Mark West Creek

Annual Environmental Monitoring Report WY2021

MARCH 30, 2022

Prepared for the Wildlife Conservation Board
By: Trout Unlimited and California Sea Grant

Contents

1. Introduction

In April 2020, Trout Unlimited (TU), California Sea Grant's Russian River Salmon and Steelhead Monitoring Program (CSG) and Sonoma Resource Conservation District (SRCD) were awarded a Wildlife Conservation Board (WCB) grant to enhance streamflow in the Mark West Creek watershed through the implementation of ten streamflow enhancement projects and to monitor key watershed characteristics. This report is the second of four annual reports that describes the results of our annual streamflow and environmental monitoring activities.

One objective of this project is to provide baseline data on streamflow, general water quality and late-summer wetted habitat conditions in critical coho and steelhead rearing reaches in order to document potential impacts of low flow on rearing salmonids and to demonstrate if and how stream conditions change with the implementation of the streamflow enhancement projects. The project overview map (Figure 1) shows the Mark West Creek watershed and the monitoring sites, including the wetted habitat survey extent, continuous water quality logger and flow gage locations and Sonoma Resource Conservation District's potential project sites.

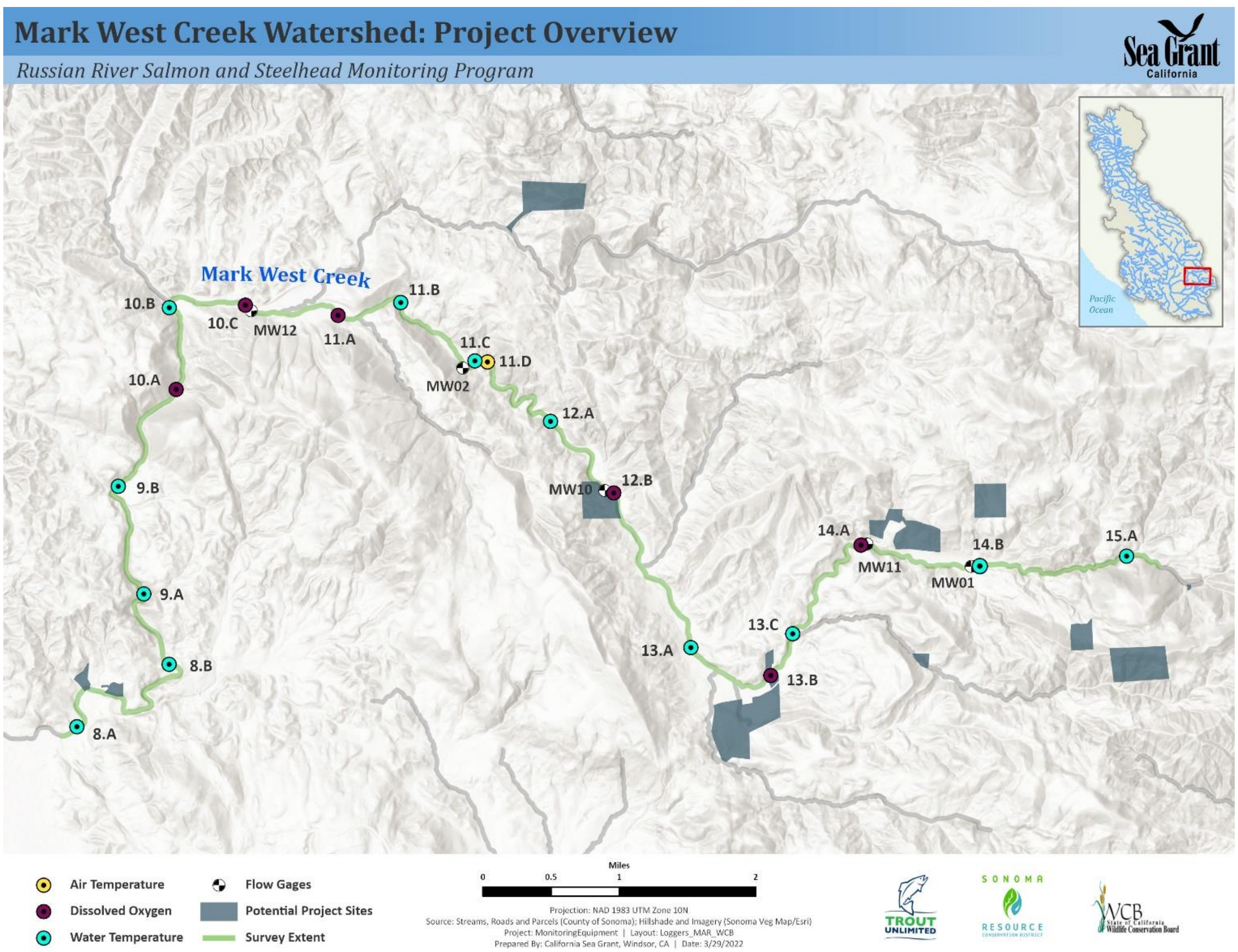

Figure 1. Project overview map, including wetted habitat survey extent, continuous water quality logger monitoring locations, flow gages and Sonoma Resource Conservation District's potential project sites.

2. Fire

The Mark West Creek watershed has experienced two recent wildfires, the Tubbs Fire and the Glass Fire (Figure 2), that have had devasting impacts on the landscape. In October 2017 the Tubbs Fire burned almost 37,000 acres and over 5,600 structure in Sonoma County (https://wildfiretoday.com/tag/tubbs-fire/), including the middle – upper portion of the Mark West Creek watershed. In September 2020 the Glass Fire burned over 67,000 acres and 1,555 structures in Sonoma and Napa counties (https://abc7news.com/glass-fire-napa-bay-area-wildfire-cal-update/6613102/), including the upper portion of the Mark West Creek watershed. The impact of the fire on streamflow and habitat conditions is largely unknown, and this report describes some of the first empirical data collected and evaluated post fire.

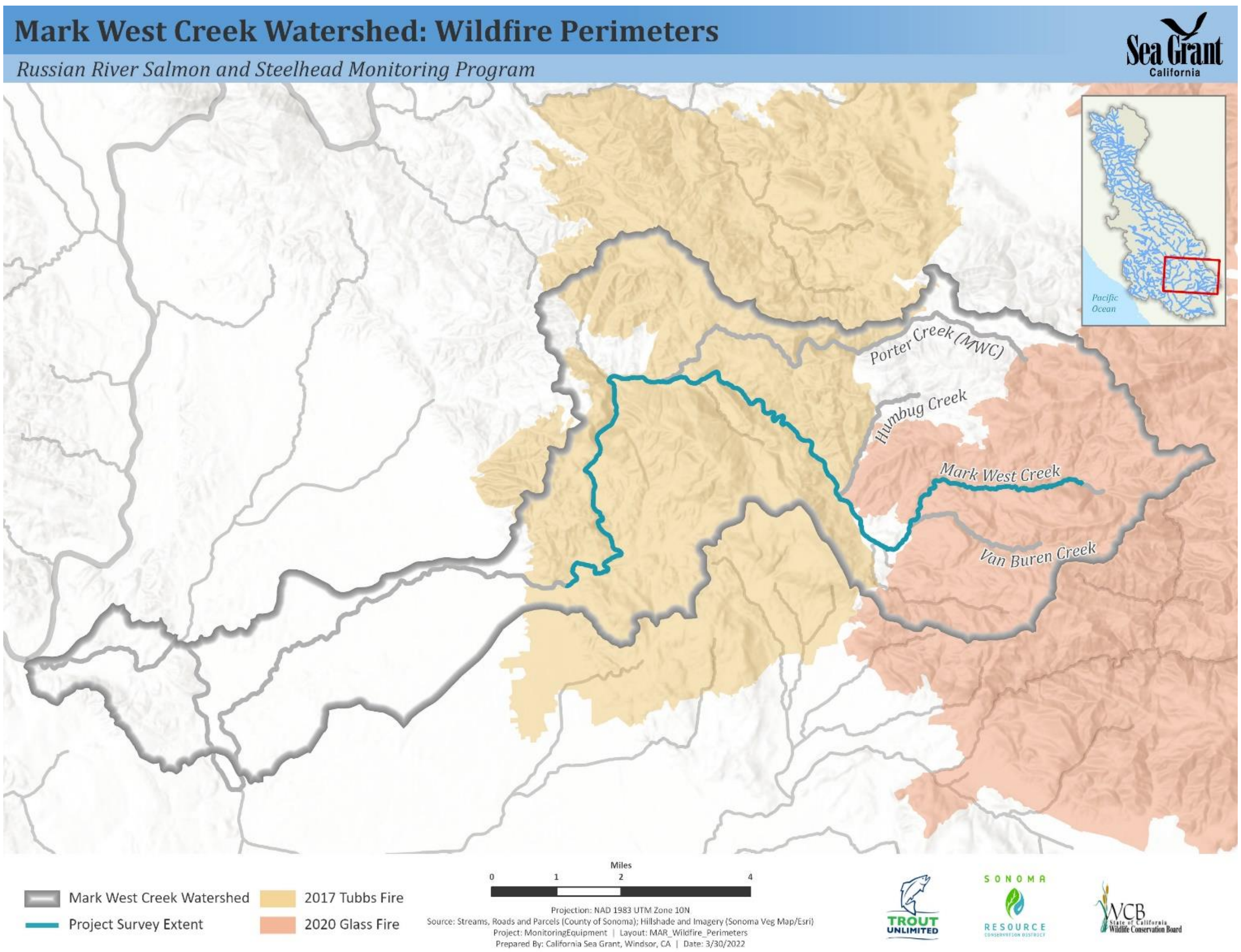

Figure 2. The Tubbs Fire and Glass Fire footprints in relation to the Mark West Creek watershed.

3. Rainfall

The Mark West Creek watershed has a climate like many watersheds in coastal California, and is considered characteristically Mediterranean — with warm, dry summers and cool, wet winters. Precipitation occurs almost exclusively as rainfall, mostly during the wet winter months (November through April).

Rainfall data were recorded over an 80-year period in nearby Healdsburg, CA at National Climatic Data Center (NCDC) Station # 3875 (Healdsburg station, hereafter), along with the median annual rainfall of 37.6 inches (Figure 2). These long-term records indicate that rainfall can be variable from one year to the next. Notably, 2021 was the driest year on record. Over the 80-year period 1941 to 2021, annual rainfall has varied from as low as 15.8 inches (2021) to as much as 83.3 inches (1983), with extended periods of low and of high rainfall throughout the historical record (Figure 2). The drought of 2018–2021 represents one of three periods of below-average rainfall for four or more consecutive years; the others were 1989-1992 and 2012-2015.

Figure 3 shows the average monthly rainfall throughout the year at this station. These data show that 90 percent of the average annual rainfall occurs during the wet half of the year November through April; less than two percent of the average annual rainfall occurs from June through September (Figure 3). While the total amount of rainfall may be variable from one year to the next, the seasonality of precipitation is consistent among all years.

The timing and amount of precipitation can have an effect on summer streamflows. Figure 4 shows the monthly rainfall recorded during each month of the 2021 study period. Rainfall can be variable from month to month, as was the case during the years of the study period, but still follows the general pattern of wet winter months and dry summer months. Studies have shown that rainfall that occurs later in the wet season (March-June) can have the effect of prolonging summer flows. In WY2021, rainfall was below average in all months.

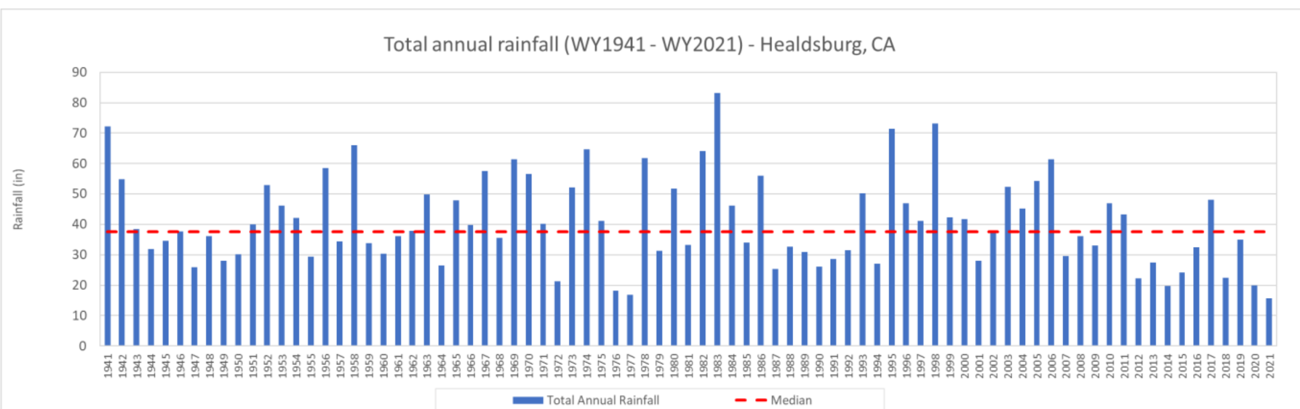

Figure 3. Total and median annual precipitation recorded in Healdsburg, CA (1941-2021) from NCDC station 3875.

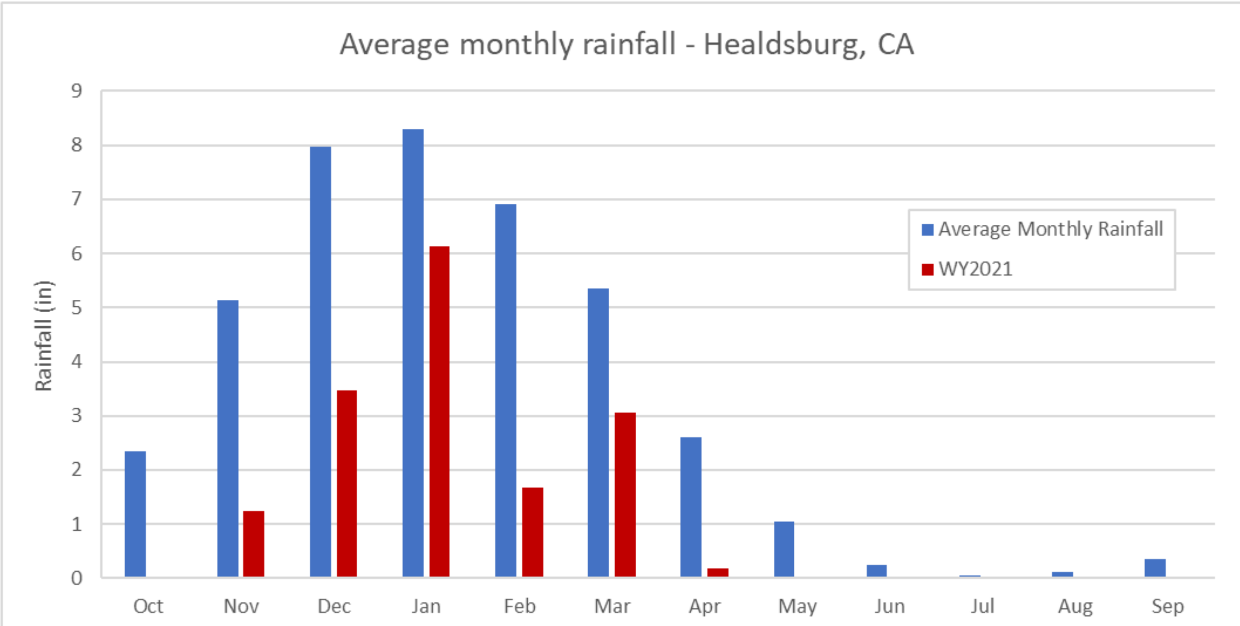

Figure 4. Total monthly precipitation in WY2021 vs monthly average rainfall recorded in Healdsburg, CA from NCDC station #3875.

