pools are disconnected from surface flow and the probability of fish survival (Obedzinski et al. 2018; Vander Vorste et al. 2020). Identifying reach-specific connectivity patterns can improve our understanding of hydrologic dynamics and support more effective planning of flow enhancement projects. It also highlights concerns about habitat disconnection acting as a barrier during the spring coho salmon smolt outmigration window.

Prior to WCB funding for this effort, CSG conducted a single wet/dry mapping survey on each of the study streams during September of each year, beginning in 2012. While this has been useful in documenting the worst conditions impacting juvenile survival annually, it has not allowed us to understand patterns of stream drying and disconnection over the course of the summer, nor to inform and evaluate flow augmentation projects occurring in the study streams. Based on the demand by resource managers in recent years for sequential surveys throughout the dry season, this grant provided funding to conduct wet/dry mapping at biweekly intervals between May and October in each of the four study streams, and to make the resulting maps available to a broad set of partners and the public electronically, on a weekly basis throughout the season.

In addition, this grant funding allowed us to bring together data from snorkeling and spawner surveys conducted by the Russian River Coho Salmon Captive Broodstock Program (Broodstock Program) and Coastal Monitoring Program (CMP) with the wetted habitat data to produce maps displaying fish distribution in relation to drying stream conditions. During this grant period, that information was provided to partners in-season and helped resource managers to prioritize and plan efforts to relocate fish from drying pools. It was also used to inform partners on the best time to initiate flow releases from sources with limited water, and to evaluate the effects of these augmentations.

Ultimately, wetted habitat data from these repeated surveys, streamflow data, precipitation data, and watershed-characterization data were used to produce a model that predicts drying under variable environmental conditions.

The following sections describe the methods and outcomes for the many field data collection activities that occurred over the 2017-2019 grant period to meet project objectives—both through the support of this award and as cost share. These include evaluations of wetted habitat, salmonid redd distribution, juvenile salmonid distribution, fish distribution in relation to wetted habitat, water quality, streamflow, surface flow connectivity, and flow release impacts.

2.2. Environmental conditions and fish distribution

2.2.1. Annual precipitation in relation to historic record

Rainfall data from the Graton, CA weather station (NOAA station USC00043578) was used to characterize conditions in the study watersheds over the course of the project period in relation to the historic record. For reference, average annual (i.e., water year, defined as October 1, XXXX through September 30, XXXX+1 for water year XXXX+1) precipitation was 41 inches over an 82-year period of record, with 89% of annual precipitation occurring between November and April, on average, and just 2% from June through September. Total annual rainfall varied from as little as 14 inches (1977) to as much as 75 inches (1983), and four prolonged drought periods occurred, with the most recent occurring from 2012 through 2016.

Over the 2017-2019 study period, total annual precipitation varied greatly (Figure 5), but still followed the normal pattern of wet winter months and very dry summer months (Figure 6). Water year (WY) 2017 was the sixth wettest year on record at the Graton station, with 63 inches of rainfall. WY2018 saw the lowest precipitation; the 25 inches of rain was well below the 10-year average of 38.5 inches and the long-term average of 41 inches. WY 2019 was an above-average year with approximately 46 inches of precipitation; 86% of which fell during the wet period, November through March, and 9% of which occurred during the month of May (Figure 6).

Although WY2017 had the highest annual precipitation of the three year study period, this did not translate into higher streamflow, increased wetted habitat or better water quality conditions, as we will see in the sections to come. We suspect this is due to lingering effects of the drought conditions that persisted for five years prior to WY2017. Much of the rainfall in WY2017 may have replenished depleted aquifers as opposed to translating to surface flow. As suggested by Deitch et al. (2018), surface flow from a given summer may be comprised of rain that fell in previous years as it works through complex subsurface terrain, and not exclusively rainfall from the previous winter. This variable subsurface residence time may perpetuate the influence of antecedent drought conditions across subsequent years.

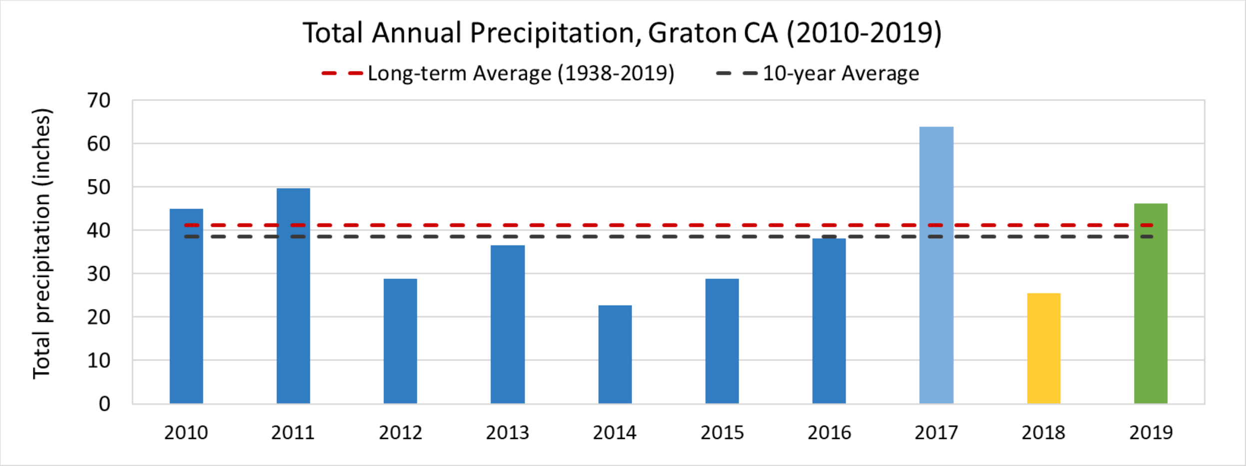

Figure 5. Total annual precipitation recorded in Graton, CA from 2010-2019, shown in relation to the 10-year average for that period and the long-term average rainfall from 1938-2019. Data from NOAA station USC00043578.

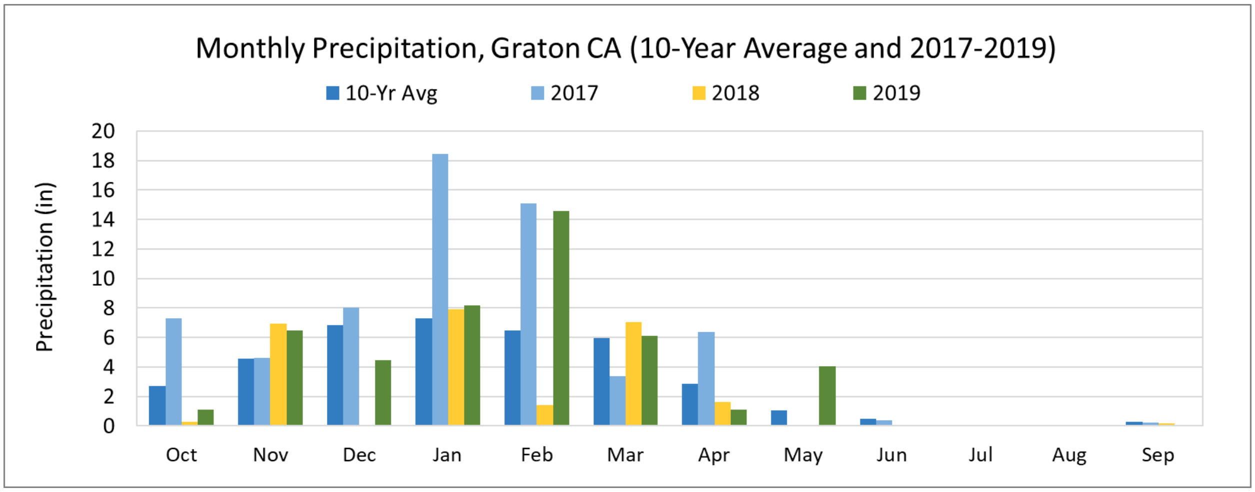

Figure 6. Total monthly precipitation recorded in Graton, CA over each year of the study period of 2017-2019, shown with average rainfall from the 10-year period of 2010-2019. Data from NOAA station USC00043578.

2.2.2. Wetted habitat assessment

To document wetted habitat conditions and stream connectivity throughout the summer season, wet/dry mapping surveys were conducted on the primary fish-bearing reaches of Dutch Bill, Green Valley, Mill, and Felta creeks at biweekly intervals over the summers of 2017-2019. The original wet/dry mapping protocol developed by CSG for Russian River tributaries was adapted to better suit the objectives of this project (https://bit.ly/WettedHabitatProtocol). Every two weeks between May and October, a crew of two surveyors walked each creek and documented surface water conditions, from the lowest confluence of the creek to the upstream limit of anadromous fish habitat (exempting sections where landowner access permission could not be acquired). A field tablet and GPS receiver unit were used to record each stream section ("line") along the entire channel as wet or dry. Water temperature and dissolved oxygen (DO) concentrations were measured in the wet sections of stream at 5-minute timed intervals, using a handheld YSI Pro20 DO meter, to determine suitability for juvenile salmonids and document trends over the study season. Upon return to the office, field crews uploaded data to an ArcGIS Online server where they were transferred to a cloud-based database. Water quality data were downloaded, error checked in Microsoft Access and transferred into a SQL database. Raw GIS line features were visually inspected for errors and any extraneous or missing line segments were manually corrected in ArcGIS. The lines were run through a geospatial tool to fine-tune continuity of line segments and provide summary statistics for wetted habitat condition for each stream and survey. The condition of “intermittent” was assigned in ArcGIS to sections of stream with alternating short lengths (<50 feet) of wet and dry lines.

During the 2017 and 2018 sample seasons, maps of wetted habitat conditions were generated for every biweekly survey and shared in weekly emails to more than 50 partners from WCB, TU, UC Berkeley, multiple branches of California Department of Fish and Wildlife (CDFW), the Regional and State Water Quality Control Boards, NMFS, Sonoma Water, Gold Ridge and Sonoma Resource Conservation Districts, Occidental Arts & Ecology Center’s WATER Institute, US Army Corps of Engineers, NFWF, the Nature Conservancy, the Coast Range Watershed Institute, and the Camp Meeker Recreation & Parks District. CSG designed a web page to summarize the project (https://bit.ly/WettedHabitatAssessments), and PDF versions of biweekly wetted habitat maps from both seasons can be viewed and downloaded from that page.

In 2019, CSG developed a web-based ArcGIS map portal to display maps and water quality data. The finalized wetted habitat lines were uploaded directly to this webpage and the associated URL link (https://bit.ly/Summer2019WettedHabitat) was shared with the partners listed above, along with weekly email updates. This map portal provided an interactive interface, with the ability to toggle between prior surveys and evaluate summary data in widget form, so users could customize views according their desired spatial and temporal extents. CSG also created a separate web-based mapping tool for the North Coast Salmon Program (NCSP) steering committee members to interact with the data so that they can identify focus areas for habitat and streamflow enhancement efforts.

Wetted habitat conditions and the associated water quality data were considered in relation to fish distribution data and used, in season, to inform CDFW fish rescues, as well as the initiation timing and effectiveness of three flow releases throughout the project period.

3.2.2 First points of disconnection

Identifying when and where streams first disconnect each year supports a better understanding of hydrologic dynamics, as well as more effective planning of flow enhancement projects designed to maintain stream connectivity and thereby improve the probability of fish survival. It also highlights concerns about disconnection acting as a barrier during the spring coho salmon smolt outmigration window, which varies slightly by year and stream but generally extends through June.

In each study year, all streams were 100% wet during the first survey in May. All survey streams experienced some surface flow disconnection in the summers of 2017-2019, but the timing and location of the first disconnection points varied by year (Figure 7-Figure 9). The earliest disconnections occurred in 2018 across all streams, corresponding to the year with the lowest winter rainfall total (Figure 5). The date and location of disconnection in the Mill/Felta system was the earliest and most consistent across all years, occurring around mid-June at the mouth of Felta Creek, followed soon after by disconnection at the mouth of Mill Creek (Figure 9). While this was not as early as in previous dry years—such as in 2008, when Mill Creek was documented as disconnected from Dry Creek as early as May 14 (RRCWRP 2015)—this June disconnection may have hindered outmigration access for some late-running smolts in 2017 and 2018. It should be noted that barriers to outmigration can occur even while surface flow is connected, as riffle crest depths may drop below the threshold for juvenile passage.

Dutch Bill and Green Valley creeks, by contrast, remained open and flowing through most or all of the smolt season in all three study years (Figure 7, Figure 8). In Dutch Bill Creek, the first stream disconnection occurred between late June and early July in the same riffle in the lowest reach, except for in the wettest year of 2019, when it was near the upstream end of the survey reach in a high-gradient section. This is in contrast to drought years, such as 2015, when widespread drying had already occurred by May 22 in lower Dutch Bill Creek (CSG unpublished data).

The greatest variation in first disconnection date within a stream was observed in Green Valley Creek, ranging from early July in 2018 to early August in 2017, for a disparity of approximately four weeks (Figure 8). By comparison, the first disconnection dates across years in Dutch Bill and Mill creeks occurred within approximately two weeks (Figure 7, Figure 9).

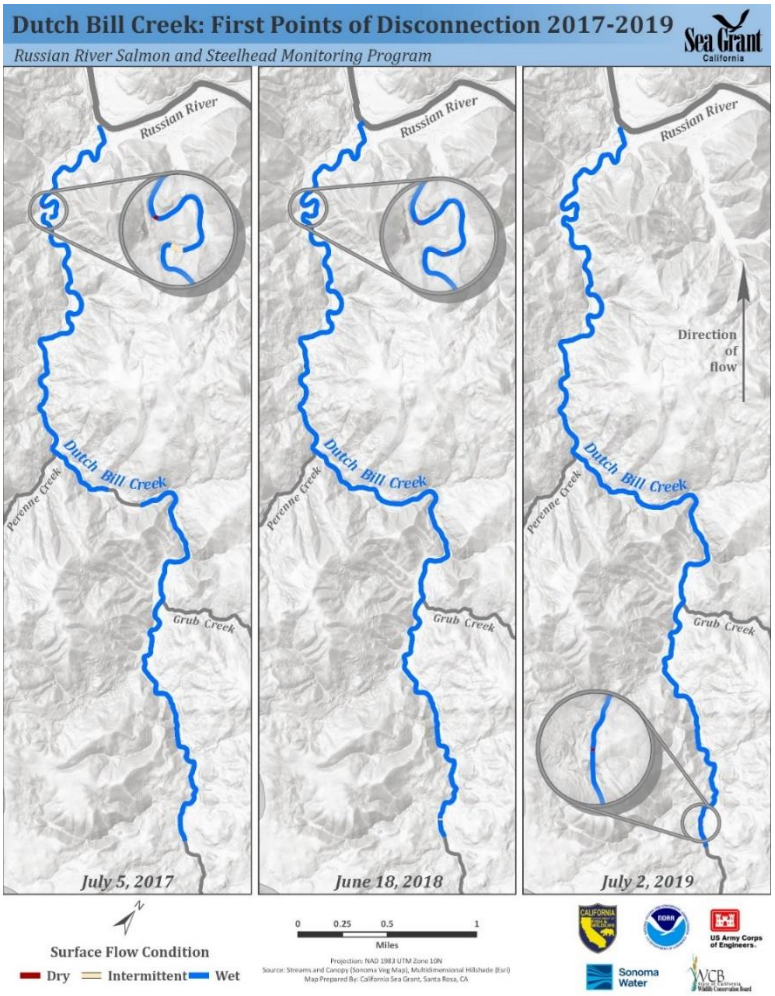

Figure 7. Dates and locations of the first surface flow disconnections documented during wet/dry mapping surveys on Dutch Bill Creek, 2017-2019.

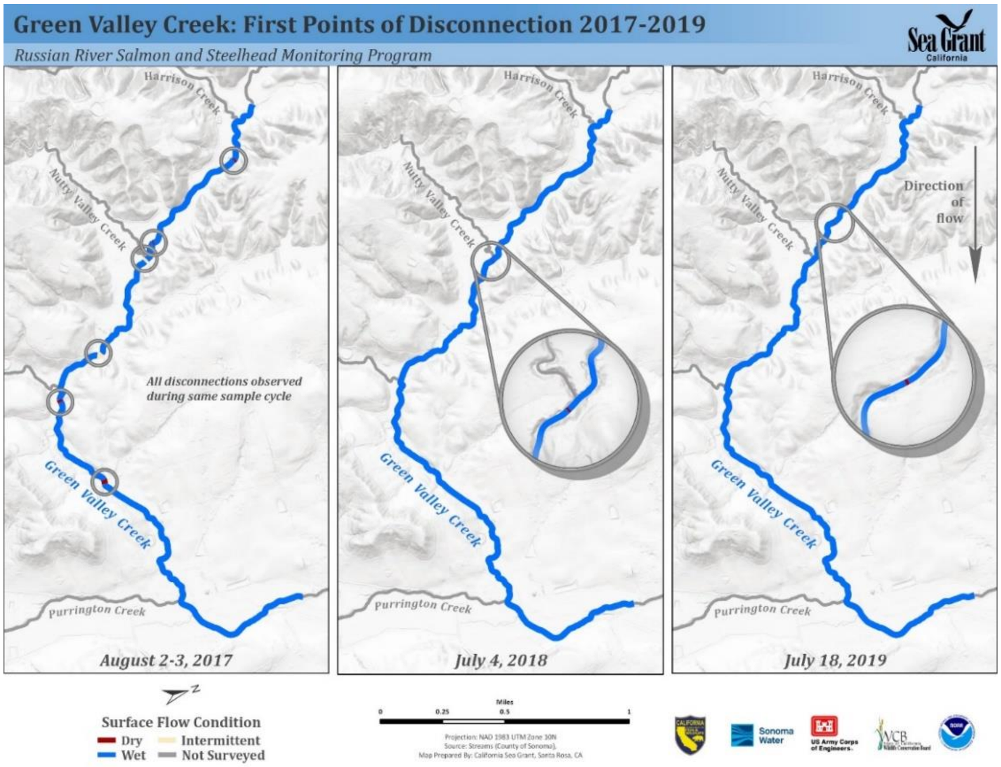

Figure 8. Dates and locations of the first surface flow disconnections documented during wet/dry mapping surveys on Green Valley Creek 2017-2019.

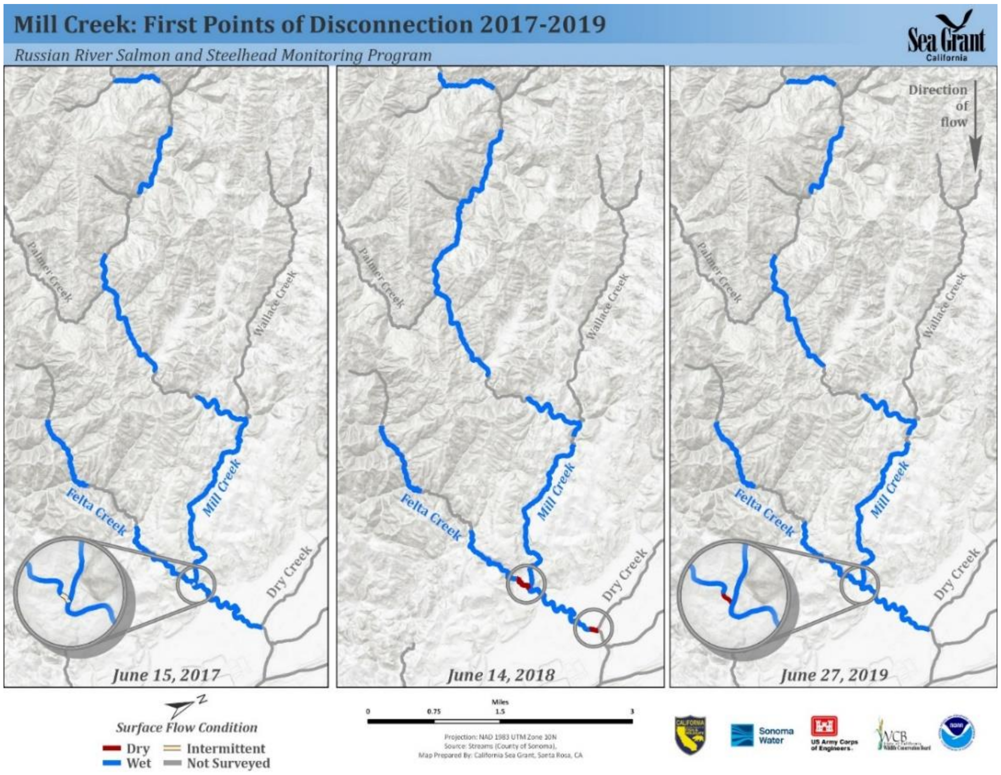

Figure 9. Dates and locations of the first surface flow disconnections documented during wet/dry mapping surveys on Mill and Felta creeks, 2017-2019.

3.2.3 Wetted habitat conditions during minimum flow

The driest instream habitat conditions documented during biweekly wet/dry mapping samples in a given year (defined as minimum flow or end-of-season conditions for the purposes of this discussion) generally occurred in September and October. In all streams, 2018 exhibited the driest minimum flow conditions, and 2019 the wettest, when evaluated by the proportion of stream length remaining wet over the dry season sample period (Table 1, Figure 10). The fact that all streams had a greater proportion of end-of-season wetted habitat in 2019 than in 2017 (which had 24% higher precipitation) was surprising and we suspect that the late spring rainfall in 2019 may have influenced this result, as well as lingering impacts of the 2012-2016 drought on the 2017 hydrograph (see ***Streamflow and connectivity***). The average proportion of habitat remaining wet all summer across the four watersheds combined was 71% in 2017, 61% in 2018, and 76% in 2019. While the fairly extensive drying in 2018 was less than ideal, it was a substantial improvement from previous drought years; the average wetted habitat available across the same streams under minimum flow conditions was 39% in 2015 (California Sea Grant 2016a).

Of all streams surveyed, Felta Creek experienced the most extensive drying through the summer season, with an average of 56% of the stream length remaining wet across all sample years, with a low of 42% in 2018 (Table 1, Figure 10). Dutch Bill Creek retained 58% wetted stream length on average for all sample years, while Mill Creek averaged 78%. Green Valley Creek was generally the wettest stream (except for in 2017 when Mill had slightly higher wetted channel length), with an average of 80% end-of-season wetted stream length. In 2019, the year with the wettest habitat conditions of the study period, 96% of the Green Valley Creek survey reach remained wet through the end of the dry season.

Interestingly, despite generally having the greatest proportion of wet stream length, Green Valley Creek exhibited substantial interannual variation in the proportion of total wet stream length at minimum flows, with a 21% disparity between the driest and wettest study years (Table 1, Figure 10). Mill and Felta creeks also varied significantly in total late-season wetted habitat, by 20% and 22%, respectively. Dutch Bill Creek displayed the least interannual variability in wetted surface flow conditions, varying only 9% between the driest and wettest years (Table 1, Figure 10). While a significant proportion of Dutch Bill Creek goes dry or becomes intermittent each year—nearly the entire lower half—it also appears to have the greatest stability across different types of water years.

Patterns of stream drying under minimum flow conditions varied, but were generally similar across years by watershed (Figure 11-Figure 19). In Green Valley Creek, the stream consistently remained wet downstream of the confluence with Purrington Creek and short sections of dry or intermittent habitat were distributed throughout the remainder of the survey reach. Dutch Bill and Mill creeks experienced extensive drying in the furthest downstream reaches, even in 2019. These reaches are characterized by deep layers of alluvium, which may explain the more extreme drying patterns. TU's investigation of groundwater dynamics in the Mill Creek watershed found that the groundwater elevation in the lowest, alluvium-dominated reach of Mill Creek is up to 16 feet below the surface water level in the adjacent stream channel (Van Docto et al. 2020). By contrast, areas underlain by bedrock appeared to retain surface flow longer. The upper reaches of Dutch Bill creek, beginning below the confluence with Perenne Creek, and the upper reaches of Mill Creek above the confluence with Wallace Creek both remained almost entirely wet and connected, even in the driest summer of 2018.

Table 1. Proportion of minimum flow (driest) wetted habitat condition by stream length in Dutch Bill, Green Valley, Mill, and Felta creeks, summers 2017-2019.

Tributary	**Survey Date**	**Wetted Habitat Condition (length in m, % of stream sampled)**		
		Dry	**Intermittent**	**Wet**
Dutch Bill Creek	10/18/2017	3,422 (37%)	647 (7%)	5,208 (56%)
	9/10/2018	3,395 (35%)	994 (10%)	5,270 (55%)
	10/21/2019	2,125 (22%)	1,352 (14%)	6,182 (64%)
Green Valley Creek	10/17/2017	167 (3%)	1,174 (22%)	4,057 (75%)
	9/26/2018	162 (3%)	1,535 (28%)	3,706 (69%)
	9/25/2019	27 (0%)	216 (4%)	5,187 (96%)
Mill Creek	10/16/2017	1,687 (13%)	486 (4%)	10,530 (83%)
	9/17/2018	2,950 (21%)	1,915 (13%)	9,533 (66%)
	10/14/2019	1,452 (11%)	338 (3%)	10,728 (86%)
Felta Creek	11/1/2017	828 (23%)	520 (14%)	2,275 (63%)
	9/17/2018	1,510 (42%)	600 (16%)	1,522 (42%)
	10/14/2019	2,122 (22%)	1,333 (14%)	6,208 (64%)
2017 Average	N/A	6,104 (20%)	2,827 (9%)	22,070 (71%)
2018 Average	N/A	8,017 (24%)	5,004 (15%)	20,031 (61%)
2019 Average	N/A	5,726 (15%)	3,239 (9%)	28,305 (76%)

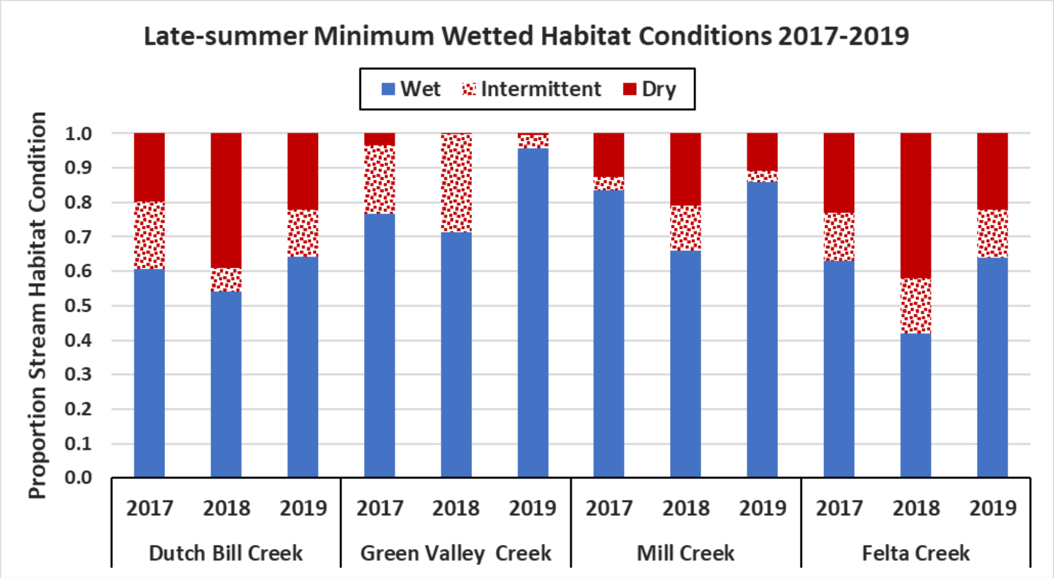

Figure 10. Proportional wetted habitat under minimum flow (driest) conditions by stream length in Dutch Bill, Green Valley, Mill, and Felta creeks, summers 2017-2019.

