Report on Water Use in the Chorro Creek Watershed

Center for Ecosystem Management and Restoration

October 31, 2014

Cover photo: water storage tanks at cattle ranch facility along Pennington Creek, San Luis Obispo County.

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1. Introduction

Central coastal California has been settled for habitation and agricultural production for over 150 years. The conditions of mixed woodland/grassland land cover and a mild Mediterranean climate in central coastal California are ideal for human settlement. One of the main drawbacks of the climate, however, is the seasonal timing of rainfall: the majority of precipitation occurs during the wet winters, with very little rainfall occurring during the summer dry season (which also corresponds to the agricultural growing season). As a result, people who live and work in the region must obtain water from ambient sources to meet water needs during the summer dry season. Streams often are seen as providing a suitable stable supply of water to meet these needs. Rights to divert water from surface streams in this region date back to the earliest days of statehood.

In addition to human settlement, many streams in central coastal California are also important habitat for native salmonids, especially steelhead trout, which over-summer in freshwater streams as juveniles before migrating to the ocean as smolts. Among these streams, Chorro Creek in San Luis Obispo County has been recognized as among the most important anchor watersheds for steelhead trout south of the San Francisco Bay (Becker et al. 2010), and its drainage network has been identified by NOAA Fisheries as Critical Habitat for the recovery of steelhead trout in the South-Central Coastal California ESU. Because of the prolonged dry

season, streams such as Chorro Creek recede toward intermittence through summer; pumping water from streams or adjacent shallow aquifers has potential to further reduce streamflow, which may have adverse effects on instream habitat during a time when the creek is naturally at its lowest levels.

The purpose of this report is to characterize the various uses of water in the Chorro Creek watershed, with an ultimate goal of developing a strategy to address low flow conditions in the Chorro Creek drainage network during the dry season. The dry season, from May through October, is the period marked by little to no precipitation and progressively lower streamflow, yet it is also the time period when water needs are highest for residential and agricultural uses. The overall project objectives presume that the amount of water in streams in summer months can be increased by finding ways for people to either reduce their summer water use or switch their period of diversion from summer to winter. Our analyses conducted elsewhere in coastal California indicate that there is sufficient water available to meet both human and ecological water needs at an annual scale, but not in summer months; however, sufficient water should be available during winter for diversion and storage to meet this summer need. In the following sections, we provide the rationale for this approach and evaluate whether there is sufficient water in the Chorro Creek watershed to meet human and environmental needs; and give recommendations for key areas of focus to restore summer base flow. This report builds on previous research conducted by the Morro Bay National Estuary Program and Trout Unlimited, especially the 2013 report titled "Water in Chorro Valley: Water Landscape and Water Rights," by incorporating the data into a comprehensive description of water needed for various human uses in the Chorro Creek watershed.

2. Watershed Characteristics

2.1 Study Area

The Chorro Creek watershed drains a basin approximately 28,300 acres (44.2 square miles) in size, comprising approximately two-thirds of the Morro Bay Estuary watershed in San Luis Obispo County. The predominant use of land in the Chorro Creek watershed is for cattle grazing and dry-farmed hay production, especially in the uplands; in addition, the watershed is home to a few small vegetable farms and vineyards, as well as a California National Guard facility (Camp San Luis Obispo), a State Prison (the San Luis Obispo Men's Colony), a County Correctional Facility, a golf course, two schools, and several rural residences in the Chorro Valley. California Highway 1 runs east-west through Chorro Valley from the city of Morro Bay to San Luis Obispo (abutting the eastern edge of the Chorro watershed). In addition to studying the overall water

use characteristics of the Chorro Creek watershed, we examined the conditions of its major subwatersheds – San Bernardo Creek, San Luisito Creek, Pennington Creek, Dairy Creek and Upper Chorro Creek, as well as the area around the mainstem Chorro Creek/Chorro Valley (Figure 1).

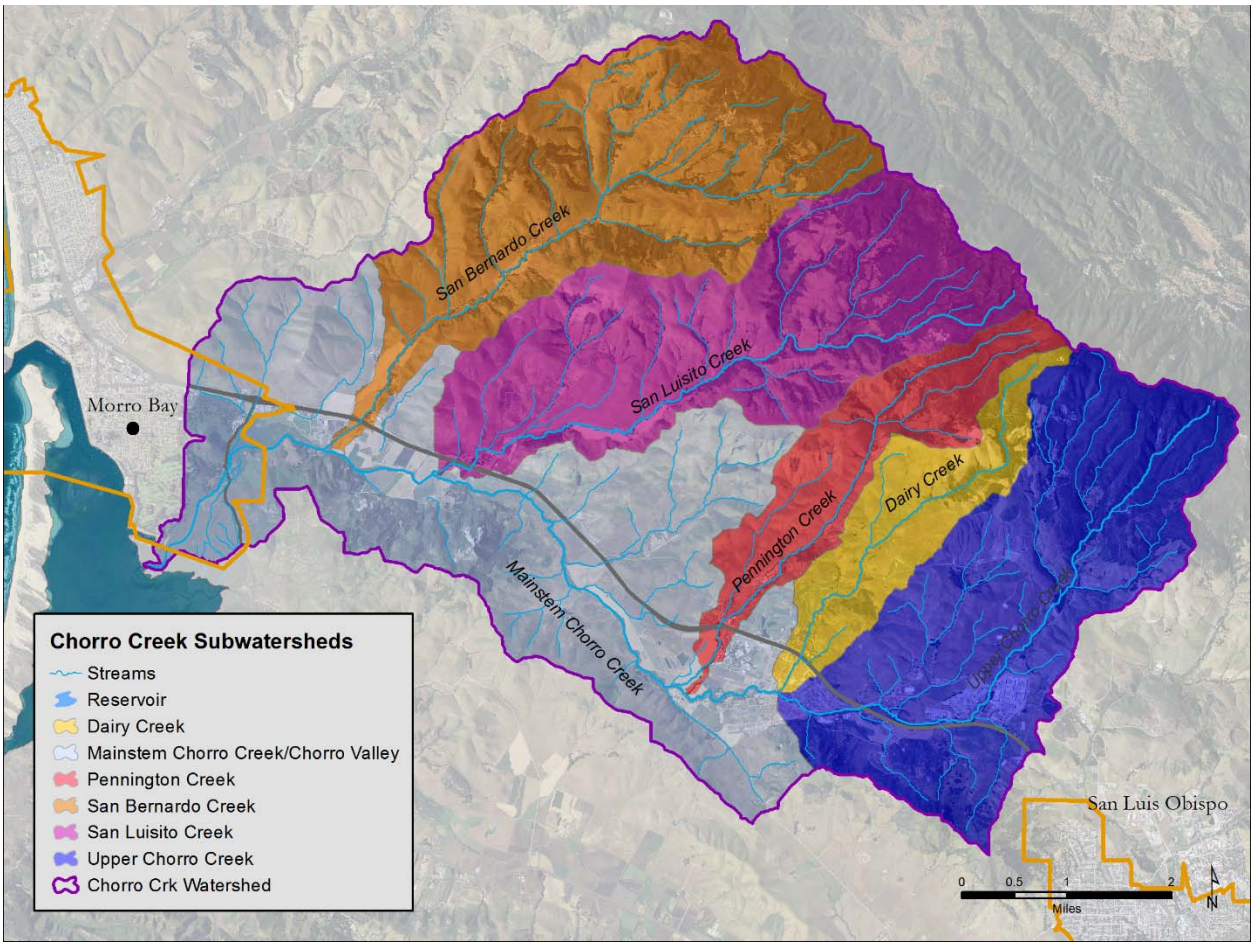

Figure 1. Locations of project watersheds.

Mainstem Chorro Creek, Chorro Valley

For the purposes of this report we identified all areas not captured in the five project watersheds listed above as the Mainstem Chorro Creek/Chorro Valley. This area describes all land adjacent to Chorro Creek below the confluence with Dairy Creek, as well as several small tributaries that drain directly into Chorro Creek. Much of the land in the Mainstem Chorro Creek/Chorro Valley is used for agriculture, open space range land, and residential properties, as well as the Cuesta College and a portion of Camp San Luis Obispo.

San Bernardo Creek

San Bernardo Creek drains a 5,390 acre (8.4 square mile) basin; at its headwaters, the creek begins in the forested mountains south of California Highway 41. From there the creek runs through

undeveloped land used primarily for cattle grazing with a few hayfields, plus a couple of small orchards. Rural residential properties are scattered along the creek in the narrow river valley. In the lower portion of the watershed the valley widens and the creek flows through a broad alluvial valley; as San Bernardo Creek reaches its confluence with Chorro Creek the land is planted with hay fields, row crops and a small orchard.

San Luisito Creek

San Luisito Creek drains a basin 5,360 acres (8.4 square miles) in size. The creek begins in the forested mountains west of Tassejera Peak. Similar to San Bernardo Creek, San Luisito Creek flows primarily through undeveloped land used for cattle grazing and hay production. The majority of rural residential properties run along the creek in the lower portion of the watershed. Near its confluence with Chorro Creek, the land is planted predominantly with hay fields and with one small vineyard.

Pennington Creek

Pennington Creek drains a basin 1,940 acres (3.0 square miles) in size. The upper and middle portions of the watershed are largely undeveloped forested and range lands (including ranch facilities owned by California State Polytechnic University). In the lower portion of the watershed residential properties and are clustered around the creek, along with a school immediately upstream of California Highway 1. The lower portion of the watershed also has irrigated lawn areas which are owned and maintained by the Dairy Creek golf course, and Cuesta College. Near its confluence with Chorro Creek hay fields cover the landscape.

Dairy Creek

Dairy Creek drains a basin of 1,690 acres (2.6 square miles). Similar to Pennington Creek, the upper and middle portions of the watershed are largely undeveloped forested and rand lands. In the lower portion of the watershed a large portion of Dairy Creek golf course is located near the stream, as well as El Chorro Regional Park and several small buildings associated with the park. Near its confluence with Chorro Creek is San Luis Obispo Botanical Garden, Grizzly Challenge Charter School and several buildings associated with Cuesta College.

Upper Chorro Creek

Upper Chorro Creek (the portion of Chorro Creek upstream of Dairy Creek) drains a basin of 5,620 acres (8.8 square miles), making it the largest sub-basin the Chorro Creek watershed. The upper headwaters are primarily forested land; the approximately 150 acre-ft Chorro Reservoir, which provides water for Camp San Luis Obispo (the water right holder for 92 acre-ft annually) is located in the upper middle portion of the watershed. This region also includes the Men's Colony state prison, the county jail and correctional facilities, and a portion of Camp San Luis Obispo. A wastewater treatment facility discharges water into Chorro Creek approximately 1 mile downstream of the Dairy Creek confluence. The watershed also has a small amount of agricultural lands – comprised of orchards and hay fields— and a few rural residences.

2.2 Rainfall and discharge

Like many coastal Californian watersheds, 90 percent of the average annual rainfall in the Chorro Creek watershed occurs during the wet half of the year November through April (Figure 2). Streamflow typically follows a similar pattern, with less than five percent of the average annual rainfall and discharge typically occurring between June and September. During spring, streamflow in coastal streams gradually recedes and diminishes to very low flow or no flow by later summer.

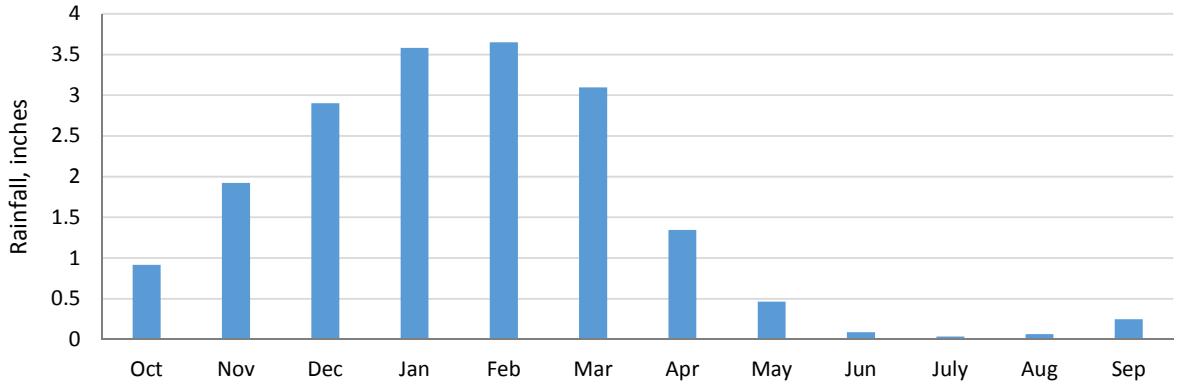

Figure 2. Average monthly rainfall recorded at Morro Bay, CA (1959 to 2011; 18.3 inches annually, on average).

Estimating Rainfall

To estimate rainfall over the entire Chorro Creek watershed, we used a spatially distributed dataset developed through the Parameter-elevation Regression on Independent Slopes Model (PRISM), a precipitation model developed by researchers at Oregon State University (considered the standard in precipitation modeling in the western United States). We converted the rainfall dataset into a shapefile and used a Geographic Information System (GIS) to depict rainfall patterns over our study area and to perform calculations. Applying these tools, we estimated 24.0 inches of rain annually fall in the Chorro Creek watershed, with up to 36 inches falling in the higher elevations in the watershed and 16 inches falling in the lower elevations (Figure 3). Output from the PRISM model (i.e., Figure 3) match long-term rainfall records available through NOAA (https://gis.ncdc.noaa.gov/map/viewer/#app=cdo) measured at Morro Bay (18 inches, on average, from 1959 to 2014), Camp San Luis Obispo (20 inches, on average, from 1946 to 1967), and at Highway 101 and Tassajara Creek Road (outside of the Chorro watershed near Santa Margarita Creek; 31 inches, on average, from 1952 to 2014).

If the average annual rainfall to the Chorro Creek watershed is approximately 24 inches, this equates to a total rainfall volume of 56,600 acre-ft falling on the Chorro Creek watershed in an average year (calculated by multiplying the average rainfall of 2 feet by the total area of 28,300 acres).