4. Streamflow

Streamflow was monitored at five sites in Mark West Creek from mid-May through late October (Figure 1). Adjusted stage data and discrete discharge measurements were used to develop hydrographs for each of the monitored sites for the study period.

At site MW01 (Mark West Creek below Tarwater Road), stage slowly decreased from mid-May to early August, with slight rises in stage occurring during the recession (Figure 5). It leveled out in late July and remained low through mid-September before rising slightly in late September and October. The atmospheric river storm event on October 24 caused stage to increase by almost 0.1 ft.

Streamflow in May 2021 was between approximately 0.4 and 0.5 ft^3/sec at site MW01, below Tarwater Road (Figure 6). Flow slowly decreased in June, before rising again slightly in mid-July. Flow reached a low baseflow of about 0.2 ft^3/sec in late July, and remained low until mid-September, when flow began in rise slightly again, and then spiked due to the late-October storm.

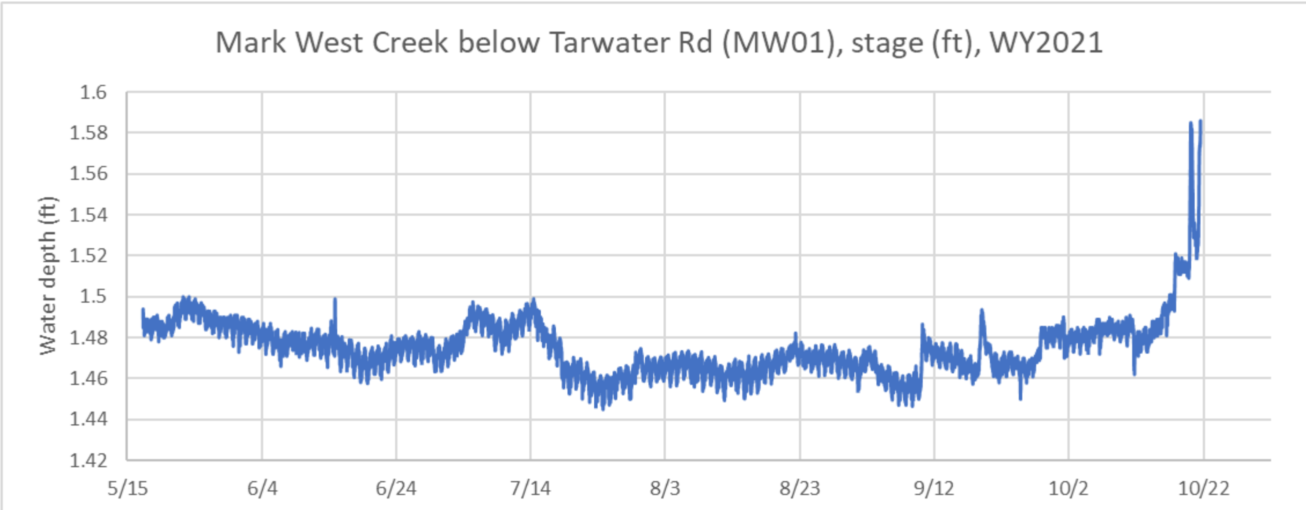

Figure 5. Stage at Mark West Creek below Tarwater Road, WY2021.

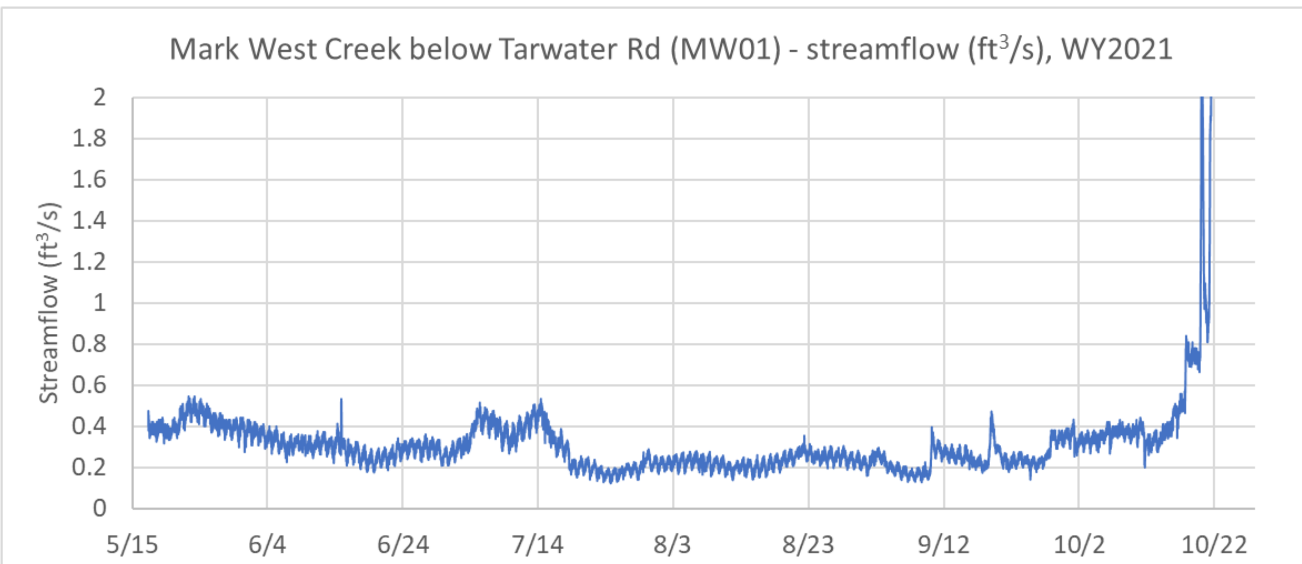

Figure 6. Streamflow at Mark West Creek below Tarwater Road, WY2021.

Stage at site MW02 (Mark West Creek above Porter Creek) decreased slowly from mid-May through mid-July (Figure 7). It dropped more quickly in late July and remained low through late September, aside from some brief increases. In late September through mid-October, stage slowly rose again, and then rose quickly in response to the late October storm.

Streamflow in May through early June 2021 was approximately 0.2 ft^3/sec (Figure 9). Flow rose and fell slightly until early July, when it dropped more steeply before drying out in late July. Flows were intermittent through

September, rising slightly at times between dry periods. In October, flows rose slightly before responding to the late October storm.

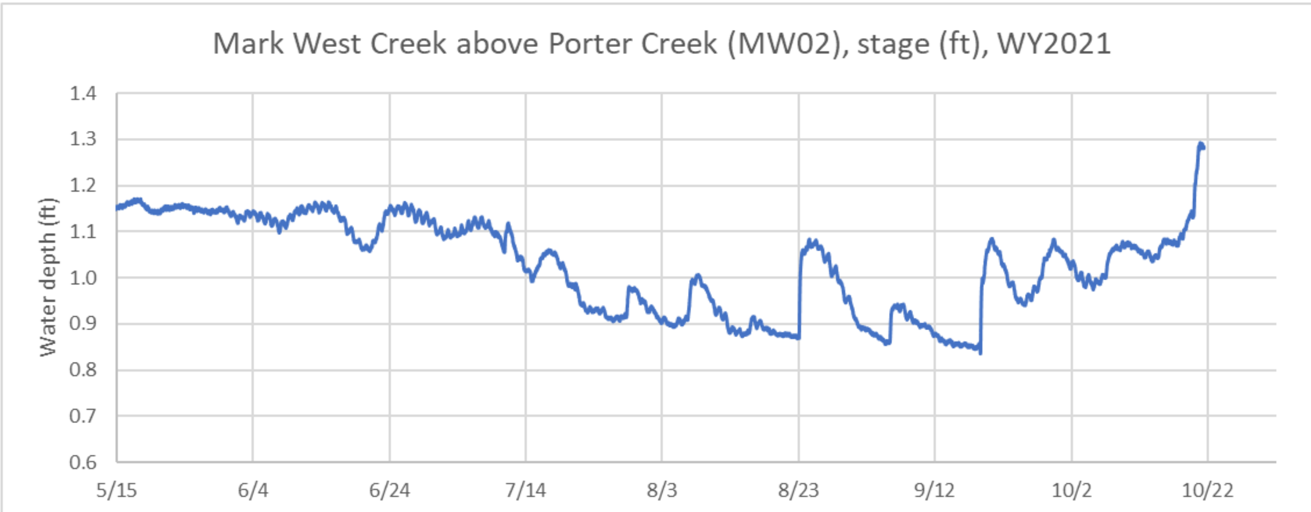

Figure 7. Stage at Mark West Creek above Porter Creek, WY2021.

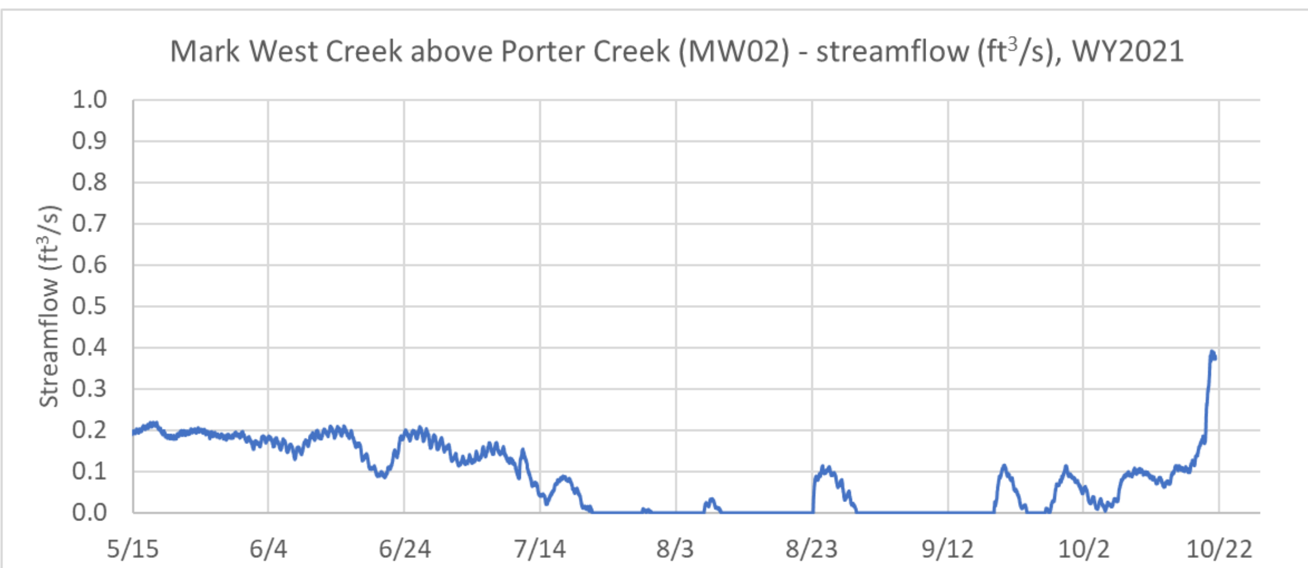

Figure 8. Streamflow at Mark West Creek above Porter Creek, WY2021.

As with other sites, shows stage slowly decreased from mid-May to mid-July, with slight rises in stage occurring during the recession, at site MW10 (Mark West Creek below Humbug Creek) (Figure 9). Stage leveled out in late July and remained low through mid-September, with slight dips and rises observed. Stage rose slightly in late September through October, and spiked in response to the October 24 rainstorm.

Streamflow below Humbug Creek in May 2021, at MW10, was around 1.2 ft^3/sec, before it dropped to a baseflow of about 0.1 ft^3/sec (Figure 10). Slight rises and dips occurred throughout the dry season. Flow began rising in mid-September, and continued to rise unevenly with spikes and dips between 0.2 and 1.0 ft^3/sec observed. Flow increased sharply due to the storm event in late October.

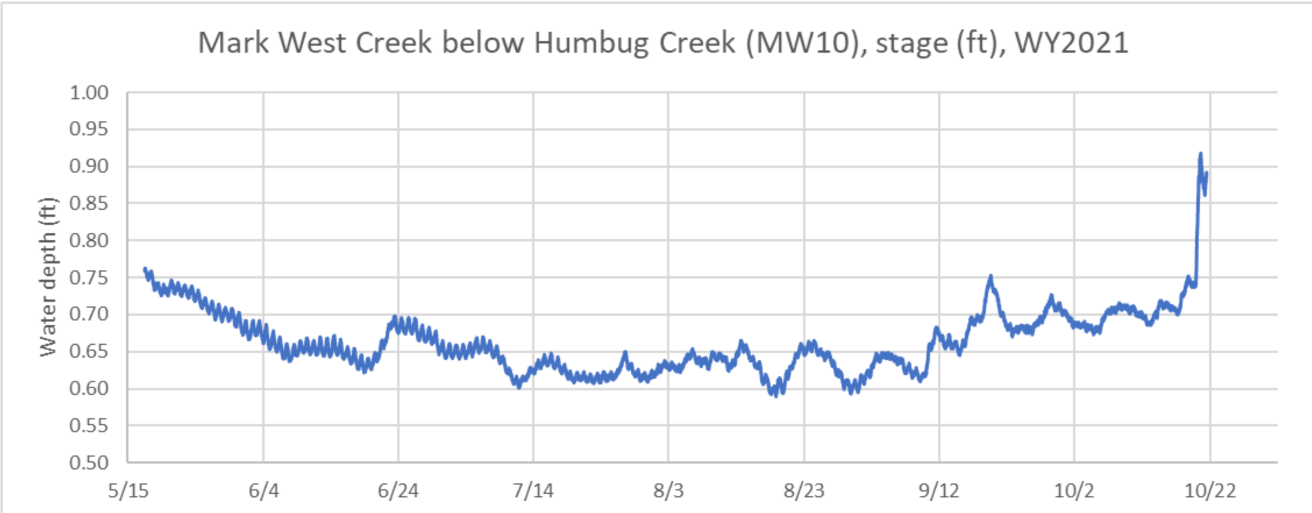

Figure 9. Stage at Mark West Creek below Humbug Creek, WY2021.