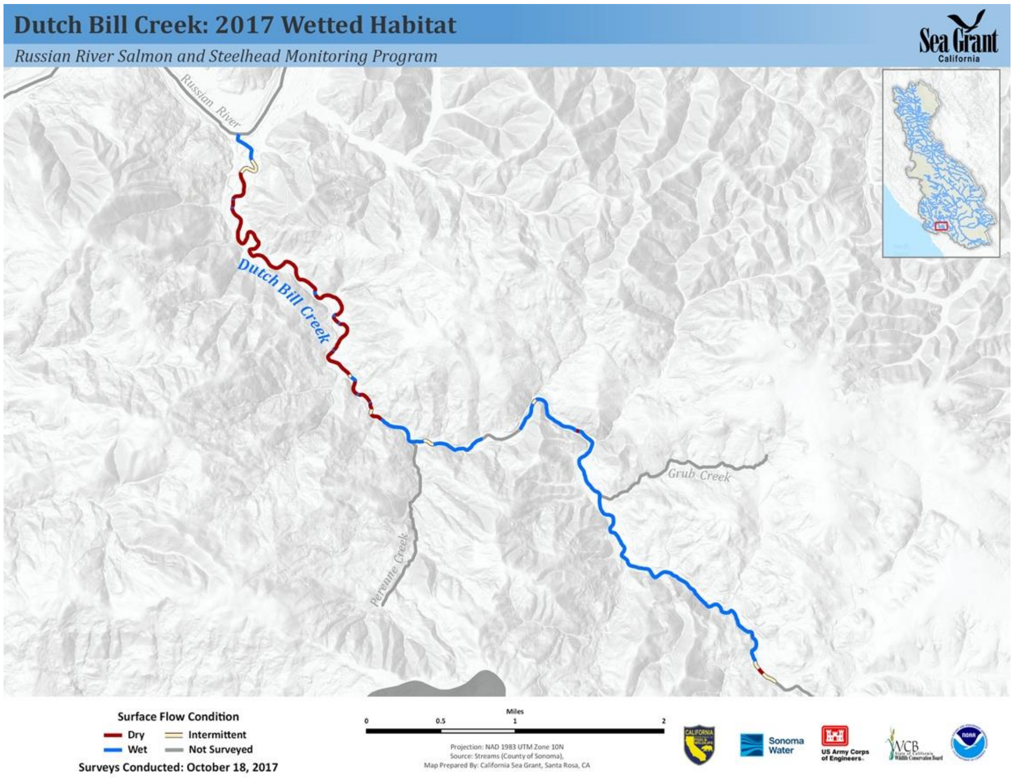

Figure 11. Wetted habitat conditions in Dutch Bill Creek on October 18, 2017; driest survey of 2017, as defined by the least amount of wetted stream length.

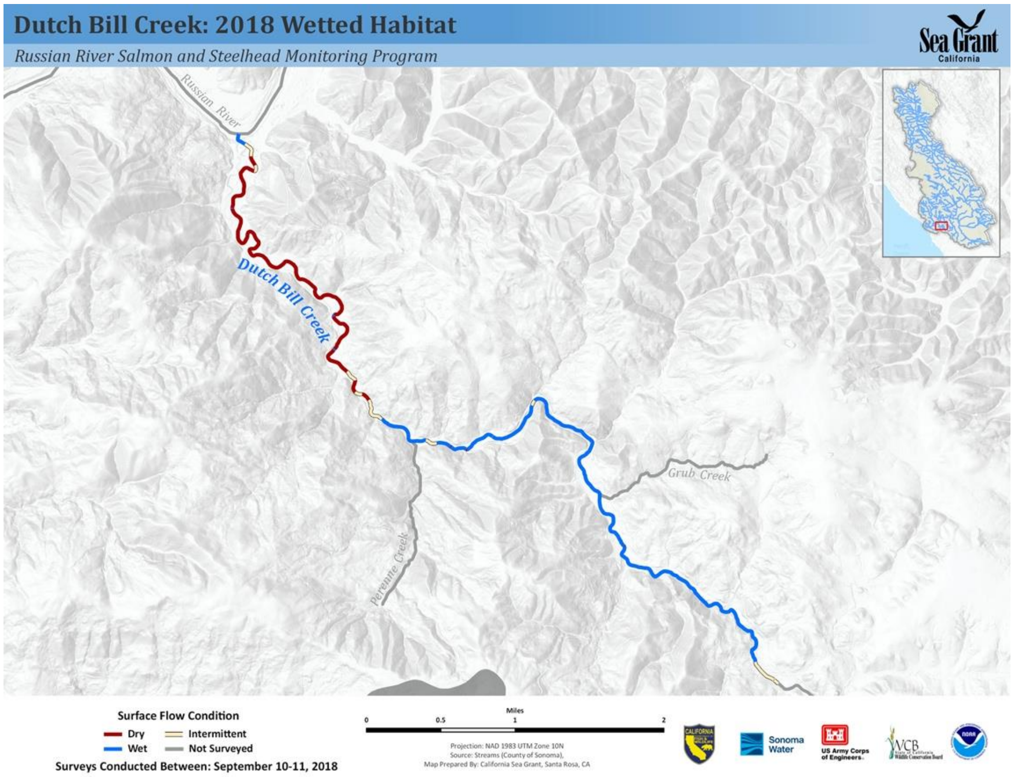

Figure 12. Wetted habitat conditions in Dutch Bill Creek on September 10-11, 2018; driest survey of 2018, as defined by the least amount of wetted stream length.

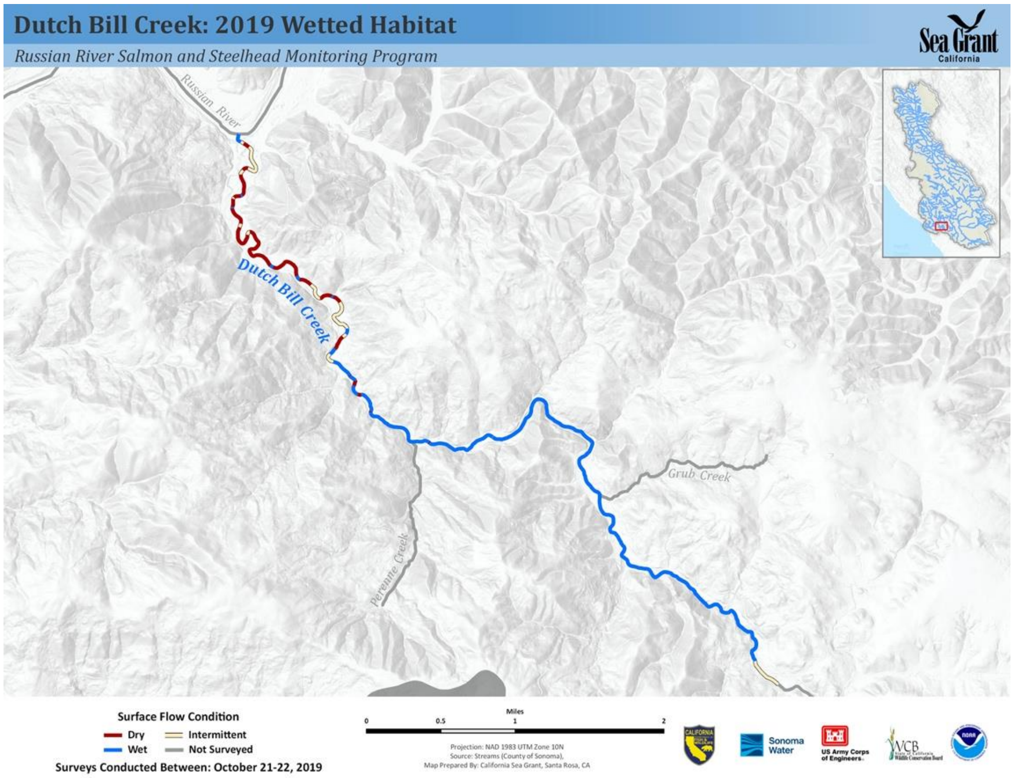

Figure 13. Wetted habitat conditions in Dutch Bill Creek on October 21-22, 2019; driest survey of 2019, as defined by the least amount of wetted stream length.

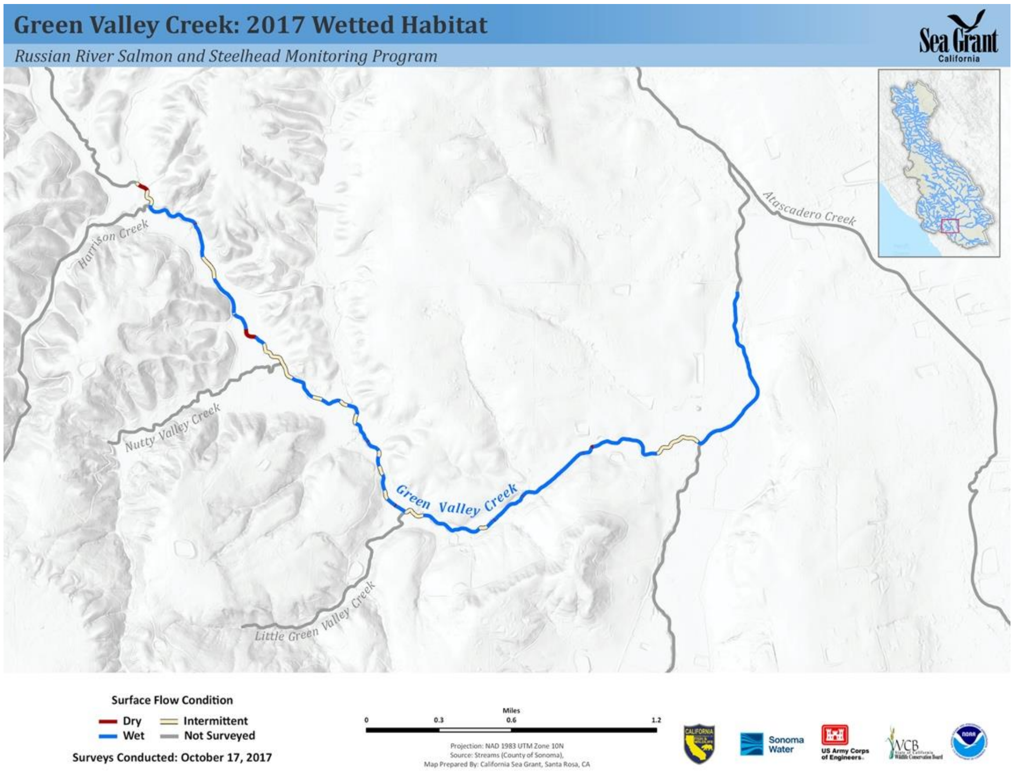

Figure 14. Wetted habitat conditions in Green Valley Creek on October 17, 2017; driest survey of 2017, as defined by the least amount of wetted stream length.

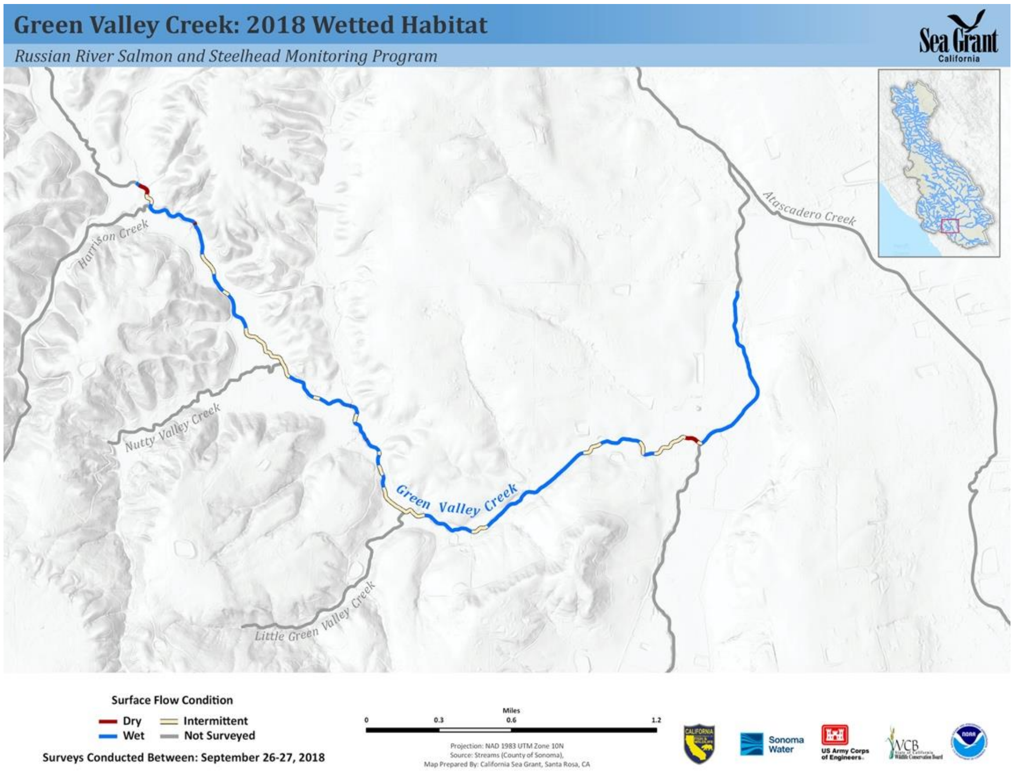

Figure 15. Wetted habitat conditions in Green Valley Creek on September 26-27, 2018; driest survey of 2018, as defined by the least amount of wetted stream length.

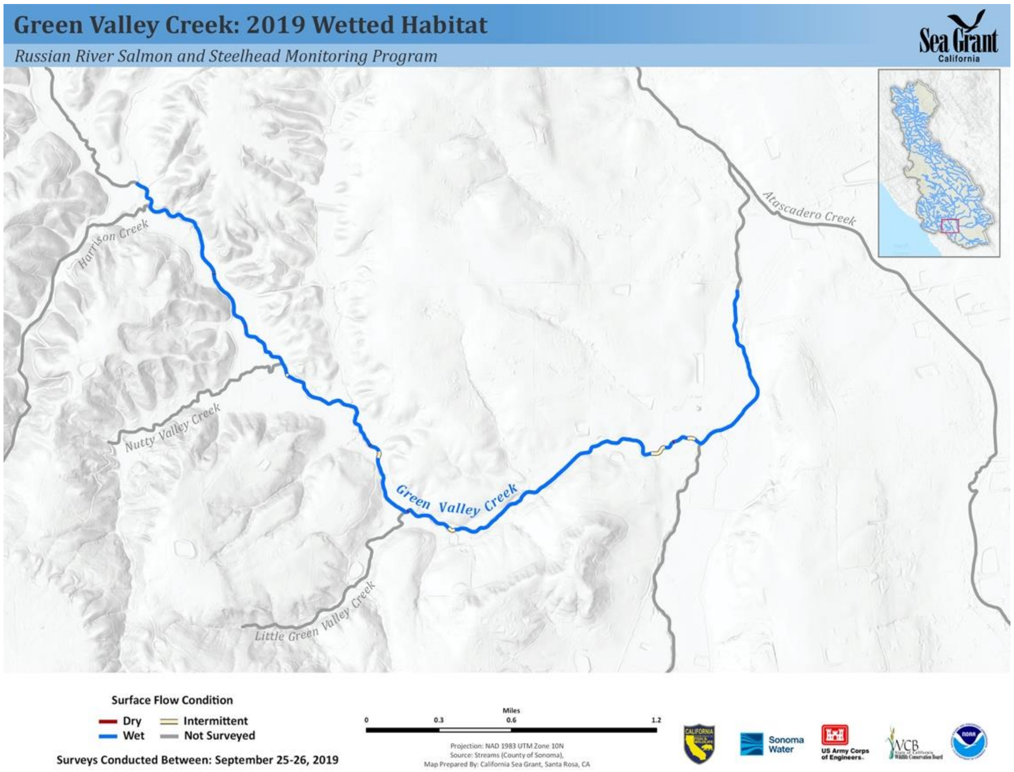

Figure 16. Wetted habitat conditions in Green Valley Creek on September 25-26, 2019; driest survey of 2019, as defined by the least amount of wetted stream length.

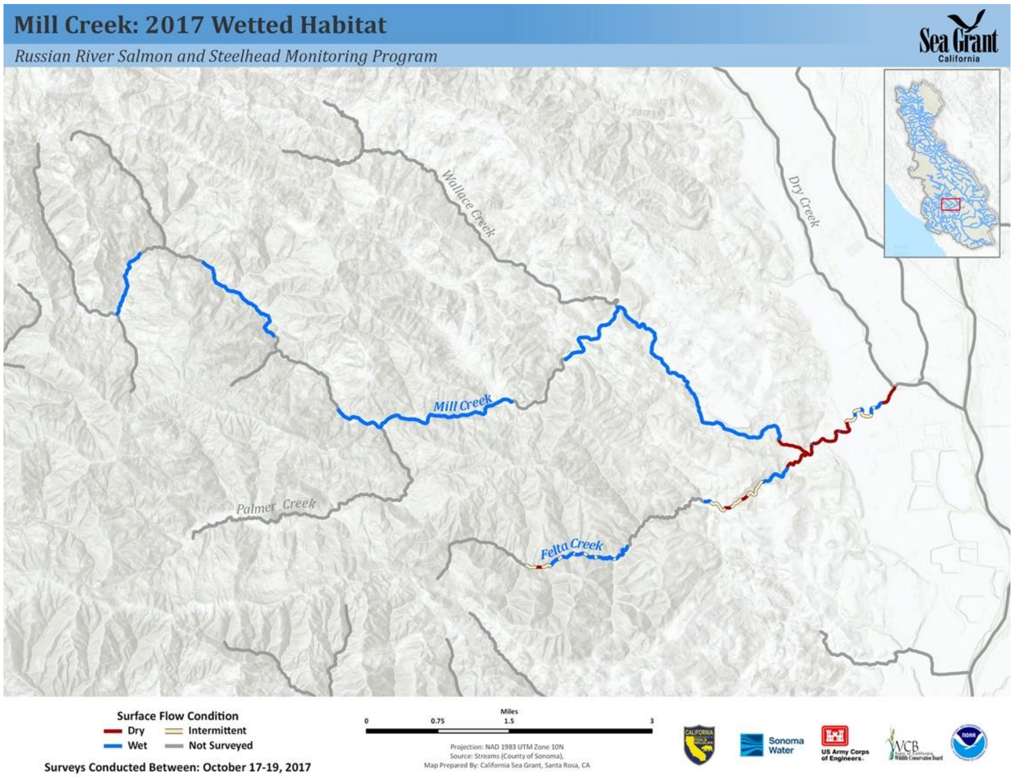

Figure 17. Wetted habitat conditions in Mill and Felta creeks on October 16-19, 2017; driest survey of 2017, as defined by the least amount of wetted stream length.

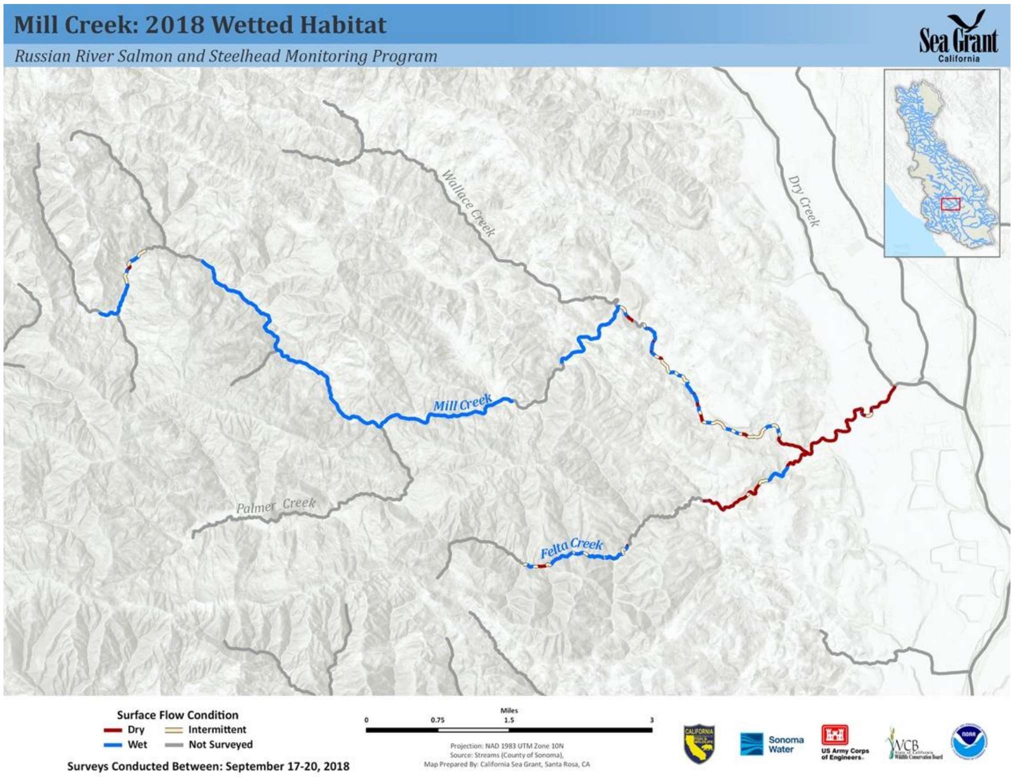

Figure 18. Wetted habitat conditions in Mill and Felta creeks on September 17-20, 2018; driest survey of 2018, as defined by the least amount of wetted stream length.

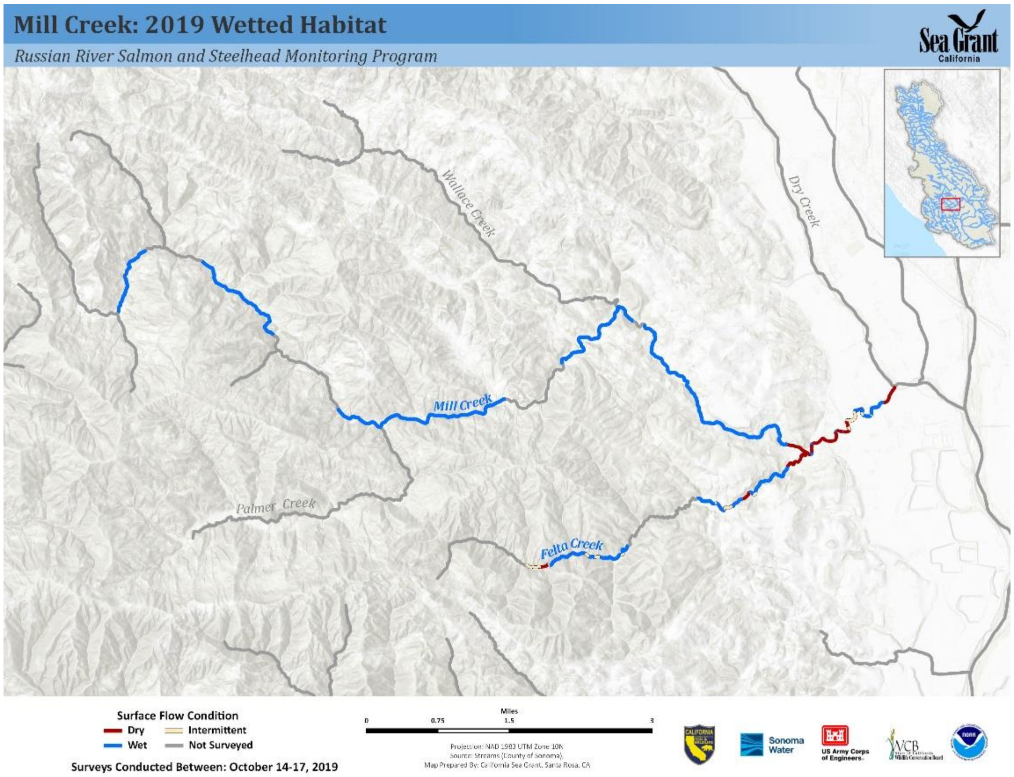

Figure 19. Wetted habitat conditions in Mill and Felta creeks on October 14-17, 2019; driest survey of 2019, as defined by the least amount of wetted stream length.

2.2.3. Salmonid redd distribution

In the winter of each grant year, spawner surveys were conducted by CSG and Sonoma Water, with financial support from the Broodstock Program and the CMP, in all accessible reaches of the Dutch Bill, Green Valley, and Mill Creek watersheds defined as coho salmon habitat by the Russian River CMP effort (Adams et al. 2011; California Sea Grant 2016b; Sonoma Water 2015). Each reach was surveyed at an interval of 10-14 days throughout the spawning season (typically December through April), following methods outlined in CSG's *Russian River Coho Salmon and Steelhead Monitoring Report: Winter 2018/19* (https://bit.ly/Winter2018-19MonitoringReport). On each survey, CSG and Sonoma Water biologists hiked reaches from downstream to upstream looking for adult salmon individuals (live or carcass) and redds. Redds were identified to species based on the presence of identifiable adult fish or from observed redd morphology. All salmonids were identified to species (coho salmon, Chinook salmon or steelhead) or as an unknown salmonid if identification was not possible. Geospatial coordinates were recorded for all redd and fish observations. Allegro field computers were used for data entry and, upon returning from the field, data files were downloaded, error checked in Microsoft Excel and transferred into a SQL database. Redds were totaled by species and mapped for each stream. Detailed outcomes from these monitoring efforts can be found in each year's winter monitoring reports at https://caseagrant.ucsd.edu/project/coho-salmon-monitoring/reports.

The total number of salmonid redds observed by year in all study streams combined was 63 in the 2017 spawner season, 71 in the 2018 season, and 108 in the 2019 season (see http://bit.ly/SalmonidDistributionSummary for counts and distribution maps for each stream).

The resulting winter redd distribution data for each study stream was spatially joined with the late-summer wetted habitat data from the driest sample each year in order to evaluate the suitability of summer rearing habitat in relation to spawning activity.

2.2.4. Juvenile salmonid distribution

In June and early July of each grant year, snorkeling surveys were conducted by CSG and Sonoma Water through the support of the Broodstock Program and the CMP, to document the relative abundance and spatial distribution of juvenile coho salmon and steelhead in all accessible reaches within the Dutch Bill, Green Valley, and Mill creek watersheds that are defined as juvenile coho salmon habitat by the Russian River CMP effort (Adams et al. 2011; California Sea Grant 2016a; Sonoma Water 2015). CSG and Sonoma Water biologists snorkeled every other pool in each stream reach and counted the number of coho salmon and steelhead yoy present using methods outlined in CSG's *Coho Salmon and Steelhead Monitoring Report: Summer 2019* (https://bit.ly/Summer2019MonitoringReport). Allegro field computers were used for data entry and, upon returning from the field, data files were downloaded, error checked in Microsoft Excel and transferred into a SQL database. Geospatial coordinates were collected at each survey pool so that juvenile densities could be spatially displayed. Because only 50% of pools are sampled during these surveys, counts are doubled, or 'expanded' for an estimate of juvenile abundance throughout the reaches. Detailed outcomes from these monitoring efforts can be found in each year's summer monitoring reports at https://caseagrant.ucsd.edu/project/coho-salmon-monitoring/reports.

The total expanded (observed count from every second pool multiplied by a factor of two) salmonid yoy counts in all fours study streams combined was 9,752 in 2017; 8,638 in 2018; and 10,592 in 2019 (see http://bit.ly/SalmonidDistributionSummary for counts and distribution maps for each stream).

Early-summer juvenile salmonid distribution data for each stream was spatially joined with late-summer wetted habitat data from the driest biweekly sample each year in order to estimate the effect of stream drying and wetted habitat condition on juvenile fish rearing in each study stream.

2.2.5. Fish distribution in relation to wetted habitat

Redd observations from winter spawner surveys and salmonid young-of-year distribution data from early-summer snorkeling surveys were overlaid with wetted habitat maps from the driest late-season survey of each season (e.g., Figure 20-Figure 21). The full set of 18 overlay maps for all streams and study years is available in PDF format at http://bit.ly/SalmonidDistributionOverlayMapbook. This information was evaluated to determine 1) what proportion of returning adult salmon and steelhead spawned in locations where their offspring would have access to sufficient wetted habitat throughout the summer, presuming that they remained in the vicinity of the redd; and, 2) what proportion of rearing juvenile salmon and steelhead were potentially impacted by drying stream conditions given their location during early-summer snorkeling surveys. While it is possible that fish observed in early-summer snorkeling surveys may have had the opportunity to move to other locations within the streams, it appears unlikely based on CSG's previous PIT-tag monitoring data from multiple seasons and common observations of fish stranding in previous years (CSG unpublished data). Mortality is presumed likely for fish observed in a pool that is later recorded as dry or intermittent during wetted habitat surveys. We did not assume survival in areas that retain surface flow, rather we viewed these as locations where fish had a chance to survive. In reaches that retained surface flow connectivity, rates of oversummer survival were likely dependent on water quality conditions, competition, and predation.