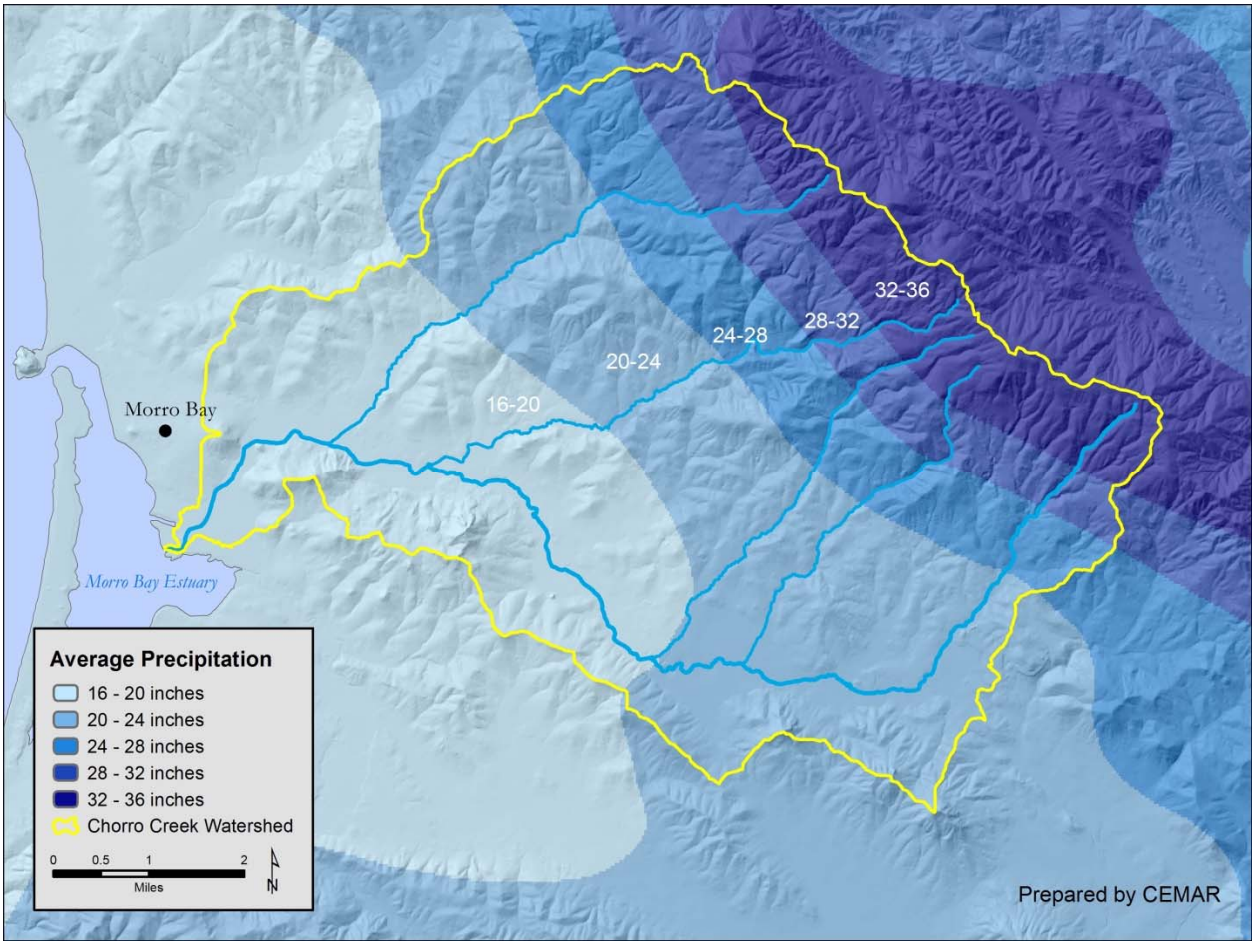

Figure 3. Average annual rainfall over the Chorro Creek watershed, based on the widely available PRISM model results.

Estimating discharge

Though Chorro Creek has not been gauged historically, the US Geological Survey has operated gauges on three streams nearby in San Luis Obispo County: Morro Creek, Toro Creek, and Lopez Creek (upstream of Lopez Reservoir; Figure 4). Nearby streamflow gauges provide the most useful resources for estimating streamflow of ungauged watersheds: they represent actual measured data in proximity to the watershed of interest and have watershed characteristics that are likely similar. Morro and Toro Creeks were only operated for the period 1971 to 1978, but Lopez Creek has a longer period of record (continuously from 1968-present; Table 1).

Table 1. Streamflow gauges near Chorro Creek operated by the US Geological Survey.

Stream, USGS gauge number	Wshd area, mi^2	Gauge duration	Gauge Lat, long	Avg upstream ppt, in
Morro C, 11142080	24.0	1971 – 1978	N 35.37851, W 120.85367	24.6
Toro C, 11142100	14.2	1971 – 1978	N 35.42528, W 120.86042	25.0
Lopez C, 11142180	20.9	1968 – present	N 35.23037, W 120.47350	28.4
Chorro C	44.2	(not gauged)		24.0

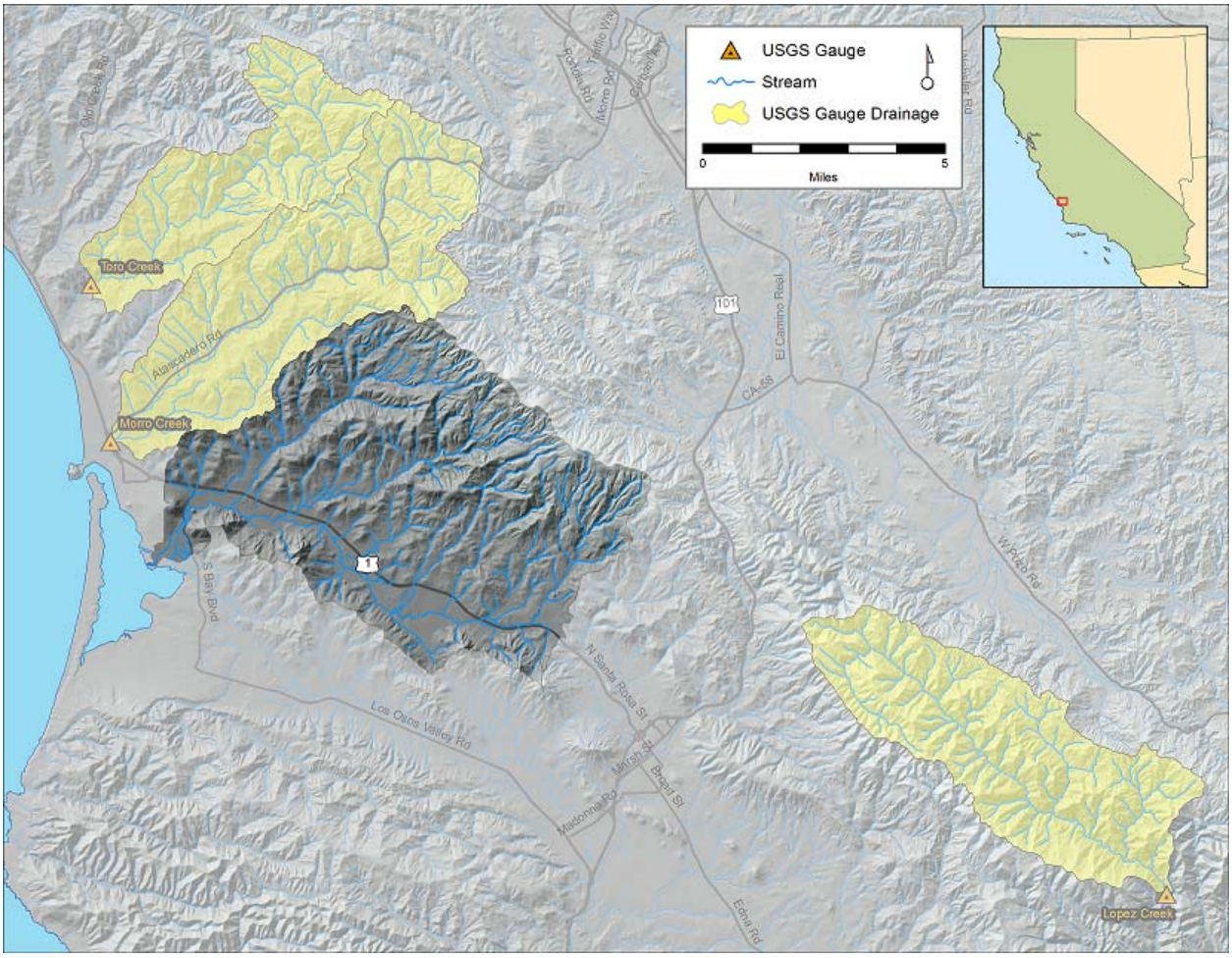

Figure 4. Map of the Chorro Creek watershed and nearby USGS streamflow gauges with their drainage basins.

We compared annual discharge data from these three gauges to evaluate the similarity of discharge data among sites. If discharge is similar but not identical among gauges, then we can estimate basic flow statistics (such as average annual discharge) for Chorro Creek based on the average of the three gauges—this assumes that discharge in Chorro Creek can be estimated as within the range of discharge as measured in nearby gauged watersheds. Watershed discharge is directly related to watershed area, so to develop a meaningfully comparable discharge statistic, we needed to standardize discharge to be independent of watershed area. We did this by dividing the average annual discharge in acre-ft by the total watershed area in acres, giving a discharge statistic in terms of feet.

During the period of concurrent operation 1971 to 1978, discharge data from the Toro, Morro, and Lopez Creek streamflow gauges show considerable variability from one year to the next; but data are relatively similar among all gauges each year (Figure 5). The most significant exception is that, in very dry years (1972, 1976, 1977), Lopez Creek carries much more water per area than Morro and Toro Creeks.

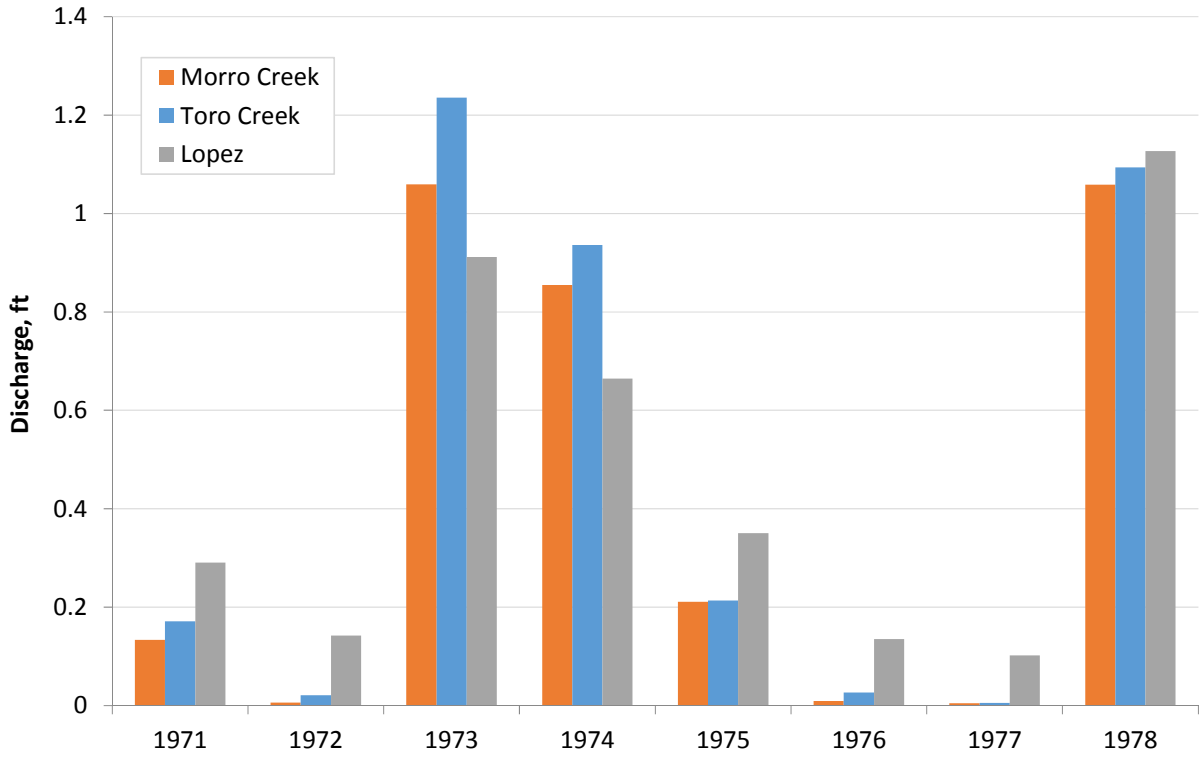

Figure 5. Discharge from Morro, Toro, and Lopez Creeks, water years 1971 to 1978.

Based on these data, the average annual discharge among all three streams during the period of concurrent record (i.e., 1971 to 1978) is 0.45 ft (with a range among sites of 0.42 to 0.47; Table 2). We made two additional small modifications to estimate discharge from Chorro Creek. First, because the 8-year concurrent period of record for these gauges may be too brief to derive an accurate representation of discharge—for example, the discharge from Lopez Creek over its entire period of record (1968 to present) was 0.53 ft, 10% wetter than over the 8-year period of concurrent record with Morro and Toro Creeks (or said another way, the period 1971 to 1978 was disproportionately dry, compared to the entirety of the last 47 years)—we modified our Chorro Creek discharge estimate based on the longer-term Lopez Creek data. We multiplied the Chorro Creek average discharge value by the ratio of Lopez Creek discharge over the short term (0.47 ft) and long term (0.53 ft) as shown in Equation 1, ratio A. Second, we scaled our discharge estimate for Chorro Creek by rainfall: based on PRISM data, Lopez Creek receives more rainfall in an average year than Chorro Creek, and therefore is assumed to produce more discharge in proportion with its ratio of rainfall. This scaling factor is shown in Equation 1, ratio B.

$$Discharge_{Chorro,long-term} = 0.45\,ft_{Chorro,1971\ to\ 1978} \times \left(\frac{0.53\,ft_{discharge\ Lopez,1967-2014}}{0.47\,ft_{discharge\ lopez,1971-1978}}\right)\left(\frac{2.00\,ft_{Chorro\ C\ ppt}}{2.38\,ft_{Lopez\ C\ ppt}}\right) \quad (1)$$

(A) **(B)**

Table 2. Watershed area, average annual rainfall, average annual discharge, and period of record for three streams gauged by the US Geological Survey in San Luis Obispo County, and for the ungauged Chorro Creek.