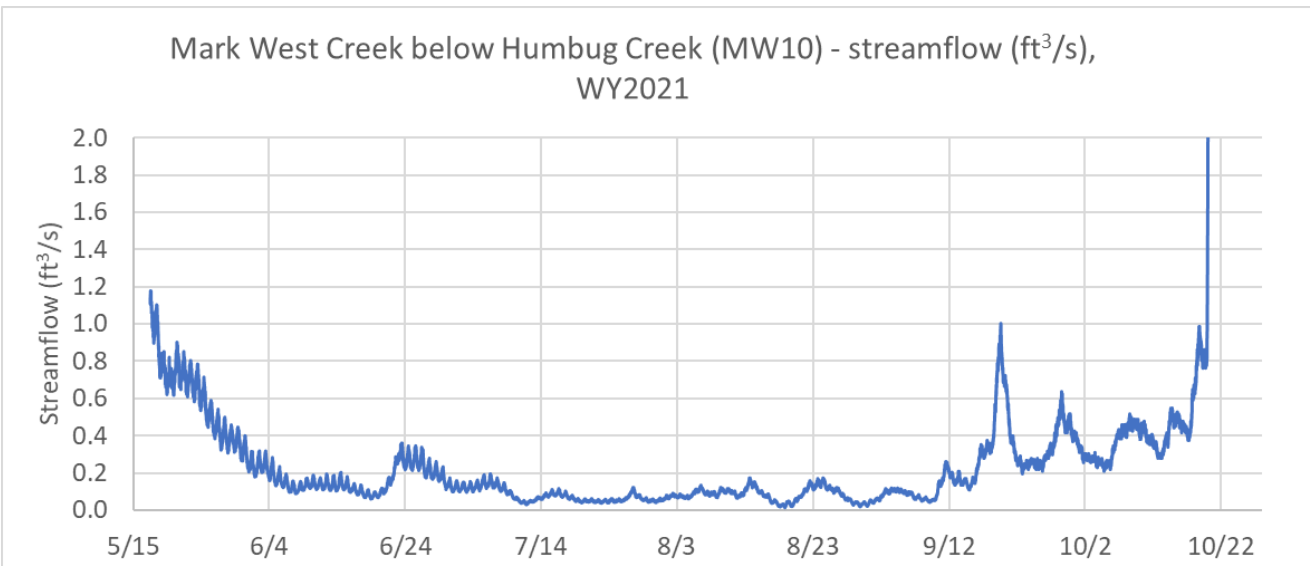

Figure 10. Streamflow at Mark West Creek below Humbug Creek, WY2021.

A gap in data exits in the record at MW11 (Mark West Creek above Ban Buren Creek) due to technological issues in late August to mid-September. However, Figure 11 shows stage slowly decreasing from mid-May to mid-July, with slight rises in stage occurring during the recession. Stage leveled out in late July and remained low through August; from mid-September through late October, stage rose steadily spiking due the large October 24 rainstorm.

Figure 12 shows streamflow at MW11 in mid-May 2021 was approximately 0.6 ft^3/sec. Flow slowly decreased from May to mid-July, with slight rises in flow occurring during the recession. From mid-July through late

August, flow stayed at a low baseflow of about 0.1 ft^3/sec. By mid-September flows had risen to about 0.4 ft^3/sec, before continuing to rise and spiking in late October.

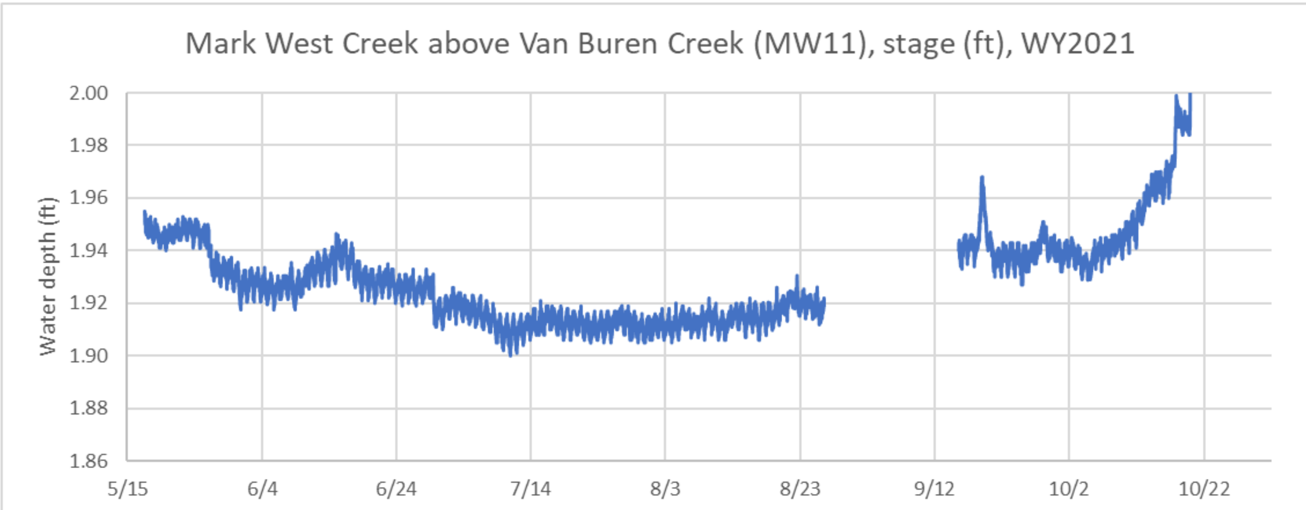

Figure 11. Stage at Mark West Creek above Van Buren Creek, WY2021.

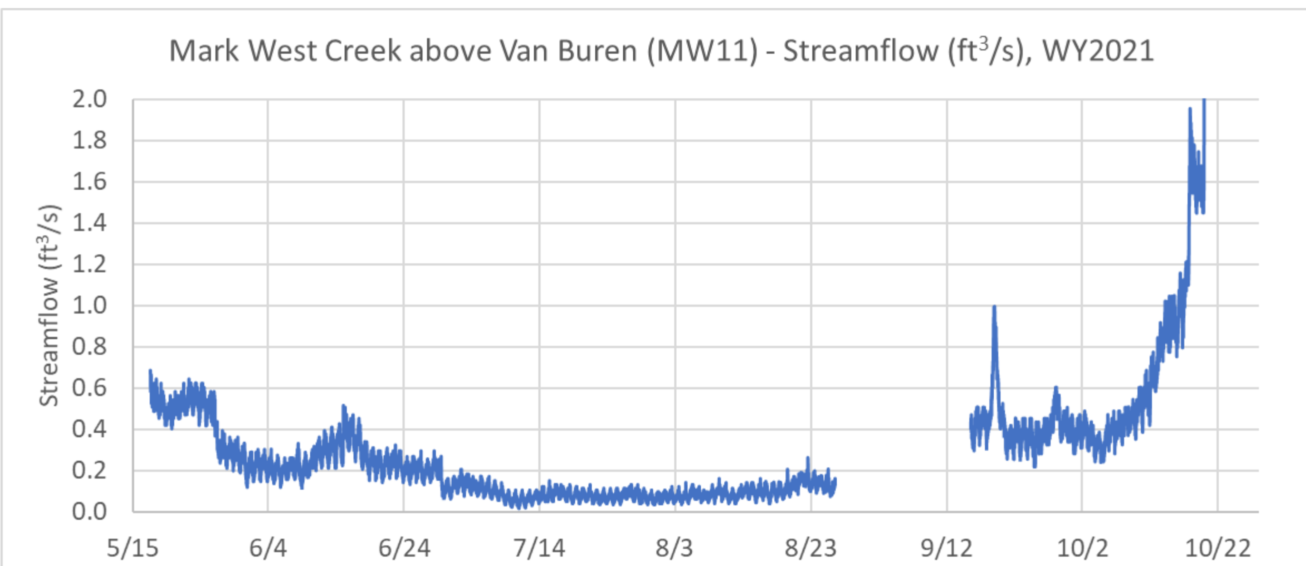

Figure 12. Streamflow at Mark West Creek above Van Buren Creek, WY2021.

Figures 13 and 14 show stage and streamflow throughout the dry season for site MW12 (Mark West Creek below Porter Creek). The period of record at this site extends until October 21, just before the October 24 storm. Figure 13 shows stage decreasing from May through June, then decreasing more slowly from July through August. Slight rises in stage punctuate the recession. As seen at other sites, stage increased in late October.

Streamflow at MW12 in mid-May 2021 was approximately 0.5 ft^3/sec (Figure 14). Flow quickly decreased through July, then reached a very low baseflow of about 0.01 ft^3/sec in August and September. In late September, flow decreased to 0 ft^3/sec and disconnected briefly, before regaining flow in early October.

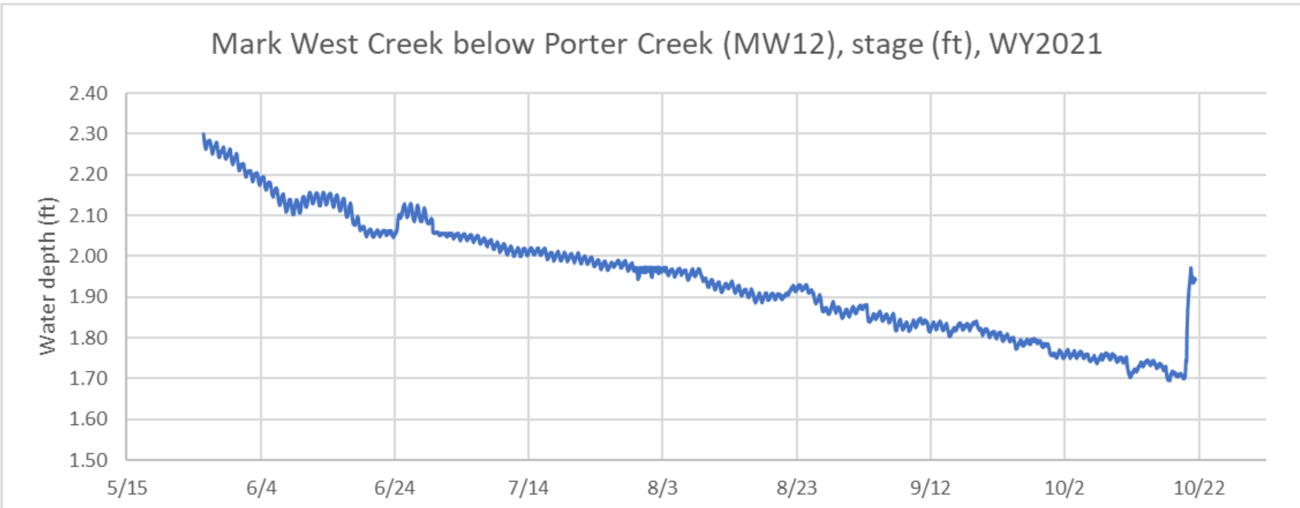

Figure 13. Stage at Mark West Creek below Porter Creek, WY2021.

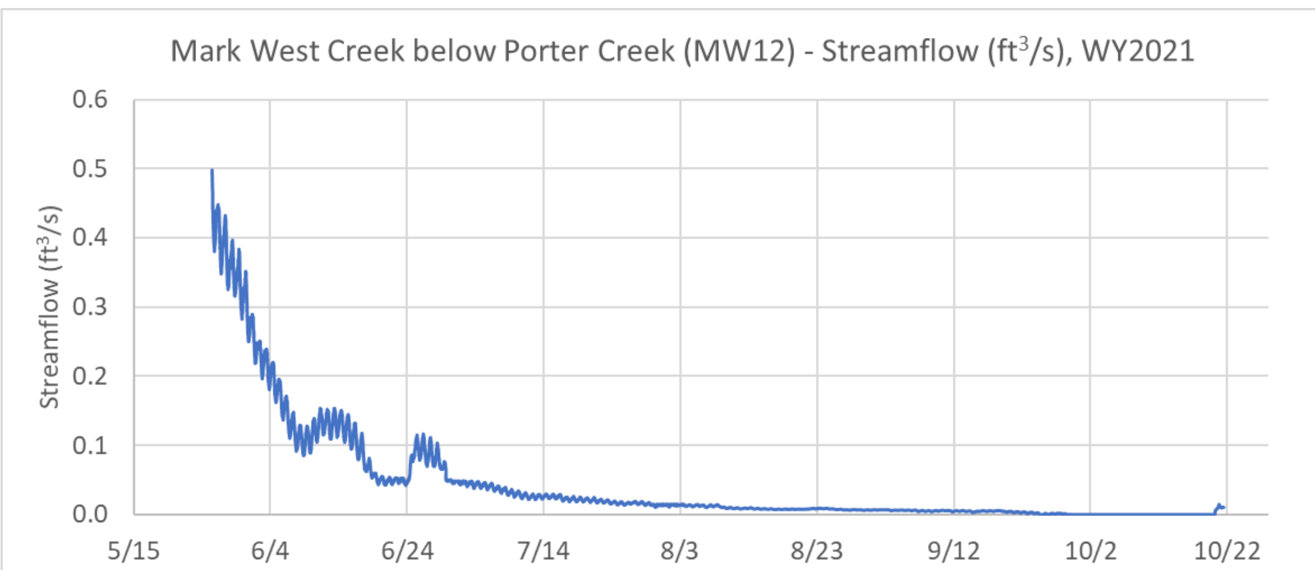

Figure 14. Streamflow at Mark West Creek below Porter Creek, WY2021.

Figure 15 shows streamflow from late March through late September, WY2021, at all sites in the Mark West Creek watershed. In May, streamflow was very low at all sites, below 1.2 ft^3/sec, and lowest at MW02 (Mark West Creek above Porter Creek). Flow slowly decreased and became intermittent at this site, as well as at MW12 (Mark West Creek below Porter Creek). Other sites remained connected at a low summer baseflow. By September, flows began to rebound and the stream reconnected by late October due to the storm.

