TECHNICAL MEMORANDUM ◦ OCTOBER 2021

Morro Bay Watershed Stream Flow Analysis




PREPARED FOR

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Cover photos: Chorro Creek and tributaries.

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1 INTRODUCTION AND PURPOSE

The Morro Bay National Estuary Program (MBENP) is a non-regulatory nonprofit that brings together citizens, organizations, agencies, and landowners to protect and restore the Morro Bay Estuary for people and wildlife. The MBNEP is seeking to identify prospective locations within the Morro Bay watershed at which ecologically relevant flow targets can be developed and long-term flow monitoring can be conducted. These flow targets will be used to determine if sufficient flows are available in these creeks to support the South-Central Steelhead, which is considered an indicator species for aquatic ecosystems. If, over time, insufficient flows are documented, the MBNEP will seek to take conservation and management actions to improve streamflow conditions where feasible.

Stream flows of various durations and magnitudes are needed seasonally to support aquatic ecosystems, which support a diversity of fauna and flora, including species of special concern such as South-Central Steelhead trout. Rather than developing comprehensive stream flow targets for all seasons, which are beyond the ability to the MBNEP to manage or change, the MBNEP has chosen to focus on the two most flow-sensitive periods for steelhead trout, namely the spring (i.e., April 1 to May 31) and summer (i.e., August 1 to September 30). In the spring, slightly higher minimal flows are required to support critical growth periods for juvenile steelhead, while in the summer (and early fall) season minimum flows are required to simply ensure juvenile steelhead survival (NOAA 2006). The work proposed herein will be based on the environmental water demand (EWD) model that Stillwater Sciences developed in 2014 for San Luis Obispo County (Stillwater Sciences 2014). The model predicts spring and summer EWD at a given location based on drainage area; however, before it can be applied to a specific location, the model needs to be validated based on local hydrologic and geologic conditions. Furthermore, the model is general in nature and does not explicitly take into account longer term annual or interannual hydrological variability.

2 APPROACH

To develop ecologically relevant flow targets at specific locations throughout the Morro Bay watershed, a two-pronged approach was taken (Sections 2 and 3): 1) A desktop analysis was conducted to inform the relationship between estimated EWD (Stillwater Sciences 2014) and water year types; and 2) A field investigation was conducted at prospective locations to evaluate the site-specific geologic, hydrologic, and logistical conditions. These two assessments were then utilized to select specific sites, to estimate EWD flow target values at those sites as a function of water year type, and to develop recommendations for interim flow target values (Section 3). Finally, recommendations for data collection and key future analyses were made (Section 4).

2.1 Watershed Summary

The Morro Bay watershed has two major sub-watersheds: the Chorro Creek and Los Osos Creek sub-watersheds (Figure 2-1).

2.1.1 Chorro Creek sub-watershed

Major tributaries to mainstem Chorro Creek include San Bernardo, San Luisito, Walters, Pennington, and Dairy creeks (Figure 2-1). The total drainage area at the mouth of Chorro Creek is approximately 43.2 square miles. Watershed elevation ranges from sea level at the mouth of the creek to approximately 2,780 feet in the headwaters. The watershed is dominated by valley grassland, coastal scrub, and oak savanna with both public and private landowners. The geology of the watershed is highly varied, consisting of complex igneous, sedimentary, and metamorphic rock. The Chorro Creek sub-watershed consists of steep pre-Quaternary non-infiltrative headwaters and a flat Franciscan low infiltrative valley (Figure 2-2).

Human water users in the watershed include, but are not limited to, agriculture (e.g., row crops, hay), irrigated lawn (including a golf course), the City of Morro Bay (which has municipal wells in the watershed), the California Men's Colony, Camp San Luis, and Cuesta College. Some of the larger water users obtain water from outside the watershed. Notably, a tertiary wastewater treatment plant that collects wastewater from major water users in the watershed, including the Men's Colony, Camp San Luis, and Cuesta College, and has an average dry weather design flow of 1.2 million gallons per day (MGD), a peak dry weather flow of 2.4 MGD, and a peak wet weather flow of 5.2 MGD. The minimum in-stream flow release requirement is 0.75 cubic feet per second (cfs) (Central Coast Regional Water Board 2012; SLO County Water Resources 2012). A portion of the treated wastewater is recycled for use by the County of San Luis Obispo to irrigate the Dairy Creek Golf Course.

Chorro Creek has been recognized as among the most important anchor watersheds for steelhead trout south of the San Francisco Bay and its drainage network has been identified by National Oceanic and Atmospheric Administration (NOAA) Fisheries as Critical Habitat for the recovery of steelhead trout in the South-Central Coastal California Evolutionarily Significant Unit (ESU). All of mainstem Chorro Creek and all its tributaries have delineated high potential steelhead rearing habitat (NOAA 2006; Stillwater Sciences 2014).

2.1.2 Los Osos Creek sub-watershed

Los Osos Creek only includes one major tributary, Warden Creek. At approximately 23.6 square miles, the Los Osos Creek sub-watershed is significantly smaller than the Chorro Creek sub-watershed and has a lower elevation (maximum elevation is approximately 1,450 feet). The Warden Creek and Los Osos Creek sub-watersheds consist of steep pre-Quaternary non-infiltrative headwaters and a flat highly infiltrative Quaternary valley (Figure 2-2).

Major private and public water users located in the watershed include agriculture, private residences, and the Golden State Water Company, which provides water to the community of Los Osos. Lower mainstem Los Osos Creek is considered primarily steelhead migratory habitat, while Upper Los Osos creek is delineated as high potential steelhead rearing habitat (NOAA 2006; Stillwater Sciences 2014). Warden Creek is delineated as low potential steelhead rearing habitat (NOAA 2006; Stillwater Sciences 2014). Warden Creek is delineated as low potential steelhead rearing habitat but eDNA analysis has shown steelhead presence in Warden Creek.

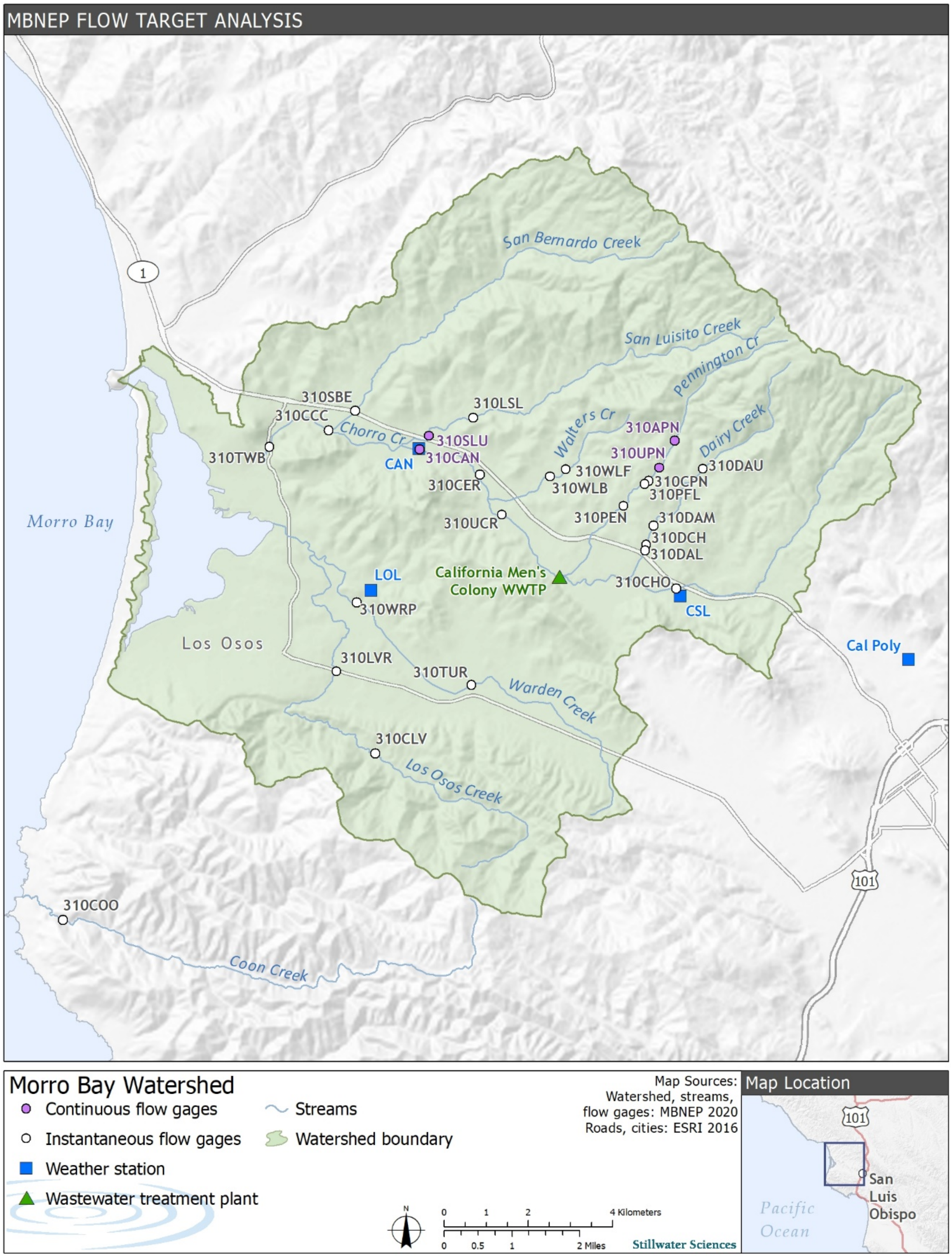

Figure 2-1. Morro Bay watershed. There are two sites on San Bernardo (USB, SBC) included in the data but not marked on this map because they are on private property.

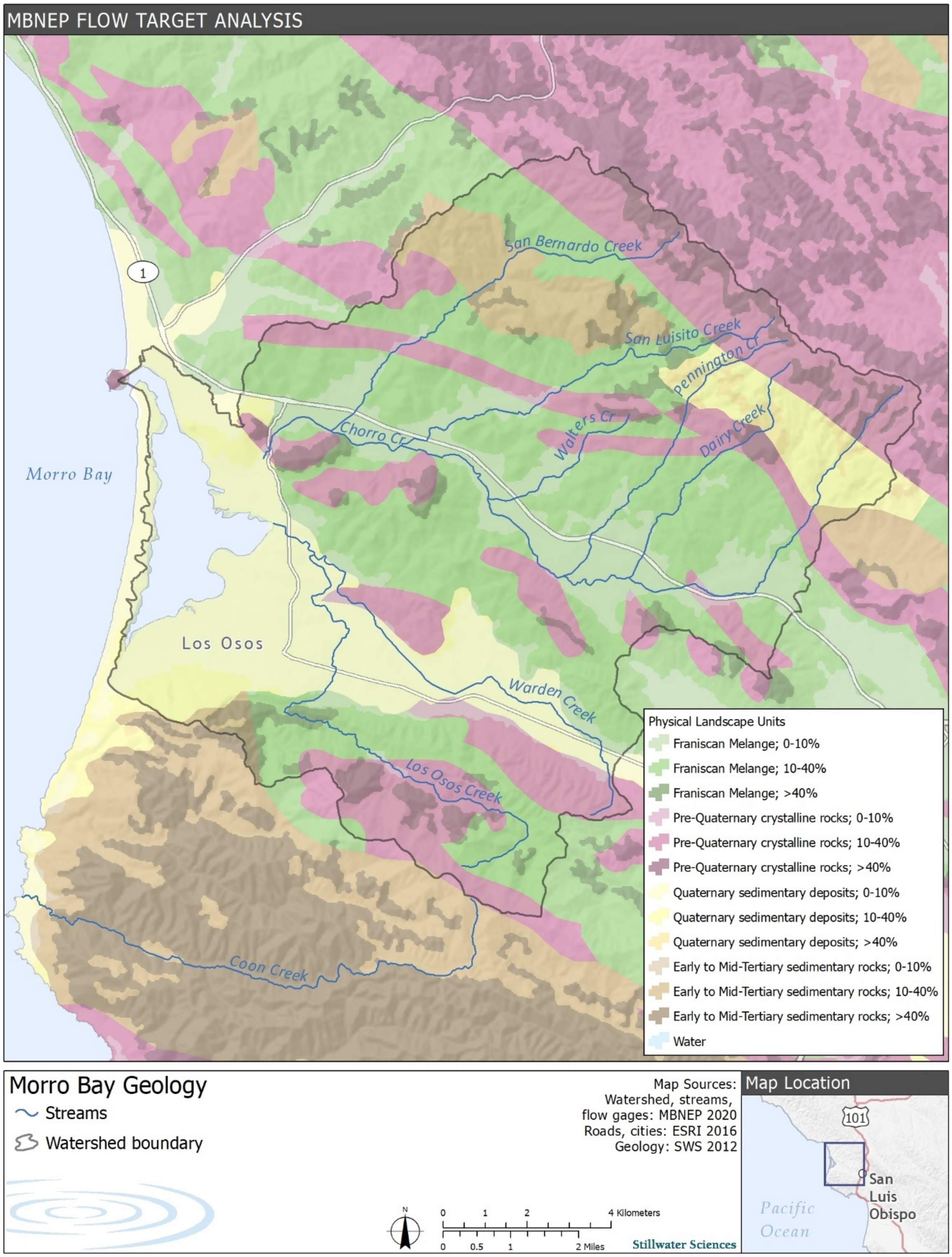

Figure 2-2. Morro Bay watershed geology.

2.2 Data Availability and QA/QC

To conduct the water year typing and associated analysis, existing hydrological data, including precipitation, instantaneous flow data, and continuous flow data, were evaluated for limitations due to data gaps, outliers, and other hydrologic data quality issues. A detailed summary of data quality assurance/quality control (QA/QC) review steps and the resulting data adjustments are summarized in Appendix A.

2.2.1 Precipitation data

Precipitation data at the Cal Poly State University (Cal Poly), Camp San Luis #713 (CSL), Los Osos Landfill #727 (LOL), and Chorro Creek at Canet Road #747 (CAN) weather stations were collected for their entire period of record (**Figure** 2-1 and Table 2-1). Precipitation data were compiled and later analyzed in terms of a "water year" (WY), defined as beginning on October 1 of the preceding year and ending on September 30 (e.g., WY 2008 started on October 1, 2007, and ended on September 30, 2008). In this analysis, annual was used to refer to the water year time period.

The QA/QC analysis included an outliers analysis of precipitation data at each weather station to identify gage malfunctions or errors in recording. The QA/QC review also identified and excluded water years when the availability of precipitation data was too limited to be confident that the recorded total water year precipitation accurately reflected the actual total water year precipitation. Infrequent recordings of precipitation or large gaps in precipitation data in a water year would likely result in inaccurate estimates of total precipitation during that water year, potentially resulting in a misclassification of the water year type and a shift in the water year precipitation thresholds for all water year types. A detailed explanation of QA/QC review and results of precipitation data is summarized in Appendix A.

Table 2-1. Weather station and precipitation data availability near the Morro Bay watershed.

Station ID	Location		**Precipitation** data collection period	**Frequency of** recording precipitation data
	Latitude	**Longitude**		
Cal Poly	35° 18’ 20” N	120° 39’ 43” W	Oct 1871–present	Monthly to 15-minute
CSL	35° 19’ 15” N	120° 43’ 28” W	July 2005–present	Daily
LOL	35° 19’ 19” N	120° 48’ 03” W	July 2005–present	Daily
CAN	35° 21’ 11” N	120° 47’ 16” W	Dec 2007–present	Daily

2.2.2 Stream flow data

2.2.2.1 Instantaneous flow

Instantaneous manual flow measurements made at locations throughout the Morro Bay watershed by the MBNEP were compiled for their entire period of record (**Figure** 2-1 and Table 2-2). Instantaneous flow measurements were assumed to have undergone a QA/QC process during their collection and initial compilation such that they were considered the most accurate quantification of flow at these sites. No additional QA/QC was performed for the instantaneous flow data.

Table 2-2. Morro Bay watershed instantaneous flow monitoring sites.

Stream name	Gage ID	Location		Flow data collection period[1]	Frequency of recording
		Latitude	Longitude		
Chorro Creek mainstem					
Chorro Creek	CHO[5,6]	35.321967	-120.722298	2004–2020	Periodic
Chorro Creek	UCR[2, 5,6]	35.33862	-120.767515	2004–2020	Periodic
Chorro Creek	CER[5,6]	35.3474	-120.773	2004–2020	Periodic
Chorro Creek	CAN[2, 3,6]	35.353149	-120.788653	2004–2017	Periodic
Chorro Creek	CCC[2, 5,6]	35.357622	-120.812345	2010–2020	Periodic
Chorro Creek	TWB[5]	35.354332	-120.82795	2004–2020	Periodic
Chorro Creek tributaries					
Dairy Creek	DAU[5,6]	35.347518	-120.714643	2005–2017	Periodic
Dairy Creek	DAM[4, 5,6]	35.335581	-120.727932	2004–2017	Periodic
Dairy Creek	DCH[5]	35.331667	-120.729917	2018–2020	Periodic
Dairy Creek	DAL[4]	35.330394	-120.730212	2004–2017[4]	Periodic
Pennington Creek	APN[2, 3, 5]	35.353713	-120.721826	2011–2020[4]	Periodic
Pennington Creek	UPN[2, 3, 5]	35.347978	-120.726051	2011–2020[4]	Periodic
Pennington Creek	CPN[2,5,6]	35.345305	-120.728875	2008–2020[4]	Periodic
Pennington Creek	PFL[2,5,6]	35.344636	-120.729929	2017–2020[4]	Periodic
Pennington Creek	PEN[4,5]	35.339991	-120.735559	2004–2020[4,5]	Periodic
Walters Creek	WLF[2]	35.348113	-120.750499	2017–2018	Periodic
Walters Creek	WLB[4]	35.346599	-120.75476	2012–2013	Periodic
San Luisito Creek	LSL[2, 4]	35.359613	-120.774506	2014–2016	Periodic
San Luisito Creek	SLU[2, 3, 5,6]	35.355948	-120.786112	2004–2020	Periodic
San Bernardo Creek	USB[6]			2010	Periodic
San Bernardo Creek	SBC[2, 5]			2014–2020	Periodic
San Bernardo Creek	SBE[5,6]	35.361735	-120.805273	2004–2020	Periodic
Los Osos mainstem					
Los Osos Creek	CLV[4, 5,6]	35.288094	-120.802086	2008–2020	Periodic
Los Osos Creek	LVR[4, 5]	35.305886	-120.81171	2004–2019	Periodic
Los Osos tributaries					
Warden Creek	TUR[4, 5,6]	35.302308	-120.776434	2011–2020	Periodic
Warden Creek	WRP[6]	35.320604	-120.806081	2012–2013	Periodic

1 Data collection periods are specified according to the water year (October 1 to September 30)
2 Continuous stage or flow data available
3 Stage-discharge rating curve available
4 Significant data gaps exist during listed period
5 Current monitoring site
6 Site evaluated for future monitoring based on access logistics and location within watershed (see Section 2.4).