Furthermore, surviving is not equivalent to thriving, and fish rearing in suboptimal habitat conditions may struggle to achieve adequate growth and conditioning needed for success later in life.

Following generation of the overlay maps, the resulting data was summarized by stream to determine the proportion of redds and juvenile fish that were observed in areas that went dry, became intermittent, or remained wet over each summer from 2017-2019, and a three-year average was calculated for stream-scale characterization over the study period (

Table **2**, Figure 22, Figure 23). Data were also averaged for all streams by year for interannual characterization (Table 3). Raw counts rather than expanded counts of salmonid yoy were used due to the reach-scale variability between the distribution of wetted habitat conditions and the individual pool habitat units that met requirements for snorkeling under CMP field protocols (https://bit.ly/Summer2019MonitoringReport). Some of the fish-bearing tributaries to these streams (Purrington, Wallace, and Palmer creeks) received a single opportunistic late-season survey to characterize minimum flow conditions in relation to fish distribution in 2017 and 2018. The fish distribution data from those surveys are shown on the maps (Figure 20, Figure 21, Figure 25, http://bit.ly/SalmonidDistributionOverlayMapbook), but are not included in the summary figures as it did not occur in every year and was beyond the scope of this project.

When averaged across all four streams by year, 2019—the year with the wettest instream habitat conditions—had the greatest proportion of redds (77%) and juvenile salmonids (75%) in locations where habitat remained wet throughout the summer season (Table 3, Figure 22, Figure 23). This was similar to 2017 when, on average, 72% of redds and 70% of juveniles were counted in areas that remained wet all season. These data suggest that even in wetter-then-average water years, summer conditions in these streams pose a challenge to juvenile salmonid survival, with 25-30% of juveniles found in locations that became dry or intermittent and likely leading to fish mortality.

On average for all streams in 2018, 55% of redds and 63% of juveniles were observed in locations that remained wet all summer (Table 3, Figure 22, Figure 23). Since 2018 was a below-average year in terms of rainfall (Figure 5), the low level of wetted habitat documented during this year is likely more representative of future conditions expected under climate change scenarios than outcomes from 2017 or 2019. Despite being an improvement upon drought years such as 2015, when only 24% of redds and 28% of juveniles remained wet through the dry season in the same streams (California Sea Grant 2016a), these suboptimal drying patterns and high inter-annual variability leave a significant proportion of juvenile salmonids vulnerable to oversummer mortality and pose a barrier to population recovery.

Evaluating the distribution of winter redds and rearing fish in concert offers an interesting evaluation of whether, and at what proportion, salmonid yoy moved out of the area where they were hatched (Figure 24). The relationship between the proportion of redds and the proportion of juveniles observed in areas that remained wetted through the summer was similar when averaged across all survey streams by year (Table 3). In 2017 when 72% of all redds were found in areas that retained flow, 70% of all observed juveniles were counted where flow persisted. Likewise, in 2019, 77% of redds were in areas that stayed wet, resulting in 75% of juveniles being counted in areas that stayed wet. There was however more variation in 2018, the driest year of the study, where 55% of redds were located in areas that stayed wet during 2018, yet 63% of juveniles were observed in areas that remained wet.

Of all the sample streams, Felta Creek consistently had the greatest proportion of adult and juvenile salmonid activity in areas that became dry over the summer, with an average of just 43% of redds and 40% of juveniles counted in areas that remained wet through the dry season (

Table **2**, Figure 22, Figure 23). Salmonids consistently spawned in lower Mill and Felta creeks, which dried substantially in each study year (Figure 20). This is despite the fact that, prior to this study, two passage barrier remediation projects were completed in the middle reaches of Mill Creek to improve spawning access to the perennial upper reaches. On average over all three study years, 66% of all redds and 70% of juvenile salmonids observed in Mill Creek were in locations that remained wet through the dry season (

Table **2**, Figure 21). This is an improvement from previous drought conditions; for example, in Mill Creek in 2013 (prior to the second barrier remediation project), only 28% of juveniles were counted in areas that stayed wet all summer (RRCWRP 2015). While the average proportion of juveniles counted in wetted habitat in Mill Creek over the summers of the study period was more than double that, it still accounts for significant losses within a stream that is considered a high-priority coho refuge. Nonetheless, the upper half of Mill Creek, upstream of the confluence with Wallace Creek, was able to provide perennial wetted habitat for rearing fish even in the driest year of 2018 (Figure 21).

In Green Valley Creek, spawning activity and juvenile salmonids tended to be more evenly distributed throughout the survey reaches and, in general, the drying occurred in a patchwork of small disconnections rather than in large swaths (Figure 25). Under these conditions, in the early summer periods it is possible that juveniles may have had a chance to move a short distance into adjacent pool units that stayed wet through the summer. When averaged over the three study years, 73% of redds and 79% of juvenile salmonids observed in Green Valley Creek were in locations that remained wet through the dry season (

Table **2**, Figure 23). Similar to the interannual variation in wetted habitat conditions, Green Valley Creek had the greatest variation in the proportion of juvenile rearing locations that remained wet across the study years, when compared to the other streams.

Salmonids tended to spawn and rear higher up in Dutch Bill Creek where conditions stay wet through the summer (Figure 26). In 2017, despite only 56% of the Dutch Bill Creek channel remaining wet, 86% of juveniles were located in those wet areas (

Table **2**, Figure 23). Again in 2018, the vast majority (93%) of observed juvenile salmonids were located within the approximately half (55%) of the stream that stayed wet. On average over all three study years, 90% of all redds and juvenile salmonids observed in Dutch Bill Creek were in locations that remained wet through the dry season; the highest proportion for both redds and juveniles out of any of the study streams (

Table **2**). This indicates that upper Dutch Bill Creek is providing refugia habitat for rearing salmonids, at least under the environmental conditions experienced during this study period.

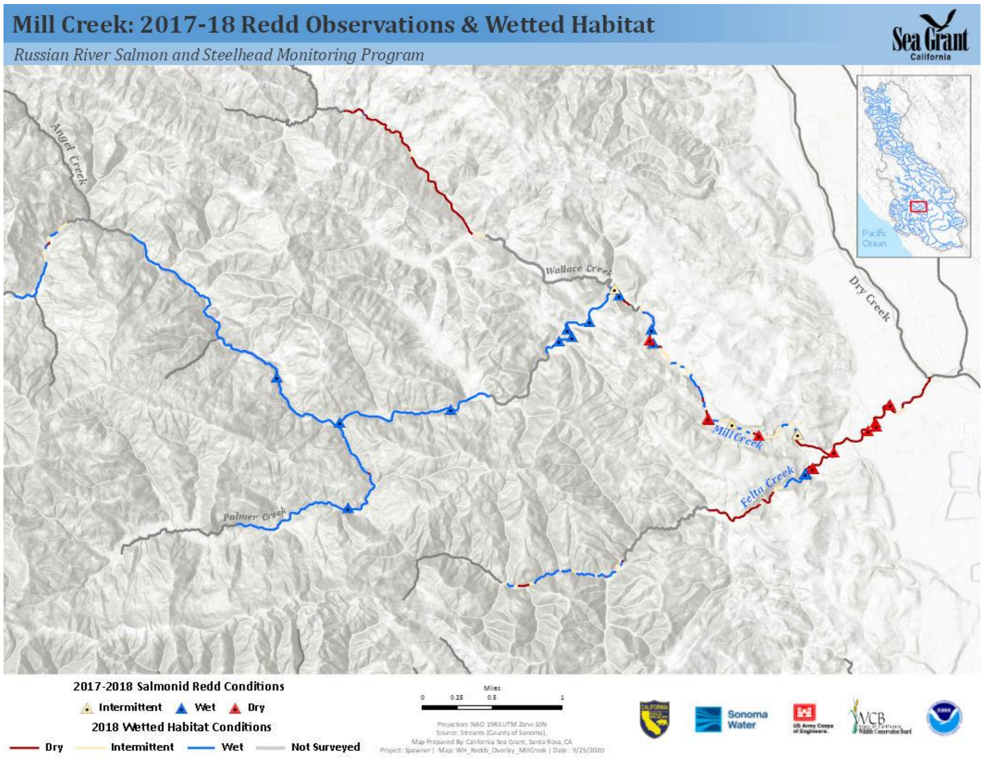

Figure 20. Winter 2017-2018 Mill and Felta creek redd locations in relation to late-summer 2018 wetted habitat conditions.

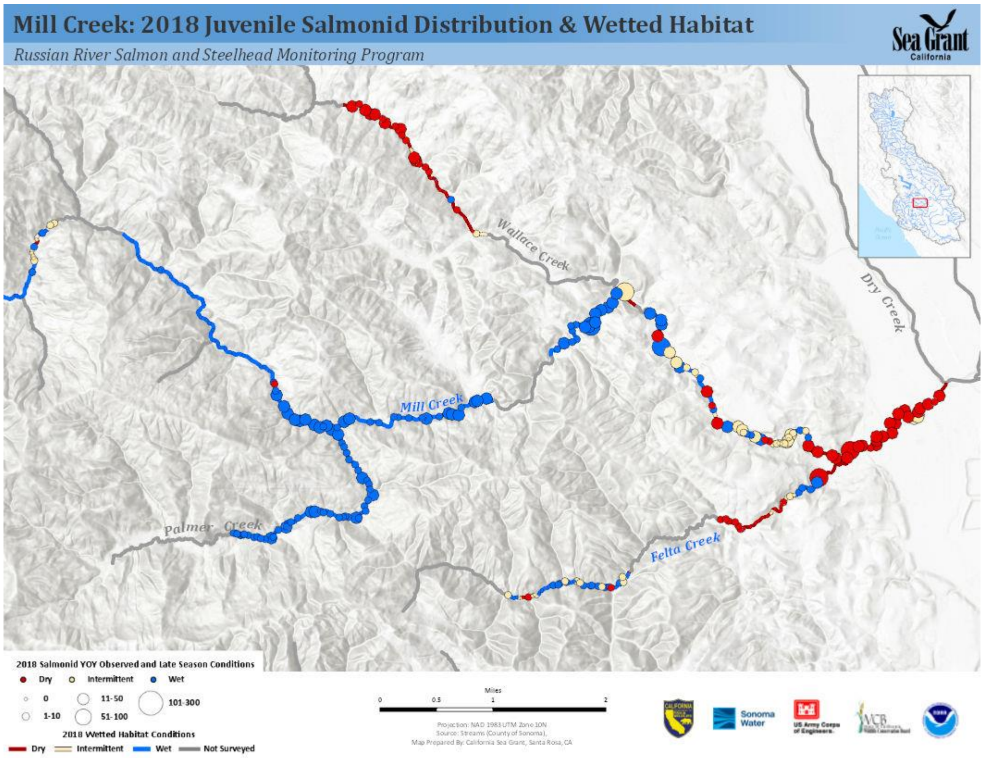

Figure 21. Early-summer salmonid young-of-year distribution in Mill and Felta creeks in relation to late-summer wetted habitat conditions, 2018.

Table 2. Number and proportion of winter salmonid redd observations in relation to late-summer minimum flow (driest) conditions, and number and proportion of early-summer juvenile salmonid observations in relation to late-summer minimum flow (driest) conditions by stream and year, and averaged by stream for all years, 2017-2019.

Tributary	Sample Year	Salmonid Redds			Juvenile Salmonids[1]		
		Dry	Intermittent	Wet	Dry	Intermittent	Wet
Dutch Bill Creek	2017	0 (0%)	1 (7%)	13 (93%)	12 (4%)	34 (10%)	280 (86%)
	2018	0 (0%)	1 (13%)	7 (88%)	12 (2%)	25 (5%)	463 (93%)
	2019	0 (0%)	1 (11%)	8 (89%)	297 (23%)	173 (13%)	841 (64%)
	3-year Average	0 (0%)	1 (10%)	9 (90%)	103 (6%)	77 (4%)	1,584 (90%)
Green Valley Creek	2017	1 (5%)	5 (26%)	13 (68%)	185 (7%)	418 (15%)	2,180 (78%)
	2018	0 (0%)	12 (44%)	15 (56%)	38 (2%)	668 (41%)	929 (57%)
	2019	0 (0%)	7 (16%)	37 (84%)	0 (0%)	59 (4%)	1,443 (96%)
	3-year Average	0 (0%)	8 (27%)	22 (73%)	74 (1%)	1,145 (20%)	4,552 (79%)
Mill Creek	2017	11 (35%)	1 (3%)	19 (61%)	223 (20%)	58 (5%)	826 (75%)
	2018	10 (42%)	4 (16%)	10 (42%)	687 (23%)	428 (14%)	1,873 (63%)
	2019	7 (16%)	2 (4%)	35 (80%)	271 (16%)	108 (6%)	1,364 (78%)
	3-year Average	9 (28%)	2 (6%)	21 (66%)	394 (20%)	198 (10%)	1,354 (70%)
Felta Creek	2017	4 (57%)	0 (0%)	3 (43%)	333 (34%)	283 (29%)	366 (37%)
	2018	2 (40%)	0 (0%)	3 (60%)	115 (39%)	43 (15%)	138 (47%)
	2019	6 (66%)	1 (11%)	2 (23%)	334 (45%)	100 (14%)	306 (41%)
	3-year Average	4 (57%)	0 (0%)	3 (43%)	261 (39%)	142 (21%)	270 (40%)

[1] *Coho salmon and steelhead young-of-the-year (yoy).*

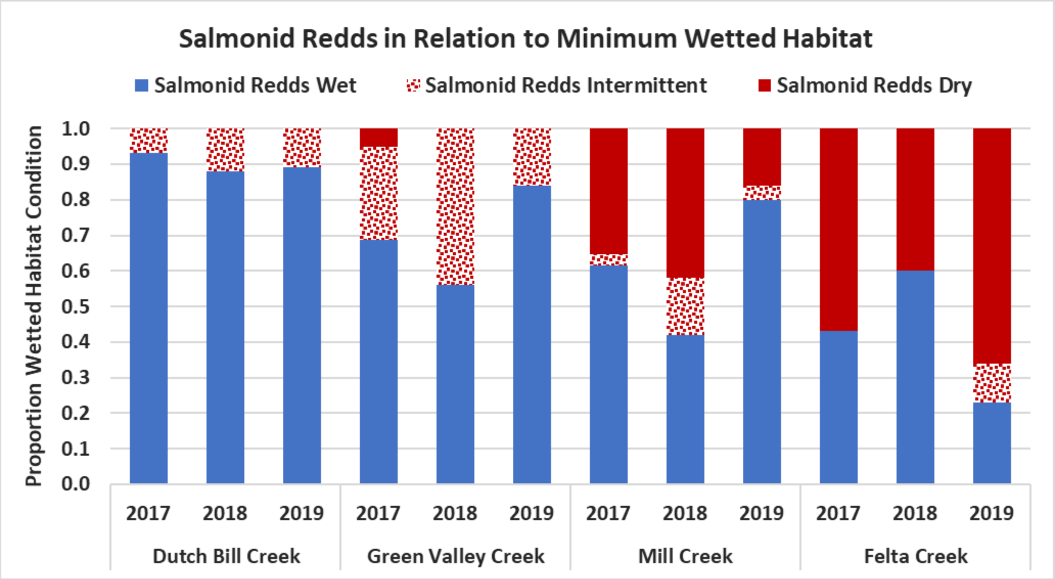

Figure 22. Salmonid redds in relation to driest wetted habitat conditions in Dutch Bill, Green Valley, Mill, and Felta creeks, 2017-2019.

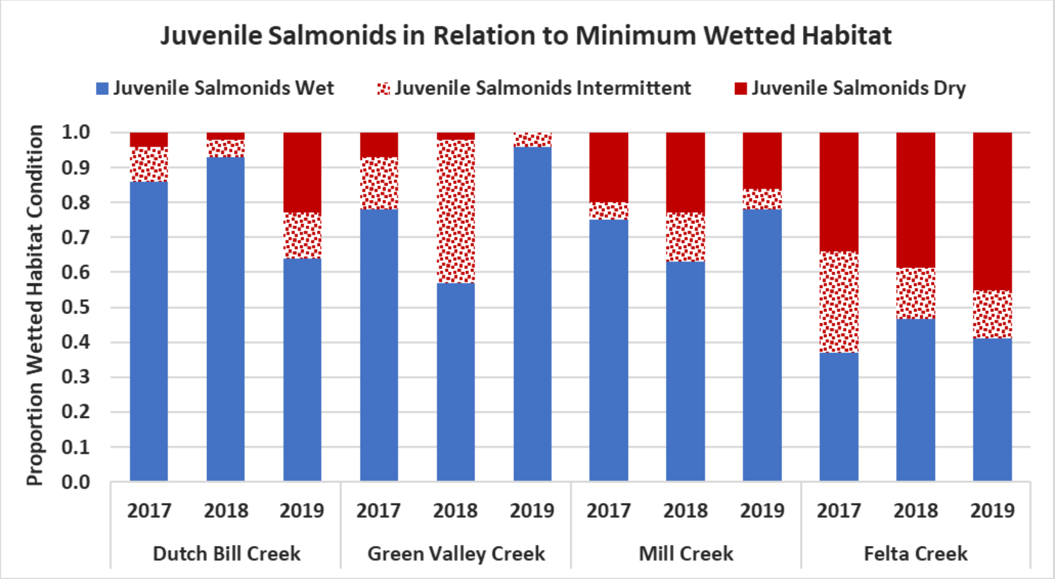

Figure 23. Juvenile salmonid young-of-year in relation to driest wetted habitat conditions in Dutch Bill, Green Valley, Mill, and Felta creeks, 2017-2019.

Table 3. Average proportion of salmonid redds and juvenile salmonids observed in relation to late-summer minimum flow (driest) habitat conditions for Dutch Bill, Green Valley, Mill, and Felta creeks, 2017-2019.

		Salmonid Redds			**Juvenile Salmonids[1]**		
Tributary	**Year**	**Dry**	**Intermittent**	**Wet**	**Dry**	**Intermittent**	**Wet**
All Streams	2017	24%	4%	72%	15%	15%	70%
	2018	19%	26%	55%	16%	21%	63%
	2019	13%	10%	77%	17%	8%	75%

[1] *Coho salmon and steelhead young-of-the-year (yoy).*

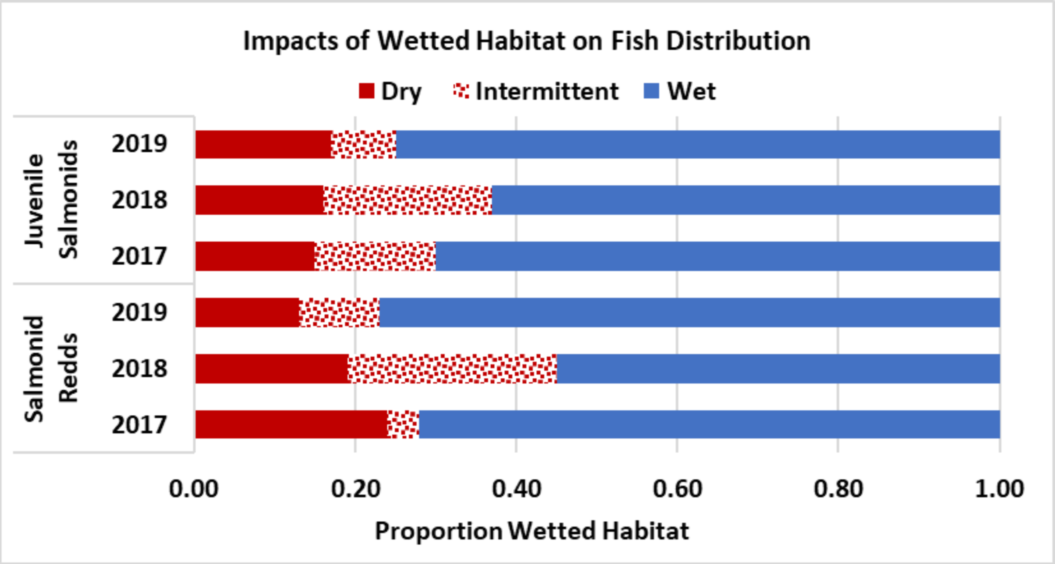

Figure 24. Annual comparison of impact of wetted habitat conditions on juvenile salmonid young-of-year and salmonid redds in Dutch Bill, Green Valley, Mill, and Felta creeks, 2017-2019.

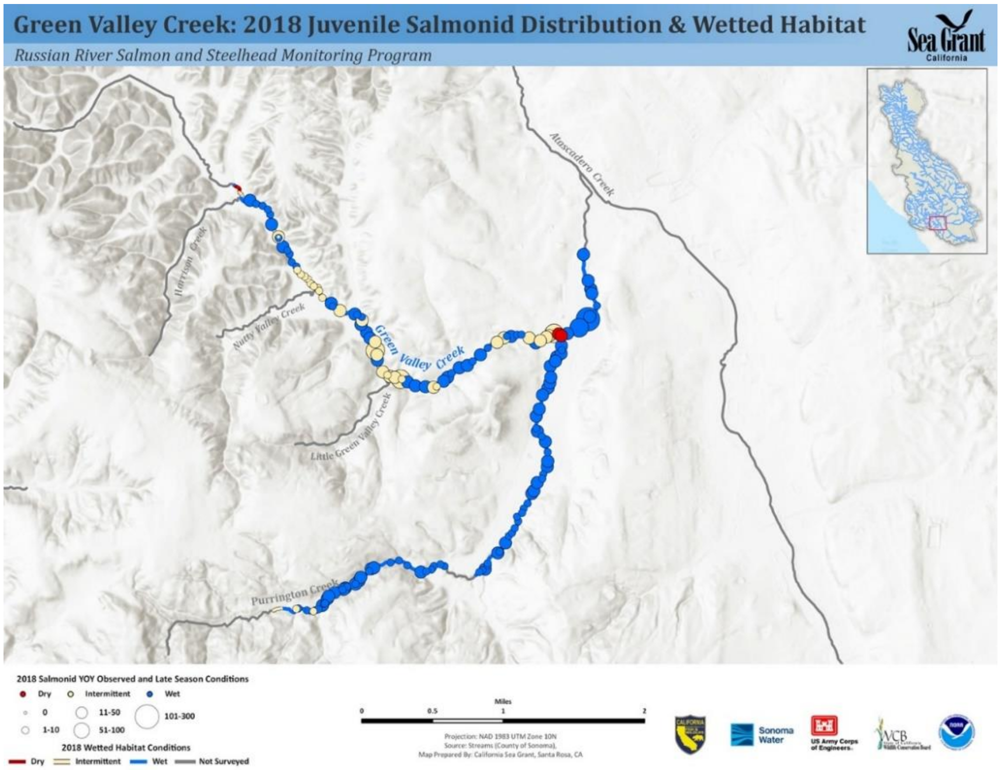

Figure 25. Early-summer salmonid young-of-year distribution in Green Valley Creek in relation to late-summer wetted habitat conditions, 2018.

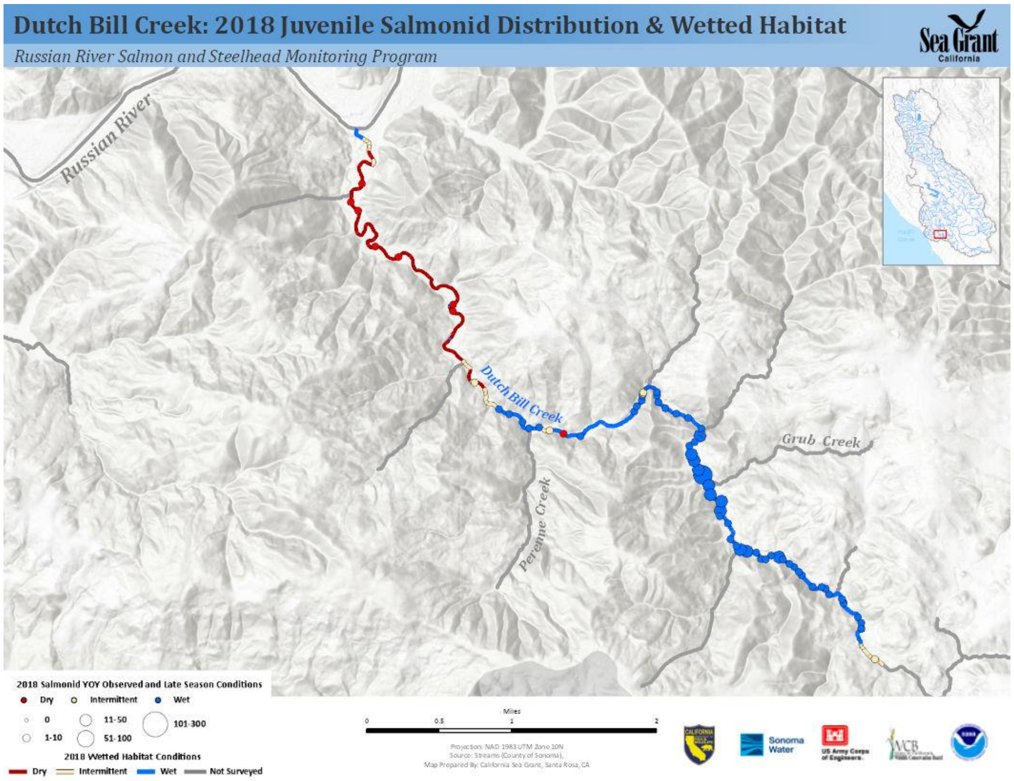

Figure 26. Early-summer salmonid young-of-year distribution in Dutch Bill Creek in relation to late-summer wetted habitat conditions, 2018.

2.2.6. Streamflow and connectivity

Through their ongoing work with the Coho Partnership, Trout Unlimited (TU) hydrologists collected three years of dry season (May through October, 2017-2019) stage and streamflow data at six stage logger sites (also referred to as gage sites) in two reaches of Dutch Bill, Green Valley, and Mill creeks, in order to support this project (Figure 27). For the purposes of this report, these sites are referred in relation to each other as in the upper and lower gage sites in each stream; however, they do not represent conditions in the driest reaches in the lowest approximately three river kilometers (rkm) of Dutch Bill and Mill creeks, or below rkm 9.78 (the first Green Valley Road crossing) in Green Valley Creek. Four of the gages were part of TU's pre-existing network. Two additional telemetered loggers were installed on lower Green Valley and lower Mill creeks in May 2018, with funding from this grant. Real-time stage data from those gages are available online at https://www.hydrovu.com (user: coho@ucsd.edu, password: CohoPartnership).

All gages were In-Situ Level Troll 500 vented pressure transducers, which recorded stream stage (water level) and water temperature within a stable pool at 15-minute intervals throughout the dry season. Staff plates were also installed at each site to account for transducer drift or other factors that could cause shifts in stage. TU hydrologists visited each logger site at approximately monthly intervals each year between May and October to download stage data, record staff plate depths, photo-document reach conditions, and measure discharge following protocols adapted from *California Department of Fish and Wildlife's Standard Operating Procedures for Discharge Measurements in Wadeable Streams* (CDFW 2013). Discharge data were used to develop rating curves and continuous streamflow datasets for each of the gaged stream reaches.

Surface flow disconnection was documented during wet/dry mapping surveys, as well as through the use of trail cameras and intermittency loggers operated in the study reaches over the summers of 2017 and 2018 with funding from the Anthropocene Institute (California Sea Grant 2017). Those data were paired with streamflow data to identify connectivity thresholds for each study reach. Connectivity thresholds are defined as the amount of streamflow needed to maintain pool connection throughout a designated stream reach. The Coho Partnership uses connectivity thresholds as a basis for determining the minimum amount of flow that needs to be restored to priority stream reaches in order to reduce the number of days of stream disconnection and, thereby, increase the probability of juvenile coho salmon survival.