Stream	Wshd area, mi^2	Period of record	Avg rainfall, ft	Avg discharge, ac-ft	Avg discharge, ft
Morro	24.0	1971 – 1978	2.05	6,410	0.42
Toro	14.2	1971 – 1978	2.08	4,150	0.46
Lopez, 1	20.9	1971-1978	2.36	6,230	0.47
Lopez, 2		1968 – present	2.36	7,060	0.53
Chorro	44.2	(not gauged)	2.00	12,170	**0.43**

Using these calculations, we estimated the average Chorro Creek discharge as **0.43 ft, or 12,170 acre-ft, annually from the watershed.**

The estimate of average annual discharge from the Chorro Creek watershed derived above (12,170 acre-ft) is considerably greater than the average annual discharge estimate cited in the MBNEP report titled "Water in Chorro Valley: Water Landscape and Water Rights" of 1,450 ac-ft annually (citing a RWQCB study). The estimate we derived above based on data from nearby gauges corresponds to approximately 22% of the water falling on the Chorro watershed (24 inches, or 2 ft) leaving as discharge (0.44 ft). We believe the estimate of 1,450 acre-ft, or approximately 2.4% of the rainfall on the Chorro Creek catchment leaving as streamflow is not realistic, given the proportion of rainfall leaving as discharge from Morro, Toro, and Lopez Creeks (21%, 22%, and 22%, respectively).

We estimated average annual discharge in each of our project tributary sub-watersheds (San Bernardo, San Luisito, Pennington, Dairy and Upper Chorro) using a similar method of scaling by a ratio of drainage area and rainfall, based on the Chorro watershed discharge. Average annual rainfall onto each sub-watershed was based on PRISM data. The overall equation used to scale discharge from Chorro Creek to each sub-watershed is:

$$Q_{sub-wshd} = Q_{Chorro\ wshd}\left(\frac{Area_{sub-wshd}}{Area_{Chorro\ wshd}}\right)\left(\frac{Annual\ \ ppt_{sub-wshd}}{Annual\ \ ppt_{Chorro\ \ wshd}}\right) \quad (2)$$

In Equation 2, the terms $Q_{sub\text{-}wshd}$, $Area_{sub\text{-}wshd}$, and $Annual\ ppt_{sub\text{-}wshd}$ refer to discharge, upstream watershed area, and average annual precipitation of the sub-watersheds; the terms $Q_{Chorro\ wshd}$, $Area_{Chorro\ wshd}$, and $Annual\ ppt_{Chorro\ wshd}$ refer to discharge, upstream watershed area, and average annual precipitation over the Chorro Creek watershed. This equation mirrors the equation found in Appendix B of the State Board's North Coast Instream Flows Policy (SWRCB 2010) as the recommended method to scale streamflow to an ungauged location to determine if sufficient flow exists to allow a new water right (SWRCB 2010). The resulting streamflow statistics are summarized in Table 3, below.

Table 3. Basin and hydrology characteristics of Morro Creek, Toro Creek, Lopez Creek, Chorro Creek, San Bernardo Creek, San Luisito Creek, Pennington Creek, Dairy Creek and Upper Chorro Creek.

Stream	Watershed Area, acres	Average annual rainfall, inches	Average annual rainfall volume, ac-ft	Average annual discharge volume, ac-ft	Average annual discharge volume, ac-ft/ac
Chorro Creek	28,301	24.0	56,600	12,200	0.43
San Bernardo Creek	5,387	24.1	10,800	2,328	0.43
San Luisito Creek	5,357	25.1	11,200	2,414	0.45
Pennington Creek	1,942	24.0	3,880	836	0.43
Dairy Creek	1,685	24.0	3,370	726	0.43
Upper Chorro	5,622	25.0	11,700	2,522	0.45

3. Water Availability and Water Need

This study is designed to examine how water supplies in the Chorro Creek watershed are being managed and to determine if altering management practices could be beneficial. In this section we identify and quantify human water needs in the watershed and then compare these estimates with the timing and availability of water supplies. These results then guide our recommendations for potential water storage projects and focus areas, in the following section.

3.1 Human Water Needs

Understanding human water needs in the Chorro Creek watershed is complicated; several large entities (such as the Men's Colony, County Correctional facility and Cuesta College) are located within the watershed, and require large amounts of water for various purposes. In addition, large portions of the watershed are used for cattle grazing – a land use difficult to measure water use for remotely, without knowing the total number of cattle. For this study we estimated human water needs in a two-step approach. First, we estimated water need using remote sensing and standardized water use estimates. Secondly, we combined the water need figures generated with remote sensing techniques with water use quantities derived from registered water right holders, based on the "Water in Chorro

Valley: Water Landscape and Water Rights" report. The methods used for both strategies and their results are described below.

3.1A Human Water Need Estimates from Remote Sensing

Our initial approach for estimating human water needs solely relied on information we generated from aerial photographs and standardized water use estimates. To do this, we hand-digitized agricultural fields, irrigated lawns, building structure locations, and reservoirs using aerial imagery in ArcMap, and modeled the human development footprint within the watershed (Figure 6).

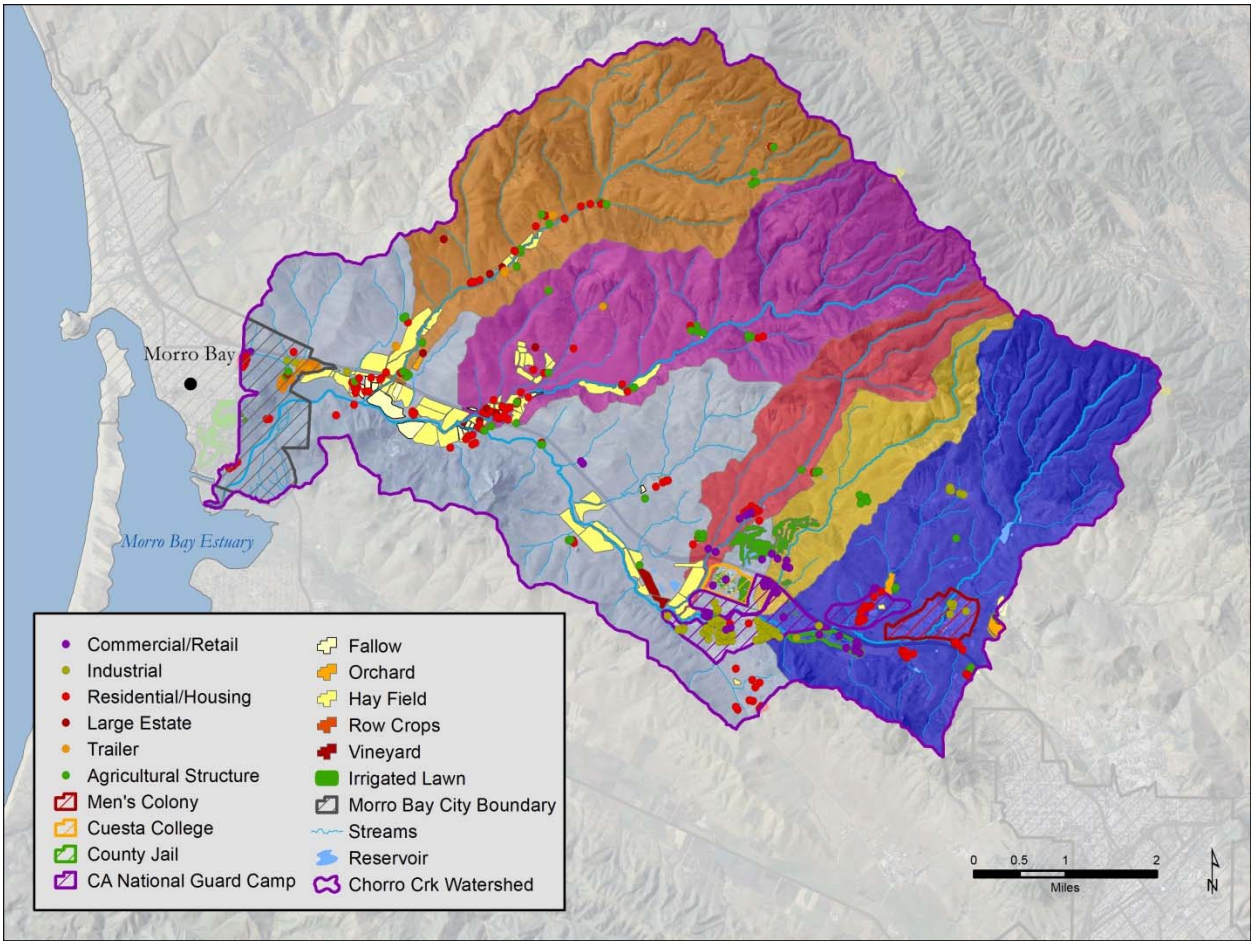

Figure 6. Chorro Creek watershed land-use.

Using these digitized features we assigned a water use factor based on standardized water use estimates from other watersheds in the region. (All of these numbers can be modified in subsequent follow-up studies based on additional site-specific information.)

- *Agricultural.* We digitized agricultural coverage as polygons to estimate the total acreage of agricultural land in each project watershed; we then calculated total agricultural water need based on regional per-area estimates of water use, differentiating among different crop types. For example, vineyard irrigation

in coastal California typically requires approximately 0.6 acre-feet of water annually per acre (Smith et al. 2004), and orchards and row crops require 2.2 acre-feet of water annually per acre (McGourty et al. 2013). Many fields that appeared clearly used for agriculture but were not irrigated based on 2012 NAIP imagery (colored brown rather than green) appeared to be hayfields, and MBNEP staff reported that hay fields in the study area are dry-farmed and use no water for irrigation during summer. Portions of the fields were, however, used for row crops in summer 2011 and 2013 (based on Google Earth imagery, e.g., Figure 7) and were green in 2011 and/or 2013; those fields were identified as either Fully Irrigated (100% of the agricultural polygon was green in summer), Mostly Irrigated (75% of the polygon green in summer), Partly Irrigated (50% green in summer), or Lightly Irrigated (25% green in summer).

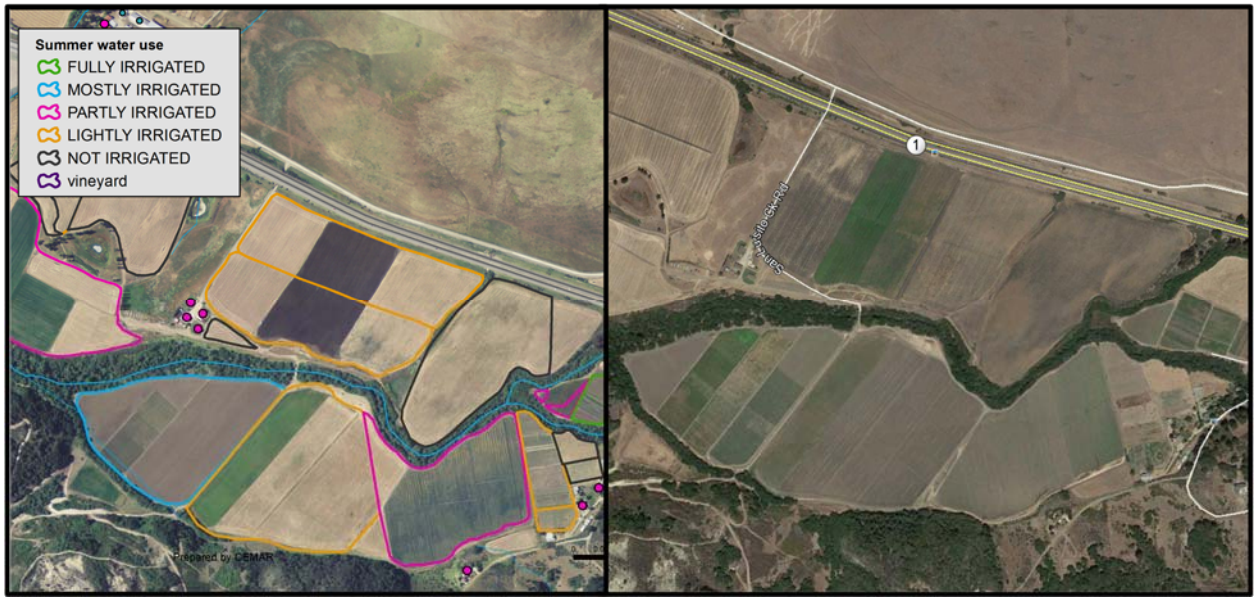

Figure 7. Agricultural field polygons in lower Chorro Creek, identified in ArcMap based on the fraction of irrigated area (left). Image on left is from NAIP (USDA) imagery imported into ArcMap; image on right is from Google Earth, August 2013.

- *Residential & Commercial.* Based on our work in a subregion of coastal northern California, we estimated rural residential water use at 305 gallons of water per household per day (using data from Santa Rosa and Ukiah, CA). This rate was applied all buildings in the Chorro watershed identified as either houses or commercial buildings to estimate the annual water need for residential and commercial structures.

-*Schools.* Based on our work in a sub region of coastal northern California, we estimated school water used based on the number of students registered. We assumed that each student uses approximately 4 gallons per day and multiplied that rate over the course of a school year. Schools in the Chorro Creek watershed include Cuesta College, the Grizzly Challenge Charter School (on the property of Camp San Luis Obispo), and an educational facility on Pennington Creek. We estimated other school water uses (e.g., outdoor landscaping needs) via aerial photos under *irrigated lawns*, below.

-*Irrigated Lawns.* We digitized all lawn areas (those not associated with specific residences) in the study area. We used a lawn irrigation value of 2 acre-feet per acre and multiplied that value by the acreage of lawn. A large portion of the irrigated lawn area (105 acres) is comprised of the Dairy Creek Golf Course. Reports indicate that the golf course recycles all of its water used onsite, but this may not mean that all the water used onsite is recycled.

We estimated the amount of water needed for human uses in the Chorro Creek watershed and its major tributaries based on the water use rate factors described above. Chorro Creek has approximately 32.3 acres of vineyards, 38 acres of orchards, 768 acres of hay and other crop fields, 145 acres of irrigated lawns, 470 residential and commercial buildings, three schools, one men's colony prison and one county correctional facility (Table 4).