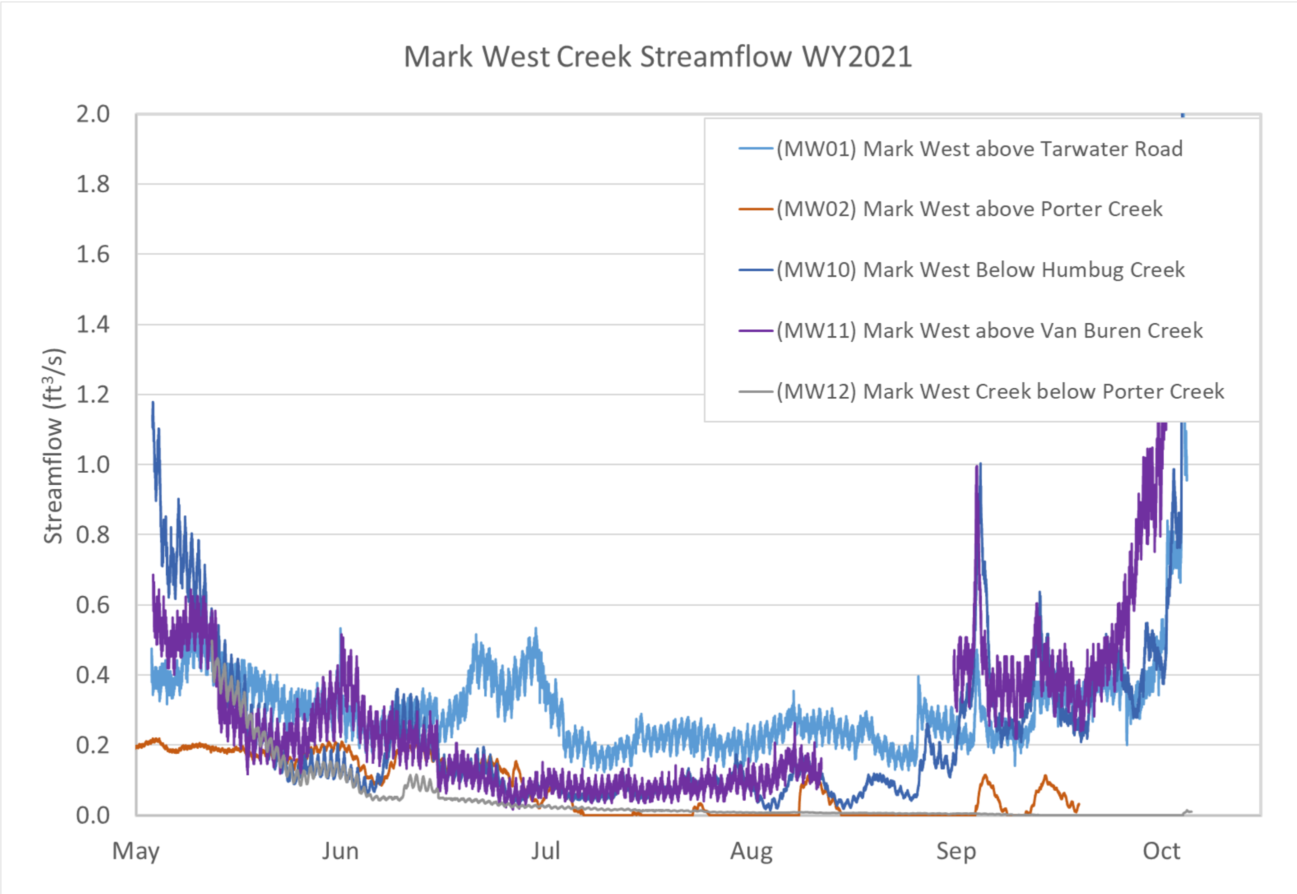

Figure 15. Streamflow at all Mark West Creek sites, WY2021.

5. Wetted habitat

Mark West Creek stream channel conditions were mapped each month over the summer of 2021 using a protocol developed by CSG to document wetted habitat available to fish. Wetted habitat surveys, also referred to as wet/dry mapping, are performed by walking the stream channel and recording wet and dry stream lines on a GPS unit. The lines are later run through a geospatial tool in ArcGIS, where the condition of "intermittent" is assigned to sections of stream with alternating short lengths (<50 feet) of wet and dry lines. Water temperature and dissolved oxygen (DO) concentrations are also measured in wet pools at 5-minute intervals. The full field protocol is available online (California Sea Grant 2021b) and data processing procedures are described in the WCB contract report *Flow and survival studies to support endangered coho recovery in flow-impaired tributaries of the Russian River Basin* (California Sea Grant 2019).

Wetted habitat surveys occurred on June 1-4, July 12-13, August 16-18 and September 13-16, 2021. Surveys began near Wikiup Bridge Way and extended approximately 23.5 km upstream to near Tarwater Road. This extent of stream corresponds to California Coastal Monitoring Program (CMP) reach designations of Mark West 8-14. Final surveys were originally planned for the week of October 25th, but on October 24th, Santa Rosa received almost eight inches of rain in 24 hours—the highest 24-hour rainfall ever recorded for the city (Minkler and Coates 2021). This tremendous amount of rainfall, which caused flooding in some parts of

Sonoma County, caused high flows that prevented crews from being able to safely wade the stream, while reconnecting the entirety of Mark West Creek.

In September, wetted habitat surveys were also conducted by Sonoma Water in Porter, Humbug, Weeks, and Van Buren creeks where landowner access permitted in order to document wet/dry conditions during the driest point of the season.

Data from the June, July, August and September wetted habitat surveys were used to create maps and evaluate changes in wetted habitat conditions over time (Figure 16 – Figure 20). The wetted habitat maps and discrete water quality measurement data for these surveys can be viewed by sample, along with all streams surveyed by CSG in all years, in our online dashboard.

The entirety of the surveyed extent of Mark West Creek was wet during the June 1-4 survey period (Figure 16). During the July 12-13 survey, crews documented 30 locations at which surface flow was disconnected (Figure 17). The most extensive drying was recorded just upstream of the confluence with Porter Creek, where nearly 400 meters were classified as either dry or intermittent. The numerous disconnections downstream and upstream of that area were relatively short, so are barely visible on the map images below, but may be seen in greater detail in the online dashboard. Overall, 2% of the stream was dry, 1% was intermittent and 97% was wet and connected (Figure 20).

By August 16-18, one month later, stream drying in the vicinity of the Porter Creek confluence had worsened (Figure 18). The intermittency in the section upstream of the next unnamed tributary entering on river left (lined in grey on the map) had also increased substantially. For this sample, 5% of the entire stream surveyed was dry, 2% was intermittent and 93% was wet and connected (Figure 6).

Driest conditions were documented September 13-16, though the change observed in the month since the August survey was minimal, with 5% of the stream dry, 3% intermittent and 92% remaining wet and connected (Figure 19 – Figure 20). There was high variability in end-of-season habitat condition between the tributary streams surveyed. The entirety of Weeks Creek (100%) and nearly all of Porter Creek (95%) were dry or intermittent, while 90% of Humbug Creek and 71% of Van Buren Creek remained wet (Figure 21).

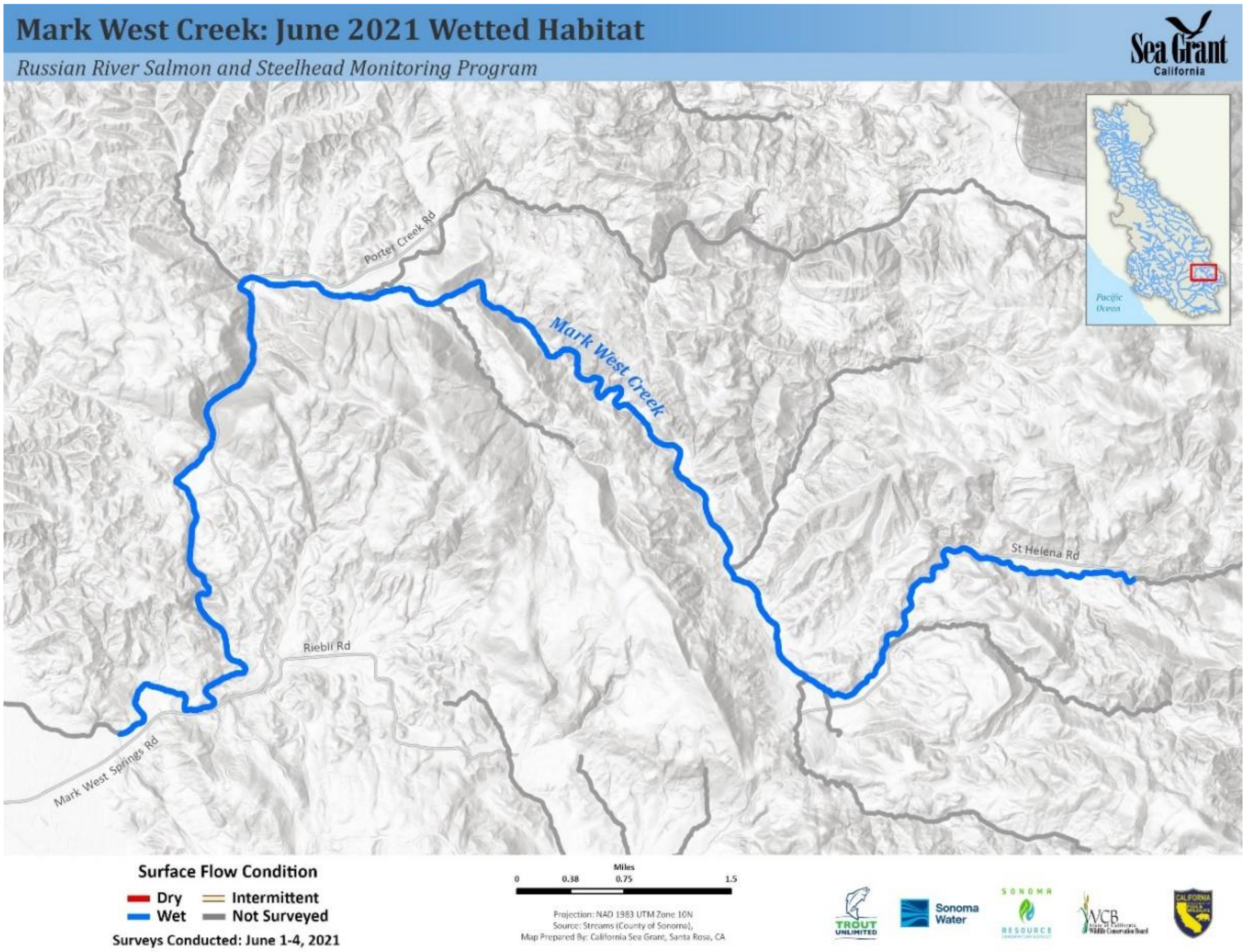

Figure 16. Wetted habitat conditions on Mark West Creek, June 1-4, 2021.

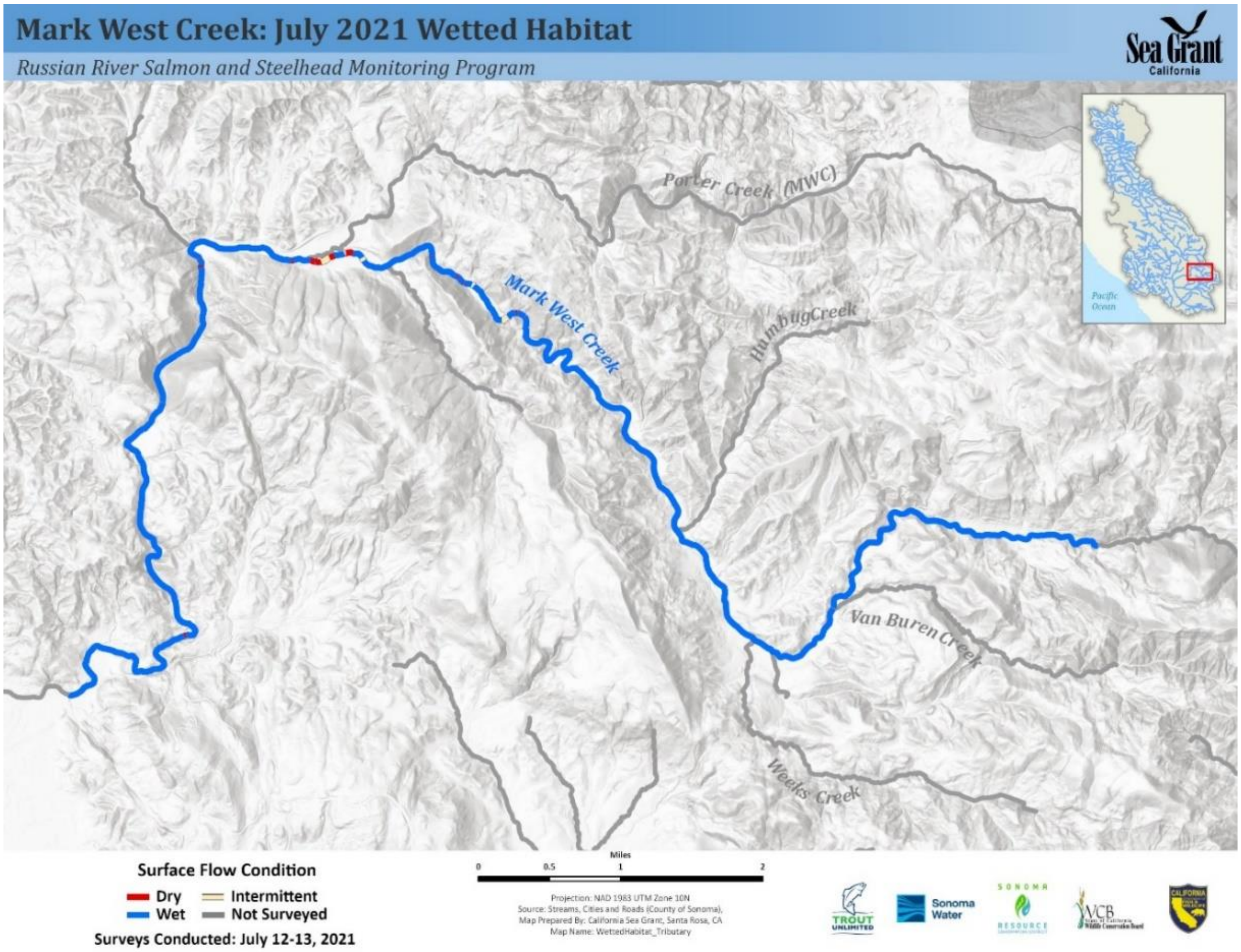

Figure 17. Wetted habitat conditions on Mark West Creek, July 12-13, 2021.

