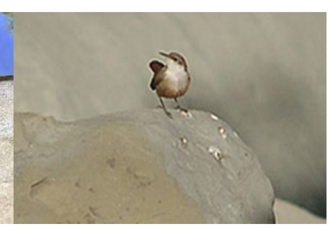
UPPER MISSION AND RATTLESNAKE CREEKS: HYDROGEOLOGIC AND BIOLOGIC INVESTIGATION, SANTA BARBARA, CALIFORNIA



PREPARED FOR THE URBAN CREEKS COUNCIL

SANTA BARBRA, CALIFORNIA

MARCH 15, 2023

UPPER MISSION AND RATTLESNAKE CREEKS: HYDROGEOLOGIC AND BIOLOGIC INVESTIGATION, SANTA BARBARA, CALIFORNIA

WITH SPECIAL REFERENCE TO MISSION TUNNEL EFFECTS ON CREEK FLOWS

PREPARED FOR THE URBAN CREEK COUNCIL

SANTA BARBARA, CALIFORNIA

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UPPER MISSION & RATTLESNAKE CREEKS: HYDROGEOLOGIC AND BIOLOGIC INVESTIGATION, SANTA BARBARA, CALIFORNIA

WITH SPECIAL REFERENCE TO MISSION TUNNEL EFFECTS ON CREEK FLOWS

Background

A study team was formed in 2021 by the Santa Barbara Urban Creeks Council (UCC) to perform a hydrologic, geomorphologic, geologic, aquatic and riparian biological study of the upper, non-urban, watershed of Mission Creek, Santa Barbara, California. The study area encompasses the watershed upstream of the confluence of Mission Creek and Rattlesnake Creek, as depicted in Figure ES.1.

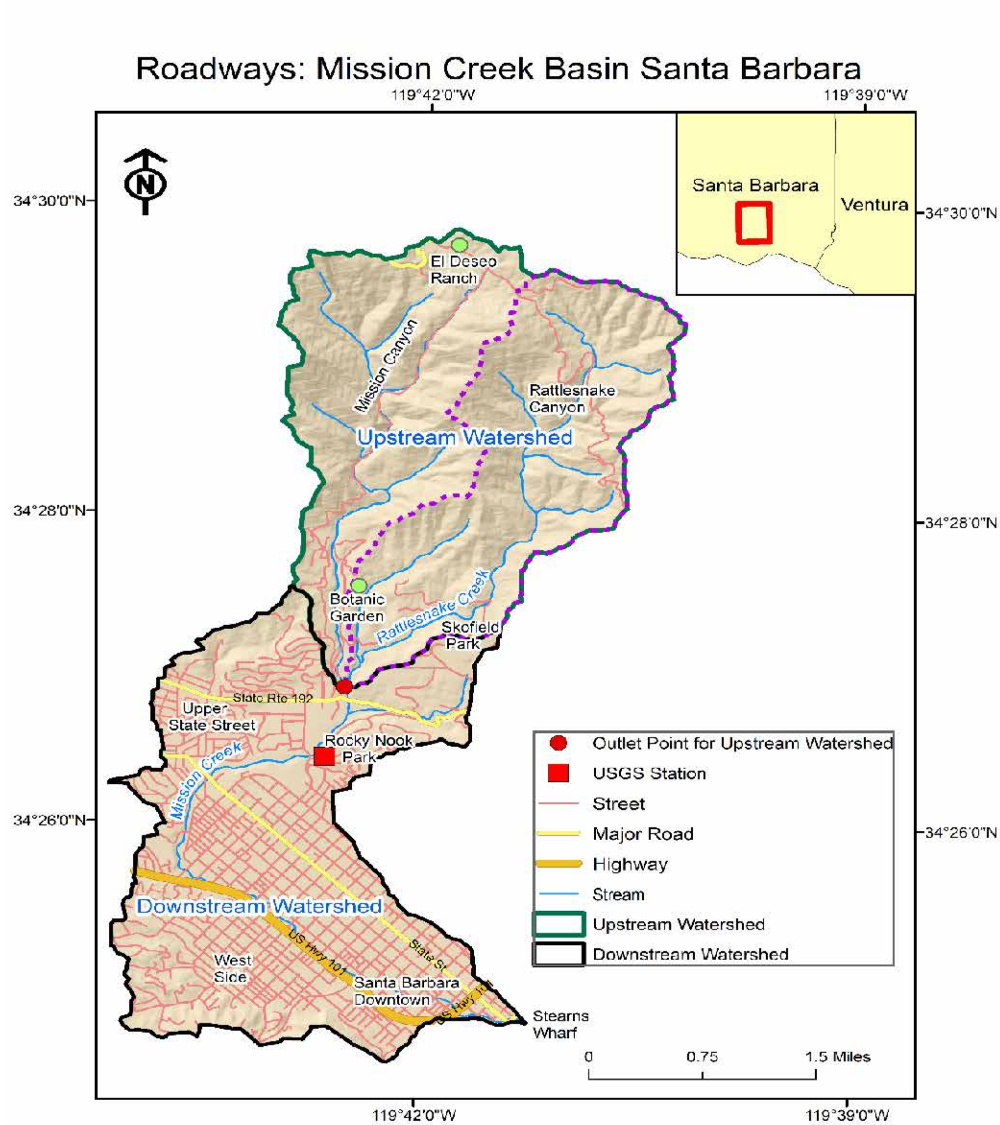


Figure ES.1. The study area is the watershed upstream of the confluence of Mission and Rattlesnake creeks. The study area encompasses 3,840 acres (6.0 square miles). The dotted purple line constitutes the boundary between Mission Creek and Rattlesnake Creek.

This study was conducted between October 2021 and December 20022, in compliance with the acknowledgement of responsibilities to perform a supplemental environmental project (SEP) agreed between the County of Santa of Barbara's Office of the District Attorney and the UCC. The study team reviewed and gathered geologic, hydrologic, and biologic data pertinent to identifying anthropogenic impacts on the watershed, and means and methods for enhancing aquatic habitat in the study area. The hydrologic, geomorphologic, geologic, and biological study identified means and methods for (i) enhancing aquatic habitat and restoring the natural streamflow, (ii) preserving water quality, (iii) restoring the natural geomorphologic characteristics of Mission Creek within the study area, and (iv) protecting or restoring the Creek's natural aquatic and riparian resources (e.g., native habitats and species).

Furthermore, the study team reviewed and gathered data with the purpose of studying and assessing the possible reduction of streamflow in Mission Creek as the result of the construction and operation of the Mission Tunnel, which was completed in 1912 and has been operated by the City of Santa Barbara as part of its water supply system.

This executive summary presents the key findings and recommendations resulting from the study of the upper, non-urban, watershed of Mission Creek (including the Rattlesnake Creek sub-watershed). This executive summary is intended to inform interested parties and guide policy makers and regulators responsible for the protection and restoration of water and creek resources in the Study Area. Background on the hydrologic, geomorphologic, hydrochemical, and biological study's scope, including a technical description of the data, methods, results, and recommendations made by the study team, are provided in chapters 1 through 7 (Chapter 1: Introduction; Chapter 2: Physical Geography and Hydrology of the Study Area; Chapter 3: Human Alteration of the Study Area; Chapter 4: Geomorphology and Biology of Mission and Rattlesnake Canyons; Chapter 5: Southern California Steelhead (*Oncorhynchus mykiss*) in the Mission Creek Watershed; Chapter 6: Mission Tunnel Impacts; Chapter 7: Recommendations to Restore the Study Area).

Key findings

Previous studies and field observations by this study's authors have established that debris basins, dams, and bridges within the Study Area have altered the stream flow and sediment transport in the study area and restricted the movement of fish and other aquatic species. These alterations also have adversely impacted aquatic and riparian habitats supporting terrestrial and aquatic species in the Study Area.

Previous studies and field observations by this study's authors indicate that trails, roads, and residential landscaping in the riparian zone cause erosion and generate sediment loading to the streams in the study area, thus adversely impacting sediment transport and deposition in Mission and Rattlesnake creeks, and degrading aquatic and riparian habitats. Planting non-native species can also introduce inappropriate exotic species into the riparian corridor, and Mission Canyon more generally. Residents should be encouraged to use native plants in residential landscaping, which are available from the Santa Barbara Botanic Garden.

Mission Tunnel reduces stream flow on average by 530 acre·feet annually in the study area. This reduction adversely affects stream flow and sediment transport, and degrades aquatic and riparian habitats. The cited adverse impacts have accumulated since 1912, the year when the Mission Tunnel was completed.

Decommissioning the Mission Tunnel would increase stream flows, improve aquatic and riparian ecological conditions, and would reduce the annual water supply to the City of Santa Barbara by an average annual 1,215 acre·feet. This reduction can be accommodated by the city, given that its water use has varied between 17,400 acre·feet in 1985 and 8,600 acre·feet in 2018. The 8,800 acre·feet of variation has occurred by adapting water use to recurring droughts through a combination of managing domestic and municipal water uses and by increasing reliance on more reliable, long-term, local water sources such as the City of Santa Barbara's Charles Meyer Desalination Facility.

Decommissioning the Mission Tunnel would end the role of Gibraltar Reservoir as a water storage and diversion structure. The transfer of water diverted from Gibraltar Reservoir to the city through the Mission Tunnel would terminate if the tunnel's use is discontinued. Water from the Santa Ynez River stored and diverted at Gibraltar Reservoir can be conveyed (with adjustment for losses) to Cachuma Lake by amending the "pass-through" agreement that has been in effect since 1989. This agreement is used to credit water to the city that is spilled from Gibraltar Reservoir and conveyed to Cachuma Lake for delivery to the South Coast through the Tecolote Tunnel (see Chapters 6 and 7 for details). Decommissioning the Mission Tunnel would consist of discontinuing water conveyance from Gibraltar Reservoir and Devils Canyon Creek, closing its north and south portals, and letting the tunnel collapse internally over time[1]. Tunnel decommissioning means sealing off the tunnel's north and south portals (that is, plugging each terminus to avoid seepage of bedrock groundwater towards the exterior) and discontinue maintenance of the tunnel so that it will cave in over time. A volume of bedrock groundwater would fill the tunnel, and that volume would be equal to the cross-sectional area of the tunnel (about 30 feet square) times the length of the tunnel (19.536 feet) for a volume equal to 30 x 19,536 = 586,000 cubic feet = or about 13.5 acre-feet. Overtime, the cross-sectional area of the tunnel would fill with rock debris and the amount of stagnant water in the tunnel will diminish. The decommissioned tunnel would cease to act as a groundwater sink.

Another option to end the dewatering of the bedrock aquifer in the study area would be to convey Gibraltar Reservoir's water diversions and Devils Canyon Creek flow to the City of Santa Barbara through a pipe to be constructed within the Mission Tunnel. This option would require (i) maintaining the integrity of the tunnel to ensure the long-term operation of the pipe, and (ii) sealing off the tunnel's south and north portals to preclude the leakage of groundwater to the tunnel's exterior. See the recommendations listed below for more details on this matter.

Several actions to address significant adverse anthropogenic effects on the natural resources of Mission (and Rattlesnake) Creek and to restore the study area were identified by this study. Their implementation would require strong and effective leadership, as well as institutional and community support. Restoration actions also would require time and funding. The recommendations to restore the Study Area are summarized below.

Recommendations to restore the study area

1. Decommissioning the Mission Tunnel. This would increase baseflow and restore springs in the upper, non-urban, watershed of Mission Creek (including Rattlesnake Creek), where bedrock groundwater is depleted by tunnel discharge. Releasing water to Mission Creek from the tunnel's south portal is an alternative that would increase flow to Mission Creek downstream from the south portal, but it would not restore springs and wells impacted by the tunnel. Decommissioning the Mission Tunnel would require the City of Santa Barbara to amend the Upper Santa Ynez River Operations Agreement (USYROA), commonly known as the "Pass-Through Agreement". The USYROA established that the City of Santa Barbara may "pass through" Santa

[1] The City of Santa Barbara has reconstructed and reinforced the Mission Tunnel in the past to repair and prevent damage caused by the partial collapse of the tunnel's walls and roof. These repair works are of a recurrent nature to maintain the tunnel.

Ynez River water from Gibraltar Reservoir to Cachuma Lake for delivery to the South Coast through the Tecolote Tunnel (see Chapters 6 and 7 for details).

2. An alternative to decommissioning the Mission Tunnel is to release water at its south portal into Mission Creek according to the following monthly schedule (all amounts in acre feet):

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow	38	43	53	51	51	45	45	42	45	41	38	38	530

3. Another possible option to circumvent the dewatering of bedrock groundwater would be to construct a pipe within the Mission Tunnel that would convey Gibraltar Reservoir's water diversions and Devils Canyon Creek flow to the City of Santa Barbara. This option would require maintaining the integrity of Mission Tunnel to ensure the long-term functioning of a conveyance pipe within it. Furthermore, the tunnel would have to be sealed off at its south and north portals to preclude the leaking of groundwater to the tunnel's exterior. This option may be of temporary usefulness, however, because its effectiveness would depend on how much longer Gibraltar Reservoir would have sufficient storage capacity to allow the diversion of Santa Ynez River streamflow as is currently practiced.

4. Remove or modify one debris basin in Mission Creek and one debris basin in Rattlesnake Creek, to allow volitional fish passage. These debris basins and their dams constitute barriers to fish passage and have altered the stream flow and sediment transport and deposition in the creeks, which affects fish spawning habitat and migration of fish and other animals.

It is noteworthy that the 2014 biological opinion by the National Marine Fisheries Services (see the reference for this work in chapter 7) recommends the complete removal of the debris basins in Mission and Rattlesnake creeks. The County of Santa Barbara Flood Control and Water Conservation District has plans for removing or modifying the debris basins. Therefore, this recommendation supports current efforts to remedy the adverse effects of the debris basins in the study area.

5. Modify Mission Dam in the Santa Barbara Botanical Gardens and the masonry dam on Rattlesnake Creek to allow volitional fish passage. These dams are barriers to fish passage and have altered stream flow and sediment transport in Mission Creek, affecting fish spawning habitat and the movement of fish and other animals. It is herein acknowledged, as it has been in other chapters of this report, that Mission Dam has a historical landmark status and any modifications to the structure would be subjected to rigorous review and approval procedures.

6. Construct energy-dissipating foundations at several bridges that span Mission Creek and Rattlesnake Creek in the proposed study area, and modify these bridges to allow fish passage. Energy-dissipating structures prevent channel and bank erosion under and downstream of bridges, which lowers the channel elevation thus creating a barrier to the migration of fish and other aquatic species. The bridges to be retrofitted are: (1) Foothill Road over Mission Creek, (2) Mission Road over Mission Creek, (3) Mission Canyon Road over Mission Creek, and (4) Las Canoas Road over Rattlesnake Creek. The removal or modification of these bridge crossings are necessary to allow the upstream and downstream movement of fish and other aquatic animals.

7. Stabilize and maintain trails and roads in the study area to prevent erosion and sediment loading to the creeks in the study area. It is recommended that erosional areas on the roads and trails be GPS mapped, and that

corrective work be performed to stabilize them. Stabilization would involve the construction of water bars along trails, filling in gullies, stabilizing unstable slopes formed by road cuts, and providing suitable drainage along trails and roads following site inspection and design. These actions would require coordination and cooperation with the Santa Barbara Trails Council.

8. Create and implement a public-education campaign to inform owners of riparian parcels that (i) certain types of landscaping and earth-moving work (filling, cutting) are prone to erosion and become a source of undesirable sediment loading to the streams and (ii) planting non-native species introduces inappropriate exotic species (plant and invertebrates) into the riparian corridor, and Mission Canyon more generally. This educational campaign also should highlight ways to reduce or eliminate the use of biocides and fertilizers near creeks. Residents should be encouraged to use native plants in residential landscaping. The armoring of creek banks must be subjected to permitting by the pertinent agencies (Santa Barbara County Flood Control & Water Conservation District, the US Army Corps of Engineers, the National Marine Fisheries Services, the California Department of Fish and Wildlife, and the City of Santa Barbara as city, county, state, and federal ordinances, regulations, and laws mandate it). The Urban Creeks Council, through its network of volunteers and community relationships, is uniquely well positioned to undertake this educational task.

9. Abandoned pipes, rock debris and trash (e.g., tires, large metal rubbish) dumped in the creeks must be safely removed and disposed of. The Urban Creeks Council, in coordination with the City of Santa Barbara's Creeks Division and the County of Santa Barbara's Project Clean Water, is well-positioned to pursue this work with the support of volunteers, city and county staff.

10. This study summarizes our current understanding of the hydrology and biology of the study area and applied conceptual models in the Upper Mission Creek watersheds. [redacted] A proposal is being prepared by several of this report's authors to seek funding for further research in the study area. More information on where and how riparian areas can be restored would benefit aquatic and riparian habitats and species.

11. Additional studies and efforts to remove or modify barriers, such as dams and road crossings, are needed to restore steelhead to their former levels. This study revealed some of the limitations on the distributions and abundances of sensitive species, e.g., the Southern California Steelhead, such as inadequate and intermittent flows, shallow pools, and restricted breeding or spawning habitat. Even if water supplies are adequate, however, barriers to steelhead migration will prevent the restoration of steelhead stocks.

CHAPTER 1. INTRODUCTION

1.1 Scope

The Mission Creek Study Team conducted a hydrologic/biologic study of the upper non-urban portion of Mission Creek watershed in compliance with the acknowledgement of responsibilities to perform a supplemental environmental project (SEP) agreed between the County of Santa of Barbara's Office of the District Attorney and the Santa Barbara Urban Creeks Council (UCC). This study provides a data summary and identifies means and methods for enhancing aquatic habitat in the upper non-urban watershed of Mission Creek (the study area). The study area encompasses the drainage basin upstream of the confluence of Mission Creek and its tributary Rattlesnake Creek at an elevation of 482 feet above mean sea level, depicted in Figure 1.1. Figure 1.2 shows a photo of the confluence of Mission Creek and Rattlesnake Creek. The identification of means and methods for enhancing aquatic habitat focused on the restoration of the natural flow in Mission Creek, the preservation of water quality, and the restoration of the natural geomorphologic characteristics of Mission Creek within the study area. The Study Team reviewed and gathered data with the purpose of studying and assessing the possible reduction of streamflow in Mission Creek as the result of the construction of Mission Tunnel, which was completed in 1912 and has been operated by the City of Santa Barbara as part of its water supply system. Figure 1.3 depicts the location of Mission Tunnel in relation to the study area. The Study Team gathered, reviewed, and evaluated geologic, hydrologic, and biologic data pertinent to identifying means and methods for restoring degraded aquatic and riparian habitats in the study area.

1.2 The Study Team

The Study Team's coordinator is Dr. Hugo A. Loaiciga, P.E., D.WRE, P.H. Dr. Loaiciga is a hydrologist with expertise in surface water/groundwater interactions and groundwater hydrology. He evaluated climatic and hydrologic data pertinent to the study region, and assessed the surface water (i.e., Mission Creek's streamflow) and groundwater (i.e., bedrock groundwater) interactions in the study region. Dr. Loaiciga also evaluated the possible role of historical climate change in the hydrologic regime of the study area. The other Study Team members are Dr. Barry Keller (PG, CHG) (who supervised the hydrogeologic analysis), Dr. Edward Keller, Dr. Paul Alessio, Dr. John Melack, Dr. Scott Cooper, and Mr. Mark Capelli. Dr. Barry Keller lead the geologic/hydrogeologic analysis of the capture of bedrock groundwater by Mission Tunnel, and the possible linkages to reduced groundwater contribution to Mission Creek's streamflow through joints, fractures, and fault zones in the study region. He has experience and knowledge with Mission Tunnel and participated in previous studies of this water work. Dr. Edward Keller[♣1] had long-term experience with the geomorphology of Mission Creek and knowledge of the geologic and natural settings of the study region. He recommended field methods for characterizing the instream habitats. Dr. Paul Alessio has expertise in geomorphology and debris flows. Dr. Alessio performed a survey of the geomorphologic features of Mission Creek in the study region pertinent to steelhead stream habitat, such as the type, frequency, and location of streambed features (riffle/pool, rapids, cascades, and step/pools) and their characteristics (length, width, frequency). Dr. Melack has four decades of experience in watershed science and led studies of the streams entering the Santa Barbara Channel as part of the Santa Barbara Coastal Long-term Ecological Research (LTER) program. He provided data, publications, and advice related to Mission Creek hydrology and climate. Mr. Capelli is the South-Central/Southern

[♣1] Our colleague Edward Keller passed away on September 9, 2022.

California Steelhead Recovery Coordinator (Santa Barbara office) of the National Marine Fisheries Service. He has long-term experience on steelhead recovery programs, and along with Dr. Scott Cooper, provided the analysis and assessment of steelhead and other aquatic species habitats in the upper non-urban portion of Mission and Rattlesnake creeks.

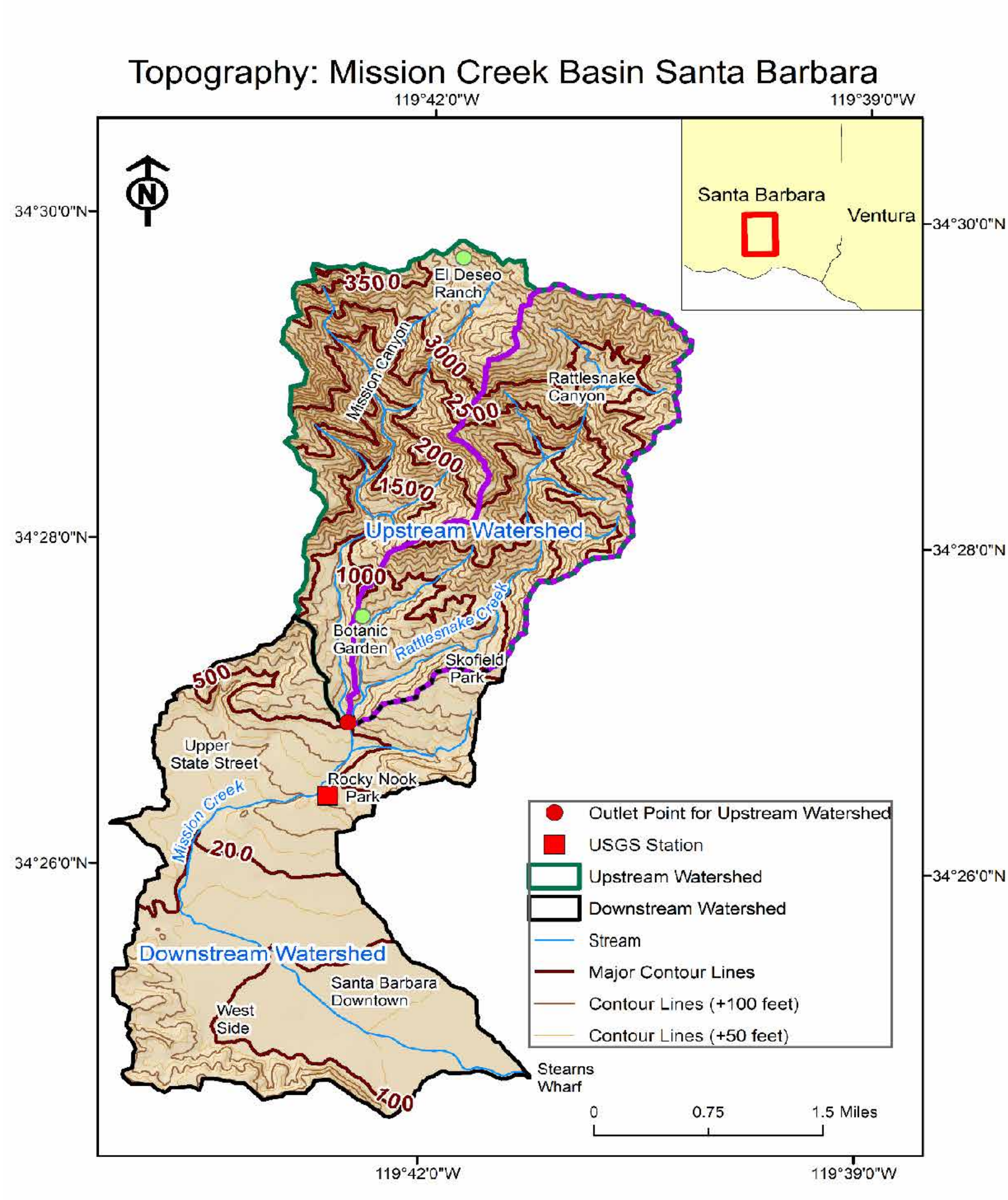


Figure 1.1. The study area (upstream watershed) equals the drainage area upstream of the confluence of Mission Creek and Rattlesnake Creek. Area = 6.00 sq. miles (3,840 acres). The purple line constitutes the boundary between Mission Creek and Rattlesnake Creek.

Figure 1.2. The confluence of Mission Creek and Rattlesnake Creek. Photo viewing upstream (north). Mission Creek flows from the left. Elevation 482 feet above mean sea level. Coordinates: 34° 26.886′ N; 119° 42.541′.

Mr. Capelli provided advice on human-induced Mission Creek's alterations that impact steelhead and on identifying the means and methods for enhancing aquatic habitat in the upper non-urban watersheds of Mission Creek. In addition, Mr. Capelli reviewed and evaluated biological information, and provided data, habitat maps, photos, and publications pertinent to this study. Dr. Cooper is a stream ecologist who identified means and methods for enhancing aquatic habitat in the upper non-urban watersheds of Mission Creek, reviewed and evaluated biological information in the study area. Mr. Dami Eyelade provided GIS services, and Mr. Conor Mcmahon evaluated the biologic characteristics of the riparian stream corridors in the study area.

1.3 Work Schedule and budget

The Study Team began work on November 1, 2021. Table 1.1 lists the various tasks completed expressed in months elapsed since the starting date.

Table 1.1. Work schedule and personnel assignment.

Task	**Month**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
GIS maps (HL, DE)	X	X	X											
Climatic evaluation (HL)	X	X	X	X										
Hydrologic evaluation (HL)			X	X	X	X								
Geologic analysis/Mission Tunnel (BK)	X	X	X	X	X	X								
Hydrogeologic Evaluation (BK; HL)			X	X	X	X	X	X	X	X				
Geomorphologic evaluation (PA, EK)		X	X	X	X	X	X	X	X	X	X			
Water quality baseline evaluation (JM; HL)		X	X	X										
Stream habitat evaluation (SC, MC, PA, CM, JM)	X	X	X	X	X	X	X	X	X	X	X	X		
Report writing (All)													X	X

BK: Barry Keller; CM: Conor McMahon; D.E: Damilola Eyelade; EK: Ed Keller; HL: Hugo Loaiciga; JM: John Melack; MC: Mark Capelli; PA: Paul Alessio; SC: Scott Cooper; All: all team members.

This study was completed with a budget of $ 75,000.

1.4 Report contents and organization

The Executive Summary presents the main study findings and recommendations for the restoration of the study area. Chapter 2 reviews the physical geography of the study area (climate, hydrology, soils, land use, vegetation and fire, streamflow, water balance, water-quality characteristics of the Mission Tunnel water). Chapter 3 describes human alteration of the study area. Chapter 4 reports the results of geomorphologic and biologic surveys performed to characterize the aquatic habitat and biologic corridors in the study area. It also presents a description of the study area's fauna, flora, and soils, and a brief history of human occupation and wildfire phenomena in the study area. Chapter 5 presents a review of the status of the steelhead (*Oncorhynchus mykiss*) in southern California. Chapter 6 suggests a conceptual model of possible effects of the Mission Tunnel on streamflow in the study area. Chapter 7 presents recommendations for hydrologic/biologic restoration and pertinent future studies in the study area.

The study area (within red perimeter) and Mission Tunnel (black dashed line).

1.5 Authors' contributions to report writing

All authors participated in writing and reviewing subsections or all the content of this report. Some authors had a leading role in writing specific chapters, with the authors being listed in alphabetical order in each case as follows: Executive Summary and Chapter 7: Mark Capelli, Scott Cooper, Barry Keller, Hugo Loaiciga, and John Melack participated in the development of the contents and the writing of the Executive Summary and Chapter 7, although unanimous consensus on all the statements written in these two parts of the report was not reached; Chapters 1 and 3: Hugo Loaiciga; Chapter 2: Damilola Eyelade and Hugo Loaiciga; Chapter 4: Paul Alessio, Scott Cooper, Edward Keller, Conor McMahon, and John Melack; Appendices 4.1 and 4.2: Paul Alessio and Conor McMahon, respectively; Chapter 5: Mark Capelli; Chapter 6: Barry Keller and Hugo Loaiciga.

CHAPTER 2. PHYSICAL GEOGRAPHY AND HYDROLOGY OF THE STUDY AREA

2.1 Introduction

This chapter presents the key features of the study area's physical geographic characteristics as they relate to its hydrologic system. Further details about the study area's flora and fauna are presented in chapter 4, which also includes a summary of human occupation and wildfire occurrence in the study area. Chapter 5 summarizes the state of our current knowledge about the steelhead (*Oncorhynchus mykiss*) in central and southern California. This fish species is endemic to the study area and is given special attention in this report because it is listed as endangered species under the federal Endangered Species Act.

2.2. Temperature, precipitation, and drought

The study area (see Figure 1.1, chapter 1) encompasses 6 square miles, ranging from an elevation of 482 feet above mean sea level at the confluence of Mission Creek and Rattlesnake Creek to an elevation of 3500 feet at the crest of the watershed. The climate is characterized by a relatively warm season extending from June through September with minimal precipitation, and a wetter, cooler, season extending from October through May. Table 2.1 lists the long-term average monthly precipitation, the average monthly high and the average monthly minimum temperatures in downtown calculated with data from 1970 through 2021 gathered in downtown Santa Barbara.

Table 2.1. Long-term average monthly precipitation, average monthly high temperature, and average minimum temperature downtown Santa Barbara.

	Average	Average	Average
Month	Precipitation	Low	High
	inch	ºF	ºF
Jan	4.36	46	65
Feb	4.55	48	65
Mar	2.92	50	66
Apr	1.24	52	69
May	0.33	55	70
Jun	0.09	58	71
Jul	0.02	60	75
Aug	0.05	60	76
Sep	0.14	60	75
Oct	0.90	56	73
Nov	1.79	50	69
Dec	3.04	47	65

Source: https://www.usclimatedata.com/climate/santa-barbara/california/united-states/usca1017

Atmospheric moisture in the study area derives primarily from cyclonic frontal storms moving eastward over the Pacific Ocean, with minor contributions from Winter (December through March) cold fronts of arctic origin and from subtropical monsoonal storms moving northward from the Gulf of California that occur during the Summer (June through September). Snowfall occurs rarely at the crest of the Mission Creek upper watershed. It amounts to a few inches when it occurs, and its snow water equivalent is negligible. The precipitation regime in the study area exhibits pronounced inter-annual variability, with wet periods interspersed with droughts. Figure 2.1 depicts the annual precipitation for the period 1868-2022, and also shows the average annual precipitation (18.00 inches).

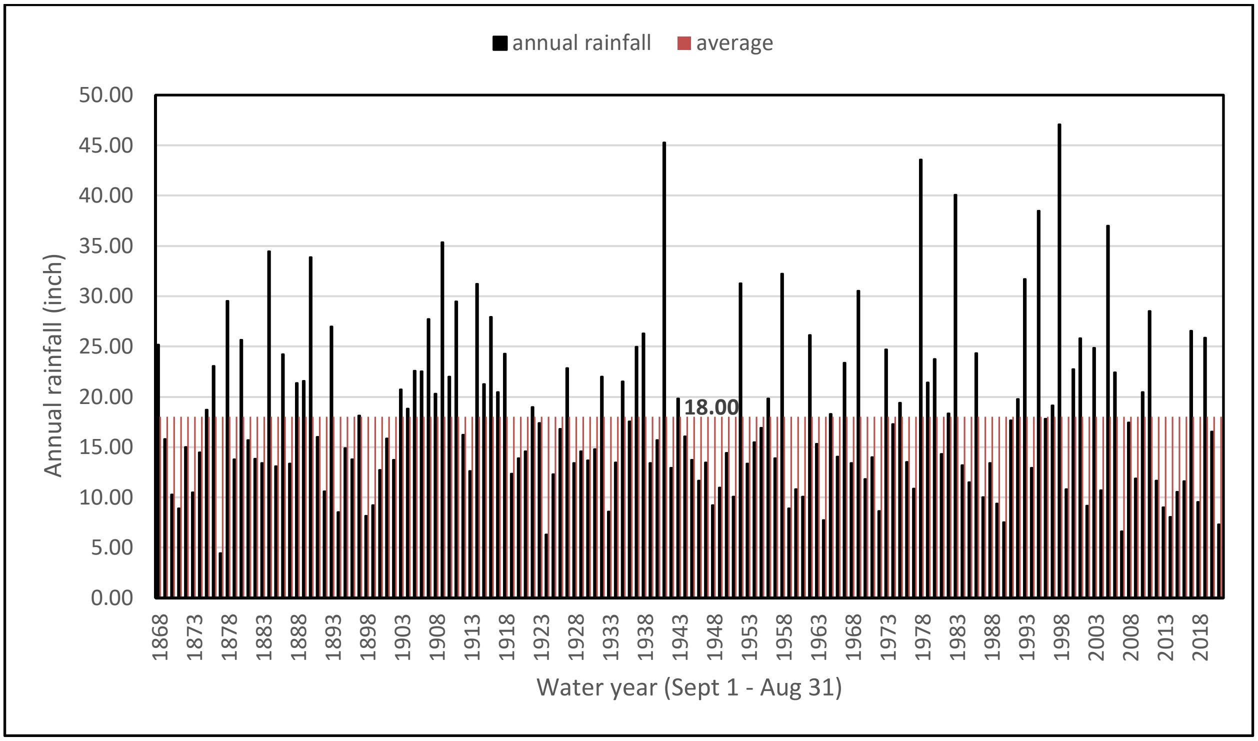


Figure 2.1. Annual precipitation and average annual precipitation in downtown Santa Barbara 1868-2022. Source: County of Santa Barbara.