Table 4. Remotely sensed development in the Chorro Creek watershed, divided among sub-watersheds.

Watershed	Vineyards (acres)	Orchards (Acres)	Other fields: hay, row crops, fallow	Irrigated Lawn (incl. golf course; Acres)	Residential and Commercial	Schools
Chorro Creek Entire Watershed	32.3	38.1	768.1	145.4	470	1
Mainstem Chorro Creek	29.7	5.9	475	88.1	340	1
San Bernardo Creek	1	3.8	120.8	0	25	0
San Luisito Creek	1.6	0	132.5	0	33	0
Pennington Creek	0	0	33.3	8.6	18	0
Dairy Creek	0	0	0	44.8	12	0
Upper Chorro Creek	0	28.4	6.5	4	42	0

Based on Table 4 as well as the water use rates previously described, we estimated the annual amount of water needed for human purposes in the Chorro Creek watershed and its major tributaries (Table 5; Figure 8). This analysis assumes that residences located in the Camp San Luis Obispo area are "residential," and does not assign a value to the Men's Colony or County Jail.

Table 5. Water needed per year, per land-use, per watershed, assuming water use values described above. (The asterisk denotes the two watersheds in which the Dairy Creek Golf Course is located.)

	Vineyards (AF/Yr)	Orchards (AF/Yr)	Other fields: hay, row crops (AF/yr)	Irrigated Lawn (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Total
Chorro Creek Entire Watershed	19.4	83.8	354.1	290.8	160.5	47.9	956.5
Mainstem Chorro Creek	17.8	13.1	292.1	176.2	116.2	47.9	663.3
San Bernardo Creek	0.6	8.3	10.8	0	8.5	0	28.2
San Luisito Creek	1	0	51.2	0	11.3	0	63.5
Pennington Creek	0	0	0	17.1	6.1	0	23.2
Dairy Creek	0	0	0	89.5	4.1	0	93.6
Upper Chorro Creek	0	62.4	0	8	14.3	0	84.7

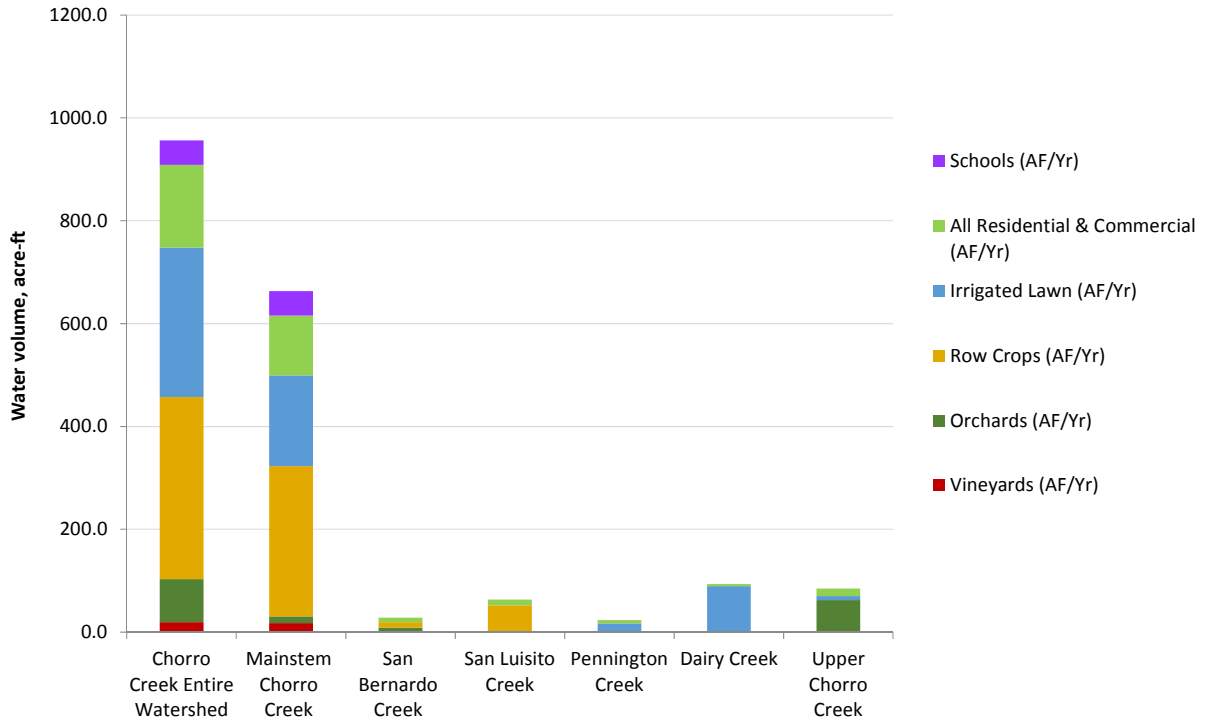

Figure 8. Water need by type, Chorro Creek watershed and sub-basins, based on remotely sensed data through aerial photographs.

3.1B Human Water Need Estimates from Remote Sensing and Water Rights

The water estimates we derived from remote sensing provide valuable insights to the human water needs in the Chorro Creek watershed, however there are several water users that are not taken into

consideration in this estimate. The City of Morro Bay, National Guard Camp, County Correctional Facility and various livestock owners are not accounted for in our initial estimate because their water use is not standardized and requires further investigation. To determine the water needs for these facilities and landowners we reviewed information derived from water right records describing the amount of water needed for various activities. Much of this information was synthesized in the Water in Chorro Valley report (MBNEP and Trout Unlimited, 2013). Due to the uniqueness of each water right we assessed each project area separately; the methods are results are described below.

Mainstem Chorro Creek/Chorro Valley

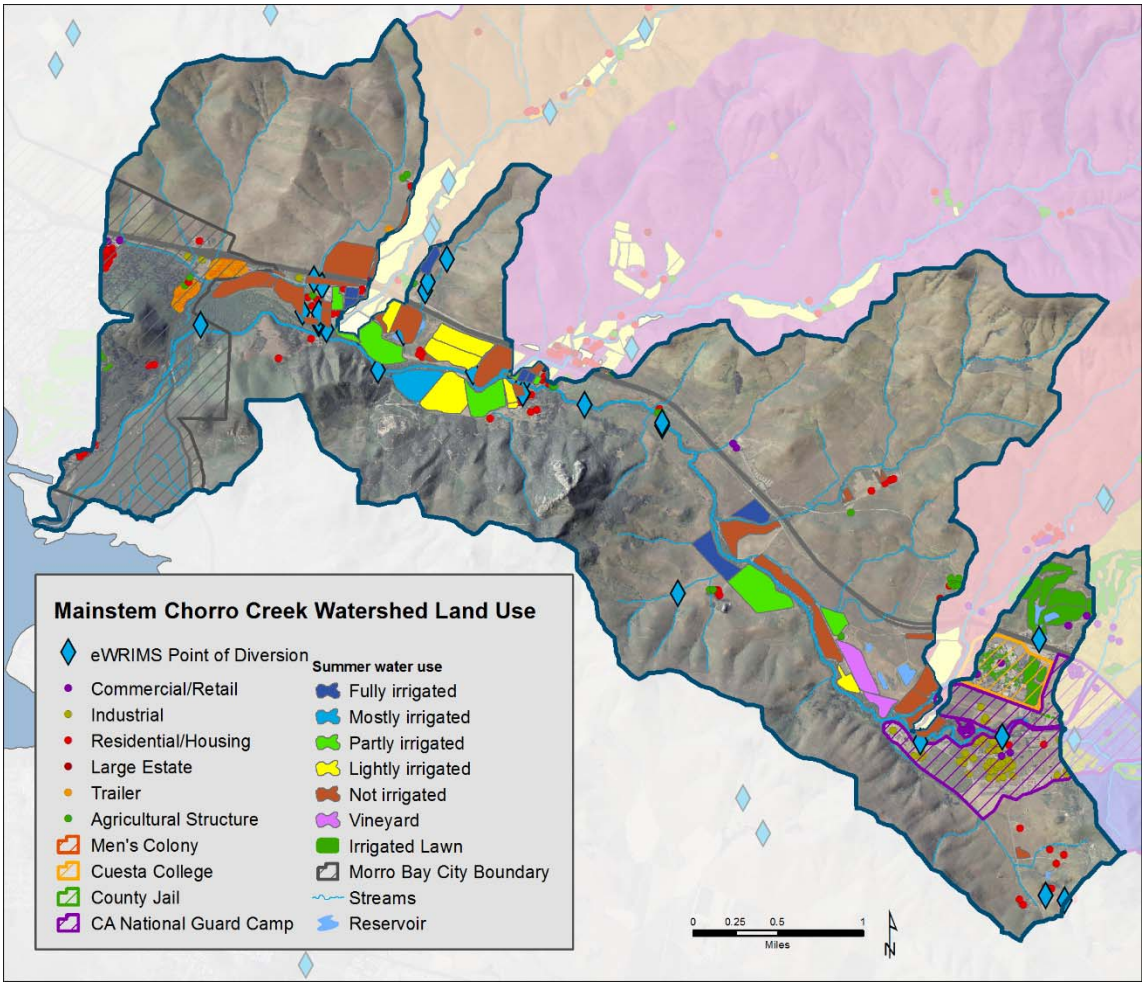

Figure 9. Human water uses in the Mainstem Chorro Creek study area.

The Mainstem Chorro Creek study area (Figure 9) has several large water right holders, including the City of Morro Bay and the National Guard. The City of Morro Bay has water rights to obtain water from the Chorro Creek subterranean aquifer. According to the 2010 Urban Water Management Plan for the city of Morro Bay, Morro Bay has one operating groundwater well that can divert up to 363 acre-ft of water annually. (This volume differs from the water right held by the city of Morro Bay, which is for 1,142.5 acre-ft per year; the city reports that the actual amount the well can take cannot exceed 363 acre-ft annually.) The National Guard Camp is also located in this portion of the watershed and has a

water right to divert up to 24 acre-ft of water annually from the mainstem Chorro Creek. Additionally, several landowners in this region have water rights for stock ponds totaling 68 acre-ft of water for livestock annually; and several others have water rights for hay irrigation, totaling 22 acre-ft of water needed annually for hay production. Lastly, the National Guard owns large parcels of land located near the confluences of Upper Chorro, Dairy Creek and Pennington Creek. In our initial remote sensing analysis we assigned structures within these property boundaries a water use figure based on their structure type. With this additional analysis, we now assume all structures within the National Guards' property have their water needs met through the National Guards' water right, and so we subtracted these structures from our initial estimate. By examining water right figures we found that there are 478 acre-ft of water allocated for land use purposes not identified in aerial photographs. Table 6 and Figure 10 show the water needed for various purposes in the Mainstem Chorro Creek portion of the watershed, in total 754.5 acre-ft of water is needed annually to meet all human water needs.

Table 6. Human water needs in the Mainstem Chorro study area by category, in acre-feet (AF) per year. Red text indicates water volumes adjusted by water right data.

	Hay Fields (AF/Yr)	Vineyards (AF/Yr)	Orchards (AF/Yr)	Row Crops, other irrigated (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay (AF/Yr)	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp	County Correct-ional Facility	Total, AF/yr
Mainstem Chorro Creek	22.0	17.8	13.1	292.1	176.2	68.0	363.0	1.0	20.5	47.9	0.0	24.0	0.0	1,045.6

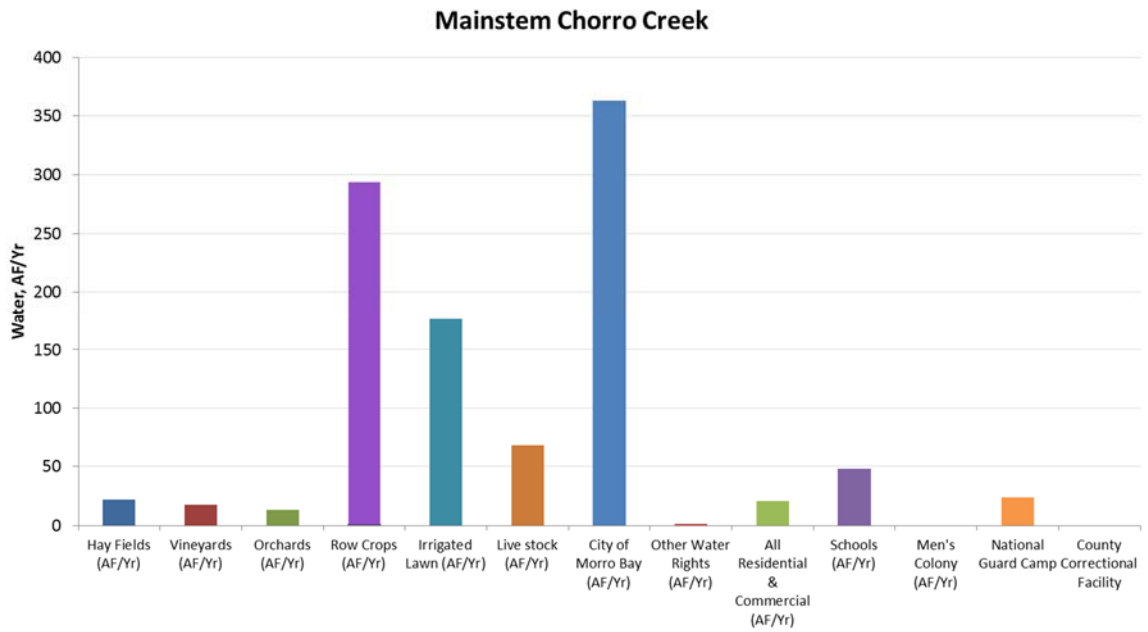

Figure 10. Human water needs by category in the Mainstem Chorro Creek study area.