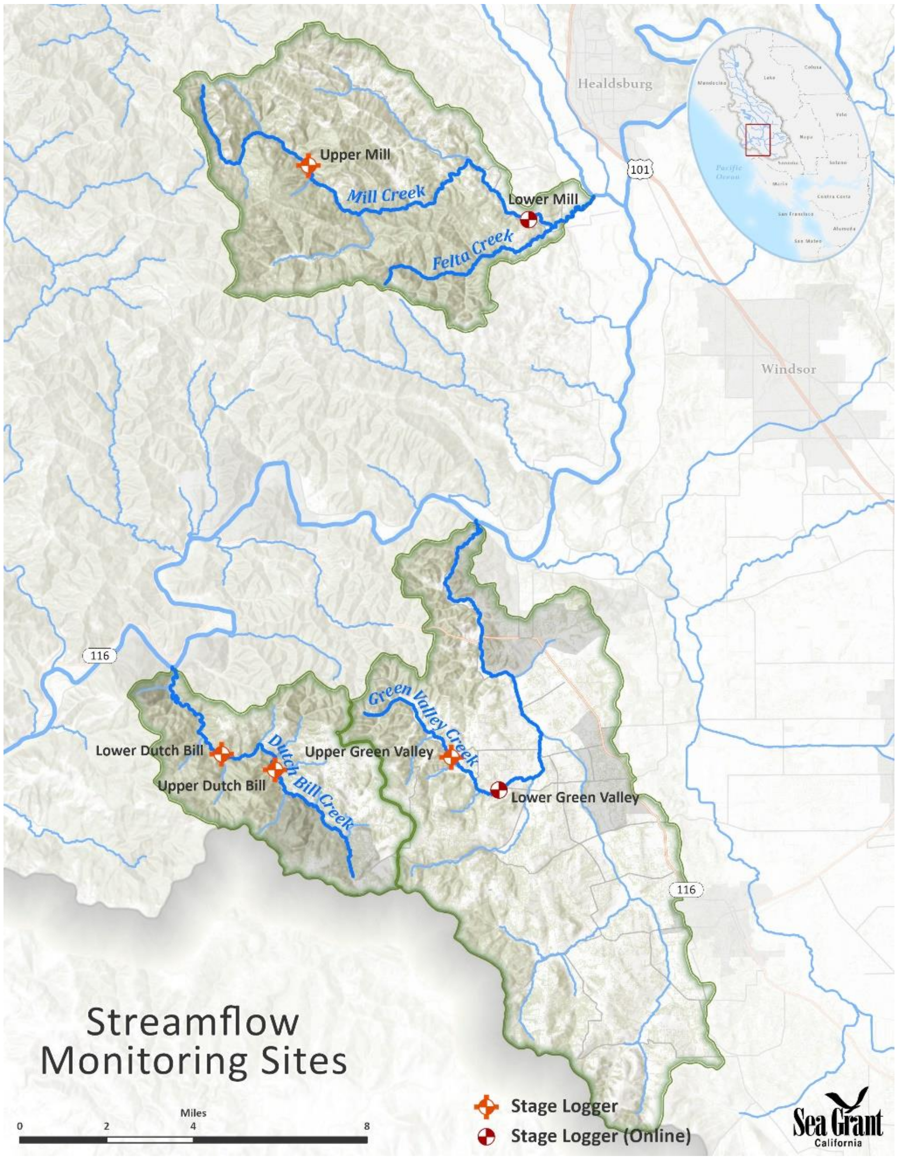

Figure 27. Pressure transducer gage (stage logger) sites on Dutch Bill, Green Valley, and Mill creeks where stage and streamflow data were collected.

2.2.6.1. Connectivity thresholds

Connectivity thresholds were only identified for stream reaches that could be reasonably represented through the existing stage logger network; reaches upstream of rkm 3.13 in Dutch Bill Creek, rkm 9.77 in Green Valley Creek, and rkm 2.98 in Mill Creek (Table 4). A connectivity threshold of 0.20 ft^3/s was estimated for each of the upper and lower study reaches in all three streams, with the exception of lower Dutch Bill Creek (Table 4). We estimated the lower Dutch Bill Creek study reach to have a substantially higher threshold of 0.50 ft^3/s, likely due to the channel geometry and substrate. Note that some connectivity thresholds are different than previously reported. This is because observations from 2018 were used to modify/increase some of the preliminary thresholds estimated by the Coho Partnership.

Because they identify the flow at which the first riffles within a designated stream reach begin to disconnect, these thresholds should be considered conservative, in the sense that some portions of each reach may maintain sufficient connectivity once flow falls below the stated threshold. Because days of disconnection has a negative relationship with juvenile salmon survival, connectivity thresholds are useful for understanding impacts and setting targets; however, they should not be confused with minimum flows needed to support salmonids. Higher flows are almost certainly needed for fish to move, grow, and survive in subsequent life stages.

Table 4. Connectivity thresholds for study reaches of Dutch Bill, Green Valley, and Mill creeks.

Stream Reach	**Extent of Reach**[1]	**Representative Flow Gage**	**Connectivity Threshold (ft^3/s)**[2]
Lower Dutch Bill Creek	3.14 - 5.97	DB04	0.50
Upper Dutch Bill Creek	5.97 - 10.59	DB02	0.20
Lower Green Valley Creek	9.78 -13.03	GV08	0.20
Upper Green Valley Creek	13.03 -16.76	GV04	0.20
Lower Mill Creek	2.99 - 9.97	MI03	0.20
Upper Mill Creek	9.97 - 15.54	MI01	0.20

[1] *Distance upstream from the mouth in river kilometers.*

[2] *Streamflow required to maintain habitat connection through entire reach. Estimated to the nearest 0.05 ft^3/s. Based on average daily streamflow on last known day of connection for years between 2010-2018, where flow data is available.*

2.2.6.2. Dutch Bill Creek Streamflow

Streamflow hydrographs were plotted for the lower (rkm 4.37) and upper (rkm 6.89) Dutch Bill Creek stage logger sites (Figure 27) from WY2017 to WY2019, along with the connectivity threshold for the respective reaches. In general, streamflow was higher at the lower gage site at the beginning of the summer season until the reach between two the sites became a losing reach by late July or August (Figure 28, Figure 29). Late-summer streamflow conditions were consistently higher at the upper Dutch Bill Creek gage site during the study period. The loss in flow between the sites is likely caused by the stream recharging the underlying alluvial aquifer, as well as seasonal evapotranspiration. Streamflow was lowest in 2017 at the upper site, lowest in 2018 at the lower site, and highest in 2019 at both gage sites. The large rain event in May 2019, significantly increased flows in early summer and resulted in an increased base flow throughout summer 2019.

Flow releases into Dutch Bill Creek from Camp Meeker Recreation and Parks District's municipal source occurred in August of 2018 and 2019, at an approximate rate of 0.09 ft^3/s and 0.07 ft^3/s, respectively. These releases, which were upstream of the upper gage site, boosted late-summer flows in both reaches in 2018 and in the upper reach in 2019. Release logistics and the impacts of these augmentations on streamflow are discussed in greater detail, along with water quality impacts, in the ***Flow release evaluation*** section of this report.

From 2017 to 2019, the number of days per year that streamflow was below the connectivity threshold for the 167-day period of May 1 to October 15 ranged from 53 to 109 days at the lower Dutch Bill gage site, and from just eight to 77 days at the upper Dutch Bill gage site (Table 5). This indicates that one or more pools were disconnected for 32% to 65% of the season in the lower reach over all years and from 5% to 46% in the upper reach, with the number of dry riffles generally starting lower and increasing over the dry season. Clearly, these data correlated with flow, with 2019 having the fewest number of days below the connectivity threshold at both sites, and with 2017 and 2018 experiencing the highest number of predicted days of disconnection at the upper and lower sites, respectively.

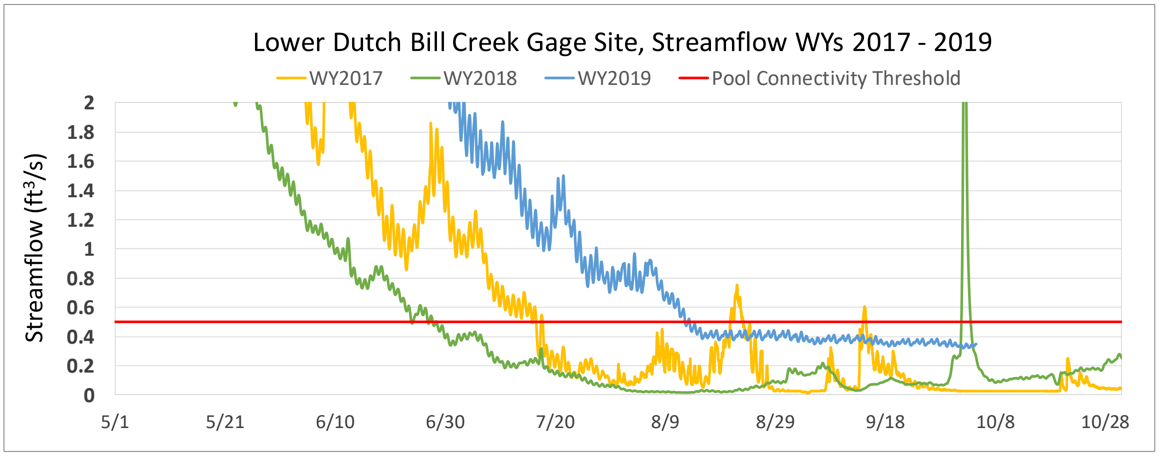

Figure 28. Streamflow recorded at TU's lower gage site in the Dutch Bill Creek watershed, and the reach-scale connectivity threshold, WYs 2017-2019. Note that data for WY2019 is complete only through October 4 due to a gage malfunction.

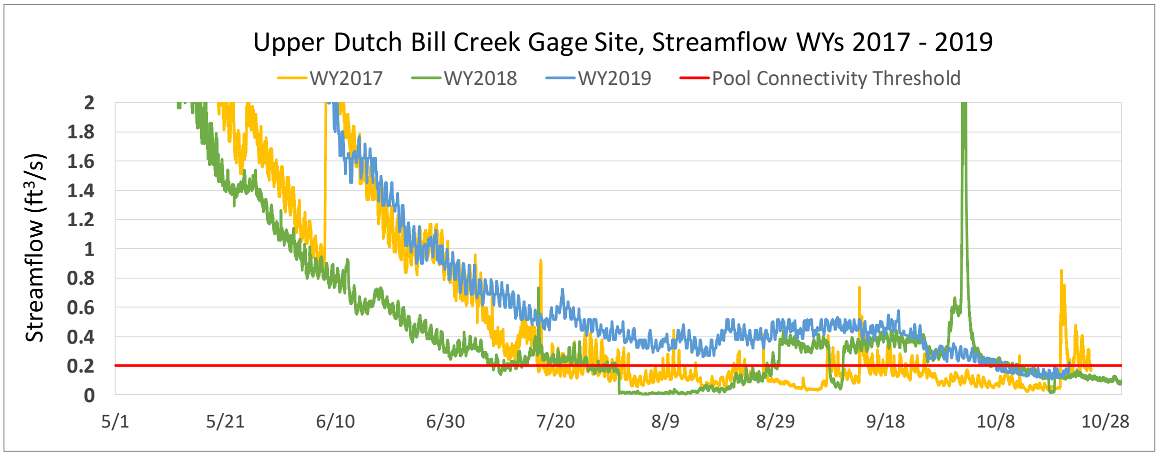

Figure 29. Streamflow recorded at TU's upper gage site in the Dutch Bill Creek watershed, and the reach-scale connectivity threshold, WYs 2017-2019.

Table 5. Number of days that streamflow was below the connectivity threshold at the upper and lower Dutch Bill Creek gage sites from May 1 to October 15 (total days = 167), WYs 2017-2019. Note that data for WY2019 is complete only through 10/4 due to a gage malfunction.

Stream Reach	Year	Days Below Connectivity Threshold[1]
Lower Dutch Bill Creek	2017	88
Lower Dutch Bill Creek	2018	109
Lower Dutch Bill Creek	2019	53
Upper Dutch Bill Creek	2017	77
Upper Dutch Bill Creek	2018	44
Upper Dutch Bill Creek	2019	8

[1] *Calculated by summing 15-minute intervals that streamflow was below threshold values and rounding to the nearest whole day.*

2.2.6.3. Green Valley Creek Streamflow

Streamflow hydrographs were plotted for the lower (rkm 12.04) and upper (rkm 14.13) Green Valley Creek sites (Figure 27) from WY2017 to WY2019, and compared to the pool connectivity threshold for the respective stream reaches (Figure 30, Figure 31). Streamflow conditions at the lower and upper gage sites were similar during the study period though, in general, streamflow was lower at the upper gage site. Flow in upper Green Valley Creek dropped to zero in summer 2017 and 2018, and the site maintained a low base flow of approximately 0.06 ft^3/s throughout summer 2019. In contrast, the lower gage site maintained surface flow in all three water years, with the stream reaching its lowest discharge of 0.02 ft^3/s in mid-September 2018.

Recorded streamflow was lowest in 2018 and highest in 2019 at both gage sites through the entire summer season. As with Dutch Bill Creek, the large rain event in May 2019 significantly increased flows in Green Valley Creek in early summer and resulted in an increased base flow throughout summer 2019. While 2017 was the highest rainfall year, summer flows in Green Valley Creek in 2017 were only slightly higher than those recorded in 2018. This is likely due to the relatively dry spring season in 2017, as well as surface flows recharging aquifers that had been depleted during the 2012-2016 drought.

In all WYs, the gages detected a large drop in flow in late May/early June which is likely linked to human activities upstream of the upper gage site. This caused flow levels to drop by approximately 0.7, 0.4, and 3.3 ft^3/s for a few days in summer 2017, 2018, and 2019, respectively (Figure 30, Figure 31).

Two flow releases were implemented on Green Valley Creek during the study period; both occurred in September of 2017, and in August of 2018 and 2019. The lower release, from an off-channel storage pond on the Jackson Family Wines property, occurred just below Bones Road at a rate of approximately 0.10 ft^3/s. This release, located between the upper and lower gage sites, was detected in the hydrograph of TU's lower gage site in 2017 and 2019. The upper flow release, also from an off-channel pond, was from the Green Valley Farms property near the top of the watershed, above the upper gage site. The signal from this augmentation was difficult to detect at either gage site, which is likely due to human activities impacting flow between the release site and the gages downstream. A detailed overview of the impacts of these augmentations on both streamflow and water quality can be found in the ***Flow release evaluation*** section of this report.

From 2017 to 2019, the number of days per year that streamflow was below the connectivity threshold for the 167-day period of 5/1 to 10/15 ranged from 66 to 99 days at the lower Green Valley gage site, and from 71 to 112 days at the upper Green Valley gage site (Table 6). This indicates that one or more pools were disconnected for approximately 40% to 59% of the season in the lower reach over all years, and from 43% to 67% in the upper reach, with the number of dry riffles generally increasing over the dry season. Clearly, these data correlated with flow, with WY2018 having the greatest number of days where pools were disconnected in both the upper and lower watershed, and 2019 having the fewest in both reaches.

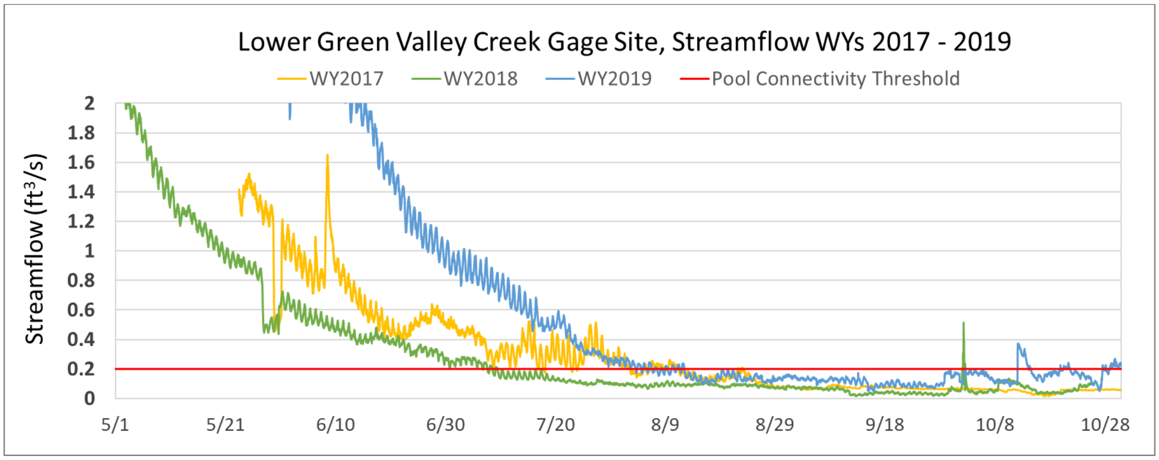

Figure 30. Streamflow recorded at TU's lower gage site in the Green Valley Creek watershed, and the reach-scale connectivity threshold, WYs 2017-2019.

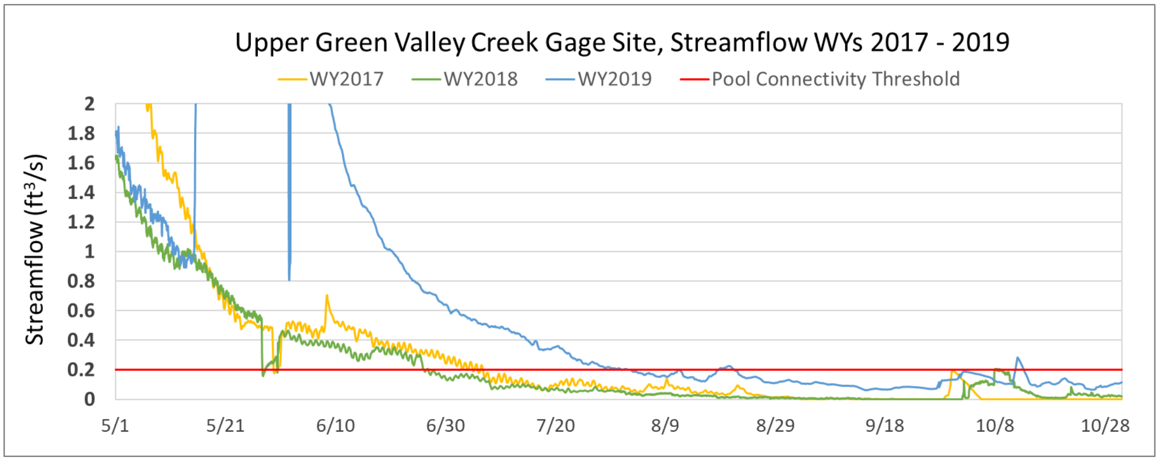

Figure 31. Streamflow recorded at TU's upper gage site in the Green Valley Creek watershed, and the reach-scale connectivity threshold, WYs 2017-2019.

Table 6. Number of days that streamflow was below the connectivity threshold at the upper and lower Green Valley Creek gage sites from 5/1-10/15 (total days = 167), WYs 2017-2019.

Stream Reach	**Year**	**Days Below Connectivity Threshold[1]**
Lower Green Valley Creek	2017	70
Lower Green Valley Creek	2018	99
Lower Green Valley Creek	2019	66
Upper Green Valley Creek	2017	103
Upper Green Valley Creek	2018	112
Upper Green Valley Creek	2019	71

[1] Calculated by summing 15-minute intervals that streamflow was below threshold values and rounding to the nearest whole day.

2.2.6.4. Mill Creek Streamflow

Streamflow hydrographs were plotted for the lower (rkm 3.11) and upper (rkm 13.19) Mill Creek stage logger sites (Figure 27) from WY2017 to WY2019, along with the pool connectivity values for these sites (Figure 32, Figure 33). Late-summer streamflow conditions observed between the lower and upper gage sites in the Mill Creek watershed were generally higher at the lower gage site during the study period, with the exception of WY2017 in which the lower gage site pool disconnected and the upper gage maintained a low base flow of approximately 0.06 ft^3/s. Recorded streamflow was lowest in 2018 and highest in 2019 at both gage sites through the entire summer season. The upper gage site experienced its lowest discharge of approximately 0.05 ft^3/s in late-September 2018. As observed in both Green Valley and Dutch Bill creeks, the large rain event in May 2019, significantly increased flows in early summer and resulted in an increased base flow throughout summer 2019. Similar to Dutch Bill Creek, but unlike Green Valley Creek, flows in 2017 were substantially higher in Mill Creek than those recorded in 2018.

From 2017 to 2019, the number of days per year that streamflow was below the connectivity threshold for the 167-day period of 5/1 to 10/15 ranged from 0 to 88 days at the lower Mill Creek gage site, and from 1 to 92 days at the upper Mill Creek gage site (Table 7). This indicates that one or more pools were disconnected for approximately 0% to 53% of the season in the lower reach over all years and from 1% to 55% in the upper reach, with the number of dry riffles generally starting lower and increasing over the dry season. Once again, these data correlated with flow, with WY2018 having the greatest number of days where pools were disconnected in both the upper and lower watershed, and 2019 having the fewest.

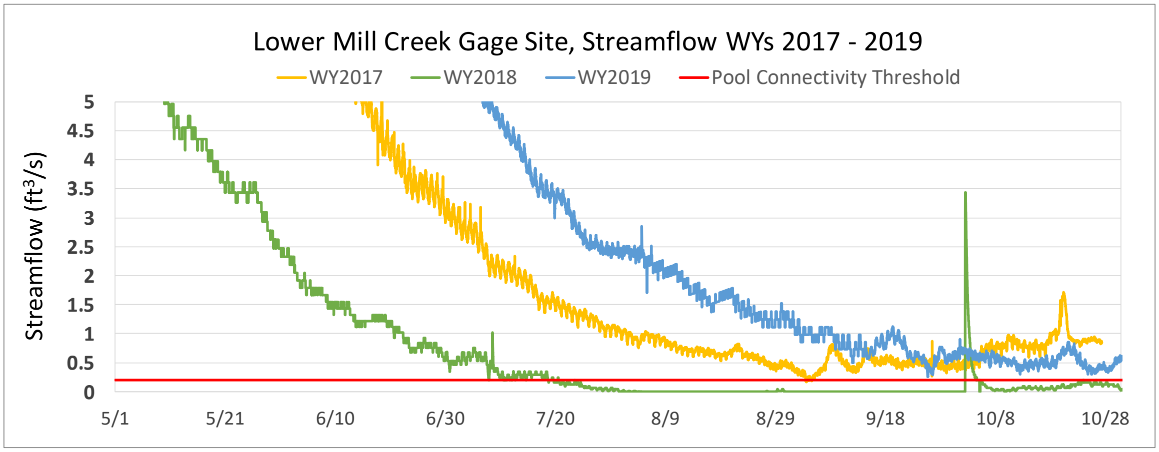

Figure 32. Streamflow recorded at TU's lower gage site in the Mill Creek watershed, and the reach-scale connectivity threshold, WYs 2017-2019. *Note change in the y-axis values from previous graphs.*

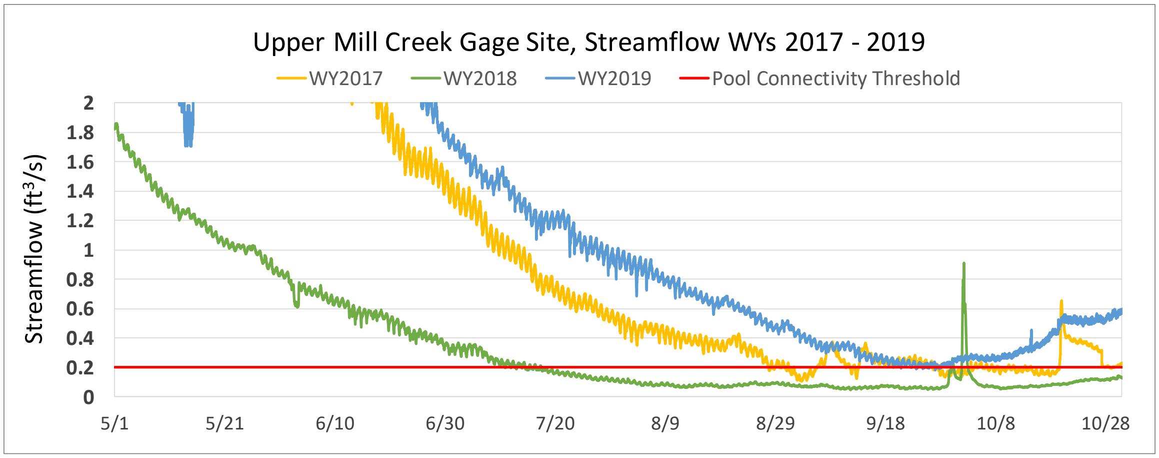

Figure 33. Streamflow recorded at TU's upper gage site in the Mill Creek watershed, and the reach-scale connectivity threshold, WYs 2017-2019.

Table 7. Number of days that streamflow was below the connectivity threshold at the upper and lower Mill Creek gage sites from 5/1-10/15 (total days = 167), WYs 2017-2019.

Stream Reach	Year	Days Below Connectivity Threshold[1]
Lower Mill Creek	2017	1
Lower Mill Creek	2018	88
Lower Mill Creek	2019	0
Upper Mill Creek	2017	24
Upper Mill Creek	2018	92
Upper Mill Creek	2019	1

[1] *Calculated by summing 15-minute intervals that streamflow was below threshold values and rounding to the nearest whole day.*

2.2.6.5. Streamflow overview and comparison among watersheds

Over the course of the 2017-2019 study period, the focus watersheds, and the greater geographic region, experienced both wet and dry water year type conditions. WY2019 experienced the highest streamflow conditions in TU's 11–year period of record. WY2018 experienced the lowest streamflow of the three-year study period, but conditions were still higher than the lowest flows during the peak of the 2012-2016 drought.

WY2018 had the lowest precipitation recorded of all three study years (Figure 5). There was significantly greater rainfall in WY2017 than in WY2019 (63 inches versus 48 inches, respectively). WY2017 was the sixth wettest year on record at the Graton station, but this did not lead to the largest volume of streamflow. WY2019 had the greatest streamflow—not only of the study period but of TU's 11-year period of record. This was likely influenced by precipitation timing; in 2017, just 0.38 inches of rainfall occurred after April 30 (until September), while in 2019, 4.04 inches fell in late May (Figure 6). In addition, we surmise this may be partially due to WY2017 being the first year of increased rainfall following the historic drought of 2012-2016, and much of the water replenished depleted groundwater aquifers rather than increasing surface flow. This phenomenon was observed in TU's gage records throughout the region. In Dutch Bill and Mill creeks, flows in 2017 were substantially higher than those recorded in 2018, while in Green Valley Creek they were only slightly higher, indicating that this effect was more pronounced in Green Valley Creek than in the other streams (Figure 34).

In general, streamflow conditions among the three watersheds were fairly similar. During the 2017-2019 study period, total summer discharge was consistently highest at the lower Mill Creek gage site and lowest at the upper Green Valley gage site (Figure 34). At all gage sites, streamflow was highest in WY2019 and lowest in WY2018. All study reaches experienced flows below the connectivity threshold over the project period, and this varied significantly by reach and year (Table 5-Table 7). The upper Green Valley Creek study reach experienced the greatest number of days below the connectivity threshold, followed by the lower Dutch Bill Creek study reach.

The gage sites in lower Dutch Bill and lower Mill creeks exhibited the greatest difference in total summer discharge between the driest and wettest years of 2018 and 2019, and both of those streams had greater variation in flow conditions overall. Gage sites in the Green Valley Creek watershed showed the smallest difference in total summer discharge between all water years. In addition, both Dutch Bill and Green Valley creeks' flow regimes were altered by flow releases that occurred in the watersheds during the study period, resulting in at least slightly higher discharge than what would have occurred naturally in all three years for Green Valley Creek and in 2018 and 2019 in Dutch Bill Creek.