Loaiciga et al. (1992, 1993) and Loaiciga (2005) defined hydrologic drought as three or more consecutive years of below-average annual precipitation. Drought so defined is a recurrent phenomenon that affects the status of vegetation and hydrologic fluxes (precipitation, streamflow, groundwater flow, evapotranspiration) in the study area. Figure 2.2 shows that there have been fifteen hydrologic droughts in the study area since 1868, ranging in duration from three to eight years.

Table 2.2 lists key variables defining a hydrologic drought, i.e., its duration in years, the interarrival time (the years elapsing between the end of the previous drought and the beginning of the new drought), the magnitude index (i.e., the absolute value of the cumulative deviations of annual precipitation from the average annual precipitation divided by the average annual precipitation), and the severity index, which integrates drought duration, interarrival time, and drought magnitude to measure the relative severity of hydrologic drought. The drought severity index (SI) presented in Table 2.2 is calculated as follows:

$$SI = DI \cdot MI + II \qquad (2.1)$$

in which DI, MI, and II denote respectively the duration index, the magnitude index, and the interarrival time index. The latter three indexes are calculated as follows:

$$DI = \frac{d}{d_{max}} \qquad (2.2)$$

in which d and d_{max} denote respectively the duration of a drought (in years) and the duration of the longest drought in record (8 years in the study area).

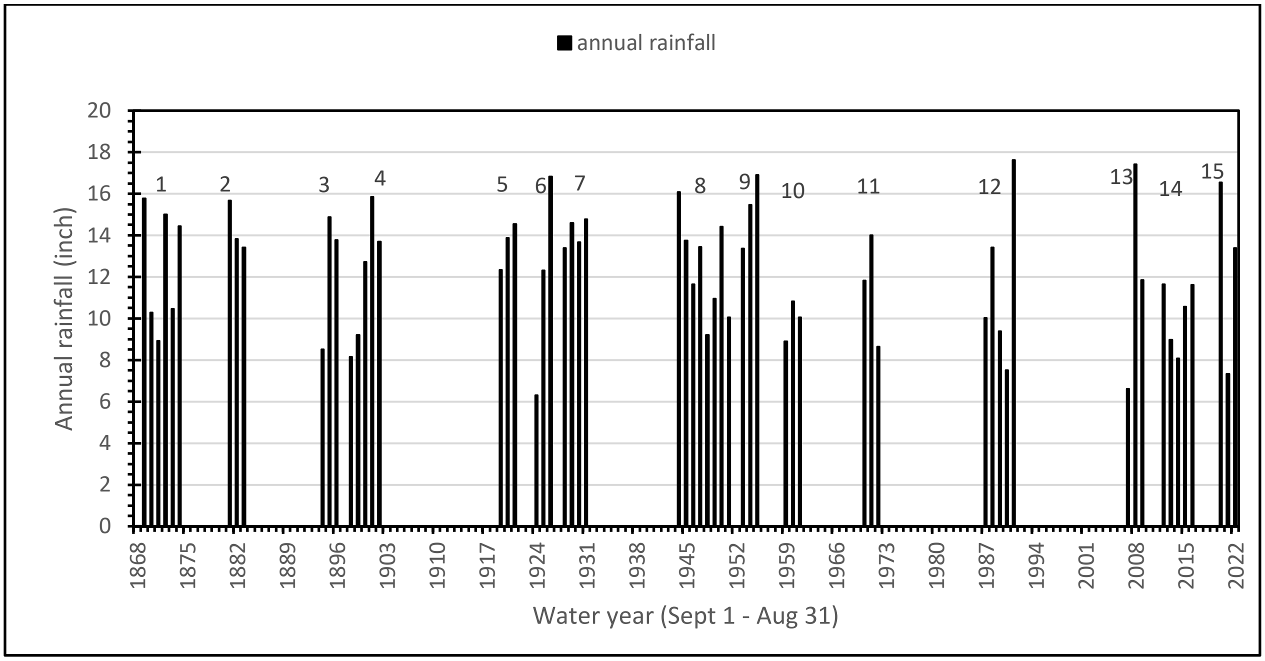


Figure 2.2. Hydrologic droughts in the study area. There have been fifteen droughts since 1868.

Table 2.2. Variables that define the severity of hydrologic drought in the study area. Red-font values denote the three most severe droughts.

drought	period	duration	DI	I	II	MI	SI
		years		years			
1	1869-74	**6**	0.750	**?**		1.84	**N.A.**
2	1881-83	3	0.375	6	0.513	0.62	0.74
3	1894-96	3	0.375	10	0.301	0.94	0.65
4	1898-1902	**5**	0.625	**1**	1.000	1.69	**2.0**
5	1919-21	3	0.375	**16**	0.135	0.74	0.41
6	1924-26	3	0.375	2	0.875	1.03	1.26
7	1928-31	4	0.500	1	1.000	0.87	1.43
8	1944-51	**8**	1.000	12	0.231	2.47	**2.70**
9	1953-55	3	0.375	1	1.000	0.46	1.17
10	1959-61	3	0.375	3	0.766	1.35	1.27
11	1970-71	3	0.375	8	0.393	1.08	0.80
12	1987-91	5	0.625	14	0.177	1.78	1.29
13	2007-09	3	0.375	15	0.155	1.01	0.53
14	2012-16	**5**	0.625	**2**	0.875	2.18	**2.23**
15	2020-22	3	0.375	3	0.766	0.93	1.12
	average	**3.86**	**0.48**	**6.71**	**0.58**	**1.22**	**1.26**

$$MI = \left|\frac{cumulative\ deviation\ from\ the\ mean}{mean\ annual\ rainfall}\right| \tag{2.3}$$

$$II = \left(e^{-\frac{I-I_{min}}{I_{max}-I_{min}}}\right)^2 \tag{2.4}$$

in which I, I_{min}, I_{max} denote respectively the interarrival time (in years) between two consecutive droughts, the minimum interarrival time (1 year), and the maximum interarrival time in record (16 years in this case).

The severity index (SI) shown in Table 2.2 is a relative measure of drought intensity. The most severe drought lasted eight years (the longest in record, 1944-1951), and had a severity index of 2.70. It is noteworthy that the 1944-1951 drought was a major reason leading to the construction of Lake Cachuma to provide multiyear water storage to supply water to the City of Santa Barbara and other communities in Santa Barbara County (Loaiciga, 2002; Hoover, 2020). It is seen in Table 2.2 that the fourteenth drought (2012-2016) with a duration of five years ranks currently as the second most severe in the study area, with a severity index of 2.23. This drought affected most of California and it provided impetus for enacting the California Sustainable Groundwater Management Act (SGMA) in 2015, which was intended to protect overdrafted groundwater basins. Notice that the 2012-2016 drought was preceded by a three-year drought with a short interarrival time of two years. The 2012-2016 drought was followed closely in severity by the 1898-1902 with a severity index equal to 2.05. The fifteenth drought (2020-2022) has a severity index of 1.12.

Another way to represent cycles of wet and dry years is by plotting the cumulative deviation of annual rainfall from the average annual rainfall as a function to time. Figure 2.2 is such a plot for the data displayed in Figure 2.1.

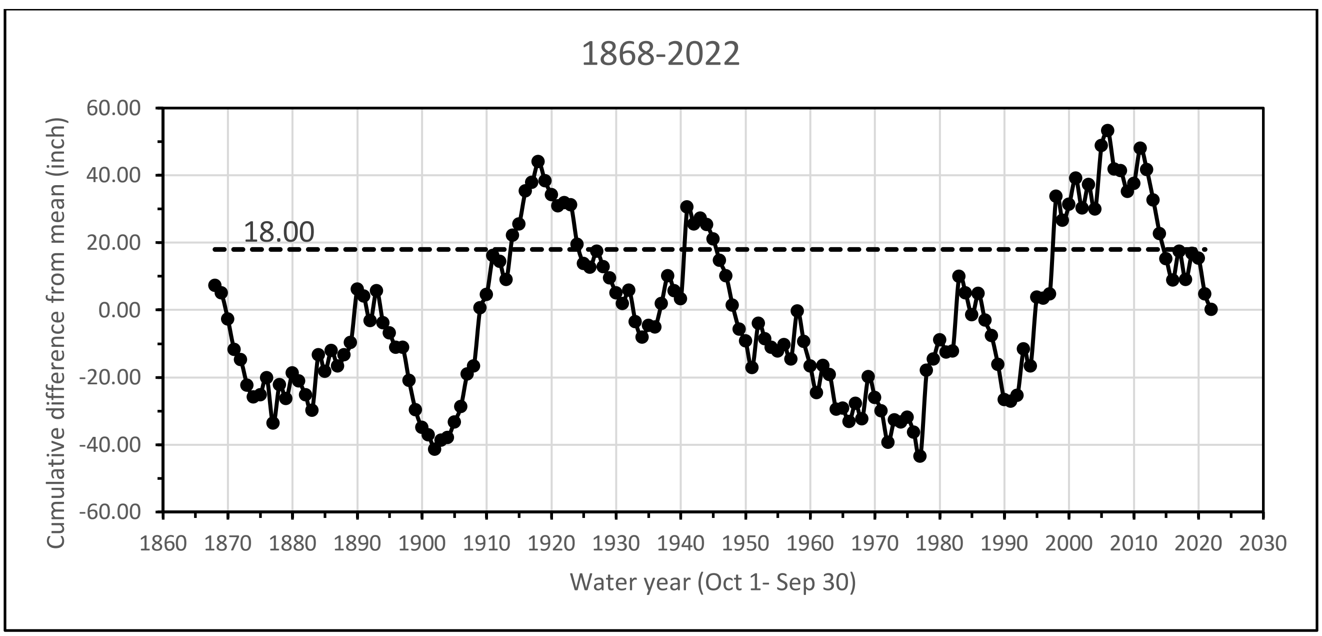


Figure 2.2. Plot of cumulative deviation of annual rainfall from the average annual rainfall for the data plotted in Figure 2.1.

The periods when the cumulative deviation declines (or rises) represent times of increasing dryness (or wetness). This means that 1868-1877, 1893-1902, 1918-1934, 1943-1977, 1983-1991, 2006-present have been periods of increasing dryness. The fauna and flora of the study region, especially the chaparral plant community and the steelhead (*Oncorhynchus mykiss*) are adapted to the climatic regime of the study area. Human disturbance of the hydrologic regime in the study area, however, may lead to significant adverse to habitat for steelhead and other aquatic species, as well as riparian species, and type conversion of native vegetation (e.g., from native chaparral to non-native grasses). Chapter 4 presents a detailed description of the study area's flora and fauna.

Precipitation data were obtained from Santa Barbara County Public Works for the rainfall gage at El Deseo Ranch (see location in Figure 2.6) located at the crest of study area (3500 feet above mean sea level). The El Deseo Ranch precipitation data were extrapolated to 1900 by regression with precipitation measured in downtown Santa Barbara. Figure 2.3 depicts the cumulative deviation of annual precipitation at El Deseo Ranch from the average annual precipitation, the latter equaling 34.38 inch/year, compared with 18.00 inch/year in downtown Santa Barbara. There is evidently a significant rise of precipitation with increasing elevation along the south-facing slope of the Santa Ynez Mountains, where the study area lies.

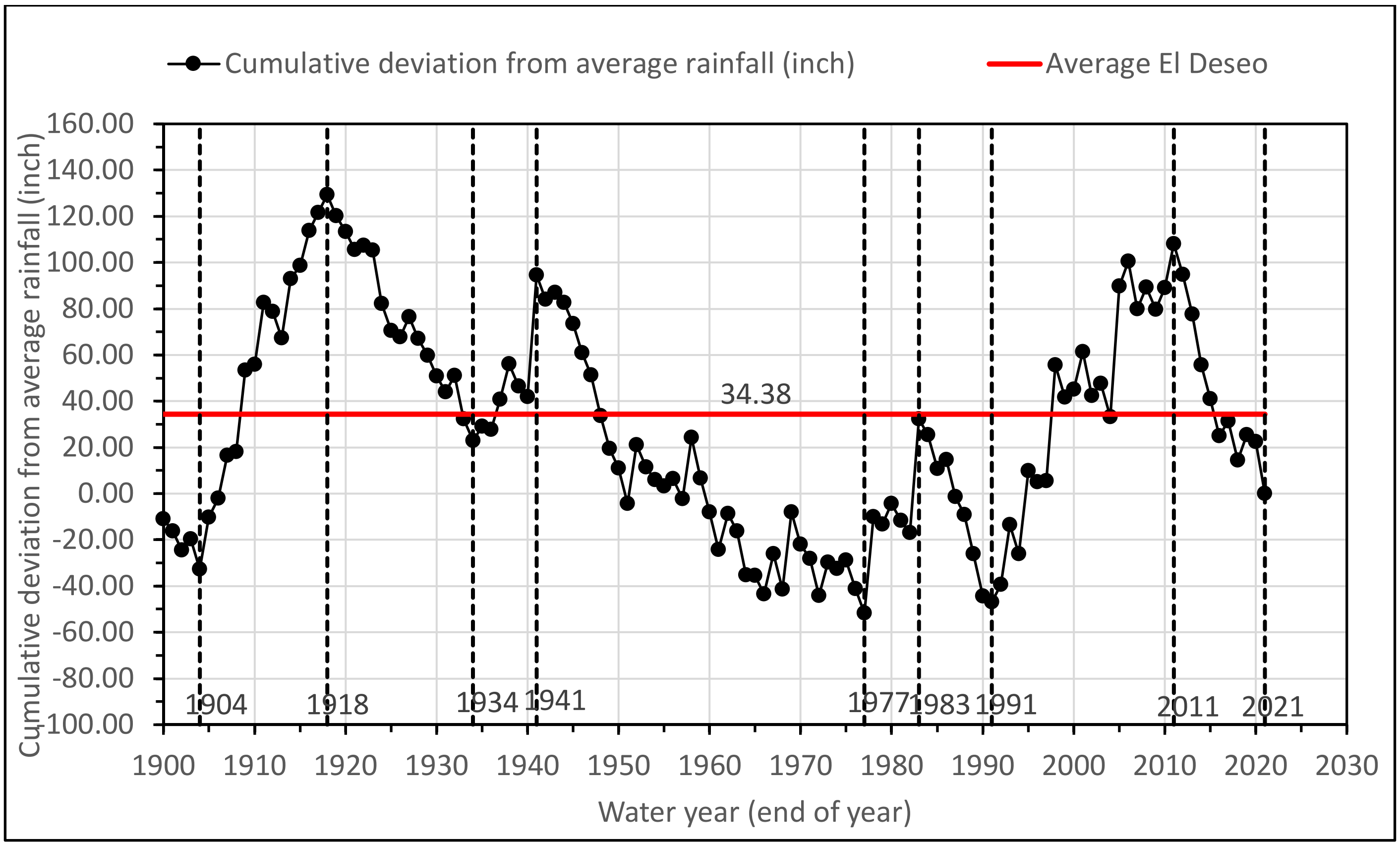


Figure 2.3. The cumulative deviation of annual precipitation from the average annual precipitation at the El Deseo Ranch rain gage.

It is seen in Figure 2.3 that increasing dryness in the study area occurred in the 1918-1934, 1941-1977, 1983-1991, 2011-present, in good agreement with the pattern observed in Figure 2.2 for precipitation in downtown Santa Barbara. Matters are compounded by a long-term declining pattern of precipitation in the study area observed in Figure 2.4. Specifically, the long-term precipitation trend implies a decline of 2.36 inches per 100 years in the study area.

Data from the National Oceanic and Atmospheric Administration (NOAA) provides further evidence that the climatic trend in Santa Barbara County in general, and in the study area in particular, exhibits rising surface air temperature and declining precipitation. Figure 2.5 depicts average temperature, minimum temperature, and maximum temperature for the period 1900-2021 spatially averaged over Santa Barbara County. The century-long rise in minimum, average, and maximum surface air temperature equals 3.2, 3.6, and 3.9 °F, respectively. This means increasing evapotranspiration in the study area, compounded by declining precipitation, thus increasing dryness in the study area and heightened risk of vegetation fire.

Feng et al. (2019) reported climatic projections with ten atmospheric ocean general circulation models for coastal Santa Barbara County. Those authors established 1961-2000 as the baseline period for model calibration, and made climate projections for the periods 2021-2060 and 2061-2100. Their main findings were: (1) reduction of spring and fall precipitation, increase in winter precipitation, very small increase in summer precipitation, (2) shorter rainy season with heavier precipitation (which implies increased potential of debris flows in burned areas), and (3) reduced streamflow in the Spring and Fall, increased streamflow in the Winter, negligible streamflow change in the Summer, with an overall small gain in streamflow annually.

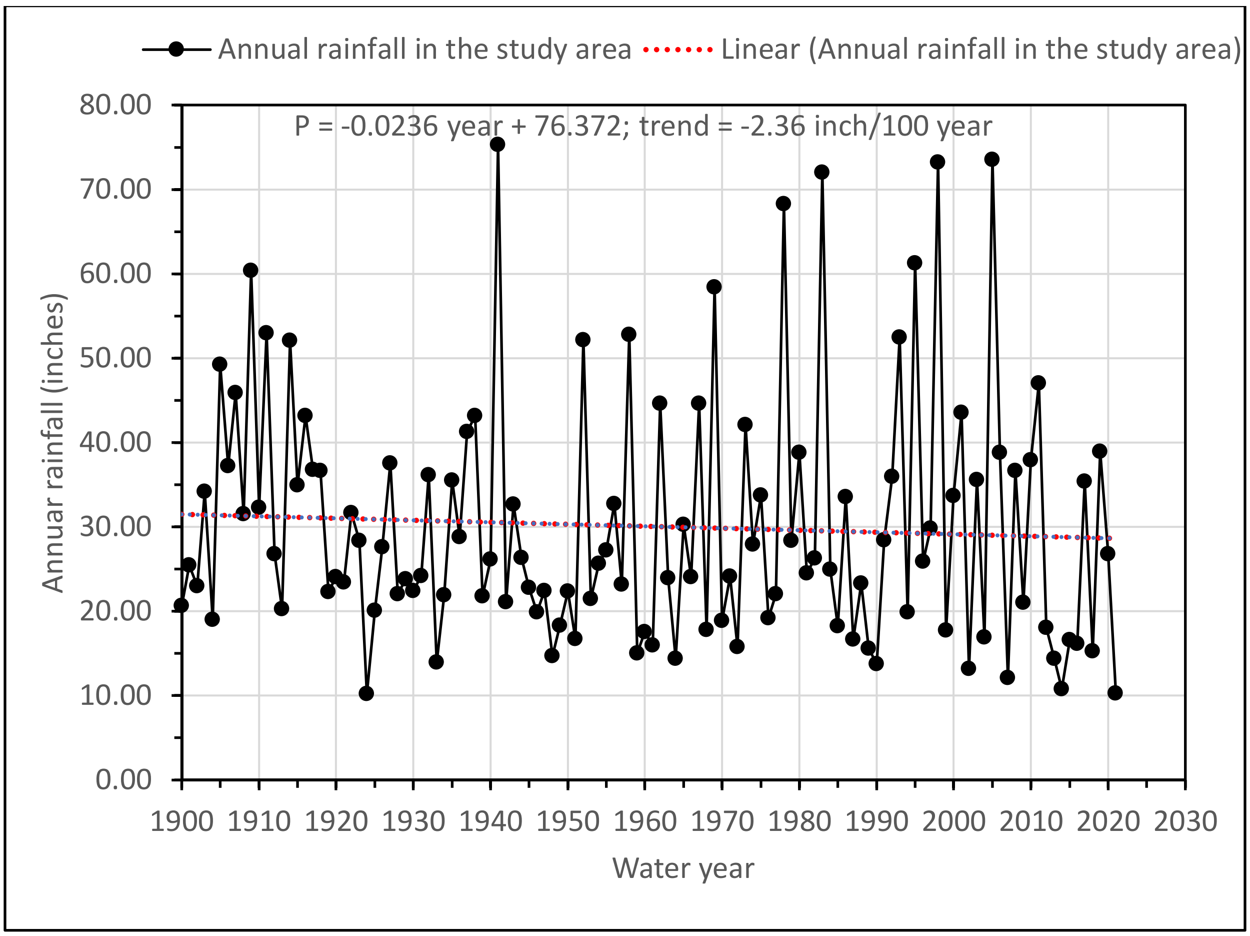


Figure 2.4. Annual rainfall at El Deseo Ranch rain gage and long-term rainfall trend. The trend is statistically significant with a p value < 0.01.

The historic climatic data and model-simulated climate projections indicate challenging times ahead in the study area from the perspective of modification of the hydroclimatic regime and associated impacts on aquatic and riparian habitat, fire, and upland vegetation management.

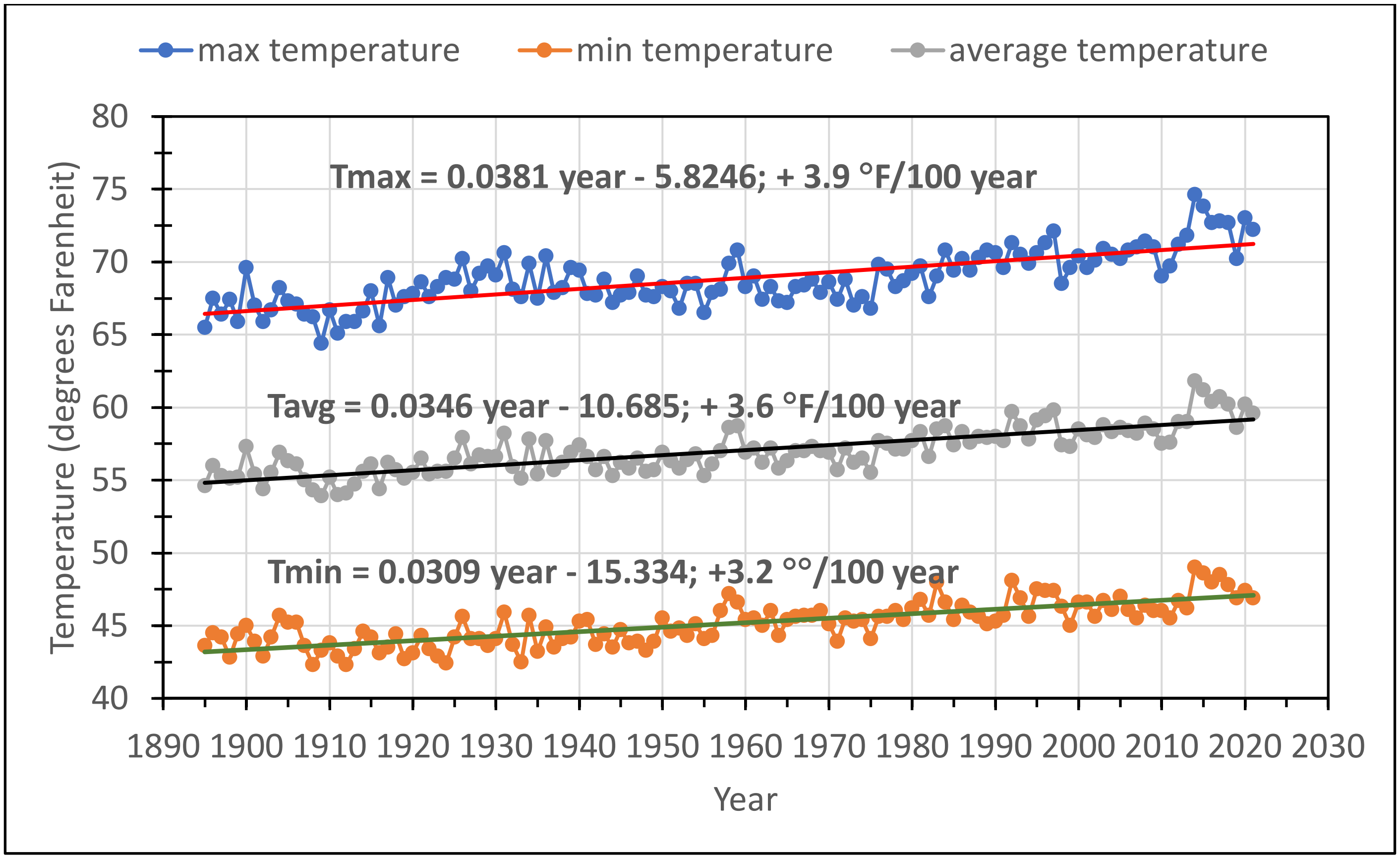


Figure 2.5. Minimum, average, and maximum surface air temperature 1900-2021 (data from NOAA www.ncdc.noaa.gov/cag/county/) and increasing trends for these variables. The values graphed are county-wide spatial averages (Santa Barbara County). The trends are statistically significant with p values < 0.01.

2.3. Land use, vegetation, fire, and soils

Land use and vegetation

Figure 2.6 depicts the land use in the Mission Creek watershed based on the US Geological Survey land-use classification categories. The study area is almost entirely covered by the chaparral plant community. Hardwood trees predominate in the riparian corridors. Homes and other buildings are scattered with low density within the study area. Quinn et al. (2006) defined the chaparral as a vegetation type and the name given to the community of coadapted plants and animals found in the foothills and mountains throughout California. The chaparral vegetation is composed of different species of evergreen drought- and fire-resistant shrubs. The canopy height can range from waist level to 20 feet tall. More than 100 species of evergreen shrubs occur in the chaparral but only a few are common throughout. Chapter 4 presents an in-depth review of the study area's fauna and flora.

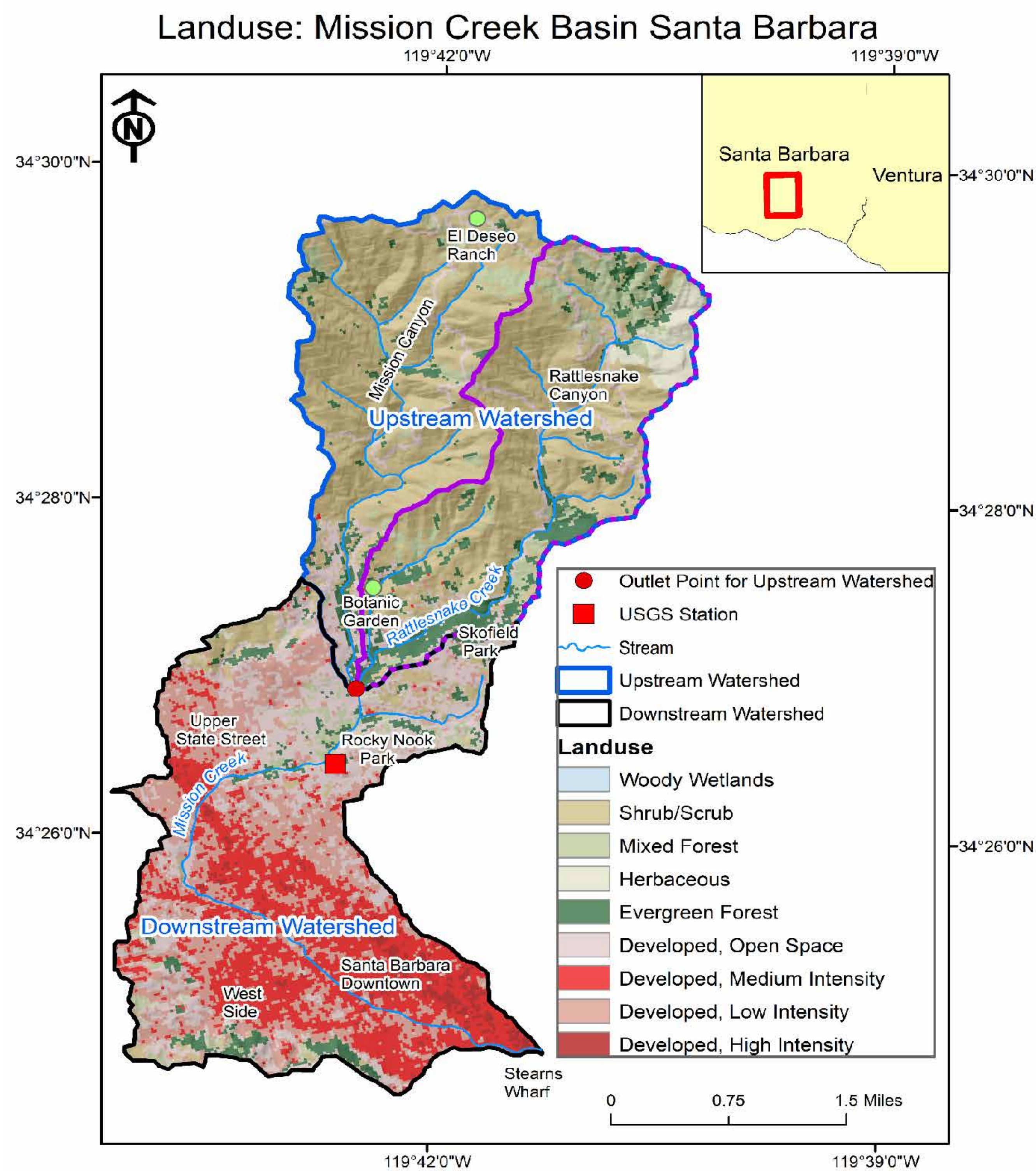


Figure 2.6. Land uses and vegetation types within the Mission Creek watershed and the study area (upstream watershed). The purple line constitutes the boundary between Mission Creek and Rattlesnake Creek.

The most common shrub species in the study area are chamise (*Adenostoma fasciculatum*, in the rose family), toyon (*Heteromeles arbutifoli*a, in the rose family), mountain mahogany (*Cercucarpus betuloides*, in the rose family), ceanothus (Ceanothus spp., more than 40 species in the buckthorn family), California coffeeberry (*Rhamnus californica*, in the buckthorn family), scrub oaks are members of the oak family (genus *Quercus*) that are generally less than 12 feet tall, manzanitas (*Arctostaphylos spp*., in the heath family), laurel sumac (*Malosma laurina*, in the sumac family), lemonadeberry (*Rhus integrifolia*, in the sumac family), sugar bush (*Rhus ovata*, in the sumac family), poison oak (*Toxicodendrum diversilobum*), coyote brush (or chaparral broom, *Baccharis pilularis*) to name some of the common species in the study area. Chaparral shrubs intermingle with other non-chaparral species, such as oak forests, grasslands, and coastal species (e.g., coastal sage scrub).

Common trees in the riparian corridor of the streams in the study area are coast live oak (*Quercus agrifolia*), western sycamore (*Platanus* racemosa), California bay (*Umbellularia californica*), white alder (*Alnus rhombifolia*), and big-leaf maple (*Acer macrophyllum*). Figure 2.7 displays chaparral vegetation along Tunnel Road/trail looking north. Mission Creek is located within its canyon to the right (east) of the road. The US Army Corps of Engineers (1987) reports a list of animals and plants found in the study area.

Figure 2.7. Chaparral vegetation along Tunnel Road/trail, looking north. Coordinates:34°28′07″N; 119°42′27″W.

Figure 2.8 depicts Rattlesnake creek and riparian vegetation.

Figure 2.8. Photo viewing in the upstream direction (north) of Rattlesnake creek and riparian vegetation. Coordinates: 34°27′30″N; 119°41′32″W.

Fire in the chaparral vegetation

Fire is a natural and normal part of the chaparral life cycle. Quinn and Keely (2006) stated that "Fire recycles and rejuvenates, and without fire many of the commonly observed chaparral plants and animals would die". The chaparral vegetation and its botanical ancestors have coexisted with fire for millions of years in California, and where there is chaparral there is fire. The fire cycle consists of the repeated pattern of burning of vegetation followed by renewal and recovery of the chaparral community until the next fire. Chaparral recovery after fire commonly takes five to ten years. Chaparral fires are naturally started by lightning. Most fires today, however, are caused by humans or their infrastructure (e.g., power lines, transformers) (Loaiciga et al., 2001). As the California climate dries chaparral fires are no longer limited to late summer and early autumn when the driest conditions prevail. Chaparral fire currently may occur any time of the year (Touma et al., 2022). The Thomas Fire in Ventura and Santa Barbara County, for instance, started on the evening of December 4, 2017 and burned a total of 281,893 acres; destroying 1,063 structures and resulting in one civilian and one firefighter fatality. In total, the Thomas Fire burned for nearly 40 days, threatening the cities of Santa Paula, Ventura, Ojai, Fillmore, and unincorporated communities, before moving into Santa Barbara County where it encircled Montecito. The Thomas Fire burned for nearly 40 days before it was 100 percent contained by January 12, 2018.

The Jesusita Fire started on May 5, 2009, in the hills the Santa Ynez Mountains bordering the City of Santa Barbara. It was contained on May 18. The fire burned 8,733 acres, destroyed 80 homes and damaged 15 more. Almost the entire study area was burned by the Jesusita fire. The fire was ignited by sparks from a domestic weed trimmer. The chaparral has recovered substantially in the intervening thirteen years (McMahon et al., 2023). Figure 2.9 depicts the burn scar caused by the Jesusita Fire.