This estimate of water need in the Mainstem Chorro Creek region likely overestimates the actual amount of water taken from this section of the watershed each year. For example, the city of Morro Bay has stated it does not take 360 acre-ft of water each year. Also, this estimate may double-count the water rights for hay fields as part of the estimate for row crops (though this would only reduce the row crop water need estimate slightly). Additionally, the estimate of water needed for Cuesta College is based on a daily attendance equal to the student enrollment. The enrollment at Cuesta College may be 13,000 (the number used to estimate water need), but the daily attendance is probably less. However, the overall order of comparison is probably close: row crops, irrigated lawn, livestock needs, and potentially Morro Bay have the greatest overall need for water in the Mainstem Chorro study area. It may even be greater than this estimate: we assume a value of 2.2 acre-ft per acre for crop water need, but it could be closer to 3.

San Bernardo Creek

Determining human water needs in San Bernardo Creek based on water rights is complicated. The San Bernardo Creek watershed has several landowners with water rights for stock ponds that equal to 61 acre-ft of water needed annually for livestock. In addition one landowner has a water right for 4.17 acre-ft of water for 4 acres of avocado trees, 55 alpaca and 10 people; however according to our calculations 4.17 acre-ft is not enough water to meet this landowner's total water need. Therefore, we assume that they may have additional sources of water, such as a well, and that they use their water right to supplement their water needs. Knowing this, we assumed that the water needed for their orchard irrigation and residential water uses were already accounted for in our remote sensing analysis, and added the 55 alpaca (a figure we could not determine with remote sensing) to our analysis. We assumed that each alpaca requires approximately 5 gallons of water per day, equaling 0.3 acre-ft per year for all 55 animals. In summary, we added an additional 61.3 acre-ft to San Bernardo Creek's water budget (water rights for livestock listed above, plus alpacas). Also, the irrigated fields identified in the remote sensing section above were omitted from this tabulation because the fields corresponded to the same property where water rights were located, and the water rights volume was greater than the remotely sensed volume needed for irrigation (Figure 11). Table 7 and Figure 12 show the water needed for various purposes in the San Bernardo Creek watershed; in total 78.1 acre-ft of water is needed annually to meet all human water needs.

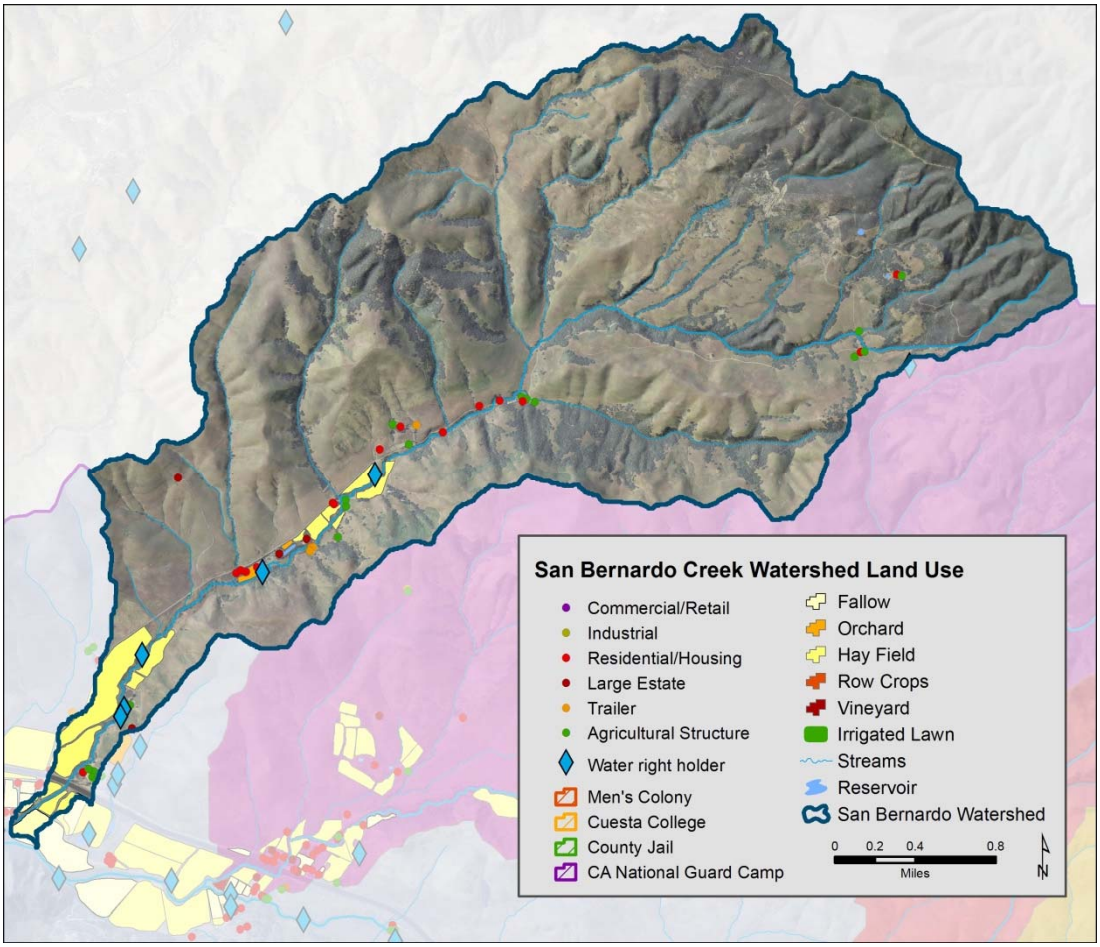

Figure 11. Human water uses in the San Bernardo Creek study area.

Table 7. Human water needs in the San Bernardo Creek watershed by category. (Red numbers indicate water amount derived from water rights information, black text indicates water amount derived from remote sensing and standardized water use factors.)

	Vineyards (AF/Yr)	Orchards (AF/Yr)	Hay fields, row crops (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay (AF/Yr)	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp	County Correctional Facility	Total
San Bernardo Creek	0.0	8.3	0.0	0.0	61.3	0.0	0.0	8.5	0.0	0.0	0.0	0.0	78.1

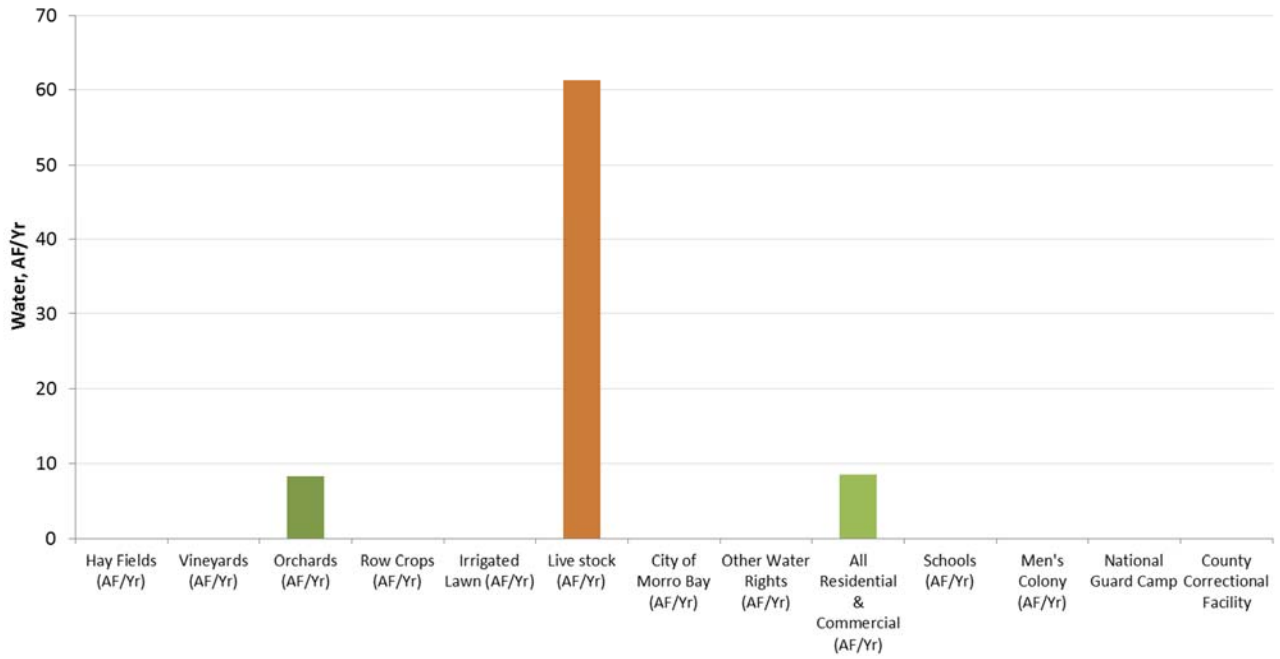

Figure 12. Human water needs by category in the San Bernardo Creek watershed.

San Luisito Creek

In addition to the water use estimate derived based on aerial photographs, the San Luisito Creek watershed has two water right holders with a combined total of 103.2 acre-ft of water for hay field irrigation (Figure 13). Combined with all other water uses needed in the San Luisito Creek watershed, the total annual human water need in San Luisito Creek is 116.9 acre-ft (Table 8, Figure 14).

Table 8. Human water needs in the San Luisito Creek watershed by category. (Red numbers indicate water amount derived from water rights information, black text indicates water amount derived from remote sensing and standardized water use factors.)

	Hay Fields (AF/Yr)	Vineyards (AF/Yr)	Orchards (AF/Yr)	Row Crops/other irrigated (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay (AF/Yr)	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp	County Correctional Facility	Total
San Luisito Creek	103.2	0.6	0.0	51.2	0.0	0.0	0.0	0.0	11.3	0.0	0.0	0.0	0.0	166.4

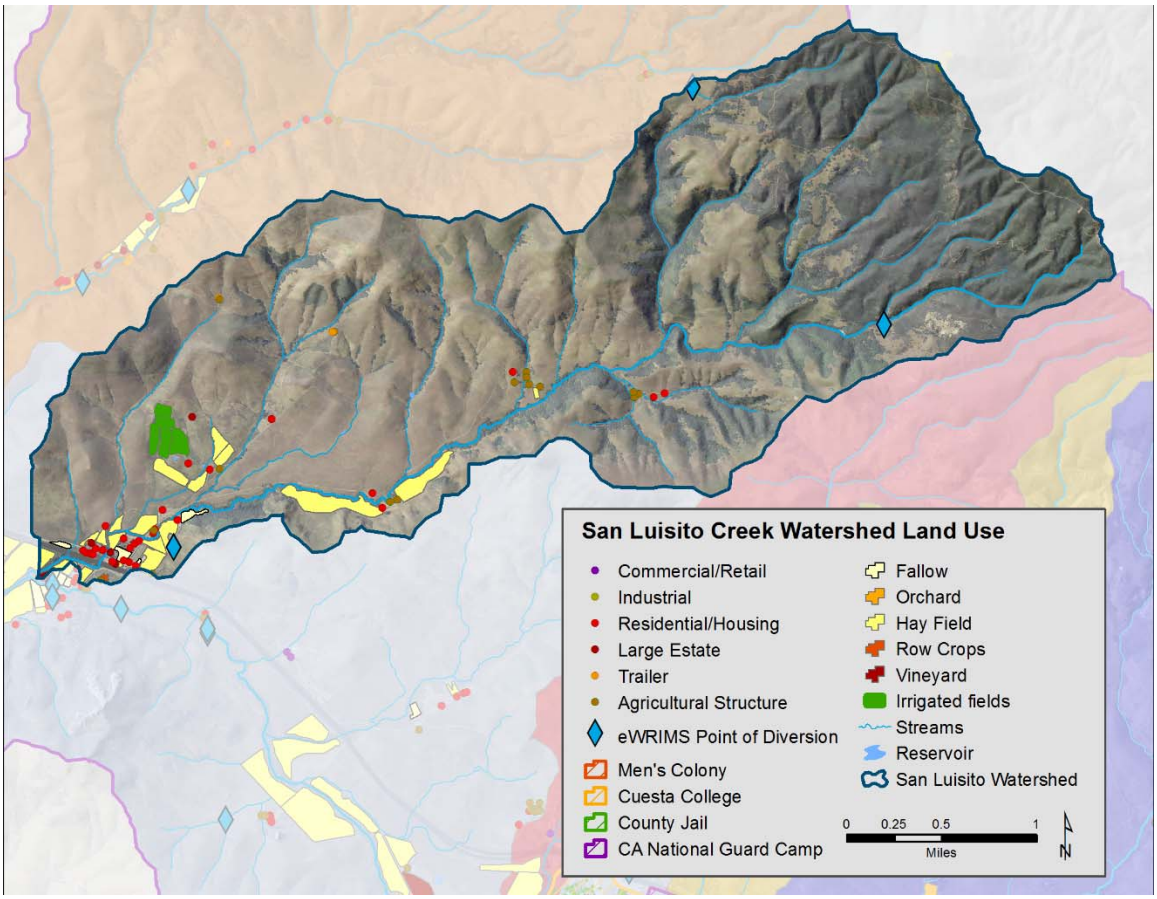

Figure 13. Human water uses in the San Luisito Creek study area.

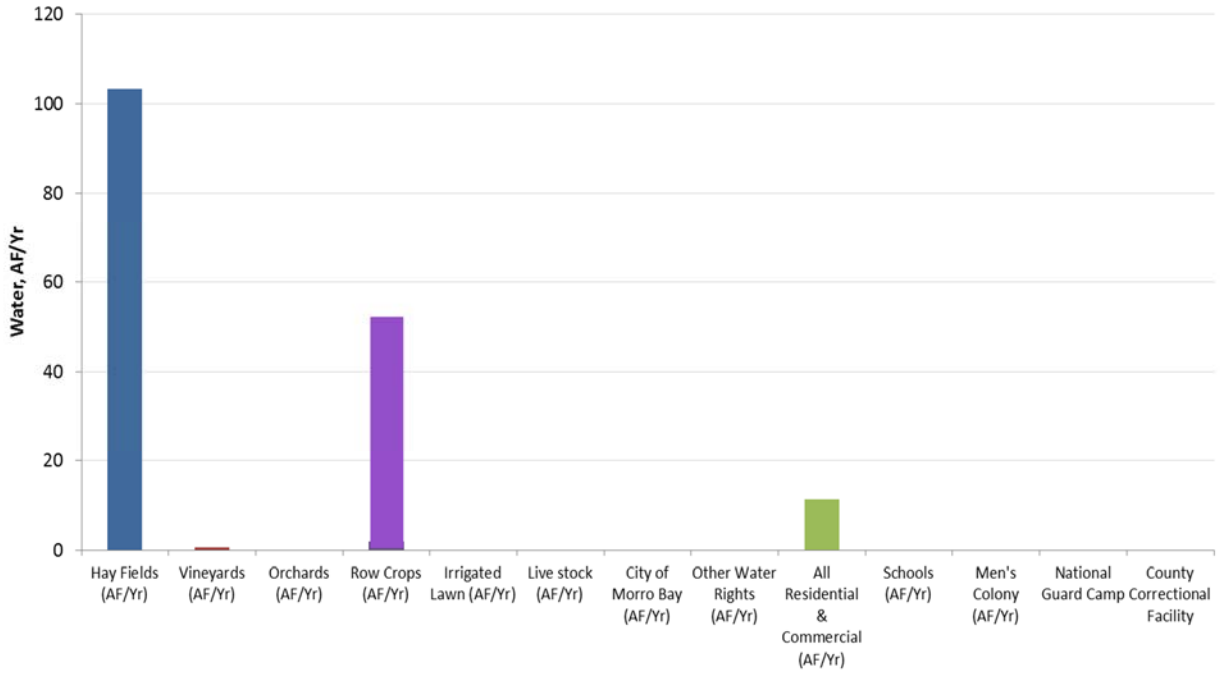

Figure 14. Human water needs by category in the San Luisito Creek watershed.