2.2.2.2 Continuous flow

Measured continuous stage and estimated continuous flow are available in four locations: 1) San Luisito Creek at Adobe Road (310SLU); 2) Pennington Creek upstream of Escuela Ranch wells (310APN); 3) Pennington Creek downstream of Escuela Ranch wells (310UPN); and 4) Chorro Creek at Canet Road (310CAN) (**Figure** 2-1 and Table 2-3). Continuous data at the Pennington sites are collected by the MBNEP and continuous data at the San Luisito Creek and Chorro Creek sites area collected by the County of San Luis Obispo Public Works Department (https://wr.slocountywater.org/). These four gage sites are the only monitoring sites in the Morro Bay watershed that have both continuous (15-minute) stage data and stage-discharge rating curves to estimate continuous flow. Sites with measured continuous stage and no stage-discharge rating curve were not summarized since the continuous flow necessary for this analysis could not be calculated without a stage-discharge rating curve for the site. A QA/QC review of the continuous flow data at each gage site was performed before further analysis to identify and exclude data outliers due to gage malfunctions, errors in recording data, or potential uncertainties in the stage-discharge rating curve. After removing outliers, the QA/QC review identified the water years in which the availability of continuous flow data was sufficient to estimate the annual discharge. Finally, the QA/QC review compared the estimated continuous flow to corresponding instantaneous flow measurements and adjusted the estimated continuous flow to better match the instantaneous flow measurements, as necessary. A detailed explanation of QA/QC review and results of continuous flow data is summarized in Appendix A.

Table 2-3. Morro Bay watershed continuous flow monitoring sites with a stage-discharge rating curve.

Stream name	Gage description	Gage ID	Location		Flow data collection period	Typical frequency of recording
			Latitude	Longitude		
San Luisito Creek	San Luisito Creek at Adobe Road	310SLU	35° 21’ 21.43” N	120° 47’ 10.05” W	Jan 2008–Dec 2020	15 min
Chorro Creek	Chorro Creek at Canet Road	310CAN	35° 21’ 11.35” N	120° 47’ 19.20” W	Jan 2010–Dec 2020	15 min
Pennington Creek	Pennington Creek upstream of wells	310APN	35° 21’ 13.39” N	120° 43’ 18.62” W	Oct 2012–Aug 2018	15 min
Pennington Creek	Pennington Creek downstream of wells	310UPN	35° 20’ 52.74” N	120° 43’ 33.83” W	Apr 2013–Sep 2018	15 min

2.3 Water Year Type Analysis

Water year types in the Morro Bay watershed were determined by conducting an exceedance probability analysis of the precipitation data from the weather station that best characterized the hydrologic conditions in watershed. As previously introduced in Section 2.2.1, a “water year” (WY) was defined as beginning on October 1 of the preceding year and ending on September 30. Water year classifications can be calculated from either precipitation or stream flow, with water year classifications typically sub-divided into either three categories representing “Dry,” “Average,” and “Wet” water year types, or five categories representing “Very Dry,” “Dry,” “Average,” “Wet,” and “Very Wet” water year types. Precipitation data were used to calculate the water year type in the Morro Bay watershed rather than flow data since (1) available precipitation datasets in or near the watershed were longer and more complete than available flow datasets; (2) data from a single weather station would characterize a wider region than a single stream gage; and (3) flow datasets were potentially contained flow altered by human uses in the watershed (e.g., diversions).

The weather station that best characterized hydrologic conditions in Morro Bay watershed streams was determined by comparing total water year precipitation with the total water year discharge. First, total water year precipitation was calculated for each of the four weather stations within or near the Morro Bay watershed (i.e., Cal Poly, CSL, LOL, and CAN) for all water years with sufficient data after the QA/QC review. Next, total water year discharge was calculated for all water years at the continuous flow gages with sufficient data after the QA/QC review. Finally, the total water year precipitation at each weather station and the total water year discharge for all the continuous flow gages with sufficient data were compared for all water years with overlapping data. There were typically fewer water years with sufficient data at the continuous flow gages than the weather stations, so number of water years compared was limited by the availability of continuous flow data and was only a subset of the available water years in the precipitation dataset. The weather station with the total water year precipitation that best correlated with the total water year discharge was selected for the water year type analysis (see Section 3 for Results).

The water year precipitation exceedance probability for the selected weather station was calculated by first sorting and ranking the total water year precipitation for all years with sufficient precipitation data. A rank of one was assigned to the year with the largest total water year precipitation, with the rank increasing for each water year with successively less total water year precipitation. The rank was the same for years with the same total water year precipitation. Once the rank was assigned for each year, the exceedance probability was calculated as follows:

$$P_{exceed,annual} = 100 * \frac{PPT_{annual,\ rank}}{n+1} \qquad \text{Eqn. 1}$$

where $P_{exceed,\ annual}$ was the exceedance probability (percent); $PPT_{annual,\ rank}$ was the rank of the total water year precipitation for an individual gage (dimensionless); and *n* was the number of years of precipitation data evaluated. Water years were sub-divided into Very Wet, Wet, Average, Dry, and Very Dry types with precipitation thresholds based on the total water year precipitation exceedance probability (Table 2-4). A Very Wet water year type was defined as the water years with the highest 10% of total water year precipitation. A Very Wet water year would occur when the total water year precipitation exceedance probability was less than or equal to 10%, since the highest 10% of total precipitation would be exceeded in 10% of the water years. The thresholds for the other water year types were defined similarly.

Table 2-4. Water year type precipitation exceedance probabilities.

Water year precipitation exceedance probability (%)	Water year type
≤10	Very Wet
>10–33	Wet
>33–66	Average
>66-<90	Dry
≥90	Very Dry

2.4 Prospective Locations for EWD Flow Target Development and Long-term Monitoring

To identify prospective locations for the development of EWD flow targets and subsequent long-term flow monitoring, the MBNEP evaluated 26 locations where instantaneous flow has been historically or is currently being measured (Table 2-2) to determine where landowner access was best suited to support long-term monitoring. Fifteen prospective locations were identified (Table 2-2) and evaluated to answer the following questions:

1. Are physical conditions at the prospective location adequate to ensure accurate flow monitoring during low flow, spring, and summer conditions using available methods (see Section 4.2.2 for monitoring methods recommendations). Physical factors evaluated in the field included channel orientation and hydraulics (e.g., no hydraulic jumps or channel bends), channel geometry (e.g., sufficient depth), and channel obstructions (e.g., complex boulder field) that would interfere with hydraulic uniform flow assumptions required for accurate flow measurements. While sites selected had adequate conditions for low flow monitoring, these conditions may not be entirely absent at each site over the full range of flows that may be encountered. For example, even in a straight clean trapezoidal channel summer flow may drop too low for flow measurements. Best practices and methods for low flow measurements are discussed in Section 4.2.2.
2. Given the best available information, is there a high potential that the prospective location historically supported perennial flow? Evaluations included interviewing the MBNEP about known historical conditions at the site, reviewing available flow data at the site, comparing the drainage area of the prospective site to other known perennial streams in the area, evaluating the local reach scale geology (e.g., bedrock channel with minimal floodplain or wide alluvium channel), and examining mapped geologic units (Figure 2-2).
3. Given the best available information, is there a high potential that the prospective location historically supported high quality steelhead rearing habitat? Evaluations included examination of previous delineations of the potential of high-quality steelhead rearing habitat occurring and field observations of general habitat suitability.

2.5 Environmental Water Demand Analysis

San Luis Obispo County (SLO, or County) developed a Master Water Report (MWR) of the current and future water resource management activities being undertaken by various entities within the county (SLO County Water Resources 2012). In addition to total water demand (which includes urban, rural, and agricultural needs), the MWR includes an estimate of EWD, which is defined as "the amount of water needed in an aquatic ecosystem, or released into it, to sustain aquatic habitat and ecosystem processes" (SLO County Water Resources 2012). Federally threatened South-Central California Coast steelhead (*Oncorhynchus mykiss)* were selected in the MWR as the target species for analysis based on their adequacy as an indicator species (i.e., a species whose habitat requirements are sensitive enough to allow for successful identification of environmental problems, yet broad enough to adequately represent a wide array of aquatic species). While the EWD in the MWR was calculated using a methodology developed by Hatfield and Bruce (2000), this approach did not estimate the EWD for specific seasons or sub-watersheds and the EWD is expressed as an annual volume of water, which does not take into account seasonal fluctuations in flow or support real time flow monitoring.

Hydrologic data, physical terrain information, and field-based instream flow assessment data were used to further refine the estimate of EWD by developing a method to estimate the seasonal EWD in watersheds throughout San Luis Obispo County (Stillwater Sciences 2014). EWD was defined as equivalent to the instream flow requirements of steelhead to be consistent with the MWR. EWD flow requirements were defined and quantified for steelhead during the two most flow-sensitive periods for minimum flow requirements: (1) a spring period from April 1 through May 31; and (2) a summer period from August 1 through September 30. A field-based instream flow assessment in 2013 surveyed 12 sites during spring (i.e., mid-April) and resurveyed 6 of those 12 sites during summer (i.e., early September) to estimate the season-specific EWD flow needed at those sites to support steelhead. Sites were distributed throughout the county, including multiple sites in the Morro Bay watershed. Estimated seasonal EWD was compared with watershed characteristics found to be related to hydrologic patterns, including drainage area, channel gradient, channel slope, and valley width. Predictive EWD models for spring and summer were then developed based on a regression analysis of the variables that best described the season-specific EWD (Stillwater Sciences 2014).

2.5.1 EWD model

EWD during the spring season (i.e., April 1 to May 31) was calculated as follows:

$$EWD_{spring} = 0.049 * A_{upstm} + 0.31 \quad \text{Eqn. 2}$$

where EWD_{spring} (cfs) was the estimated environmental water demand during the spring season and A_{upstm} (square miles [sq. miles]) was the upstream drainage area. The EWD_{spring} model had an R^2 of 0.93 for the 12 field assessment sites used in the model calibration, indicating upstream drainage area was a very good predictor of the EWD_{spring} at sites across San Luis Obispo County (Stillwater Sciences 2014). EWD during the summer season (i.e., August 1 to September 30) was calculated as follows:

$$EWD_{summer} = 0.012 * A_{upstm} + 0.20 \quad \text{Eqn. 3}$$

where EWD_{summer} (cfs) was the estimated environmental water demand during the summer season (and A_{upstm} (sq. miles) was the upstream drainage area. The EWD_{summer} model had an R^2 of 0.96 for the six sites evaluated. The EWD_{summer} model had an R^2 of 0.96 for the 12 field assessment sites used in the model calibration, indicating upstream drainage area was a very good predictor of the EWD_{summer} at sites across San Luis Obispo County (Stillwater Sciences 2014).

The seasonal EWD models should only cautiously be extrapolated to sites with upstream drainage area or flow outside of the range in the dataset used to calibrate the models. The EWD models for spring and summer were developed and calibrated based on 12 sites distributed throughout the County with upstream drainage areas ranging from 2.2 sq. miles to 67.9 sq. miles, with observed flows ranging from 0 cfs (wetted with no water velocity) to 6 cfs during spring 2013 and 0 cfs to 5.8 cfs during summer 2013. No channel was observed to maintain sufficient habitat with flows less than 0.5 cfs (spring) or 0.2 cfs (summer), which corresponded to the smallest measured channel with smallest drainage area of 2.2 sq. miles. It is unknown whether the linear relationship between upstream drainage area and EWD would hold for drainage areas less than 2.2 sq. miles (Stillwater Sciences 2014).

2.5.2 Comparison of flow and EWD at Morro Bay watershed sites

At instantaneous flow sites identified for potential long-term monitoring and continuous flow sites, the EWDs for spring and summer were calculated by estimating the upstream drain area using the online USGS Stream Stats tool (USGS 2021) and the respective seasonal EWD model (see Section 2.5.1). At sites with sufficient data, flow was compared with the seasonal EWD estimates to determine how frequently the seasonal EWDs were met and whether were correlated with water year types.

Sites with continuous flow data first were compared with the seasonal EWD estimates since these sites would more completely quantify seasonal flow variations than sites with periodically measured instantaneous flow data. At continuous flow sites, the frequency at which the flow met the seasonal EWD estimate was calculated for each season in all the individual water years with sufficient data. Each water year was assigned a water year type based on the Morro Bay water year type analysis (see Section 2.3), then the average frequency the flow met the seasonal EWDs was calculated for each water year type.

Sites with sufficient instantaneous flow data also were evaluated. Instantaneous sites with at least four measurements per season distributed across 80% or more of the season were assumed to have sufficient data to characterize the frequency flow met the EWD during a season and were included in the analysis. Instantaneous sites with less than four measurements per season or measurements distributed over less than 80% of the season were excluded from further analysis. For example, a site with four measurements distributed between April 1 and May 19 (characterizing 81% of the spring season) would be included in the analysis, but a site with four measurements distributed between April 1 and May 2 (53% of the spring season) or three measurements distributed between April 1 and May 30 (98% of the spring season) would not be included in the analysis. A threshold of at least four measurements per season distributed across 80% or more of the season was chosen for analysis of instantaneous sites because (1) it was plausible historical monitoring recorded instantaneous flow this frequently, and (2) four data points across 80% of a season would reduce the potential for individual instantaneous measurements to obscure trends across the entire season. At these instantaneous flow sites with sufficient data, the frequency that flow met the seasonal EWDs was calculated for each season in individual water years, then the average frequency the measured instantaneous flow met the seasonal EWDs was calculated for each water year type based on the Morro Bay water year type analysis (see Section 2.2.1).

Trends between water year type and the average frequency the seasonal EWDs were met were evaluated across the assessed sites in the Morro Bay watershed to identify trends specific to individual sites. This understanding of broader watershed-spanning trends is critical to select achievable interim and long-term flow target values for maintaining EWD in streams in the Morro Bay watershed.

3 RESULTS

3.1 Water Year Type Analysis

3.1.1 Weather station comparison

As the first step in determining the weather station to use in the water year type analysis, the total water year (annual) precipitation was calculated for each of the four weather stations within and near Morro Bay watershed, and general precipitation trends between the four weather stations were compared. Annual precipitation at these four weather stations had similar overall trends between 2006 and 2020, but there were several key differences between the annual precipitation at the CSL, LOL, and CAN weather stations within the Morro Bay watershed and the Cal Poly weather station to the east of the watershed (

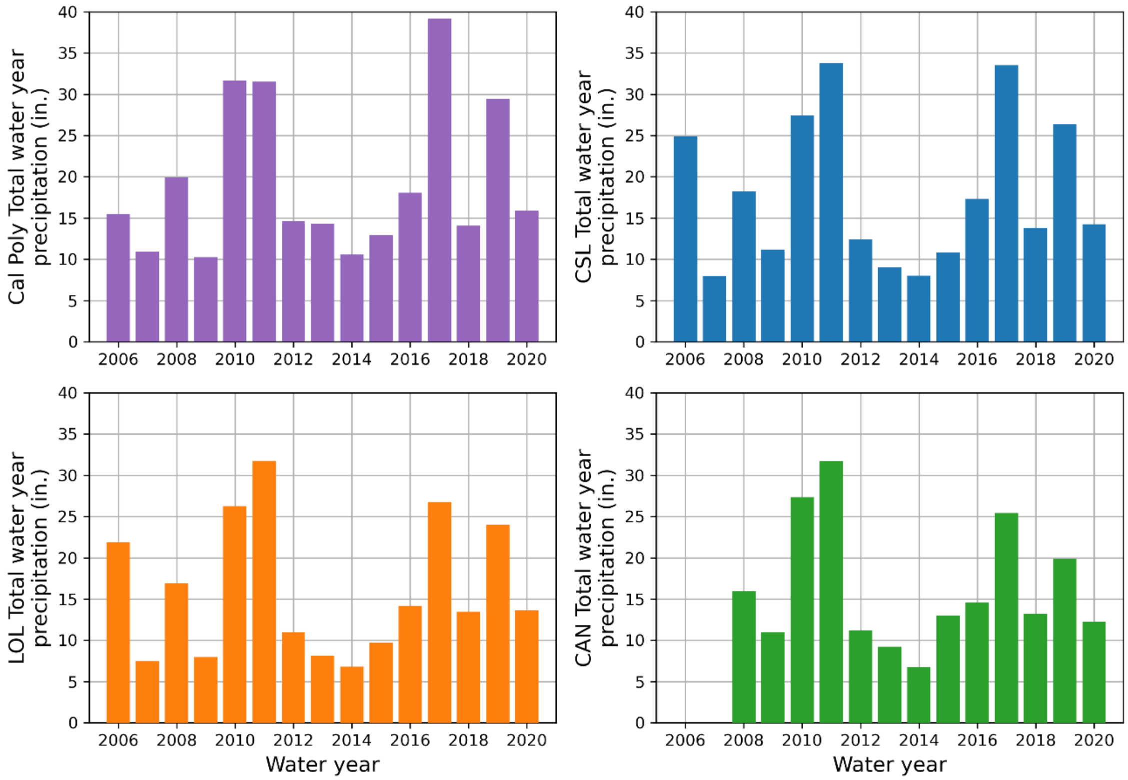

Figure 3-1 and Appendix B). Morro Bay watershed weather stations tended to have a slightly lower annual precipitation that the Cal Poly weather station. In 2006, annual precipitation at the Morro Bay watershed weather stations with data (i.e., CSL and LOL) was significantly different than the annual precipitation at the Cal Poly weather station. Annual precipitation consistently increased between 2010 and 2011 at CSL, LOL, and CAN, but annual precipitation was approximately the same in both years at Cal Poly. While differences in annual precipitation between the three Morro Bay watershed weather stations and the Cal Poly weather station were relatively subtle, they all indicated annual precipitation trends in the Morro Bay watershed would not be fully characterized by annual precipitation trends at Cal Poly. Analysis of the water year type based on the Cal Poly annual precipitation would potentially classify some water years differently than the analysis of the water year type based on annual precipitation at Morro Bay watershed weather stations (e.g., 2006), obscuring a relationship between water year type and stream flow.