The hydrophobic conditions created in burned soils may trigger debris flows in sloping terrain whenever intense rainfall falls in the burned areas (DeBano, 2000). A case in point are the debris flows that occurred on January 9, 2018, in Montecito, California, when more than one half-inch of rain fell in about 15 minutes over the area previously burned by the Thomas Fire triggering a large debris flow. The debris flow resulted in twenty-three fatalities, damaged or destroyed over 500 homes, damaged infrastructure, closed Highway 101 for thirteen days, and caused one billion dollars in economic losses (County of Santa Barbara OEM, 2018; Niehaus, 2018, 2019; Lancaster et al., 2021; Kean et al., 2019; Keller et al. 2019, 2020; Gurrola and Rogers, 2022).

The inevitable fire hazard and human intervention aimed at preventing catastrophic wildfire in the urban-wildland zone must be carefully considered in the management of the study area. To these concerns one must add the need to preserve the streams of the study areas as viable habitat for the endangered steelhead and other aquatic species. Chapters 3, 4, 5, 6, and 7 expand on the matter of human impacts in the study area and recommended measures to protect it. Chapter 4 reviews the relationship between wildfire and the biological resources in the study area.

Soils

Figure 2.10 depicts a soils map for the study region. Notice that the study area is underlain predominantly by inceptisols, followed in abundance by mollisols and vertisols. Inceptisols are one of the twelve soil orders in the United States Department of Agriculture (USDA) soil taxonomy. Inceptisols are soils of relatively new origin and are characterized by having only the weakest appearance of horizons, or layers, produced by soil-forming factors. They are the most abundant on Earth, occupying almost 22 % of all the nonpolar continental land area. Inceptisols in the study area result from in-situ weathering of rock whose fragments are not subsequently transported. Therefore, they are also known as residual soils (Holtz et al., 2011). Mollisols (from Latin mollis "soft") are characterized by a thick, dark surface horizon. This fertile surface horizon, known as a mollic epipedon, results from the long-term addition of organic materials derived from the chaparral roots. Mollisols are formed where the slope permits transport and accumulation of weathered material. Vertisols are clayey soils that have deep, wide cracks for some time during the year. They shrink as they dry and swell as they become moist. The formation of mollisols is influenced by the presence of the chaparral vegetation and sediment accumulation in areas of gentle slope. The reader is referred to the US Department of Agriculture's (USDA) for a thorough descriptions of soil taxa (USDA, 1999). See chapter 4 for further details about the soils of the study area.

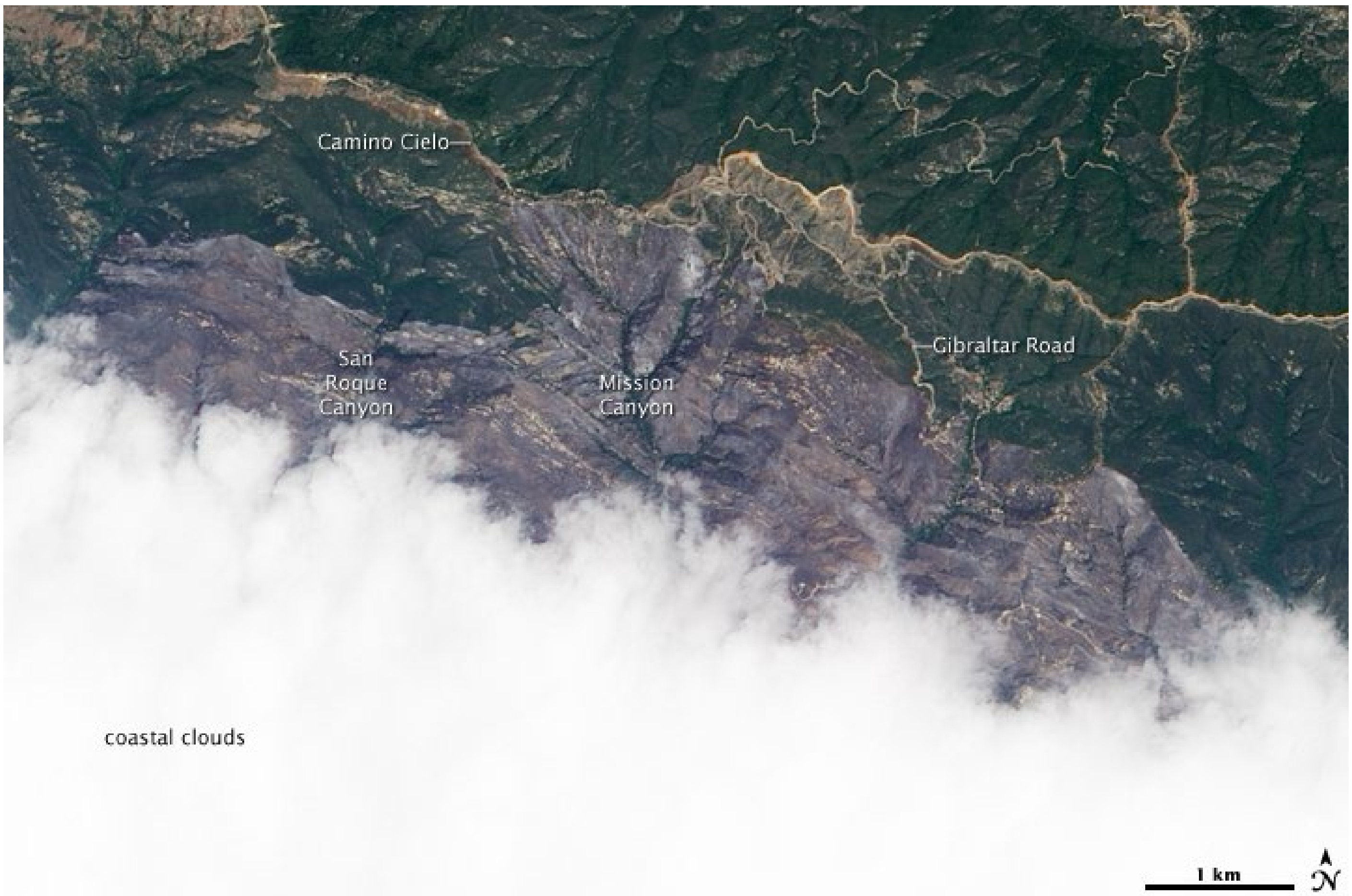


Figure 2.9. The burn scar caused by the Jesusita Fire (May 5-18, 2009) which burned almost the entire study area. The chaparral vegetation has nearly fully recovered. Earth Observing-1 (EO-1) satellite image.

2.4. Streamflow and flood frequency

Water that falls as precipitation within the study area is partitioned as follows. (1) Some of it infiltrates or is intercepted by vegetation. The intercepted water evaporates after rainfall. A portion of the infiltrated water is absorbed by plants to build new tissue and some of it is transpired through stems and leaves and evaporated. The reminder of the infiltrated is added to soil moisture storage, and, except in very wet years, it evaporates, or the infiltrated water moves deeper into the soil (deep infiltration or recharge) and becomes groundwater and flows to support streamflow or either leaves the study area by gravitational subsurface flow or it is added to groundwater storage. Over an annual water cycle there is no increase in soil moisture or groundwater storage except in very wet years. (2) Some of the water reaches the channels of Rattlesnake Creek and Mission Creek and flows out the study area through its basin outlet located at the confluence of Mission Creek and Rattlesnake Creek. Some of the streamflow evaporates as it flows towards the outlet, and some is absorbed by riparian vegetation, thus diminishing the streamflow leaving the study area. The total water evaporated (intercepted water, evaporated soil water, evaporated groundwater, streamflow evaporation, and transpiration) is called evapotranspiration. Section 2.5 ***Water balance in the study area*** provides details of the annual water balance in the study area.

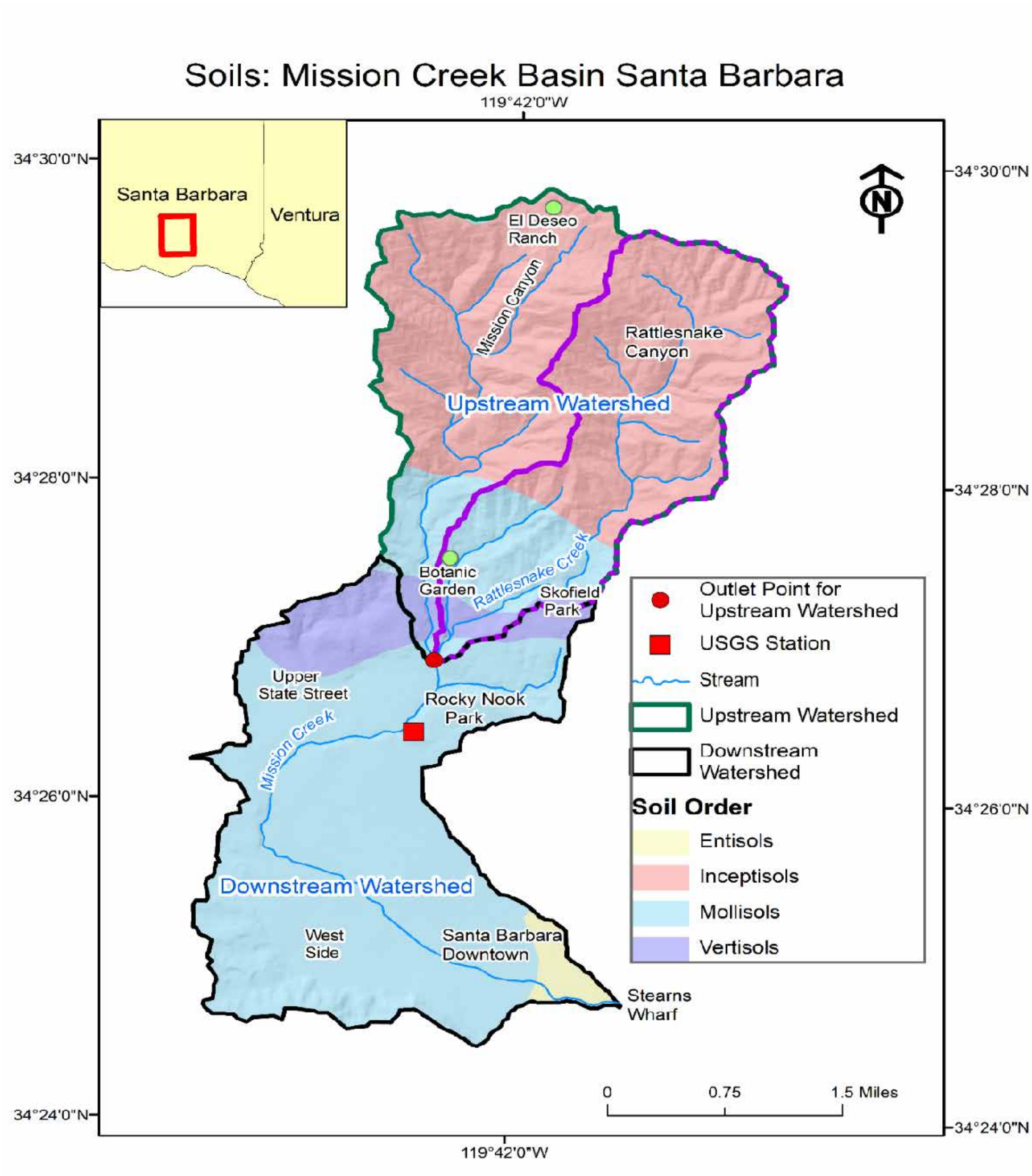


Figure 2.10. Soils map for Mission Creek and the study area (upstream watershed). Sources: USDA soil maps.

Streamflow in Mission Creek is measured at the US Geological Survey (USGS) stream gaging station located on Mission Creek at Rocky Nook Park. The stream gage location is shown in Figures 2.6 and 2.10. Figure 2.11 displays a photo of the of control box for the USGS stream-gaging station, which is located upstream and adjacent to the stone bridge where Mission Creek flows under Mission Road near the Santa Barbara Mission. This station has been operational since 1983 with some interruptions. Its operation is funded by the USGS and the City of Santa Barbara through a matching-funds agreement.

Figure 2.11. The control box for the USGS stream-gaging station # 11119745 at Rocky Nook Park. Paige Tripp poses for scale. The stone bridge on Mission Road over Mission Creek is seen in the background.

Flow measurements at Rocky Nook Park were transformed to flow values at the confluence of Mission Creek and Rattlesnake Creek by the ratio of drainage areas corresponding to each of these two locations. Table 2.3 lists the pertinent drainage areas used in this study.

Table 2.3. Areas for various basins.

	Basin name			
	Upper Mission Creek watershed	Rattlesnake Creek watershed	Study area= total upstream watershed	Upstream Rocky Nook USGS station
Area of basin	(1)	(2)	(3) = (1) + (2)	(4)
Area (acres)	1824	2016	3840	4224
Area (sq. mile)	2.85	3.15	6.00	6.60

Figure 2.12 displays the average monthly streamflow in the total upper watershed (the study area), Upper Mission Creek watershed, and Rattlesnake Creek watershed. The study area's flows were calculated from the measured flows at the Rocky Nook gaging station as follows:

$$Q_{SA} = Q_{RN} \frac{A_{SA}}{A_{RN}} \quad (2.5)$$

in which A_{SA}, A_{RN}, Q_{RN}, and Q_{SA} denote the area of the total upper watershed (the study area, 6.0 sq. miles), the drainage area upstream of the Rocky Nook Park stream-gaging station (6.6 sq. miles), streamflow measured at the Rocky Nook stream gaging station, and the calculated streamflow at the confluence of Upper Mission Creek and Rattlesnake Creek (the total upper watershed).

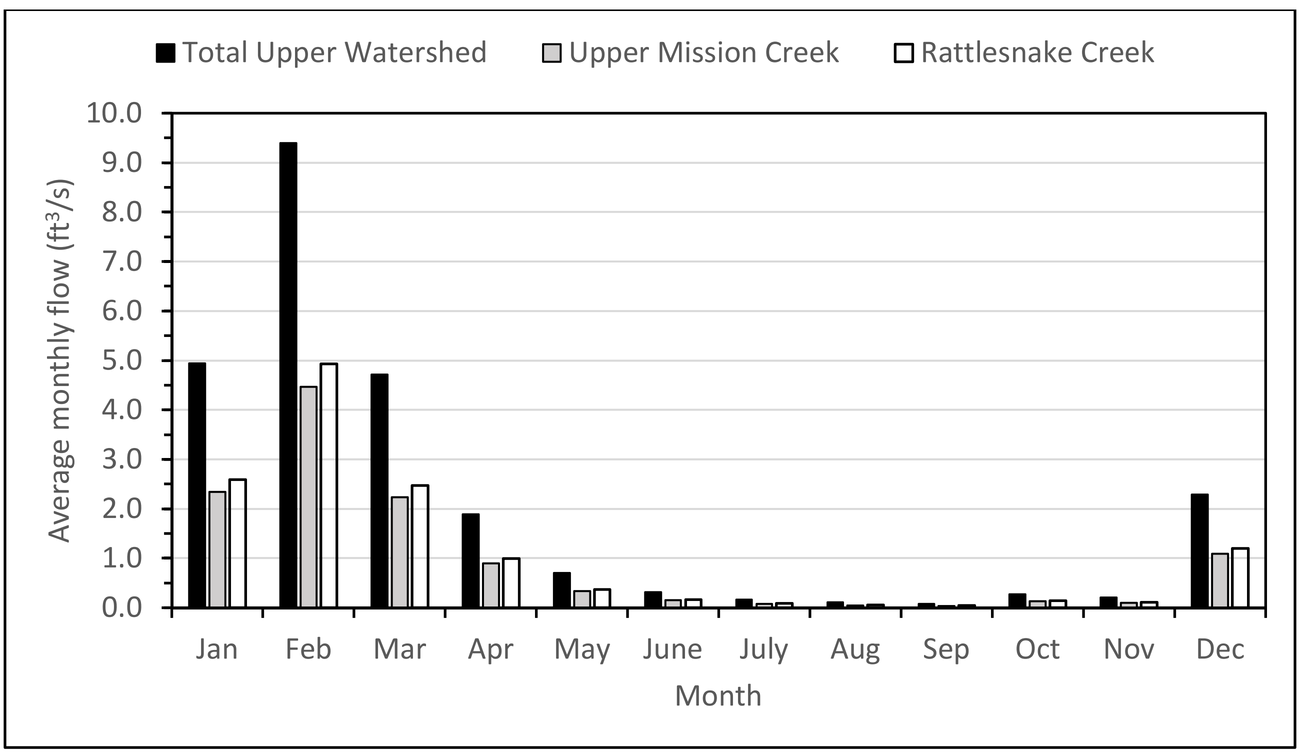


Figure 2.12. Average monthly streamflow at the confluence of the Upper Mission and Rattlesnake creeks' confluence and corresponding to the total upper watershed, Upper Mission Creek, and Rattlesnake Creek.

The scaling formula (2.5) is based on the fact that the drainage areas upstream of the Rocky Nook stream gaging station and the confluence of Upper Mission Creek and Rattlesnake Creek share nearly identical precipitation, land use, soils, and geologic features. The average monthly streamflow in Rattlesnake Creek (Q_{RSC}) and Upper Mission Creek (Q_{UMC}) at their confluence was calculated from their combined streamflow (Q_{SA}) in proportion to the ratio of each basin's area to the combined area of the two basins (A_{SA}):

$$Q_{RSC} = Q_{SA} \frac{A_{RSC}}{A_{SA}} \tag{2.6}$$

$$Q_{UMC} = Q_{SA} \frac{A_{UMC}}{A_{SA}} \tag{2.7}$$

in which A_{RSC} and A_{UMC} denote respectively the areas of Rattlesnake Creek watershed (3.15 sq. miles) and Upper Mission Creek watershed (2.85 sq. miles) (see Table 2.3), and all other variable have been previously defined. The monthly variation of streamflow in the various watersheds herein studied is useful because the steelhead migrate and spawn in the study area's streams during specific seasons of the year. It is shown in Chapter 6 that the average monthly streamflows graphed in Figure 2.12 are lower than what they would be because of streamflow depletion by the Mission Tunnel.

Monthly variation in streamflow affects steelhead populations, because anadromous steelhead migrate upstream and spawn in the study area's streams in winter through early spring (Dec. through April), juvenile steelhead (smolts) usually migrate to the ocean in March and April, and resident fish and steelhead in stream pools that are one to two years old migrate to the ocean over summer. In addition, stream invertebrates show seasonal and interannual differences in species composition and abundance, with mayfly, stonefly, and caddisfly taxa being more abundant during wet periods or in more perennial water, and fly, beetle, true bug, and dragonfly/damselfly larvae predominating in drier conditions.

Flood frequency

Flood-frequency analysis is performed to calculate the peak annual streamflows associated with specific return intervals (Loaiciga and Marino, 1991). For instance, the 100-year peak annual streamflow is such that over a long period to time (i.e., hundreds of years) it would occur on average every 100 years. Similar definitions hold for other commonly used return intervals (e.g., 2, 5, 10, 25, and 50 years). A time series of peak annual streamflow contains chronologically ordered values of the peak streamflow observed every year forming the time series. Peak annual streamflows corresponding to the period 1983-2021 at the Rocky Nook stream-gaging station were downloaded from the web-based USGS National Water Information System. The flood-frequency curve relating return interval to peak annual streamflow at the Rocky Nook stream gaging station was calculated via regression analysis. The flood-frequency curve is depicted in Figure 2.13. The peak-annual values in Figure 2.13 reach an upper threshold for return periods of 25 years or longer, an anomalous circumstance. The flood-frequency curve at the same location was calculated using a method reported in the USGS Water Resources Investigations (WRI) 77-21 (Waananen and Crippen, 1977) and is also shown in Figure 2.13. The WRI 77-21 method calculates the peak annual streamflow corresponding to a return interval (RI) based on regression functions in terms of the drainage area (A, in sq. miles) and average annual precipitation (P, in inches). The regression functions vary across regions of California. The ones applied in this work correspond to the South Coast Region as mapped by Waananen and Crippen (1977). The formula for the peak annual streamflow corresponding to a specific regression interval (Q_{RI}, in ft^3/s) is given in generic form as follows:

$$Q_{RI} = a_{RI} \cdot A^{b_{RI}} \cdot P^{c_{RI}} \quad (2.8)$$

in which a_{RI}, b_{RI}, and c_{RI} denote regression coefficients (Waananen and Crippen, 1977). The coefficients are listed in Table 2.4. The drainage or basin area A that appears in equation (2.8) is that corresponding to the drainage area upstream of the Rocky Nook stream-gaging station (=6.60 sq. miles), and P equals the average annual precipitation associated with the 6.60 sq. mile drainage area (P= 28.00 inches). The formulas presented by Waananen and Crippen (1977) apply to return intervals RI= 2, 5, 10, 25, 50, and 100 years.

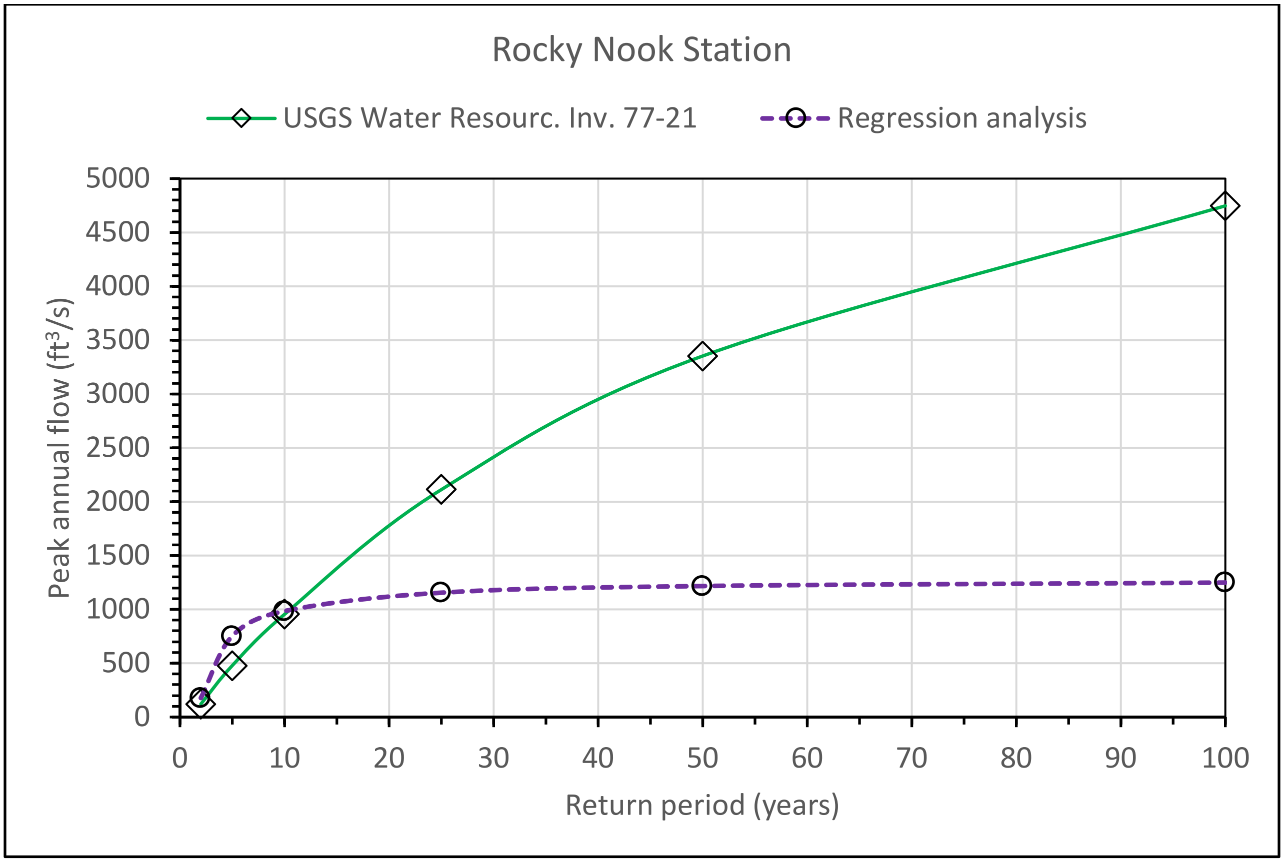


Figure 2.13. Flood-frequency curves at the Rocky Nook stream-gaging station calculated with the USGS Water-Resources Investigations 77-21 method and by regression analysis performed on the time series of peak annual streamflow measured at the Rocky Nook stream-gaging station. The peak annual flows represent values of short duration (typically less than 10 minutes) at the stream-gaging station.

Table 2.4. Coefficients applied in equation (2.8) (from Waananen and Crippen (1977)).

	Return interval (years)					
Coefficients	**2**	**5**	**10**	**25**	**50**	**10**
a_{RI}	0.14	0.40	0.63	1.10	1.50	1.95
b_{RI}	0.72	0.77	0.79	0.81	0.82	0.83
c_{RI}	1.62	1.69	1.75	1.81	1.85	1.87

There is a remarkable difference between the peak annual streamflows for return intervals estimated by regression analysis of the historic peak annual streamflow measured at the USGS stream-gaging station and those estimated with the WRI 77-21 method. It is natural for the peak annual streamflow to increase with increasing return interval as is the case with the WRI 77-21 estimates depicted in Figure 2.13. The estimated flood frequency curve based on the peak annual streamflow measured at the USGS stream-gaging station reaches a maximum of 1248 ft^3/s for the 100-year interval, not much different from the 25-year and 50-year values of 1154 ft^3/s and 1216 ft^3/s, respectively. We attribute this anomalously low rise of the peak annual streamflow with increasing return interval to the capture of baseflow by the Mission Tunnel that would otherwise would become streamflow. This assertion is supported with evidence presented in Chapter 6. This evidence indicates that during wet periods such as those associated with relative long return intervals (i.e., equal to or longer than 25 years) a substantial portion of the rainfall recharges to groundwater and it is captured by Mission Tunnel.

Figure 2.14 displays the estimated flood-frequency curves estimated with the WRI 77-21 method and by regression analysis of the peak annual streamflows measured at the USGS stream-gaging station. In this instance the flood-frequency curves correspond to the confluence of Mission Creek and Rattlesnake Creek. The anomalous pattern of low increase of the peak annual streamflow with increasing return interval observed for the regression analysis of peak annual streamflow at the USGS stream-gaging station is similar to that present in Figure 2.13, and the cause of the anomaly is identical in both cases.

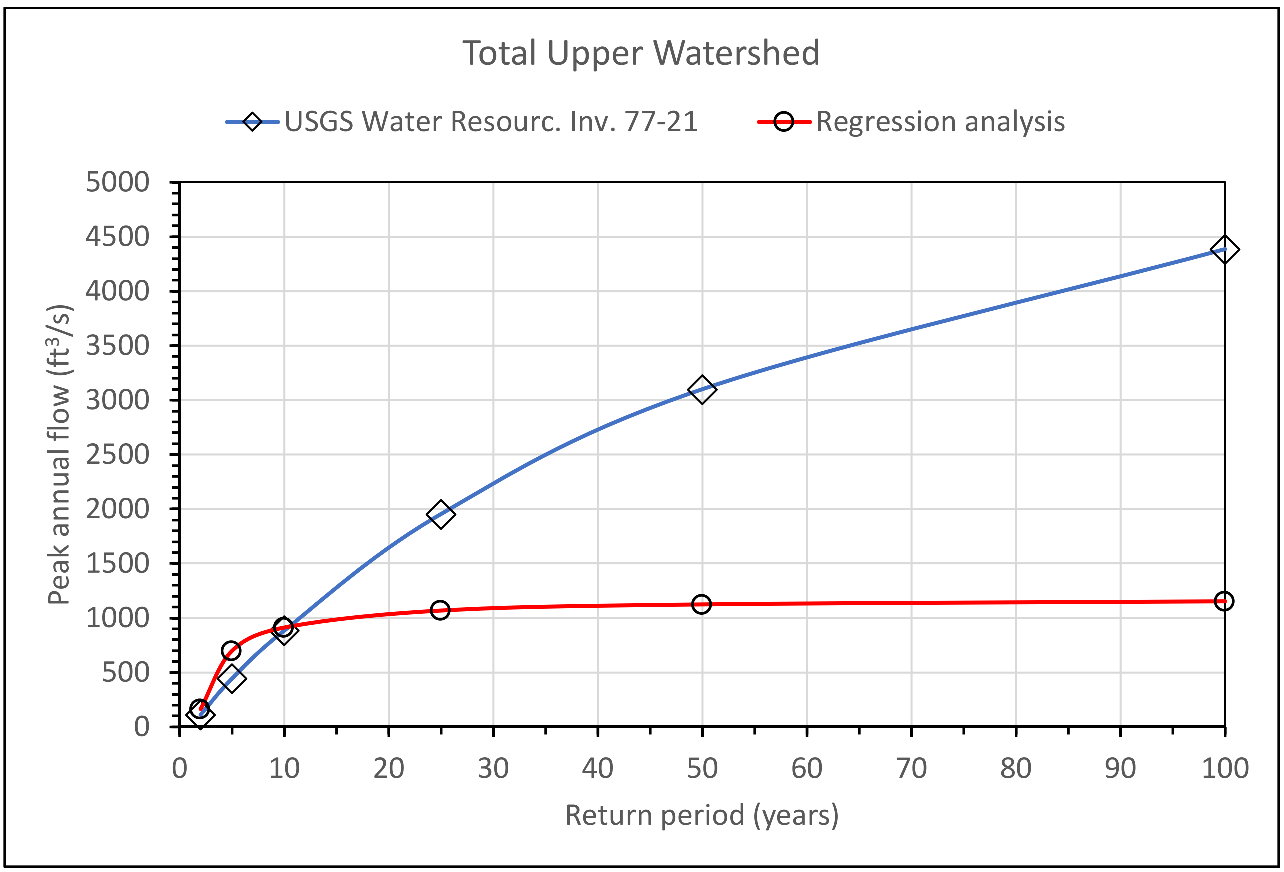


Figure 2.14. Flood-frequency curves at the confluence of Rattlesnake Creek and Mission Creek calculated with the USGS Water-Resources Investigations 77-21 method and by regression analysis performed on the

time series of peak annual streamflow measured at the Rocky Nook stream-gaging station. The peak annual flows represent values of short duration (typically less than 10 minutes) at the stream-gaging station.

The WRI 77-21 flood-frequency curve displayed in Figure 2.14 was calculated with the following formula:

$$Q_{RI} = a_{RI} \cdot A^{b_{RI}} \cdot \ P^{c_{RI}} \qquad (2.9)$$

in which a_{RI}, b_{RI}, and c_{RI} denote regression coefficients (Waananen and Crippen, 1977) (see Table 2.4 above). The drainage or basin area A that appears in equation (2.9) is that corresponding to the drainage area upstream of confluence of Mission Creek and Rattlesnake Creek (=6.00 sq. miles), and P equals the average annual precipitation associated with the 6.00 sq. mile drainage area (P= 28.00 inches). The formulas presented by Waananen and Crippen (1977) apply to return intervals RI= 2, 5, 10, 25, 50, and 100 years. The flood-frequency curve in Figure 2.14 developed by regression analysis of the peak annual streamflows measured was obtained as follows (Waananen and Crippen, 1977):

$$Q_{SA} = Q_{RN}\left(\frac{A_{SA}}{A_{RN}}\right)^{b_{RI}} \qquad (2.10)$$

in which A_{RN}, A_{SA}, b_{RI}, Q_{RN}, Q_{SA} denote respectively the drainage area upstream of Rocky Nook Park (=6.6 sq. miles), the drainage area of the study area (=6.0 sq. miles), the exponent of the drainage area in equations (2.8) and (2.9) (see Table 2.4), the peak annual flow at Rocky Nook Park stream-gaging station, and the peak annual flow at the confluence of Mission and Rattlesnake creeks.

Table 2.5 lists the estimated peak annual streamflows shown in Figures 2.13 and 2.14. Recall that the streamflows corresponding to the drainage areas equal to 6.0 and 6.6 sq. miles are associated respectively with streamflow at the confluence of Mission and Rattlesnake creeks and at the USGS stream-gaging station.

Table 2.5. Peak annual streamflow estimated at Rocky Nook Park (6.6 sq. miles) and at the confluence of Mission and Rattlesnake creeks (6.0 sq. miles).

	Area = 6.6 squared miles		Area = 6.0 squared miles	
	Peak flow	Peak flow	Peak flow	Peak flow
Return interval	WRI 77-21	historic regression	WRI 77-21	historic regression
RI years	ft^3/s	ft^3/s	ft^3/s	ft^3/s
2	120	177	112	165
5	477	751	444	698
10	953	984	884	913
25	2111	1154	1955	1069
50	3352	1216	3100	1125
100	4747	1248	4386	1153

2.5. Water balance in the study area

An algorithm was developed as part of this work to calculate the annual water balance in the study area. Precipitation, soil moisture, and evapotranspiration are the controlling variables of the water balance in the study area. The average total depth of the soil column in the study area was determined by field observations to be six feet (72 inches), with a porosity of 50%, which means the column of void or pore space equals 36 inches. These observations have been made in soils exposed along road cuts and trails in the study area dating back to 1989. Soil moisture has two other thresholds of central importance: the field capacity (f_C) and the residual capacity (f_R). The field capacity is the water content at which gravitational drainage within the soil becomes negligible (Veihmeyer and Hendrickson, 1949; Hillel, 1982; Dingman, 2015). The soil capacity of the soils in the study area was estimated from field observations to be 30%, or equivalent to 24 inches of pore water. The residual soil moisture (f_R) in the study area equals 3 inches, so that plants do not absorb water from the soil when the soil moisture is equal to or less than 3 inches. The minimum soil moisture equals the residual capacity. As long as the precipitation (P) plus the initial moisture (M) in any year is less than the porosity (36 inches) $P + M$ generates streamflow (Q) according to the following expression:

$$Q = \begin{cases} P + M - f_C \; if \; P + M > f_C \\ 0 \quad otherwise \end{cases} \tag{2.11}$$

Notice that the annual streamflow (Q) generated within the study area is partly composed of baseflow (B).