Pennington Creek

Like the San Luisito watershed, Pennington Creek has only a few water rights and water uses in its watershed (Figure 15). The San Luis Obispo County Office of Education has a water right of 3 ac-ft per year for an educational pond in the Pennington Creek watershed. In addition Cal Poly has a 1.3 ac-ft per year water right for 200 cattle and their field station. Combined with all other water uses needed in the Pennington Creek watershed, the total annual human water need in Pennington Creek is 27.6 ac-ft per year (Table 9, Figure 16).

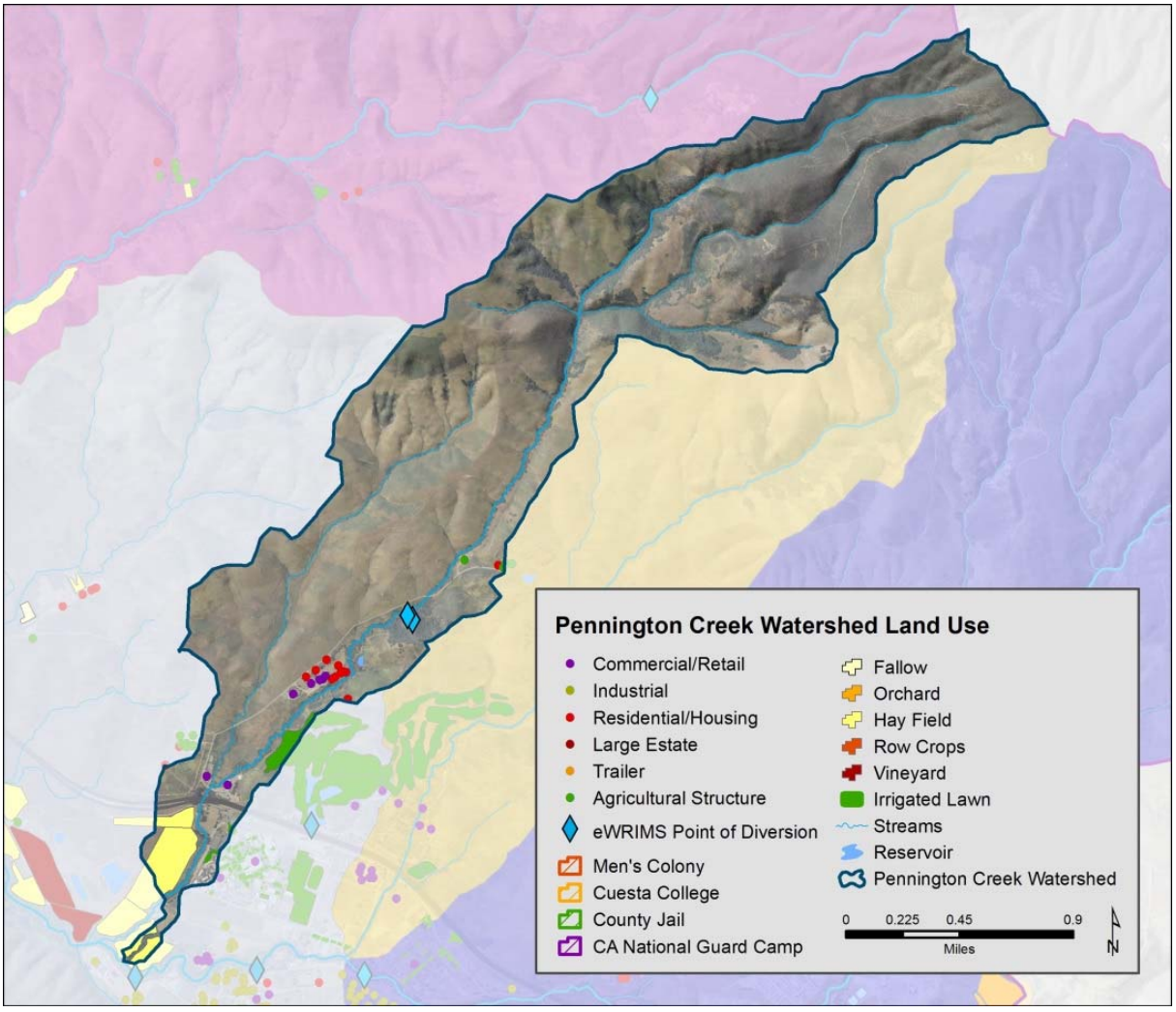

Figure 15. Human water uses in the Pennington Creek study area.

Table 9. Human water needs in the Pennington Creek watershed by category (lawn is comprised of the portion of the Dairy Creek golf course in the Pennington watershed).

Water Need By Subwatershed	Hay Fields (AF/Yr)	Vineyards (AF/Yr)	Orchards (AF/Yr)	Row Crops (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay (AF/Yr)	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp	County Correctional Facility	Total
Pennington Creek	0.0	0.0	0.0	0.0	17.1	1.3	0.0	3.0	6.1	0.0	0.0	0.0	0.0	**27.6**

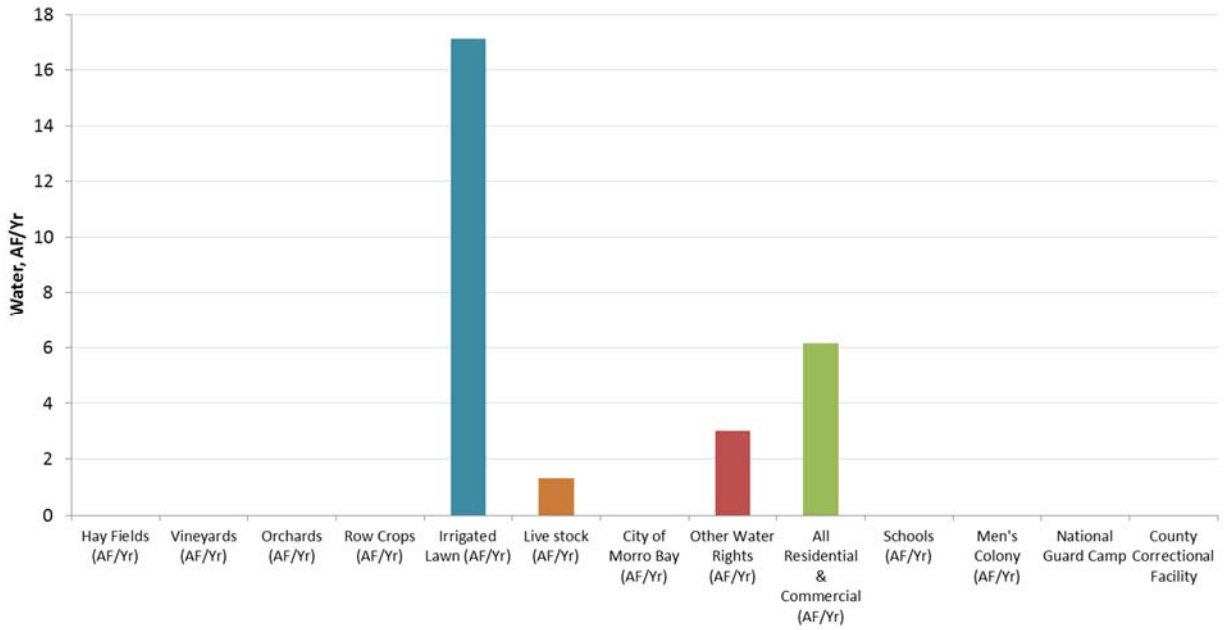

Figure 16. Human water needs by category in the Pennington Creek watershed.

Dairy Creek

In the Dairy Creek watershed there are no registered water right holders. However, a portion of commercial structures identified using our remote sensing techniques fall within the National Guard Camp property (Figure 17). The National Guard currently holds a water right to extract water from the mainstem Chorro Creek to meet their water needs. We assumed that all structures and agricultural fields within the property boundary of the National Guard have their water needs met through their water rights and so we subtracted the commercial structures water need value out of our original analysis. The total annual human water need in the Dairy Creek watershed is 91.2 ac-ft, mostly comprised of water needed for the Dairy Creek golf course (Table 10, Figure 18).
Much of the water needed for the golf course assumed here to be in the Dairy Creek watershed may not actually come from the Dairy Creek watershed. The golf course has a water right for 29 ac-ft outside of the watershed, and it also has a large structure that is possibly a pump house near its reservoirs outside the watershed. Additionally, the reclaimed water likely comprises a very small fraction of daily water used for irrigation.

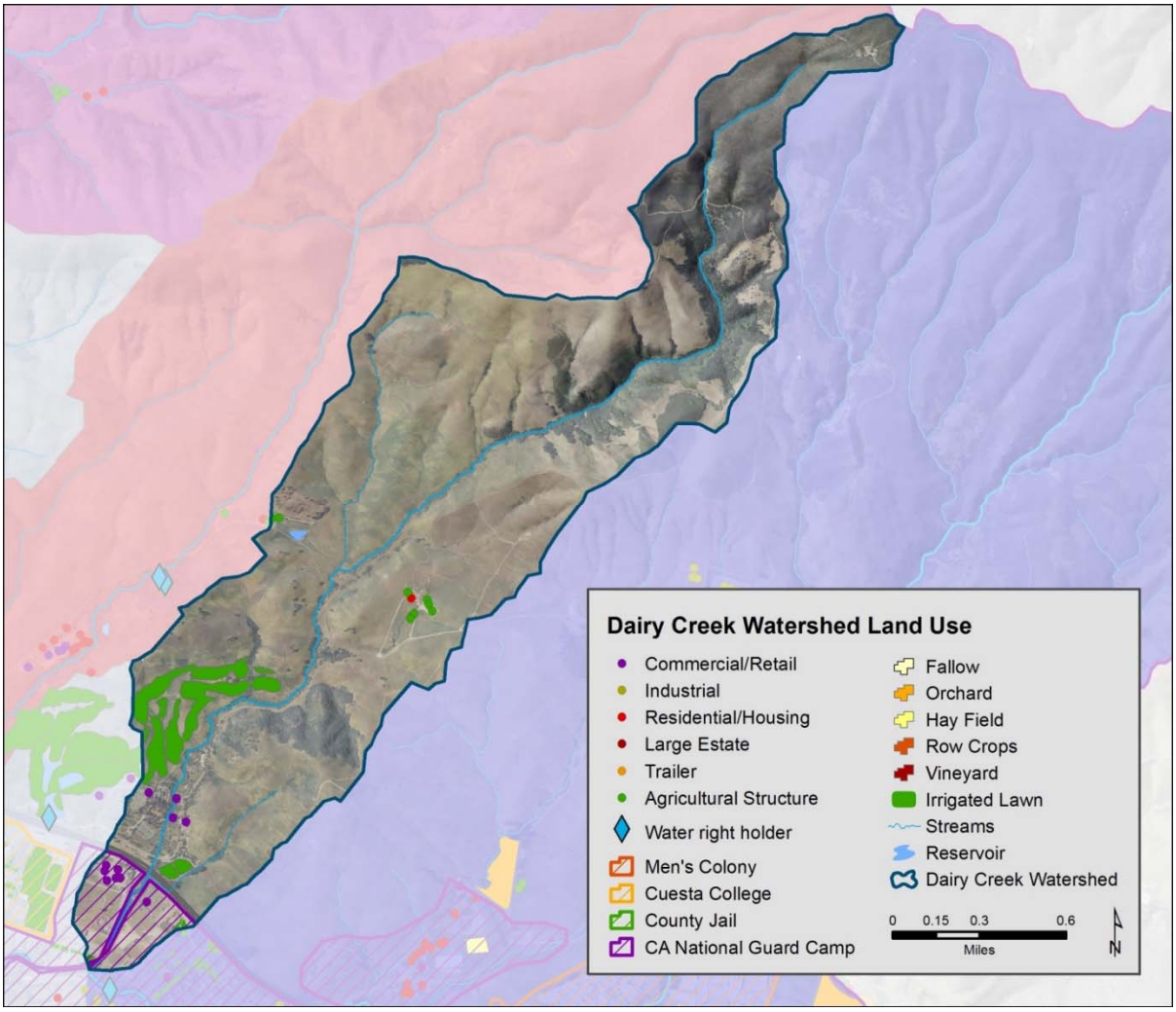

Figure 17. Human water uses in the Dairy Creek study area.

Table 10. Human water needs in the Dairy Creek watershed by category. (Red numbers indicate water amount derived from water rights information, black text indicates water amount derived from remote sensing and standardized water use factors.)