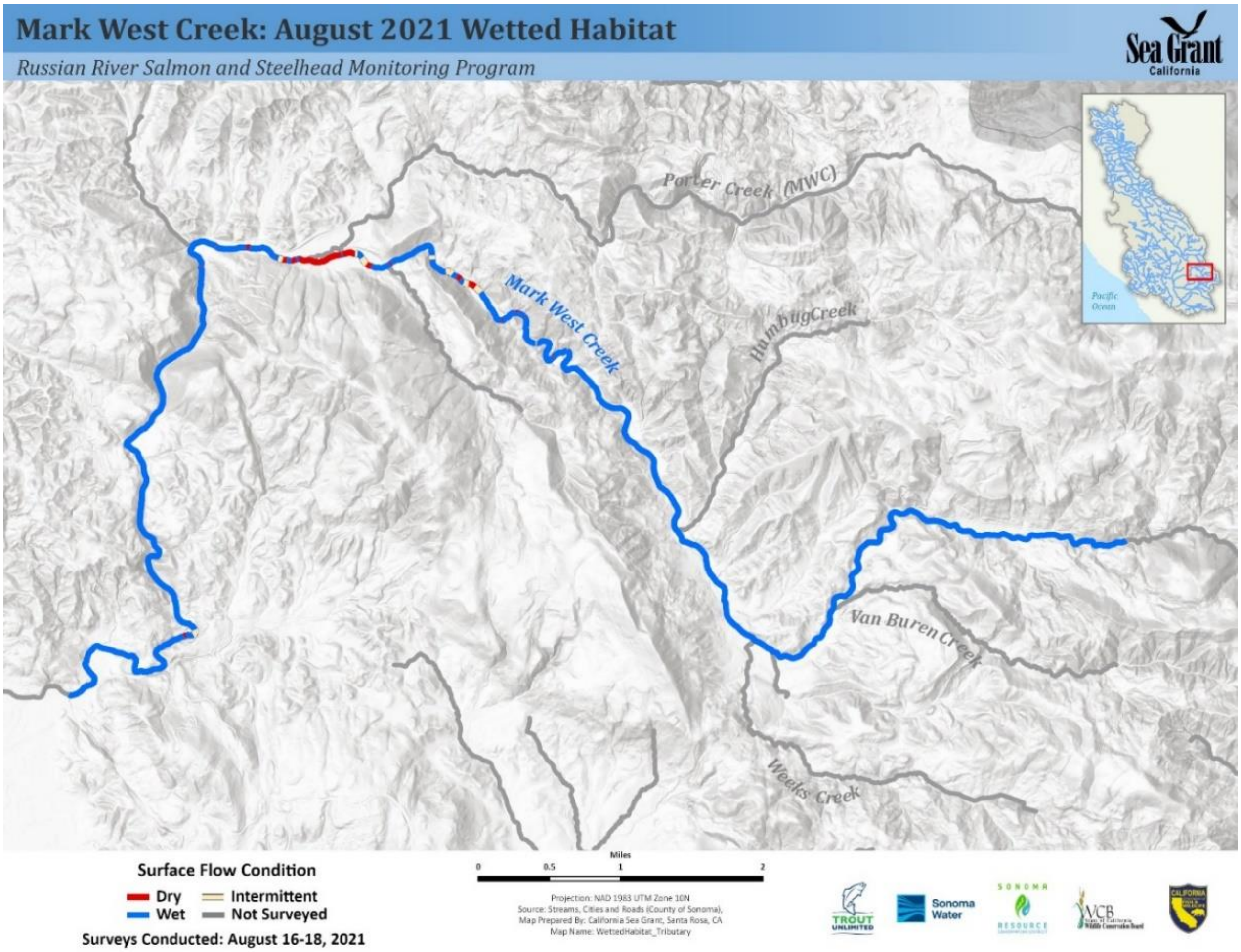

Figure 18. Wetted habitat conditions on Mark West Creek, August 16-18, 2021.

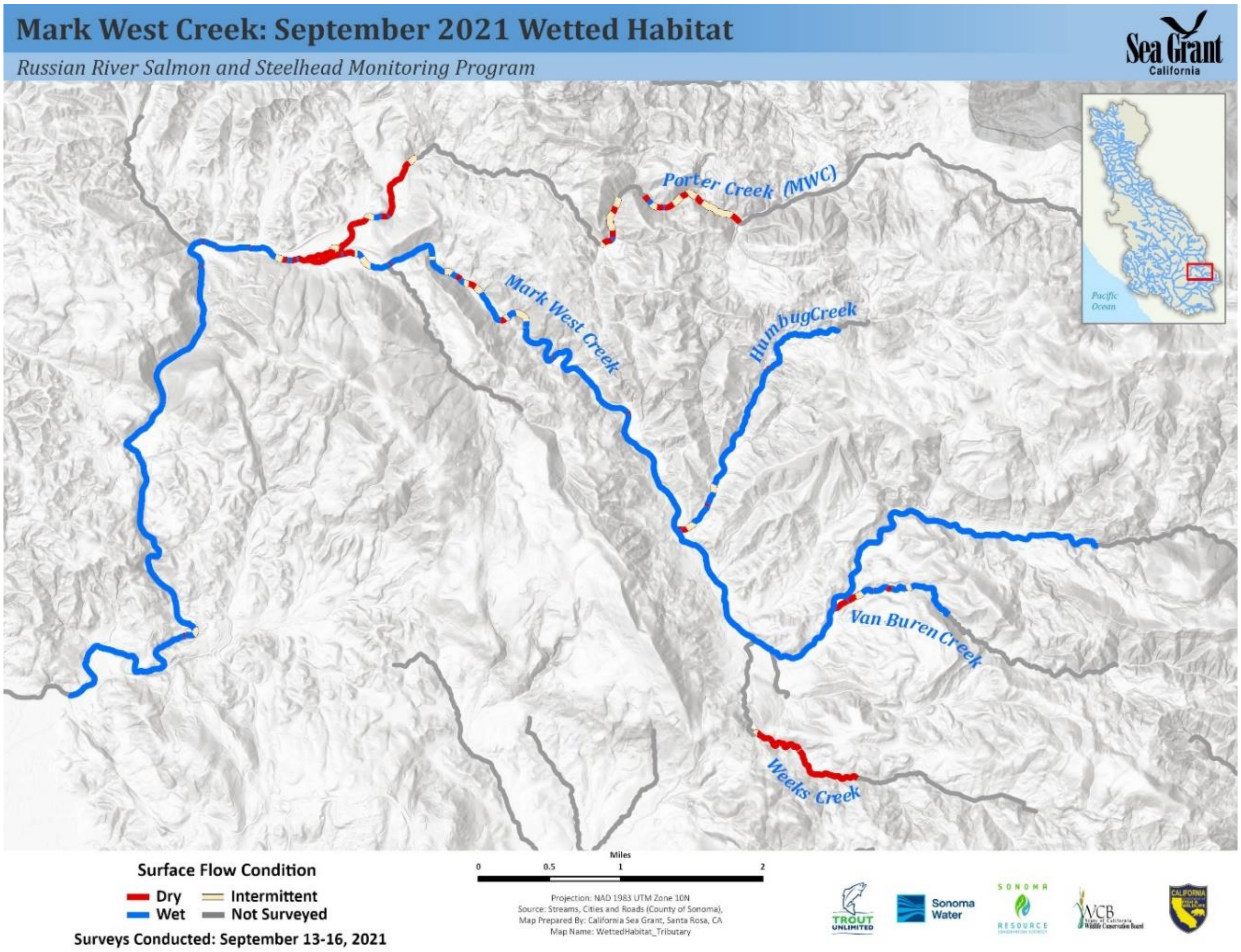

Figure 19. Wetted habitat conditions on Mark West Creek and tributary streams Porter, Humbug, Weeks and Van Buren creeks, September 13-16, 2021.

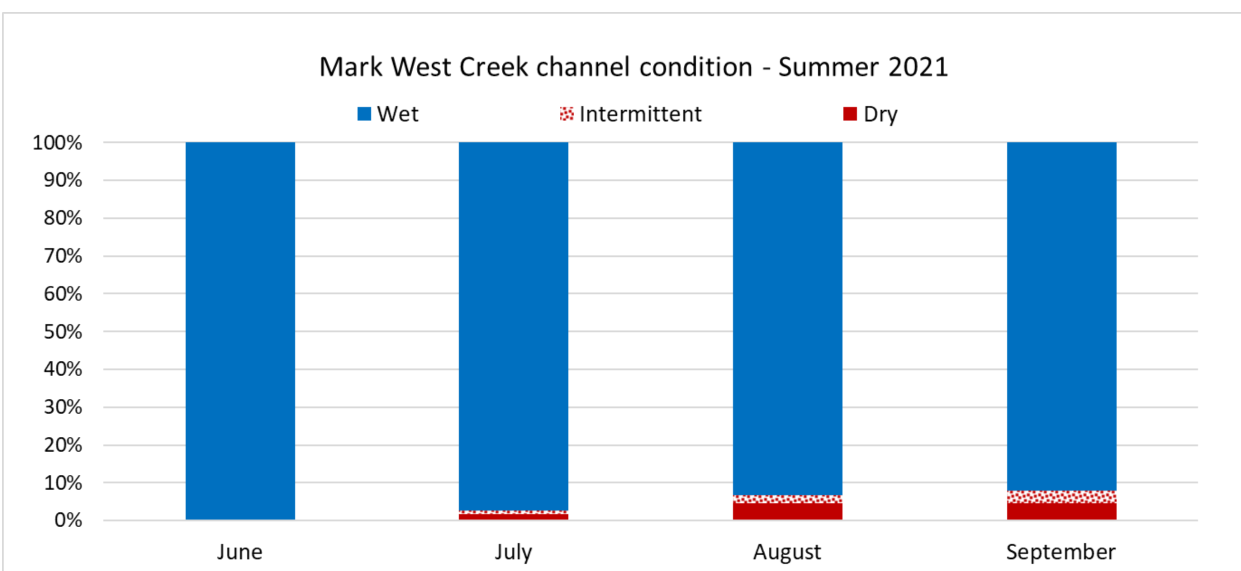

Figure 20. Total proportion of wet, dry and intermittent habitat present in Mark West Creek on June 1-4, July 12-13, August 16-18 and September 13-16, 2021.

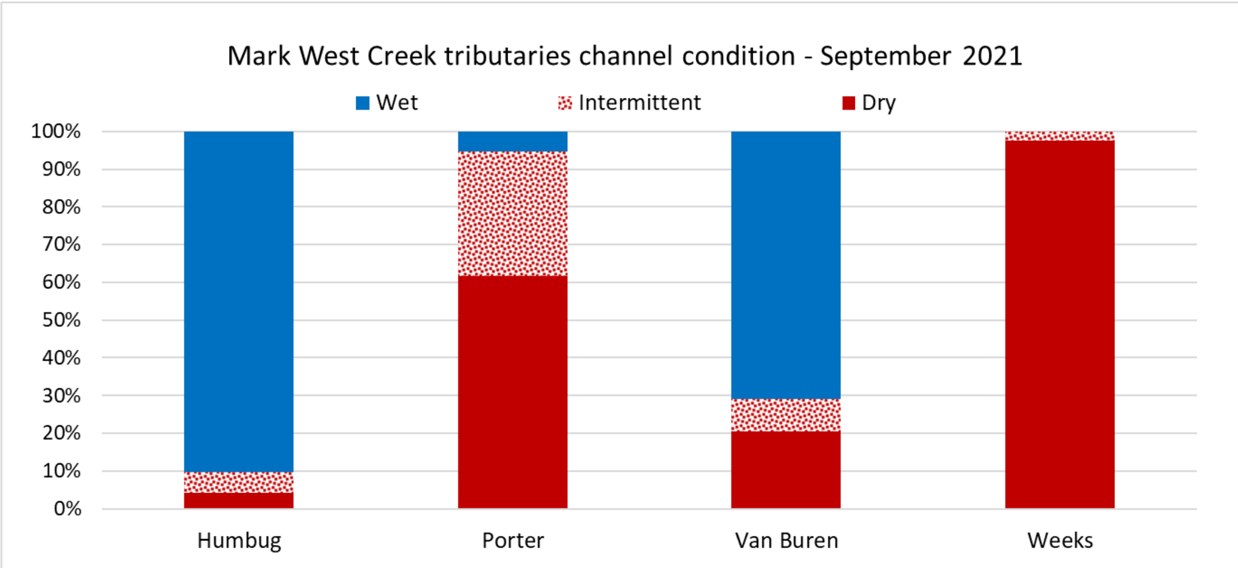

Figure 21. Total proportion of wet, dry and intermittent habitat present in Humbug, Porter, Van Buren and Weeks creeks on September 13-16, 2021.

6. Salmonid distribution in relation to wetted habitat

6.1 Salmonid redds

In the winter of 2020/21, spawner surveys were conducted in Mark West Creek by CSG and Sonoma Water for the California Coastal Monitoring Program (CMP), with financial support from California Department of Fish and Wildlife. Survey methods followed procedures outlined in *Russian River Coho Salmon and Steelhead Monitoring Report: Winter 2020/21* (California Sea Grant 2021a). No spawner surveys were conducted in tributaries to Mark West Creek.

A total of 37 salmonid redds were observed in the monitored reaches of Mark West Creek (California Sea Grant 2021a). Approximately one quarter of those were downstream of the confluence with Porter Creek. The redd distribution data were spatially joined with the late-summer wetted habitat data from the driest sample (September) in order to evaluate the suitability of summer rearing habitat in relation to spawning activity. Of all redds observed in Mark West Creek, two were identified as coho salmon, six as unknown salmonids and 31 as steelhead. Two of those redds were seen downstream of the wetted habitat survey reach. Of the 37 redds within the wetted habitat survey extent, 32 (86%) were in locations that remained wet through the 2021 dry season (Figure 22). However, one steelhead redd was in an area that became intermittent and a total of four redds (three steelhead and one unknown salmonid) were in locations that dried completely.

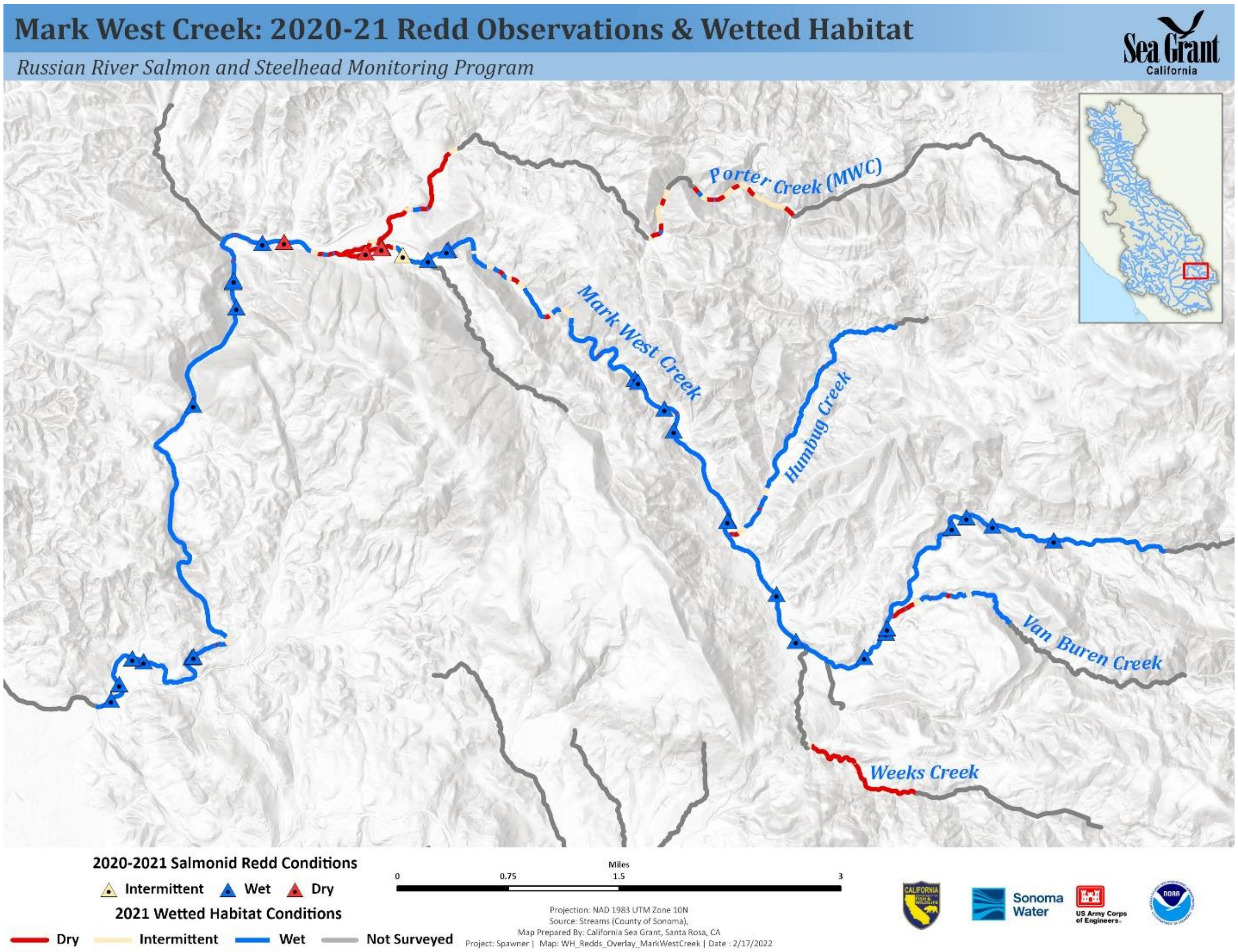

Figure 22. Winter 2020/21 Mark West Creek redd locations in relation to late-summer 2021 wetted habitat conditions.