The actual annual evapotranspiration (ET_A) depends on (i) the annual available water once streamflow is deducted from it and (ii) the annual evaporative capacity (ET_C) in the study area. The annual evaporative capacity is a function of the annual reference evapotranspiration (ET_0) and soil moisture. The reference evapotranspiration is the depth of water evaporated from the chaparral vegetation when soil moisture is not limiting. It was herein calculated with the Hargreaves and Samani (1985) formula, which is based on air temperature, solar radiation, and the latitude of the site where the reference evapotranspiration is calculated (Task Committee on Revision of Manual 70, 2016). Specifically, the reference evapotranspiration in the J-th day of the year (ET_{0J}) (J=1 means January 1st, J= 365 or 366 means December 31st) expressed in mm/day is given by the following expression:

$$ET_{0J} \left[in \frac{mm}{day}\right] = 0.0023 \cdot R_{AJ} \cdot \sqrt{TD_J} \cdot \left(T_J + 17.8\right) \tag{2.12}$$

in which R_{AJ}, TD_J, T_J denote respectively the average daily radiation at the top of the atmosphere in the J-th day J of the year expressed in equivalent evaporation units (mm/day), the average air temperature in the J-th day of the year (°C), and the difference between the average maximum and average minimum temperature in the J-th day of the year (°C). The annual reference evapotranspiration (ET_0) is calculated by summing the daily reference evapotranspirations. It is then converted from mm/year to inches/year. The annual evaporative capacity evapotranspiration (ET_C) is calculated by multiplying ET_0 by a coefficient (k_s) that reflects soil moisture conditions:

$$ET_C = k_s \cdot ET_0 \tag{2.13}$$

The coefficient k_s depends on the annual available water, on the field capacity, and on the residual soil moisture (f_R) as described by the following formula:

$$k_s = \begin{cases} 0 \;\; if \; P + M < f_R \; inches \\ \frac{P+M-f_R}{f_C-f_R} \;\; if \; f_R \le P + M < f_C \\ 1 \quad if \; P + M \ge f_C \end{cases} \tag{2.14}$$

The actual annual evapotranspiration is calculated as follows:

$$ET_A = smaller\ of\ [P + M - Q - f_R; ET_C] \quad (2.15)$$

The water balance presented in this chapter assumes that evapotranspiration occurs after streamflow (Q) is realized. The actual annual evapotranspiration was calculated for the water years 1899-1900 through 2020-2021. Figure 2.15 depicts the calculated actual annual evapotranspiration. The average actual annual evapotranspiration in the study in the period 1899-1900 through 2020-2021 equals 19.7 inches, which is within the range of ET_A calculated by Crippen (1965) in watersheds of the Transverse and Peninsular ranges of California. The maximum ET_A equals 21 inches per year, which is the difference between the field capacity (24 inches) and the residual capacity (3 inches). The calculation of the actual annual evapotranspiration with equation (2.15) assumes that there is no change in the storage of subsurface water over an annual water cycle. Therefore, it represents conditions that would prevail if there is no diversion of subsurface water from the subsurface (Miller and Rapp, 1968).

When $P + M$ exceeds the porosity (36 inches) there is streamflow (Q) draining the study area plus subsurface runoff (Y), the latter leaving the study area bypassing the stream network through the subsurface (Muir, 1968; Freckleton et al., 1998). The subsurface runoff is generated from groundwater storage. In this case:

$$Q + Y = \begin{cases} P + M - f_C\ if\ P + M > f_C \\ 0 \quad otherwise \end{cases} \quad (2.16)$$

The actual annual evapotranspiration is calculated according to equation (2.15) thus implying natural flow conditions without the withdrawal of groundwater by the Mission Tunnel.

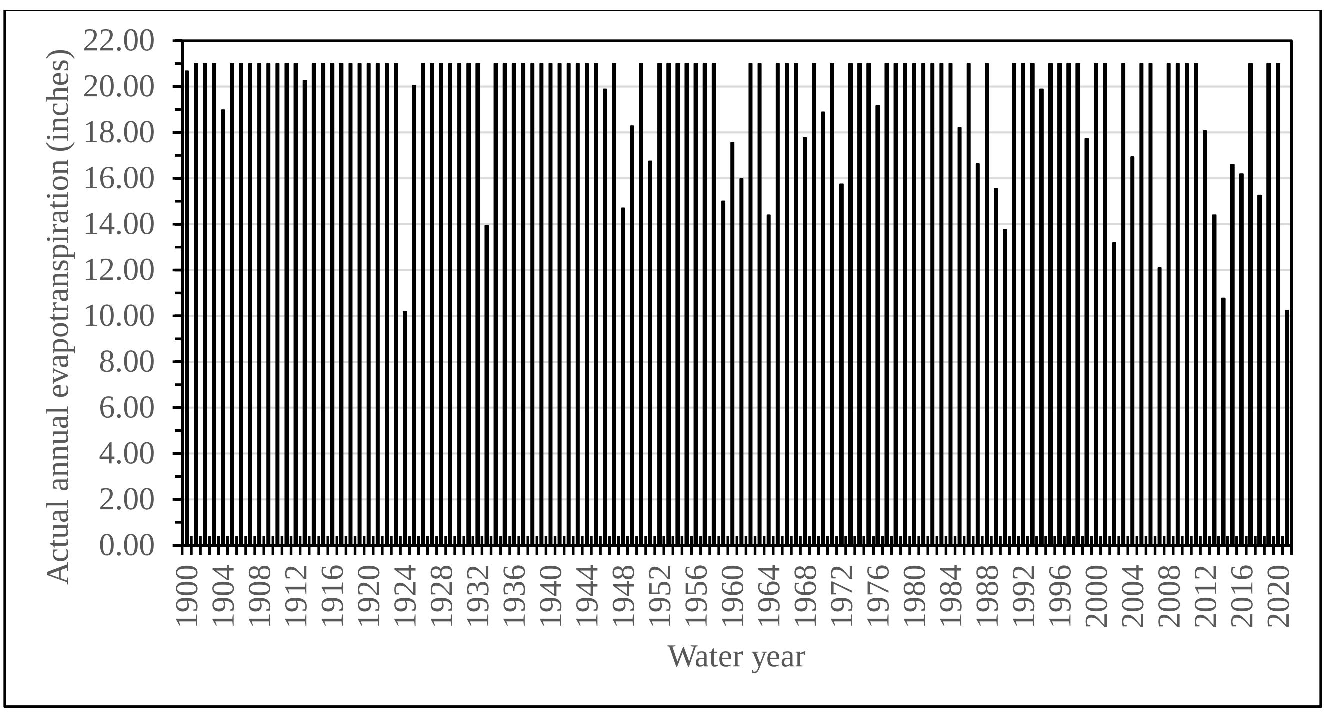


Figure 2.15. Calculated actual annual evapotranspiration. Maximum, average, minimum = 21.0, 19.7, and 10.2 inches, respectively.

There are available measurements of streamflow at the USGS stream-gaging station in the water years 1984-85 through 2020-2021, except for water years 1987-1988 through 1996-1997 when the station did not operate. Streamflow measurements can be converted to streamflow at the confluence of Mission and Rattlesnake creeks by multiplying the Rocky Nook streamflow by the ratio of areas 6.00/6.60 as discussed above. The calculated streamflow (Q) permits refining the water balance to account for change in groundwater storage and for capture of groundwater by the Mission Tunnel. This is accomplished by examining the value of precipitation – streamflow – tunnel outflow - actual evapotranspiration: $P - Q - T - ET_A$.

When $P - Q - T - ET_A$ is larger than zero we have that:

$$P - Q - T - ET_A = \Delta G > 0 \tag{2.17}$$

in which T and ΔG denote respectively the annual Mission Tunnel outflow and the change in groundwater storage. Measured values of Mission Tunnel outflow are presented in Chapter 6. If $P - Q - ET_A - T > 0$ there is a rise in groundwater storage and subsurface flow bypassing the river network (Y) occurs, but it is not possible to assess their individual values.

If $P - Q - ET_A - T \leq 0$ we have that:

$$P - Q - ET_A - T = \Delta G < 0 \tag{2.18}$$

in which ΔG denotes the reduction in groundwater storage, and the subsurface flow is $Y = 0$.

Assuming that the actual annual evapotranspiration in the period of streamflow measurement is approximated by the values shown in Figure 2.15 changes in groundwater storage were calculated for the years in which streamflow measurements were available and are presented in Figure 2.16.

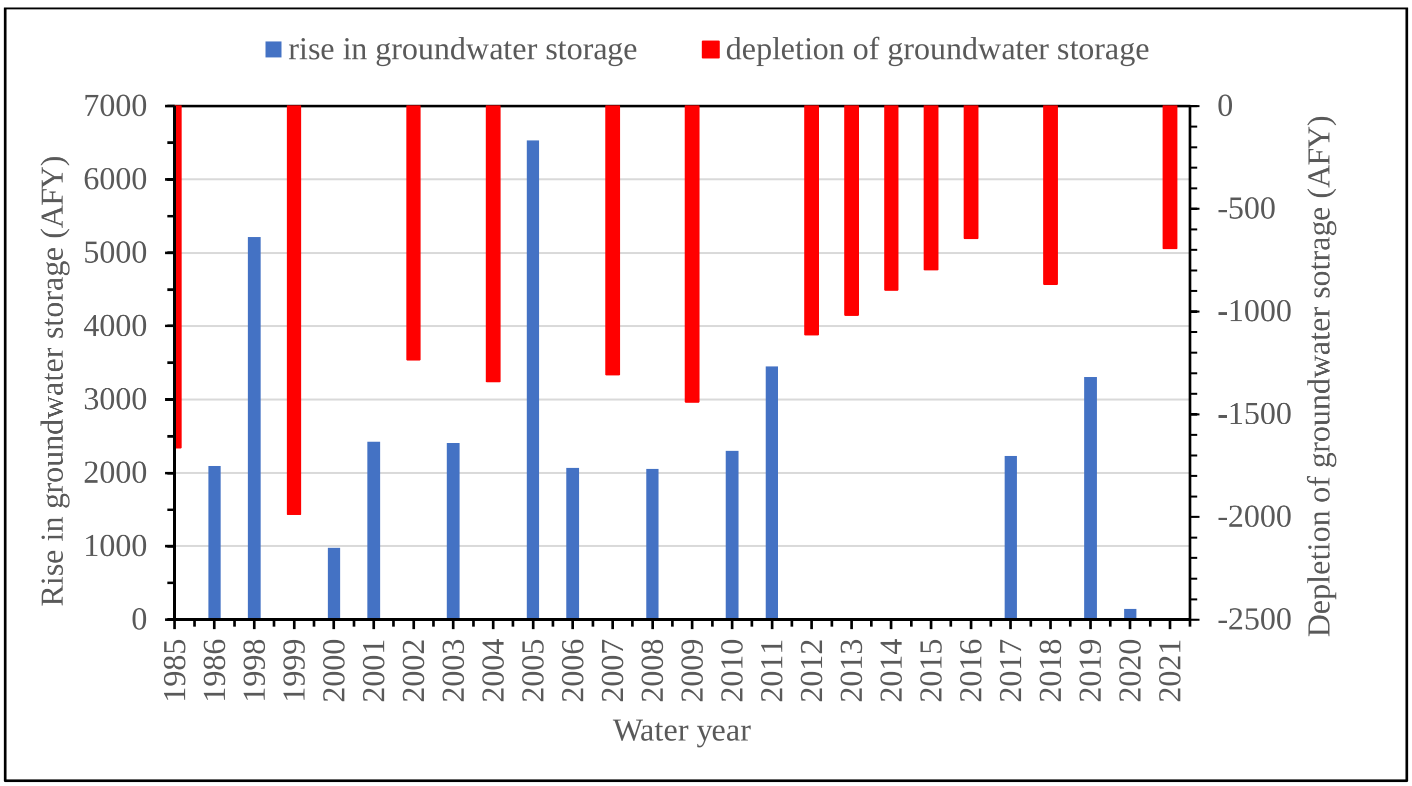
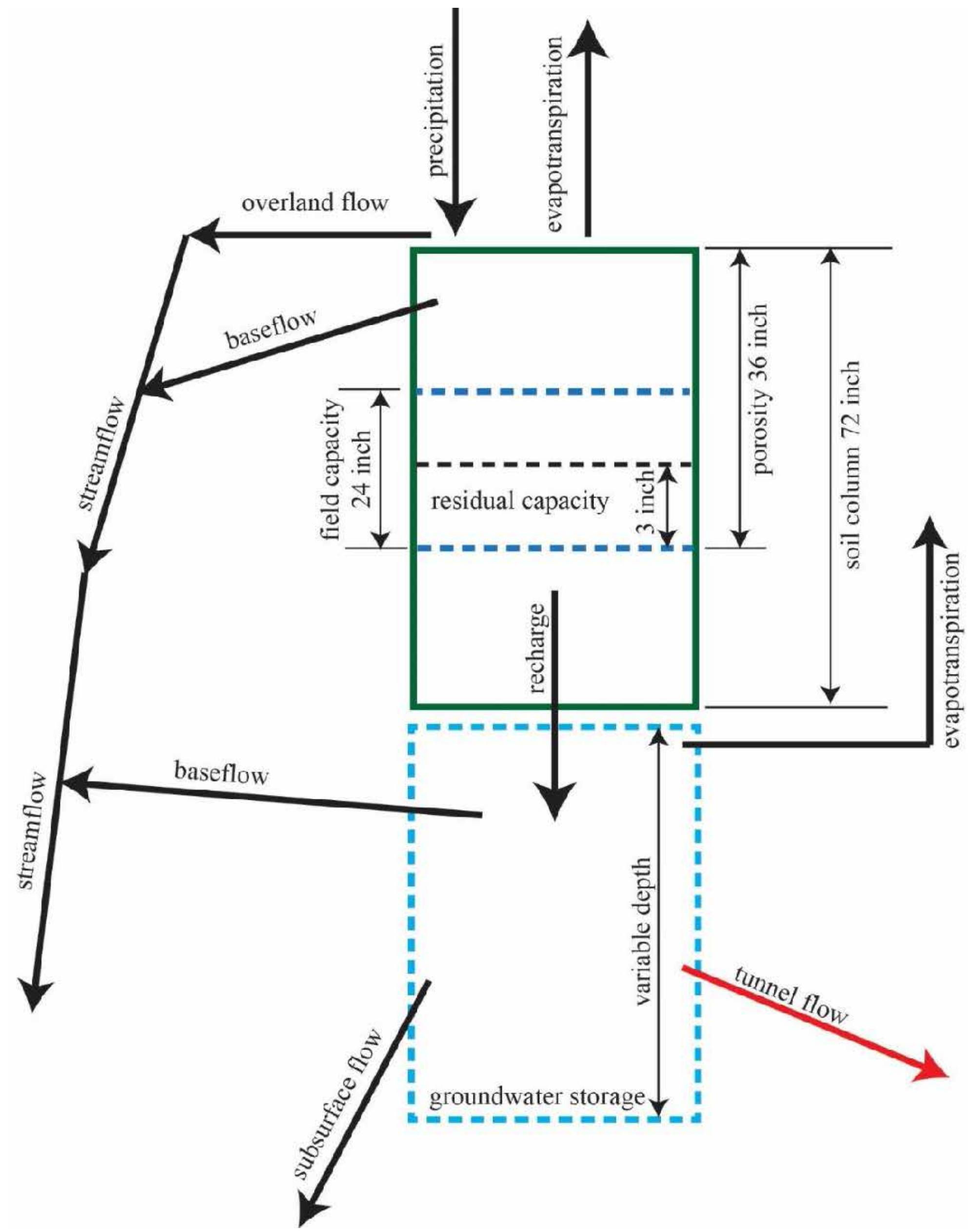


Figure 2.16. Estimated changes in groundwater storage in the study area. (AFY: acre feet/year).

The changes in groundwater storage show how dynamic subsurface water is in the study area, even though the exact disposition of the rise or depletion of groundwater storage among several fluxes such as baseflow, subsurface flow, and evapotranspiration cannot be resolved. It can be inferred from Figure 2.16, however, that depletion of groundwater storage most likely supports Mission Tunnel flow and reduces subsurface flow from the area. It also reduces baseflow and streamflow. Further evidence for the latter statement is presented in Chapter 6. The dynamic nature of groundwater storage depicted in Figure 2.16 tests the assumption made by previous authors concerning, for example, estimates of subsurface flow in the study area (see, e.g., Muir, 1968). Figure 2.17 provides a conceptual representation of the water fluxes in the study area and how they interact with each other.



Conceptual representation of the water fluxes and water storage in the study area.

2.6. Water-quality characteristics of the Mission Tunnel water

BCI Geonetics Inc. (1990) reported chemical analyses for 11 water samples collected in Mission Tunnel. Table 2.6 summarizes their results.

Table 2.6. Summary of water-quality characteristics obtained from 11 water samples collected in Mission Tunnel (BCI Geonetics Inc. (1990).

Constituent	**Units**	**Minimum value**	**Maximum Value**
Calcium	mg/L	30	160
Magnesium	mg/L	4	49
Sodium	mg/L	20	201
Potassium	mg/L	1	2
Total hardness (as $CaCO_3$)	mg/L	80	560
Bicarbonate	mg/L	148	456
Sulfate	mg/L	86	406
Chloride	mg/L	8	21
Fluoride	mg/L	0.1	2.9
Total Alkalinity (as $CaCO_3$)	mg/L	120	375
pH		7.2	8.6
Electrical conductivity	µmhos/cm	506	1120
Total dissolved solids (TDS)	mg/L	324	832
Cupper	mg/L		≤50
Iron	mg/L	≤100	300
Manganese	mg/L	≤30	240
Zinc	mg/L	≤50	70

The results listed in Table 2.6 indicate that the Mission Tunnel water is hard to very hard, alkaline, unsuitable for human drinking because of high TDS and in some instances high fluoride concentration. Chapter 4 reviews the water-quality characteristics of Mission Creek and Rattlesnake Creek waters.

2.7. Geology

The geologic features of the study area are described in Chapters 4 and 6.

2.8. References

BCI Geonetics Inc. (1990). Investigation of the feasibility for increasing groundwater inflow to the Mission Tunnel, Santa Barbara, California. Santa Barbara, California.

Crippen, J.R. (1965). Natural Water Loss and Recoverable Water in Mountain Basins of Southern California. U.S. Geological Survey Professional Paper 417-E. United States Government Printing Office, Washington, D.C.

DeBano, L.F. (2000). The role of fire and soil heating on water repellency in wildland environments: a review. Journal of Hydrology, 231-232, 195–206. https://doi.org/10.1016/S0022-1694(00)00194-3

Dingman, S.L. (2015). Physical hydrology. 3rd. ed., Waveland Press, Long Grove, Illinois.

Feng, D., Beighley, E., Raoufi1, R., Melack, J., Zhao, Y., Iacobellis, S., Cayan, D. (2019). Propagation of future climate conditions into hydrologic response from coastal southern California watersheds. Climatic Change (2019) 153:199–218.

Freckleton, J.R., Martin, P., Nishikawa, T. (1998). Geohydrology of Storage Unit III and a Combined Flow Model of the Santa Barbara and Foothill Ground-Water Basins, Santa Barbara County, California. U.S. Geological Survey Water-Resources Investigations Report 97-4121. Denver, Colorado.

Gurrola, L.D., Rogers, J.D. (2018). Fire, flood, and landslide dam history: Community and vicinity Southern Santa Barbara County, California. The Project for Resilient Communities, Santa Barbara, California.

Hargreaves, G.H., Samani, Z.A. (1985). Reference crop evapotranspiration from temperature. Applied Engineering in Agriculture, 1(2), 96-99. (doi: 10.13031/2013.26773)

Hillel, D. (1982). Introduction to soil physics. Academic Press, Orlando.

Holtz, R.D., Kovacs, W.D., Sheahan, T.C. (2011). Geotechnical Engineering. 2nd ed., Pearson Education, Inc., Upper Saddle River, New Jersey.

Hoover, M.F. (2020). Drought and flood. The history of water in Santa Barbara and Montecito. Kieran Publishing, Santa Barbara, California.

Task Committee on Revision of Manual 70. (2016). Evaporation, evapotranspiration, and irrigation water requirements. ASCE Manuals and Reports on Engineering Practice No. 70, M.E. Jensen & R.G. Allen, eds., American Society of Civil Engineers (ASCE), Reston, Virginia.

Kean, J.W., Staley, D.M., Lancaster, J.T., Rengers, F.K., Swanson, B.J., Coe, J.A., Hernandez, J.L., Sigman, A.J., Allstadt, and D.N., Lindsay, D.N. (2019). Inundation, flow dynamics, and damage in the 9 January 2018 Montecito debris-flow event, California, USA: Opportunities and challenges for post-wildfire risk assessment. Geosphere, 15(4),1140-1163.

Keller, E. A., Adamaitis, C., Alessio, P., Anderson, S., Goto, E., Gray, S., Gurrola, L., Morell, K. (2019). Applications in geomorphology: Geomorphology. Doi:10.1016/j.geomorph.2019.04.001.

Keller, E. A., Adamaitis, C. Alessio, P., Goto, E, Gray, S. (2020). Montecito debris flow of 9 January 2018: Physical processes and social implications. In Heermance, R. V. and Schwartz, J. J. eds., From the Islands to the Mountains: A 2020 View of Geologic Excursions ion Sothern California: Geological Society of America Field Guide 9, v. 0059, p. 95-114, doi:10.11130/2020.0059(o3).

Lancaster, J.T., Swanson, B.J., Lukashov, S.G., Oakely, N.S., Lee, J.B., Spangler, E.R., Hernandez, J.L., Olson, B.P.E., DeFrisco, M.J., Lindsay, D.N., Schwartz, Y.J., McCrea, S.E., Roffers, P.D., and Tran, C.M. (2021). Observations and analyses of the 9 January 2018 debris-flow disaster, Santa Barbara County, California, Environmental Engineering Geoscience, 27(1), 3-27.

Loaiciga, H.A. and Marino, M.A. (1991). Recurrence interval of geophysical events. Journal of Water Resources Planning and Management 117, 367-382.

Loaiciga, H.A, Pedreros, D., Roberts, D. (2001). Wildfire-streamflow interactions in a chaparral watershed. Advances in Environmental Research 5, 295-305. https://doi.org/10.1016/S1093-0191(00)00064-2

Loaiciga, H.A., Michaelsen, J., Garver, S., Haston, L., and Leipnik, R.B. (1992). Droughts in river basins of the western United States. Geophysical Research Letters 19, 2051-2054 https://doi.org/10.1029/92GL01697

Loaiciga, H.A., Haston, L., and Michaelsen, J. (1993). Dendrohydrology and long-term hydrologic phenomena. Reviews of Geophysics 31, 151-171.

Loaiciga, H.A. (2002). Reservoir design and operation with variable lake hydrology. J. Water Resources Planning and Management, 128(6), 399-405.

Loaiciga, H.A. (2005). On the probability of droughts: the compound renewal model. Water Resources Research, 41, W01009, doi:10.1029/2004WR003075.

McMahon, C., Cooper, S.D., and Wiseman, S.W. (2023). Post-fire stream responses to spatial fire patterns in riparian and upland zones. *In Biogeomorphic Responses to Wildfire in Fluvial Systems*, Geological Society of America (GSA) Books, Special Paper.

Miller, G.A, Rapp, J.R. (1968). Reconnaissance of the groundwater resources of the Ellwood-Gaviota area, Santa Barbara County, California. US Geological Survey 68-182, Menlo Park, California.

Muir, K.S. (1968). Ground -Water Reconnaissance of the Santa Barbara-Montecito Area, Santa Barbara County, California. U.S. Geological Survey Water-Supply Paper 1859-A. Government Printing Office, Washington, D.C.

Niehaus, R.D. (2018). The Economic Impacts of the Montecito Mudslides: A Preliminary Assessment: Electronic document, available at http://www.rdniehaus.com/rdn/wp-content/uploads/2018/03/RDN_Montecito_Mudslides_Impacts-1.pdf

Niehaus, R.D. (2019). The Montecito Debris Flow One Year Later: Housing Market Impact and Recover: Electronic document, available at http://www.rdniehaus.com/rdn/wp-content/uploads/2019/03/RDN_Montecito-Debris-Flow_Housing-Market-Impact_03-19.pdf

Quinn, R.D., Keeley, S.C. (2006). Introduction to California Chaparral. University of California Press, Oakland, California.

Touma, D., Stevenson, S., Swain, D.L., Singh, D., Kalashnikov, D.A., Huang, X. (2022). Climate change increases risk of extreme rainfall following wildfire in the western United States. Science Advances., 8 (13), eabm0320. DOI: 10.1126/sciadv.abm0320

U.S. Army Corps of Engineers. (1987). Lower Mission Creek Interim Santa Barbara County Streams, California, Feasibility Report and Environmental Impact Statement. South Pacific Division, US Corps of Engineers, San Francisco, California.

U.S. Department of Agriculture. (1999). Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Government Printing Office, Washington, D.C.

Veihmeyer, F.J., Hendrickson, A.H. (1949). Methods of measuring field capacity and wilting percentages of soils. Soil Science, 32 181-193.

Waananen, A.O., Crippen, J.R. (1977). Magnitude and frequency of floods in California. US Geological Survey Water Resources Investigations 77-21. Menlo Park, California.

See also:

Bleifuss, C. Bobroff, J. Espinoza, J. Jagedo. (2020). Quantifying Climate Change Impacts to City of Santa Barbara Water Supplies. Bren School, University of California, Santa Barbara.

Boles, J. R. (2004). Rapid growth of meter-scale calcite speleothem in the Mission Tunnel, Santa Barbara, California. In Water-Rock Interaction, Wanty and Seal (Eds). Taylor & Francis Group.

Brown, N. N. (2009). Draft Framework for Evaluating the Relationship of Mission Tunnel Infiltration and Mission Creek Streamflow. Prepared for City of Santa Barbara. March 3, 2009.

McFadden, M. C., K. G. Polinoski, and P. Martin. (1991). Measurement of Stream flow Gains and Losses on Mission Creek at Santa Barbara, California, July and September 1987. U.S. Geological Survey Water-Resources Investigations Report 91-4002. Prepared in Cooperation with the City of Santa Barbara.

Rademacher, L. K. J. F. Clark, J. R. Boles. (2003). Groundwater residence times and flow paths in fractured rock determined using environmental tracers in the Mission Tunnel; Santa Barbara, County, California, USA. Environmental Geology, 43 (3003):557-567.

CHAPTER 3. HUMAN ALTERATION OF THE STUDY AREA

3.1 Alterations in the Upper Mission Creek watershed.

This chapter documents human alterations in the study area. More evidence of such alterations is presented in chapters 4, 5, and 6. The purpose of surveying human impacts in the study area is to document (i) changes made to streams and to the riparian zones of streams, (ii) the construction of roads and bridges that affect the sediment and flow regimes in the streams within the study area, and (iii) other patterns of land use that pose a hazard to the inhabitants and the flora and fauna of this high-risk fire area.

One of the main impediments to streamflow and a feature disruptive of sediment transport in Mission Creek is Mission Dam (Shott, 2005). It is located within the Santa Barbara Botanic Garden (coordinates 34° 27.521′N; 119° 42.607′ W). The dam was completed in 1807. It was part of a water-supply project for the Santa Barbara Mission (Chapman, 1919). Mission Dam is a mixed masonry structure built with native rock materials. It is 121 feet wide at its crest, with a thickness of 16 feet (perpendicular to the direction of flow), and a maximum vertical length of 31 feet. On the right bank (the right bank of the stream looking in the direction of flow) of the dam there are the ruins of a stone flume or aqueduct that conveyed water by gravity from Mission Creek to the Mission (Imwalle, 1996). The water-supply service lasted for almost one century under various water purveyors (Hyles and Bevan, 2016). Mission Dam is a California State Historic Landmark (No. 309) and a Santa Barbara County Landmark (No. 24). The drainage area upstream of the dam equals 2.7 square miles (1728 acres). The dam site is within a narrow and incised canyon. The stream channel and its riparian corridor developed in upper Pleistocene intermediate alluvial deposits (designated by the symbol Qia in Minor et al., 2009). The basement rock underlying Mission Creek and its riparian corridor and outcropping in the canyon walls consists of lower Miocene Rincon shale (Tr, in Minor et al., 2009). The stream reach encompassing Mission Dam is incised, has low width to depth ratio, low sinuosity, and the channel slope in the vicinity of the dam ranges between 4% and 6%. [redacted] A visual inspection by these authors of Mission Creek upstream of Mission Dam where the aggradation of the stream caused by sediment deposition resulted in subsurface flow in this reach. The deposits are constituted by boulders, thus refining the stream classification to an A2 stream.

Figure 3.1 depicts Mission Dam viewed in the upstream direction. It is seen in Figure 3.1 a 5 feet-wide and 16 feet-deep rectangular notch cut through the dam to allow the passage of stream flow without overtopping the structure. The dam has a vertical length of about 31 feet measured from its crest downward to its base below the rectangular notch shown in Figure 3.1. Figure 3.2 shows Mission Dam viewed in the downstream direction. The deposition of boulders upstream of the dam is seen in Figure 3.2. The vertical extent of the rectangular notch on this side of the dam is 6 feet, compared with the 16 feet on the downstream side of the dam. It was estimated by this report’s authors that the original water storage capacity behind Mission Dam was 17,650 cubic yards, of which 14,230 cubic yards have filled with sediment. Sediment trapping of this type breaks the tendency of natural streams to move matter and energy that flow into and through them by arranging themselves (in cross-sectional shape, slope, sinuosity) in a such a manner that reduces the amount of work and distributes that work as evenly as possible (Mount, 1995). The disruption of sediment transport causes a stream to lose its self-regulating capacity (Schumm, 1977). The ensuing disequilibrium forces the stream into a stage of geomorphologic adjustments whose consequences are unpredictable (Loáiciga, 2001; Rosgen, 2006).

Figure 3.1. Photo of Mission Dam viewed in the upstream direction. A wooden portion of the ancient aqueduct is seen on the left side of the photo (the right bank of the stream). This photo was taken after the heavy rains in January 2023. The storms of January 2023 transported large amounts of woody debris downstream from the upper Mission Creek watershed, causing the dam to be over-topped, and eroding portions of the west abutment. The unreinforced boulder and brick dam may be subject to potential catastrophic failure in future flood events. Coordinates: 34° 27.521′ N; 119° 42.606′, elevation 733 feet above mean sea level.

Figure 3.2. Photo of Mission Dam looking downstream. Large-size bedload is seen upstream Mission Dam.

Figure 3.3 depicts one of the most disruptive human alterations effected on Mission Creek, namely a debris basin (National Marine Fisheries Service, 2014), coordinates: 34° 27.746′ N; 119° 42.641′ W. The photo was taken looking upstream. The dam in the debris basin is intended to trap debris generated during debris flows following chaparral fire, but it disrupts the natural hydrologic and sediment transport processes that have created the habitats that are characteristic of Mission Creek (see Keller et al., 2004; Keller, 2011; Keller et al., 2019; Keller et al., 2020, for accounts of debris flows in the study area and its vicinity). This debris dam is 72 feet wide at the crest, 70 feet thick (at the crest, in the direction perpendicular to flow), and has a vertical length from its crest to the water level downstream of the dam equal to 25 feet (photo taken on December 28th, 2021, following rain). The culvert through which flow passes is 4-feet in diameter. The authors estimated from field observations that this debris basin had originally a bulk volume (pores plus solids) of 14,640 cubic yards to store sediment, of which 8,580 cubic yards have filled with sediment. The debris basin has been periodically dredged to maintain its maximum sediment trapping capacity (Santa Barbara County Flood Control and Water Conservation District 20202).

Figure 3.4 shows a view of the Mission Creek (debris) dam looking in the downstream direction. There is an access road to this area on the left bank of Mission Creek upstream of the debris dam that allows equipment to access and dredge it.

Figure 3.5 is a photograph of the access road to the debris basin. These roads become sources of sediment loading to streams.

Figure 3.6 shows a photo of sediment dredged from the debris basin that has been filled and compacted on the left bank of Mission Creek. This site is about 500 feet upstream of the debris dam and has an area of about 1 acre. The filled material poses landslide hazard caused by heavy rain and by earthquakes.

Figure 3.7 depicts Mission Canyon Road bridge over Mission Creek. A deep pool forms downstream from the bridge. The bridge's foundation is an obstacle to fish passage.

Figure 3.8 illustrates the yard work in a private residence on the right bank of Mission Creek upstream of Mission Dam (coordinates: 34° 27.652′ N; 119°.42.616′ W). The right bank is destabilized by yardwork generating fine sediment that covers gravely bedload and interferes with benthic invertebrate production, as well as with steelhead spawning and rearing. This type of disruptive alteration caused by private residences is common in the riparian corridors of Mission Creek and Rattlesnake Creek.

Figure 3.9 presents a photo of yardwork in a private residence that destabilizes Mission Creek's right bank and generates sediment loading to the stream (coordinates: 34° 27.647′ N; 119° 42.615′ W).

Figure 3.10 displays private trail and yardwork on the right bank of Mission Creek adjacent the Botanic Garden (coordinates: 34° 27.597′ N; 119° 42.604′ W).