	Hay Fields (AF/Yr)	Vineyards (AF/Yr)	Orchards (AF/Yr)	Row Crops (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay (AF/Yr)	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp	County Correctional Facility	Total
Dairy Creek	0.0	0.0	0.0	0.0	89.5	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	**91.2**

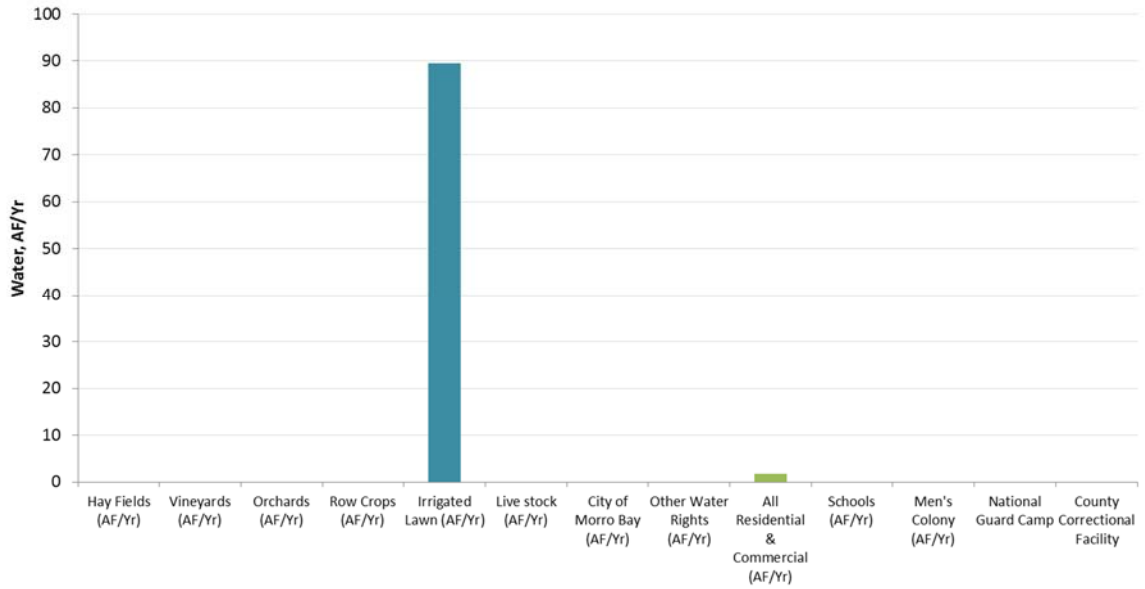

Figure 18. Human water needs by category in the Dairy Creek watershed.

Upper Chorro Creek

There are several large water right holders in the Upper Chorro Creek watershed – including the Men's Colony, County Jail, and National Guard (Figure 19). The Men's Colony holds a water right for 180 ac-ft of water annually, the County Correctional Facility has a water right for 165 ac-ft of water annually, and the National Guard has a water right for 92 ac-ft of water annually from the Upper Chorro Creek watershed. Additionally, a private landowner has a total water right for 16.5 ac-ft of water annually for stock ponds. Similar to Dairy Creek, there are several structures from our remote sensing analysis that fall in the property boundaries of the Men's Colony, County Correctional Facility, and National Guard. We assumed that these structures met their annual water needs through the associated water rights and so we subtracted these structures' water needs out of our original analysis. We estimate the total annual human water need in the Upper Chorro Creek watershed is 530 ac-ft per year (Table 11, Figure 20). Though this is the second-largest sum of water need among our project regions (behind the Mainstem Chorro Valley area), the majority of water use is comprised of only a few institutional water users.

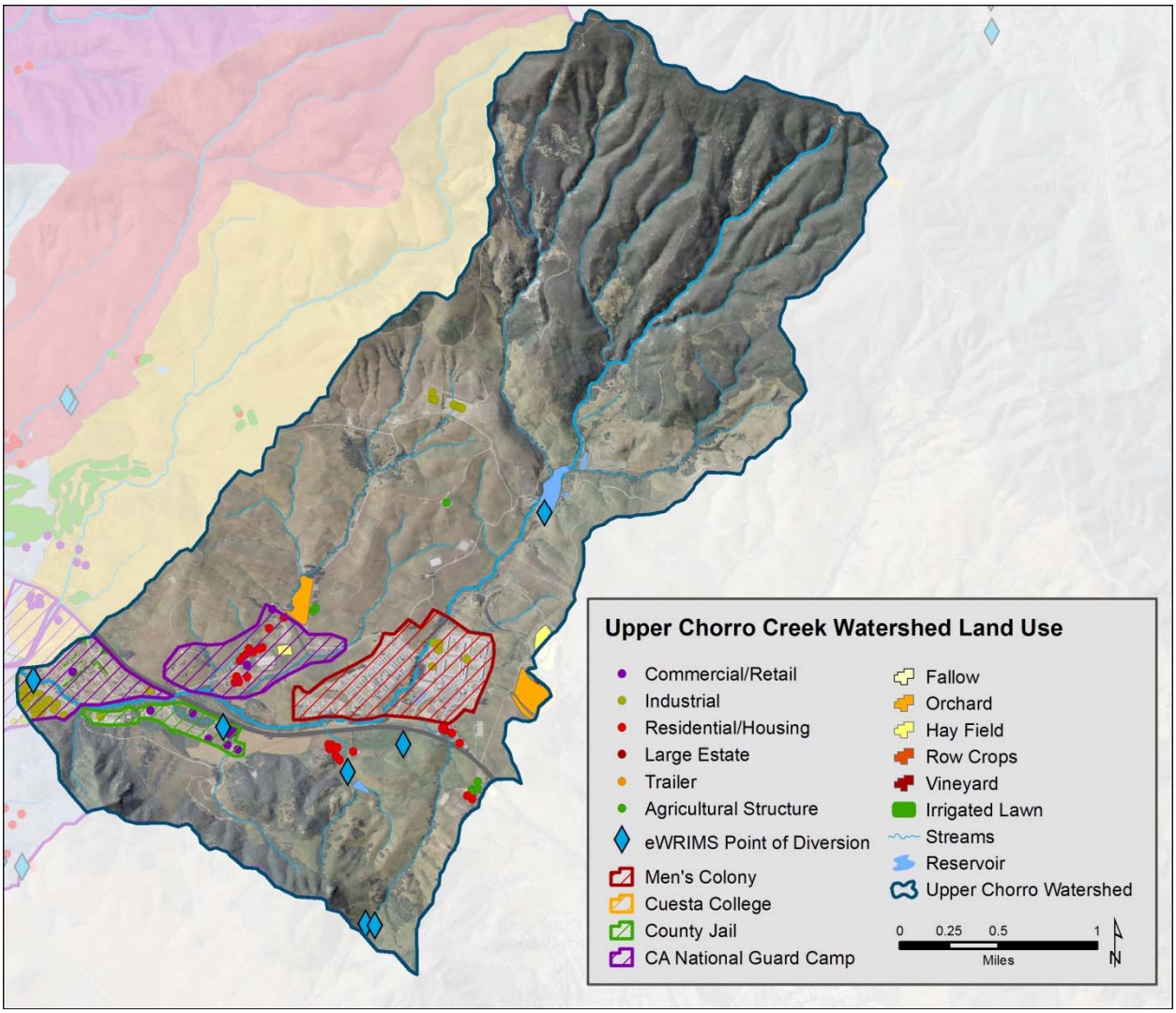

Figure 19. Human water uses in the Upper Creek study area.

Table 11. Human water needs in the Upper Chorro Creek watershed by category.

	Hay Fields (AF/Yr)	Vineyards (AF/Yr)	Orchards (AF/Yr)	Row Crops (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay (AF/Yr)	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp	County Correctional Facility	Total
Upper Chorro Creek	0.0	0.0	62.4	0.0	8.0	16.5	0.0	0.0	6.1	0.0	180.0	92.0	165.0	**530.0**

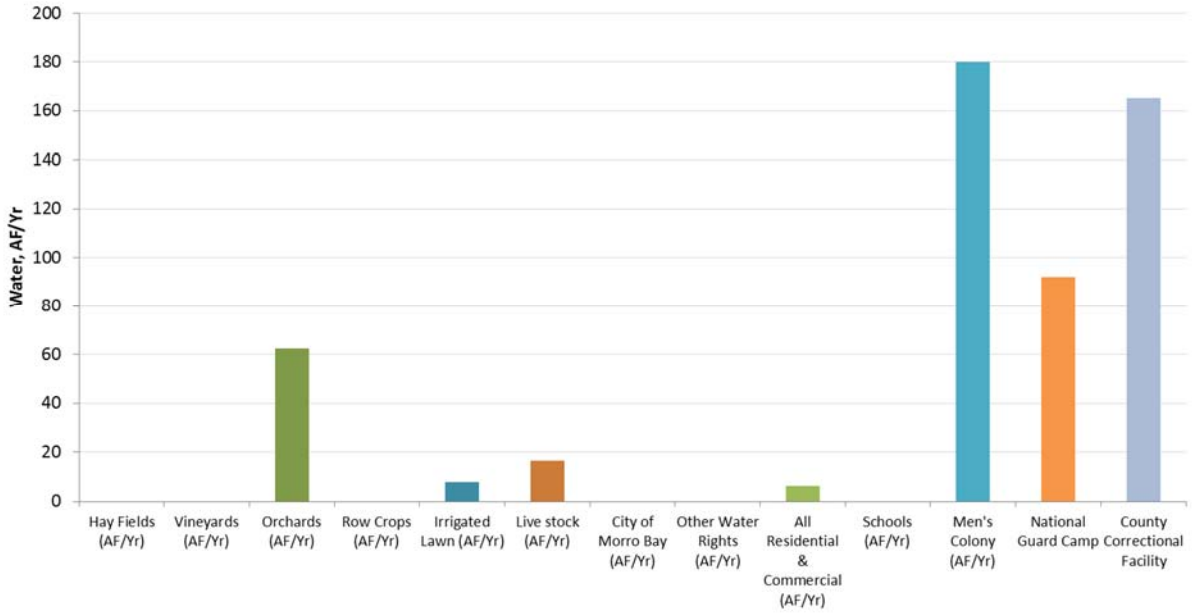

Figure 20. Human water needs by category in the Upper Chorro Creek watershed.

Total Human Water Need for the Entire Chorro Creek Watershed

We recalculated the total amount of water needed for human uses in the Chorro Creek watershed and its major tributaries based both on the remote sensing and water use rate factors, and water rights information. Additionally we recalculated water needed for different structures (residential, commercial, etc.) by subtracting any structures that lie within the property boundary of an entity with a known water right. Table 12 and Figure 21 show the final human water use estimates for the Chorro Creek watershed, in total human water needs in Chorro Creek require 1,451 ac-ft of water annually.

	Hay Fields (AF/Yr)	Vineyards (AF/Yr)	Orchards (AF/Yr)	Row Crops (AF/Yr)	Irrigated Lawn (AF/Yr)	Livestock (AF/Yr)	City of Morro Bay	Other Water Rights (AF/Yr)	All Residential & Commercial (AF/Yr)	Schools (AF/Yr)	Men's Colony (AF/Yr)	National Guard Camp (AF/Yr)	County Correctional Facility (AF/Yr)
Entire Chorro Creek Watershed	125.2	18.4	83.8	343.3	2.9	290.8	363.0	4.0	54.3	47.9	180.0	116.0	165.0
Mainstem Chorro Creek	22.0	17.8	13.1	292.1	1.1	176.2	363.0	1.0	20.5	47.9	0.0	24.0	0.0
San Bernardo Creek	0.0	0.0	8.3	0.0	0.0	0.0	0.0	0.0	8.5	0.0	0.0	0.0	0.0
San Luisito Creek	103.2	0.6	0.0	51.2	1.9	0.0	0.0	0.0	11.3	0.0	0.0	0.0	0.0
Pennington Creek	0.0	0.0	0.0	0.0	0.0	17.1	0.0	3.0	6.1	0.0	0.0	0.0	0.0
Dairy Creek	0.0	0.0	0.0	0.0	0.0	89.5	0.0	0.0	1.7	0.0	0.0	0.0	0.0
Upper Chorro Creek	0.0	0.0	62.4	0.0	0.0	8.0	0.0	0.0	6.1	0.0	180.0	92.0	165.0

Table 12. Water need by type, Chorro Creek watershed and sub-basins, based on a combination of remotely sensed data (through aerial photographs) and water right data for larger institutional uses (red numbers indicate water amount derived from water rights information, black text indicates water amount derived from remote sensing and standardized water use factors).

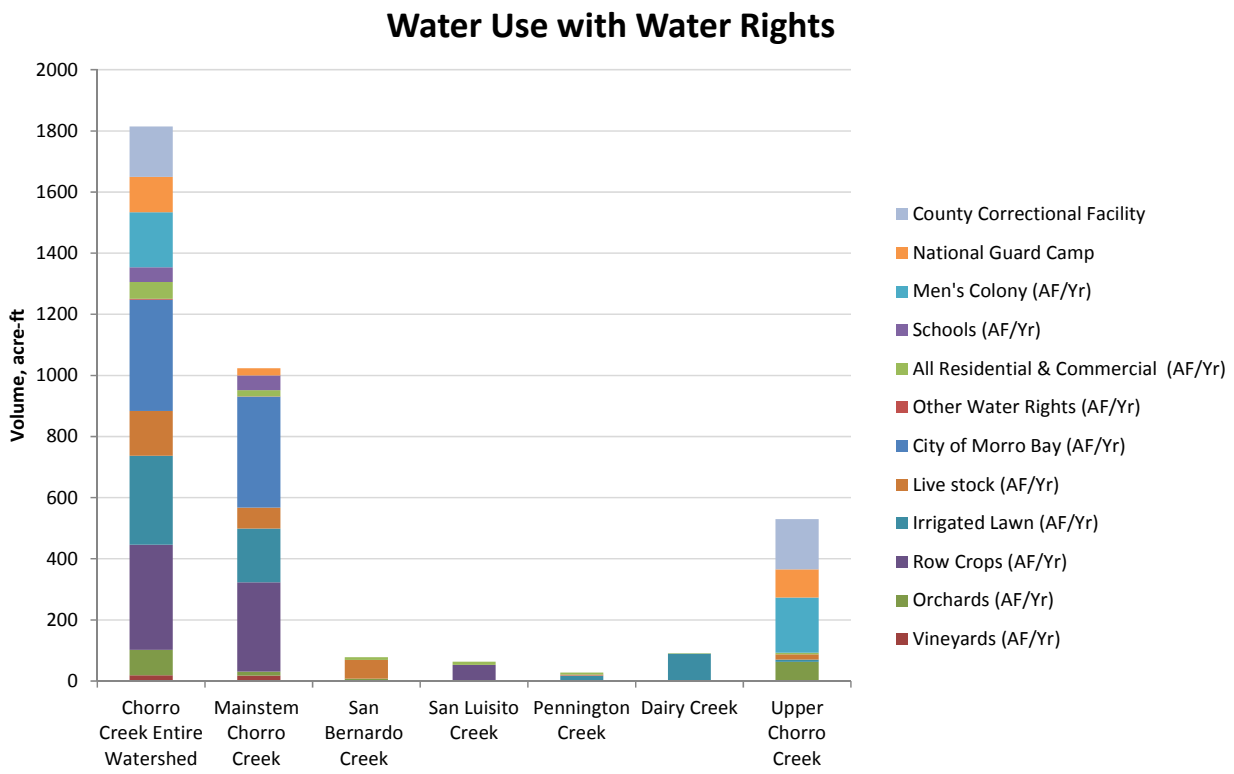

Figure 21. Water need by type, Chorro Creek watershed and sub-basins, based on a combination of remotely sensed data (through aerial photographs) and water right data for larger institutional uses.