6.2 Juvenile salmonids

In July and August, snorkeling surveys were conducted by CSG and Sonoma Water to document the relative abundance and spatial distribution of coho salmon and steelhead young-of-the-year (yoy) in Mark West Creek. CMP reaches 9-14 were snorkeled for the CMP effort and additional surveys were conducted in reaches 8 and 14 specifically to support this project. Coho salmon and steelhead yoy were counted in every second pool using methods outlined in *Coho Salmon and Steelhead Monitoring Report: Summer 2021* (California Sea Grant 2022). No snorkeling surveys were conducted in tributaries to Mark West Creek.

The majority of coho yoy were documented in the lower sections of Mark West Creek, though in very low densities. Twenty-three coho salmon yoy and 203 steelhead yoy were counted in every second pool of CMP reaches 8-15 of Mark West Creek during the summer 2021 snorkeling surveys. These numbers were used to generate an estimate of 46 coho and 406 steelhead throughout all reaches surveyed.

Juvenile salmonid distribution data were spatially joined with the September wetted habitat data (the driest sample of 2021) and the total proportion of all yoy counted in each habitat condition — wet, dry and intermittent — was calculated in order to estimate the effect of stream drying and wetted habitat condition on juvenile rearing fish. Overall, 92% of all salmon and steelhead yoy observed were seen in pools that stayed wet and connected, with just 8% in locations that became dry or intermittent (Figure 23).

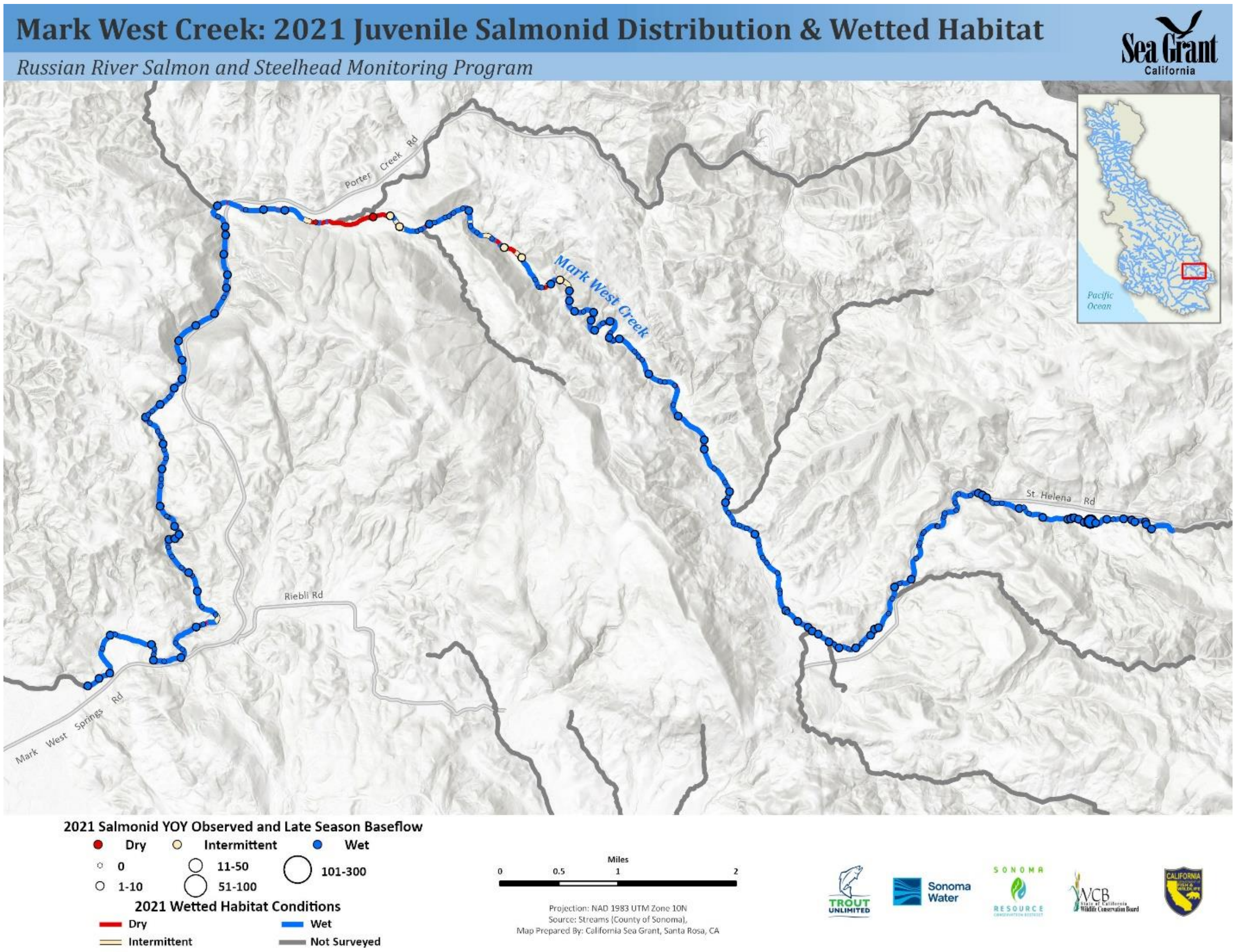

Figure 23. Summer 2021 Mark West Creek salmonid young-of-the-year observations in relation to September 2021 wetted habitat conditions.

7. Water quality monitoring

Continuous dissolved oxygen (DO) loggers, which also measure temperature, were deployed in six pools throughout the survey reaches of Mark West Creek, noted by river kilometer in Table 1. These Onset U26 loggers measured DO concentrations and water temperatures at 15-minute intervals from mid-May through late October. The logger deployment pools were selected to generally represent conditions in the surrounding area, though it should be noted that DO concentrations are generally site-specific, particularly under low flow conditions. Three of the DO loggers were placed in the same location as TU flow gages, with the intention of comparing DO and streamflow over the course of the project.

Twelve continuous water temperature loggers were also deployed in the survey reaches, with locations noted by river kilometer in Table 1. Considerations for the site selection included data gaps described by O'Connor Environmental Inc. (Kobor et al. 2020), as well as spatial distribution. One continuous logger was deployed to measure air temperature near the center of the surveyed extent.

Data calibration and processing procedures are described in the WCB contract report *Flow and survival studies to support endangered coho recovery in flow-impaired tributaries of the Russian River Basin* (California Sea Grant 2019).

Due to the immense amount of rainfall and subsequent rapid stream level rise that occurred during the atmospheric river event in late October, one DO logger and five temperature loggers were washed out. The loggers lost in this storm event are shaded in grey in Table 1. Complete datasets were obtained from all other loggers, except for the DO logger at site 10.A, which was erroneously set to 5-minute sampling intervals and consequently ran out of battery early in the season.

Suitable DO concentrations, which generally decrease under low flow conditions during the dry season, are essential for fish survival and fitness. The North Coast Regional Water Quality Control Board (NCRWQCB) has listed 6.0 mg/L as a daily minimum DO objective for the Russian River Hydrologic Unit (NCRWQCB 2015); decreases in swimming speed and growth rate occur below this concentration (U.S. Environmental Protection Agency 1986). Juvenile salmonids consistently avoid waters with DO concentrations below 5.0 mg/L (Washington State University Department of Ecology 2002). The lower limit to avoid mortality in salmonids is 3.0 mg/L (U.S. Environmental Protection Agency 1986), though juvenile fish have been observed surviving in lower concentrations within Russian River streams (Obedzinski et al. 2018). Continuous DO data from the summer period were compared to the 6.0 mg/L minimum daily objective and the 3.0 mg/L salmonid mortality threshold in order to evaluate conditions experienced by juvenile salmonids.

The optimum summer water temperature range for juvenile coho salmon is 10° to 15°C (McMahon 1983). At water temperatures greater than 20°C, significant decreases in swimming speed and increases in mortality due to disease have been noted, and water temperatures exceeding 25.5°C are lethal to coho (McMahon 1983). In the nearby Mattole River watershed, coho salmon were not present in suitable rearing habitat when the maximum weekly average temperature (MWAT) exceeded 16.7°C and maximum weekly mean temperature (MWMT) exceeded 18°C (Welsh et al. 2001). We chose to summarize the continuous water temperature in comparison to the 18°C avoidance threshold described in the Mattole River study due to the geographic proximity of that watershed to the Mark West system in the southern end of the coho salmon native range.

Continuous DO concentrations in Mark West Creek were variable between sites, as illustrated by the heat map showing summarized data trends over time (Figure 24). The furthest upstream site, 14.A, consistently had the highest concentrations, frequently exceeding 9.0 mg/L. Site 10.C, located downstream of the confluence with Porter Creek, experienced DO impairment through the vast majority of the sample period. Sites 12.B (Figure 24, Figure 27) and 13.B experienced considerable variation between and within days. For the duration of data collection at the furthest downstream site, 10.A (through late July), values did not fall below the objective threshold for DO and were most similar to values observed at the furthest upstream site, 14.A.

Daily minimum DO was well above 6.0 mg/L in all sample pools when the loggers were deployed in late May, but in early June began to differ between sites (Figure 25). Daily minimum concentrations decreased sharply at all sites in late June, corresponding to a heat wave, but rebounded at 10.A and 14.A. Daily minimum concentrations began to improve at all sites, other than 10.C, in mid-September.

Site 14.A was the only location (with a complete dataset) to maintain daily minimum concentrations above the NCRWQCB objective throughout virtually the entire season, falling below 6.0 mg/L on just two days in August (Figure 26). These low concentrations occurred so infrequently that they did not comprise a full percentage of the total number of 15-minutes measurements, therefore 100% of the samples were at or above the objective (Table 2).

Sites 12.B and 13.B experienced substantial fluctuations in daily minimum DO concentrations from day to day (Figure 25). Both sites did not meet the regional objective threshold on the majority of sample days (Figure 26), but the majority of continuous 15-minute DO measurements collected over the course of the season were above the regional objective (Table 2). Diurnal fluctuations of DO, which are not visible in the heat map, frequently swung below and then above our reference thresholds, as seen at site 12.B (Figure 27). Of all 15-minute values recorded, 72% at 12.B and 87% of those from 13.B were at or above 6.0 mg/L.

DO concentrations at site 10.C were notably impaired. DO dropped below the 3.0 mg/L mortality threshold in late June and was completely depleted throughout September and October (Figure 25). This site did not meet the minimum daily objective nearly every day of the sample period after late May (Figure 26). Only 13% of all 15-minute values recorded were at or above 6.0 mg/L (Table 3).

Continuous water temperatures also varied by site (Figure 29). In general, sites in the upper reaches of Mark West Creek (above approximate rkm 35) experienced lower temperatures than the sites further downstream. Water temperatures at all sites increased during a heatwave in mid-June, then remained generally high until beginning to decline in September.

Daily maximum water temperatures corresponded with the daily maximum air temperature recorded at site 11.D (Figure 30). The warmest water temperature of the sample period was 25.6 °C, measured at site 9.B on June 18, during the peak of the heatwave in which air temperature reached 38.7 °C.

Overall, site 8.B was the warmest site, followed by 8.A, 9.B and 11.B (Figure 28, Table 3). The coolest sites were 12.A, 13.B and 13.C. All of the sample sites, except for the three coolest (12.A, 13.B and 13.C) experienced daily maximum temperatures above 18° C for the majority of days in the sample period (Figure 30). At site 8.B, daily maximum temperatures exceeded 18° C on 89% of the sample days (141 of 158). The maximum daily water temperature at the coolest site, 13.B, exceeded the avoidance threshold on 30% (48) of sample days. Temperature measurements were above 18 °C for more than half of the continuous 15-minute samples at four of the 12 sites (Table 3).

Table 1. Water quality monitoring sites in Mark West Creek, summer 2021. Dissolved oxygen loggers also measured water temperature. Grey shading indicates loggers for which data were not retrieved due to loss or damage in the late October atmospheric river event.