Figure 3.11 displays the photograph of a private ladder on the right bank of Mission Creek adjacent to Mission Creek's debris dam. These access structures generate debris and promote accelerated weathering of the creek's canyon walls.

Figure 3.12 depicts the deleterious effect of roads constructed in the chaparral vegetation and steep slopes of Mission Creek canyon. This photo shows (i) metal screens placed to stabilize the rocky slope on the right side of the road, (ii) metal fence, berm, and K-shaped retaining wall placed on the left side of the wall for the purpose of containing rock falls from reaching the creek's riparian corridor. This site is on the Tunnel trail uphill from the terminus of Tunnel Road, and on the right bank of Mission Creek (coordinates: 34° 28.963′ N; 119° 42.426′ W).

Figure 3.13 is a photograph of rockfall originating from exposed slope along Tunnel trail (see Figure 3.11) that has reached Mission Creek's Channel (coordinates: 34° 28.963′ N; 119° 42.426′ W).

Figure 3.3. Debris dam in Mission Creek. Photo taken viewing in the upstream direction (coordinates: 34° 27.746′ N; 119° 42.641′ W).

Figure 3.4. Photograph of the debris basin in Mission Creek looking downstream. A concrete intake structure was built to reduce obstructions by large woody debris inside the culvert.

Figure 3.5. Access road to Mission Creek debris basin on the creek's left bank upstream from the basin.

Figure 3.6. Compacted dredged sediment from Mission Creek's debris basin. It is located on the left bank of Mission Creek about 500 foot upstream from the debris basin.

Figure 3.7. Photo of Mission Canyon Road over Mission Creek, viewing north or in the upstream direction (coordinates: 34° 27.124′ N; 119° 42.564′ W).

Figure 3.8. Yardwork in a private residence destabilizes Mission Creek’s right bank creating a source of fine sediment that interferes with steelhead spawning. Many such alterations occur in the study area (coordinates: 34° 27.652′ N; 119°.42.616′ W).

Figure 3.9. Alteration of Mission Creek's right bank by yardwork in a private residence (coordinates: 34° 27.647′ N; 119° 42.615′ W).

Figure 3.10. Private trail and yardwork on Mission Creek's right bank adjacent to the Botanic Garden. These works generate sediment loading to the creek (coordinates: 34° 27.597′ N; 119° 42.604′ W). Note also the introduction of non-native plants

Figure 3.11. Private ladder on Mission Creek’s right bank about 500 feet upstream from the debris dam. These access structures generate debris and promote accelerated weathering of the creek’s canyon walls.

Figure 3.12. Photo of remedial measures taken to contain rockfalls into Mission Creek: metal screens, metal fences, berm, and K-shaped concrete wall. Photo looking south along Tunnel trail, uphill from the right bank of Mission Creek. Coordinates: 34° 28.963′ N; 119° 42.426′ W.

Figure 3.13. Rockfall reaching Mission Creek’s channel. Rockfall originated from canyon slope exposed along Tunnel trail (see Figure 3.11). Coordinates: 34° 28.963′ N; 119° 42.426′ W.

Figure 3.14 is a photograph of an eroding slope along Tunnel trail. The sediment mixes with runoff which if captured by the manhole seen at the base of the slope from where a culvert under the trail conveys the sediment-laden runoff to Mission Creek (coordinates 34° 27.988′ N; 119° 42.672′ W).

Figure 3.14. Photo of the right side of Tunnel trail viewing south. The eroding slope and manhole at the base of the slope convey moves sediment laden runoff through a culver towards Mission Creek located towards the left of the trail. Dense chamise chaparral covers the mountain side.

Figure 3.15 is a photograph of the reinforced left bank of Mission Creek in a private residence. The reinforcement is intended to protect bank erosion. There is constructed reinforcement near the base of the eucalyptus tree on the left bank.

Figure 3.15. Reinforcement of the left bank of Mission Creek. Photograph viewing in the downstream direction about 100 feet downstream from the Mission Canyon Road bridge over Mission Creek (see Figure 3.14).

3.2 Alterations in the Rattlesnake Creek watershed

Figure 3.16 displays a photograph viewing south and east over Rattlesnake Creek towards the eastern slope of Skofield Park. Houses are built within the chaparral vegetation in a zone designated as a high-risk fire area. Many houses built in the chaparral within the study area were burned by the Jesusita fire.

Figure 3.16. Houses built within the chaparral vegetation on the eastern slope of Skofield Park.

Figure 3.17 depicts a photo of the Las Canoas Road bridge over Rattlesnake Creek. There is a 5-foot vertical drop from the spillway cutoff to the water level, measured on December 19th, 2021. This type of human alteration is the most severe with respect to fish migration.

Figure 3.17. Photo viewing in the upstream direction at Las Canoas Road bridge over Rattlesnake Creek (coordinates: 34° 27.441′ N; 119° 41.525′W).

Figure 3.18 illustrates the damage caused by trails in the chaparral vegetation. There is gully formation and erosion causing sediment loading to Rattlesnake Creek. The width of the gully in the center of the photo is about 3 feet, the length of the Pulasky axe lying on the ground.

Figure 3.18. Photo of gully in Rattlesnake trail, viewing north (coordinates: 34° 27.646′ N; 119° 41.490′).

Figure 3.19 shows a little-known masonry dam in Rattlesnake Creek. Remnants of corroded iron in this area suggest this dam was used as a water-diversion point at some time in the past. The gap allowing water through the dam is 10 feet wide and with a vertical length of 14 feet to the water level in the downstream pool measured on December 19th, 2021.

Figure 3.19. Masonry dam in Rattlesnake Creek, partly collapsed (coordinates: 34° 27.762′ N; 119° 41.456′ W). Photo viewing upstream.

Figure 3.20 is a photo of a debris dam in Rattlesnake Creek. This a masonry structure, 125 feet wide, 65 feet thick (perpendicular to the direction of flow), with vertical drop in elevation from the crest of the dam to the toe of the dam equal to 29 feet. The culvert is 4 feet in diameter. This structure is an impassable obstacle for the steelhead. These authors estimated from field observations that the bulk volume (pores plus solids) available to store sediment was originally 22,890 cubic yards of sediment, of which 13,420 cubic yards have filled with sediment behind the dam in the debris basin.

Figure 3.20. Debris dam in Rattlesnake Creek. Photo viewing upstream (coordinates: 34° 27.587′ N; 119 41.531′ W).

Figure 3.21 shows a view of the Rattlesnake Creek debris dam and basin viewing downstream. There is an inlet structure with 4 foot-diameter openings that reduces blockage by woody debris.

Figure 3.21. Photograph of the debris dam and basin in Rattlesnake Creek, viewing downstream ((coordinates: 34° 27.587′ N; 119 41.531′ W).

Figure 3.22 depicts access road from Las Canoas Road to the Rattlesnake Creek debris basin. The road gate on Las Canoas Road is situated about 300 feet west of the Las Canoas bridge over Rattlesnake Creek at the Rattlesnake Creek trailhead. Sediment dredged from the debris basin is filled in this area.

Figure 3.22. Access road and fill area for sediment dredged from the Rattlesnake Creek debris dam and basin. Photograph looking south.

Figure 3.23 displays what appears to be an abandoned 24-inch diameter iron pipe crossing Rattlesnake Creek. This structure obstructs the passage of coarse bedload and large woody debris.

Figure 3.23. 24-inch iron pipe across Rattlesnake Creek. Photo looking upstream (coordinates 34° 26.99′ N; 119° 42.526′ W).

Figure 3.24 is a photograph of a garden in a private residence within the right bank of Rattlesnake Creek. Soil disturbance in this area generates sediment loading to Rattlesnake Creek.

Figure 3.24. Private garden and soil disturbance on the right bank of Rattlesnake Creek (coordinates 34° 27.040′ N; 119° 42.431′ W).

Figure 3.25 is a photograph of a bridge on Las Canoas Road over a tributary stream to Rattlesnake Creek. These structures constitute obstructions to fish passage.

Figure 3.25. Bridge on Las Canoas Road over a tributary stream to Rattlesnake Creek. Photograph looking downstream (coordinates: 34° 27.124′ N; 119° 42.564′ W).

3.3 Summary

The photographs presented in this chapter illustrate some of the key alterations effected by humans within the study area. The photographs are not an exhaustive survey of such alterations but they are representative. Chapters 4, 5, and 6 discuss other adverse human alterations found in the study area. Some of these alterations are associated with public services related to transportation (e.g., bridges over creeks, roads, leisure (trails), or flood protection (e.g., debris dams). Other are remnants of water diversions without current function. Furthermore, other alterations are the results of private actors who dwell within the study area, and they are primarily related to garden construction and bank reinforcement. Mission Creek and Rattlesnake Creek are suffering from "a thousand cuts", i.e., multiple alterations whose cumulative effects radically have changed streamflow, sediment transport, and related habitat features within the study area. Streams are naturally dynamic and have a great capacity to recover from natural and human disturbances. It is possible to restore the habitats functions in the study area through modifications of some of the disruptive developments and practices described above and in the following chapters. Recommendations for restoration of the study area are the topic of chapter 7.

3.4 References

Chapman, J. D. (1919). Water Supply of City of Santa Barbara. Santa Barbara Historical Society.

Hyles, J., Bevan, S. (2016). Santa Barbara Botanic Garden Old Mission Dam Fish Passage Feasibility Study. Final prepared for the National Marine Fisheries Service, HDR, San Diego, California.

Imwalle, M. H. (1996). Mission Canyon Aqueduct (CA-SBA-1852). Research Project. Prepared for the Santa Barbara Botanic Garden. March 1996.

Keller, E. A., Gurrola, L., Selting, A., Urban, R. (2004). The Natural History of Mission Creek: A Story of Earthquakes and Debris Flows: A Journey Through Time. Environmental Studies and Geological Sciences, University of California, Santa Barbara.

Keller, E. A. (2011). Santa Barbara Land of Dynamic Beauty: A Natural History. Santa Barbara Museum of Natural History.

Keller, E. A., Adamaitis, C., Alessio, P., Anderson, S., Goto, E., Gray, S., Gurrola, L., Morell, K. (2019). Applications in geomorphology: Geomorphology. Doi:10.1016/j.geomorph.2019.04.001.

Keller, E. A., Adamaitis, C. Alessio, P., Goto, E, Gray, S. (2020). Montecito debris flow of 9 January 2018: Physical processes and social implications. In Heermance, R. V. and Schwartz, J. J. eds., From the Islands to the Mountains: A 2020 View of Geologic Excursions ion Sothern California: Geological Society of America Field Guide 9, v. 0059, p. 95-114, doi:10.11130/2020.0059(o3).

Loáiciga, H. A. (2001). Flood damages under changing flood-plain conditions: a forensic-hydrology case study, Journal of the American Water Resources Association 37(2), 467-478. https://doi.org/10.1111/j.1752-1688.2001.tb00982.x

Minor, S.A., Kellogg, S.K., Stanley, R.G., Gurrola, L.D., Keller, E.A., Brandt, T.R. (2009). Geologic map of the Santa Barbara coastal plain area, Santa Barbara, County, California. U.G. Geological Survey Scientific Investigations Map 3001, Menlo Park, California.

Mount, J.F. (1995). California Rivers and Streams. University of California Press, Berkeley, California.

National Marine Fisheries Service. (2014). Biological Opinion. Permit Santa Barbara County Flood Control District's Annual Stream Maintenance Plan, Debris Basin Management Plan, and Goleta Slough Maintenance Program. West Coast Region, National Marine Fisheries Service. SWR-2010-03496. March 11, 2014.

Rosgen, D. (1996). Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado.

Rosgen, D. (2006). Watershed Assessment of River Stability and Sediment Supply. Wildland Hydrology, Fort Collins, Colorado.

Shott, H. E. (2005). The Santa Barbara Mission Dam: A Sturdy Construction in a Stable Environment. Senior Thesis, Department of Environmental Studies. University of California, Santa Barbara

Schumm, S.A. (1977). The Fluvial System. John Wiley & Sons, New York.

Also see:

Abramson, L., M. Chennell, E. Eisch, A. Glassco and T. Holley. (2009). Post-fire sedimentation and flood risk potential in the Mission Creek watershed of Santa Barbara. Group Project Report for the degree of Master's in Environmental Science and Management. University of California, Santa Barbara, CA.

NMFS. (2014). Endangered Species Act Section 7 Consultation. Biological Opinion for Flood Control Operations including Annual Stream Maintenance, Debris Basin Maintenance, Goleta Slough Dredging and Long-term Atascadero Creek Channel Maintenance permitted by the U.S. Army Corps of Engineers, and implemented by the Santa Barbara County Flood Control District in designated waters occurring within Santa Barbara County. 243 pp.

Stoecker, M. W. (2002). Steelhead assessment and recovery opportunities in southern Santa Barbara County, California. Conception Coast Project, Santa Barbara, California. 427 pp.

CHAPTER 4. GEOMORPHOLOGY AND BIOLOGY OF MISSION AND RATTLESNAKE CANYONS

4.1. Background

Mission Creek and its tributary, Rattlesnake Creek, drain south-facing catchments of the Santa Ynez Mountains above the City of Santa Barbara (Santa Barbara County, California, USA; see Chapters 1 and 2). The Santa Ynez Mountains rise steeply from the Pacific Ocean to peaks reaching ca. 4600 feet. Drainage basins in this range are underlain by shale and sandstone bedrock, with overlying alluvial deposits in flatter areas, such as coastal plains and terraces. The study region above the confluence of Mission and Rattlesnake Creeks encompasses an area of ca. 6 square miles and elevations ranging from 480 to 3500 feet (146 to 1067 m). This region has a Mediterranean climate, being wet and cool from November through March and dry and warm from April through October. Average annual precipitation ranges from 39 inches along the mountain ridge to 18 inches at sea level (Keller and Keller, 2011). Precipitation and stream discharge show high seasonal and interannual variability, with multi-year droughts interspersed by years with large winter storms (Figure 4.1).

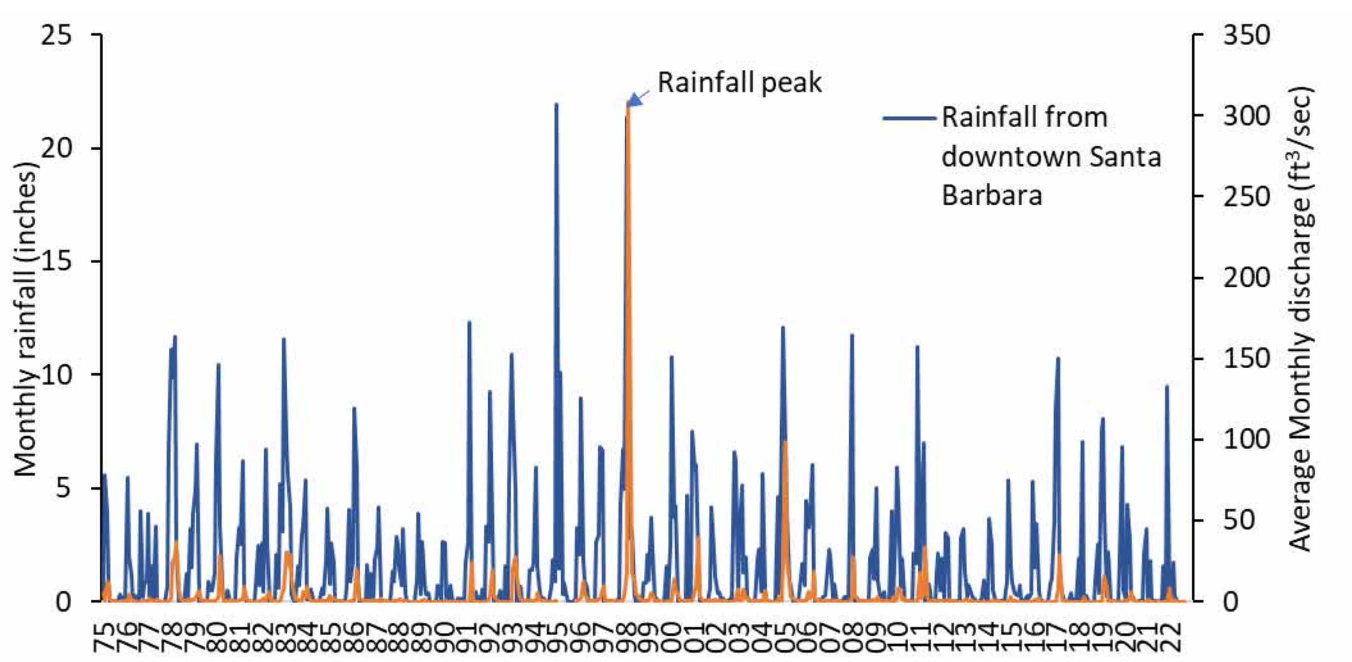


Figure 4.1. Monthly rainfall in downtown Santa Barbara, California, and average monthly discharge from a nearby stream (San Jose Creek, USGS gauging station # 11120500). Discharge for San Jose Creek is shown because this creek has a longer hydrographic record (back to 1941) than Mission Creek, which is covered in previous chapters.

The morphology of Mission and Rattlesnake Creeks in the study area are dominated by step-pools, forced pools, or a combination of these types (maximum depths = 0.3 to 1.6 m) created by boulders or bedrock, connected in the dry season by narrow shallow riffles or waterfalls (Montgomery and Buffington, 1997). During drought and in the summer-fall, some stream reaches are reduced to a series of semi-isolated or isolated pools or, at the extreme, dry completely. Even these stream reaches, however, contain water for some portion of the wet season after rains. There is also longitudinal flow variation – alluvial stream sections and headwater reaches with low contributing areas often become dry during dry times, whereas some spring-fed pools at intermediate elevations retain water even during the driest periods (see below).

Upland areas in this region are dominated by mixed and *Ceanothus* chaparral, with patches of oak (*Quercus agrifolia*) woodland, non-native grasslands, and coastal sage scrub (Lentz, 2013). Riparian zones are dominated by broad-leafed trees, including California sycamore (*Platanus racemosa*), white alder (*Alnus rhombifolia*), willows (*Salix* spp.), and, more rarely, black cottonwood (*Populus trichocarpa*) and bigleaf maple (*Acer macrophyllum*). Oaks and California bay laurel (*Umbellularia california*) are found in dense woodlands around the channel, and may dominate the channel itself in drier areas (see below). Pacific poison oak (*Toxicodendron diversilobum),* blackberry (*Ribes* spp.), gooseberry (*Rubus* spp.), toyon (*Heteromeles arbutifolia*), and a variety of other shrubs, herbs, and grasses are found in the riparian understory. The channel itself is often scoured clear of vegetation, but in some places invasive weeds are present along the channel, including vines such as cape ivy (*Delairea odorata*) and common ivy (*Hedera helix*), shrubs such as Japanese pittosporum (*Pittosporum japonicum*) and common fig (*Ficus carica*), and herbs such as common periwinkle (*Vinca major*) and nasturtium (*Tropaeolum majus*). In particularly wet sections, the channel is covered with wetland herbs including horsetail (*Equisetum telmateia*).

Past and current land uses and human activities in the Mission Creek watershed would have large impacts on stream ecosystems, so it is important to outline human history and current activities in this basin. Human uses of this watershed have a very long history. Chumash visits to Mission and Rattlesnake Canyons for hunting and gathering stretch back millennia as evidenced by artifacts found near or along the streams. Cabrillo's expedition in 1542 encountered a large fishing village, *syuxtun*, with 500 to 600 residents near the mouth of Mission Creek and later expeditions documented a small inland village, *xana'yan*, near the confluence of Mission and Rattlesnake Creeks (Johnson, 1986; Telleen-Lawton, 2006). Major Chumash food resources found in these canyons included deer, rabbits, acorns, and various plants and seeds. The Chumash living along Mission Creek were absorbed into the Spanish Mission of Santa Barbara after it was dedicated in 1786, and constructed two dams, one on Mission Creek (1807) and one on Rattlesnake Creek (1808), with associated tile aqueducts and redwood pipes to deliver water to the mission's vineyards, gardens, and grain fields (Gunnerson, 1957; Tompkins, 1978). After the missions were secularized by the Mexican government in the 1830s, the Santa Barbara Mission fell into disrepair and by 1850 was being rented to Goleta Valley ranchers.

During the post-1850s American era, many homes were built near or along Mission and Rattlesnake Creeks in the vicinity of the mission. By 1880, the Mission Canyon population was large enough to support its own elementary school. The Mission Water Company bought the mission water system in 1872 and the De La Guerra Garden Springs Company, which was incorporated in 1888, built a second water system, with both merging in 1891 to form the Santa Barbara Water Company. The City of Santa Barbara built its own water system in 1897 and purchased the Santa Barbara Water Company in 1911, the same year it constructed the Mission Tunnel. Throughout the Spanish, Mexican and early American eras, up to the time of the construction of the Mission Tunnel in 1911, Mission Creek was consistently observed to flow year around. Many prominent Santa Barbara institutions, including Rockwood (the Santa Barbara Women's Club), the Santa Barbara Museum of Natural History, and the Santa Barbara Botanic Gardens were constructed in Mission Canyon in the 1920s. The Mission Cañon Association, which deals with fire protection issues, was founded in 1918 as the Upper Mission Canyon Improvement Association. Various homesteads, such as Tin Can Flats in upper Rattlesnake Canyon, were started in the early 1900s under the Homestead Act (1862 – 1905) with routes of parts of the current trail and road system, such as Gibraltar Road, dating to this period. A dairy farm was operated in lower Rattlesnake Canyon in the early 1900s, fed by waters delivered via a tunnel from upper Rattlesnake Creek. Ray Skofield bought parts of Rattlesnake Canyon in 1928, maintaining it in a natural state for family outings and civic groups, such as the Rancheros Visitadores who bought the area now known as Skofield Park from Hobart Skofield, Ray's son, in 1950. The Rancheros Visitadores sold their property, which became Skofield Park, to the City of Santa Barbara in 1964 and Hobart Skofield sold his remaining 450 acres of Rattlesnake Canyon to the city in 1970 to become a natural park, deemed the Rattlesnake Canyon Wilderness Park at Hobart's request (Telleen-Lawton, 2006). With the exception of this park and lands managed by the US Forest Service along the western side of upper Mission Canyon, the rest of upper Mission and Rattlesnake Canyons are under the jurisdiction of the County of Santa Barbara. Residences are found along lower Rattlesnake Creek, up to Las Canoas Road, and along Mission Creek to above the debris basin, as well as at higher elevations and along ridges further up these canyons, including Saint Mary's Seminary on the west side of Rattlesnake Canyon and the former Mt. Calvary Monastery on its east side, which burned down in the 2008 Tea Fire. Figure 4.2 shows the density of residential development along lower Mission and Rattlesnake Creeks, which can have large impacts on water quantity and quality, stream and riparian habitat, and the terrestrial and aquatic biota, as outlined in later sections of this chapter. After the Coyote Fire of 1964, which burned most of upper Mission and Rattlesnake Canyons, the County of Santa Barbara Flood Control District built two debris dams on Mission and Rattlesnake Creeks, above the Santa Barbara Botanic Gardens and above the Las Canoas Bridge, respectively.

The rest of this chapter focuses sequentially on other characteristics of upper Mission and Rattlesnake Canyons, including those pertaining to geology, stream geomorphology, surface hydrology, vegetation (particularly riparian vegetation), the aquatic biota, and wildlife, particularly birds. These aspects of the natural history of Mission and Rattlesnake Canyons are intertwined, with the geological setting determining hydrological processes and stream flows, which, in turn, determine the composition, abundance, and health of the riparian and aquatic biota.

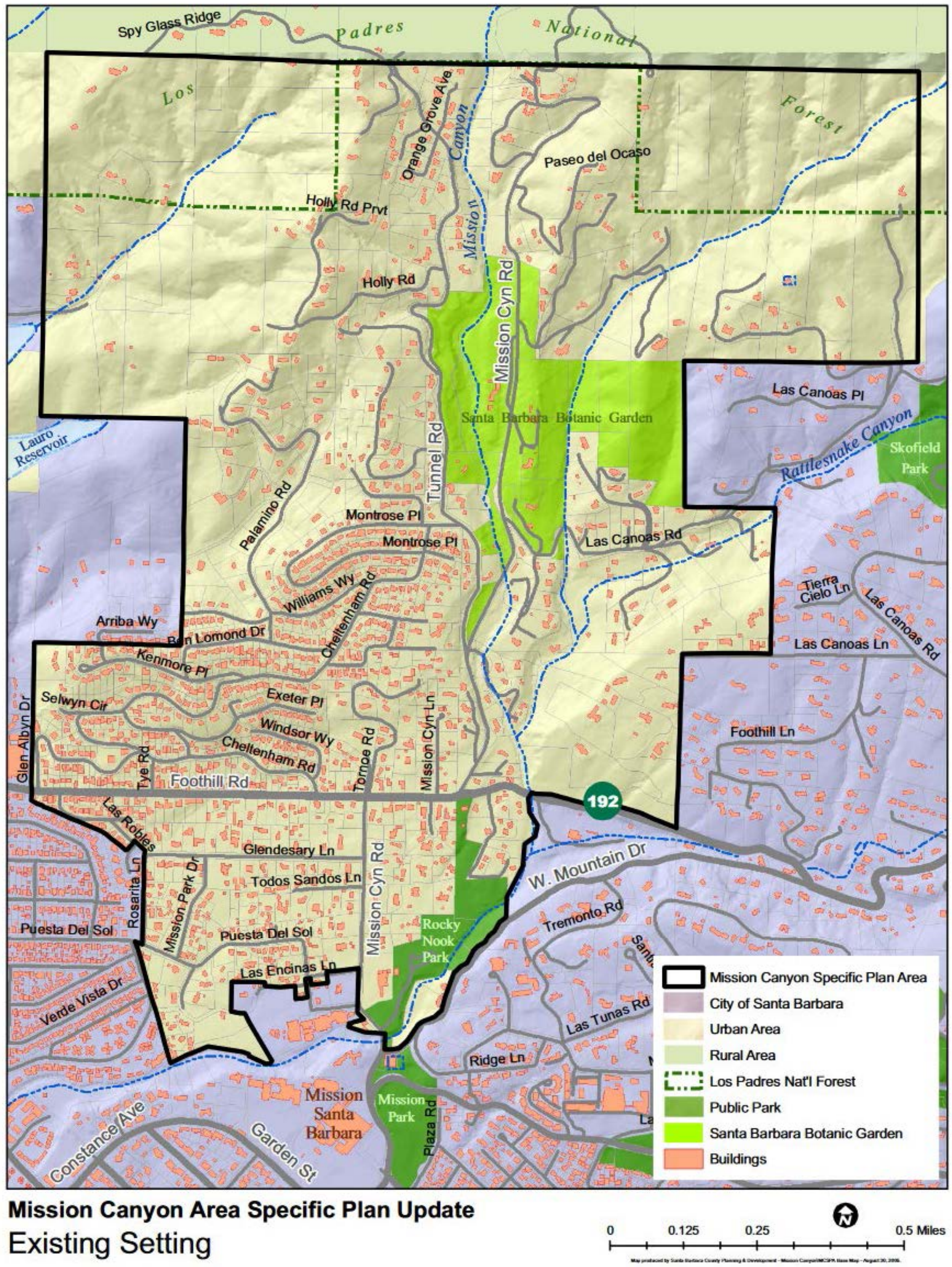


Figure 4.2. Buildings in Mission Canyon (Mission Santa Barbara upstream to above the debris dam) and lower Rattlesnake Canyon (from the County of Santa Barbara Planning and Development Department).

Topography, geology, geomorphology, springs/surface water

During a number of summer-fall field surveys in 2021 and 2022 this report's authors mapped the distribution of pools, springs, and groundwater seeps in upper Mission and Rattlesnake Creeks, as well as the dimensions of pools and whether they contained water or not (Figure 4.3). We examined relationships between springs, underlying geological formations and features (landslide scars, debris flow deposits), and the distribution of pools containing surface water during the dry season.

The Mission and Rattlesnake Creek catchments drain a series of alternating sandstone and shale formations that consist of steeply southward dipping and overturned beds of marine and terrestrial sedimentary rocks (Minor et al., 2009, Dibblee, 1966). Each unit also contains inter-bedded lenses of either shale or sandstone (Minor et al., 2009, Dibblee, 1966). The alternating lithologies are eroded by the southward-flowing stream network into topographic zones with rugged, near vertical ridges on the sandstones and lower, smoother, convex ridges on the shales (Keller et al., 2020). Stream channels contain sandstone boulders ranging from 0.25 ~ 6 m in diameter that are derived primarily from the Coldwater and Matilija Sandstone Formations. Although frequently found, gravel is commonly limited to occasional deposits in low-gradient sediment storage sites in pools and downstream of boulder accumulations.

We surveyed 169 pools in Mission Creek and 161 pools in Rattlesnake Creek, mapping their distributions and depths, evaluating geological influences on their development, examining their associations with springs and seeps, and identifying potential impediments to steelhead migration. We described stream geomorphology, potential aquatic habitat, and the effects of anthropogenic features in these creeks extending upstream from Rocky Nook Park to their uppermost tributaries (see Appendix 4.1). We collected data on pool type (step, forced, combined, plunge), step height, grain size in the pool tail, and the presence of water at each pool location during dry baseflow conditions. ~15% of the surveyed reaches contained surface water supplied by groundwater springs, constituting the major rearing and refuge habitat for steelhead trout (*Oncorhynchus mykiss*) and other sensitive aquatic species (Figure 4.3).

Pools and surface flows throughout the lower-half of the study area are generally connected over reach length scales of 100's of meters, but are disconnected by multiple human-made barriers, including bridges at Highway 192, Las Canoas Road, and Mission Canyon Road, and the Mission Dams and debris dams on both Mission and Rattlesnake Creeks. These barriers have the potential to impede the migration or instream movement of steelhead (Figure 4.3).

Pool formation is associated with boulders and resistant sandstone beds throughout the study area. The boulders are derived from the Coldwater and Matilija Sandstone Formations, as well as from sparse sandstone lenses that occur within the Cozy Dell and Juncal Shale Formations. In general, the location, type, and spacing of pools is regulated by the spatial and size distribution of boulder deposits, and resistant sandstone beds that create substantial elevation drops (i.e., waterfalls).

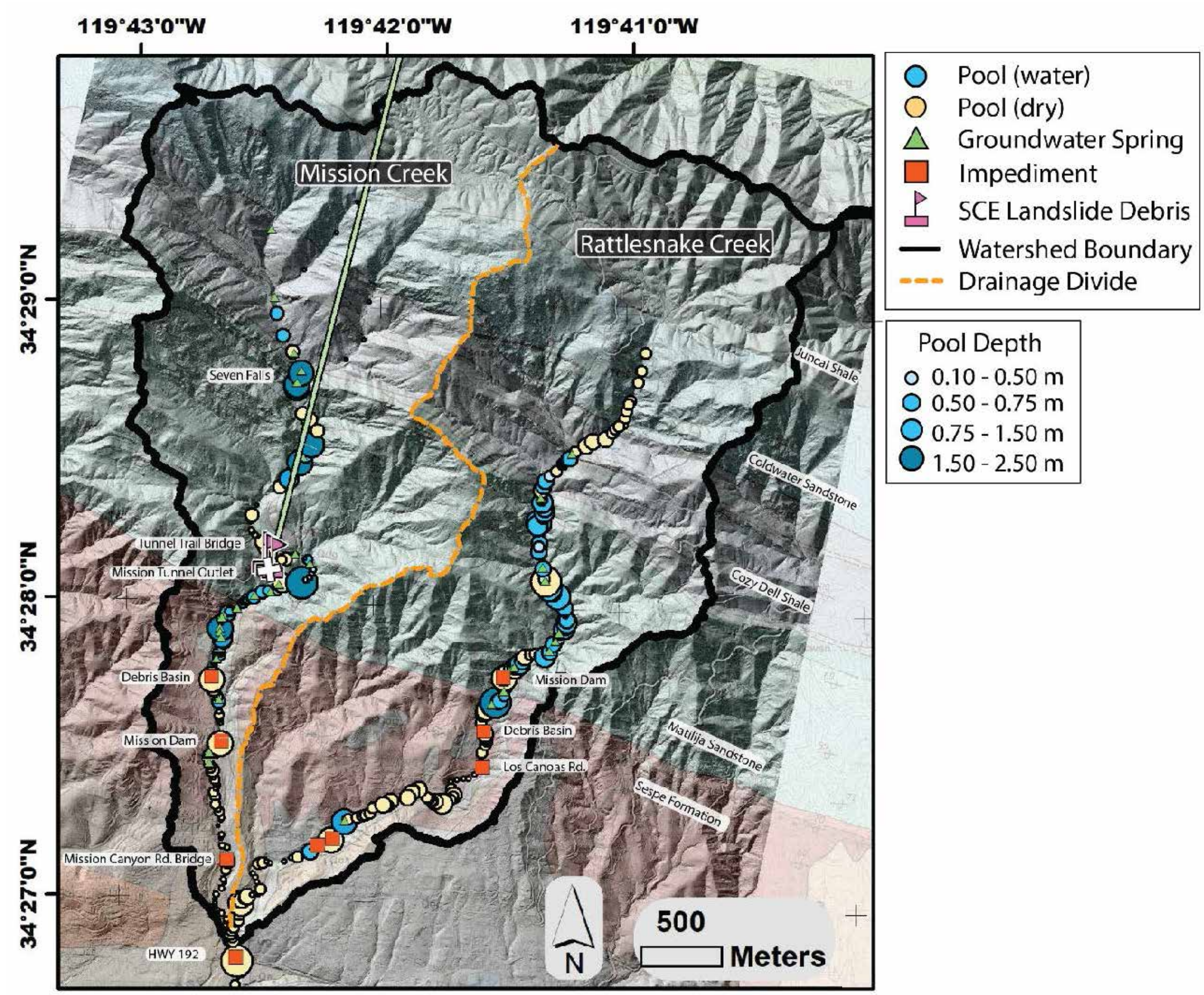


Figure 4. 3. The distribution of pools, pool depths, and surface water in Mission and Rattlesnake Creeks during summer-fall, 2021 and 2022. Pools are indicated as dots, with blue dots indicating surface water, yellow dots denoting dry pools, and blue dot size indicating pool depth (in m). Light blue lines indicate stream channels whether wet or dry. Green triangles are groundwater springs, pink symbols delineate stream segments affected by Southern California Edison's (SCE's) grading activities, and red squares represent labeled potential impediments to steelhead migration. Underlying color bands indicate labeled geological formations. We surveyed pools upstream of the Tunnel Trail bridge in Mission Creek, and upstream of the Coldwater / Cozy Dell contact in Rattlesnake Creek, in early summer of 2021 after flows had receded to low levels. The presence of water and pool depths downstream of the Tunnel Trail bridge in Mission Creek and the Coldwater/Cozy Dell Contact in Rattlesnake Creek were mapped in late summer (September) of 2022.