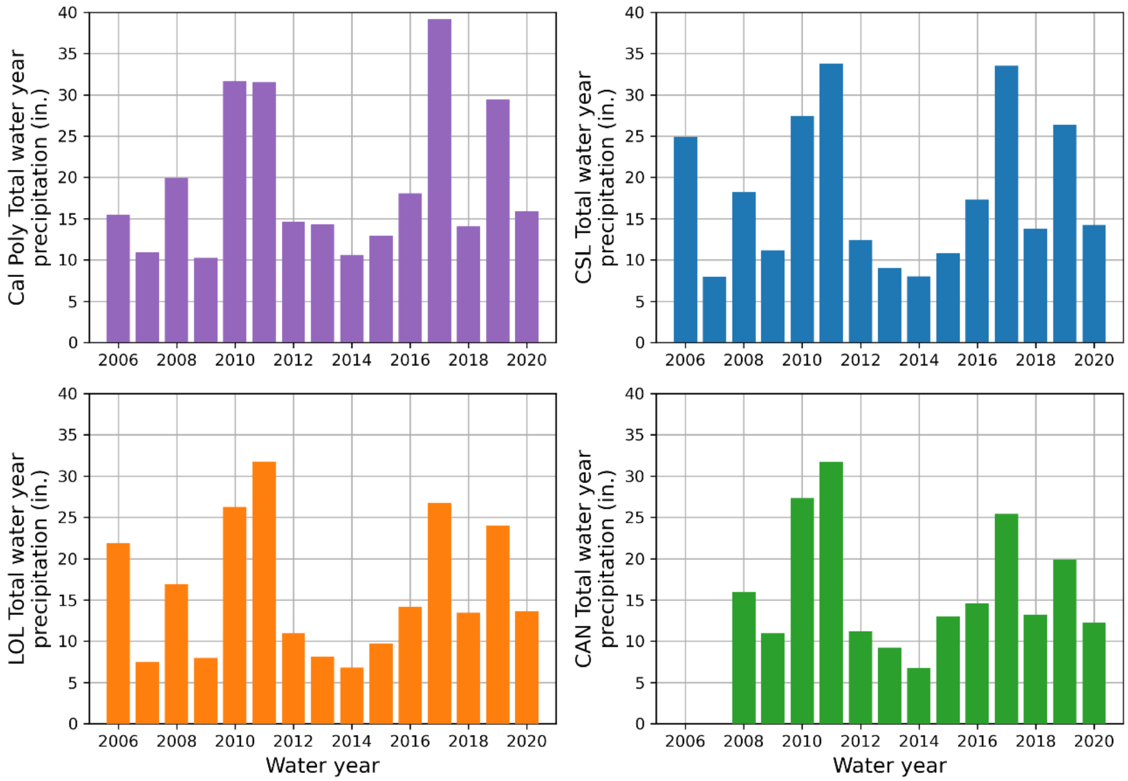

Figure 3-1. Annual precipitation at weather stations within or near the Morro Bay watershed from 2006 to 2020.

3.1.2 Annual discharge comparison

As the next step in determining the weather station for the water year type analysis, the total water year (annual) discharge was calculated at 310SLU and 310CAN and general trends between the gages were compared before assessing whether annual discharge at the gages correlated with annual precipitation at any of the weather stations. Annual discharge at 310SLU and 310CAN had similar overall trends between 2010 and 2020, but the annual discharge at 310CAN was approximately 4 to 30 times greater than the annual discharge at 310SLU (Figure 3-2). The magnitude of the difference between annual discharge at 310SLU and 310CAN could be an overestimate since annual discharge at 310CAN was calculated from unadjusted continuous flow data that would overestimate flow compared to the instantaneous measurements (see Appendix A for details on adjusting the continuous flow data to improve agreement with instantaneous measurements). Continuous flow was not adjusted for the calculation of annual discharge at 310CAN since the regression relationships between continuous and instantaneous flow varied seasonally and they would not be applicable throughout a water year (see Appendix A for regression analysis). However, the range of annual discharges estimates at 310SLU (211 to 6,167 acre-feet [AF], with an average of 1,571 AF) and 310CAN (1,991 to 26,102 AF, with an average of 9,788 AF) are comparable to the average annual discharge estimated by CEMAR (2014) for the San Luisito Creek watershed (2,214 AF) and the Chorro Creek watershed (12,200 AF) from scaling the flow in those watersheds to the flow in other nearby watersheds with historical flow records (e.g., USGS Torro Creek, Lopez Creek). Regardless, observed differences between continuous and instantaneous flow did not alter the overall discharge trends across water years, so annual discharge at 310CAN calculated from unadjusted continuous flow was still expected to characterize overall trends even if it overestimated the magnitude of the annual discharge.

While the timing of maximum annual discharge was the same at both 310SLU and 310CAN (i.e., WY 2017), the water year with the minimum annual discharge at 310SLU and 310CAN was different (WY 2014 and WY 2015, respectively) and potentially highlighted differences between hydrologic conditions in the watersheds upstream of the gages. Annual discharge at the continuous gages had similar variations over time as the annual precipitation at the four weather stations, with annual discharge typically higher during the years with higher annual precipitation and lower during the years with lower annual precipitation. However, the water year with maximum or minimum annual discharge did not necessarily correspond to the water year with maximum or minimum annual precipitation. Maximum annual discharge occurred in WY 2017 at both continuous gages similar to the timing of maximum annual precipitation at Cal Poly, but different from the timing of maximum annual precipitation at CSL, LOL, and CAN, which all occurred in WY 2011. Minimum annual discharge at 310SLU occurred in WY 2014 during the same water year as the minimum annual precipitation at all four weather stations, but the minimum annual discharge at 310CAN occurred one year later in 2015. These trends indicate that annual discharge was influenced by more than just annual precipitation and annual discharge would not tightly correlate with annual precipitation.

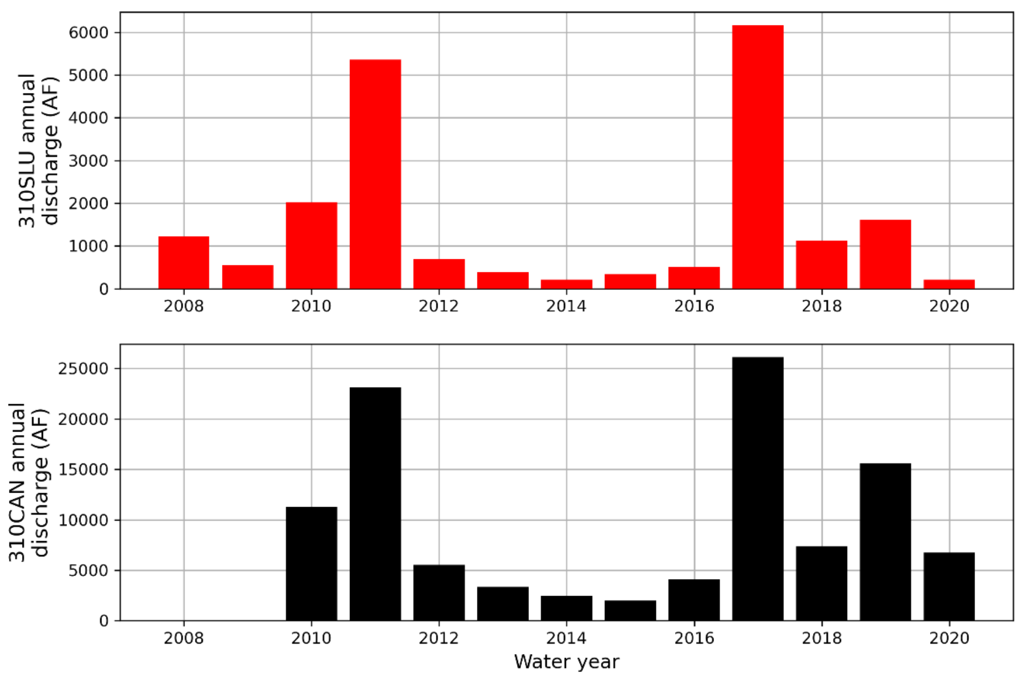

Figure 3-2. Annual discharge calculated from the continuous flow data at 310SLU and 310CAN. Please note the y-axis scale is different for the top and bottom figures.

3.1.3 Selection of precipitation gage for water typing

Finally, annual precipitation at each weather station was compared with the annual discharge at 310SLU and 310CAN to determine the weather station that best correlated with the hydrologic conditions in the Morro Bay watershed. Annual discharge at 310SLU and 310CAN best correlated with the annual precipitation at the CSL weather station (Figure 3-3). The annual precipitation at CSL explained approximately 79% of the variation in annual discharge at 310SLU (i.e., $R^2 = 0.79$) and approximately 88% of the variation in annual discharge at 310CAN (i.e., $R^2 = 0.88$). While annual precipitation at Cal Poly, LOL, and CAN explained only slightly less of the overall variation in annual discharge at 310SLU and 310CAN than annual precipitation at CSL, annual precipitation at CSL and annual discharge at 310SLU and 310CAN had a more linear clustering with less spread of data points along a linear trendline than annual precipitation at Cal Poly, LOL, or CAN and annual discharge at the continuous flow gages. As such, the annual precipitation at CSL was selected for the water year type analysis.

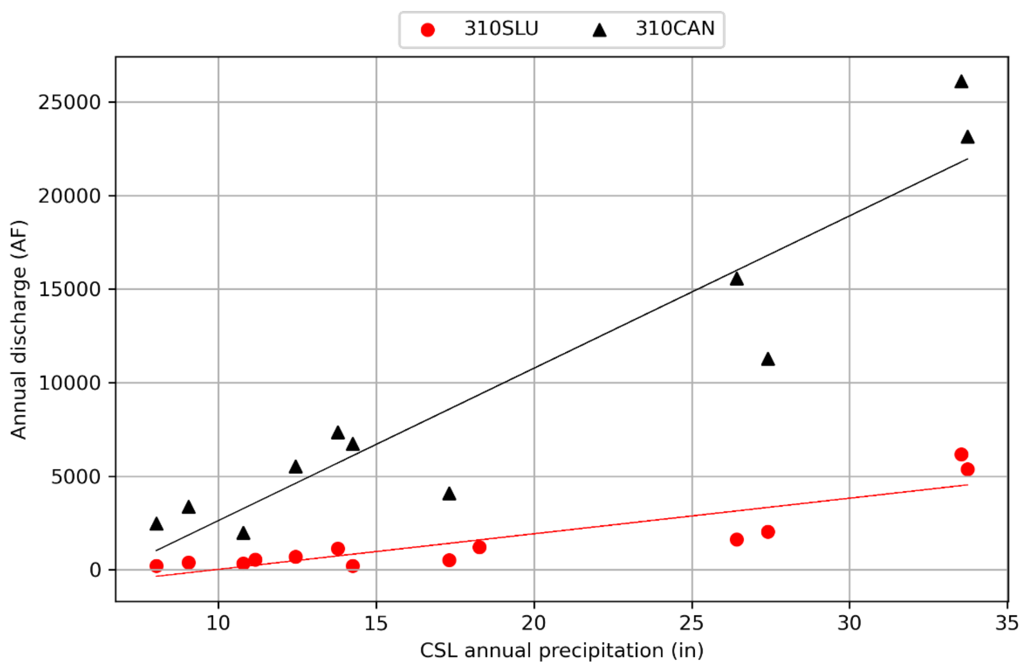

Figure 3-3. Comparison of CSL annual precipitation with annual discharge at 310SLU and 310CAN.

3.1.4 Water year typing

Morro Bay watershed annual precipitation water year type thresholds for Very Wet, Wet, Average, Dry, and Very Dry water years were calculated based on the CSL annual precipitation from 2006 to 2020 (Table 3-1), then individual water years were classified accordingly (Figure 3-4 and Appendix B). While the entire range of water year types was represented between 2006 and 2020, drier water years occurred more frequently during this period than wetter water years. Six of the fifteen water years (i.e., 40%) were classified as Dry or Very Dry, while only four of the fifteen water years (i.e., 27%) were classified as Wet or Very Wet. The frequency of the drier water years primarily occurred from 2012 to 2015, coinciding with the widespread 2012–2016 California drought (Lund et al. 2018).

Table 3-1. Morro Bay watershed water year type thresholds.

Water year precipitation exceedance probability (%)	Water year type annual precipitation threshold (in)
10	33.6
33	24.9
66	12.6
90	8.5

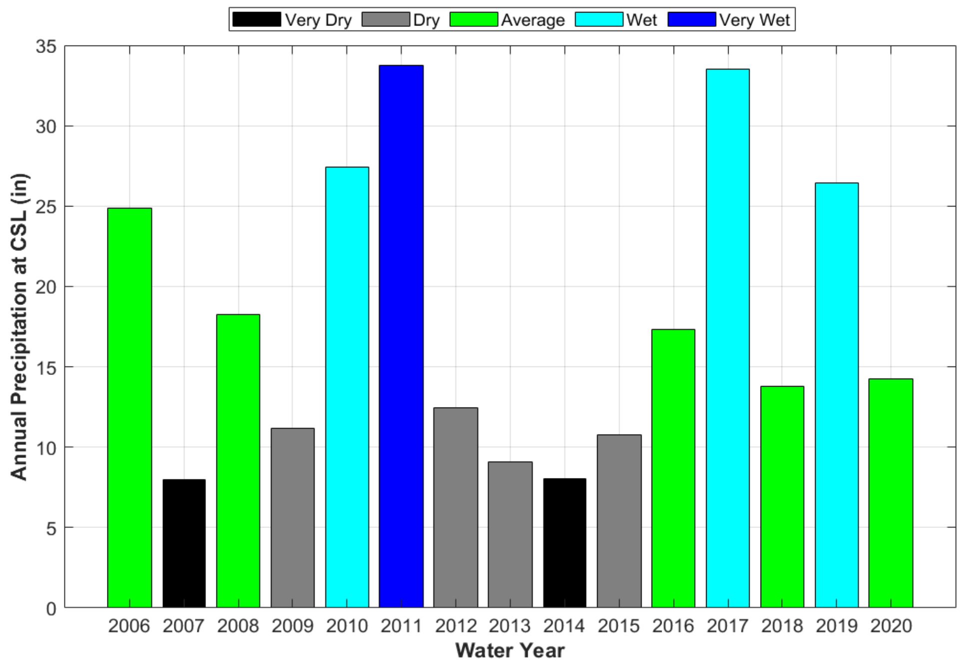

Figure 3-4. Morro Bay watershed water year types from 2006 to 2020 based on annual precipitation at CSL.

Water year types are a useful way to group and evaluate hydrologic trends in a watershed, but water year types may not fully represent hydrologic conditions when annual precipitation is close to a water year type threshold. While WY 2017 is classified as a Wet water year, annual precipitation is only 0.1 inches below the water year type precipitation threshold for a Very Wet water year. Transitional water year types with annual precipitation close to a water year type threshold may have hydrologic conditions corresponding to the water year type on either side of the threshold. Analysis of hydrologic trends by water year type must take into consideration the potential influence of transitional water years, especially when transitional water years make up a larger percentage of a water year type (i.e., WY 2017 is 33% of the Wet water years).

3.2 Field Assessment

Of 15 prospective locations which were field evaluated (Table 2-2) for subsequent long-term flow monitoring to determine if EWD targets are being met, 9 sites were selected (Figure 3-5). The six sites that were evaluated but not selected included sites that upon further inspection had suboptimal landowner access (310USB); had suboptimal channel geometry and channel conditions for flow monitoring (310PFL); were logistically difficult for crews to access (310DAU); were duplicative of other nearby sites proposed for monitoring (310CER); and were not located within high potential rearing habitat (310TUR and 310WRP). Furthermore, two proposed sites (310CLV and 310CAN) require specific flow monitoring access or methodological considerations that are discussed in Section 4.2.2.

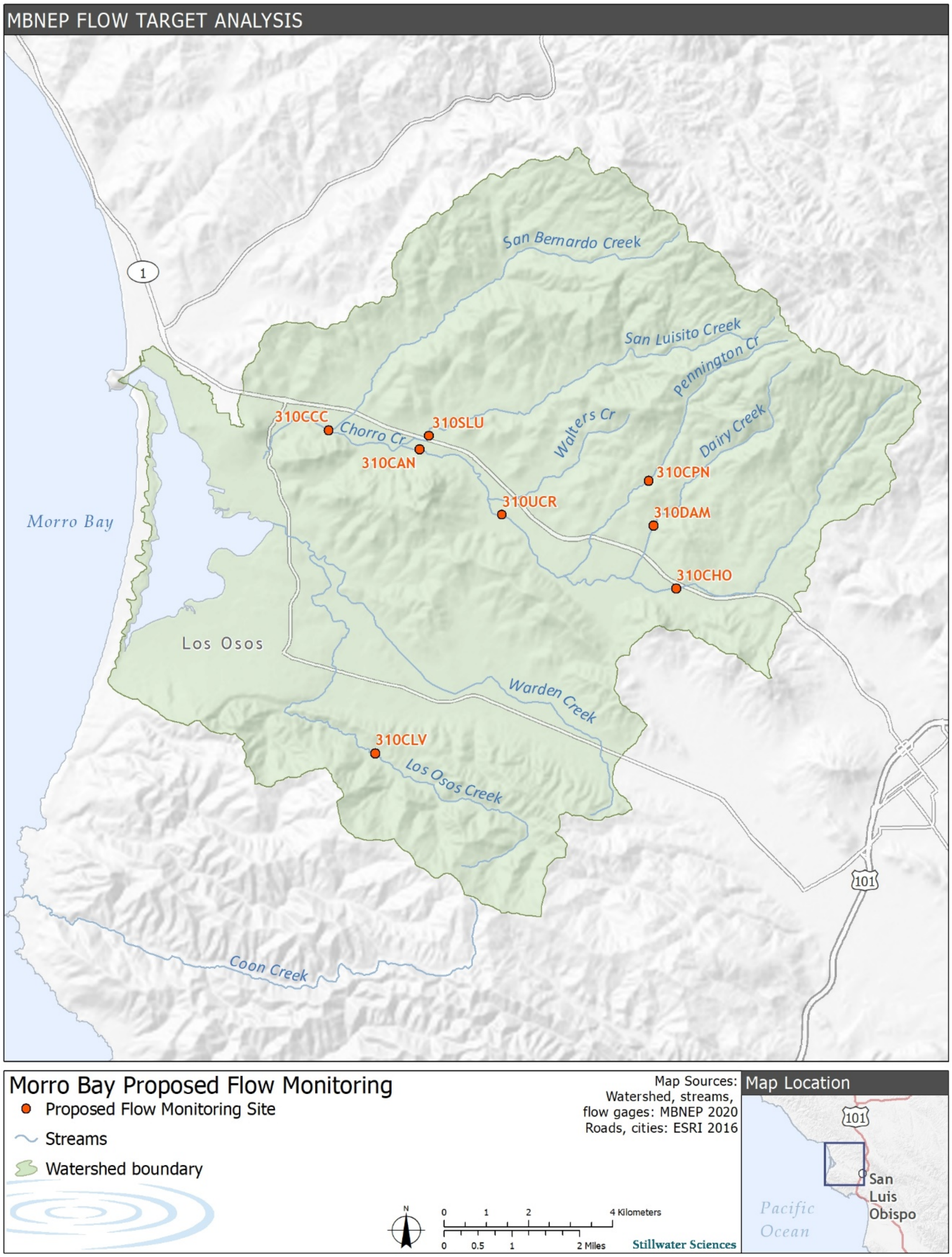

Figure 3-5. Proposed EWD flow monitoring sites. One proposed site San Bernardo (SBC) is not shown because it is on private property.