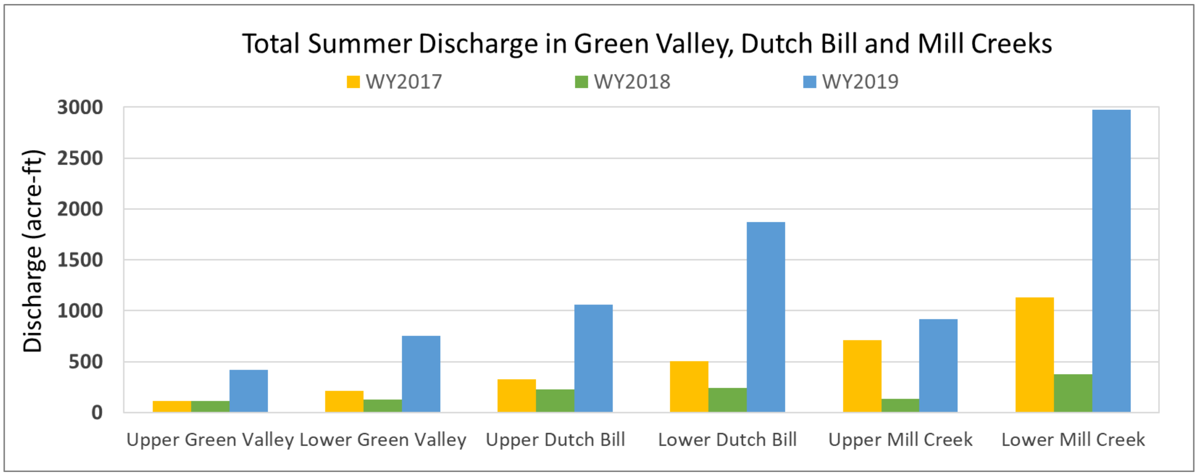

Figure 34. Total summer discharge at the upper and lower Dutch Bill, Green Valley, and Mill creek gage sites, WYs 2017-2019.

2.2.7. Water quality

In addition to the spot measurements of DO collected during wet/dry mapping surveys in the summers of 2017-2019 (https://bit.ly/WettedHabitatProtocol), continuous water quality data, including DO and water temperature, were collected in Dutch Bill, Green Valley, and Mill creeks between June and October each year. Two pools were selected in each stream to represent conditions in both the lower extent of the survey reaches (referred to as the "lower" site in each stream) and the upper extent of the survey reaches (referred to as the "upper" site in each stream), for a total of six sites (**Figure 35**). The intention was to represent reach-scale conditions with limited instrumentation, but it should be noted that DO concentrations can vary among and even within habitat units, particularly when streamflow is at or near disconnection from surface flow.

Onset U26 DO loggers were deployed at these sites to measure DO concentrations and water temperature at 15-minute intervals over the dry season. Loggers were field calibrated at biweekly intervals. At the end of the study period, the loggers were downloaded and DO data were adjusted for drift with field calibration values using HOBOware software. The corrected data were then exported to Microsoft Excel and uploaded to a SQL database. The exception was with the upper Green Valley reach data in 2019, because the logger at that site experienced technical failure. DO and water temperature data from all sites for the summers of 2017-2019 were submitted to the California Environmental Data Exchange Network in December, 2019.

To evaluate summer water quality conditions, continuous DO data for all years were compared to the Regional Water Quality Control Board's minimum daily DO objective for the North Coast of 6.0 mg/L (NCRWQCB 2011), as well as the observed salmonid mortality threshold of 3.0 mg/L (McMahon 1983). The percentage of all 15-minute samples that met the 6.0 mg/L regional objective between June 16 and October 14 was calculated for each stream reach and year.

The Mill Creek and upper Dutch Bill creek gaging sites generally had the highest DO concentrations over the study period, (Table 8, Figure 36-Figure 38). In the upper Mill Creek reach, DO met or exceeded the regional objective 99-100% of the time in all three summer seasons. The upper Dutch Bill study site also had optimal DO concentrations more than 90% of the time (91-100%), followed by lower Mill, where 100% of the 15-minute samples met or exceeded the regional DO objective in 2017 and 2019, dropping to 85% in 2018. Both Mill Creek reaches generally had the fewest number of days of streamflow below connectivity thresholds, as compared to the other reaches, followed by upper Dutch Bill Creek (Table 5-Table 7), which may have contributed to the comparatively high-quality conditions exhibited in the study pools in those reaches.

The lower Dutch Bill, and lower and upper Green Valley Creek sites all experienced DO concentrations below the regional objective for more than 25% of recorded samples in both 2017 and 2018. In 2017, both of the reaches of Mill Creek remained stable and maintained DO concentrations above the regional objective 100% of the time, but sample sites on Dutch Bill and Green Valley creeks experienced large DO fluctations over the study period (Figure 36). Also, concentrations of 0 mg/L were observed in Dutch Bill and Green Valley creeks in 2017, the only year in which this occurred. While conditions in 2018 were still generally favorable for salmonids in Mill and upper Dutch Bill creeks, it was the only year that the Mill Creek study sites experienced daily minimum DO concentrations below the objective (both sites), or below the mortality threshold (lower Mill Creek only) (Table 8, Figure 37). It is unclear why an anamolous, substantial drop in DO occurred in the lower Mill Creek site in late-August 2018 (Figure 37), but it is possible that it could have been due to an input into the stream channel, as it lasted for a relatively short period and was not experienced at the other gaging sites.

DO concentrations across all streams were highest in 2019 and were lower and more variable between streams during the summer of 2017. In all years, DO met the regional objective more than 50% of the June 16-October 14 period in every reach (Table 8, Figure 36-Figure 38). When averaged across all sites by year, 78% of all continuous samples met the DO objective in 2017, 81% in 2018, and 99% in 2019. This is interesting in that streamflow was substantially greater in 2017 than in 2018 in all reaches except for upper Green Valley Creek (Figure 34), yet DO outcomes were very similar.

Lowest daily minimum DO concentrations occurred in August and September of all years. In 2018 and 2019, all streams followed a similar trend; daily minimum concentrations were above 6.0 mg/L until the end of July, then became more variable between streams until the first two weeks of October (Figure 37, Figure 38). This increased variability is likely explained by a combination of reduced flow and increased temperatures, an effect that is minimized by the higher streamflow and lower temperatures that correspond to seasonal shifts in evapotranspiration and ambient temperatures in early fall.

Temperature data were compared to the optimum coho salmon summer water temperature range of 10°-15°C described by the U.S. Fish and Wildlife Service (McMahon 1983). At water temperatures greater than 20°C, significant decreases in swimming speed and increases in mortality due to disease have been noted to occur (McMahon 1983). Since coho salmon in Russian River study streams are at the southern end of the species' geographic range, it's possible that local fish may be adapted to warmer temperatures; however, more investigation is needed to define watershed-specific tolerance levels, so the documented thresholds of 20°C and 15°C were used. The maximum weekly maximum temperature (MWMT) and maximum of weekly average temperature (MWAT) (Dunham et al. 2005) were calculated using code adapted from the USFS Rocky Mountain Research Station (Chandler n.d.; Isaak et al. 2010).

Daily maximum water temperature in all study sites and years commonly exceeded the optimal range for salmon, but were below the 20°C tolerance range 98-100% of the time in all reaches except for lower Mill Creek, which had a range of 82-90% of 15-minute samples below 20°C (Table 8, Figure 39-Figure 41). Temperatures were generally similar between years, but 2017 had the most days above 20°C and 2018 had the fewest days above the 20°C threshold, when averaged across all sites. This may have been influenced by ambient conditions, but air temperature data were not collected or evaluated through this study.

The maximum weekly maximum temperature (MWMT) and maximum of weekly average temperature (MWAT) values were calculated and show that 2017 was the warmest of the three study seasons (Figure 42, Figure 43). MWMT was below 20°C 100% of the time in 2018 in all of the study reaches, with the exception of the lower Mill Creek reach. The MWMT and MWAT were highest in Mill Creek for all years, indicating reduced temperature-resilience, particularly in the lower reach. Across all reaches, lower Mill Creek stands out as the least temperature-resilient, as it generally had the highest maximum water temperatures of all reaches and the highest proportion of samples with maximum daily temperatures above 20°C (Table 8, Figure 39-Figure 41).

Between the wetter-than-average summer seasons in the study period (2017 and 2019), 2017 had a much higher proportion of DO concentrations below 6 mg/L, as well as the highest percentages of temperatures exceeding 20°C (Table 8). It is likely that warmer water temperatures contributed to lower DO this year, as DO and temperature share an inverse relationship. In our experience, however, it seems as though temperature more commonly amplifies poor DO conditions under streamflow conditions lower than those observed in 2017. The regionally-low DO concentrations observed in 2017—in many cases even lower than in the much drier summer of 2018—suggests that streams may be experiencing a legacy effect on water quality conditions from the 2012-2016 drought; however, more investigation into that assumption is needed. This appears to align with TU's finding that substantially more rain at the Graton, CA weather station in WY2017 did not translate into the anticipated volume of streamflow (Figure 5, Figure 34).

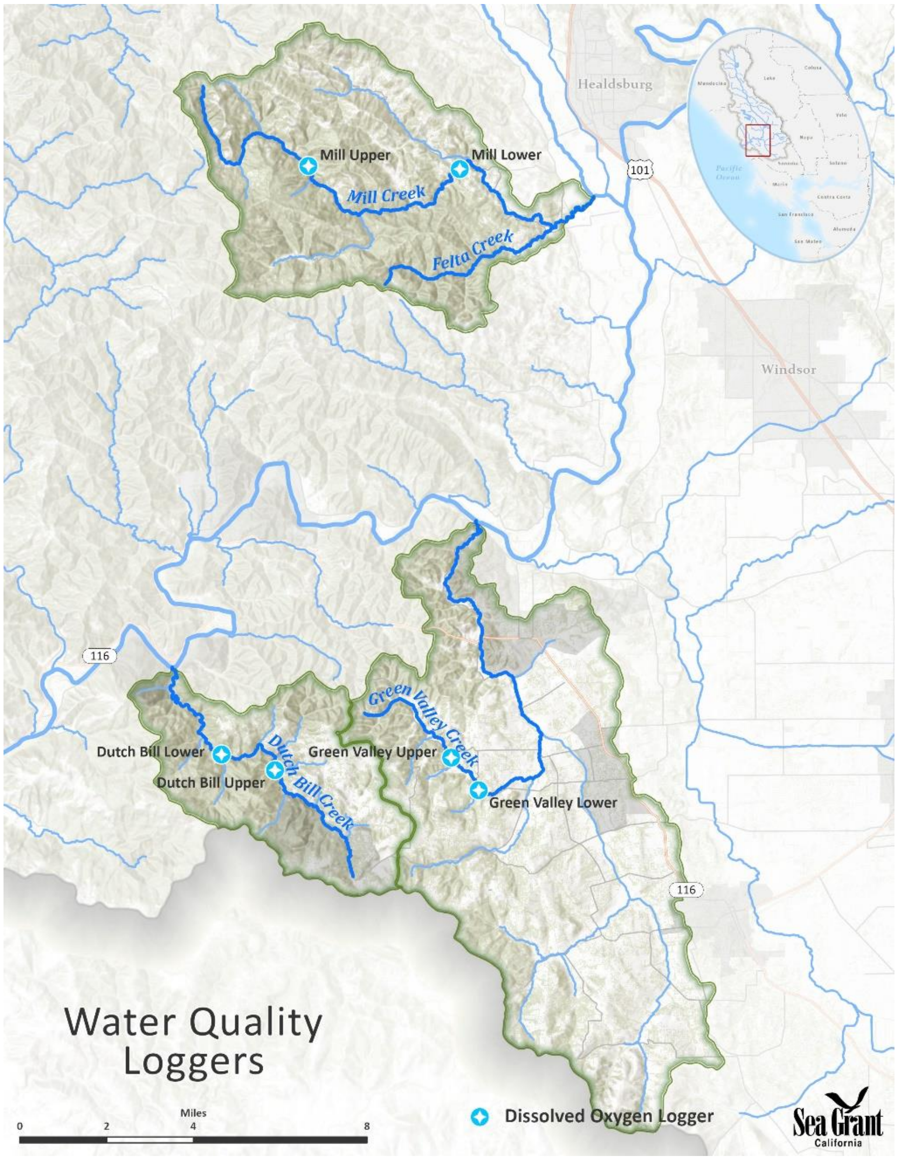

Figure 35. Dissolved oxygen logger sites in Dutch Bill, Green Valley, and Mill creeks. These loggers also recorded water temperature data.

Table 8. Location of water quality loggers and percentage of all 15-minute water temperature and DO samples that met suitability criteria between June 16 and October 14, years 2017-2019.

			2017		2018		2019	
Stream	Study Reach	River Kilometer[1]	% Time Temperature Suitable[2]	% Time DO Objective Met[3]	% Time Temperature Suitable[2]	% Time DO Objective Met[3]	% Time Temperature Suitable[2]	% Time DO Objective Met[3]
Dutch Bill	Lower	3.87	100%	57%	100%	75%	100%	96%
Dutch Bill	Upper	6.51	99%	91%	100%	97%	100%	100%
Green Valley	Lower	12.16	98%	61%	99%	61%	100%	97%
Green Valley	Upper	13.40	99%	59%	100%	71%	N/A	N/A
Mill	Lower	6.10	82%	100%	91%	85%	90%	100%
Mill	Upper	12.39	100%	100%	100%	99%	100%	100%

[1] *Approximate distance upstream of mouth along stream channel.*

[2] *Within the salmon tolerance range of ≤ 20 ° C.*

[3] *Meets the regional objective of ≥ 6 mg/L daily minimum DO concentration, rounded to the nearest percentage.*

[4] *Above lab-observed salmonid mortality threshold of 3 mg/L.*

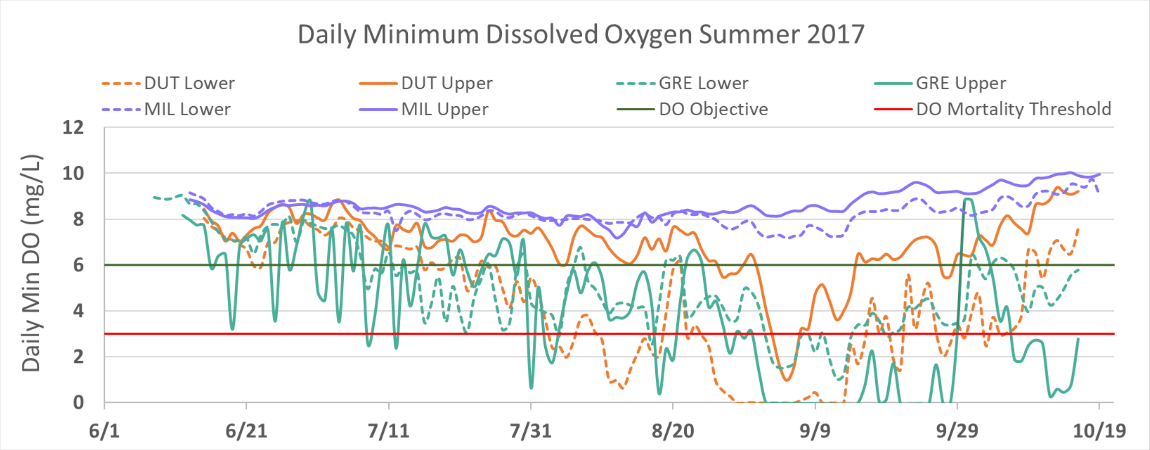

Figure 36. Daily minimum dissolved oxygen concentrations in the Dutch Bill, Green Valley, and Mill creek study pools, plotted with regional daily minimum DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L), June-October 2017.

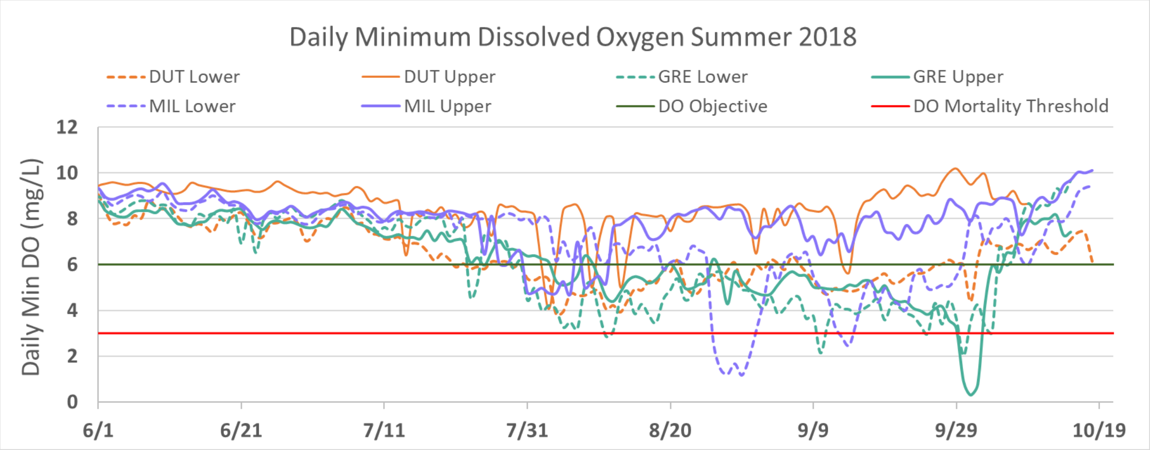

Figure 37. Daily minimum dissolved oxygen concentrations in the Dutch Bill, Green Valley, and Mill creek study pools, plotted with regional daily minimum DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

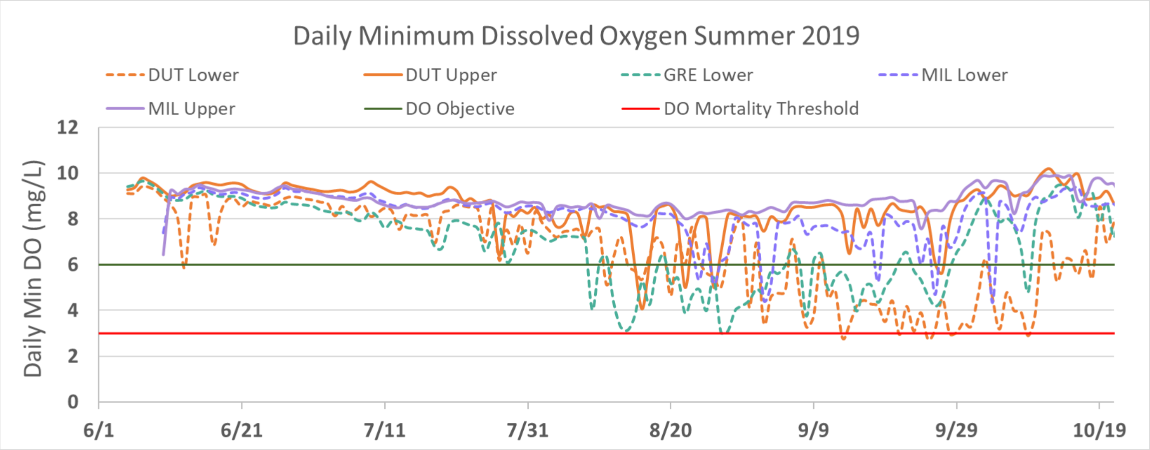

Figure 38. Daily minimum dissolved oxygen concentrations in the Dutch Bill, Green Valley, and Mill creek study pools, with the exception of Upper Green Valley, plotted with regional daily minimum DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

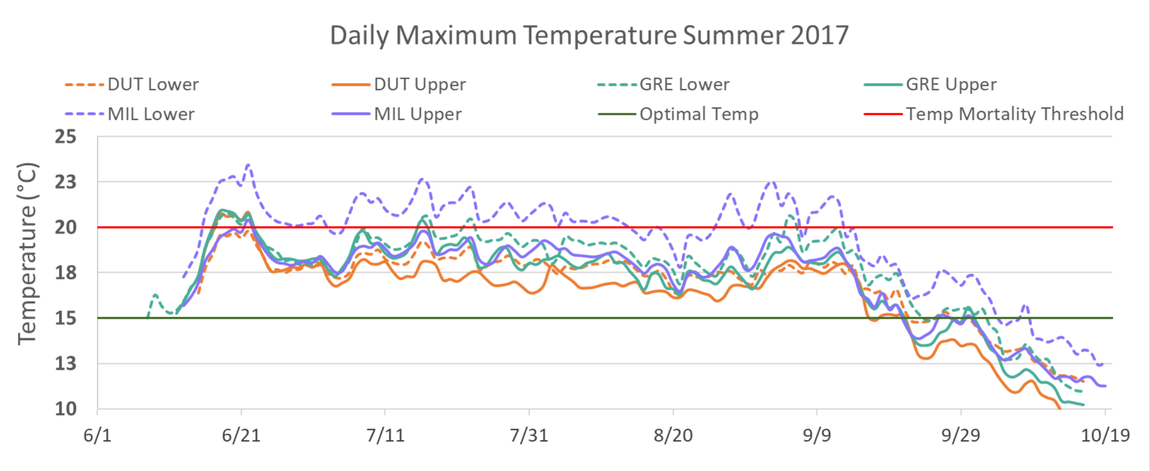

Figure 39. Daily maximum water temperature in the Dutch Bill, Green Valley, and Mill creek study pools, plotted with optimal temperature (15°C) and salmonid mortality threshold (20°C).

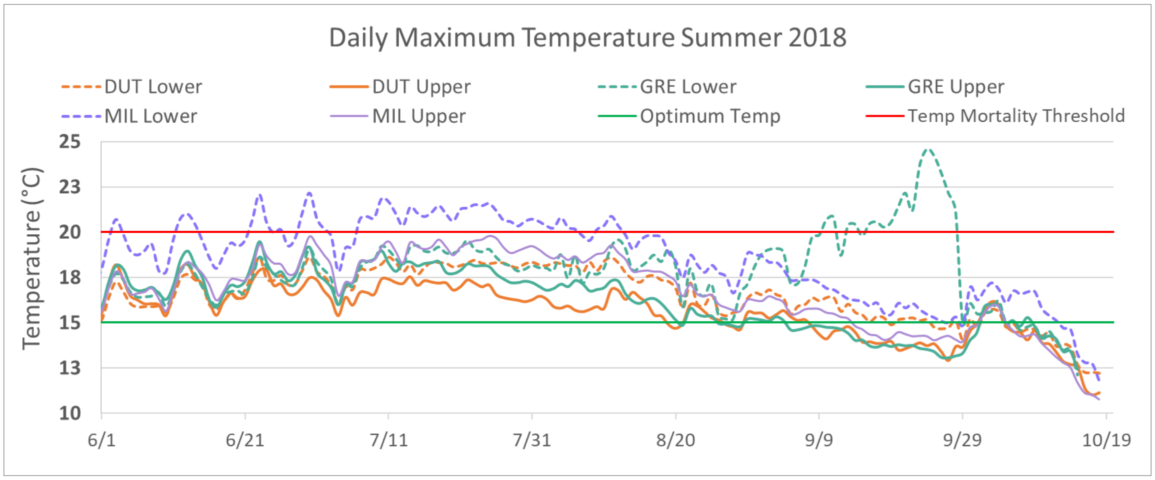

Figure 40. Daily maximum water temperature in the Dutch Bill, Green Valley, and Mill creek study pools, plotted with optimal temperature (15°C) and salmonid mortality threshold (20°C).

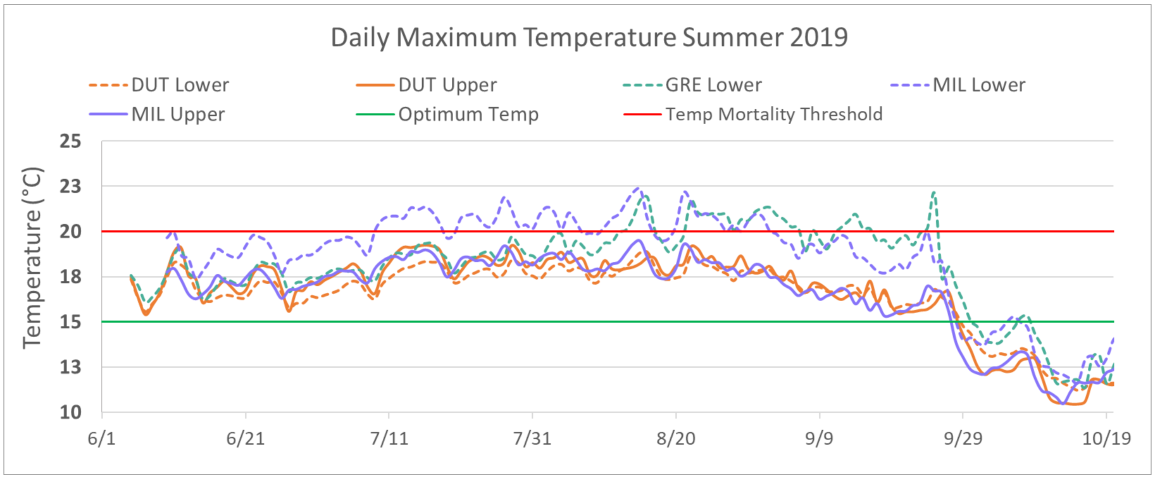

Figure 41. Daily maximum water temperature in the Dutch Bill, Green Valley, and Mill creek study pools, plotted with optimal temperature (15°C) and salmonid mortality threshold (20°C). Upper Green Valley Creek data were not included due to logger failure.

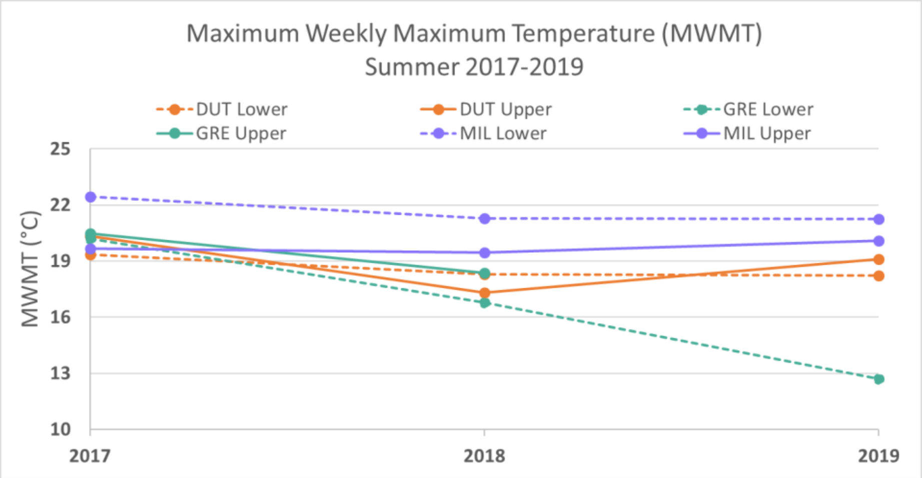

Figure 42. Maximum weekly maximum temperature (MWMT) for the Dutch Bill, Green Valley, and Mill creek reaches, June-October 2017-2019.

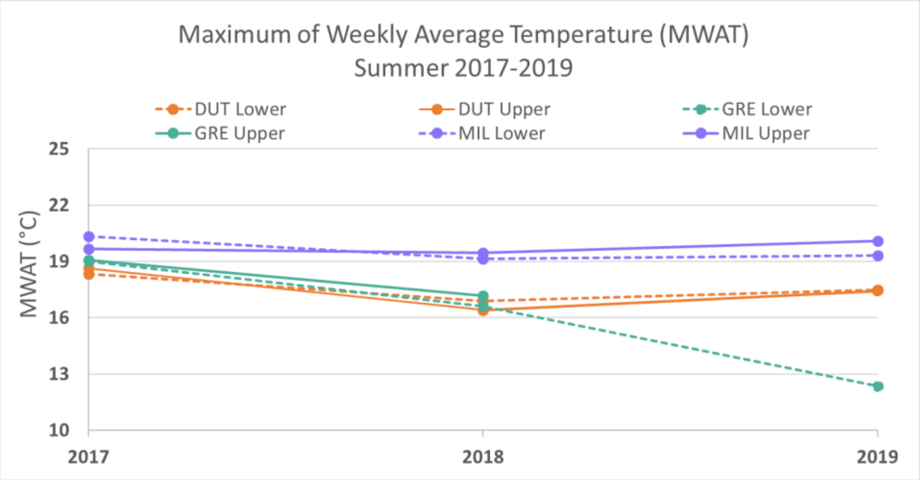

Figure 43. Maximum of weekly average temperature (MWMT) for the Dutch Bill, Green Valley, and Mill creek reaches, June-October 2017-2019.