Site name	Approximate river kilometer	Logger type
15.A	47.91	Temperature
14.B	45.29	Temperature
14.A	44.41	Dissolved oxygen, temperature
13.C	42.74	Temperature
13.B	42.14	Dissolved oxygen, temperature
13.A	40.95	Temperature
12.B	38.56	Dissolved oxygen, temperature
12.A	37.43	Temperature
11.C	35.81	Temperature
11.D	35.81	Temperature (air)
11.B	34.36	Temperature
11.A	33.49	Dissolved oxygen, temperature
10.C	32.26	Dissolved oxygen, temperature
10.B	31.27	Temperature
10.A	30.20	Dissolved oxygen, temperature
9.B	28.70	Temperature
9.A	27.19	Temperature
8.B	26.11	Temperature
8.A	23.61	Temperature

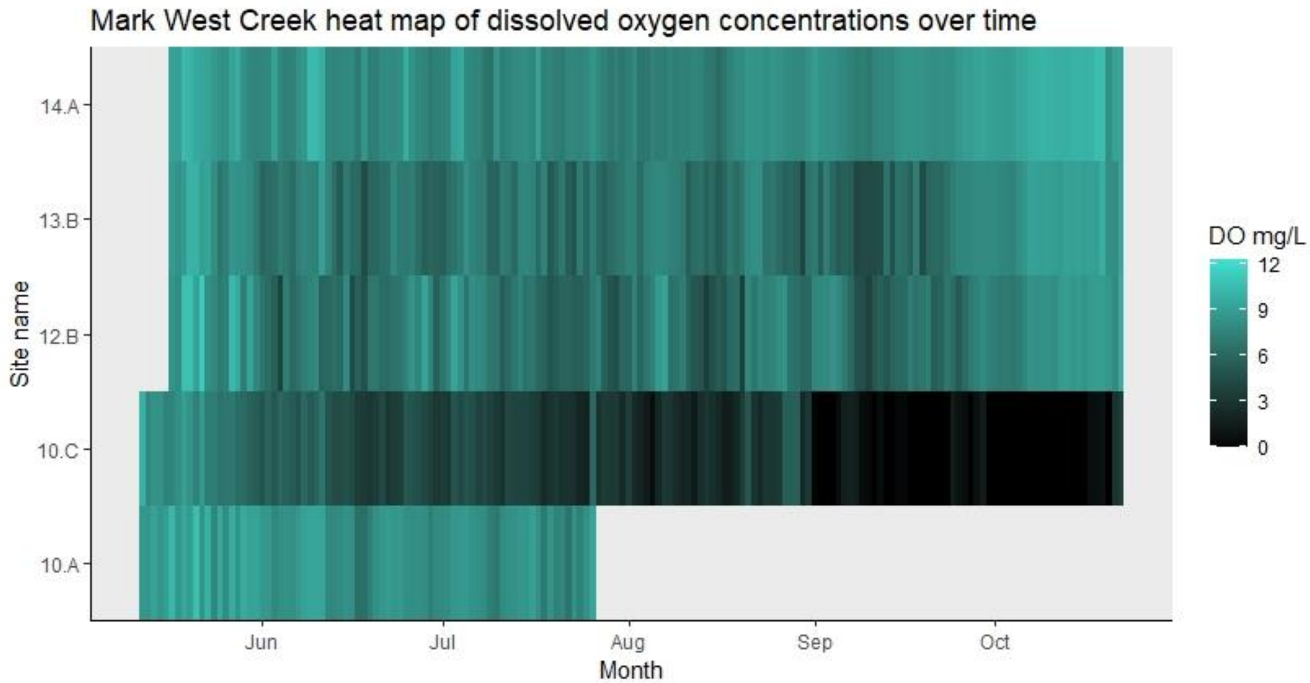

Figure 24. Heat map of dissolved oxygen concentrations at Mark West Creek logger sites, May-October 2021. Sites are in consecutive order from downstream to upstream on the Y axis. Data collection ceased at site 10.A in late July. Lighter shades indicate higher concentrations of DO and darker shades indicate lower concentrations.

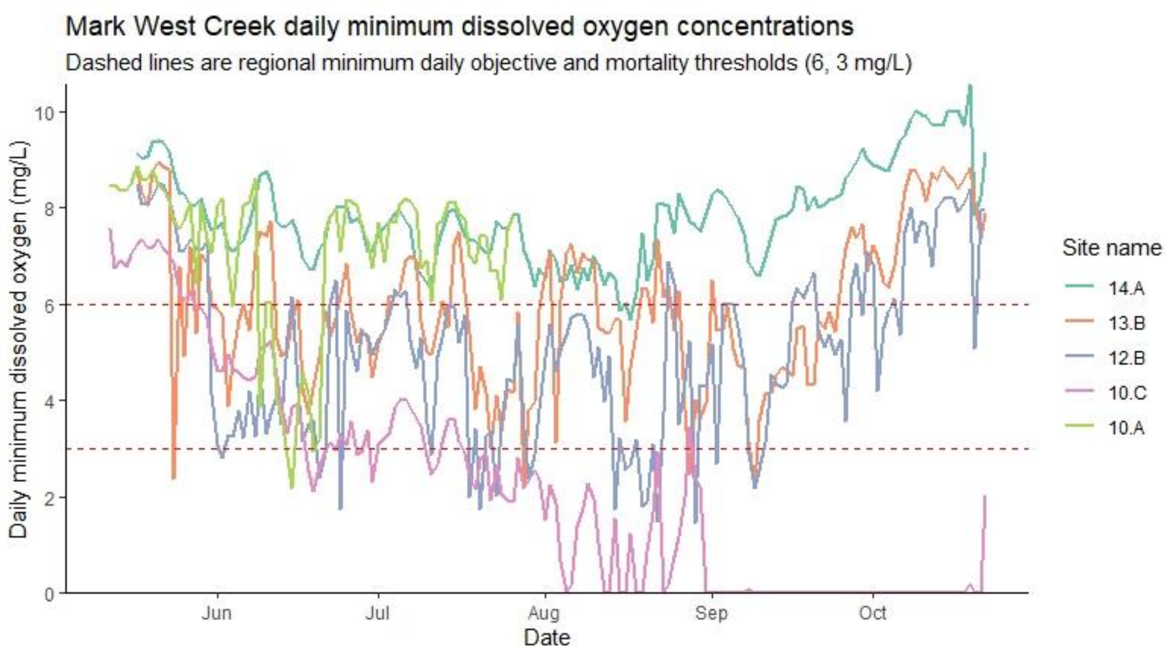

Figure 25. Daily minimum dissolved oxygen at Mark West Creek logger sites plotted with the daily minimum objective of 6.0 mg/L and the mortality threshold of 3.0 mg/L, May-October 2021. Data collection ceased at site 10.A in late July.

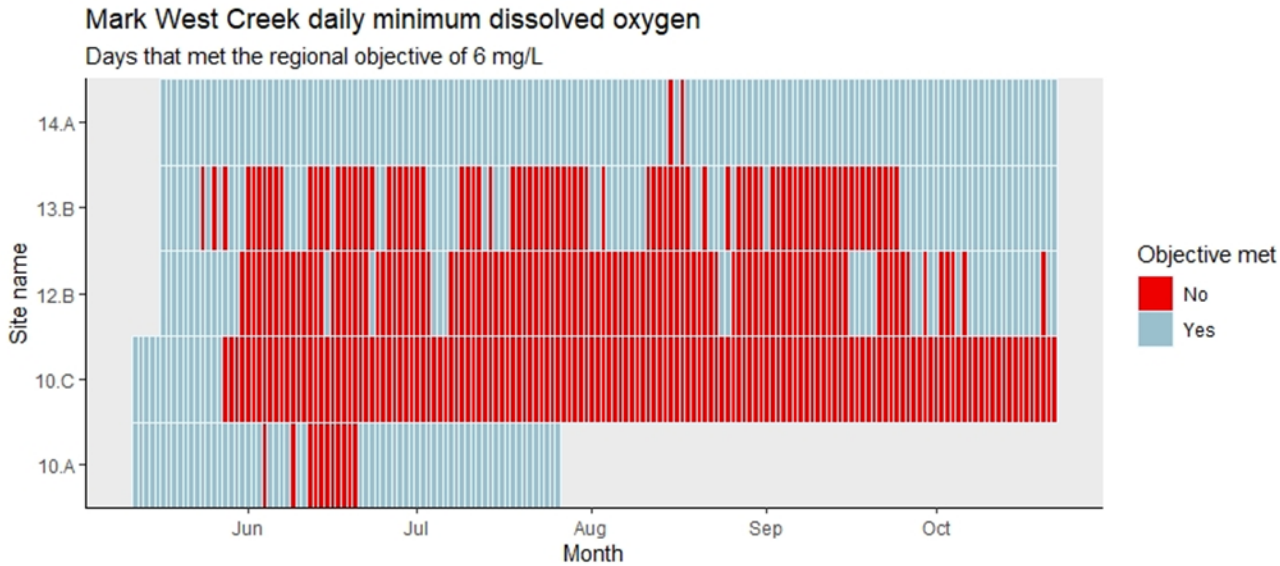

Figure 26. Days in which dissolved oxygen was at or above the daily minimum regional objective at Mark West Creek logger sites, May-October 2021. Sites are in consecutive order from downstream to upstream on the Y axis. Each line represents one day. Data collection ceased at site 10.A in late July.

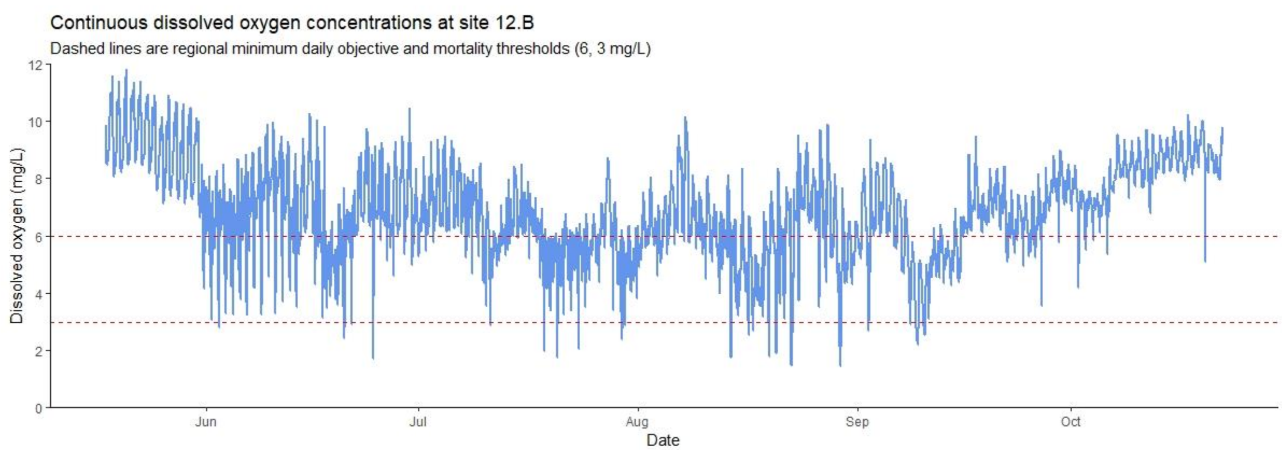

Figure 27. Continuous dissolved oxygen measurements at site 12.B, plotted with the daily minimum objective of 6.0 mg/L and the mortality threshold of 3.0 mg/L, May-October 2021.

Table 2. Proportion of all dissolved oxygen measurements at or above the daily minimum regional objective at Mark West Creek logger sites, May-October 2021. Data collection ceased at site 10.A in late July.

Site name	Percentage at or above 6.0 mg/L
14.A	100%
13.B	87%
12.B	72%
10.C	13%
10.A	99%

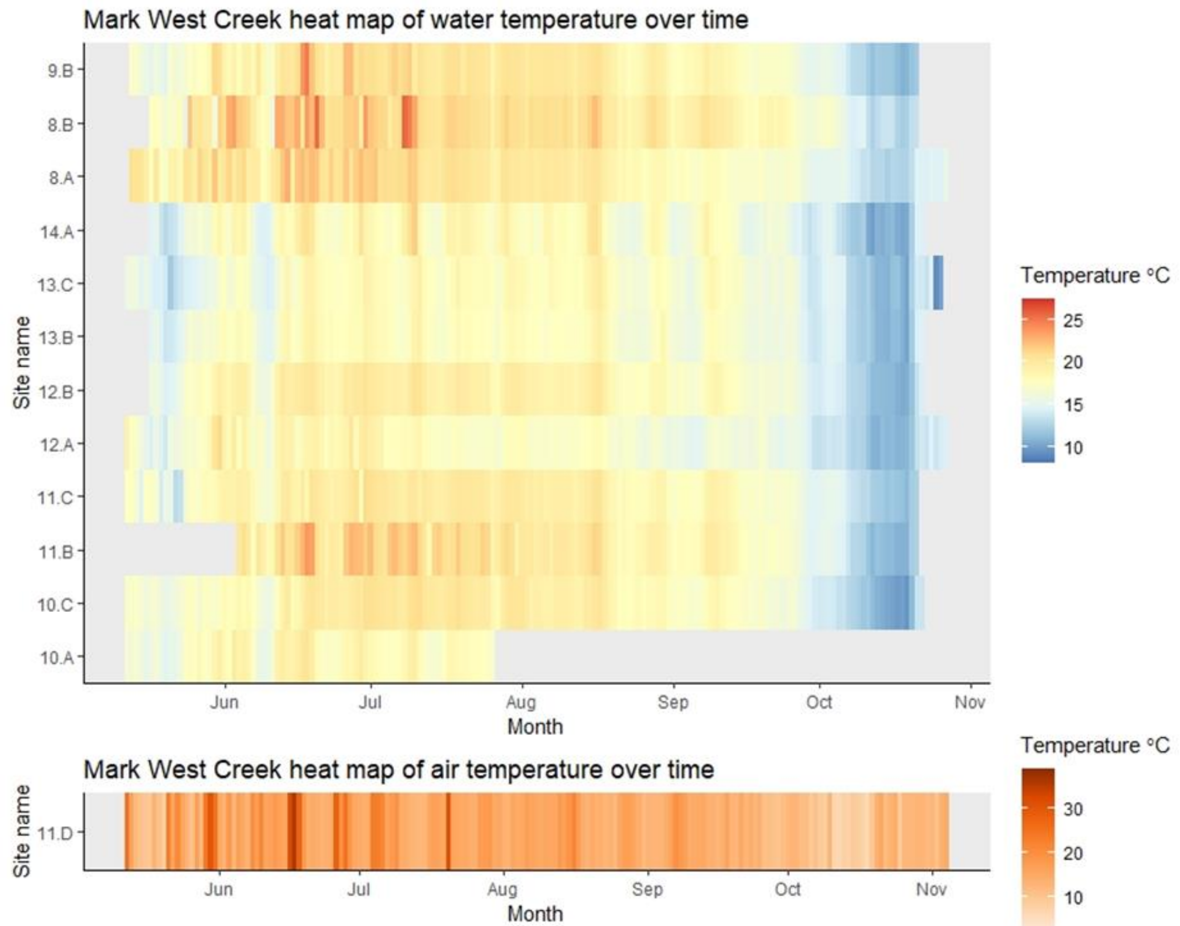

Figure 28. Heat map of water temperatures (above) and air temperature (below) at Mark West Creek logger sites, May-October 2021. Sites are in consecutive order from downstream to upstream on the Y axis. Data collection ceased at site 10.A in late July.