3.3 EWD Analysis

Seasonal EWD were calculated for all the continuous flow gage sites with a rating curve (i.e., 310SLU, 310CAN, 310APN, and 310UPN) and instantaneous flow measurements sites identified as a proposed monitoring site (Table 3-2). Mainstem Chorro Creek sites had spring EWDs ranging from 0.71 to 2.29 cfs and summer EWDs ranging from 0.30 to 0.69 cfs. Chorro Creek tributary sites had spring EWD ranging from 0.38 to 0.71 cfs and a summer EWD ranging from 0.22 to 0.30 cfs. All three sites on Pennington Creek had an upstream drainage area less than the minimum used to develop the EWD models (i.e., 2.2 sq. miles). The estimated spring EWDs at these three sites were less than 0.5 cfs, the minimum spring flow that had been found to maintain sufficient spring steelhead habitat, but the estimated summer EWDs at the sites were greater than 0.2 cfs, the minimum summer flow for which suitable summer steelhead rearing habitat was encountered in the Stillwater Sciences (2014) study. Additional field measurements are recommended (see Section 4.2) to determine whether the calculated seasonal EWDs would support sufficient habitat at sites with a drainage area less than 2.2 sq. miles, as recommended by Stillwater Sciences (2014). The mainstem Los Osos site had a spring EWD of 0.54 cfs and a summer EWD of 0.26 cfs.

Table 3-2. Seasonal EWD at continuous and instantaneous flow sites in the Morro Bay watershed.

Description	Gage ID	Upstream drainage area (sq. miles)	EWD (cfs)	
			Spring (Apr 1–May 31)	Summer (Aug 1–Sep 30)
Chorro Creek Mainstem				
Upper Chorro Flats	CCC[1]	40.5	2.29	0.69
Chorro Creek at Canet Road	CAN[1,2]	21.8	1.38	0.46
Upper Chorro Reserve, at the upstream boundary of the Ecological Reserve	UCR[1]	17.7	1.18	0.41
Upper Chorro Creek at Hwy 1 bridge	CHO[1]	8.2	0.71	0.30
Chorro Creek Tributaries				
San Bernardo Creek, private property	SBC[1]	6.8	0.64	0.28
San Luisito Creek, at Adobe Rd	SLU[1,2]	8.1	0.71	0.30
Pennington Creek, at the bridge	CPN[1]	1.8[3]	0.40	0.22
Pennington Creek, downstream of wells	UPN[1,2]	1.7[3]	0.39	0.22
Pennington Creek, upstream of wells	APN[1,2]	1.5[3]	0.38	0.22
Dairy Creek, middle, near the dog park	DAM[1]	2.2	0.42	0.23
Los Osos Mainstem				
Upper Los Osos Creek	CLV[1]	4.7	0.54	0.26

[1] Instantaneous flow measurement site.
[2] Continuous flow gage site with a stage-discharge rating curve available.
[3] Upstream drainage area less than 2.2 sq. miles.

3.4 Comparison of Flow and EWD at Morro Bay Watershed Sites

To inform how frequently the seasonal EWD could be met at proposed long-term EWD monitoring sites, historical continuous flow at 310SLU and 310CAN and historical instantaneous flow at 310CCC and 310UCR were analyzed and compared to the seasonal EWDs calculated for those sites using the Stillwater Sciences EWD model.

3.4.1 310SLU (San Luisito Creek at Adobe Road)

Continuous flow at 310SLU between spring and summer tended to be greater than the associated seasonal EWD during wetter water years and less than the associated seasonal EWD during average to drier water years. In spring, the continuous flow at 310SLU was consistently greater than the EWD_{spring} during both Very Wet and Wet water years, but there was substantial variability in the frequency continuous flow met EWD_{spring} during Average, Dry, and Very Dry water years (Figure 3-6 and Table 3-3). Flow tended to meet EWD_{spring} at the beginning of April during Average to Very Dry water years, and flow typically dropped below or just barely met the EWD_{spring} by mid-April to May 1. In most water years, flow consistently decreased during spring such that flow did not increase above EWD_{spring} after it initially decreased below EWD_{spring}, and periodic instantaneous measurements would characterize the overall flow trends and the frequency EWD_{spring} was met. However, there were occasional temporary increases in flow during several water years due to precipitation events. Precipitation events during April increased the frequency flow met the EWD_{spring} during some drier water years, but the frequency flow met EWD_{spring} typically increased only several days to approximately a week.

There was an overall decrease in the frequency that flow met EWD_{spring} as the water year ranged from Very Wet to Very Dry, but the frequency flow met EWD_{spring} did not consistently decrease from wetter to drier water years. The range the frequency flow met EWD_{spring} between April 1 and May 31 overlapped during Average, Dry, and Very Dry water years and was highly variable (Table 3-3). Some of the overlap and variability may be due to the limited number of each water year type in the available data record at 310SLU (e.g., only one Very Dry water year) or multi-year effects (e.g., a Dry year following a Very Wet year). For example, the wide range of frequency flow met EWD_{spring} during Dry water years (2 to 74%) could be due to one Dry water year following a Very Wet water year or precipitation during April increasing the frequency flow was greater than EWD_{spring}. Additional years of flow data and analysis may provide insight into the processes that influence the variability in the frequency flow meets EWD_{spring}.

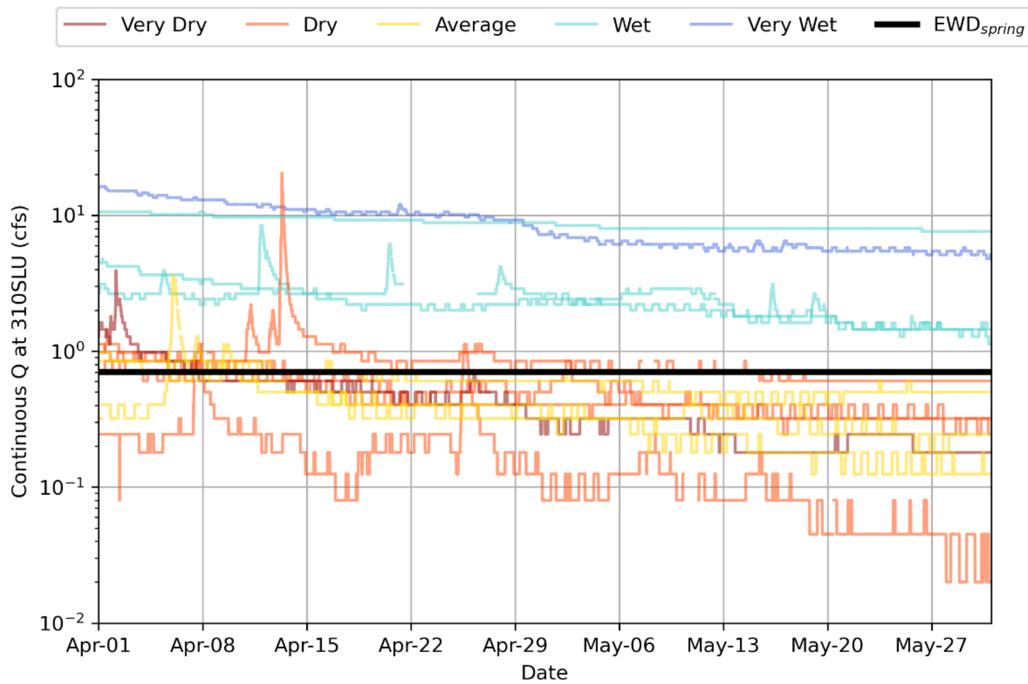

Figure 3-6. Comparison of WY 2009 through WY 2020 continuous flow at 310SLU from April 1 through May 31 with ***EWD$_{spring}$***. Note that the y-axis is log-scale to show both the high and low range of flows.

In summer, flow at 310SLU typically decreased or remained approximately constant, excluding the small magnitude daily flow variability, but there was one Wet water year where flow increased consistently throughout the summer (Figure 3-7). In the Wet and Average water years where the flow was greater than *EWD$_{summer}$* on August 1, flow typically decreased to approximately the *EWD$_{summer}$* or decreased below the *EWD$_{summer}$* around late August/early September. Flow trends were sufficiently consistent (increasing or decreasing) throughout individual water years to suggest periodic instantaneous measurements across the summer would characterize the overall seasonal flow trends and the frequency *EWD$_{summer}$* was met.

The frequency flow at 310SLU met *EWD$_{summer}$* between August 1 and September 30 decreased from wetter to drier water years, but the frequency flow met *EWD$_{summer}$* decreased more rapidly as the water year became drier during summer than spring (Table 3-3). The frequency flow met the *EWD$_{summer}$* decreased from 69 to 100% during Wet water years to 0% during Average water years. Additionally, there was an extremely wide range of frequency flow at 310SLU, where 310SLU met *EWD$_{summer}$* during Dry water years (i.e., 0 to 100%) caused by one of the four Dry water years (i.e., WY 2012) exceeding *EWD$_{summer}$* throughout the summer. As noted for spring, the high frequency flow met *EWD$_{summer}$* during the Dry WY 2012 may be due to that water year following a Very Wet water year or precipitation during mid-April in WY 2012 increasing baseflow above *EWD$_{summer}$* throughout the summer. Additional years of flow data and analysis may provide insight into the processes that influence the variability in the frequency flow meets *EWD$_{summer}$*.

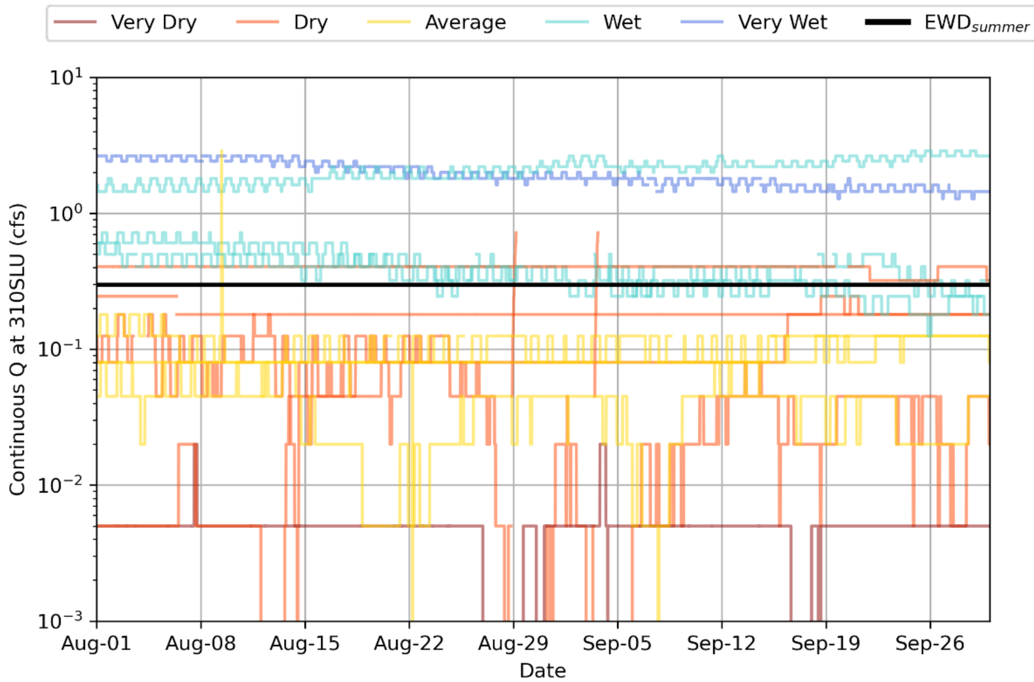

Figure 3-7. Comparison of WY 2009 through WY 2020 continuous flow at 310SLU from August 1 to September 30 with EWD_{summer}. Note that the y-axis is log-scale to show both the high and low range of flows.

Table 3-3. Frequency of continuous flow at 310SLU was above the seasonal EWDs per water year.

Water year	Water year type	Frequency flow above EWD_{spring} (%)	Frequency flow above EWD_{summer} (%)
2009	Dry	20	8
2010	Wet	100	91
2011	Very Wet	100	100
2012	Dry	74	100
2013	Dry	16	0
2014	Very Dry	11	0
2015	Dry	2	0
2016	Average	14	0
2017	Wet	100	100
2018	Average	32	0
2019	Wet	100	69
2020	Average	6	0

Overall, the average frequency flow at 310SLU met the seasonal EWDs correlated with water year type, with the average frequency flow met seasonal EWDs generally decreasing from Very Wet to Very Dry water years (**Figure** 3-8). However, the rates the average frequency flow met seasonal EWDs decreased were not linear and there were abrupt decreases in the frequency flow met the seasonal EWDs between Wet and Average water years that followed an approximately inverse s-shape curve. Very Wet and Wet water years met the seasonal EWDs 87 to 100% of the time and Average, Dry, and Very Dry met the seasonal EWDs 0 to 27% of the time. Increases in the frequency flow in Dry water years met the seasonal EWDs compared to Average water years were primarily due to flow in one Dry water year (i.e., WY 2012) behaving differently than other Dry water years. The frequency flow met the seasonal EWD would more consistently decrease from Average to Very Dry water years if WY2012 was not considered. The sensitivity of the average frequency flow met the seasonal EWDs to individual water years is likely due to the limited number of water years with continuous flow data available for this analysis.

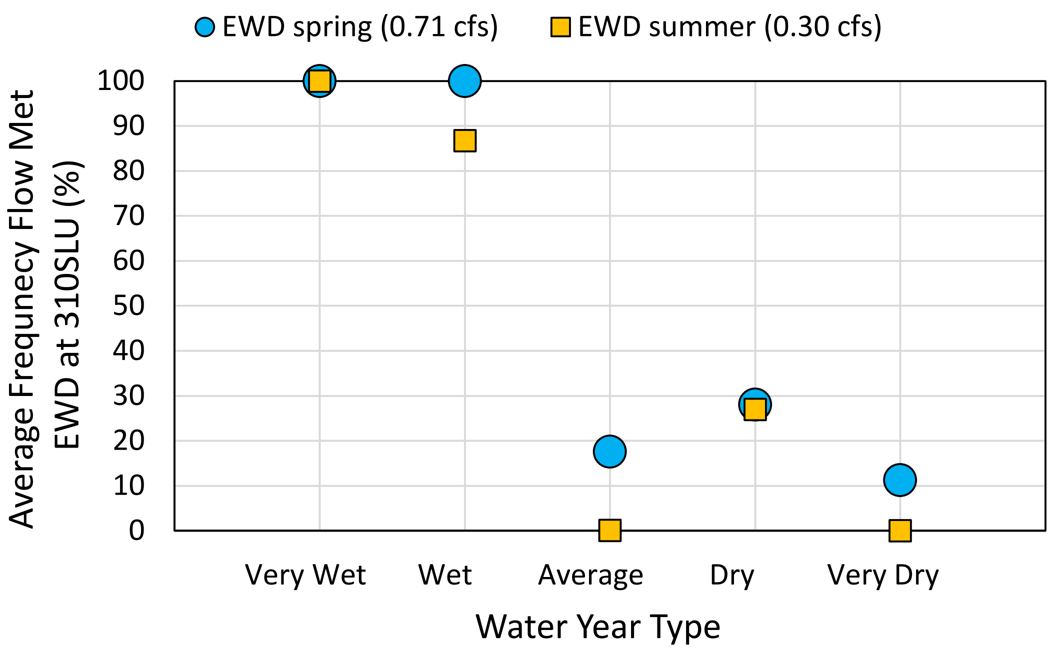

Figure 3-8. Average frequency flow met the seasonal EWD per water year type at 310SLU.

3.4.2 310CAN (Chorro Creek at Canet Road)

Adjusted continuous flow at 310CAN during spring (April 1 through May 31) and summer (August 1 through September 30) was greater than the associated seasonal EWDs more frequently during wetter water years and less frequently during drier water years. In spring, flow at 310CAN was consistently greater than the EWD_{spring} during Very Wet through Average water years, but continuous flow often met EWD_{spring} less frequently during Dry and Very Dry water years (**Figure** 3-9 and Table 3-4). Flow at 310CAN typically decreased consistently from April 1 to May 31, excluding periods when precipitation events caused an increase in flow for several days to approximately a week. In the water years when the flow decreased below the EWD_{spring}, either it was below the EWD_{spring} at the beginning of April and remained below throughout the spring or it decreased below the EWD_{spring} mid- to late May. Flow trends were sufficiently consistent during spring throughout individual water years to suggest periodic instantaneous measurements across the spring would characterize the overall seasonal flow trends.

The frequency flow met EWD_{spring} between April 1 and May 31 did not consistently decrease between Dry to Very Dry water years and overlapped during Dry and Very Dry water years (Table 3-4). The overlap between the frequency flow met EWD_{spring} in Dry and Very Dry water years was due to flow in one Dry water year (i.e., WY 2015) meeting EWD_{spring} much less than the other two Dry water years (i.e., WY 2012 and WY 2013). The overlap was potentially due to the limited number of each water year type in the available data record (e.g., only one Very Dry water year) or multi-year effects (e.g., a Dry year following a Very Dry year), but additional years of flow data and analysis would be required to investigate further.

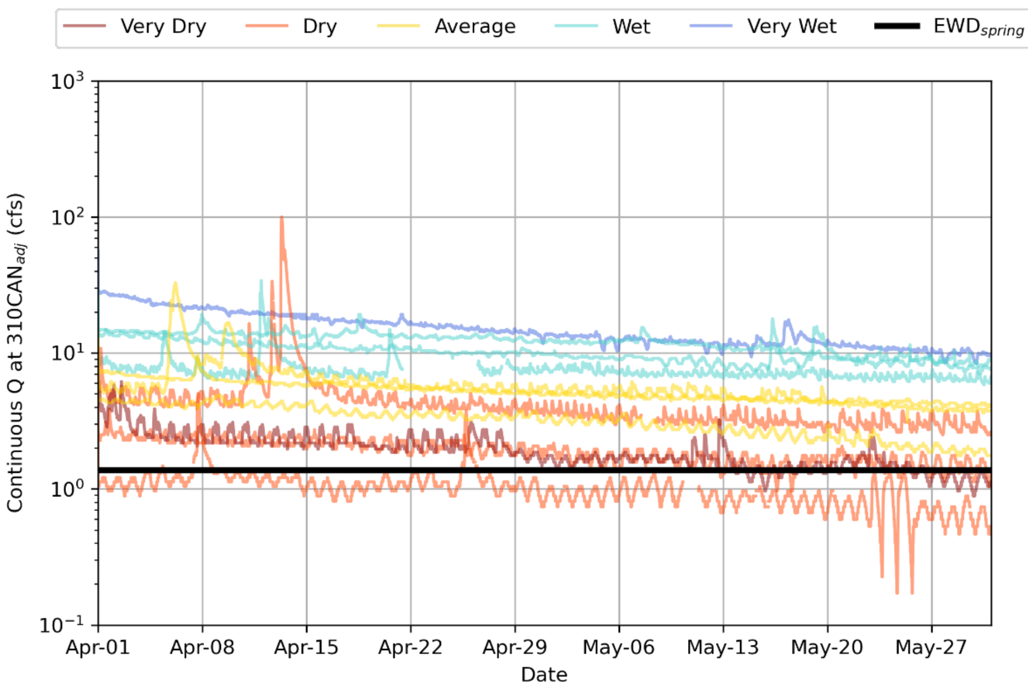

Figure 3-9. Comparison of WY 2011 through WY 2020 continuous flow at 310CAN from April 1 through May 31 with EWD_{spring}. Please note that the y-axis is log-scale to clearly show both the high and low range of flows.