2.2.8. Flow release evaluation

The study streams at the focal point of this project, like many other tributaries to the Russian River, typically become intermittent in early- to mid-summer and in drought years as early as late-spring. Since 2015, small-scale flow releases from private or municipal sources have been used in Green Valley and Dutch Bill creeks to augment streamflow during the dry summer months. These efforts emerged as a management tool during the peak of the drought, when landowners and multiple supporting organizations, including the Coho Partnership and local resource agencies, came together to provide relief for rearing juvenile salmonids. Once their ability to improve habitat and water quality conditions became evident, flow releases gained traction as an effective, short-term flow and habitat improvement tool and their use has continued.

Instream flow augmentations can yield beneficial effects when timed appropriately. However, due to the limited amount of water available for release and the dynamic nature of stream drying under variable climatic conditions, the timing, duration, and rate of each release must be determined strategically in order to maximize beneficial impacts. Stream habitat units typically exhibit a downward trend in surface flow connectivity and DO concentrations over the summer season; but the date at which disconnection occurs and DO falls below fish impairment levels varies annually, depending on weather as well as local conditions. In Russian River tributaries, the number of days a pool is disconnected from surface flow is a strong driver of juvenile coho salmon survival and the lowest rates of survival have been observed between late-August and mid-September, when conditions are driest (Obedzinski et al. 2018). Studies like this help to inform the science of how small-scale flow releases can be used most effectively to improve the probability of fish survival.

While it was not a specific deliverable under this grant, CSG researchers recognized that the data being collected through this project offered a valuable opportunity to provide insight into flow release strategies and effectiveness evaluation in streams where WCB-funded monitoring and releases were co-occurring, and that this fit well under the project objective to inform flow improvement efforts. We used data from the biweekly wet/dry mapping efforts implemented through this grant to inform partners facilitating the Dutch Bill and Green Valley creek flow releases in regards to release needs and timing. The frequent wetted habitat surveys allowed us to identify the onset of water quality impairment and the most appropriate timing of flow releases to maximize beneficial impacts of the limited augmentation water. We maintained ongoing communication with managers and alerted them when conditions began to worsen, but before they became critical for salmonids.

Three flow releases were implemented during the three-year study period—one on Dutch Bill Creek in 2018 and 2019, and two on Green Valley Creek in all study years (Figure 44, Figure 45, Table 9). While the releases ranged from just 0.02-0.10 ft^3/s, this volume often comprised a substantial proportion of the summer base flow prior to release implementation (Figure 46).

To evaluate the success of these flow releases, streamflow, surface flow connectivity, riffle crest thalweg (RCT) depth, DO, and water temperature were examined before and after release initiation. Discrete measurements of DO, water temperature, and RCT depth collected during the wet/dry surveys, along with the wetted habitat maps, were used to inform release timing and to assess in-season effectiveness. At the end of the monitoring season, continuous streamflow data generated from select stage logger (a.k.a. flow gage) sites and water quality data from select DO logger sites (Figure 44, Figure 45) were used to quantify and evaluate impacts of the streamflow augmentations. The methods for these efforts, including descriptions of instruments used and data adjustment processes, are described in the ***Streamflow and connectivity*** and ***Water quality*** sections of this report.

Adjusted continuous DO data were plotted in relation to the regional daily minimum DO objective of 6.0 mg/L (NCRWQCB 2011) and the 3.0 mg/L documented mortality threshold for coho salmon (McMahon 1983). While it is not included in the plots, it should be noted that maintaining DO concentrations greater than 5.0 mg/L can maintain food consumption, growth, and swimming efficiency in juvenile salmonids (Bjornn and Reiser 1991; Herrmann et al. 1962). Temperature data were compared to the optimal juvenile coho salmon water temperature range of 10°-15°C, and 20°C, the temperature at which significant decreases in swimming speed and increases in mortality due to disease have been observed (McMahon 1983). RCT depths were compared to 0.20 ft, a depth at which declines in water quality can become detrimental to juvenile salmonids (Nossaman Pierce et al. 2019).

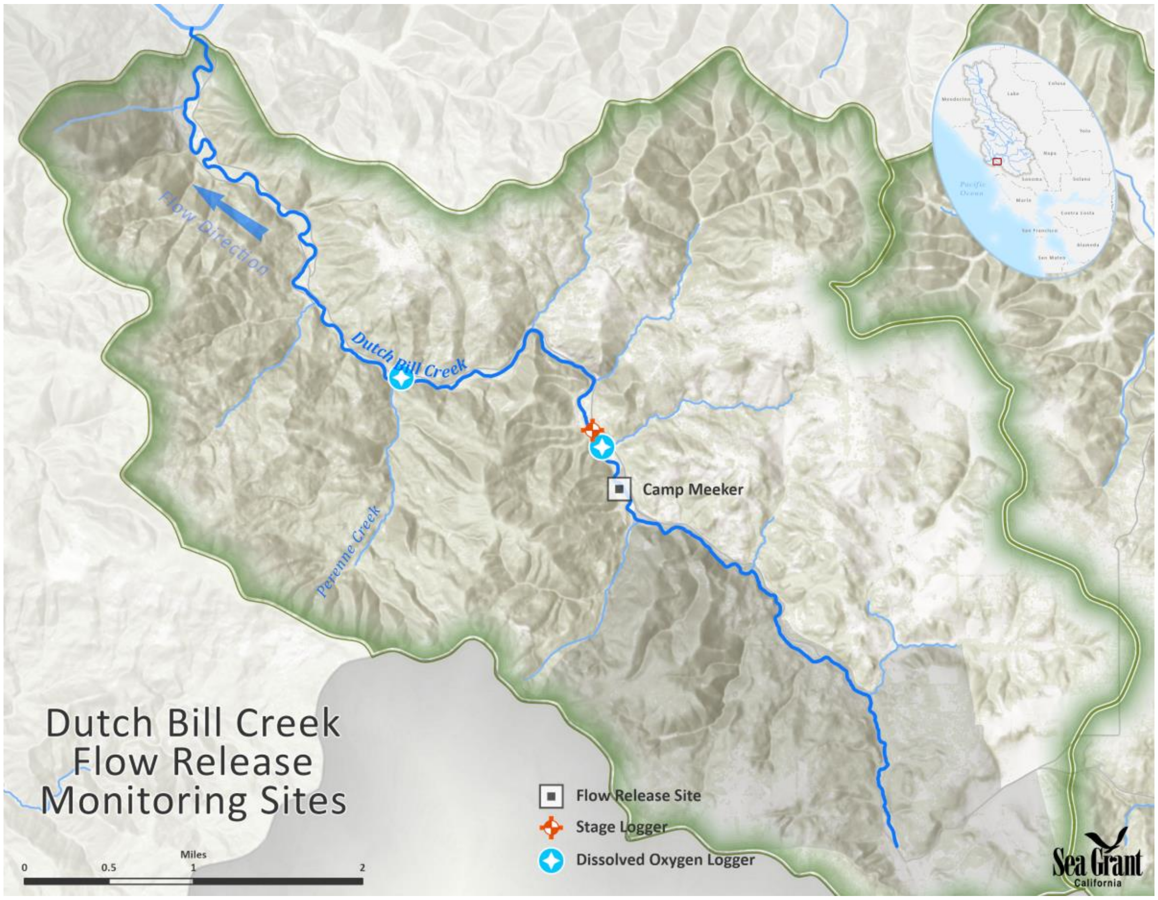

Figure 44. The Camp Meeker (CMRPD) flow release site, and stage (flow) and water quality (DO and temperature) loggers used to monitor release effects in Dutch Bill Creek, years 2018-2019.

Figure 45. The Jackson Family Wines (JFW) and Green Valley Farms (GVF) flow release sites, and stage (flow) and water quality (DO and temperature) loggers used to monitor release effects in Green Valley Creek, years 2017-2019.

Table 9. Approximate location of flow release sites in Dutch Bill and Green Valley creeks, and release start dates, 2017-2019.

				2017		2018		2019	
Stream	**Flow Release**	**Water Source**	**Rkm**[1]	**Start Date**	**Avg. Rate (ft^3/s)**[2]	**Start Date**	**Avg. Rate (ft^3/s)**[2]	**Start Date**	**Avg. Rate (ft^3/s)**[2]
Dutch Bill	Camp Meeker (CMRPD)	Municipal	7.48	N/A		8/29	0.09	8/19	0.07
Green Valley	Jackson Family Wines (JFW)	Off-channel pond	12.83	9/28	0.1	8/20	0.1	8/16	0.1
Green Valley	Green Valley Farms (GVF)	Off-channel pond	16.37	9/29	0.05	8/29	0.02	9/17	0.05

[1] *Approximate river kilometers upstream of mouth along stream channel.*

[2] *Average flow rates are approximated over the release period.*

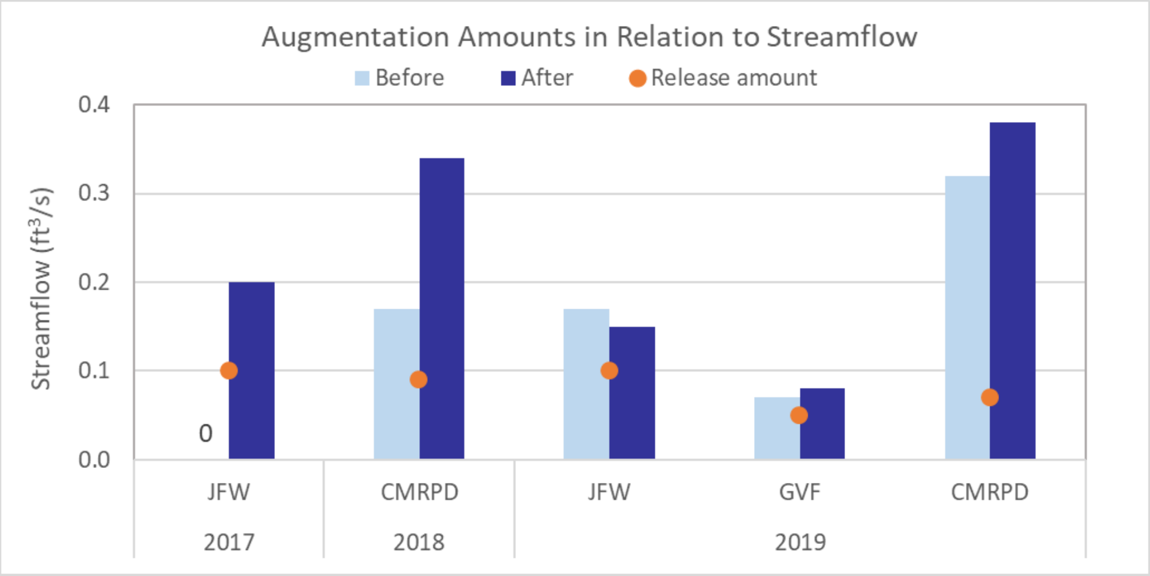

Figure 46. Streamflow at the nearest downstream gage one day prior to flow releases, four days after release initiation, and the average rate of water released at each site by year. At CMPRD in 2018, flow was impacted by a fire hydrant break that contributed an unknown but relatively substantial amount of additional water for a short period of time.

2.2.8.1. Camp Meeker release, Dutch Bill Creek

The Dutch Bill Creek flow release originated from the Camp Meeker Recreation and Parks District (CMRPD) municipal water source at approximate rkm 7.48 (Figure 44, Figure 47). It was initiated in mid-to-late August in 2018 and 2019 (Table 9), shortly after stream connectivity and water quality began to decline at the end of July. No release occurred in 2017 due to wet antecedent conditions. An average rate of 0.09 ft^3/s was released until the end of November 2018 without interruptions. In 2019, and average rate of 0.07 ft^3/s was released beginning in mid-August and continued until early-December, though there was a week-long halt in releases as a result of Kincade Fire in October. The average volume of water released, though small, was equivalent to 45% of the prior day's average flow in 2018 and 19% in 2019 (Figure 46). Data from a TU gage and two CSG water quality loggers downstream of the release point were used to assess impacts to streamflow, DO, and water temperature (Figure 44).

In early August 2018, streamflow at the upper Dutch Bill Creek stage logger/gage site (Figure 44), was essentially zero, but increased slightly by mid-month (Figure 48) due to water released from a broken fire hydrant. We do not know the quantity or duration of that input, and it was not possible to discern the effects of this incidental addition of water separately from the augmentation amount of 0.09 ft^3/s, but it appears that the hydrant water had a "priming" effect on the stream. The day before the August 29 release was initiated, average flow was 0.20 ft^3/s, and one day after initiation daily average flow was 0.38 ft^3/s, a proportional increase of 90%. Streamflow peaked at 0.42 ft^3/s on September 5, and when the rate of augmentation was reduced to 0.04 ft^3/s on September 10, 2018, flow at that site immediately dropped to 0.05 ft^3/s, indicating that the augmentation was providing the majority of the measured surface flow at the driest part of the summer. When the flow augmentation was resumed several days later, streamflow immediately increased again.

The increase in streamflow resulting from the initial flow augmentation translated into an increase in surface flow connectivity downstream of the release point. Prior to the release, there were sections of dry and intermittent stream channel between the release point and the confluence with Perenne Creek, approximately 3 rkm downstream. The discharge measurement transect above Perenne Creek was documented as dry on the

August 14, 2018 wet/dry survey, two weeks before release initiation. By September 25, the transect was rewetted and had measureable flow, and only one point of intermittency remained between the release point and Perenne Creek.

Beneficial impacts to water quality were also observed at the study sites 500 m and 3,000 m downstream of the release point in 2018 (Figure 48). DO was relatively stable compared to other streams at the same time of year, possibly due to the bedrock underlying these reaches of Dutch Bill Creek, which has been shown to maintain favorable water quality and stream connectivity conditions when compared to other types of underlying geology (May and Lee 2004; Nossaman Pierce et al. 2019; Obedzinski et al. 2018). DO at the lowest monitoring site was decreasing at the beginning of August and frequently dropping below the 6.0 mg/L regional objective, but conditions were improved by the fire hydrant water and the flow release, and higher DO concentrations were generally maintained throughout the season, during a time when they would typically be declining.

In 2018, the augmentation caused DO in the logger pool 500 m downstream to increase to concentrations greater than 8 mg/L for the majority of the release period (Figure 48)—values that are typically observed in these tributaries in the spring and winter months, prior to streamflow recession. In addition to providing water quality benefits, the 2018 Dutch Bill Creek augmentation increased pool volume and maximum depth at both study sites, though the increases were more pronounced at the upstream site closer to the release (Figure 49). Greater pool volume and maximum depth have both been shown to be beneficial to juvenile salmonid over-summer survival (Grantham et al. 2012; May and Lee 2004; Obedzinski et al. 2018; Vander Vorste et al. 2020; Woelfle-Erskine et al. 2017).

Water temperatures at the lower study site, 3,000 m downstream, were slightly warmer than at the upper study site and peaked at 16.8°C on September 2, 2018, then proceeded to decline at both sites for the duration of the season (Figure 50), which could be explained by a combination of release impacts and the seasonal shift towards cooler weather. There were no observed detrimental impacts to water temperature caused by the flow augmentation in 2018. Overall, this flow release appeared to improve and sustain favorable conditions for juvenile salmonids until the rain event in early October which marked the shift to late-fall and early winter stream conditions.

In 2019, subtle improvements to streamflow were recorded a few days before the August 19 release for unknown reasons (Figure 51). Despite this, the augmentation appeared to result in a more substantial increase in flow. Average daily streamflow at the upper Dutch Bill Creek stage logger site one day prior to the release was 0.36 ft^3/s. The following day, it increased to 0.47 ft^3/s and remained between approximately 0.40 ft^3/s and 0.50 ft^3/s through September 25, when the augmentation was reduced. Similar to 2018, the decrease in release amount was reflected by a sudden, noticeable drop in the hydrograph, indicating that the augmentation was substantially contributing to streamflow. There were no disconnection points downstream of the release within the extent of stream anticipated to benefit from this augmentation, so there was no documented change to stream connectivity. It is likely that the release may have helped to support continued connectivity, but there was no method of determining this.

Improvements in water quality were also noted at the Dutch Bill Creek study sites 500 m and 3,000 m downstream beginning three days prior to the 2019 release, for reasons unclear to us (Figure 51). The augmentation appeared to support continued improvements. At the site closer to the release point, 500 m downstream, DO increased in the days following the release and higher concentrations were maintained until the release amount was decreased on September 25. The decrease in release rate was followed by a quick decline in DO concentrations before a small rain event in early October improved water quality. At the lower site, high DO concentrations persisted through mid-September when the daily minimums began to experience more extreme lows, a change that corresponded with a decrease in average RCT depths collected during routine wet/dry surveys. The augmentation water, after traveling almost 3,000 m downstream, had a stabilizing effect on DO, halting the downward trend observed the second week of August. Daily average and daily maximum DO values were similar at this site before and after the release, though between August 19 and September 25, approximately half of the days experienced DO minimums less than 6.0 mg/L, and three of the days experienced daily minimums less than 3.0 mg/L. The range of water temperatures at each site were generally similar before and after the release, though they began to decrease several weeks after release initiation, likely due to a seasonal shift to cooler weather (Figure 52).

Overall, the CMPRD flow releases into Dutch Bill Creek were successful in improving habitat conditions for fish in both years. In 2018, the release reconnected dry sections of creek and increased streamflow by almost 100%. In 2019, the augmentation, though relatively small in volume, improved RCT depths and helped to maintain daily average DO concentrations beneficial for rearing juvenile salmonids as far as 3 rkm downstream, with the most notable beneficial impacts closest to the release point. There were no negative impacts to water temperature in either year. These results indicate the flow releases, when timed appropriately, have beneficial impacts even in wetter-than-average years.

Figure 47. Dutch Bill Creek flow release point, August 2019.

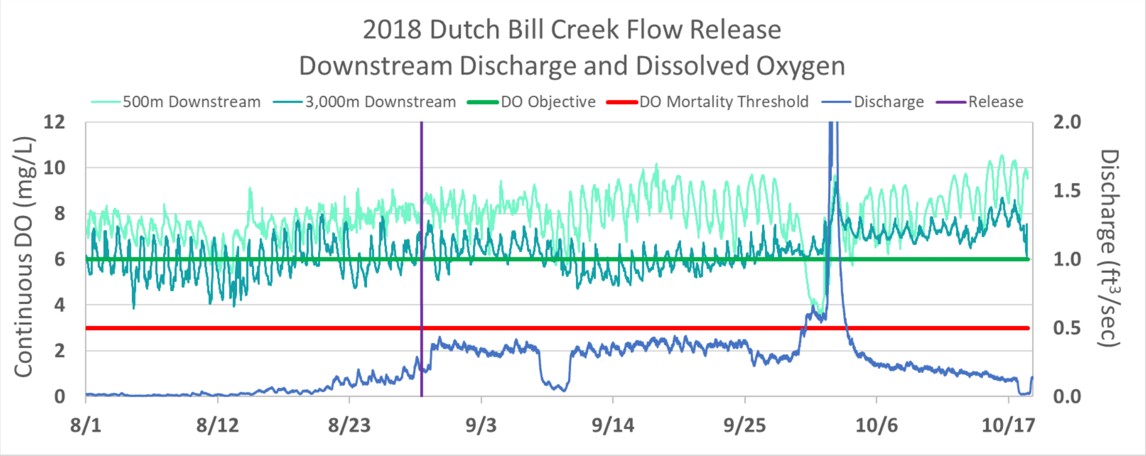

Figure 48. Discharge at the upper Dutch Bill gage site, and continuous dissolved oxygen 500 m and 3,000 m below the release plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L). Flow increases prior to the release date caused by a fire hydrant break.

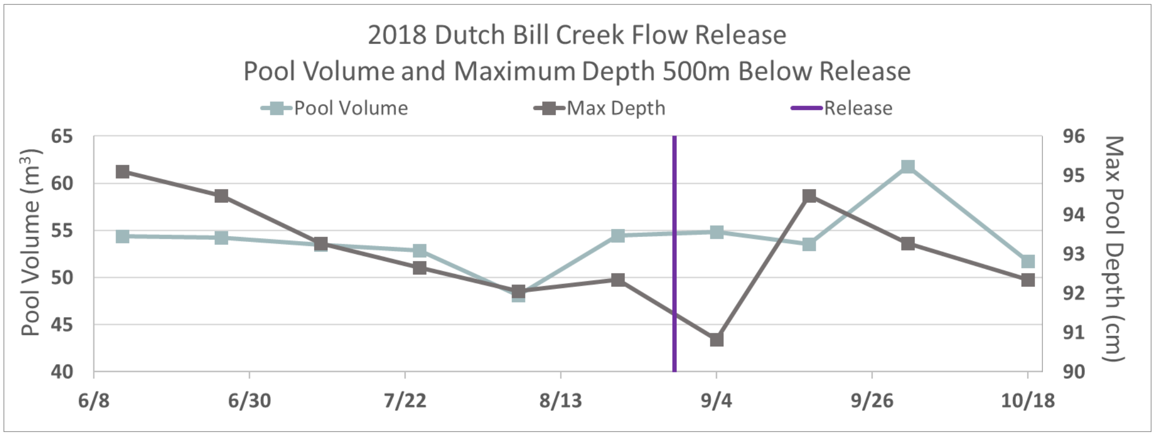

Figure 49. Pool volume and maximum pool depth at the upper Dutch Bill Creek study site 500 m below the flow release. Increases in volume and depth prior to the release caused by a fire hydrant break.

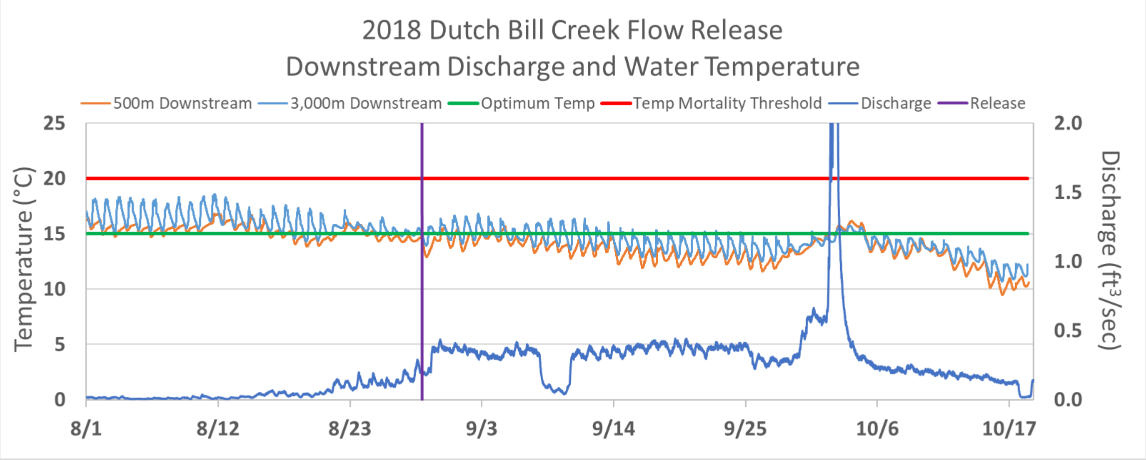

Figure 50. Discharge at the upper Dutch Bill gage site, and continuous water temperature 500 m and 3,000 m below the release plotted with optimal temperature for juvenile coho salmon (15°C) and the threshold for mortality (20°C). Note that a broken fire hydrant resulted in flow increases prior to the release date.

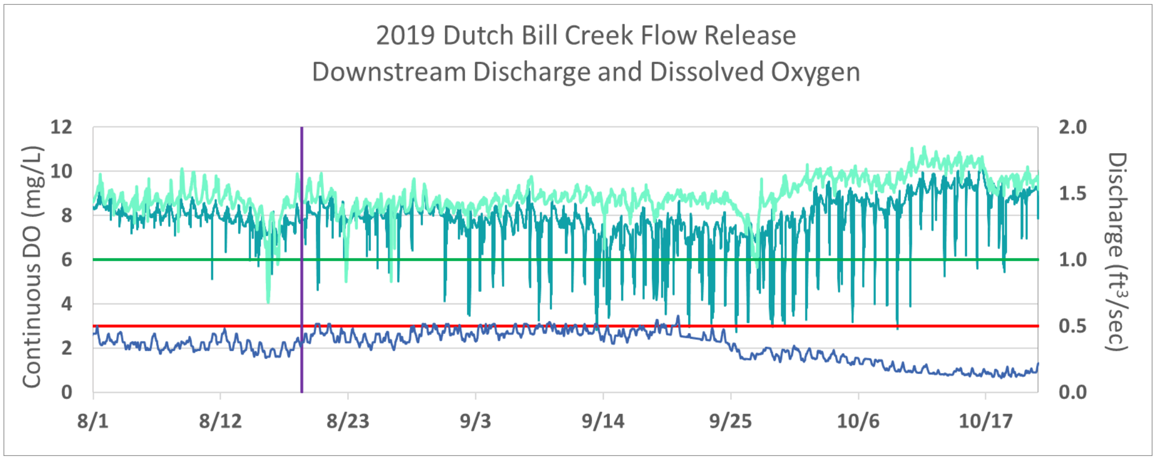

Figure 51. Discharge at the upper Dutch Bill gage site, and continuous dissolved oxygen 500 m and 3,000 m below the release plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

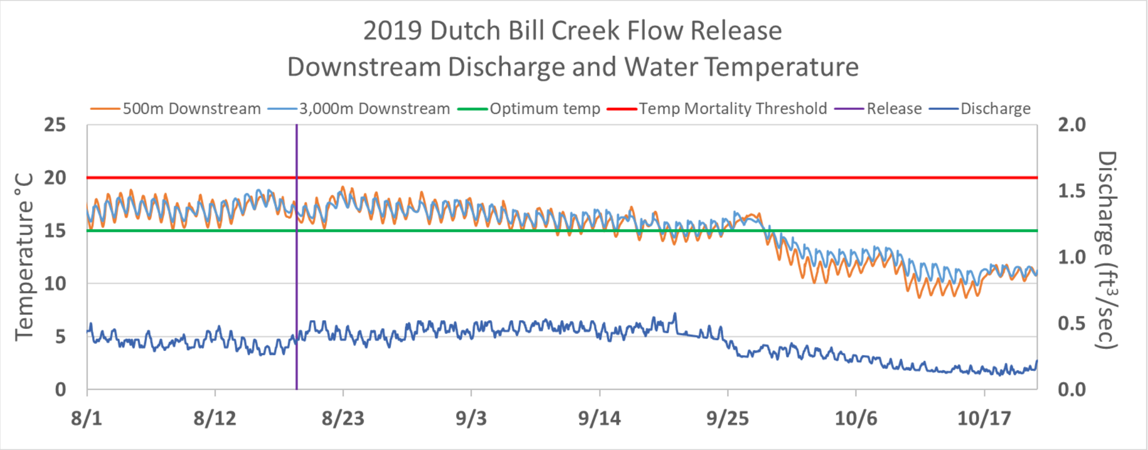

Figure 52. Discharge at the upper Dutch Bill gage site and continuous water temperature 500 m and 3,000 m below the release plotted with optimal temperature for juvenile coho salmon (15°C) and the threshold for mortality (20°C).

2.2.8.2. Jackson Family Wines release, Green Valley Creek

The lower of the two releases implemented on Green Valley Creek was located at approximate rkm 12.83 on the Jackson Family Wines property and will be referred as the JFW release (Figure 45, Table 9). This augmentation, which was sourced from an off-channel storage pond, occurred in each summer of the study period. To limit water loss due to evaporation, reduce water temperatures, and extend the duration of the augmentation, the water was strategically released for 12 hours a day, from 6:00 PM to 6:00 AM.

Originally, there was no release planned at the JFW site in 2017 due to wetter-than-normal winter conditions but, as the dry season progressed, CSG biologists documented worsening stream connectivity and water quality conditions in areas where more than 3,700 juvenile coho salmon and steelhead trout had been observed during the June CMP snorkel surveys. By mid-September 2017, discrete measurements of DO collected on the wet/dry surveys averaged 3.90 mg/L and 65% of the pools sampled were below salmonid impairment levels. On the stream-scale, thousands of juvenile salmonids were facing potential mortality, stress, disease, and impairment to feeding, growth, and swimming ability caused by low DO conditions (Bjornn and Reiser 1991; Brett and Blackburn 1981; Carter 2005; Matthews and Berg 1997). In response, partners and landowners worked quickly to initiate this release on September 28 (Table 9, Figure 53), and continuous DO loggers were deployed downstream of the release site.