Pool depths are variable owing to variation in the size distribution of boulders that are deposited in the stream channel, but also depend on the height of the waterfall at the pool head with some of the deepest plunge pools in Mission and Rattlesnake Creeks located just below waterfalls. Boulders > 1~2 m in diameter typically are immobile during floods and are usually transported by debris flow processes. In turn, the spatial distribution of the boulders in both Mission and Rattlesnake Creeks is set by (i) stochastic debris flow events that transport and deposit boulders at lower elevations in the mountain channel network (Morell et al., 2021) and (ii) stochastic colluvial mass wasting processes such as bank collapse and rockfall (Keller et al., 2015). These large boulder accumulations, which are often composed of meter-sized boulders lining the channel, also affect the distribution of groundwater springs.

Based on our observations and mapping, we conclude that:

1. The deepest pools, and highest density of pools with depths > 0.75 m, are found between Mission Dam and the Mission Tunnel Outlet on Mission Creek and from the Las Canoas Road bridge upstream to the contact zone between the Coldwater and Cozy Dell Geological Formations. Both of these stream reaches had surface flow and pools that were partially to completely full throughout the summer and fall. Steelhead have been most consistently sighted in these sections of these reaches.

2. Proceeding downstream from the top of the watershed, pools fed by groundwater begin appearing at the contact zones between the Coldwater Sandstone and Cozy Dell Shale Formations. Our results suggest that water infiltrates extensively through the highly-fractured shales and sandstones, and that groundwater is channeled through fractures and fissures emerging as springs where these fissures intercept the surface with groundwater, and also flows beneath debris-flow deposits. Groundwater flowing beneath debris-flow deposits is shallow and does not always reach the surface because of the stream channel's geometry and the permeability of the channel deposits. This shallow water emerges to the surface at the nose of the debris flow or where the groundwater intercepts an escarpment. Figure 4.3 indicates that water in the form of pools and springs is found throughout the reaches of Mission Creek and Rattlesnake creeks that were surveyed. See chapter 6 for the presentation of an equivalent geologic model that transforms the complex 3D pathways of bedrock groundwater flow into a 2D approximate representation of groundwater flow along the Mission Tunnel in the study area.

3. Our results suggest that groundwater emerges as surface water over the Cozy Dell and Matilija Formations more frequently and extensively in Rattlesnake than Mission Creeks. The Mission Creek and Rattlesnake Creek catchments are very similar, with the major difference being the presence of the Mission Tunnel under the Mission Creek catchment. Farther downstream, water percolating through fractured sandstone beds often emerges at the downstream end of large debris flow and landslide deposits in Mission Creek.

4.3. Soil and Water Chemistry

Soils in the Mission and Rattlesnake catchments are predominantly sandy loams, classified as Typic Dystroxerepts from the Maymen series (Hanan et al., 2016). See Figure 2.10 (chapter 2) for a soils map of the study area based on the United States Department of Agriculture (USDA) soil taxonomy. Bedrock is highly fractured, primarily marine Cretaceous through Miocene arkosic sandstones and shales (Dibblee, 1966). See Chapter 6 for an in-depth description of the study area's geologic setting. Because study catchments are dominated by uplifted marine sandstones and shales, stream waters have high calcium, magnesium, sulfate, and bicarbonate (listed as alkalinity) concentrations, a slightly alkaline pH, and low nutrient (nitrogen (N) and phosphorous (P)) concentrations (Table 4.1).

Aguilera and Melack (2018) presented nutrient and suspended sediment concentrations and fluxes in relation to hydrological variability, and fire and landscape characteristics, for the Rattlesnake Creek and Mission Creek (above Rocky Nook) catchments for water years 2002 to 2015. Concentrations of nitrate, ammonium and phosphate were low, except after wildfires, when initial post-fire flushing led to much higher values. Export was higher in years with more rainfall and runoff (e.g., 2005) and after fires (e.g., 2010 and 2011) (Figure 4.4)

Goodridge et al. (2018) investigated the relative balance among N loss, plant and soil microbial N uptake, and stream N export for Rattlesnake Canyon after 61% of the catchment was burned by the high intensity 2009 Jesusita Fire. Soil N in the burn scar was 324% higher than soil N in an unburned area at the beginning of the first post-fire wet season, but had returned to pre-fire levels in about 2 months. Stream N export was 1500% higher than pre-fire export during the first post-fire storm, then returned to pre-fire levels after about 3 months.

Nitrate concentrations in 2008 to 2011 were higher in Mission Creek just above the Botanic Garden than at two sites in Rattlesnake Creek, even before the Jesusita Fire occurred, and the nitrogen stable isotope (dN15) signatures of algivores and predators were much higher at Mission than Rattlesnake Creek in 2010 (Cooper et al. 2015; Klose et al. 2015; Page et al. 2019). These data suggest increased inputs from more extensive residential development near and above the Botanic Gardens in Mission compared to sites draining undeveloped lands in Rattlesnake Creek, perhaps owing to septic tank leakage.

Although residential development and wildfires can increase nutrient, contaminant, and sediment inputs to streams (see above and below), the distribution and abundance of sensitive aquatic species also can depend on water temperature and dissolved oxygen concentration. Point daytime measurements of temperature and dissolved oxygen in Mission and Rattlesnake Creeks indicate that temperatures remained cool, below upper threshold limits for steelhead (ca. 25^{o}C, Myrick and Cech, 2001), from 2008 through 2022, probably because remaining stream pools were fed by cool springs during the hot, dry season (Figure 4.5).

Nicole-Berry Frazier (2018) analyzed a much more comprehensive, continuous temperature dataset from the UCSB Santa Barbara Channel Long-term Ecological Research (SBC LTER) program and found that average minimum daily temperature in the winter was 9.6 ^{o}C and the average maximum daily temperature in the summer was 19.6 ^{o}C for Mission Creek (Mission Canyon Bridge) with very similar results from Rattlesnake Creek at the Las Canoas Bridge (9.7 to 20^{o} C). Using models of temperature fluctuations, Nicole-Berry Frazier (2018) estimated that temperatures would exceed 25^{o}C at these sites for 4 (Mission) and 11 (Rattlesnake) hours per year. These two LTER stations were lower in their watersheds and more intermittent than sites where sensitive species, such as steelhead, were sighted in dry periods, and individual Southern California Steelhead have been observed at temperatures nearing 30^{o}C (Sloat and Osterback, 2013). This report's authors found that daytime water temperatures ranged from 17.1 to 21.5 ^{O}C in upper Mission Creek pools in late September, 2022.

Table 4.1. Chemistry of water from Rattlesnake Creek (March 1984 to March 1985) and of precipitation from Santa Barbara (winters of 1981-82 and 1982-83). Stream samples were taken monthly and precipitation was sampled on an event basis. Range of values measured are shown. Concentrations are in micro eq/L. From: Melack et al. (1986).

Characteristic	Rattlesnake Creek	Precipitation
pH	[7.72, 8.46]	[3.73, 6.07]
Alkalinity	[3511, 4400]	--
NH_4^+	[0, 0.3]	[0, 28]
PO_4^{3-}	[0, 0.6]	[0, 3]
NO_3^-	[0, 4]	[0.1, 11]
SO_4^{2-}	[4261, 5361]	[10, 130]
Cl^-	[231, 334]	[10, 375]
Ca^{2+}	[4667, 5915]	[2, 50]
Mg^{2+}	[2462, 3198]	[4, 100]
Na^+	[831, 1119]	[14, 350]
K^+	[36, 74]	[1, 30]

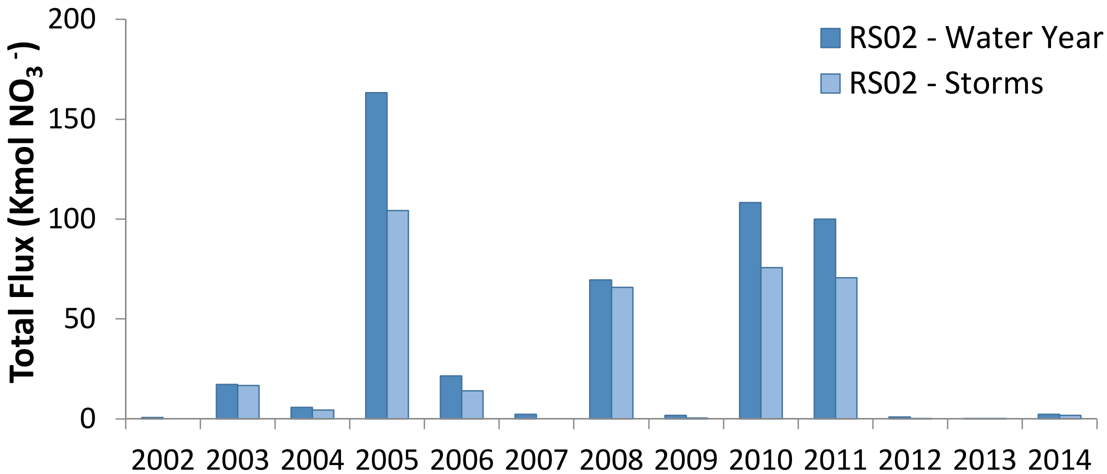


Figure 4.4. Nitrate fluxes (cumulative water year and during storms) from the catchment drained by Rattlesnake Creek (RS02) from 2002 to 2014. figures for Rattlesnake, RS02).

Dissolved oxygen (DO) levels vary greatly over daily, weekly, seasonal, and interannual cycles. DO levels are influenced by many factors, including flow rates or volumes, temperature, turbulence, the decomposition of organic material, algal photosynthesis, and community respiration (Cox, 2003). Based on data collected from local streams from 2008 to the present, we observed that daytime DO levels in Mission and Rattlesnake Creeks declined during the 2012-16 drought and were a function of flow continuity, i.e., the degree to which pools were isolated or sustained substantial flows (Figure 4.5).

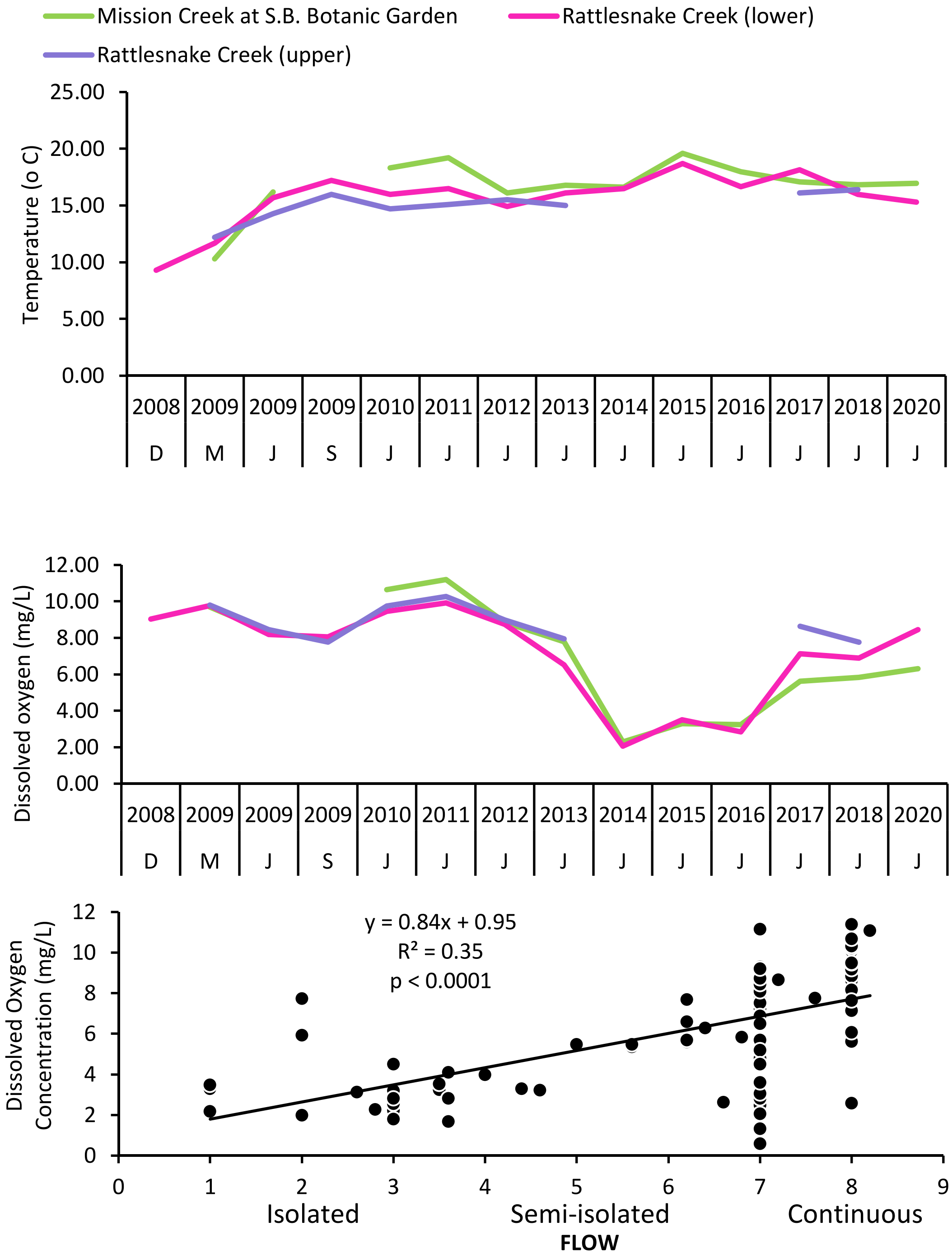


Figure 4.5. Daytime point measurements of temperature (top) and dissolved oxygen concentration (middle) at stations in Rattlesnake and upper Mission creeks from Dec. 2008 to Sept. 2009, then at annual intervals (June-July) from 2010 through 2020. Bottom graph shows the relationship between DO concentration and flow continuity (isolated to well-connected pools) with associated regression statistics. Flow continuity (FLOW) was scored on a 10-point scale, representing isolated (FLOW = 1 – 3), semi-isolated (FLOW = 4 – 6, a trickle into each pool), and well-connected pools with substantial inflow (FLOW = 7 – 9).

We also observed that steelhead disappeared from two stream reaches with pools containing surface water during the drought, presumably because dissolved oxygen (DO) levels declined to near or below lethal steelhead limits ($\leq$ 2 mg/L). Embryos and larvae of steelhead or rainbow trout require > 8 mg DO/L for high survivorship, whereas adults and juveniles show high mortality at < 3 mg DO/L with diminished feeding and growth rates at < 6 to 8 mg DO/L (Carter 2005). In general, water quality often deteriorates as flows recede and pools become more isolated.

4.4. Catchment vegetation

Upland vegetation across the watershed is dominated by chaparral with a diverse array of shrubs and forbs. Many of these plants provide critical food resources to wildlife: toyon berries are important for birds; holly-leaf cherry and manzanita berries for mammals (including bear, coyote, and fox); and sage seeds for granivorous birds and rodents.

On mountains in dry climates, creeks are often the only place where water is readily available during dry seasons. The availability of relatively large amounts of water in an otherwise mostly dry landscape renders riparian vegetation distinctive, typically with higher biomass and different seasonal trends than upland vegetation. Riparian woodlands are biodiversity hotspots, provide many ecosystem services, and support water, food resources, habitat, and migration corridors for terrestrial and aquatic animals.

Within our region, deciduous riparian trees like sycamore (*Platanus racemosa*), alder (*Alnus rhombifolia*), and willow (*Salix* sp.) are obligate riparian species with shallow roots typically less than 2 to 2.5 m deep, and generally require constant access to shallow groundwater along creeks (Cooper, 1922; Stromberg, 1993; Canadell 1996; Kibler, 2021). By contrast, evergreen trees like coast live oak (*Quercus agrifolia*) and bay-laurel (*Umbellularia californica*) can have roots up to 10 m deep (Cooper, 1922; Canadell, 1996), allowing them to tap deeper groundwater tables or live at sites with no accessible groundwater. Often, our mountain creeks are characterized by a narrow band of deciduous vegetation along the channel (particularly sycamore or alder) adjacent to an upslope woodland of evergreen trees (live oak and bay-laurel).

For this study, we conducted surveys in the field and analyzed remotely-sensed data products (USGS, 2018; Copernicus, 2021) to assess the composition and condition of riparian vegetation along Mission and Rattlesnake Creeks (Fig. 4.6). We measured canopy cover with a densiometer and mapped surface water and riparian tree composition in fall of 2021 and 2022, at the end of the dry season when water levels were lowest and vegetation experienced maximal water stress. We used LiDAR data collected in 2018 to generate maps of terrain elevation, slope, and vegetation height across the watershed (Fig. 4.7), and aggregated satellite time series imagery to build monthly maps of vegetation greenness. We compared data and maps of riparian plant vigor to geologic, topographic, and hydrologic data. We focused on relationships between plant vigor metrics and geological layers relevant to ground and surface water dynamics.

Figure 4.6. Examples of trees characteristic of riparian woodlands in our area. Left, white alder (*Alnus rhombifolia*), and right, California bay-laurel (*Umbellularia californica*).

We found that canopy cover and the fraction of obligate riparian trees were 11% and 96% higher, respectively, within 5 m of surface water sources during our surveys (Fig. 4.8). In the vicinity of Mission Tunnel's south portal, Mission Creek was consistently drier than Rattlesnake Creek at corresponding elevations within the same rock formation (the Coldwater Sandstone). On the Coldwater Formation, Rattlesnake Creek's riparian corridor had 365% more areal coverage of obligate riparian deciduous woodland and 71% greater average vegetation height than Mission Creek (Fig. 4.8). Although our evergreen trees are less sensitive to deeper water tables than our deciduous trees, evergreen riparian woodland extent also was reduced in patches along Mission Creek, and chaparral or introduced annual plants had invaded dewatered sections. On the Sespe Formation to the south, below the lowest elevation of the Mission Tunnel, surface water was more extensive on Mission Creek (22.8%) than on Rattlesnake Creek (4.6%). In this area, the Mission Creek riparian woodland was slightly more vigorous than that on Rattlesnake (e.g., 12% greater mean vegetation height, 17% greater cover of obligate riparian woodland), although the differences were much smaller than those observed on the Coldwater Sandstone Formation (Fig. 4.8).

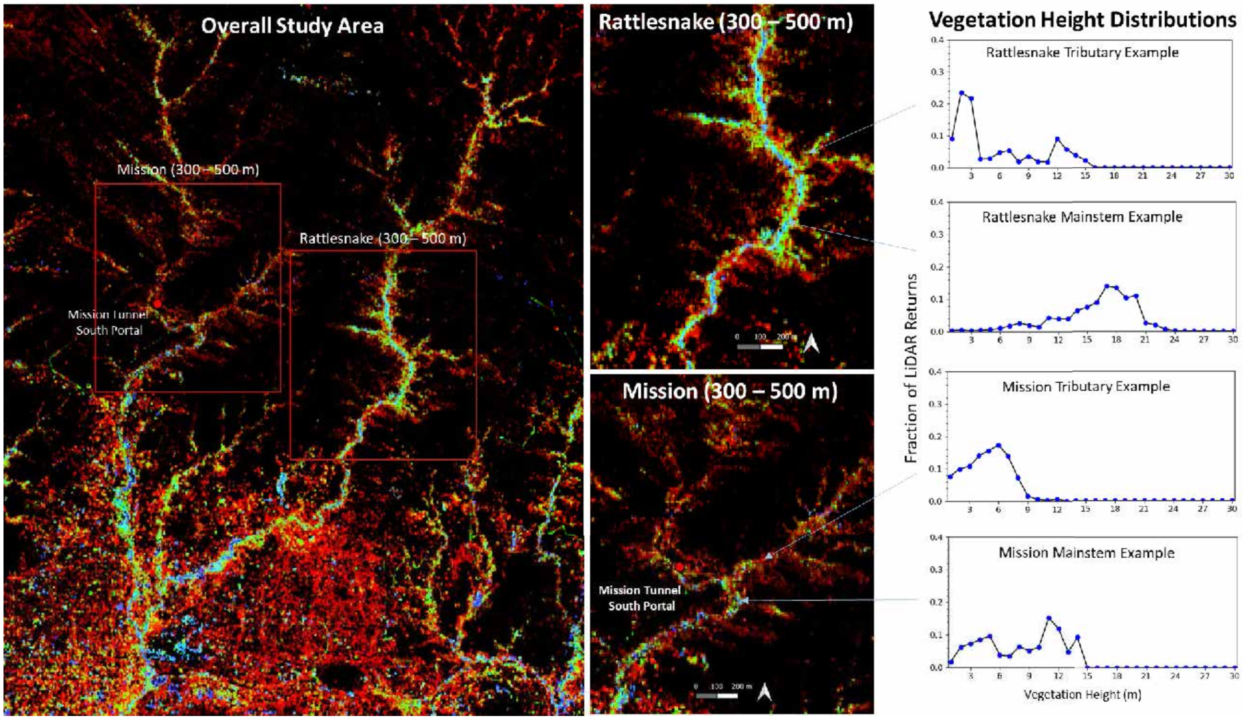


Figure 4.7. Vegetation height distributions mapped across the Mission and Rattlesnake Watershed with LiDAR (left), with red rectangles indicating magnified images (center) ranging from approximately 300 to 500 m elevation along each creek. Magnified areas correspond roughly to the reaches overlying the Coldwater Sandstone Formation. In both raster images, color scale is Red: fraction of vegetation 5-10 m in height; Green: fraction 10-15 m; Blue: fraction $\geq$15 m. The approximate location of Mission Tunnel's south portal is shown as a red dot. At right, example vegetation height distributions for select points are shown (locations indicated by gray arrows).

Rattlesnake's Sespe reach had less surface water and was more dominated by shorter evergreen trees, but it did not show substantial loss of woodland and invasion of other vegetation types, as was observed in the Mission Creek reach overlying the Coldwater formation. This difference may imply a much smaller difference between creeks in underlying groundwater elevation on the Sespe (below the Tunnel) than on the Coldwater (at or near the Tunnel's south portal).

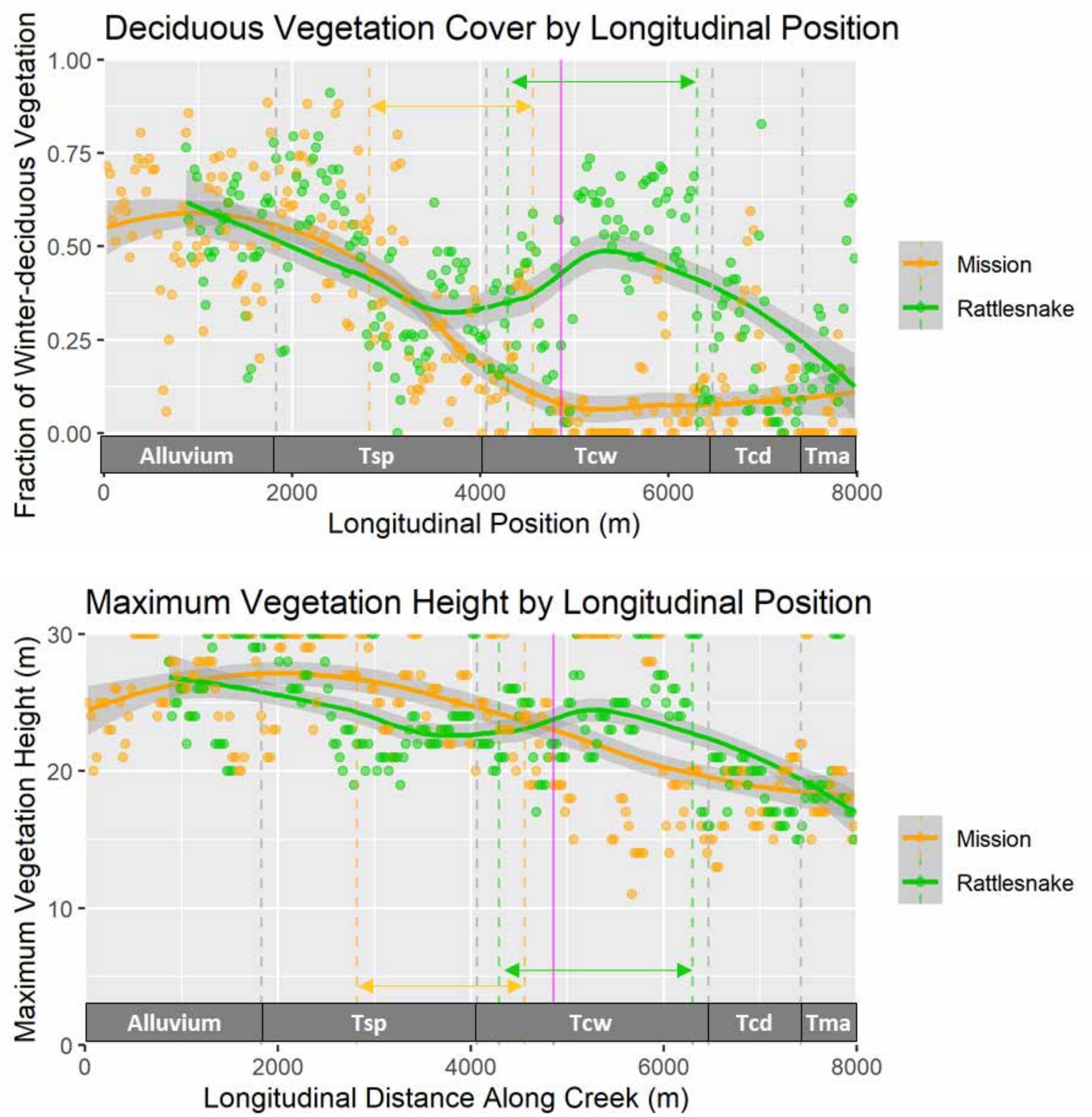


Figure 4.8. Fraction of shallow-rooted deciduous riparian trees (above) and mean vegetation height (below) by distance upstream from the lowest boundary of Rocky Nook Park. We plotted separate LOESS regression curves for Mission Creek and Rattlesnake Creek, with 95% confidence intervals shown by gray bands. The pink vertical line shows the location of the Mission Tunnel's south portal. Green and orange arrows and vertical dashed lines, respectively, indicate the spatial extent of surface water during summer in Rattlesnake Creek and Mission Creek. Geological formations are indicated and labeled at the bottom of the plot and creek transitions between geologic formations are indicated by gray dashed lines. Geologic formation codes are as follows: Tsp for Sespe Formation; Tcw for the Coldwater Sandstone; Tcd for the Cozydell Shale; and Tma for the Matilija Formation.

In addition to water availability, the composition and health of vegetation is affected by wildfire (see Figure 4.9). Vegetation responds differentially to fire based on its composition, structure, and foliar moisture levels. Chaparral usually burns at natural intervals of 30 to 100 years, but quickly resprouts from basal burls or regenerates from a dormant seed bed activated by fire. Similarly, oaks are resistant to fire and both oaks and bay-laurel recover quickly from fires via resprouting. By contrast, riparian woodlands often burn less frequently and intensely than upland vegetation in this region, because of their moist environment and high leaf water content. However, this pattern depends on the access of riparian trees to water, with vegetation at intermittent stream sites tending to burn more severely than that at perennial sites (Cooper et al. 2021; McMahon et al., 2023). When they do burn, riparian trees can rapidly re-establish and grow provided water supplies are sufficient. When the Tea and Jesusita Fires burned the Mission and Rattlesnake Watersheds in 2008 and 2009, riparian vegetation burned at a lower severity than nearby upland vegetation, but both vegetation types recovered to pre-fire greenness in about eight years, even when stalled by a major drought (2012-2016) (McMahon et al., 2023). During the fires, more riparian vegetation burned at Mission Creek than Rattlesnake Creek (e.g., riparian burn extent of 90% and 81% at two Mission sites, compared to 42% and 44% at two Rattlesnake sites).

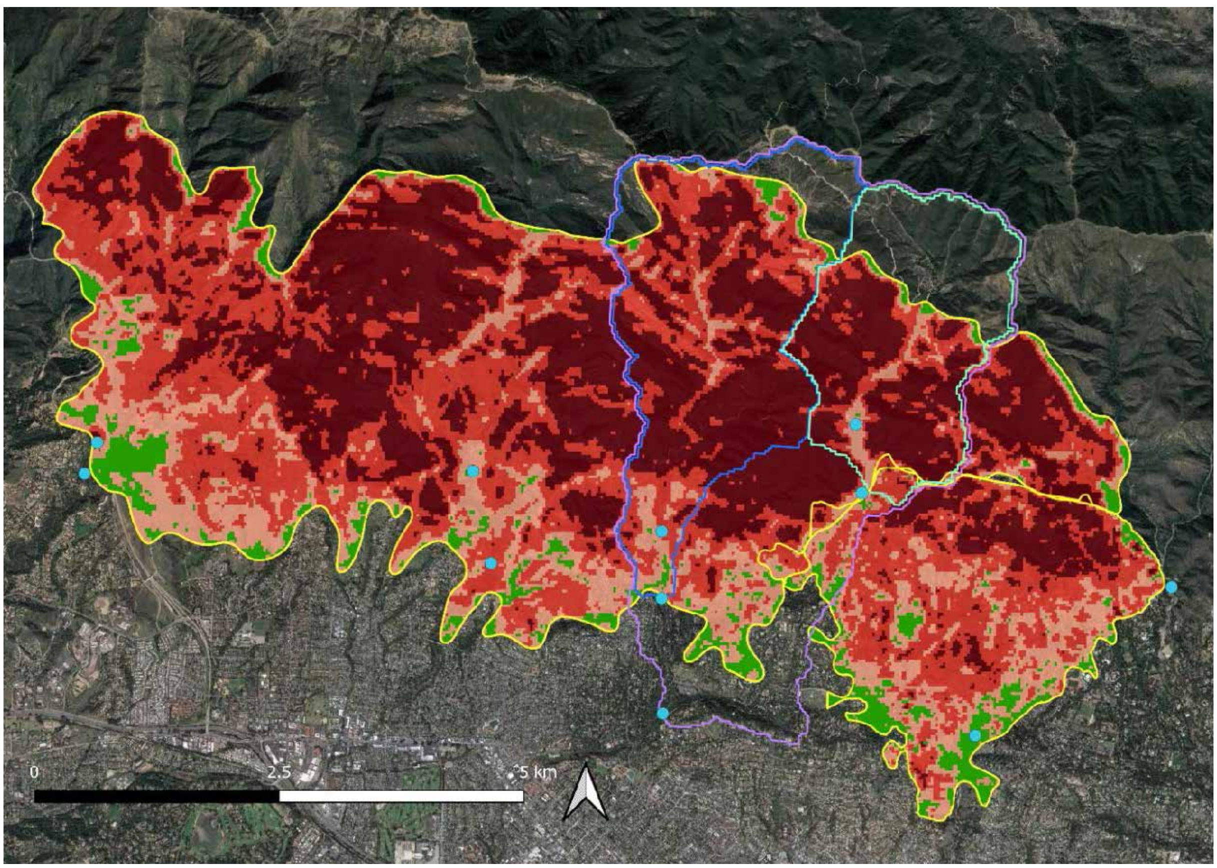


Figure 4.9. Fire severity map for Mission and Rattlesnake Watersheds during the Tea (2008 (lower right, outlined with yellow line)) and Jesusita (2009) Fires (yellow line surrounding the left side of map, adjacent to Tea Fire). Burn severity is indicated as: green= unburned; pink = low severity burn; red = moderate severity burn; and dark red = high severity burn. The overall watershed for Mission and Rattlesnake Creeks upstream from Rocky Nook Park is indicated with a purple line (McMahon et al. 2023).

These investigations emphasize the primacy of water availability in determining the composition, width, height, and health of riparian vegetation, and its resistance and resilience to wildfire. Any increase in water inputs and flows in Mission Creek should increase the vigor of riparian vegetation and contribute to its function as a barrier to the spread of wildfire.