In summer, flow at 310CAN typically decreased or remained approximately constant between August 1 and September 30, excluding the small magnitude, daily flow variations observed in all years. These daily flow variations often resulted in flow oscillating above and below the EWD_{summer} as the flow approached within approximately 1 cfs of the EWD_{summer}, so the timing of when flow decreased below the EWD_{summer} in some Average, Dry, and Very Dry water years was not clearly associated with a specific time period during summer. While flow trends were sufficiently consistent throughout individual water years to suggest periodic instantaneous measurements across the summer would characterize the overall seasonal flow trends and the frequency EWD_{summer} was met, daily flow variations would potentially result in periodic instantaneous measurements across the summer mischaracterizing overall seasonal flow trends and frequency EWD_{summer} was met if instantaneous flow measurements captured the flow at different points along the daily variations. For example, measurement of peak flow in an oscillation followed by measurement of a valley, peak, and peak would suggest a decrease then an increase in flow over time rather than an oscillation around a central tendency.

The frequency of when flow at 310CAN met EWD_{summer} between August 1 and September 30 decreased from wetter to drier water years, but the frequency flow met EWD_{summer} decreased more rapidly as the water year became drier during summer than spring (**Figure** 3-10 and Table 3-4). Flow met EWD_{summer} throughout Very Wet and Wet water years at 310CAN, but flow only met EWD_{summer} 86 to 100% during Average water years, 20% to 100% during Dry water years, and 35% during the one Very Dry water year. The wide range of frequency flow at 310CAN met EWD_{summer} during Dry water years was caused by one of the three Dry water years (i.e., WY 2015) only meeting EWD_{summer} 20% of the time, while the other two Dry water years (i.e., 2012 and 2013) meeting EWD_{summer} 65 to 100% of the summer. As noted for spring, the range of frequency flow met EWD_{summer} during Dry water years may be due to one Dry water year following a Very Dry water year, but additional years of flow data and analysis would be required to investigate further.

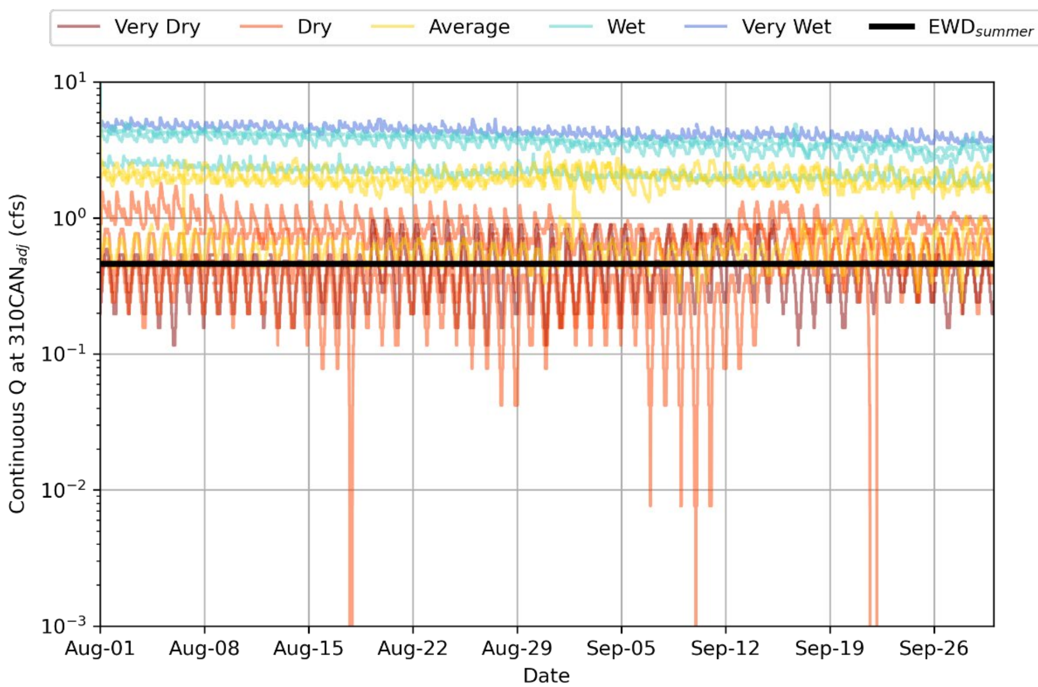

Figure 3-10. Comparison of WY 2011 through WY 2020 continuous flow at 310CAN from August 1 to September 30 with EWD_{summer}. Note that the y-axis is log-scale to show both the high and low range of flows.

Table 3-4. Frequency adjusted continuous flow at 310CAN was above the seasonal EWDs per water year.

Water year	Water year type	Frequency flow above EWD_{spring} (%)	Frequency flow above EWD_{summer} (%)
2011	Very Wet	100	100
2012	Dry	100	100

Water year	Water year type	Frequency flow above EWD_{spring} (%)	Frequency flow above EWD_{summer} (%)
2013	Dry	93	65
2014	Very Dry	87	35
2015	Dry	6	20
2016	Average	100	86
2017	Wet	100	100
2018	Average	100	100
2019	Wet	100	100
2020	Average	100	100

Overall, the average frequency flow at 310CAN met seasonal EWDs decreased from Very Wet to Very Dry water years, but it typically remained high (i.e., 86 to 100%) in Very Wet to Average water year before decreasing during Dry and Very Dry water years (**Figure** 3-11). Decreases in the frequency flow met seasonal EWDs were significantly influenced by individual water years due to the limited number of water years with continuous flow data available for this analysis. The relatively low frequency flow met seasonal EWDs in the Dry WY 2015 (i.e., 6% in spring and 20% in summer) compared to other Dry water years decreased the average frequency flow met seasonal EWDs in Dry water years by 30% in spring and 20% in summer. Decreases in the frequency flow met seasonal EWDs would have been more gradual had WY 2015 not been considered in the analysis.

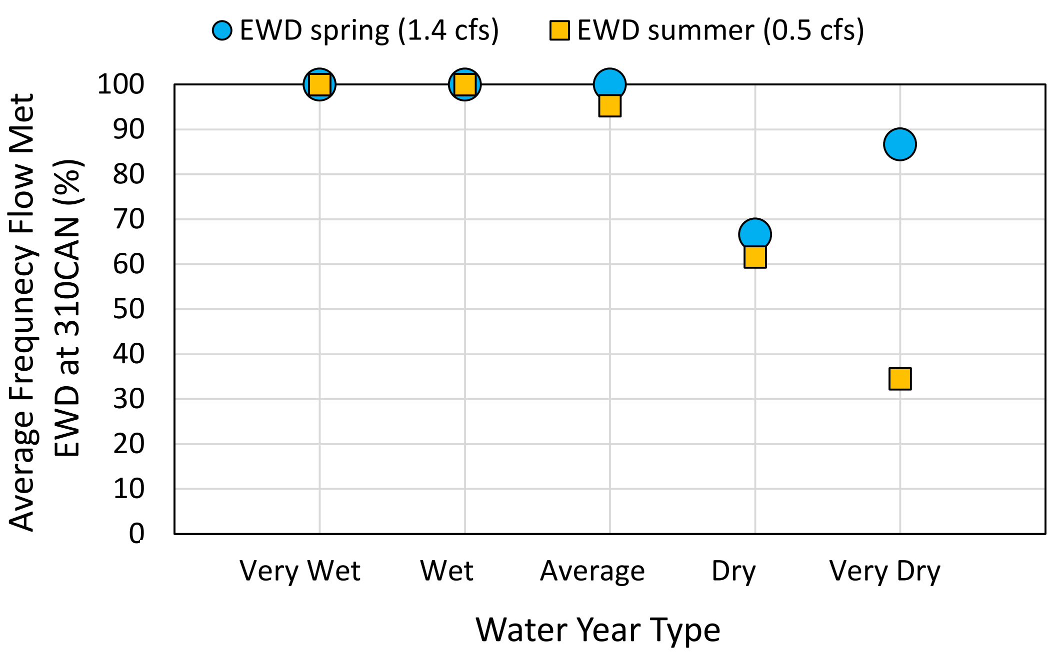

Figure 3-11**.** Average frequency flow met the seasonal EWD per water year type at 310CAN.

3.4.3 Instantaneous flow measurement sites

The 310CCC and 310UCR sites on mainstem Chorro Creek were the only sites identified as a proposed monitoring site that also had sufficient instantaneous flow data (i.e., at least four measurements per season distributed across 80% or more of the season) to evaluate the frequency flow met seasonal EWDs during several water years. The 310CCC site only had sufficient instantaneous flow data to calculate the frequency flow met EWD_{spring} for Wet through Very Dry water years and the frequency flow met EWD_{summer} for Wet water years. The 310UCR site only had sufficient instantaneous flow data to calculate the frequency flow met EWD_{spring} for Dry water years and the frequency flow met EWD_{summer} for Wet through Very Dry water years.

At 310CCC, the frequency of when instantaneous flow met EWD_{spring} decreased from wetter to drier water years (**Figure** 3-12). Instantaneous flow was greater than EWD_{spring} throughout Wet water years, greater than EWD_{spring} approximately 67 to 100% of the season during Average water years, and greater than EWD_{spring} approximately 0 to 20% of the season during Dry and Very Dry water years. Similar to the adjusted continuous flow at the upstream 310CAN site, flow at 310CCC during the Dry water year (i.e., WY 2015) met EWD_{spring} less frequently than the flow during the Very Dry water year (i.e., WY 2014). The low frequency flow met EWD_{spring} during the Dry WY 2015 was potentially due to WY 2015 occurring after the Very Dry water year, but additional years of flow data and analysis would be required to investigate further. The frequency instantaneous flow met EWD_{summer} at 310CCC could not be compared with the water year type during summer since only Wet water years had sufficient data at this site (**Figure** 3-13). Instantaneous flow met EWD_{summer} throughout the two Wet water years in the available data.

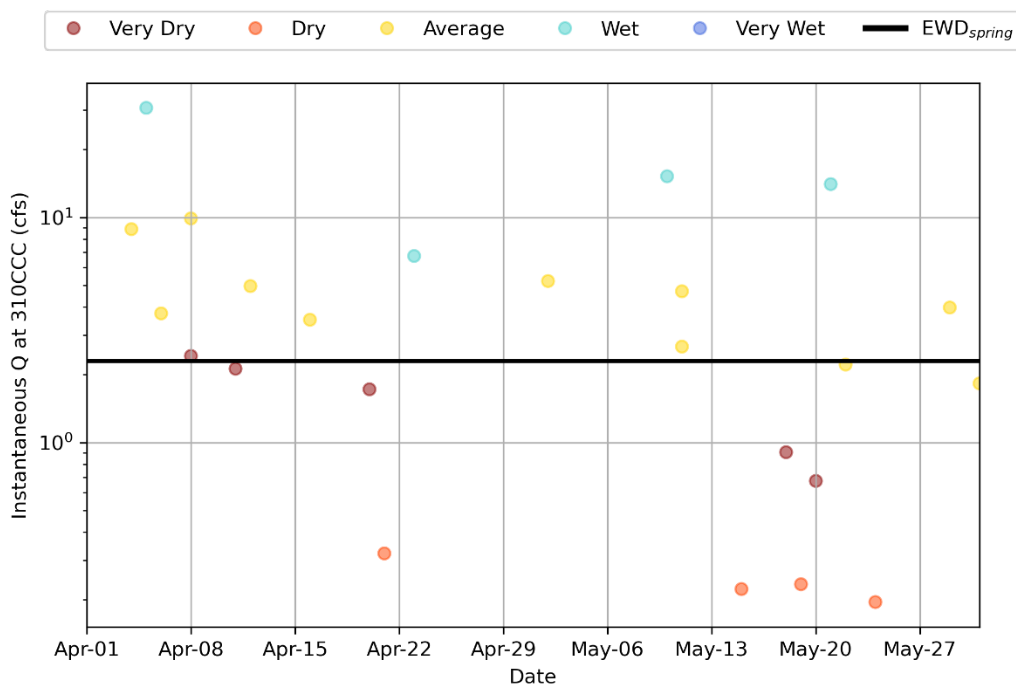

Figure 3-12. Comparison of WY 2014 through WY 2018 instantaneous flow at 310CCC from April 1 through May 31 with EWD_{spring}. Please note that the y-axis is log-scale to clearly show both the high and low range of flows.

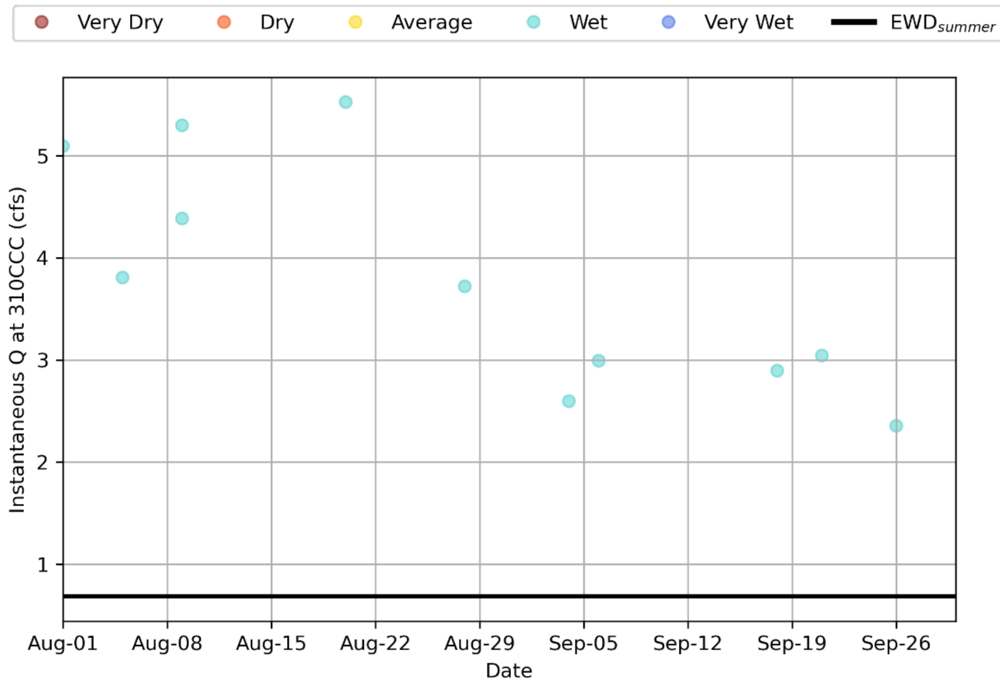

Figure 3-13. Comparison of WY 2017 and WY 2019 instantaneous flow at 310CCC from August 1 to September 30 with EWD_{summer}.

Overall, the average frequency flow met seasonal EWDs was very similar to the frequency flow met seasonal EWDs per water year type discussed above, since most water year types were represented by only one year in the available data at 310CCC. The average frequency flow at 310CCC met EWD_{spring} correlated with water year type, with the average frequency flow met EWD_{spring} remaining high (i.e., 83 to 100%) in Wet to Average water year before decreasing during Dry and Very Dry water years (**Figure** 3-14). As explained for the frequency flow at 310CCC met EWD_{summer} per water year, the average frequency flow met EWD_{summer} could not be assessed across various water year types since there was only data for Wet water years. The average frequency flow at 310CCC met EWD_{summer} during Wet water year types (i.e., 100%) was consistent with the upstream 310CAN site. The average frequency flow met seasonal EWDs was very similar to the frequency flow met seasonal EWDs per water year type, since most water year types were represented by only one year in the available data at 310CCC.

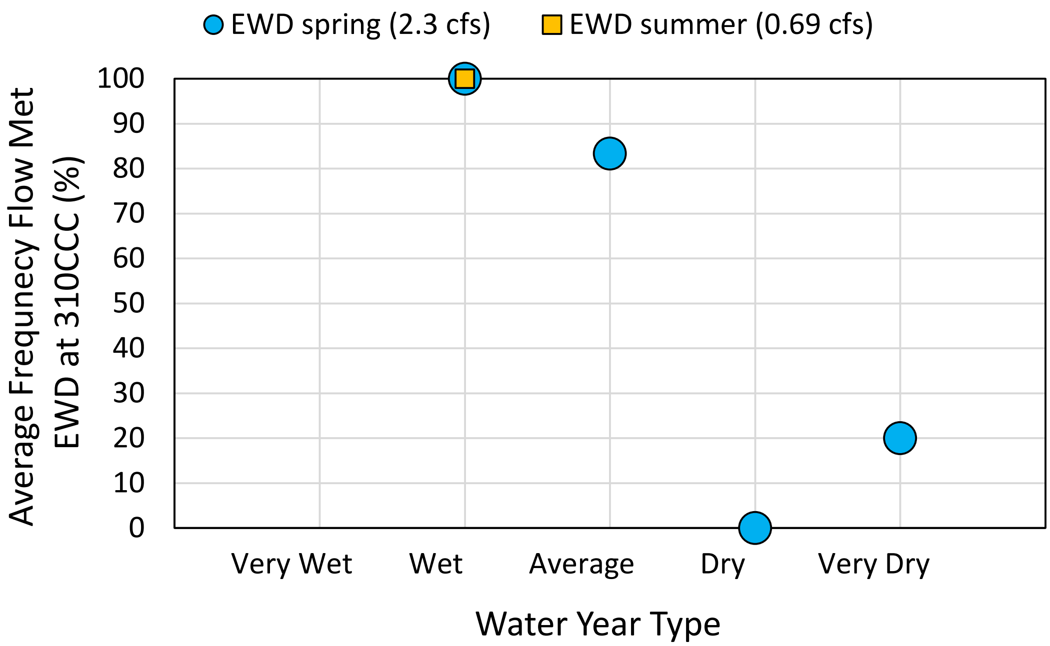

Figure 3-14. Average frequency flow met seasonal EWD per water year type at 310CCC.

At 310UCR, the frequency of when instantaneous flow met seasonal EWDs per water year either could not be compared with the water year type due to lack of data or did not correlate with water year type. The frequency flow met EWD_{spring} could not be compared with the water year type since only Dry water years had sufficient data at this site during spring. The frequency flow met EWD_{spring} at 310UCR ranged from 20% to 100% during Dry water years (**Figure** 3-15). As observed at the downstream 310CCC and 310CAN sites, the frequency that flow met EWD_{spring} during the Dry water year following a Very Dry water year was much less than the frequency flow met EWD_{spring} during other Dry water years. Additional flow data and analysis would be required to investigate this further. The frequency that instantaneous flow at 310UCR met EWD_{summer} did not vary by water year type, with flow meeting EWD_{summer} throughout the summer during all water years in the available data (**Figure** 3-16). There was no correlation between the frequency instantaneous flow at 310UCR met EWD_{summer} and water year type because instantaneous flow was always greater than the EWD_{summer} at 310UCR (i.e., 0.41 cfs). While flow decreased from August 1 to September 30 during Wet water years, flow typically remained between approximately 0.5 to 1.0 cfs during Average through Very Dry water years. The California Department of Corrections and Rehabilitation Wastewater Treatment Plant (WWTP) upstream of 310UCR has a minimum in-stream flow release requirement is 0.75 cfs (Warner and Hendrix 1984; SLO County Water Resources 2012). The similar magnitude of the instantaneous flow at 310UCR in summer and the required minimum in-stream flow at the upstream WWTP suggest the absence of a correlation between the frequency instantaneous flow at 310UCR met EWD_{summer} and water year type was due to upstream releases to Chorro Creek. Summer flow at 310UCR during Average through Very Dry water years was controlled by releases from the California Department of Corrections and Rehabilitation WWTP.