Surface flow disconnection at the monitoring site 200 m downstream of the JFW release occurred on September 3. At this time, streamflow observed at TU's stage logger/gage approximately 270 m downstream of the release point (Figure 44), was 0.0 ft^3/s. DO concentrations had dropped to less than 3.0 mg/L (Figure 54) and water temperatures were also increasing and peaked at 20.5°C on September 5 (Figure 55), shortly after disconnection was documented.

On September 30, just two days after the augmentation of 0.10 ft^3/s began, the study unit 200 m downstream was reconnected to surface flow and every riffle from the release point to approximately 285 m downstream (the furthest extent of the survey reach, to the confluence with the next incoming tributary) had rewet. In addition, the volume of the DO logger pool more than quadrupled, going from 3.5 m^3 to 15.6 m^3 between the habitat survey on September 18 (two weeks after unit disconnection) and October 2 (four days after release initiation). Juvenile salmonids and other native fishes were observed persisting in this pool during a snorkel survey on September 18. Pool reconnection likely occurred on October 2, when streamflow 270 m downstream of the release increased from 0.0 ft^3/s to 0.13 ft^3/s and DO conditions jumped from below 4.0 mg/L to 8 mg/L and above (Figure 54). Water temperatures also decreased, though this may have been influenced by cooler seasonal air temperatures (Figure 55).

Despite a later-than-optimal initiation date, the 2017 release of 0.10 ft^3/s gave surface flow, stream connectivity, DO, and water temperature a much-needed boost that was sustained for the duration of the augmentation period (Figure 54, Figure 55). This release provided direct relief for juvenile salmonids persisting in shrinking, isolated pools and increased the number of days over the summer period that pools were connected, thereby increasing the probability of fish survival (Obedzinski et al. 2018).

After the notable success of the 2017 JFW release, cooperating partners (Coho Partnership members, resource managers, and landowners) planned to release at a rate of 0.10 ft^3/s in the summer of 2018 regardless of the antecedent precipitation amount. The augmentation was scheduled for September 20 and DO and water temperature loggers were placed both above and below the release point; however, after the release initiation the stream continued to dry (Figure 56). Frequent wet/dry surveys allowed CSG to inform partners of the continued stream drying during the release period, and post-season evaluation of continuous streamflow and DO data indicated that this release had no impact on streamflow or water quality (Figure 57). It was determined that the infrastructure had failed and the augmentation water did not make it into the stream channel. The information collected during WCB-funded monitoring led partners to implement infrastructure improvements for the 2019 release.

The 2019 JFW release was planned for mid-August, when the study reaches of Green Valley Creek upstream of the confluence with Atascadero Creek typically begin to experience large changes in stream connectivity and water quality. However, similar to observations during the same year on Dutch Bill Creek, there were fewer points of disconnection in this remarkably wet summer than in previous years. On the August wet/dry survey preceding the augmentation, 98% of the surveyed stream length was still wet and connected. Streamflow below the release was far higher than in August of previous years and stream-scale averages of discrete DO and water temperature measurements were still within appropriate ranges for juvenile salmonids (Figure 58). Some RCT depths, however, were under 0.20 ft, a depth below which declines in water quality have been observed in these same Russian River streams (Nossaman Pierce et al. 2019). Streamflow was slowly declining in the days prior to the release initiation on August 16, 2019, and average streamflow at the gage approximately 270 m downstream of the release was 0.15 ft^3/s one day before release initiation (Figure 58). The 0.10 ft^3/s release translated to an additional 0.03 ft^3/s of instream flow, yielding a daily average of 0.18 ft^3/s. While the amount of water provided by the augmentation may seem small, it contributed the equivalent of 20% of the pre-release streamflow.

Prior to the release in 2019, DO and water temperature loggers were placed both upstream and downstream of the release site (Figure 45). The JFW flow augmentation initially stabilized the DO conditions in the study pool 200 m downstream, then caused a steady increase in DO that was maintained for the rest of September (Figure 58). In the week following the release initiation, only 3% of 15-minute DO samples were below the regional objective, compared to 43% of the samples recorded by the logger above the release point. While conditions were stable or improving downstream of the release, DO recorded at the logger 100 m upstream of the release point continued to decline and frequently dropped below the mortality threshold throughout the month of September (Figure 58). Without this release, DO conditions downstream of the release would have likely followed the same downward trend observed upstream of the release.

In addition, the 2019 release was correlated with a reduction in water temperatures to less than 15°C, and to less than 10°C for several days in September at the site 200 m below the release, while the sites approximately 100 m above the release and 285 m downstream maintained near-identical temperatures (Figure 59). Despite the concerns regarding the potential poor water quality from this small private pond, CSG only documented improvements to water quality in the years when the JFW release was successful in adding water to the stream. This suggests that the strategy of releasing at night and aerating the water before it reached the stream was effective in mitigating any impact from high water temperatures and low DO that may have been occurring in the pond environment.

Figure 53. The JFW flow release into Green Valley Creek, August 2016.

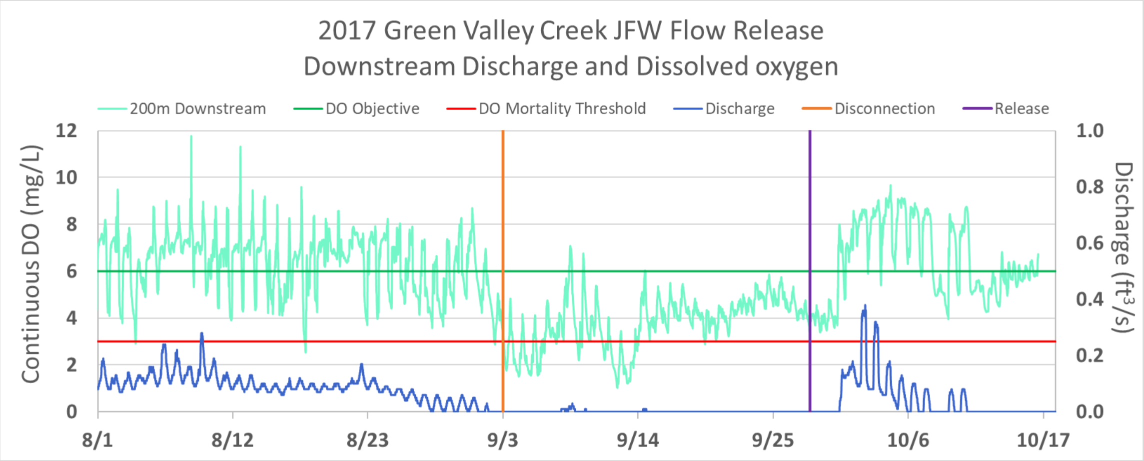

Figure 54. Discharge in Green Valley Creek approximately 270 m below the release and continuous dissolved oxygen 200 m below the release plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

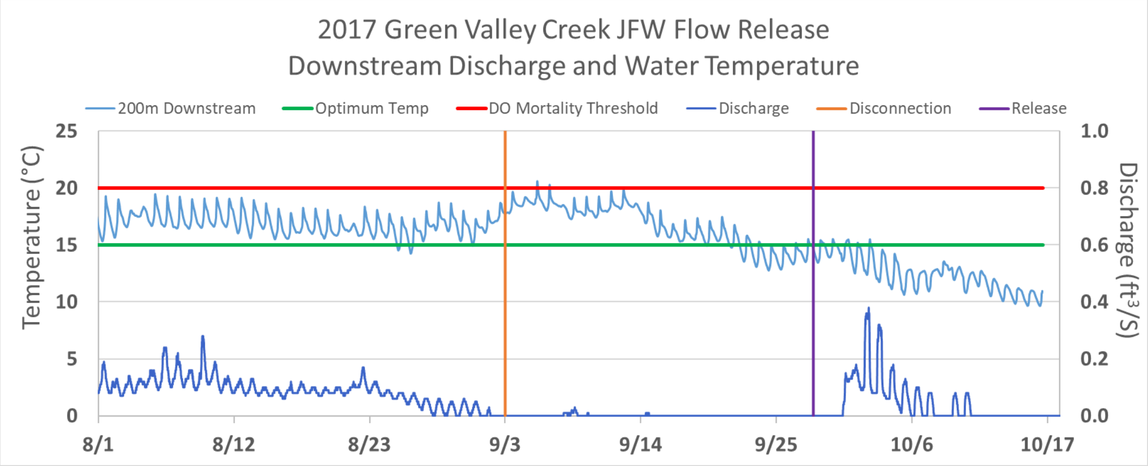

Figure 55. Discharge in Green Valley Creek approximately 270 m below the release, and continuous water temperature 200 m below the release plotted with optimal temperature for juvenile coho salmon (15°C) and the threshold for mortality (20°C).

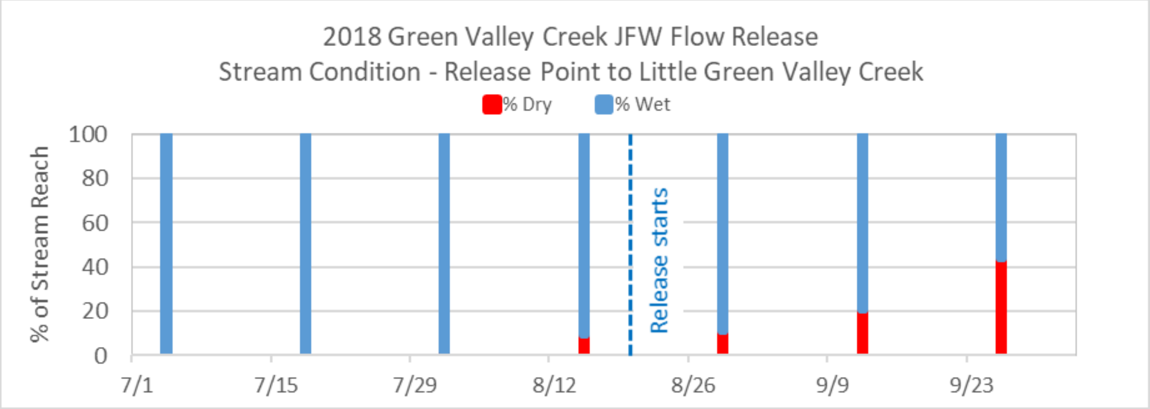

Figure 56. Wetted habitat conditions from the JFW release site downstream to Little Green Valley Creek.

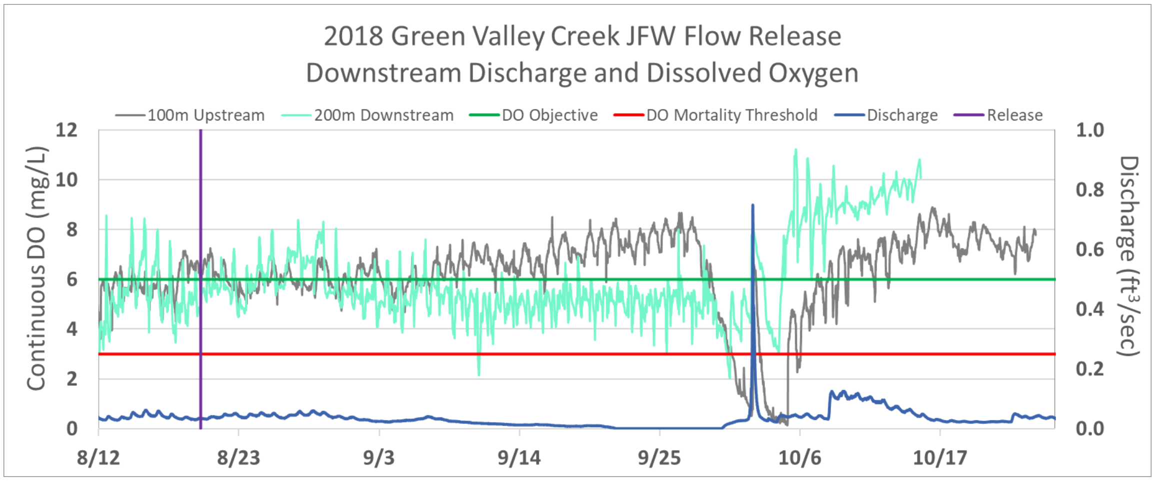

Figure 57. Discharge in Green Valley Creek approximately 270 m below the release and continuous dissolved oxygen 100 m above and 200 m below the release plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

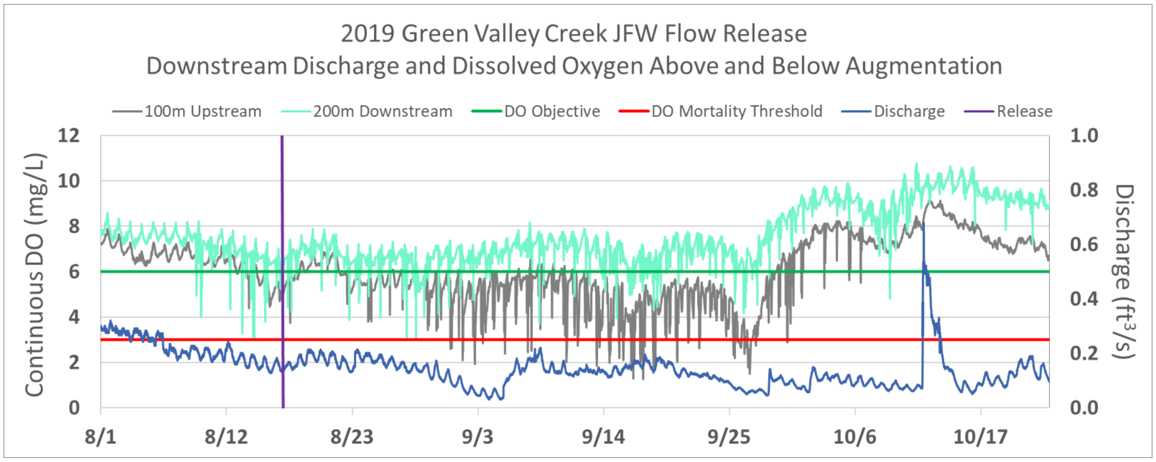

Figure 58. Discharge in Green Valley Creek approximately 270 m below the release and continuous dissolved oxygen 100 m above and 200 m below the release plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

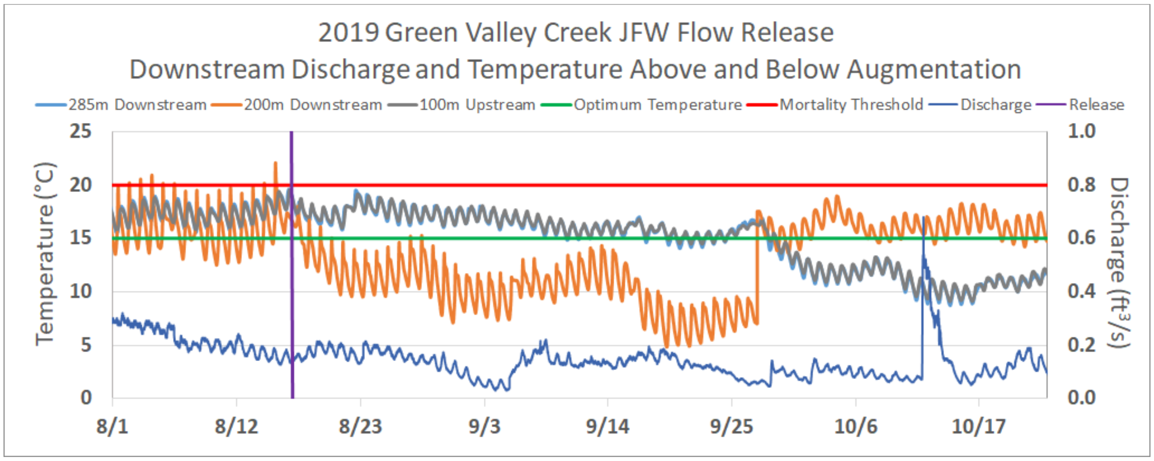

Figure 59. Discharge in Green Valley Creek approximately 270 m below the release and continuous temperature 100 m above, 200 m, and 285 m below the release plotted with optimal temperature for juvenile coho salmon (15°C) and the threshold for mortality (20°C).

2.2.8.3. Green Valley Farms release, Green Valley Creek

The second release occurred on the uppermost reach of Green Valley Creek on the Green Valley Farms property, at approximate rkm 16.37, and will be referred to as the GVF release (Figure 45, Table 9). It was sourced from a small, privately-owned, off-channel storage pond and occurred each summer of the three-year study period.

The effects of the GVF release were variable and generally more difficult to quantify due to its location outside of the wet/dry mapping reach, despite the fact that additional DO loggers were added in 2019 in an attempt to improve the monitoring infrastructure (Figure 44). Compared to the JWF and Dutch Bill Creek flow releases, the rate of the augmentation was relatively low (Table 9). In addition, the monitoring sites were farther away from the release point and there were signs of human impact between the release and the gaging sites, both of which likely contributed to the difficulties in assessing augmentation impacts.

In 2017, the GVF augmentation began on September 29, at an approximate rate of 0.05 ft^3/s. By early September, streamflow at the upper Green Valley Creek gage 1,500 m downstream of the release site was close to 0.0 ft^3/s (Figure 60). As streamflow receded, DO declined to levels below 6.0 mg/L and dropped below the 3.0 mg/L mortality threshold on several occasions in the month before the release, with 26 days in August and September reaching daily minimums of less than 1.0 mg/L. After the release, both flow and DO experienced a sharp, immediate increase; however, the effect was relatively brief, and levels declined over the following week. This release may have been more effective if it had started before DO reached persistent, sub-lethal values.

In 2018, the release began almost one month earlier, on August 29; however, there were no subsequent changes observed in DO (Figure 61). As with the JFW release, it became clear that infrastructure issues were the cause for the lack of impact in 2018 and, again, information collected during WCB-funded monitoring informed managers and led to infrastructure improvements the following year (Figure 62).

In 2019, it took approximately ten days for the September 17 GVF flow release to reach the upper Green Valley Creek flow gage site 1,500 m downstream of the release point. At that site, there was a 0.03 ft^3/s increase in streamflow (Figure 63), which equated to 41-83% of the average daily flow observed in the two weeks prior to the release.

In 2019, CSG researchers were able to deploy additional DO loggers closer to the GVF release, approximately 630 m and 780 m downstream of the release point (Figure 45); however, the logger deployed at the same study site as in 2017 and 2018 experienced technical failure. Before the September 17 release, DO conditions in both of the study pools were poor; 100% of the samples 630 m downstream of the release and 65% of the samples 780 m downstream of the release were below the regional objective (Figure 63). These low DO concentrations were temporary at the lower DO logger, but persisted at the upstream logger and rarely exceeded the mortality threshold.

After release initiation, DO concentrations appeared to respond to the augmentation almost immediately, spiking above the regional objective at the logger 630 m downstream on the same day (Figure 63). It took several days for the GVF flow augmentation to reach the DO logger 780 m downstream, showing up in the DO signal on September 27. The proportion of samples below 6.0mg/L recorded by this DO logger decreased from 65% the week before the augmentation to only 4% the week after, a substantial improvement. The initial improvement in water quality following the augmentation is likely attributed entirely to the release, while the sustained increases in DO were may have been due to a combination of the augmentation and the seasonal shift towards cooler temperatures. Improved DO conditions in early fall have been observed in other California streams under natural conditions (Matthews and Berg 1997).

The augmentation had no impact, positive or negative, on water temperature at the monitoring sites (Figure 64), which steadily declined in the first weeks of September and, after a slight increase on September 27, continued to decline and remained below 15°C as the season transitioned from summer to fall.

Of all of the flow augmentations on lower Russian River tributaries, the GVF augmentation has the smallest amount of available water and, subsequently, the lowest release rate. However, in years that the approximate 0.05 ft^3/s makes it into the stream channel, there are noticeable improvements to DO concentrations.

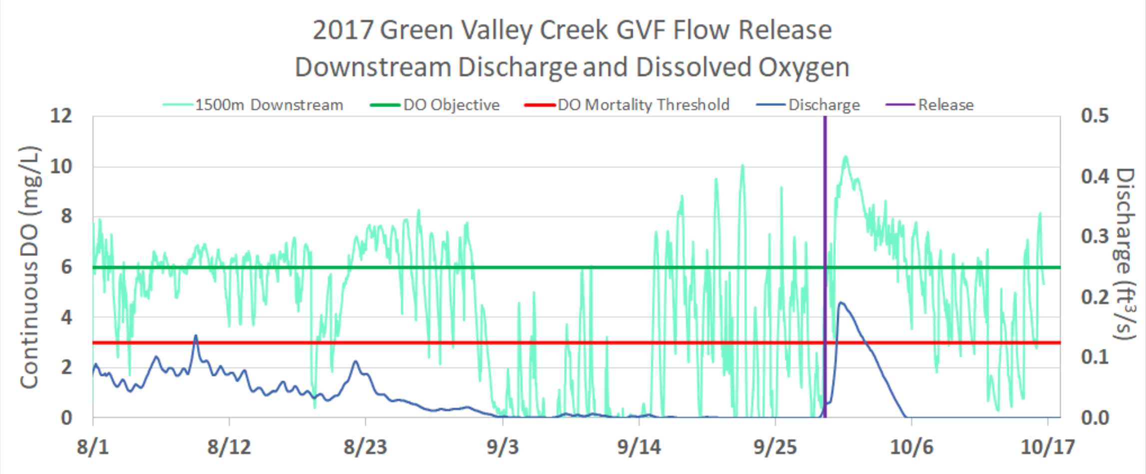

Figure 60. Discharge at the upper Green Valley Creek gage, 1,500 m downstream of the GVF release, and continuous dissolved oxygen from the same site plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

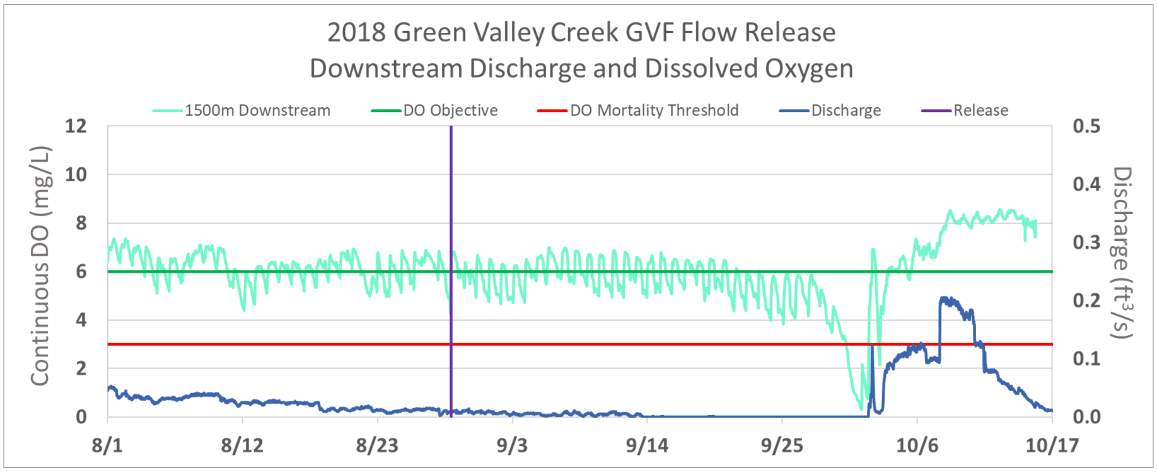

Figure 61. Discharge at the upper Green Valley Creek gage, and continuous dissolved oxygen from the same site plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

Figure 62. Improved pond outlet manifold for the GVF release, photo courtesy of GRRCD, July 2019.

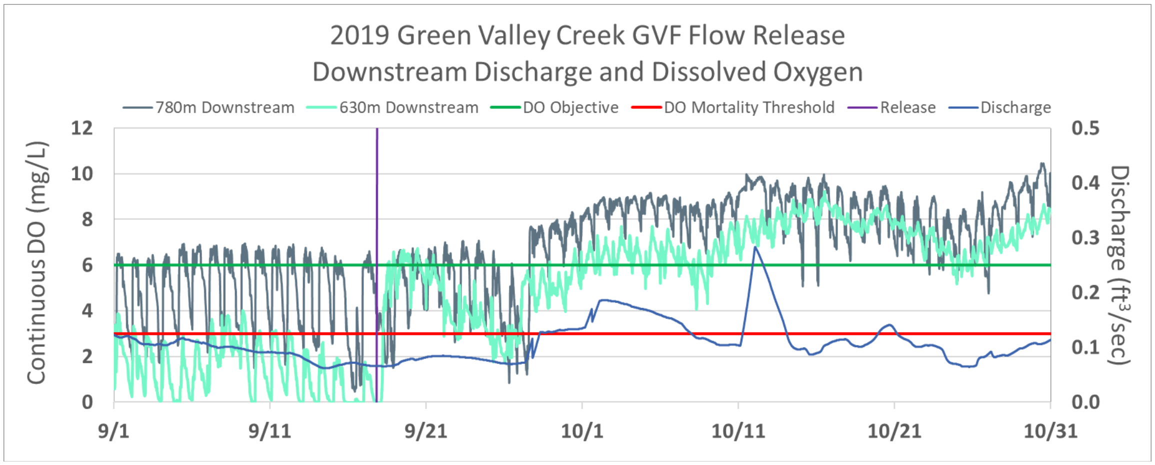

Figure 63. Discharge at the upper Green Valley Creek gage, and continuous dissolved oxygen 780 m and 630 m downstream of the release point plotted with regional DO objective (6.0 mg/L) and salmonid mortality threshold (3.0 mg/L).

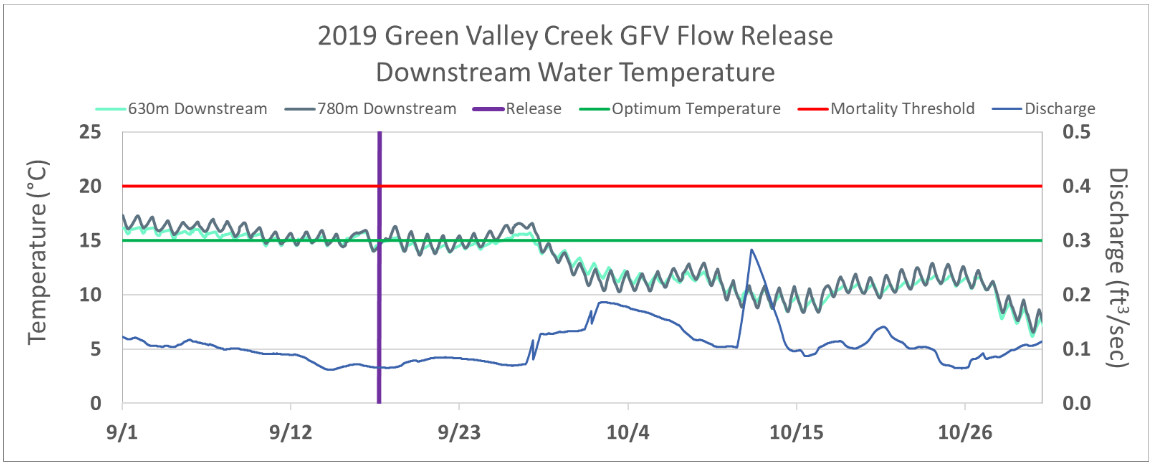

Figure 64. Discharge at the upper Green Valley Creek gage, and water temperature 780 m and 630 m downstream of the release point plotted with optimal temperature for juvenile coho salmon (15°C) and the threshold for mortality (20°C).