3.2 Water Availability and Timing

Understanding the timing and availability of water sources and supply is fundamental to managing the resource effectively. We first compared the total annual human water need to the total water supply (rainfall and stream discharge) to determine if human water needs can be met though the water resources available on site. Our analysis indicates that human water need comprises a small fraction of the total annual rainfall and discharge available annually (Figure 22).

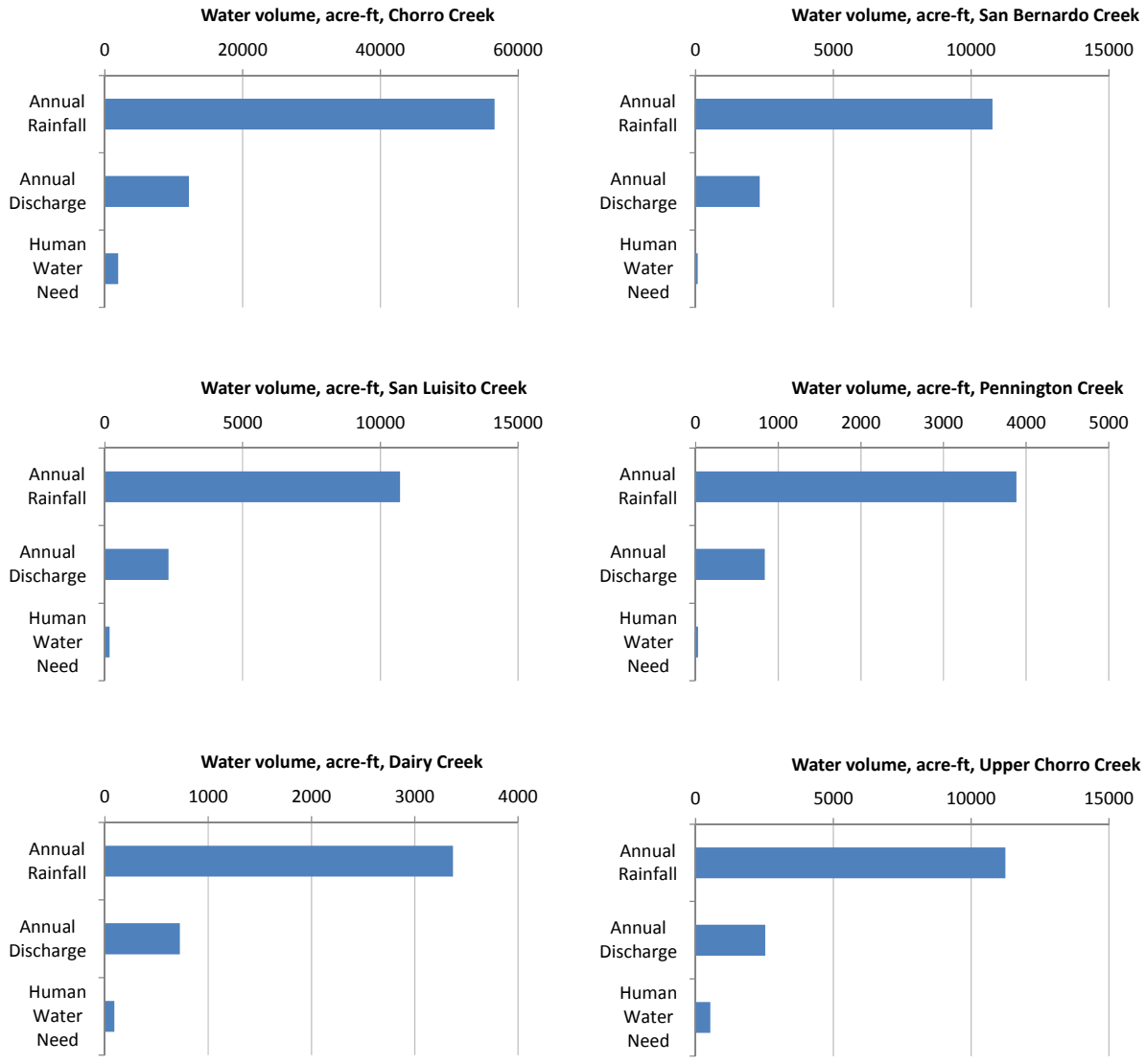

Figure 22. Comparison of rainfall, streamflow, and human water need in the Chorro Creek watershed and in the tributary watershed.

While Figure 22 paints an optimistic picture of water availability in the Chorro Creek watershed, many human water activities take place in the dry season when rainfall and discharge is limited. Examining streamflow against human water need on a monthly basis provides a more accurate view of Chorro Creek's water supply conditions and possible ecological interactions. We developed a monthly discharge data set for Chorro Creek by scaling average monthly streamflow measured in Morro Creek, a nearby drainage network, from May through October – historically considered to be the driest months of the year. We then estimated human water need during this time period based on our analysis described in the previous section. The results, shown in Figure 23, indicated that water need in May is

less than likely discharge, but need is at least two times greater than discharge from July through September.

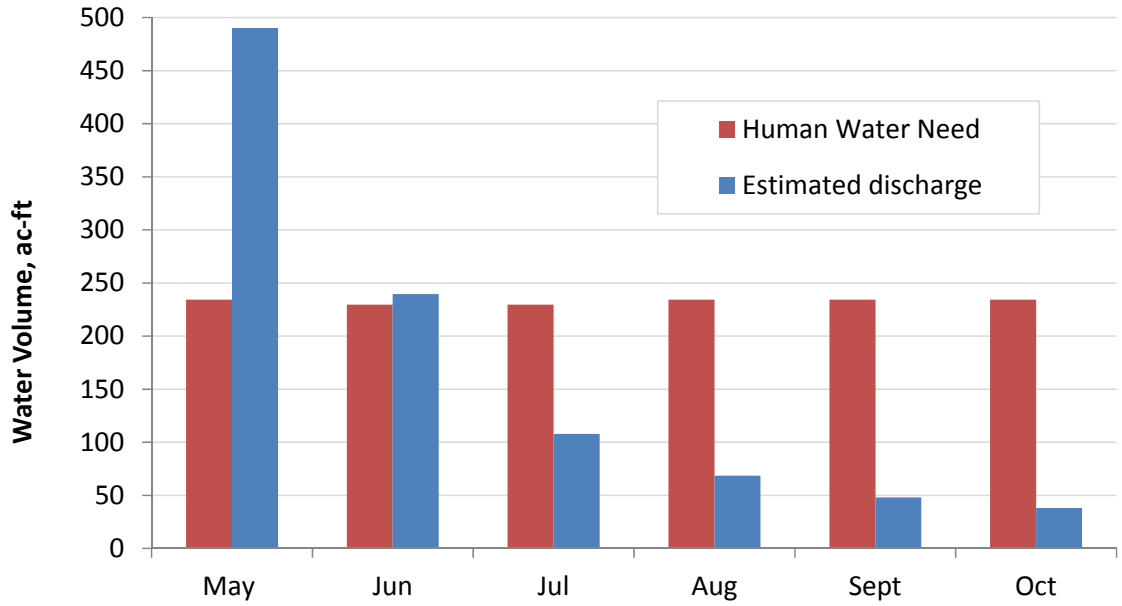

Figure 23. Estimated dry season monthly discharge and water need in the Chorro Creek watershed.

Depending on how these summer water needs are met (i.e. through stored water, groundwater extraction or direction surface flow diversion), fulfilling human water need may profoundly reduce base flows, and potentially decrease the quality of ecological habitats. Our remote sensing analysis shows that there is not sufficient water storage available within the watershed to meet human water needs in summer months. However, streamflow improvement projects (i.e., water storage systems) can be implemented to reduce the impact of human water diversions in the dry season.

4. Streamflow Improvement Projects

A Streamflow improvement project amends current water diversion practices by altering the season water diversion takes place (from summer months to winter months). This approach is not only beneficial for ecological purposes but it is also advantageous to landowners because they provide water security in a variable and unpredictable climate. However, streamflow improvement projects require substantial investments of time, expertise and funding; therefore, it is imperative that the selection of storage projects is done in a strategic way.

Our human water need analysis provides important tools for determining focus areas to pursue streamflow improvement projects. In the Chorro Creek watershed there are a variety of water users that require various amount of water to meet their needs (Figure 24). Additionally, there are several entities that require large amounts of water; the Men's Colony, National Guard Camp, County

Correctional Facility, Dairy Creek Golf Course and the City of Morro Bay are all single entities that if their water needs were met through storage could significantly increase summer bases flows to Chorro Creek and their associated tributaries.

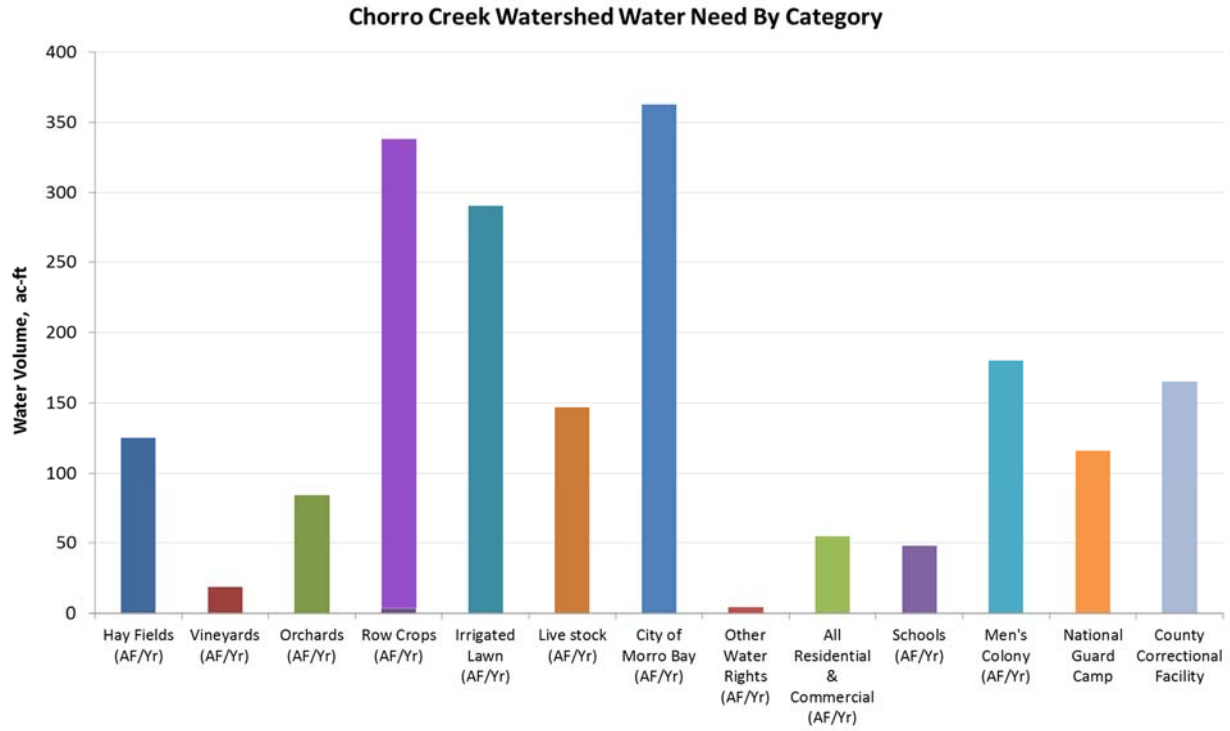

Figure 24. Chorro Creek Watershed water need by category.

In the Mainstem Chorro Creek/Chorro Creek Valley study area there are several landowners that could benefit from streamflow enhancement projects. For example, Cuesta College has a substantial area of irregated lawn, this area could benefit from either water storage or drought tolerant grass species. Additionally, there is a significant amount of agricultural fields planted along mainstem Chorro Creek. Based on our remote sensing analysis, there are several fields that are fallow near the confluence with San Bernardo Creek and farther upstream; and historical aerial photo comparisons showed that in some summers these fields are planted with row crops. If this area is planted again in the future or if the existing hay fields in the area transition into alternative forms of agriculture this area would highly benefit from storage ponds. The observation of row crops in some years but not in others also suggests that people might benefit from using water if it can be obtained, but it may not always be available.

In the San Bernardo, San Luisito, Pennington Creek, Dairy Creek and Upper Chorro Creek watersheds small domestic storage tanks could benefit many of the landowners living adjacent to the creek whom obtain their water either through surface water diversions or by pumping groundwater from a well adjacent to a creek. In these watersheds the cummlative effect of multiple households and small

agricultural lands transitioning from summer surface water diversions to summer storage could increase baseflows in their associated tributaries and to the mainstem Chorro Creek.

5. Conclusion

This study gives several conclusions that may help determine direction for future streamflow enhancement projects. Our analysis also shows that water is available in each project area described above to satisfy both human and biological needs. Our estimated streamflow and water use volumes on an annual and monthly basis show seasonal water conflicts, but importantly, it does not show a problem of annual over-allocation. (This conclusion could, however, be more problematic in a dry-type year, when streamflow may be much less.) This conclusion suggests that efforts to build water storage to enhance dry season streamflow could have benefits to increase streamflow in the Chorro Creek drainage network and benefit water security for its human residents as well.

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