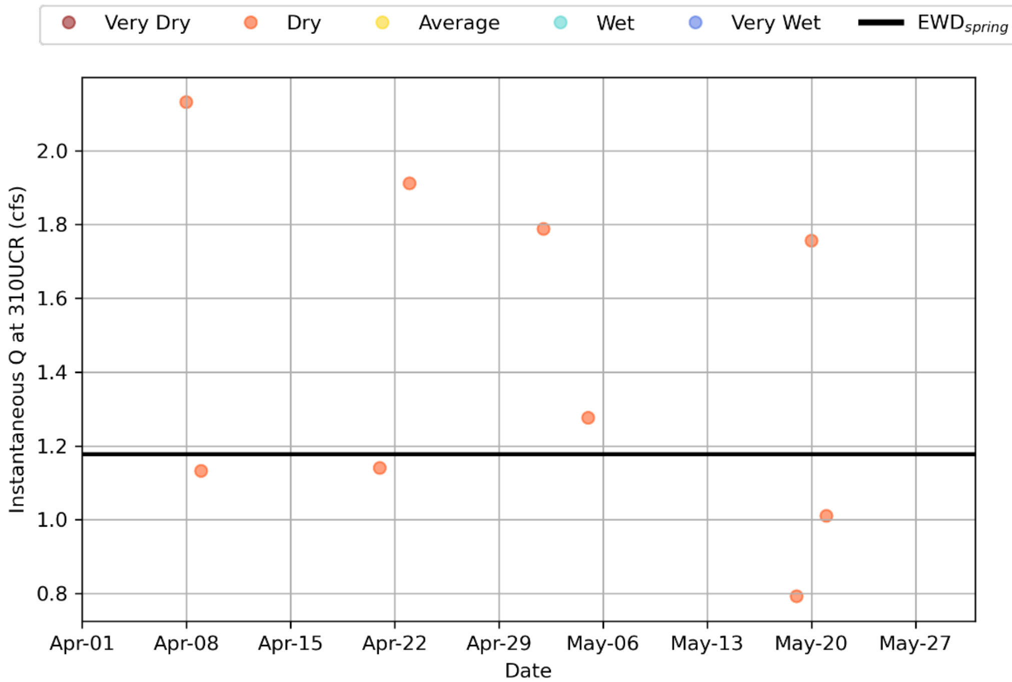

Figure 3-15. Comparison of WY 2013 and WY 2015 instantaneous flow at 310UCR from April 1 through May 31 with EWD_{spring}.

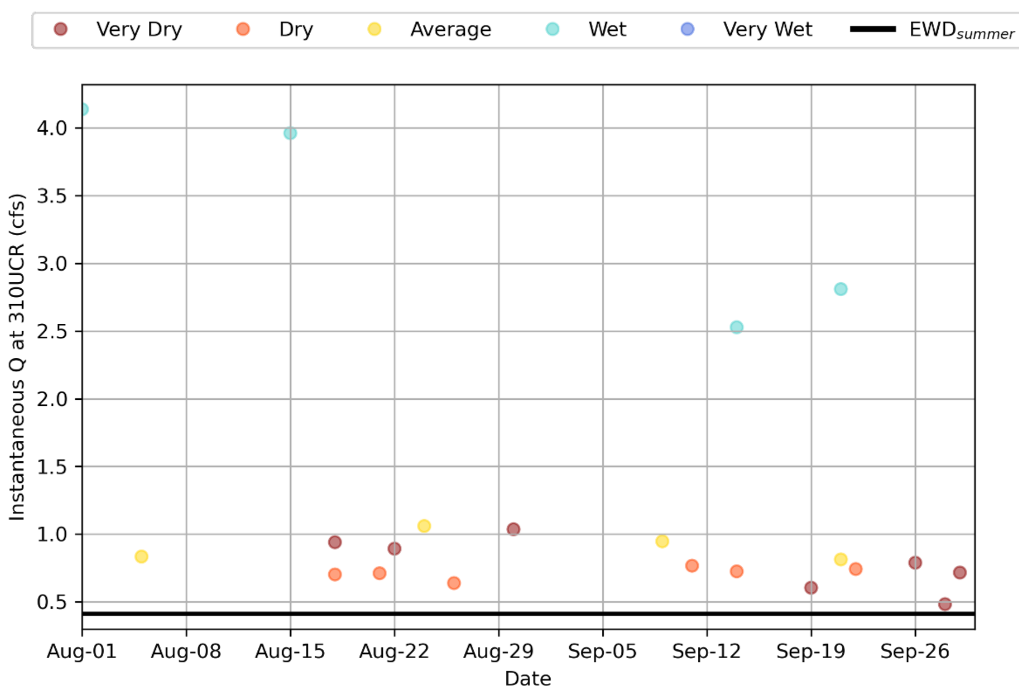

Figure 3-16. Comparison of WY 2014 through WY 2017 instantaneous flow at 310UCR from August 1 to September 30 with EWD_{summer}.

The average frequency flow met seasonal EWDs was very similar to the frequency flow met seasonal EWDs per water year type discussed above, since most water year types were represented by only one year in the available data at 310UCR (**Figure** 3-). The average frequency instantaneous flow met EWD_{spring} could not be compared with the water year type due to lack of data. The average frequency instantaneous flow met EWD_{summer} did not correlate with water year type since the flow remained above the EWD_{summer} throughout the summer in all water year types. As discussed above, the absence of a correlation between the average frequency instantaneous flow at 310UCR met EWD_{summer} and water year type likely was due to upstream minimum in-stream releases of 0.75 cfs to Chorro Creek from the California Department of Corrections and Rehabilitation WWTP maintaining flow greater than the EWD_{summer} in all water year types.

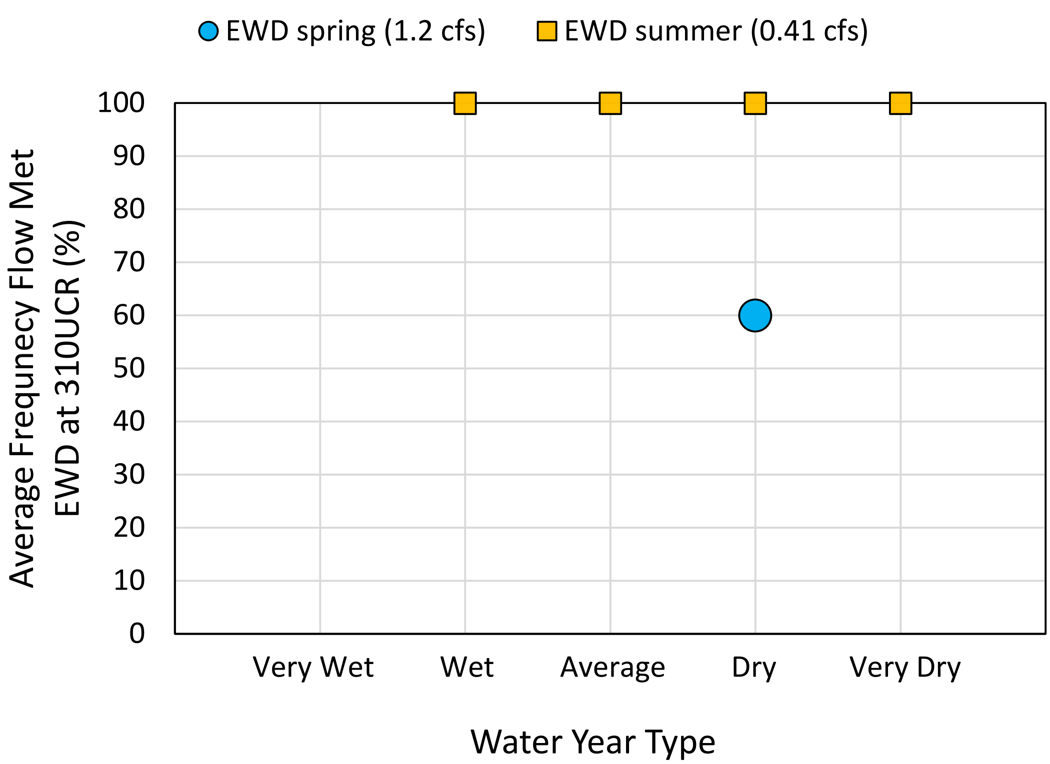

Figure 3-17. Average frequency flow met seasonal EWD per water year type at 310UCR.

4 DISCUSSION AND RECOMMENDATIONS

4.1 Synthesis of EWD Results

The frequency of when flow met seasonal EWD estimates generally correlated with the water year type at the sites evaluated in the Morro Bay watershed, except at the 310UCR site, which was likely influenced by upstream releases to the stream (**Figure 4-1** and **Figure 4-2**). Flow in both the spring and summer typically met seasonal EWD estimates more frequently in wetter years and less frequently in drier water years, but the frequency the flow met the EWD_{spring} was greater across various water year types than the frequency the flow met the EWD_{summer}. For example, mainstem Chorro Creek flow at 310CAN met EWD_{spring} throughout the spring in Very

Wet through Average water years, but the only met EWD_{summer} throughout the summer in Very Wet through Wet water years. Similar trends were observed in San Luisito Creek (i.e., 310SLU), suggesting these trends would occur in streams throughout the Morro Bay watershed.

There were general trends consistent across all sites evaluated, but the average frequency where flow met seasonal EWD estimates varied between sites (Figure 4-1a and b; Figure 4-2a and b). The average frequency flow met seasonal EWDs decreased more gradually between water year types at mainstem Chorro Creek sites (Figure 4-1a; Figure 4-2a) at the middle and upstream sites (i.e., 310UCR and 310CAN). Limited data at 310UCR during spring and at 310CCC during summer combined with minimum upstream in-stream releases of 0.75 cfs to the mainstem Chorro Creek may have influenced these trends. While the average frequency flow met seasonal EWD decreased gradually between water year types at several sites on mainstem Chorro Creek, the average frequency flow met seasonal EWD estimates at the San Luisito Creek site (Figure 4-1b; Figure 4-2b) transitioned rapidly between Wet and Average water year types, with seasonal EWD estimates being met only 0 to 30% of the time in Average through Very Dry water years. Broad trends between the frequency flow met seasonal EWDs and water year types across tributaries in the Morro Bay watershed could not be evaluated since the San Luisito Creek site was the only tributary site with sufficient flow data to determine frequency flow met seasonal EWDs. However, the average frequency flow met seasonal EWDs during the different water year types at other tributary sites would be expected to be within the range observed at the mainstem Chorro Creek site 310CAN and the San Luisito Creek site 310SLU.

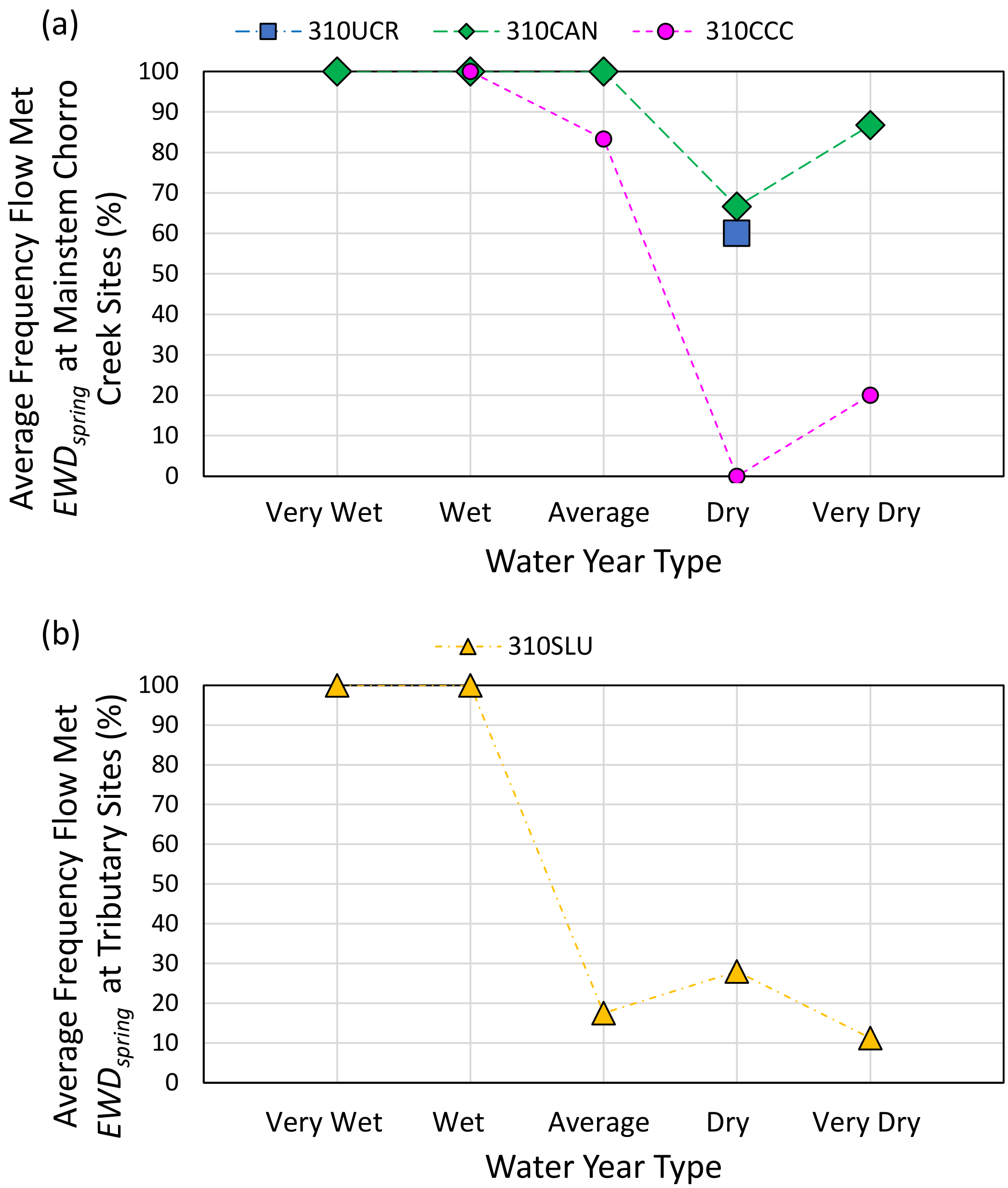

Figure 4-1. Average frequency flow met *EWD_{spring}* at (a) mainstem Chorro Creek and (b) tributary sites.

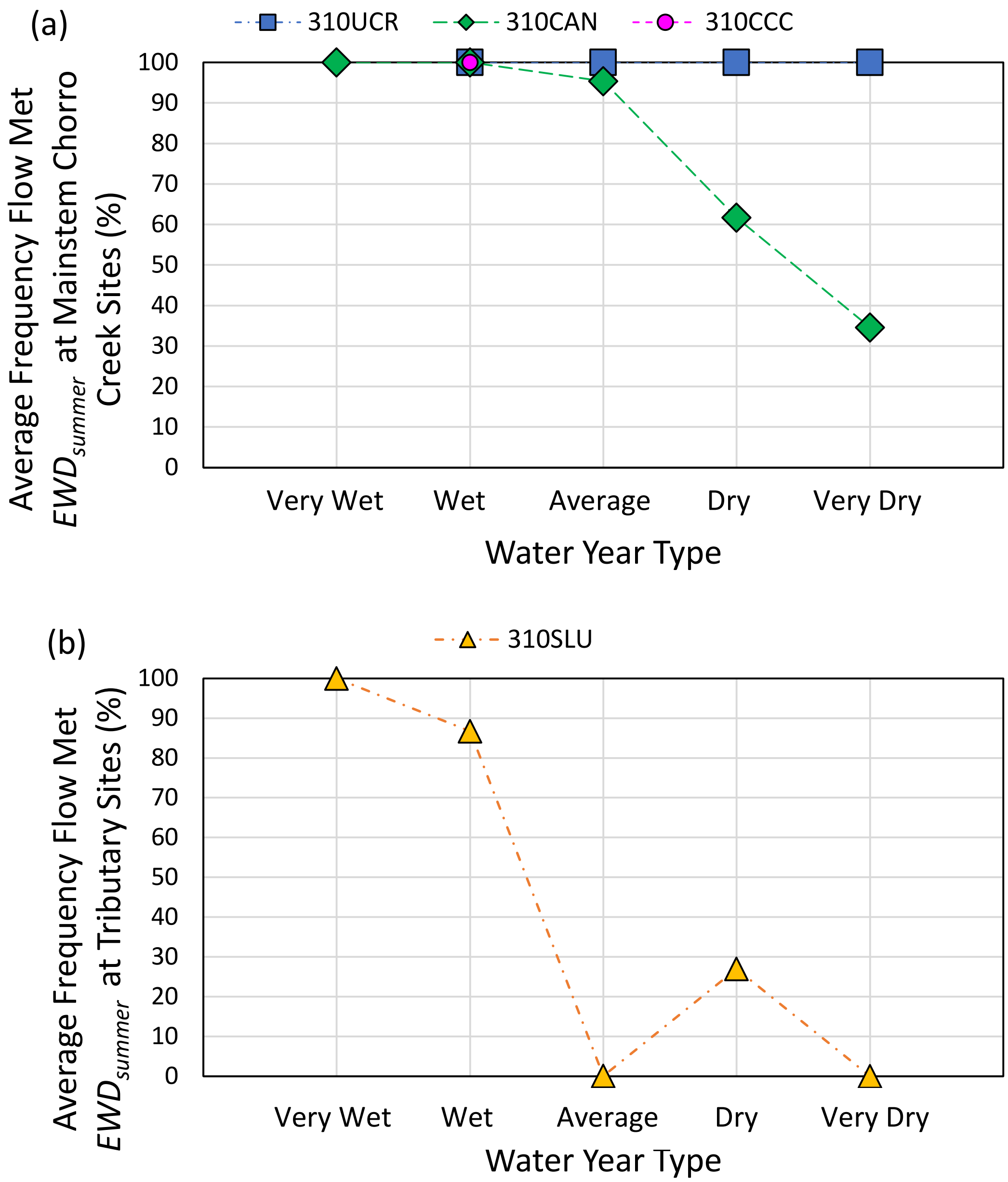

Figure 4-2. Average frequency flow met EWD_{summer} at (a) mainstem Chorro Creek and (b) San Luisito tributary site

4.2 Recommendations

4.2.1 Morro Bay watershed flow targets

The Morro Bay Estuary Program is establishing measurable targets for a sub-set of priority issues within their Comprehensive Conservation Management Plan (CCMP). The CCMP defines the priority issues facing the health of the Morro Bay estuary and watershed. Adequate freshwater flow is one of those priorities. The MBNEP collects and analyzes data to better understand long-term ambient conditions and identify areas of concern that merit future actions or to determine the effectiveness of such actions. As habitat restoration and other projects often implement improvements that support steelhead, better understanding of when and where EWD targets are being met in different times of year can help guide and assess these efforts.