2.2.9. Summary and recommendations

Overall, the wetted habitat, fish distribution, water quality, streamflow and connectivity data collected and summarized through this project demonstrated unequivocally that insufficient summer streamflow is negatively impacting oversummer survival of juvenile salmon and steelhead. Over the summers of the project period, a minimum of 25% rearing juveniles were observed in locations that became dry or intermittent later in the season, when averaged across all streams. While this is better than in drought years such as 2015, when on average in these streams only 28% of juveniles were seen in locations that stayed wet (California Sea Grant 2016a), the fact that 25-30% of rearing fish in four of the highest priority coho salmon streams in the watershed were threatened by stream drying or disconnection even in wetter-than-average water years like 2017 and 2019—and that this increased to 37% in a below-average water year like 2018—is concerning. In the driest stream—Felta Creek, where coho salmon adults and yoy are observed every year—just 40% of the habitat where juveniles were rearing during early summer snorkel surveys remained wet through the dry season, on average over the study period. These results indicate that summer flow impairment is a limiting factor to juvenile salmonid survival, even in non-drought years.

Changes in stream condition across time can help us to understand the stability of available instream habitat in the face of climate variability (i.e., which streams are reliably dry, reliably wet, or exhibit high year-to-year variability). Green Valley Creek generally had the greatest proportion of end-of-season wetted stream length, yet also exhibited substantial interannual variation in first disconnection date, end-of-season wetted habitat condition, and proportion of rearing juvenile salmonids affected by stream drying and intermittency. Mill and Felta creeks also exhibited high interannual variability. Overall, the inconsistent and unreliable nature of summer rearing habitat available in these streams presents a clear challenge to salmonid recovery.

Dutch Bill Creek displayed the lowest interannual variability in end-of-season wetted habitat conditions, which suggests that it is less sensitive to changes in environmental conditions than the other watersheds, though flow releases in 2018 and 2019 may have influenced this result. While a significant proportion of the stream goes dry or becomes intermittent each year—nearly the entire lower half—it also appears to have the greatest consistency across different types of water years. The upper reaches of Dutch Bill Creek (above Tyrone Gulch) and the upper reaches of Mill Creek (above the confluence with Wallace Creek) both remained almost entirely wet and connected, even in 2018. In addition, the upper Dutch Bill Creek and upper Mill Creek water quality monitoring sites experienced near-optimal conditions over the study period. This indicates that these areas offer reliable summer refugia for rearing fish, though more salmonids appear to be taking advantage of that habitat in Dutch Bill than in Mill, as indicated by the disproportionately high number of fish distributed in the perennial reaches of Dutch Bill Creek.

It is interesting to note that, despite significantly greater total precipitation in WY2017, WY2019 experienced substantially higher streamflow—the highest in TU's period of record. While this was likely influenced by the late-spring storms that occurred in 2019, data also suggest that the 2012-2016 drought may have had a lingering impact on WY2017 streamflow and associated water quality conditions. Despite streamflow being higher in 2017 than in 2018 in all reaches except for upper Green Valley Creek, DO outcomes were very similar and the poorest water quality conditions were observed in 2017.

In season, the biweekly wetted habitat maps were used by partners at CDFW to organize fish rescues where large densities of coho salmon were known to be located in areas experiencing drying. While fish rescue may be a necessary emergency action, we do not think that relying on opportunistic fish rescues is a sustainable solution, given that it requires ongoing human intervention. This is not only resource-intensive but also counters the primary objective of the Broodstock Program—to establish a self-sustaining population of coho salmon in the Russian River watershed.

Improving summer streamflow is a necessary step towards addressing this bottleneck and achieving recovery of Russian River salmonid populations. Additional flow enhancement projects, such as those being implemented in these watersheds through the Coho Partnership, may help to mitigate the current bottlenecks to juvenile summer survival and should be supported and encouraged in all the study streams. In Green Valley Creek, which had the highest end-of-season wet stream length, proportionally, yet generally experienced the poorest DO conditions, small flow improvements may yield a greater benefit by improving stream connectivity and water quality. In the case of Green Valley Creek, this could be particularly beneficial due to the relatively high density of salmonid activity in that system. Flow improvements might also help to remediate the late-summer DO impairment observed in the lower Dutch Bill Creek study reach and high water temperatures in the lower Mill Creek reach.

Studies like those conducted in the Green Valley and Mill creek watersheds by O'Connor Environmental Inc. and the Pepperwood Foundation are very valuable for assessing the potential impacts of different flow enhancement scenarios. The expansion of these studies, and similar ones, should be supported to ensure efficient project prioritization and planning, and greater project effectiveness (Kobor and O'Connor 2016; Kobor and O'Connor 2018).

Environmental data collected through this award allowed us to document the success and constraints of three different small-scale instream augmentations into Dutch Bill and Green Valley creeks. Overall, we found that flow augmentations as small as 0.05 ft^3/s were successful in improving streamflow, surface flow connectivity, RCT depth, and DO, with no detrimental impacts to water temperature, in all types of water years. The feedback generated by this monitoring also informed release initiation timing and led to improvements in release infrastructure over the course of the grant period. Identifying the furthest downstream extent of flow release impacts in Dutch Bill and Green Valley creeks warrants further investigation, but the relatively localized improvements to surface flow and water quality conditions and resulting benefits to rearing salmonids are clear.

As a general strategy for releases of limited volume, it is logical to plan for mid-August initiation in watersheds with low summer base flow similar to Dutch Bill and Green Valley creeks. In cases where more water is available, earlier releases can yield greater benefits and reduce stress on rearing fish by stabilizing habitat conditions before they reach intolerable levels. Determining the precise date of implementation each year will require consideration of the amount of release water available, the scale and limitations of the infrastructure, and dynamic environmental conditions (e.g., antecedent precipitation, streamflow, weather). There is no one-size-fits-all approach to small-scale flow augmentations but, when implemented thoughtfully, they can offer significant beneficial impacts by improving stream connectivity and water quality conditions, thereby increasing the likelihood of survival for juvenile salmonids rearing in these systems (Deitch et al. 2018; Nossaman Pierce et al. 2019; Obedzinski et al. 2018; Vander Vorste et al. 2020; Woelfle-Erskine et al. 2017).

We anticipate that augmentations like these will likely continue to prove themselves useful as climate change intensifies. The lessons learned from the monitoring efforts have been used to refine and inform flow release strategies within the Russian River watershed, but can also serve as a model for similar salmonid-bearing streams throughout coastal California. All flow release projects should be approached with the understanding that they are not a substitute for addressing underlying streamflow impairment, but are a useful management tool that can yield beneficial impacts when implemented correctly and, most importantly, when combined with more comprehensive flow enhancement strategies. A holistic, long-term approach to instream flow restoration that includes efforts to recharge the water table is necessary to provide adequate late-summer habitat for salmonids in the study streams of Dutch Bill, Green Valley, Mill, and Felta creeks, as well as additional tributaries throughout the Russian River watershed.

2.3. Development of predictive wetted habitat model

UC Berkeley PhD student, Hana Moidu, used data from the wet/dry mapping and GIS data to create statistical models that predict the spatial and temporal distribution of wetted habitat in tributaries to the Russian River. To address the timing of initial drying, she developed a random forest model to predict the date of initial drying for Russian River tributaries (Figure 65). This model had a predictive accuracy of $R^2 > 60\%$, with 46% of the reach predictions within seven days of the observed drying date. This model was developed using a subset of the data, with the omitted sites used for validation and to evaluate model performance.

To expand on this model, she used end-of-season wet-dry mapping from 25 streams in the Russian River watershed, including Dutch Bill, Green Valley, and Mill Creek, surveyed between 2012-2019, to understand the spatial distribution of end-of-season condition. Using random forest models, she identified key physical drivers of wetted habitat and predicted the degree and distribution of wetted habitat at the end of the dry season for Dutch Bill, Green Valley, and Mill creeks (Figure 66). The analysis suggests that antecedent precipitation (from the previous winter and the previous three to five years), drainage area, and soil permeability have the strongest influence on end-of-season wetted habitat conditions. The influence of antecedent precipitation helps to explain the limiting effects of the 2012-2016 drought on 2017 streamflow and water quality, despite record rainfall in that water year. The model had high predictive accuracy of ($R^2 > 75\%$) and low bias.

Using a similar approach, Moidu also developed a model to predict interannual variability in end-of-season wetted habitat conditions. These models are useful for understanding the resiliency of streams to climate variability (i.e., which streams are reliably dry, reliably wet, or exhibit high year-to-year variability in wetted conditions at the end of the dry season). She found that different streams and different reaches within streams showed different levels of interannual variability and that watershed lithology, vegetation, and soil conditions were influential factors (Figure 67, Figure 68). The model had high predictive accuracy of ($R^2 > 70\%$) and low bias. For both the end-of-season and interannual variability models, a leave-one-out cross-validation method was used to assess model performance, in which models were iteratively trained with subsets of the data that randomly excluded data from five streams. The omitted sites were then returned to the training class for the next iteration, with a different subset of streams being reserved for effective ground-truthing. In each iteration, model predictions were made at the sites that were excluded from the dataset and performance was assessed by comparing observed with predicted values.

The trained models were then used to predict end-of-season wetted conditions and interannual variability in all streams in the lower and middle Russian River watershed (Figure 68). Applying these models to the whole watershed can provide us with information on how the system's streams function and respond to antecedent conditions and climate variability. The ability to predict where the wetted channel will persist through the dry season is critically important for sustaining aquatic biodiversity in intermittent systems, and can be used by managers for river restoration and habitat recovery strategies. Further, these models can be applied to identify reaches of relative stability and concern in regions that have not had prior wetted channel mapping.

A manuscript related to these results is in preparation and will be submitted to *Water Resources Research* for publication consideration in early 2021.

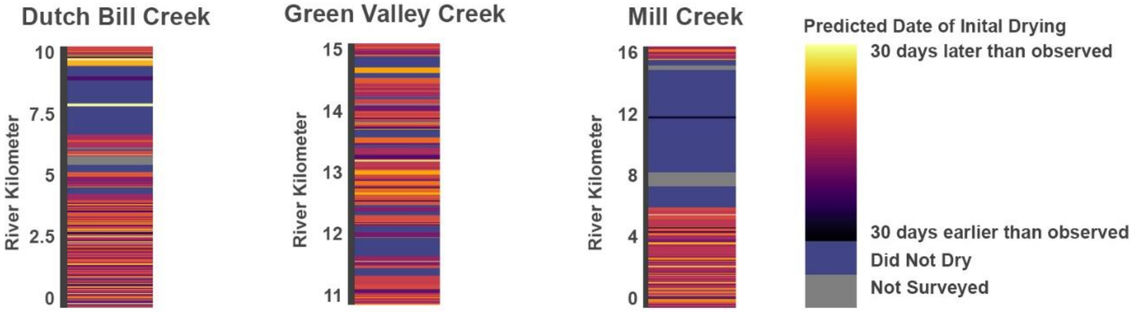

Figure 65. Model performance of the predicted date of initial drying for Dutch Bill, Green Valley, and Mill creeks.

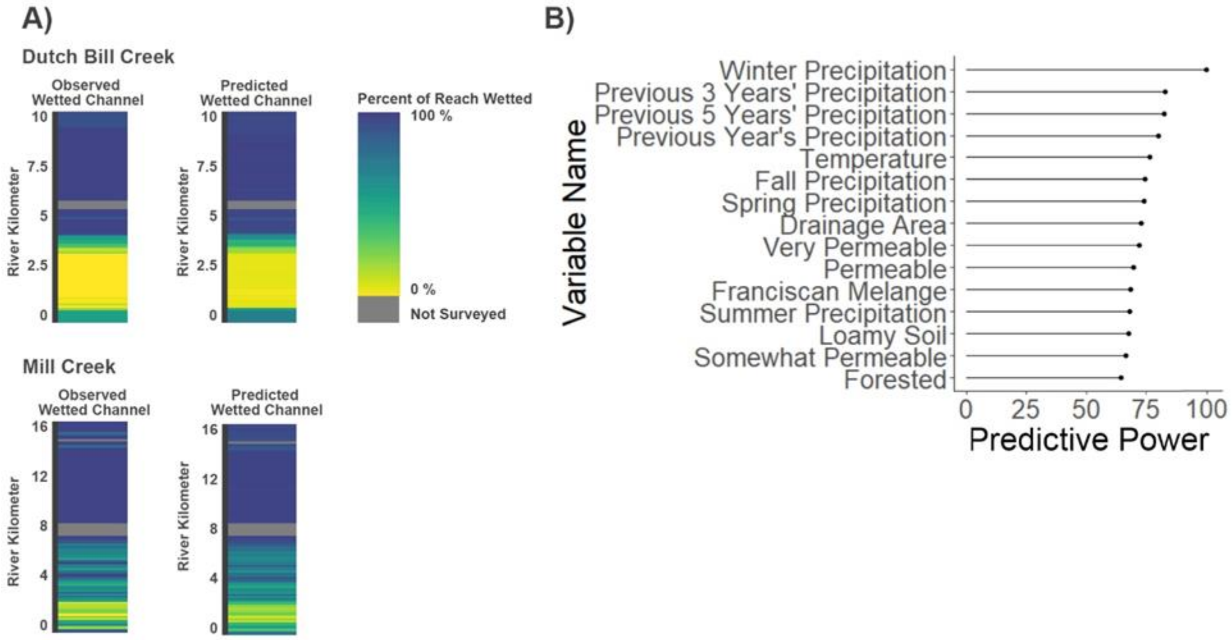

Figure 66. (A) Examples of observed versus predicted end-of-season wetted habitat conditions for Dutch Bill and Mill creeks, and (B) variable importance plot indicating the influence of climatic and physical watershed features on end-of-season wetted habitat conditions.

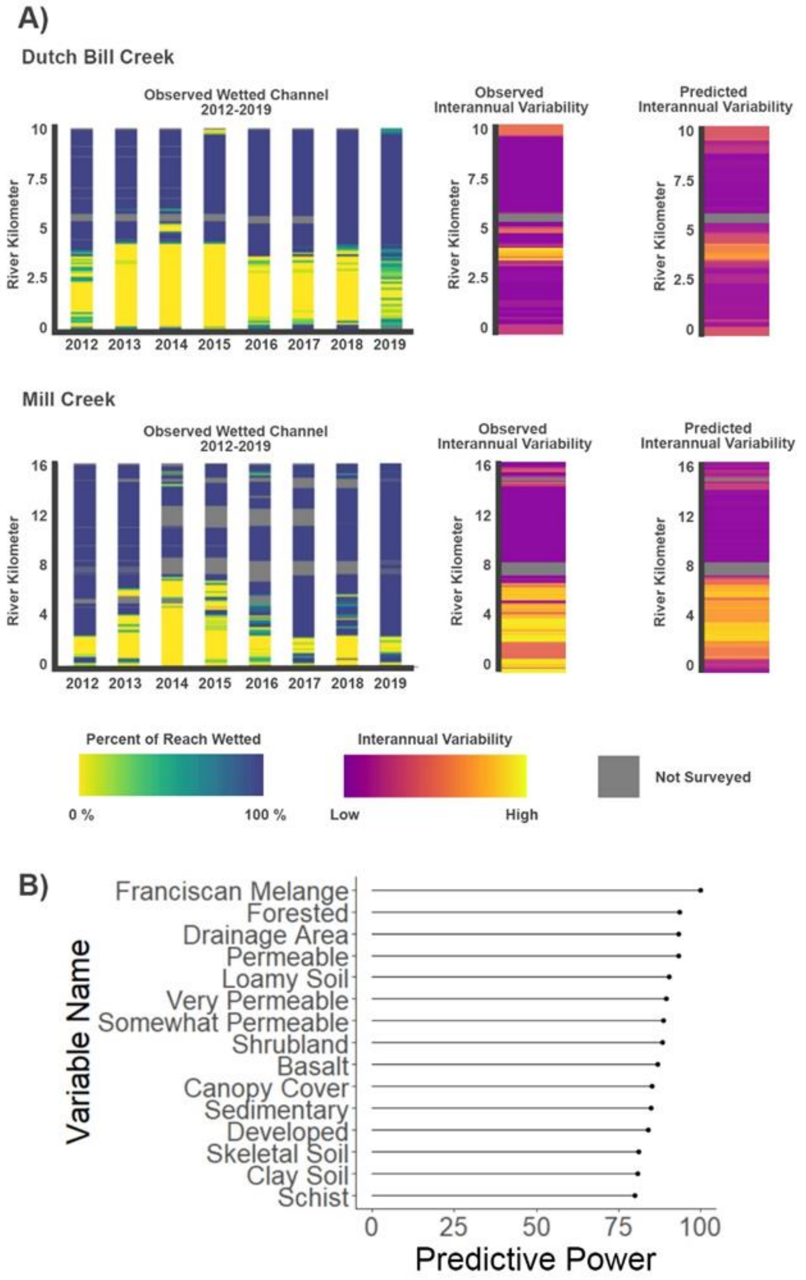

Figure 67. (A) Examples of observed versus predicted interannual variability in wetted habitat conditions for Dutch Bill and Mill creeks, and (B) variable importance plot indicating the influence of climatic and physical watershed features.

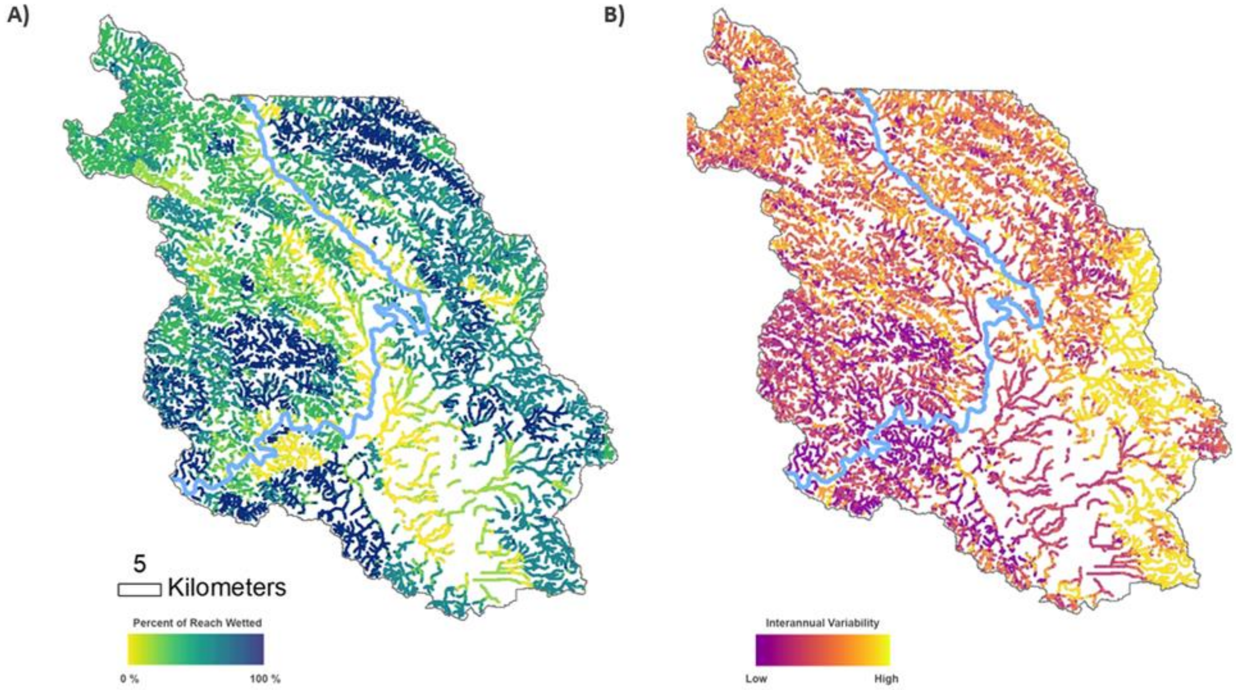

Figure 68. Model-predicted values for streams in the lower Russian river watershed, indicating (A) the average proportion (0-100%) of each reach wetted at the end of the dry season and (B) the degree of inter-annual variation (low to high) in end-of-season wetted habitat conditions.

3. Task 3: Coordination meetings and dissemination

In addition to sharing the in-season wetted habitat information with project partners via weekly emails, CSG's website, and the interactive web application, CSG held three annual meetings in order to share updates on WCB-funded grant activities and to coordinate dry-season field work among partners; one each in March of 2018 and 2019, and a third meeting in virtual format in October 2020 (recording available online at http://bit.ly/WCB_Meeting2020). The primary objectives of these meetings were to share outcomes from this project and to provide a forum for all organizations engaged in evaluating and addressing streamflow impairment in Russian River tributaries to exchange information about their recent and upcoming efforts. The meetings filled an unmet need by creating an opportunity to promote communication regarding the various complimentary efforts occurring within the watershed and to coordinate related low-flow activities among cooperating partners. Between 33 and 54 individuals from up to 13 different partner agencies and organizations attended the meetings each year.

At each annual meeting, CSG and UC Berkeley researchers presented updates on all of the tasks outlined in this project. Additional presentations by CSG focused on the results of an investigation into indicators of dry-season DO suitability, and outcomes from an effort to evaluate the effects of a flow augmentation on smolt outmigration in Porter Creek. Many other partner organizations also contributed a wealth of information to the three meetings. CDFW staff from the Water Branch and the Cannabis and Instream Flow Branch presented outcomes from their work related to cannabis monitoring and the Mark West Creek Habitat and Instream Flow Study. State Water Quality Control Board staff shared updates on their groundwater modeling efforts and analysis of water use datasets in Russian River tributaries, as well as updates on the California Water Action Plan in Mark West Creek, flow-ecology efforts in the Eel River watershed and drought planning. O'Conner

Environmental, Inc. presented an in-depth overview of the results of their Mark West Creek Flow Availability Analysis and Mill Creek Watershed Streamflow Study. Staff from the North Coast Regional Water Quality Control Board discussed their various efforts and the recruited collaborators for the development of a Russian River Tributary Monitoring Plan. TU shared preliminary findings from the Lower Mill Creek Groundwater Study and the Coho Partnership's Green Valley Creek groundwater monitoring effort. A UC Berkeley doctoral student presented on his work researching hydraulic controls on juvenile salmon outmigration in Russian River streams. Finally, staff from NOAA, the Gold Ridge RCD and TU discussed the status of flow releases on Dutch Bill and Green Valley creeks. CSG staff also facilitated discussion and coordination of upcoming dry-season activities among all partners and development of a general summer monitoring plan for the summers of 2018 and 2019. This was not possible in 2020, due to pandemic-related restrictions causing the meeting to be postponed until the fall. Overall, the meetings met the intended objectives with great success.

Other meetings in which results from this project were shared included bimonthly Coho Partnership steering committee meetings, Broodstock Program TAC and workgroup meetings, and North Coast Salmon Program (NCSP) steering committee meetings. Over the three-year period, results were also regularly relayed to individual CDFW staff to help guide fish rescue and broodstock collection activities. Wetted habitat and fish distribution data collected during this project have been incorporated into a web-based mapping tool that CSG created for the NCSP steering committee members to interact with the data so that they can identify focus areas for habitat and streamflow enhancement efforts.

In addition to the WCB-sponsored annual meetings and other technical advisory committee meetings, we organized two sessions focused on evaluating and addressing streamflow impairment for the Salmonid Restoration Federation’s annual conference in 2019. Information related to the many components of this project was disseminated in those sessions and through additional presentations at other professional society conferences, including the American Fisheries Society, Society for Freshwater Science and the American Geophysical Union (presentations listed in chronological order):

> Moidu, H., R. Leidy, T. Grantham, and S. Carlson. Linking landscape-level processes and aquatic refugia in intermittent streams of Central California. Annual Meeting of the Society for Freshwater Science. Detroit, MI. May 21, 2018. *Best Poster Presentation in Basic Research Award.*
>
> Vander Vorste, R., M. Obedzinski, S. Nossaman Pierce, T. Grantham, and S. Carlson. Abiotic drivers of juvenile Coho salmon survival in intermittent streams. Annual Meeting of the California Aquatic Bioassessment Workgroup. Davis, CA. October 24, 2018.
>
> Moidu, H., R. Vander Vorste, M. Obedzinski, S. Nossaman Pierce, T. Grantham, and S. Carlson. 2019. Predicting the spatial and temporal distribution of wetted habitats in intermittent streams and its Implications for long-term drought impacts. Salmonid Restoration Federation 37th Annual Conference. Santa Rosa, CA, April 25, 2019.
>
> Nossaman Pierce, S., M. Obedzinski, E. Ruiz, A. McClary, A. Bartshire, B. McFadin, and L. Le. 2019. Dynamics that influence dissolved oxygen concentrations in salmonid rearing pools and possible implications for management. Salmonid Restoration Federation 37th Annual Conference. Santa Rosa, CA. April 26, 2019.

Obedzinski, M., A. Bartshire, N. Bauer, S. Nossaman Pierce, A. McClary, G. Horton, and A. Johnson. 2019. Impacts of low summer streamflow on salmonids rearing in Russian River tributaries. Salmonid Restoration Federation 37th Annual Conference. Santa Rosa, CA, CA. April 26, 2019.

Ruiz, E., S. Nossaman, M. Obedzinski, A. Bartshire, A. McClary, and C. O' Keefe. 2019. Just add water: an overview of small-scale flow releases and monitoring tools to support salmonid recovery in the lower Russian River Basin. Salmonid Restoration Federation 37th Annual Conference. Santa Rosa, CA, April 26, 2019.

Vander Vorste, R., T. Grantham, S. Carlson, M. Obedzinski, S. Nossaman-Pierce. 2019. Effects of extreme drought on juvenile coho salmon survival in the Russian River. Salmon Restoration Federation 37th Annual Conference. Santa Rosa, CA. April 26, 2019.

Moidu, H., R. Vander Vorste, P. Rodrigues Lazano, M. Obedzinski, S. Carlson, T. Grantham. 2019. Predicting the spatial and temporal distribution of wetted habitats in intermittent streams and its implications for long-term drought impacts. Society for Freshwater Science Annual Conference. Salt Lake City, UT, May 21, 2019.

Vander Vorste, R., T. Grantham, S. Carlson, S. Nossaman-Pierce, M. Obedzinski. 2019. Extreme drought limits survival of endangered coho salmon in intermittent streams. Society for Freshwater Science Annual Conference. Salt Lake City, UT, May 21, 2019.

Obedzinski M., A. Bartshire, N. Bauer, S. Nossaman Pierce, A. McClary, G Horton and A. Johnson. 2019. Low summer streamflow limits endangered coho salmon recovery in coastal California streams. American Fisheries Society and the Wildlife Society 2019 Joint Annual Conference. Reno, NV. October 1, 2019.

Moidu, H., R.V. Vorste, M. Obedzinski, S. Carlson, T. Grantham. 2019. Predicting the spatial and temporal distribution of wetted habitats in intermittent streams and its implications for threatened fish populations. American Geophysical Union Fall Meeting. San Francisco, CA. (Poster). December 9, 2019.Hana Moidu has also been invited to share her predictive modeling work for this project to Sonoma Water and will present her findings at the Society for Freshwater Science annual meeting in 2021.

The publication of the article written through the support of this award, *Refuges and ecological traps: Extreme drought threatens persistence of an endangered fish in intermittent streams* (Vander Vorste et al. 2020), generated the following news coverage (listed in chronological order):

What Does Drought Mean for Endangered California Salmon? Environmental News Network, May 18, 2020. https://www.enn.com/articles/63607-what-does-drought-mean-for-endangered-california-salmon.

What does drought mean for endangered California salmon? Drought threatens salmon habitat, but strategic conservation efforts could keep essential streams flowing. Science Daily, May 18, 2020, https://www.sciencedaily.com/releases/2020/05/200518144857.htm.

Sexton, Chrissy. Conservation efforts are needed to save California salmon. Earth.com News, May 19, 2020, https://www.earth.com/news/conservation-efforts-are-needed-to-save-california-salmon/.

Can California's endangered salmon survive continued drought? Pools serving as drought refuges critical. The Columbia Basin Bulletin Fish & Wildlife News, May 21, 2020, https://www.cbbulletin.com/can-californias-endangered-salmon-survive-continued-drought-pools-serving-as-drought-refuges-crucial/.

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Tighe, Mike. UWL biology professor fishes for facts to save endangered salmon in California; Research team studies how to boost survival during increasingly severe droughts. News8000, June 8, 2020, https://www.news8000.com/uwl-biology-professor-fishes-for-facts-to-save-endangered-salmon-in-california/.

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