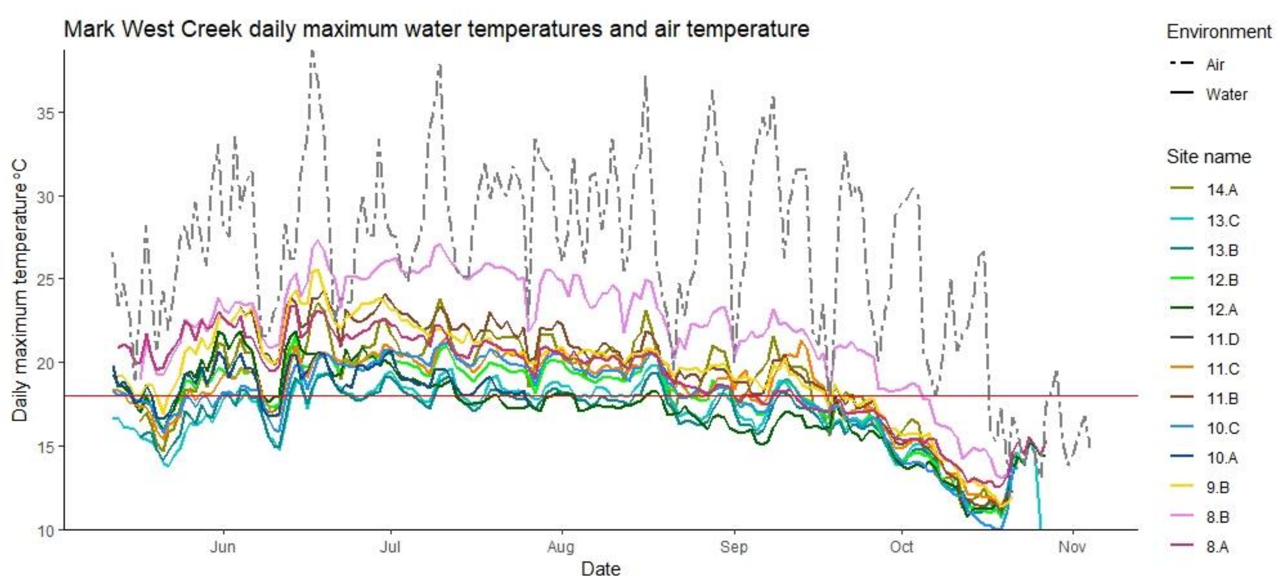

Figure 29. Maximum daily water temperatures and air temperature (site 11.D) at Mark West Creek logger sites, May-October 2021, plotted with the 18 °C avoidance threshold. The intention of this plot is to illustrate seasonal trends in water temperature as they relate to air temperature, not to compare conditions between sites.

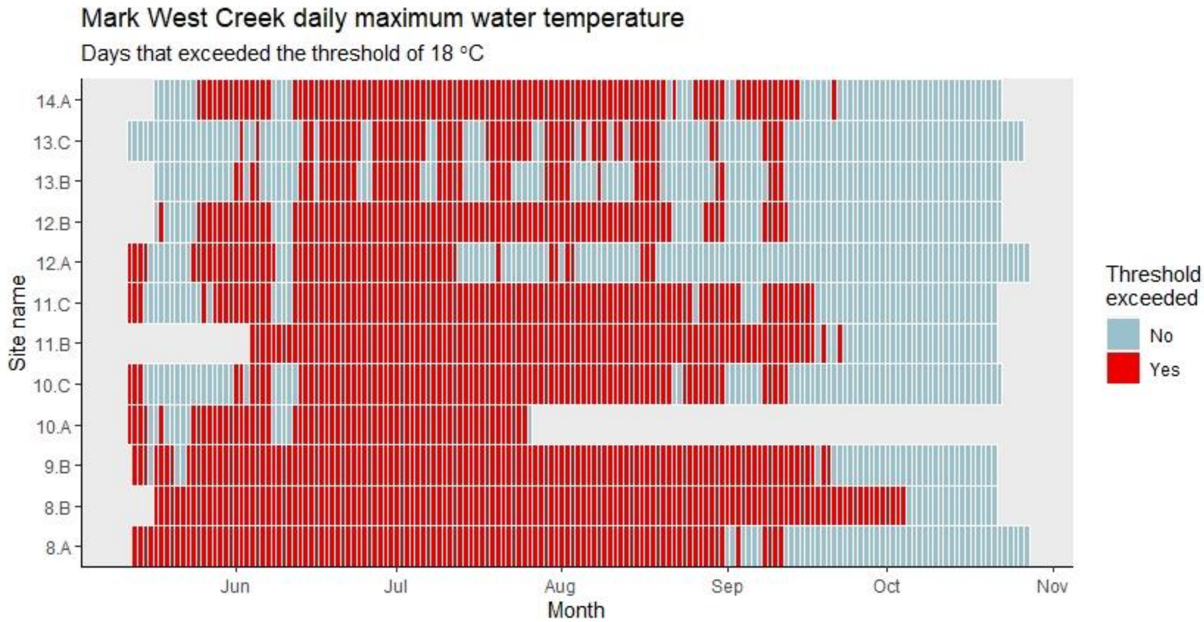

Figure 30. Days in which the daily maximum water temperature was below the avoidance threshold of 18 °C at Mark West Creek logger sites, May-October 2021. Sites are in consecutive order from downstream to upstream on the Y axis. Each line represents one day. Data collection ceased at site 10.A in late July.

Table 3. Proportion of continuous temperature measurements below the 18 °C threshold at Mark West Creek logger sites, May-October 2021. Note: data collection ceased at 10.A in late July.

Site name	Percentage below 18 °C
14.A	68%
13.C	83%
13.B	88%
12.B	65%
12.A	85%
11.C	54%
11.B	42%
10.C	56%
10.A	68%
9.B	47%
8.B	27%
8.A	46%

8. Discussion

In 2021, the Russian River watershed, like much of the western region of the United States, experienced exceptional drought conditions on the heels of the severe drought of 2020 (https://droughtmonitor.unl.edu/Maps/MapArchive.aspx). Water Year 2021 was the second driest year in state record (California Department of Water Resources 2021) and the driest on record at the Healdsburg station. Some Russian River tributaries began disconnecting as early as February and as the dry season progressed, many streams experienced extensive drying and water quality impairment. Streamflow receded throughout the Russian River Basin over the course of the summer, and the driest conditions of the season were documented in mid-September. Overall, streams in the greater Russian River basin were drier than in 2015, when the driest in-stream conditions were documented during the recent historic drought (on average over all streams sampled; CSG unpublished data). Of the 45 streams where CSG conducted wetted habitat mapping in the lower Russian River basin in 2021, only 51% of the 120 miles sampled remained wet and connected through the dry season (CSG unpublished data). Only 20% of all streams sampled in 2021 had ≥ 90% wetted habitat remaining at the end of the season.

While WY2021 was an historically dry year, streamflow conditions recorded at TU's gage network in Mark West Creek were higher (though still low) than expected from climate alone. The watershed was heavily burned by the Tubbs Fire in 2017 and the Glass Fire in 2020, and this year's data collection represent some of the first post-fire data available for the watershed. TU manages a network of 30 streamflow gages in the lower Russian River, and flow conditions reported in Mark West Creek in summer 2021, were among the highest recorded. Despite the fact that 2021 was a drier year than 2015 (Figure 3), streamflow conditions documented at TU's gage site MW01 show that flowers were higher in 2021 (Figure 31). Furthermore, even at its driest point, Mark West Creek was still 92% wet and connected, demonstrating a measure of drought resilience that the majority of Russian River tributaries do not exhibit. While we do not have comparable pre-and post-fire streamflow and wetted habitat data, and the hydrologic response to fire disturbance can vary between watersheds in California (Bart 2016), we believe the wildfire likely reduced summer evaporative demand, leading to a seasonal increase in streamflow and greater summer stream connectivity.

Low flows were observed at the five streamflow gaging stations in the Mark West Creek watershed, with streamflow at all sites below 1.2 ft^3/sec in mid-May, and drying to very low baseflows in the summer. Two sites in the upper watershed dried entirely for periods of the summer. MW02 (Mark West Creek above Porter Creek) dried out in late July, then was intermittent through September, rising slightly at times between dry periods, before rebounding October. At MW12 (Mark West Creek below Porter Creek), flow disconnected briefly in late September before reconnecting in early October. The three other streamflow gaging sites remained connected throughout the water year.

The most extensive stream drying occurred above and immediately below the Porter Creek confluence. The relatively low numbers of salmonid yoy present in Mark West Creek this summer corresponded to generally low numbers throughout the Russian River basin, but the fish that did spawn and rear there had a high occurrence of being in habitat that remained wet. Of the redds observed in the survey reaches, 86% were in locations that remained wet through the season and 92% of all coho salmon and steelhead yoy were observed in pools that stayed wet and connected. This indicates that fish distribution in relation to available wet summer habitat was generally very favorable.

Drying patterns were extremely variable in the tributaries where September wetted habitat surveys were conducted. Porter and Weeks creeks were incredibly dry, with just 5% and 0% of wetted habitat remaining in the surveyed extent, respectively, at the end of the season. On the contrary, 90% of Humbug Creek and 71% of Van Buren Creek remained wet. No biological monitoring was conducted in these streams so we do not know how habitat conditions compared to fish distribution, but we can conclude that Porter and Weeks creeks are not able to support rearing fish and do not provide substantial hydrological inputs, at least in dry years such as

2021. The main stem of Mark West Creek stayed wet and primarily connected for a good distance downstream of both Van Buren and Humbug creeks, suggesting that these tributaries contribute substantial flow inputs to the system.

Despite the relatively high amount of wetted habitat available in Mark West Creek, portions of the stream were consistently DO and/or temperature impaired. The site downstream of the Porter Creek confluence (10.C) had the poorest DO conditions of the five monitored pools. This site was unable to meet the minimum daily DO objective after late May, and by August the majority of measurements were below the salmonid mortality threshold of 3.0 mg/L. Of all 15-minute measurements recorded at this site, 87% of them were below the 6.0 mg/L regional objective. This is not surprising given that fairly extensive disconnection was observed in the reach upstream of the confluence during the July survey. Additionally, continuous water temperatures at site 10.C exceeded 18 °C almost half of the time, which likely contributed to the persistent hypoxic conditions. It is likely that the logger site within the disconnected reach above Porter Creek (11.A) also experienced extreme DO impairment, but that logger was lost in the October atmospheric river event. A new logger will be deployed at that site in 2022.

Conditions farther downstream, at site 10.A, were notably better than at 10.C for the limited period of data collection through late July, indicating that hydrologic inputs between the two sites, such as Leslie Creek, may help to maintain more suitable DO conditions in this stream reach. Continued DO data collection at that site in 2022 will likely help to further support or dispel this hypothesis.

Sites 12.B and 13.B are two locations where the continuous DO measurements tell a more complex story than the daily minimum concentrations. While daily minimums were below the regional objective for most of the season, there was high diurnal variability and those low concentrations generally did not persist for long, as seen in Figure 13. Even in 2021, one of the worst drought years in recorded history, 72% and 87% of all continuous DO measurements at those sites were at or above the 6.0 mg/L objective. This suggests that fish may be able to withstand the lower DO concentrations because the short durations are interrupted by intermittent periods of higher concentrations. It also indicates that there may be an opportunity to improve DO resiliency in this area. The majority of the proposed streamflow improvement projects are upstream of these measurement sites. It will be interesting to compare conditions pre- and post-project, as well as in wetter water years.

Water temperature at all measurement sites commonly rose above the 18°C salmonid avoidance threshold, with maximum daily temperature at even the coolest site (13.B) exceeding this on 30% of sample days. This indicates that temperature conditions in Mark West Creek are potentially stressful for rearing salmonids, despite the consistent presence of surface water. The most pronounced water temperature impairment occurred in the lowest reaches of the stream, below approximate rkm 36, which aligns with the O'Conner Environmental, Inc (OEI) reach-scale fish habitat suitability model (Kobor et al. 2020). The OEI report noted the need for additional temperature data in these reaches and the 2021 data appears to fill that data gap and support their reach designations for habitat quality.

At a glance, daily minimum DO concentrations and maximum water temperatures throughout most of Mark West Creek indicate that the fish frequently experienced stressful conditions. However, the continuous data indicate that there is some relief for juvenile salmonids throughout each diurnal cycle when values rebound to suitable levels and only at a few sites, such as 10. C, are fish being subjected to long durations of poor water quality conditions.

Overall, the best conditions for over-summering juvenile salmonids were observed in the upper reaches of Mark West Creek, above approximate rkm 37, where DO concentrations and water temperatures were within the preferred range for salmon for the majority of measurements. Interestingly, the loss of canopy cover caused by the 2020 Glass Fire did not result in poor water quality conditions in the uppermost reaches of Mark West Creek, indicating that streamflow, groundwater intrusion, or other factors may play a larger role than solar radiation in Mark West Creek water temperatures. The presence of the highest quality habitat in the upstream extent of the stream may be particularly beneficial for steelhead, as the adults generally spawn higher in the system than coho salmon

The primary take-away from our first year of monitoring is that Mark West Creek, particularly the upper half of the stream extent sampled, provides valuable and relatively rare flow refugia for rearing juvenile coho and steelhead even during extreme drought conditions, though water quality conditions are generally in need of improvement. Moving into the 2022 sample year, we plan to continue the full extent of streamflow monitoring, wetted habitat surveys and water quality data collection in order to fill remaining data gaps, establish patterns and trends over the three-year project period, document changes after streamflow project implementation, and investigate how streamflow and other measured parameters are influencing water quality conditions.

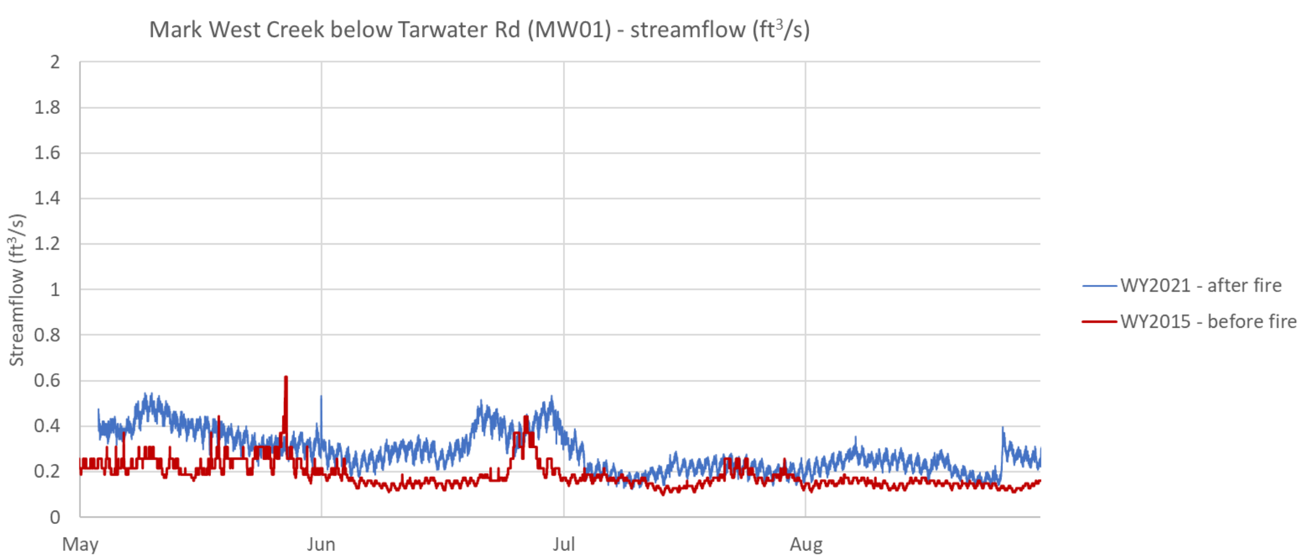

Figure 31. Streamflow conditions before (2015) and after (2021) the 2017 Tubbs Fire and 2020 Glass Fire footprints Gage data shows an increase in streamflow after the fire, despite 2021 being a drier year than 2015.

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