Seasonal interim and future Morro Bay watershed stream flow targets during spring and summer are recommended for nine sites distributed across mainstem Chorro Creek, Chorro Creek tributary, and mainstem Los Osos sites based on the seasonal EWD estimates and the average frequency that the flow meets the seasonal EWDs per water year type. The recommended flow targets for spring and summer are presented in **Table 4-**1 and 4-2. These targets will be reviewed overtime to consider where additional management is needed. The recommended flow targets for sites are specified as percent of the season the seasonal EWDs for the site are met per water year type since analysis of flow data from three mainstem Chorro Creek sites (i.e., 310CCC, 310CAN, and 310UCR) and one Chorro Creek tributary site (i.e., 310SLU) indicates flow and the frequency seasonal EWDs are met at sites varies with water year type. Interim flow targets are designed to be reasonably met based on analysis of existing flow conditions at the sites, while future flow targets are those that would be potentially achievable in the longer term (e.g., 10+ years) with conservation and management actions to improve stream flow in the watershed. Flow targets have been recommended for nine sites because (1) these nine sites represent a wide range of conditions in the Morro Bay watershed that potential provide habitat to steelhead, and (2) a field assessment of sites across the watershed identify these as feasible monitoring sites.

Table 4-1. Proposed Morro Bay watershed spring (i.e., April 1 to May 31) stream flow targets.

Description	Gage ID	EWD_{spring} (cfs)	Interim flow target	Future flow target
Chorro Creek Mainstem				
Upper Chorro Flats	CCC	2.29	EWD_{spring} maintained 100% of the season during Very Wet, Wet, 75% of the season in Average water years, and 25% of the season in Dry and Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 50% of the season in Dry and Very Dry water years
Chorro Creek at Canet Road	CAN	1.38	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 75% of the season in Dry and Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 90% of the season in Dry and Very Dry water years
Upper Chorro Reserve, at the upstream boundary of the Ecological Reserve	UCR	1.18	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 75% of the season in Dry and Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 90% of the season in Dry and Very Dry water years
Upper Chorro Creek at Hwy 1 bridge	CHO	0.71	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 75% of the season in Dry and Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet, Wet, and Average water years, and 90% of the season in Dry and Very Dry water years
Chorro Creek Tributaries				
San Bernardo Creek, private property	SBC	0.64	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 25% of the season in Average and Dry water years, and 10% of the season in Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 50% of the season in Average water years, and 25% of the season in Dry and Very Dry water years
San Luisito Creek, at Adobe Crk Rd	SLU	0.71	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 25% of the season in Average and Dry water years, and 10% of the season in Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 50% of the season in Average water years, and 25% of the season in Dry and Very Dry water years

Description	Gage ID	EWD_{spring} (cfs)	Interim flow target	Future flow target
Pennington Creek, at the bridge	CPN	0.40	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 25% of the season in Average and Dry water years, and 10% of the season in Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 50% of the season in Average water years, and 25% of the season in Dry and Very Dry water years
Dairy Creek, middle, near the dog park	DAM	0.42	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 25% of the season in Average and Dry water years, and 10% of the season in Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 50% of the season in Average water years, and 25% of the season in Dry and Very Dry water years
Los Osos Mainstem				
Upper Los Osos Creek	CLV	0.54	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 25% of the season in Average and Dry water years, and 10% of the season in Very Dry water years	EWD_{spring} maintained 100% of the season during Very Wet and Wet water years, and 50% of the season in Average water years, and 25% of the season in Dry and Very Dry water years

Table 4-2. Proposed Morro Bay watershed summer (i.e., August 1 to September 30) stream flow targets.

Description	Gage ID	EWD_{summer} (cfs)	Interim flow target	Future flow target
Chorro Creek Mainstem				
Upper Chorro Flats	CCC	0.69	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years, 90% of the season in Average water years, and 50% of the season in Dry water years, and 30% of the season in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet, Wet, and Average water years, and 50% of the season in Dry and Very Dry water years
Chorro Creek at Canet Road	CAN	0.46	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years, 90% of the season in Average water years, and 50% of the season in Dry water years, and 30% of the season in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet, Wet, and Average water years, 75% of the season in Dry water years, and 50% of the season in Very Dry water years
Upper Chorro Reserve, at the upstream boundary of the Ecological Reserve	UCR	0.41	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years, 90% of the season in Average water years, and 50% of the season in Dry water years, and 30% of the season in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet, Wet, and Average water years, 75% of the season in Dry water years, and 50% of the season in Very Dry water years
Upper Chorro Creek at Hwy 1 bridge	CHO	0.30	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years, 90% of the season in Average water years, and 50% of the season in Dry water years, and 30% of the season in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet, Wet, and Average water years, 75% of the season in Dry water years, and 50% of the season in Very Dry water years

Description	Gage ID	EWD_{summer} (cfs)	Interim flow target	Future flow target
Chorro Creek Tributaries				
San Bernardo Creek, private property	SBC	0.28	EWD_{summer} maintained 100% of the season during Very Wet water years, 90% in Wet, 20% in Average water years, 10% in Dry water years, and 1% in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years, 40% in Average water years, and 10% in Dry and Very Dry water years
San Luisito Creek, at Adobe Crk Rd	SLU	0.30	EWD_{summer} maintained 100% of the season during Very Wet water years, 90% in Wet, 20% in Average water years, 10% in Dry water years, and 1% in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years; 40% in Average water years, and 10% in Dry and Very Dry water years
Pennington Creek, at the bridge	CPN	0.22	EWD_{summer} maintained 100% of the season during Very Wet water years, 90% in Wet, 20% in Average water years, 10% in Dry water years, and 1% in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years; 40% in Average water years, and 10% in Dry and Very Dry water years
Dairy Creek, middle, near the dog park	DAM	0.23	EWD_{summer} maintained 100% of the season during Very Wet water years, 90% in Wet, 20% in Average water years, 10% in Dry water years, and 1% in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years; 40% in Average water years, and 10% in Dry and Very Dry water years
Los Osos Mainstem				
Upper Los Osos Creek	CLV	0.26	EWD_{summer} maintained 100% of the season during Very Wet water years, 90% in Wet, 20% in Average water years, 10% in Dry water years, and 1% in Very Dry water years	EWD_{summer} maintained 100% of the season during Very Wet and Wet water years; 40% in Average water years, and 10% in Dry and Very Dry water years

4.2.2 Monitoring and recommendations

4.2.2.1 Manual instantaneous flow measurements

For manual measurements at wadable flows, a hand-held electromagnetic velocity meter (e.g., Hach FH950) and standard top-set wading rod are recommended following the CDFW Standard Operating Procedures for Discharge Measurements in Wadeable Streams (CDFW-IFP-002) (CDFW 2013), which follows standard USGS guidelines but is based on hand-held electromagnetic meters which are preferred under low flow conditions because they have a smaller, streamlined probe and are thus more accurate (CLC 2020). If possible, field crews collecting flow measurements should be trained by an experienced hydrologist or hydrologic technician with low flow monitoring experience. Special consideration during low flow measurement at a given site may include:

1. Utilizing a stadia rod placed across the stream for station, because in narrow streams it does not sag and reduces the potential for tape errors;
2. Collecting duplicate flow measurements at all or a subset of sites;
3. Ensuring flow meters are calibrated and serviced per protocols and manufacturer recommendations; and
4. Ensuring each field effort entails completion of standardized datasheets, recording of site conditions and equipment integrity, and subsequent review by non-field personnel to ensure QA/QC.
5. Flow measurements should be collected at sites where steady, uniform flow occurs and flows are not impacted by obstructions or turbulence. During the field assessment, preferred locations within each sub reach which meet this criterion where identified, except at 310CAN and 310CLV. Presence of large boulders at 310CAN and sheet flow over a concrete apron at 310CLV require additional investigation. Tentatively flow at 310CAN could be collected in the box culvert which is free of bounders if minimum velocity criteria can be met and flow at 310CLV could be collected immediately downstream of the road crossing, if landowner permission is obtained.

A minimum of four instantaneous flow measurements are recommended per season. Furthermore, measurements should be distributed throughout the season so that the first and last measurement span approximately 80% of the season. Once flow measurements fall below EWD estimates at a given site, accuracy is less of an issue since the goal is to accurately identify when the flow drops below the EWD estimate.

4.2.2.2 Potential future analysis

Several analyses are recommended to better quantify in Morro Bay watershed streams the processes that control flow to meet the seasonal EWDs, the variations in habitat created by variations in flow near the seasonal EWDs, and the multi-year trends in the frequency flow meets seasonal EWDs. Specifically, the following potential analyses should be considered:

1. A comprehensive assessment and mapping of impoundments, diversions, minimum in-stream flow releases, groundwater pumping near streams, and other human-use modifications of the stream flow is recommended to determine the opportunities for conservation and management actions in the watershed. While minimum in-stream flow releases from the California Department of Corrections and Rehabilitation WWTP were likely maintaining stream flow above the summer EWD at some Chorro Creek sites, other human-use modifications potentially result in less stream flow to meet seasonal EWDs. A list of the locations where human-use modifications of stream flow occur, along with the

timing, quantity, would determine where there are opportunities for conservation and management actions to increase the frequency stream flow meets flow targets. It is also recommended to analyze any available flow data from sites upstream or downstream of these human-use modifications to determine if there are correlations between modifications and changes in the frequency seasonal flow targets are met at monitoring sites.

2. After collecting several years of flow data, additional field evaluations of the habitat changes with flow may be warranted at key monitoring sites that were not assessed in Stillwater Sciences (2014) to better quantify how variations in the frequency flow targets are met alters habitat availability in Morro Bay watershed streams. Field evaluations could be conducted during both spring and summer periods when flows are above and below the seasonal EWDs to estimate habitat changes most accurately as flow varies around the seasonal EWDs. These evaluations may be especially useful at sites with a drainage area less than 2.2 sq. miles, which is the lower limit of available data that was utilized to develop the Stillwater Sciences EWD model.
3. After collecting additional water years of flow data, an investigation of the potential influence of sequences of multiple water years on trends in the frequency flow met the seasonal EWDs at the monitoring sites is recommended. The frequency flow met the seasonal EWD was consistently different in the Dry water year following a Very Dry water year than typical Dry water years at mainstem Chorro Creek sites, while frequency flow met the seasonal EWDs was different in the Dry water year following a Very Wet water year than typical Dry water years at the San Lusito Creek site 310SLU. While analysis of the available flow data suggested that hydrologic conditions in Dry water years were susceptible to being influenced by conditions in the preceding year when the preceding year was a hydrologic extreme (i.e., Very Wet or Very Dry), the analysis was based on extremely limited data. There was only one instance of a Dry year preceded by a Very Dry or Very Wet water year. Observed changes in the frequency flow met the seasonal EWDs based on one water year do not consistent a trend and it may be an outlier or the result of other processes in the watershed.
4. Developing wet/dry maps or spatial maps of flow conditions across key reaches for set period during each season is recommended. To achieve this, mapping and/or flow measurements need to occur in a short period of time (e.g., several days to a week).

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Appendices

Appendix A

Data Availability and QA/QC Analysis

Precipitation Data Methods

Precipitation data outliers were identified by: (a) comparing the precipitation recorded at the individual weather stations to a probable maximum precipitation that would be recorded at the timescale of the precipitation recordings (i.e., daily or monthly) and (b) evaluating spatial precipitation variations between nearby weather stations (Table A-1). If a precipitation data outlier filter threshold was not met, the data was further reviewed to determine the likelihood it was an error or a potentially accurate measurement of an extreme precipitation event (e.g., a maximum precipitation per month threshold was exceeded, but high daily precipitation was recorded throughout the watershed and the daily precipitation amounts were plausible). Precipitation data was only classified as an outlier and excluded from further analysis after not meeting the outlier filter thresholds and if it was determined to likely be an error upon closer review.

Table A-1. Weather station precipitation outlier filter thresholds.

Time-step	Maximum precipitation per time-step (inches)	Maximum precipitation difference between weather stations per time-step (inches)	Minimum number of precipitation recordings per year
Daily	10	5	360
Monthly	30	10	12

Precipitation data at the four weather stations were recorded at different timescales, so the outlier filter analysis was first applied to the daily timescale precipitation data at CSL, LOL, and CAN using daily maximum and spatial variation precipitation thresholds (Table A-1). Next, individual water years at each weather station were evaluated for sufficient availability of daily precipitation data to estimate the water year type. Water years with less than 360 days of precipitation data were excluded from further analysis. Next, monthly precipitation totals were calculated from the filtered daily data. The outlier filter analysis was applied again to the monthly precipitation data at Cal Poly, CSL, LOL, and CAN using monthly maximum and spatial variation precipitation thresholds (Table A-1). After excluding outliers in the monthly precipitation data, individual water years at each weather station were evaluated for sufficient availability of monthly precipitation data to estimate the water year type. Water years with less than 12 months of precipitation data were excluded from further analysis.

Precipitation Data Results

No precipitation data outliers were identified in any of the weather station datasets. There were no data gaps in the monthly Cal Poly weather station precipitation data from 1871 to 2021 and all water years were retained for further analysis. No information was recorded on the CSL, LOL, and CAN weather station daily reports when the precipitation was zero, but there were no notes indicating the weather station was not operating during any time period. It was assumed there were no gaps in the precipitation data at CSL, LOL, and CAN. Precipitation data at weather stations typically started mid-water year (e.g., July). Partial water years at the beginning of the CSL, LOL, and CAN precipitations datasets would not accurately quantify the total water year precipitation at those stations. As such, these initial partial water years were excluded, but all subsequent complete water years were retained for further analysis.

Instantaneous Flow Data

Instantaneous manual flow measurements at Morro Bay watershed sites were collected for their entire period of record. Instantaneous flow measurements were assumed to have undergone a QA/QC process during their collection and initial compilation, so no additional QA/QC was performed. The number of flow data points during spring (i.e., April 1 to May 31) and summer (i.e., August 1 to September 30) and the percent of the season represented by those data points were determined for each site (see footnotes in Table 2-2).

Continuous Flow Data Methods

Continuous flow data outliers were identified by: a) comparing changes in continuous flow to a probable maximum flow change at the timescale of the continuous recordings (i.e., typically every 15 minutes) during periods without precipitation; and b) comparing the continuous flow to a maximum flow threshold for the streams. Increases in flow greater than 5 cubic feet per second (cfs) between continuous flow data points (typically every 15 minutes) when there had been no precipitation recorded in the watershed for a week prior to the time of the continuous flow data point were classified as outliers since it would be improbable for flow to naturally increase this much in such a short timeframe. Additionally, continuous flow data points greater than 10,000 cfs were classified as outliers since flows greater than this threshold were assumed to be unlikely to occur based on historical peak flows in the watershed (MBNEP 2021). After filtering out flow data outliers, the remaining data was visually reviewed to verify the outlier filter thresholds were neither too strict (created discontinuities by removing valid data points) or too permissive (did not filter out outlier data points that created discontinuities).

After removing outliers, the availability of continuous flow data was evaluated at each gage site to determine the water years with sufficient data to estimate the annual discharge. Gaps in the continuous flow data would potentially result in an underestimate of the annual discharge, with gaps during the wetter part of the year when flows typically would be higher more likely to produce an underestimate of annual discharge. It was assumed that water years with continuous flow data more than 95% of the entire year and 99% during the December to March wet season would accurately estimate the annual discharge.

Estimated continuous flow from stage-discharge rating curves and measured instantaneous flow were compared at sites with overlapping data by calculating the percent bias (PBIAS) and root mean square error (RMSE). As noted in Section 2.2.2.1, measured instantaneous flows were considered the most accurate quantification of the flow at the gage sites. Stage-discharge rating curves used to estimate the continuous flow were developed and periodically revised from measured instantaneous flow data at the gage sites, but multiple factors can result in stage-discharge rating curves over or underestimating the actual flow (e.g., changes in the streambed at the gaging site). Estimated continuous flow that over or underestimated the actual flow would potentially mischaracterize the frequency flow thresholds were met. As such, differences between the estimated continuous flow and the measured instantaneous flow were quantified before conducting further analysis to determine if the estimated continuous flow needed to be adjusted to improve agreement with the measured instantaneous flows.

In this analysis of PBIAS and RMSE, estimated continuous flow represented "simulated" data since it was calculated from a calibrated stage-discharge rating curve (i.e., a model), while measured instantaneous flow represented observed data. PBIAS quantified the tendency for the estimated continuous flows to be greater than or less than the measured instantaneous flows, with positive values indicating continuous flows overestimating instantaneous flows and negative values indicating continuous flows underestimating instantaneous flows. RMSE quantified the difference between the estimated continuous and measured instantaneous flows. RMSE can only be positive, with larger values indicating there was a larger difference between estimated continuous and measured instantaneous flows. The optimum value for both PBIAS and RMSE was zero, but the acceptable PBIAS was +/- 10% and the acceptable RMSE was less than 1.5 cfs in this analysis.

When the PBIAS or the RMSE was outside of the acceptable range for a gage site, a least-square regression analysis was conducted between the overlapping estimated continuous flow and measured instantaneous flow data points. The accuracy of stage-discharge rating curves may vary with flow due to the channel shape at the gage site, the range of flows and number of data points used to calibrate the rating curve, and the likelihood the channel shape would change over time. As such, the regression analysis was separately conducted on continuous and instantaneous flow data points during the spring (i.e., April 1 to May 31) and summer (i.e., August 1 to September 30). In this manner, the regression analysis evaluated the accuracy of continuous flows compared to instantaneous flows over the range most likely to occur during the periods evaluated in the subsequent EWD analysis. If the regression analysis identified a relationship between the continuous and instantaneous flows that improved the PBIAS and RMSE so it was within the acceptable range, estimated continuous flow at the gage was adjusted based on the least-squares regression equation and the adjusted continuous flow was used in subsequent analyses. If the regression analysis did not identify a relationship between the continuous and instantaneous flows that sufficiently improved the PBIAS and RMSE, estimated continuous flow at that gage was excluded from further analysis. If the number of overlapping continuous and instantaneous flow data points during a season was less than five or the overlapping data points were significantly unevenly distributed across the range of flows that occurred occur during a season (e.g., primarily clustered at lower or higher flows), the availability of the overlapping flow data was considered too sparse to conduct a regression analysis.

Continuous Flow Data Results

Measured continuous stage and estimated continuous flow at the 310SLU, 310CAN, 310APN, and 310UPN gage sites were collected and a QA/QC review was performed for each dataset. The flow outlier filter removed approximately 0.1% (478 of 444,166 data points) of the continuous flow data at 310SLU and approximately 0.1% (406 of 383,088 data points) of the continuous flow data at 310CAN. The flow outlier filter did not remove any data from 310APN or 310UPN. The flow outlier filter primarily removed data points when the flow increased faster than 5 cfs between data points when there had been no precipitation recorded in the watershed for a week prior, but it also removed several data points of flow greater 10,000 cfs at 310SLU.