4.5. Aquatic food webs and biota

Aquatic food webs in Mission and Rattlesnake creeks are supported by leaf litter that falls into the streams and by the production of algae, which grow in the streams (Figure 4.10). Most undisturbed streams in this region are shaded by riparian vegetation, which results in cool water temperatures, stabilizes banks and soils, intercepts upland contaminant and sediment inputs, acts as habitat and movement corridors for wildlife, and delivers leaf litter and terrestrial invertebrates to streams (Naiman and Décamps, 1997). Leaves that fall into the stream are colonized and decomposed by a variety of microbes (bacteria and fungi), which make leaf litter more nutritional and palatable to stream consumers (Allan et al., 2021). The microbes are consumed, in turn, by the meiofauna (0.04 to 0.5 mm), such as unicellular protozoans and multicellular round worms, rotifers (wheel animalcules), gastrotrichs, tardigrades (water bears), and other microscopic animals; by microcrustaceans that are just visible to the naked eye (< 2 mm) such as copepods, cladocerans (water fleas), and ostracods (seed shrimp); and by a variety of macroinvertebrates, such as aquatic insects, crustaceans (scuds or amphipods), aquatic earthworms (oligochaetes), and mollusks (such as fingernail clams and snails). Leaf litter that has been conditioned by microbes is ingested and fragmented by macroinvertebrates called shredders, primarily cased caddisfly larvae in local streams, producing smaller detrital particles that are ingested by collectors, including filterers that use head fans or nets to collect small particles carried downstream in the water column by currents and deposit feeders that ingest small particles after they have settled on the bottom (various oligochaetes, mayfly nymphs, true fly and midge larvae) (Fig. 4.10). Stream and riparian ecosystems exchange substantial subsidies, because many larval aquatic insects emerge into a terrestrial, flying adult stage that forms the primary food source for many riparian predators (birds, bats, frogs, toads, newts, spiders, predatory insects). Terrestrial insects, which are consumed by surface insects (whirligig beetles, water striders, backswimmers) and steelhead, fall into the stream from riparian vegetation.

Where riparian vegetation is damaged or destroyed by human or natural disturbances, the canopy opens up, more light reaches the stream bottom, and stream temperatures increase, engendering the proliferation of algae (Cooper et al., 2015; Klose et al., 2015). Although various algae, particularly unicellular diatoms, are commonly found in shaded streams, opening the canopy often causes blooms of filamentous green algae, particularly when combined with increased nitrogen and phosphorous inputs from leaky septic systems and during spring runoff (Klose et al., 2015). Diatoms, both those growing on the stream bottom and on filamentous algae, are the dominant food source for grazers, including both frog tadpoles and invertebrates that collect loose algae or scrape attached algae from substrate surfaces (Allan et al., 2021). Although vascular plants, such as water cress, cattails, sedges, and rushes occur in local streams, they are usually resistant to grazing and enter food webs via detrital pathways (i.e., after they die and decompose).

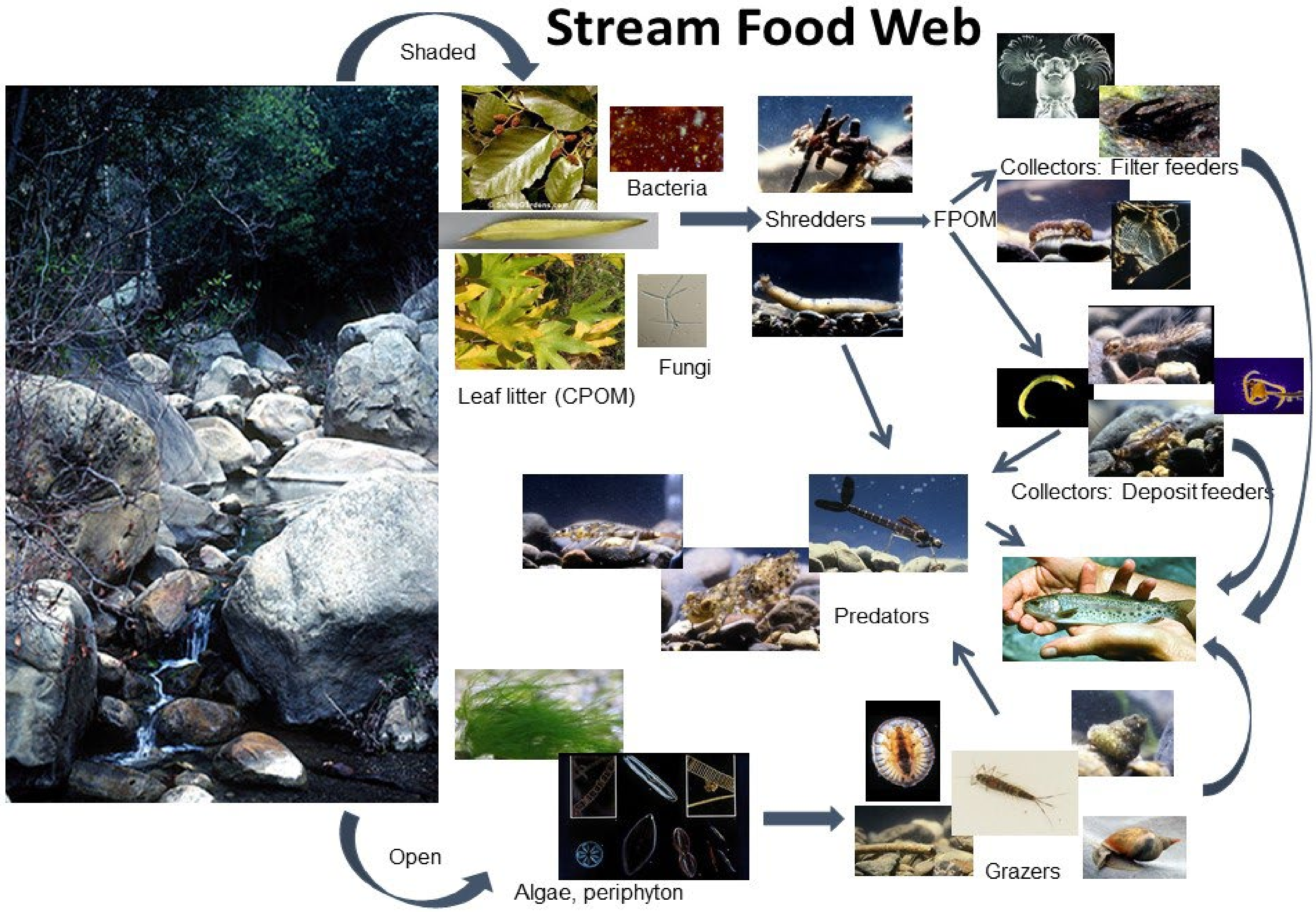


Figure 4.10. Typical aquatic food web in Santa Barbara coastal streams. Most pictures are of organisms collected from Mission and Rattlesnake Creeks. Site picture is of Rattlesnake Creek.

The top predators in local, headwater streams often are steelhead, although California newts can also function in this role. When currents are slow or non-existent, such as in stream pools during the dry season, steelhead assume a cruising foraging mode, i.e., they swim more continuously throughout pools and consume prey that are found at the surface (e.g., terrestrial invertebrates that fall into streams from riparian vegetation), in the water column, or on top of the bottom (Cooper, 1984; Rossi et al., 2021). In these cases, steelhead reduce large, epibenthic, water column, and often predatory invertebrates, such as various damselfly, dragonfly, true bug, and active beetle (Odonata, Hemiptera, Coleoptera (OCH) taxa, resulting in an increase in the prey of these invertebrate predators, such as some mayfly nymphs (Hemphill and Cooper, 1984; Cooper, 1988; Wiseman et al., 1993). These trophic cascades from steelhead to invertebrate predators to invertebrate grazers are often short-lived, however, because steelhead switch to smaller, algivorous prey (mayflies, ostracods, snails) after they have reduced large, exposed predatory OCH taxa. These trophic cascades also can vary seasonally, because stonefly larvae, some mayfly (e.g., *Ameletus*, *Baetis*) nymphs, and blackfly and net-veined midge larvae are most abundant when flows are high (winter and spring of wet years), whereas many OCH taxa, tadpoles, other mayflies (*Callibaetis*), and mosquito larvae are most abundant when flows are low and pools are semi-isolated or isolated (summer-autumn, drought years). Because the Southern California Steelhead is an apex predator and an iconic, endangered, umbrella, and flagship species, we consider this species in more detail in a separate chapter (Chapter 5) of this report. In general, water quality and habitat conditions that support steelhead also will support many other sensitive aquatic and riparian species.

Microbes, algae, plants, and animals in local streams also are affected by disturbances, such as floods, drought, wildfire, and debris flows. After floods or drying, microbes and diatoms quickly colonize substrate surfaces followed by visible macroalgae, such as filamentous green algae then colonial cyanobacteria, depending on nutrient availability, a function of current speeds and nutrient concentrations, as well as light levels (Busse et al., 2006; Klose et al., 2012, 2015). Many aquatic animals also are reduced by disturbances such as large floods, drying during drought, and scouring floods and debris flows after wildfires (Cooper et al., 2015, 2021). Many aquatic insects have aerial adult forms that can return to and lay eggs in streams, with the larvae of some taxa, such as those of blackflies, midges, and baetid mayflies, quickly re-colonizing streams and reaching high abundances after disturbances. Taxa with longer life cycles or that spend their entire lives in aquatic environments often colonize more slowly and may take some time to recover to pre-disturbance levels.

Two fires (2008 Tea, 2009 Jesusita) affected at least parts of the Mission Creek catchment in recent years. The impacts of wildfires on local streams depend on the extent, intensity, severity, frequency, timing, and spatial distribution of wildfires and ensuing rain events, as well as on local topographic, geologic, and vegetation conditions (Verkaik et al., 2013; Bixby et al., 2015). The destruction or damage of upland vegetation and changes in soil microbes and chemistry by fires often result in short-term (< 1 – 2 years) increases in water, sediment, and solute (e.g., nutrient) inputs to local streams, but decreases in leaf litter, other organic matter, and organisms owing to wash-out or burial (Klose et al., 2015; Cooper et al., 2021; McMahon et al., 2023). The long- term effects of fire on streams depend on whether or not fires destroy or reduce riparian vegetation (Verkaik et al., 2013; Cooper et al., 2015, 2021). In watersheds where upland vegetation burns but riparian vegetation does not, the recovery of stream communities is often rapid. If wildfires or ensuing debris flows damage or destroy riparian vegetation, then water temperatures, light levels, and algal biomass increase, but bank stability and leaf litter inputs decrease, with bottom-up effects on the food web (McMahon et al., 2023; Fig. 4.11). Wildfire impacts can range from no to severe impacts on the aquatic biota mediated through changes in habitat (flow and geomorphology) and both bottom-up (via increases in nutrients and light) and top-down (via loss of key consumers) processes. In the latter case, post-fire scouring and debris flows, as well as drought, have extirpated some local steelhead populations, resulting in an increase in invertebrate OCH predators in a year or two after disturbance. Invertebrate grazers appear to be a fulcrum for bottom-up versus top-down effects on local aquatic food webs, because they respond to both increases in algae (positively) and invertebrate predators (negatively).

The effects of land use change and human activity on local streams are similar to those for wildfire, since both are mediated through the destruction of terrestrial vegetation and changes to hydrological, geomorphological, and hydrochemical processes (Cooper et al., 2013). One important difference, however, is that wildfire impacts on streams generally do not persist for more than 5 – 10 years, concordant with the recovery of terrestrial vegetation, whereas the impacts of land use changes and other human perturbations on streams are much more permanent and sustained. Another difference is that human development and activity often result in the introduction of non-native species, which can have negative competitive or predatory impacts on native species (Riley et al., 2005; Cooper et al., 2013). Within the aquatic realm, local introduced species include non-native fish (e.g., green sunfish, mosquitofish), frogs (e.g., the bullfrog), and invertebrates (e.g., the New Zealand mud snail, Louisiana red swamp crayfish). The steep, headwater reaches of local streams, however, often lack non-native species, because these species are not adapted to the floods and drying that occur frequently in local headwater streams draining catchments with native vegetation.

Possible impacts of residential development on the lower reaches of Mission and Rattlesnake Creeks are illustrated in Chapter 3 and the hydrochemical section of Chapter 4 (above). Southern California Edison road grading activities in upper Mission Canyon resulted in damage to rock formations, soils, and vegetation along Tunnel Trail. This damage included rock and debris falls from trail verges, in some cases down to the Mission Creek channel just below the Tunnel Trail bridge and Mission Tunnel outlet.

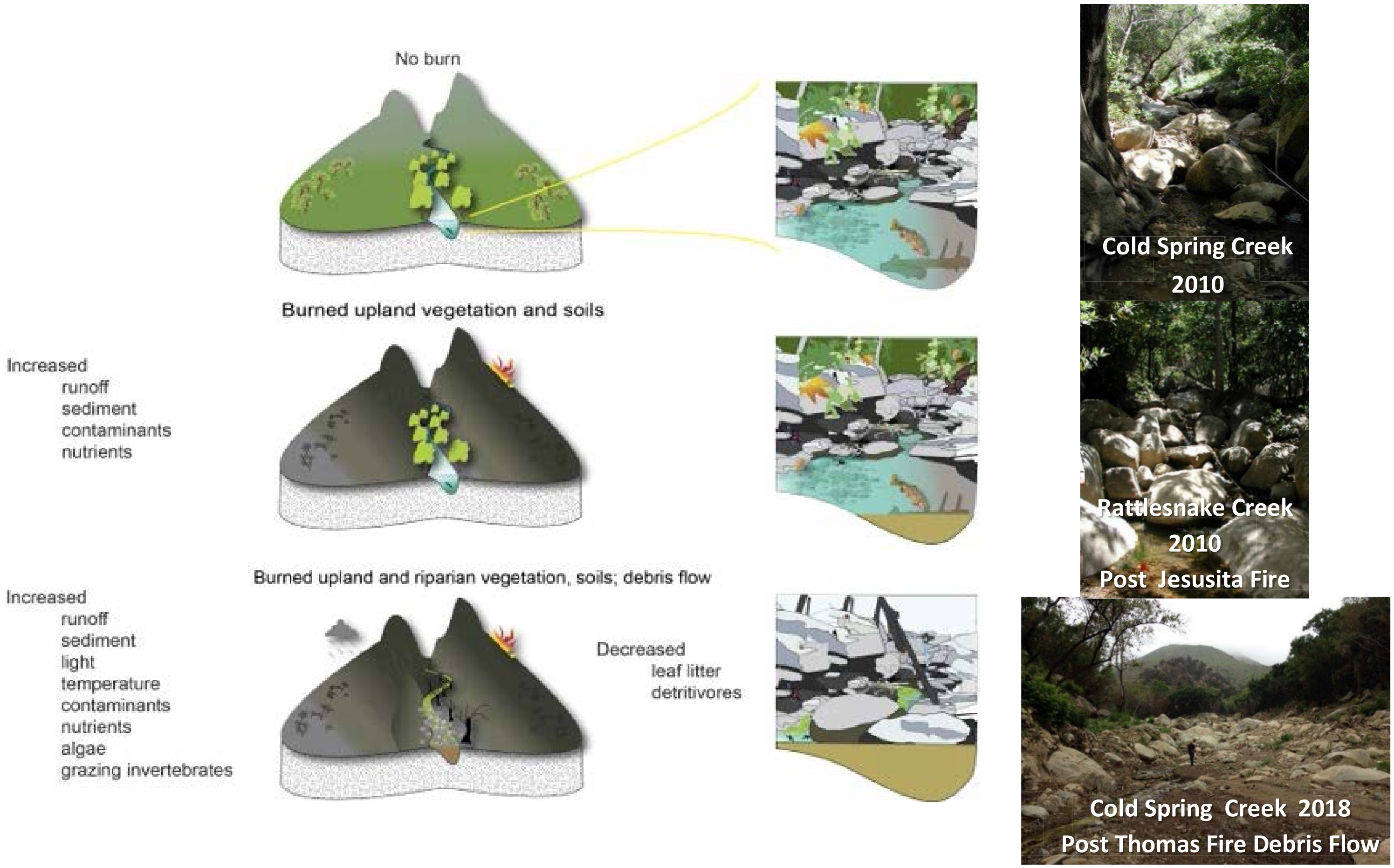


Figure 4.11. Effects of wildfire on local stream ecosystems. Panels are arranged from top to bottom as streams in catchments that were unburned (top), where upland but not riparian vegetation was burned (middle), and where upland and riparian vegetation burned followed by a debris flow (bottom), respectively.

4.6. Wildlife

A variety of amphibians and reptiles use aquatic habitats in Mission and Rattlesnake Creeks, including tadpoles of the Baja California and California tree frogs (*Pseudacris hypochondriaca*, *P. cadaverina*) and Western toad (*Bufo boreas*), larvae and adults of the California newt (*Taricha torosa*), the western pond turtle (*Clemmys mamorata*), and the aquatic two-striped garter snake (*Thamnophis hammondi*) (Ecology Consultants, Inc. 2015, 2019). Frog and newt adults enter streams to lay and fertilize eggs in spring (usually May) with larvae developing and growing quickly over the dry season, then metamorphosing into the adult form by autumn (usually September). The garter snake often preys on aquatic vertebrates, including tadpoles and small fish.

This watershed also supports many terrestrial vertebrate species in its riparian, oak woodland, and chaparral habitats, with birds constituting one of the most abundant, conspicuous, and diverse groups. Typical chaparral birds include California Thrasher, Wrentit, California and Mountain Quail, and Lesser Goldfinch (Fig. 4.12). Oak woodlands are frequented by numerous species, some of which specialize on acorns, including the Oak Titmouse, California Scrub-Jay, Acorn Woodpecker, and Band-tailed Pigeon. Other characteristic oak woodland birds include White-breasted Nuthatch, Western Screech-Owl, Spotted Owl, Northern Pygmy-Owl, and Hutton's Vireo.

In Southern California, a unique assemblage of bird species breeds exclusively in intact riparian woodlands. Characteristic species in this group include the Yellow Warbler (*Setophaga petechia*), Wilson's Warbler (*Cardellina pusilla*), Warbling Vireo (*Vireo gilvus*), Swainson's Thrush (*Catharus ustulatus*), Yellow-breasted Chat (*Icteria virens*), Willow Flycatcher (*Empidonax traillii*), Yellow-billed Cuckoo (*Coccyzus americanus*), and Bell's Vireo (*Vireo bellii*), among others (Lehman 2021). Because of the widespread loss of riparian woodland habitat, only the Yellow Warbler, Wilson's Warbler, and Warbling Vireo, which were once widespread, persist in our area, where they are now uncommon and local breeders (Lehman 2021).

We conducted bioacoustic surveys in summer 2022 to monitor riparian bird communities across the county, including along Mission and Rattlesnake Creeks. We deployed automated recording units (Hill 2019) across 27 riparian sites in the Mission Creek watershed, as well as across 118 additional riparian sites across Santa Barbara County (concentrated on the South Slopes of the Santa Ynez Mountains). We collected a total of 5600 hours of audio recordings across all sites (1053 hours at Mission and Rattlesnake Creeks). We extracted metrics of bird species composition and vocal frequency at study sites (Kahl, 2019, Table 4.2), then compared these data to information on vegetation and hydrologic conditions at each monitoring site, particularly whether sites contained or lacked surface water.

Figure 4.12. Examples of bird species in the Mission and Rattlesnake Creek Watersheds. At left, an American Robin (*Turdus migratorius*) perched on a toyon (*Hetermoeles arbutifolia*), an important riparian and chaparral shrub which provides berries to birds. At right, a California Quail (*Callipepla californica*), a common bird of chaparral areas throughout the watershed.

A broad-scale analysis across the south County revealed that the presence of surface water in summer is critically important to all of our most sensitive riparian breeding species (see Appendix).

Along Rattlesnake and Mission Creeks, we detected a total of 37 bird species. The following three are riparian-associated breeding birds which were associated particularly with wet riparian environments. Below they are listed along with the factor by which they were more frequently detected at wet than dry sites along Mission and Rattlesnake Creeks:

Canyon Wren (7.0), Hairy Woodpecker (5.6), Pacific-Slope Flycatcher (2.25)

The following woodland birds were detected more frequently in dry than wet riparian habitats in the Mission and Rattlesnake drainages. The factor by which birds were more frequently detected at dry creek sites is listed in parentheses; birds with an X were not detected at wet creek sites:

Acorn Woodpecker (7.6), American Crow (4.9), Band-tailed Pigeon (14.2), Cooper's Hawk (13.6), Dark-eyed Junco (2.5), Northern Pygmy-Owl (X), Oak Titmouse (2.5), Red-shouldered Hawk (6.6), Spotted Owl (X), Spotted Towhee (2.8), Western Screech-Owl (3.2), White-breasted Nuthatch (5.5)

One other species that generally nests in oak woodland, Hutton's Vireo, was still more frequently detected at wet than dry riparian sites (factor = 1.96).

Table 4.2: Differences in the frequency of the audio detection of bird species for wet vs. dry sites across the bioacoustics sampling domain. The "factor" gives the rate at which a bird was more frequently detected in one environment than the other. For example, Purple Finch was detected 26 times more frequently at wet than dry creek sites and White-breasted Nuthatch was detected 4 times more frequently at dry than wet sites. These data include surveys of riparian habitats conducted across the South County, including along creeks outside of the Mission and Rattlesnake Watersheds.

More Common in Wet Sites		**More Common in Dry Sites**	
Bird Common Name	**Factor**	**Bird Common Name**	**Factor**
Purple Finch	26	White-breasted Nuthatch	4.0
American Robin	8.0	Band-tailed Pigeon	2.6
Yellow Warbler	5.0	Cooper's Hawk	2.5
Wilson's Warbler	5.0	Dark-eyed Junco	2.2
Bullock's Oriole	4.5	Allen's Hummingbird	2.0
Canyon Wren	4.0	Acorn Woodpecker	1.9
Pacific-slope Flycatcher	2.4	Orange-crowned Warbler	1.7
Scaly-breasted Munia	2.0	American Crow	1.6
Chestnut-backed Chickadee	1.8	Oak Titmouse	1.3
Song Sparrow	1.8		
Common Yellowthroat	1.4		

Other birds that were detected in the Mission and Rattlesnake Creek watersheds are generalist or upland species that may occasionally enter or nest in riparian environments, including:

> Anna's Hummingbird, Ash-throated Flycatcher, Bewick's Wren, Black Phoebe, Bushtit, California Scrub-Jay, California Towhee, Hooded Oriole, House Finch, Lesser Goldfinch, Mourning Dove, Nuttall's Woodpecker, Orange-crowned Warbler, Red-tailed Hawk, Rock Pigeon, Scaly-breasted Munia, Song Sparrow, Turkey Vulture, Western Bluebird, Wrentit

Across the broader study region, we detected riparian bird species, i.e., those considered specialist breeders in riparian woodlands (Lehman 2021), 1.8 to 26 times more frequently at sites with surface water than at sites that were dry in the dry season. By contrast, we detected oak woodland and generalist bird species more frequently along creek reaches that dried seasonally.

Overall, the riparian zones of Mission and Rattlesnake Creeks had fewer of the species most strongly associated with riparian habitats (column 1 of Table 4.2) than did other, similar creeks in the southern County. Some bird species that nest exclusively in riparian environments were not encountered along the Mission or Rattlesnake Creek riparian corridors, including the Yellow Warbler and Warbling Vireo, although they do occur as uncommon and localized breeders in other, nearby watersheds. Both species still nest in high elevation sycamore-oak riparian woodlands, such as those along upper San Jose Creek. The restoration of dry season flows to Mission Creek should help improve nesting conditions for these species, in particular the Yellow Warbler, a Bird Species of Special Concern in California, which was 5 times more likely to occur in wet than dry riparian habitats in our larger surveys.

In addition to birds, Mission and Rattlesnake Canyons host a variety of terrestrial reptile and mammal species, including snakes, lizards, small rodents, insectivores (shrews, moles), and bats, and more conspicuous species, such as gray squirrels, pack rats, rabbits, mule deer, skunks, raccoons, non-native opossums, bobcats, grey foxes, coyotes, black bears, and pumas. Many of these vertebrate species use riparian zones and creeks for water, food, habitat, and movement corridors.

Our results emphasize the primacy of water in dictating ecosystem health and promoting biodiversity within our riparian woodlands. Obligate riparian-breeding bird species are almost all declining in this region and across the Western United States, and are now limited to a few select watersheds on the South Coast of Santa Barbara County (Holmgren 2020, Lehman 2021). Adequate supplies of surface and groundwater are crucial for sustaining habitats and protecting the terrestrial riparian biota associated with local streams.

4.7. Conclusions and recommendations to enhance aquatic/riparian habitat and life

Our studies indicate that water is critical in maintaining and enhancing aquatic and riparian habitat in Mission and Rattlesnake Canyons. The health, cover, and height of riparian vegetation, and abundances of sensitive aquatic and riparian species, such as steelhead and riparian birds, are associated with surface water in the dry season. Pools with surface water during the dry season and dry years constitute refuges for many sensitive species in and around Mission and Rattlesnake Creeks, allowing them to re-expand into formerly dry reaches when flows return. As stream reaches dry, habitat and water quality decline and the species composition of the aquatic biota shifts from sensitive to more tolerant forms, particularly when pools become isolated (Herbst et al. 2019; Cooper et al. 2021). In addition, stream reaches with surface flow often support vigorous riparian vegetation with high foliar moisture levels, which act as a barrier to the ignition and spread of wildfires, as well as habitat and movement corridors for wildlife. As a consequence, enhanced, perennial surface flows can increase biodiversity, the abundances of sensitive species, and wildlife corridors, and provide for some degree of fire protection, arguing for augmenting surface flows, particularly during the dry season and droughts.

Riparian zones are biodiversity hotspots, provide many ecosystem services, and support water, food resources, habitat, and migration corridors for terrestrial and aquatic animals. At present, however, we need to know more about the factors driving riparian vegetation health to guide management efforts, such as the mitigation of damage to riparian vegetation caused by drought or human activity. Given our previous studies, we believe that a significant gap deals with relationships between groundwater, surface water, riparian vegetation, and wildlife, the focus of our Phase 2 proposal. More information on where and how riparian areas can be restored should rebound to the benefit of both aquatic and riparian habitats and species.

This study also illustrates some of the limitations on the distributions and abundances of sensitive species, e.g., the Southern California Steelhead, such as inadequate and intermittent flows, shallow pools, and restricted breeding or spawning habitat. Even if water supplies are adequate, however, barriers to steelhead migration will prevent the restoration of steelhead stocks (Chapter 5). As a consequence, additional studies and efforts to remove or modify barriers, such as dams and road crossings, are needed to restore steelhead to their former levels.

4.8. References

Aguilera, R. and J.M. Melack. (2018). Nutrient fluxes as a function of hydrologic variability, land cover and fires in coastal California catchments. *J. Geophys. Res. – Biogeosci*. 123: 2568–2589. doi.org/10.1029/ 2017JG004119

Allan, J.D., Castillo, M.M., and Capps, K.A. (2021). *Stream ecology: structure and function of running waters*: Springer International Publishing, XVII, 485 p.

Bixby, R.J., Cooper, S.D., Gresswell, R.E., Brown, L.E., Dahm, C.N., and Dwire, K.A. (2015). Fire effects on aquatic ecosystems: an assessment of the current state of the science: *Freshwater Science*, v. 34, p. 1340–1350, doi:10.1086/684073.

Busse, L.B., Simpson, J.C., and Cooper, S.D. (2006). Relationships among nutrients, algae, and land use in urbanized southern California streams: *Canadian Journal of Fisheries and Aquatic Sciences*, v. 63, p. 2621–2638, doi:10.1139/f06-146.

Canadell, J., Jackson, R. B., Ehleringer, J. R., Mooney, H. A., Sala, O. E., and Schulze, E. D. (1996). Maximum rooting depth of vegetation types at the global scale, *Oecologia*, 108, p. 583-595.

Carter, K. (2005). The effects of dissolved oxygen on steelhead trout, coho salmon, and chinook salmon biology and function by life stage. North Coast Region, California Regional Water Quality Control Board, Santa Rosa, California. (Available from: http://www.swrcb.ca.gov/northcoast/water_issues/programs/tmdls/shasta_river/060707/29appendixbetheeffectsofdissolvedoxygenonsteelheadtroutcohosalmonandchinooksalmonbiologyandfunction.pdf)

Cooper, S.D. (1984). The effects of trout on water striders in stream pools. *Oecologia*, v. 63, p. 376–379.

Cooper, S.D. (1988). The responses of aquatic insects and tadpoles to trout. *Verh. Internat. Verein. Limnol*., v. 23, p. 1698–1703.

Cooper, S.D., Dudley, T.L., and Hemphill, N. (1986). The biology of chaparral streams in Southern California, *in Proceedings of the Chaparral Ecosystems Research Conference*, Santa Barbara, CA USA, California Water Research Center, v. 62, p. 139–151.

Cooper, S.D., Klose, K., Herbst, D.B., White, J., Drenner, S.M., and Eliason, E.J. (2021). Wildfire and drying legacies and stream invertebrate assemblages. *Freshwater Science*, v. 40, p. 659–680, doi:10.1086/717416.

Cooper, S.D., Lake, P.S., Sabater, S., Melack, J.M., and Sabo, J.L. (2013). The effects of land use changes on streams and rivers in mediterranean climates. *Hydrobiologia*, v. 719, p. 383–425, doi:10.1007/s10750-012-1333-4.

Cooper, S.D., Page, H.M., Wiseman, S.W., Klose, K., Even, T., Sadro, S., Nelson, C.E., and Dudley, T.L. (2015). Physicochemical and biological responses of streams to wildfire severity in riparian zones. *Freshwater Biology*, v. 60, p. 2600–2619.

Cooper, W. S. (1922). *The broad-sclerophyll vegetation of California: An ecological study of the chaparral and its related communities*. Carnegie Institution of Washington, p. 89-92.

Copernicus Sentinel data. (2021). Retrieved from Google Earth Engine, October 2022, processed by European Space Agency. Accessed from https://developers.google.com/earth-engine/datasets/catalog/COPERNICUS_S2_SR_HARMONIZED

Cox, B. A. (2003). A review of dissolved oxygen modeling techniques for lowland rivers. *Science of the Total Environment* 314–316:303–334.

Dibblee, T.W. (1966). Geology of the Central Santa Ynez Mountains, Santa Barbara County, California. *California Division of Mines Geological Bulletin 186*.

Diehl, S., Cooper, S.D., Kratz, K.W., Nisbet, R.M., Roll, S.K., Wiseman, S.W., and Jenkins, T.M. (2000). Effects of Multiple, Predator-Induced Behaviors on Short-term Producer-Grazer Dynamics in Open Systems. *The American Naturalist*, v. 156, p. 293-313.

Douglas, P.L., Forrester, G.E., and Cooper, S.D. (1994). Effects of trout on the diel periodicity of drifting in baetid mayflies. *Oecologia*, v. 98, p. 48–56, doi:10.1007/BF00326089.

Dudley, T.L. (1992). Beneficial Effects of Herbivores on Stream Macroalgae via Epiphyte Removal. *Oikos*, v. 65, p. 121–127, doi:10.2307/3544894.

Dudley, T.L., and D'Antonio, C.M. (1991). The Effects of Substrate Texture, Grazing, and Disturbance on Macroalgal Establishment in Streams. *Ecology*, v. 72, p. 297–309, doi:10.2307/1938923.

Ecology Consultants, Inc. (2015). Southern Coastal Santa Barbara Streams and Estuaries Bioassessment Program, 2015 Report. Prepared for City of Santa Barbara, Creeks Division and County of Santa Barbara, Project Clean Water. 91 pp.

Ecology Consultants, Inc. (2019). Santa Barbara Streams and Estuaries Bioassessment Program, 2019 Report. Prepared for City of Santa Barbara, Creeks Division and County of Santa Barbara, Project Clean Water. 139 pp.

Goodridge, B.M., E.J. Hanan, E. Wetherley, R. Aguilera, Y.-J. Chen, C.M. D'Antonio and J.M. Melack. (2018). Retention of nitrogen following wildfire in a chaparral ecosystem. *Ecosystems*, doi.org/10.1007/s10021-018-0243-3

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, v. 202, p. 18-27.

Gunnerson, M. (1957). The Old Mission Water System. *Noticias.* Santa Barbara Historical Museum, v. 3, p. 6–7.

Hanan, E.J., D'Antonio, C.M., Roberts, D.A., Schimel, J.P. (2016). Factors regulating nitrogen retention during the early stages of recovery from fire in coastal chaparral ecosystems. *Ecosystems* 19:910–26.

Hemphill, N., and Cooper, S.D. (1984). Differences in the community structure of stream pools containing or lacking trout. *Verh. Internat. Verein. Limnol*., v. 22, p. 1858–1861.

Herbst, D. B., Cooper, S.D., Medhurst, R.B., Wiseman, S.W., and Hunsaker, C.T. (2019). Drought ecohydrology alters the structure and function of benthic invertebrate communities in mountain streams. *Freshwater Biology*, vol. 64, p 886-902. doi: 10.1111/fwb.13270.

Hill, A. P., Prince, P., Snaddon, J. L., Doncaster, C. P., and Rogers, A. (2019). AudioMoth: A low-cost acoustic device for monitoring biodiversity and the environment. **HardwareX** 6, e00073. Elsevier B.V.

Holmgren, M. and O'Loghlen, A. (2020). Santa Barbara County Breeding Bird Study. Santa Barbara Audubon Society. Accessed October 1, 2021 from https://santabarbaraaudubon.org/santa-barbara-county-breeding-bird-study/

Johnson, J. (1986). The Chumash History of Mission Creek. *Noticias*. Santa Barbara Historical Museum, v. 32, p. 20–37.