After removing the outliers, the QA/QC review assessed data gaps in the estimated continuous flow at the four gages to identify water years without enough data to accurately characterize the total water year discharge. At 310SLU and 310CAN, no water years were excluded from further analysis since data gaps were always less than 24 hours. At 310APN, there was a data gap from November 2013 to January 2014, so continuous flow data from WY 2014 was excluded from the total water year discharge analysis for 310APN. At 310UPN, there were data gaps in early 2016 and September 2016 to August 2017, so continuous flow data from WY 2016 and WY 2017 were excluded from the total water year discharge analysis for this gage. Data from the excluded water years at 310APN and 310UPN were still included in the comparison of specific overlapping continuous and instantaneous flow since the seasonal analysis of the frequency flow met EWD was not dependent on data for the entire water year being available.

Comparison of the estimated continuous flow data to overlapping measured instantaneous flow data at 310SLU, 310CAN, 310APN, and 310UPN revealed significant differences between the continuous and instantaneous flow at three of the four gages that required continuous flow data at those gages to be adjusted or discarded from further analysis (Table A-2). Continuous flow data at 310SLU was within the acceptable PBIAS and RMSE thresholds during spring, but it exceeded the acceptable PBIAS by 0.2% and it was within the acceptable RMSE during summer. Comparison of the continuous and instantaneous flow data at 310SLU highlighted that most of the continuous flow data agreed well with the instantaneous flow data and most of the differences quantified by the PBIAS and RMSE were due to only two data points during spring and two data points during summer (Figure A-1). Both sets of two data points are from WY 2017 and comprise all of the WY 2017 data considered in this analysis. The overall consistency between the continuous and instantaneous flow data points across the range of spring and summer flows indicates the analysis of the continuous flow data would not cause an overall overestimate of the frequency the EWD was met at 310SLU, even though there is a slight exceedance of the acceptable PBIAS in summer. As such, continuous flow data at 310SLU was accepted for further analysis of the frequency flow met seasonal EWDs without any adjustment.

Continuous flow data at 310CAN exceeded the acceptable PBIAS and RMSE thresholds during both spring and summer, with the PBIAS and RMSE indicating the continuous flow data was consistently greater than the instantaneous flow data (Table A-2). Comparison of the continuous and instantaneous flow data at 310CAN further highlighted that the continuous flow data would overestimate the actual flow at Chorro Creek at Canet Road (Figure A-2). Analysis of the continuous flow data with adjustment would cause an overall overestimate of the frequency the EWD was met at 310CAN, so a least-squares regression was conducted to adjust the continuous flow data. A linear least-squares regression was calculated between the continuous and instantaneous flow data and applied to the continuous flow data. Comparison of the adjusted continuous and instantaneous flow data was within the acceptable PBIAS and RMSE during spring and summer. During spring, PBIAS and RMSE were equal to 7.0×10^{-15} % and 0.85 cfs, respectively, while PBIAS and RMSE were equal to 7.0×10^{-15} % and 0.69 cfs, respectively, during summer. As such, analysis of adjusted continuous flow data at 310CAN would accurately characterize the frequency the EWD was met at the gage and the adjusted continuous flow data was accepted for further analysis of the frequency flow met seasonal EWDs.

Continuous flow data at 310APN was within the acceptable PBIAS and RMSE thresholds during spring, but it significantly exceeded the acceptable PBIAS and it was within the acceptable RMSE during summer (Table A-2). While there were overlapping continuous and instantaneous flow data points at 310APN to calculate the PBIAS and RMSE, there were only five points during spring and two points during summer. Comparison of the continuous and instantaneous flow data points during spring and summer further indicated that the available overlapping flow data points at 310APN were too sparse to adjust the continuous flow data based on a regression analysis (Figure A-3). The shape of the relationship between continuous and instantaneous flow was unknown because the available overlapping flow data points either clustered at two ends of the potential flow range with no data between those two ends (spring) or were only two points (summer). As such, the estimated continuous flow data at 310APN could not be adjusted to improve agreement with the measured instantaneous flow data to within PBIAS and RMSE thresholds and the continuous flow data at 310APN was not used in further analysis.

During spring and summer, continuous flow data at 310UPN exceeded the acceptable PBIAS threshold by approximately 10 to 42%, but it was within the acceptable RMSE threshold (Table A-2). The available overlapping continuous and instantaneous flow data points were distributed across a range of flows, but there were too few data points to determine the relationship between continuous and instantaneous flow within a reasonable level of uncertainty (Figure A-4). There were only eight overlapping data points during spring and four overlapping data points during summer. The available overlapping data points indicated continuous and instantaneous flow were not linearly related across the entire range of flows, but the number of data points were too sparse to determine whether a piecewise linear, power, or polynomial regression would accurately represent the relationship between continuous and instantaneous flow. As such, the estimated continuous flow data at 310UPN was not adjusted to improve agreement with the measured instantaneous flow data to within PBIAS and RMSE thresholds and the continuous flow data at 310UPN was not used in further analysis.

Table A-2. Estimated continuous flow accuracy compared to measured instantaneous flow.

Gage ID	Number of overlapping continuous and instantaneous data points during spring (Apr 1–May 31) [1]	$PBIAS_{spring}$[2] (%)	$RMSE_{spring}$[3] (cfs)	Number of overlapping continuous and instantaneous data points during summer (Aug 1–Sep 30) [1]	$PBIAS_{summer}$[2] (%)	$RMSE_{summer}$[3] (cfs)
310SLU	29	9.2	1.2	16	10.2	0.3
310CAN	19	78.7	6.7	22	157.7	3.1
310APN	5	3.1	0.36	2	-45.3	0.21
310UPN	8	19.7	0.18	4	-51.5	0.23

1 Continuous and instantaneous data points were considered overlapping when date-time were less than one day apart. The closest data points were selected for the analysis.
2 PBIAS = Percent bias
3 RMSE = Root mean squared error

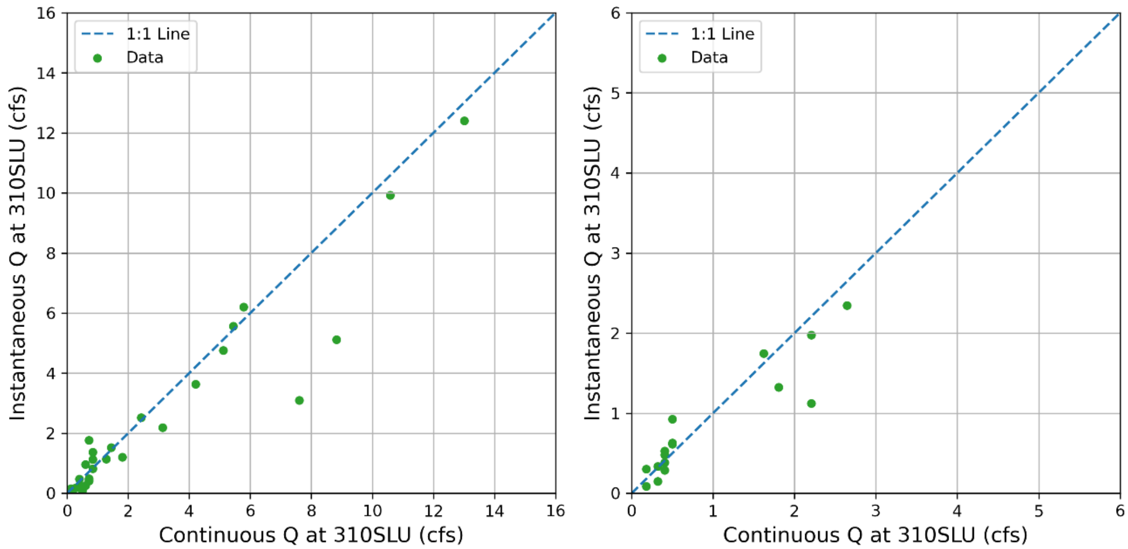

Figure A-1. Comparison of continuous and instantaneous flow data at 310SLU (San Luisitos at Adobe Road) during spring (left) and summer (right).

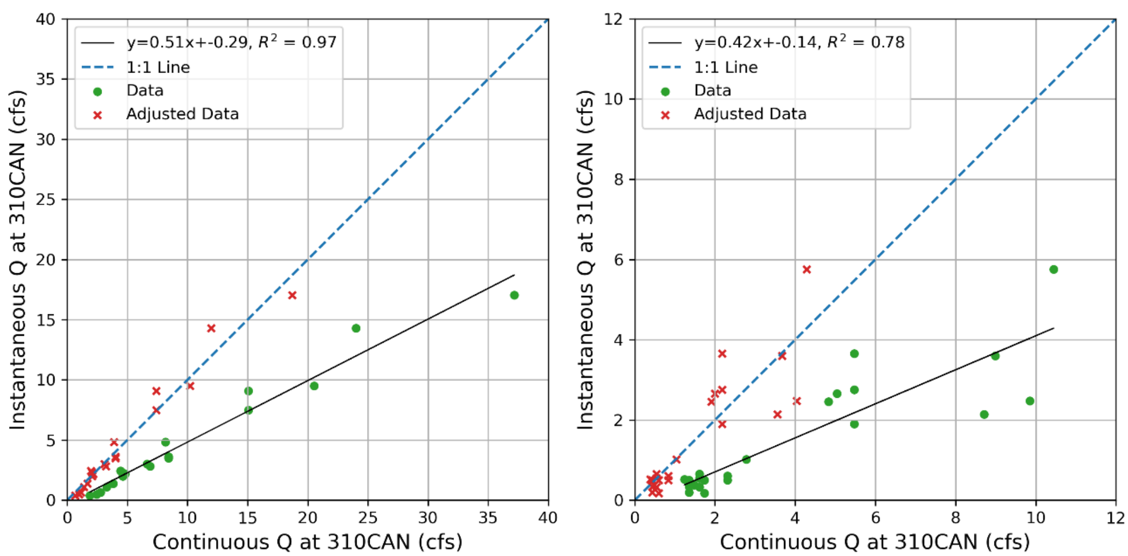

Figure A-2. Comparison of continuous and instantaneous flow data at 310CAN (mainstem Chorro Creek at Canet Road) during spring (left) and summer (right) along with a comparison of the adjusted continuous and instantaneous flow data.

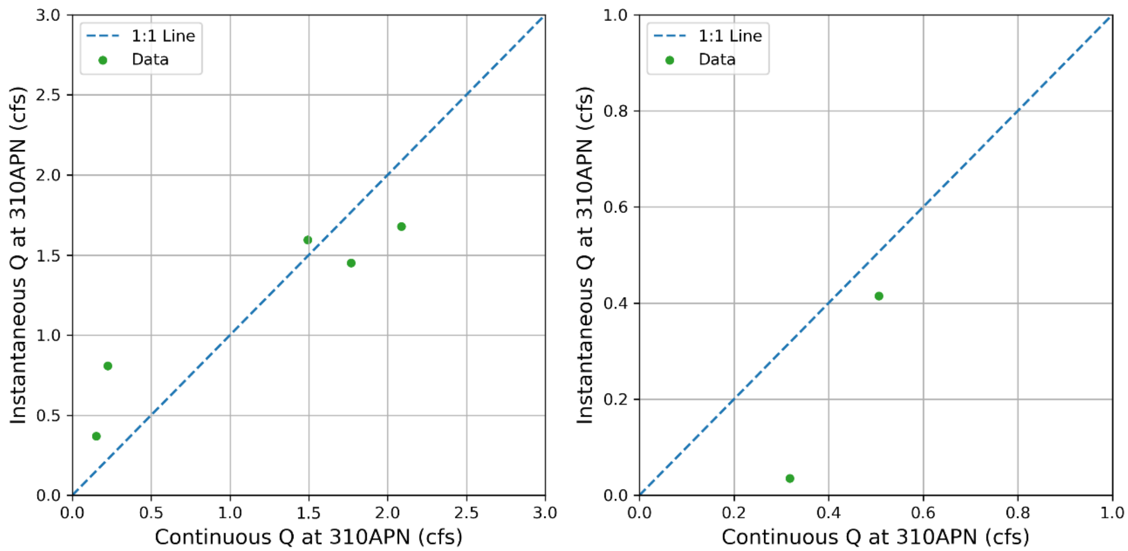

Figure A-3. Comparison of continuous and instantaneous flow data at 310APN (Pennington Creek upstream of wells) during spring (left) and summer (right).

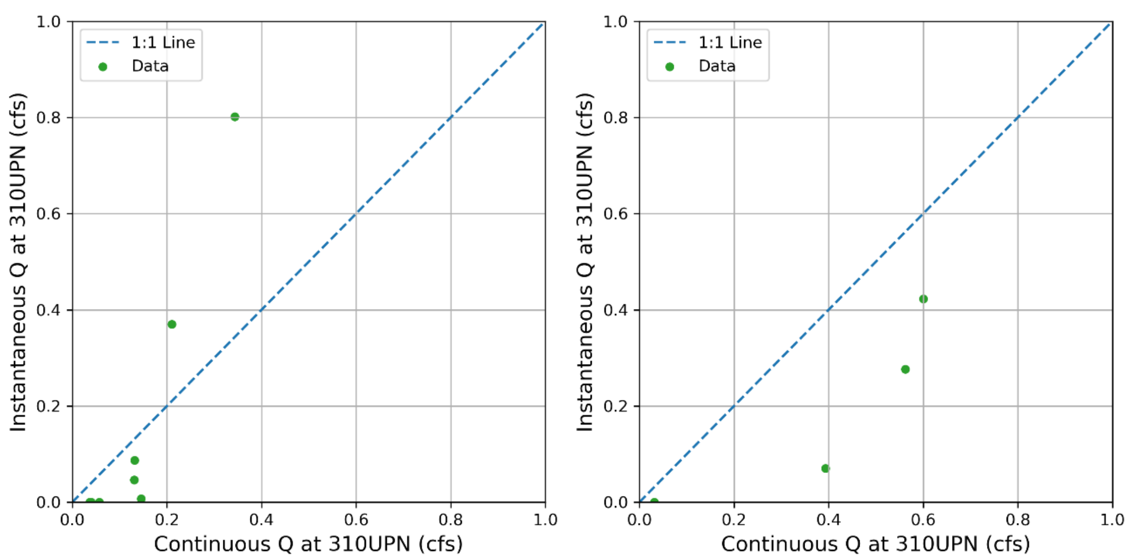

Figure A-4. Comparison of continuous and instantaneous flow data at 310UPN (Pennington Creek downstream of wells) during spring (left) and summer (right).

Appendix B

Total Water Year Precipitation

Water year	Total water year precipitation (in)[1]			
	Cal Poly	CSL	LOL	CAN
1871	12.97			
1872	27.02			
1873	12.79			
1874	20.52			
1875	19.69			
1876	30.12			
1877	8.15			
1878	30.6			
1879	11.66			
1880	25.82			
1881	24.09			
1882	16.63			
1883	17.01			
1884	42.4			
1885	17.59			
1886	29.3			
1887	18.61			
1888	16.28			
1889	19.54			
1890	39.55			
1891	18.96			
1892	16.06			
1893	30.43			
1894	11.64			
1895	20.96			
1896	17.99			
1897	20.58			
1898	7.33			
1899	17.13			
1900	17.21			
1901	31.68			
1902	21.68			
1903	18.49			
1904	20.59			
1905	19.99			
1906	28.16			
1907	24.78			
1908	18.83			

Water year	Total water year precipitation (in)[1]			
	Cal Poly	CSL	LOL	CAN
1909	30.55			
1910	21.23			
1911	34.03			
1912	17.17			
1913	9.02			
1914	30.24			
1915	28.18			
1916	28.86			
1917	21.11			
1918	18.79			
1919	17.77			
1920	14.47			
1921	19.64			
1922	22.96			
1923	23.98			
1924	7.53			
1925	21.68			
1926	18.73			
1927	24.68			
1928	21.33			
1929	17.35			
1930	15.06			
1931	14.55			
1932	30.4			
1933	15.66			
1934	15.04			
1935	26.63			
1936	23.56			
1937	33.04			
1938	31.58			
1939	10.37			
1940	24.3			
1941	42.96			
1942	23.58			
1943	26.05			
1944	22.44			
1945	21.42			
1946	17.91			

Water year	Total water year precipitation (in)[1]			
	Cal Poly	CSL	LOL	CAN
1947	14.25			
1948	15.5			
1949	14.05			
1950	19.45			
1951	15.21			
1952	29.26			
1953	16.78			
1954	19.77			
1955	17.29			
1956	25.16			
1957	13.88			
1958	35.32			
1959	11.54			
1960	15.18			
1961	11.15			
1962	25.97			
1963	24.99			
1964	14.61			
1965	21.72			
1966	16.88			
1967	27.65			
1968	16.75			
1969	54.62			
1970	16.3			
1971	20.65			
1972	12.27			
1973	40.05			
1974	28.68			
1975	24.16			
1976	15.68			
1977	11.62			
1978	49			
1979	19.78			
1980	33.35			
1981	18.48			
1982	28.54			
1983	47.15			
1984	18.8			

Water year	Total water year precipitation (in)[1]			
	Cal Poly	CSL	LOL	CAN
1985	14.79			
1986	30.48			
1987	14.04			
1988	19.87			
1989	17.14			
1990	12.22			
1991	18.11			
1992	22.51			
1993	30.46			
1994	19.34			
1995	41.93			
1996	23.11			
1997	31.42			
1998	44.27			
1999	16.85			
2000	24.73			
2001	24.52			
2002	14.84			
2003	22.88			
2004	15.99			
2005	29.81			
2006	15.46	24.84	21.89	
2007	10.95	7.95	7.48	
2008	19.92	18.27	16.93	
2009	10.27	11.18	7.99	10.93
2010	31.66	27.40	26.26	27.33
2011	31.5	33.74	31.77	31.70
2012	14.64	12.45	10.94	11.19
2013	14.35	9.06	8.11	9.22
2014	10.56	8.03	6.81	6.78
2015	12.94	10.79	9.69	13.00
2016	18.05	17.32	14.14	14.56
2017	39.21	33.53	26.79	25.40
2018	14.06	13.79	13.47	13.18
2019	29.48	26.42	24.02	19.90
2020	15.88	14.25	13.60	12.27

[1] Water years without sufficient precipitation data (see Section 2.2.1) to calculate the total water year precipitation are blank.

Water year	CSL total water year precipitation (in)	Water year type
2006	24.84	Average
2007	7.95	Very Dry
2008	18.27	Average
2009	11.18	Dry
2010	27.40	Wet
2011	33.74	Very Wet
2012	12.45	Dry
2013	9.06	Dry
2014	8.03	Very Dry
2015	10.79	Dry
2016	17.32	Average
2017	33.53	Wet
2018	13.79	Average
2019	26.42	Wet
2020	14.25	Average