Kahl, S. (2019). *Identifying Birds by Sound: Large-scale Acoustic Event Recognition for Avian Activity Monitoring*. PhD thesis, Chemnitz University of Technology, Chemnitz, Germany.

Keller, E.A., and Keller, V.R. (2011). *Santa Barbara, land of dynamic beauty: a natural histor*y. Santa Barbara, CA, USA, Santa Museum of Natural History.

Keller, E.A., Bean, G. and Best, D. (2015). Fluvial geomorphology of a boulder-bed, debris-flow—Dominated channel in an active tectonic environment. *Geomorpholog*y, 243, pp.14-26.

Keller, E., Adamaitis, C., Alessio, P., Anderson, S., Goto, E., Gray, S., Gurrola, L. and Morell, K., (2020). Applications in geomorphology. *Geomorphology*, 366, p.106729.

Kibler, C. L., Schmidt, E. C., Roberts, D. A., Stella, J. C., Kui, L., Lambert, A. M., and Singer, M. B. (2021). A brown wave of riparian woodland mortality following groundwater declines during the 2012–2019 California drought. *Environmental Research Letters* v. 16, 8, p. 1-12.

Klose, K., Cooper, S.D., and Bennett, D.M. (2015). Effects of wildfire on stream algal abundance, community structure, and nutrient limitation. *Freshwater Science*, v. 34, p. 1494–1509, doi:10.1086/683431.

Klose, K., Cooper, S.D., Leydecker, A.D., and Kreitler, J. (2012). Relationships among catchment land use and concentrations of nutrients, algae, and dissolved oxygen in a southern California river. *Freshwater Science*, v. 31, p. 908–927.

Lehman, P. E. (2021). The Birds of Santa Barbara County, California. Accessed on October 1, 2021 from http://www.sbcobirding.com/index_html_files/BOSBC.2020Spring.pdf

Lentz, E.J. (2013). *A naturalist's guide to the Santa Barbara region*. Berkeley, CA, USA, Heyday Books.

McMahon, C. (2020a). Dirt Or Leaf: an open library for segmenting plant and ground returns from aerial point clouds. Accessed https://github.com/conormcmahon/dirt_or_leaf

McMahon, C. (2020b). LiDAR Raster stats: an open library for creating raster products from LiDAR point clouds. Accessed https://github.com/conormcmahon/lidar_raster_stats

McMahon, C., Cooper, S.D., and Wiseman, S.W. (2023). Post-fire stream responses to spatial fire patterns in riparian and upland zones. *In Biogeomorphic Responses to Wildfire in Fluvial Systems*, Geological Society of America (GSA) Books, Special Paper.

Melack, J.M. and J.O. Sickman. (1986). Major solute chemistry of stream water and rain in a southern California chaparral watershed. *In Proceedings of the Chaparral Ecosystems Research Conference*, Santa Barbara, CA USA, California Water Research Center, vol. 62, p. 81-87.

Minor, S.A., Kellogg, K.S., Stanley, R.G., Gurrola, L.D., Keller, E.A. and Brandt, T.R. (2009). *Geologic Map of the Santa Barbara Coastal Plain Area, Santa Barbara County, California* (p. 38). US Department of the Interior, US Geological Survey.

Morell, K.D., Alessio, P., Dunne, T. and Keller, E. (2021). Sediment Recruitment and Redistribution in Mountain Channel Networks by Post-Wildfire Debris Flows. *Geophysical Research Letters*, 48(24), p.e2021GL095549.

Myrick, C.A. and Cech J.J. (2001). Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Bay-Delta Modeling Forum. Technical Publication 01-1.57 pp. www.cwemf.org/Pubs/TempReview.pdf

Montgomery, D.R., and Buffington, J.M. (1997). Channel-reach morphology in mountain drainage basins. *Geological Society of America Bulletin*, v. 109, p. 596–611, doi:10.1130/0016-7606(1997)109<0596:CRMIMD>2.3.CO;2.

Naiman, R.J., and Décamps, (1997). The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics*, v. 28, p. 621–658, doi:10.1146/annurev.ecolsys.28.1.621.

Nicole-Berry Frazier, H. (2018). *Ecosystem productivity and water temperature in coastal California streams*. Ph. D. thesis, Department of Geography, University of California – Santa Barbara. 189 pp.

Page, H.M., Cooper, S.D., Wiseman, S.W., Bennett, D., Klose, K., Sadro, S., Nelson, C. and Even, E. (2017). Comparisons of stable isotope (C, H, N) signatures for revealing organic matter sources and trophic relationships in headwater streams. *Canadian. Journal of Fisheries and Aquatic Sciences,* 74: 2110-2121. dx.doi.org/10.1139/cjfas-2016-0322.

PDAL Contributors, 2020. PDAL Point Data Abstraction Library. doi:10.5281/zenodo.2556737

Power, M.E. (1992). Top-Down and Bottom-Up Forces in Food Webs: Do Plants Have Primacy. *Ecology*, v. 73, p. 733–746, doi:10.2307/1940153.

Power, M.E., Parker, M.S., and Dietrich, W.E. (2008), Seasonal Reassembly of a River Food Web: Floods, Droughts, and Impacts of Fish. *Ecological Monographs*, v. 78, p. 263–282, doi:10.1890/06-0902.1.

Riley, S.P.D., Busteed, G.T., Kats, L.B., Vandergon, T.L., Lee, L.F.S., Dagit, R.G., Kerby, J.L., Fisher, R.N., and Sauvajot, R.M. (2005). Effects of Urbanization on the Distribution and Abundance of Amphibians and Invasive Species in Southern California Streams. *Conservation Biology*, v. 19, p. 1894–1907, doi:10.1111/j.1523-1739.2005.00295.x.

Rossi, G.J., Power, M.E., Pneh, S., Neuswanger, J.R., and Caldwell, T.J. (2021). Foraging modes and movements of Oncorhynchus mykiss as flow and invertebrate drift recede in a California stream. *Canadian Journal of Fisheries and Aquatic Sciences*, v. 78, p. 1045–1056, doi:10.1139/cjfas-2020-0398.

Sarnelle, O., Kratz, K.W., and Cooper, S.D. (1993). Effects of an invertebrate grazer on the spatial arrangement of a benthic microhabitat. *Oecologia*, v. 96, p. 208–218, doi:10.1007/BF00317734.

Sloat, M.R. and Osterback, A.K. (2013). Maximum stream temperature and the occurrence, abundance, and behavior of steelhead trout (*Oncorhynchus mykiss*) in a southern California stream. *Canadian Journal of Fisheries and Aquatic Sciences*, vol. 70, p. 64-73. dx.doi.org/10.1139/cjfas-2012-0228

Stromberg, J. (1993). Root patterns and hydrogeomorphic niches of riparian plants in the American Southwest. *Journal of Arid Environments*, v. 94, p. 1–9

Swindle, C., P. Shankin-Clarke, M. Meyerhof, J. Carlson and J. Melack. (2021). Effects of wildfires and ash leaching on stream chemistry in the Santa Ynez Mountains of southern California. *Water,* 13, doi.org/10.3390/w13172402

Telleen-Lawton, K. (2006). *Canyon Voices - The Nature of Rattlesnake Canyon* (W. Miller, Ed.). Santa Barbara, Calif, Mission Creek Studios, 128 p.

Tompkins, W.A. (1978). Old mission - Mission Canyon. Santa Barbara, Calif, Southern Santa Barbara County Board of Realtors, *Neighborhood series* ; no. 2, 12 p.

United States Geological Survey. (2018). USGS LPC CA SoCal Wildfires B4 2018 LAS 2019. Distributed by OpenTopography. Accessed: 2021-11-01 from https://s3-us-west-2.amazonaws.com/usgs-lidar-public/USGS_LPC_CA_SoCal_Wildfires_B4_2018_LAS_2019/ept.json

Verkaik, I., Rieradevall, M., Cooper, S.D., Melack, J.M., Dudley, T.L., and Prat, N. (2013), Fire as a disturbance in mediterranean climate streams. *Hydrobiologia*, v. 719, p. 353–382, doi:10.1007/s10750-013-1463-3.

Wiseman, S.W., Cooper, S.D., and Dudley, T.L. (1993). The effects of trout on epibenthic odonate naiads in stream pools. *Freshwater Biology*, v. 30, p. 133–145, doi:10.1111/j.1365-2427.1993.tb00794.x.

APPENDIX 4.1

Stream and Physical Habitat Characterization of Mission and Rattlesnake Canyons

Mission Canyon

4.1.1 Summary

Surveys were conducted along 8.5 km of Mission Creek from November 17th, 2021 to February 3rd, 2022, to map the distribution of pools, evaluate the geological influences on their development, and identify potential impediments to steelhead migration. The October, 2021, through September, 2022, water year was anomalous, with over 70% of rain (15.9 cm) falling in December, no rain falling in January or February, and another 3.8 cm falling in March and April. General descriptions of stream morphology, potential aquatic habitat, and the effects of anthropogenic features were described beginning at Rocky Nook Park and extending upstream to the upper tributaries of the watershed above Seven Falls. Data on the pool type, step height, grain size in the pool tail, and the presence of water and refugia habitat were collected at each pool location. Conditions at the times of the survey were representative of base flow conditions. ~45% of the surveyed reach contained surface water supplied by groundwater springs, the primary habitat sustaining steelhead trout (*Oncorhynchus mykiss*), as well as other, sensitive aquatic species.

In total, 169 pools were identified within the surveyed section. Step-pools were the most common pool type, accounting for 56% of the pools, followed by forced pools (20%), combination pools (13%) (a combination of step and forced), and plunge pools (11%). Pool formation primarily was facilitated by boulder deposits that were present throughout the stream corridor. In general, the spatial distribution of the largest boulders (> 1 - 2 m in diameter) regulated the location and spacing of pools throughout the watershed. The boulders are primarily sourced from the Coldwater and Matilija Sandstone Formations, as well as from sparse sandstone lenses that occur within the Cozy Dell and Juncal Shale Formations. The spatial distribution of the largest boulders (> 1 – 2 m in diameter) are controlled by stochastic colluvial mass wasting processes (rockfall and bank collapse) and infrequent debris flow events that have transported boulders to lower elevations within the stream network. These boulders are typically immobile during normal flow conditions and are only moved during extreme events, such as post-wildfire debris flows, with very long return intervals. The boulder accumulations and their size distributions within the channel cause variability in the type, location, dimensions, and spacing of pools. Although variability exists, pools and surface flows generally have good connectivity over length scales of 100’s of meters, but are isolated by multiple human-made barriers, including the bridges for Highway 192 and the Mission Canyon bridge, and the Mission Dam and a debris dam. These obstructions impede steelhead migration and instream movement. Multiple locations along the urbanized segments of Mission Creek also contain small private developments such as stream-side benches and private trails that intrude into the riparian and stream environment and increase the erosion of fine sediments into the stream channel.

4.1.2 Geology of the Upper Mission Canyon Watershed

The Mission Creek watershed drains a series of alternating sandstone and shale formations that consist of steeply southward dipping and overturned beds of marine and terrestrial sedimentary rocks (Minor et al., 2009). The rock units within the watershed include the Sespe Formation at the base of the range and, proceeding upwards in elevation, the Matilija Sandstone, Cozy Dell Shale, Coldwater

Sandstone, and finally the Juncal Shale formation at the ridgeline. Each unit also contains interbeds of either shale or sandstone (Minor et al., 2009). The alternating lithologies are eroded by the southward-flowing stream network into topographic zones with rugged, near vertical ridges on the sandstones and lower, smoother, convex ridges on the shales. Channels within the range are incised into the bedrock due to active fold growth and uplift of the Western Transverse Ranges (Melosh & Keller, 2013).

The channel sediments in these steep mountain drainages primarily consist of sandstone boulders sourced from the Coldwater and Matilija Sandstone Formations with sizes ranging from 0.25 – 6.0 m in diameter. Boulders >1 ~ 1.5 m in diameter are generally immobile during floods and require flows with high sediment concentrations, such as hyper-concentrated or debris flows, to be transported downslope and downstream. The distribution of boulder deposits and their characteristics within the channel network depend on 1) the lateral flux from rockfalls and landslides on hillslopes, and bank collapses along channel margins, and 2) their downstream translocation from debris flows during high-magnitude floods, often after wildfires. Gravel is a common substratum in the channel, but is commonly limited to occasional deposits in low gradient sediment storage sites in pools and downstream of boulder accumulations.

4.1.3 Stream and Physical Habitat Characterization

The stream was divided into distinct reaches where natural breaks in channel morphology, gradient, and sediment size distributions affect hydrological conditions and pool development.

Lower Mission Canyon Survey Reach

The Lower Mission Creek reach extends 800 m upstream from Rocky Nook Park to the Mission and Rattlesnake Creek confluence and is entrenched into alluvial, colluvial, and matrix-supported debris flow deposits (intermittent boulders dispersed in a silty-sandy matrix). Bank collapses from the undercutting of erodible channel banks supply the channel with meter scale boulders. Discontinuous fluvial terraces occur from 3 - 6 m above the active channel and where average channel gradient is 3.5% (2°). Step pools are the most common pool type (75%), followed by forced pools (15%), and combination pools (10%).

This reach is characterized by a series of ~0.3 – 1 m deep step pools formed by boulder accumulations with tail outs primarily composed of silt, sand, and gravel. Low gradient (2-3%) (1-2°) riffles separate the step pools, and intermittent forced and combination pools are formed by larger boulders that partially obstruct the channel. Continuous surface flows connect pools throughout the downstream portion of the reach (Figure 1), even during low flow conditions. Boulder refugia[12] are present in 40% of the pools, which infrequently contain woody debris and exposed roots from undercut banks. Surface water was present at the downstream portion of the reach at the time of the survey, and is supplied by ground water springs near the inferred traces of the More Ranch Fault and Mission Ridge Fault System

[1] Boulder refugia are deeper aquatic habitats created by boulders that provide shade, escape cover, or resting areas for fish and other aquatic species.

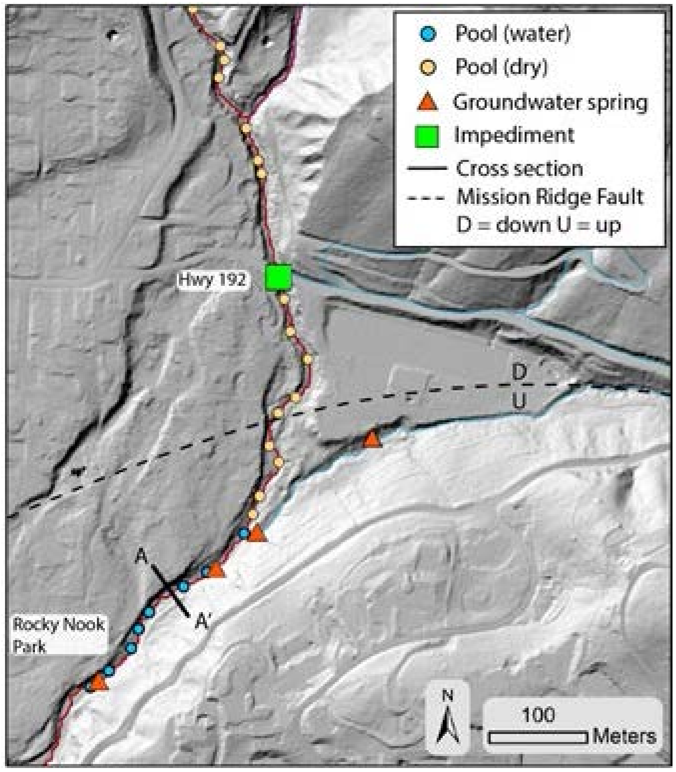
The Highway 192 bridge over Mission Creek impedes upstream fish migration for steelhead, and potentially other aquatic species. At its downstream end, a concrete slab creates a small plunge pool with a 1 m jump to a concrete ramp below the culvert entrance with a total step height of 3 m. Upstream of the culvert, the natural flow of sediment is disrupted, and the deposition of coarse sediments inhibit pool development and connectivity between aquatic habitats for ~50 m upstream (Figure 4.1.1).

Mission and Rattlesnake Creek Confluence to Botanic Gardens Study Reach

The reach upstream of the Mission and Rattlesnake Creek confluence extends for 800 m up to the southern portion of the Santa Barbara Botanic Gardens. Debris flow deposits and boulder accumulations line the channel and create a series of small step pools ~0.3 - 1 m deep with boulder-lined tails and sparse deposits of sand and gravel (Figure 4.1.2). Step pools are the most common pool type (70%), followed by forced pools (20%), and combination pools (10%). Boulder refugia are present in 30% of the pools, which infrequently contain woody debris and exposed roots from undercut banks. Boulders deposited in the channel range from 1 – 4 m in diameter. Larger step and forced pools with depths up to 1 m are found where debris flows and bank collapses have deposited boulders >1.5 m in diameter across the channel. The channel is entrenched with steep channel banks that are composed of silt, sand, cobbles, and increasing amounts of clast-supported, boulder debris flow deposits upstream (Figure 4.1.2). The average channel gradient is 5% (3°) and terrace heights range from ~3 – 6 m above the stream bed. The pools along this section were dry at the time of the survey and no surface water was present.

The Mission Canyon Rd. bridge crossing impedes upstream fish passage for steelhead and potentially other aquatic species. At its downstream end, a plunge pool formed by the concrete culvert creates a ~3 m high jump (Figures 4.1.3, 4.1.4). Impounded cobbles and boulders (trapped sediment) upstream of the culvert create a sediment wedge extending ~20 m upstream that inhibits pool development and surface flow connectivity between aquatic habitats. Flow velocities within the culvert also may impede or prevent fish passage/migration upstream during high stream flows.

(a)



(b)

Figure 4.1.1. (a) Map of Lower Mission Creek survey reach showing the location of pools, groundwater springs, and impediments to fish passage. Note the lack of pool development upstream of Hwy 192. (b). The confluence of Mission Creek and Rattlesnake Creek is upstream of Hwy 192. Cross-section representing the channel geometry for this reach (A– A′).

(a)

(b)

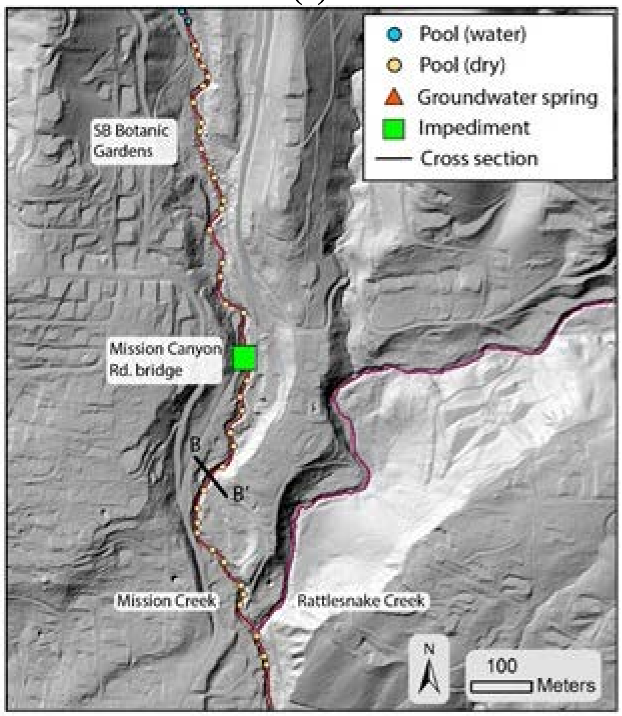
Figure 4.1.2. (a). Narrow, boulder-lined channel with shallow step pools upstream of the Mission and Rattlesnake Creek confluence. (b). Large boulders derived from bank collapse form intermittent forced pools. Note clast-supported debris flow deposits in channel bank. Photos taken during base flow conditions on December 12, 2021.

(a)

(b)

Figure 4.1.3. Fish passage impediments at the Mission Canyon Rd. bridge. The scour depth of the channel bed sediments at its downstream end is ~1.5 m creating a ~3 m jump to the channelized concrete culvert. (a). Photograph taken on December 12, 2021 during dry - low flow conditions, and (b) during moderate flow conditions on December 14, 2021.

(a)



(b)

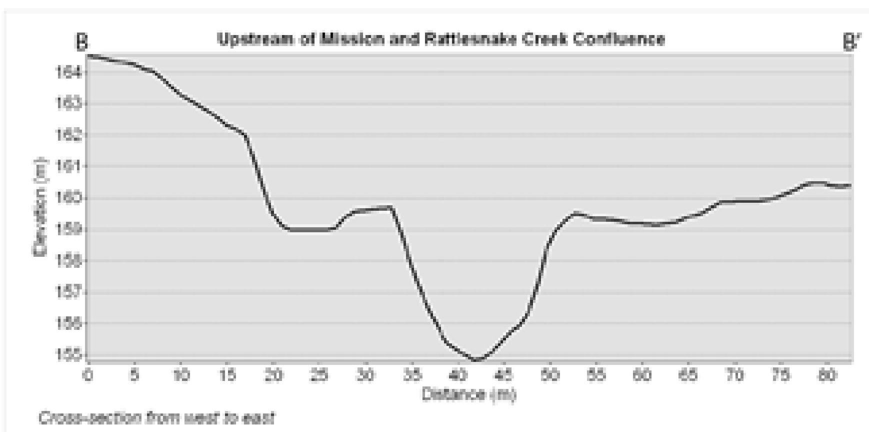


Figure 4.1.4. (a). Map showing the location of pools, groundwater springs, impediments to fish passage, and channel geometry upstream of the Mission and Rattlesnake Creek confluence. (b). Note sparse pool development upstream of the Mission Canyon bridge. Cross-section represents the channel geometry for this reach (B – B′).

Santa Barbara Botanic Gardens Study Reach

The reach through the Santa Barbara Botanic Gardens extends 1.2 km upstream to a debris dam. The stream is entrenched into alluvial and debris flow deposits primarily consisting of boulders and cobbles with a silty, sandy matrix. This reach is characterized by a series of ~0.5 – 1 m deep step pools formed by boulder accumulations with tail outs mainly composed of boulders, cobbles, and gravel (Figure 4.1.5). Sparse gravel deposits occur between boulder accumulations where a mix of high and low gradient riffles separate step pools, as well as in forced pools with continuous surface flows during drought base-flow conditions. Step pools are the most common pool type (60%), followed by forced pools (20%), combination pools (13%), and plunge pools (7%). Boulder refugia are present in ~50% of the pools, along with an increase in the amount of woody debris relative to the downstream reaches.

(a)

(b)

Figure 4.1.5. (a), (b). Step and forced pools with boulder refugia are common downstream of Mission Dam. Photos taken during base flow conditions on December 9, 2021

The average gradient from the southern portion of the Botanic Gardens to the base of Mission Dam is 5% (3°), and 6% (3.5°) upstream from Mission Dam to the debris dam. The distribution of pools, refugia, and continuity of surface flows supplied by groundwater springs throughout this reach provide potential habitat suitable for steelhead and other aquatic species; however, there are two significant impediments to fish passage within this reach (see Mission Dam in Figure 4.1.6).

The Mission Dam impedes upstream fish passage for steelhead, and potentially other aquatic species. In addition, the sediment wedge above the dam creates a base flow discontinuity between upstream and downstream reaches, which interrupts the instream movement of fishes and other aquatic species during base flow conditions. The plunge pool at the base of the dam is ~1.5 m deep with a step height of ~6 m to the flow notch above the pool water level (Figure 4.1.6). Sediment is impounded upstream of the dam and the channel is backfilled with boulders and cobbles.

(a)

(b)

Figure 4.1.6. (a). Mission Dam in the Botanic Garden during base flow conditions on December 9, 2021. (b). During moderate flow conditions on December 28, 2021.

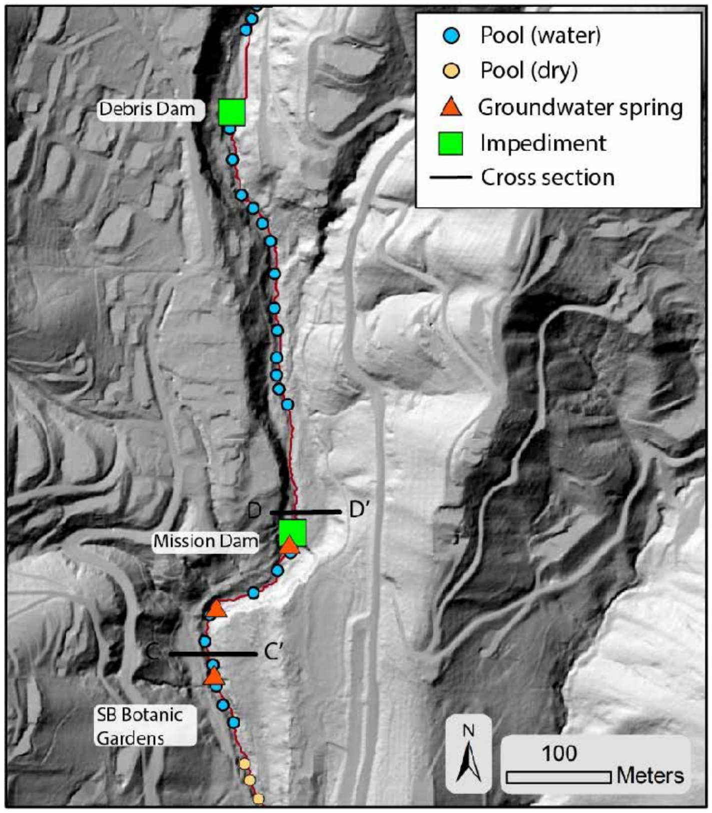
The sediment wedge behind the dam extends upstream for ~130 m, where the surface flow disappears until re-emerging at the downstream face of the dam (Figure 4.1.7). Upstream of the sediment wedge created by Mission Dam, the stream is characterized by step pools and forced pools with depths of 0.5 – 1.5 m, and continuous surface flows were present at the time of the survey. Figure 4.1.8 depicts a map of Mission Creek in the Botanic Garden.

(a)

(b)

Figure 4.1.7 (above): Sediment wedge upstream of Mission Dam during low flow conditions on December 9, 2021 (left) and during moderate flow conditions on December 14, 2021 (right).

(a)



(b)

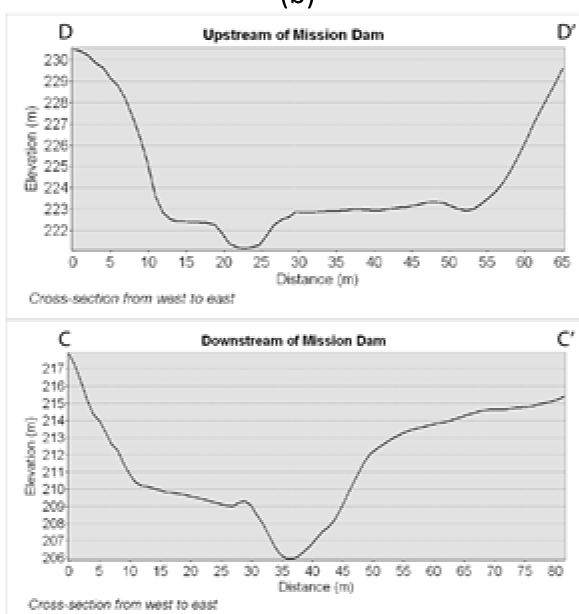


Figure 4.1.8. (a). Map of the Santa Barbara Botanic Gardens section of Mission Creek. (b). Channel cross-sections above and below Mission Dam shown (sections C-C', D-D').

Several areas upstream of Mission Dam contain streamside benches and private trails that intrude into the riparian and stream environment and increase erosion of fine sediment into the stream channel (Figure 4.1.9). A flood control debris dam also impedes the upstream passage of steelhead, and potentially other aquatic species. In addition, the sediment wedge above the dam creates a base flow discontinuity between upstream and downstream reaches (Figure 4.1.10).

Figure 4.1.9: Construction of streamside bench and private trail upstream of Mission Dam. Small construction projects by homeowners intrude into the riparian and stream environment and increase erosion of fine sediment into the stream channel. Photo taken on December 9, 2021.

(a)

(b)

Figure 4.1.10. (a). The plunge pool on the downstream side of the debris dam is ~2m deep, and the top of the debris dam is ~6.5 m above the water surface. Photo taken on December 28, 2021. (b). View looking upstream for ~ 65 m from the debris dam. Photo taken on December 9, 2021.

Tunnel Rd. Survey Reach

The reach upstream of the debris basin extends 1.6 km to the Tunnel Road bridge crossing (Figure 4.1.11). The average stream gradient in this reach is 7.5% (4.5°). The channel is deeply entrenched/incised into the Coldwater Sandstone, creating steep channel banks and narrow constrictions formed by large boulders, landslides, and bedrock outcrops. Step pools with depths ranging from 0.5 - 1.5 m are the most common pool type throughout the reach, accounting for 50% of the pools, with the remainder being forced (25%), combination (17%), and plunge pools (8%), owing to a large number of boulders > 2 m in diameter and bedrock outcrops of Coldwater Sandstone (Figures 4.1.12 and 4.1.13). Large forced and plunge pools with depths ranging from 1 ~ 2.5 m are formed by boulder and bedrock steps (Figure 4.1.13). In general, pools are deeper and occur more frequently along this reach relative to downstream reaches.

Pool tail-out substrata are primarily dominated by boulders with sparse cobbles and gravel. Boulder pool refugia are present in 75% of the pools, and groundwater spring flows supply surface water during base flow conditions. Increases in the number of groundwater springs and surface flow levels are probably due to increased bedrock outcrops and flow through fracture sets in the Coldwater Sandstone Formation. Surface flow was continuous in >90% of the reach and groundwater springs were commonly observed downstream of the Mission Tunnel outlet. However, neither surface water nor groundwater springs were observed upstream of the Mission Tunnel outlet / Tunnel Road bridge (Figure 4.1.11). Downstream of the Tunnel Road bridge, angular blocks and landslide debris were deposited in the channel by construction activities conducted by Southern California Edison (Figure 4.1.14). The pools and continuity of surface flows supplied by groundwater springs throughout this reach provide potentially suitable habitat for steelhead; however, groundwater spring flow necessary to support steelhead rearing habitat or habitat for other aquatic species may be lost/routed into the Mission Tunnel through fractures in the Coldwater Sandstone upstream. The channel at the Tunnel Road bridge is at the same elevation as the Mission Tunnel outlet.

(a)

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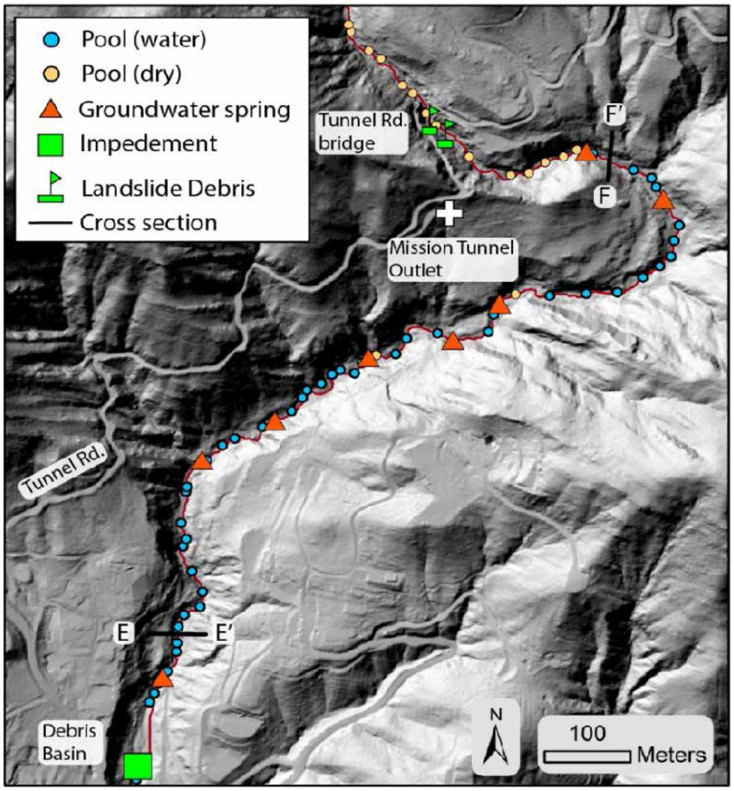


(b)

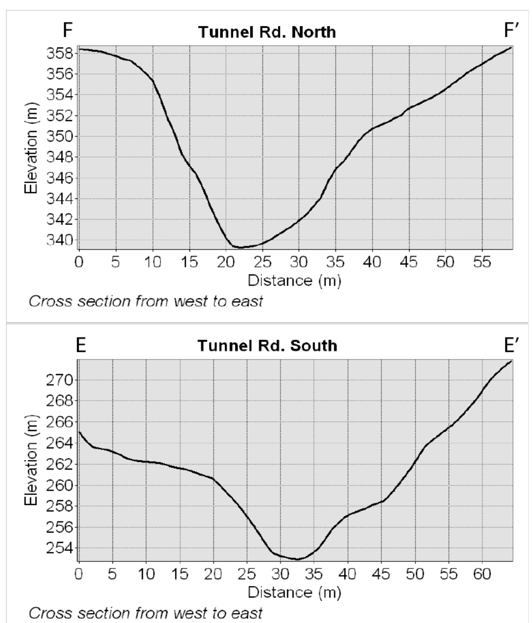


Figure 4.1.11. (a). Map of the Tunnel Rd. reach. Green flags = location of landslide debris deposited in the channel by SCE construction activities. (b). Channel cross-sections (E- E', F-F').

Figure 4.1.12. Increased, continuous surface flow from groundwater springs supplies step, forced, and combination pools downstream of the Mission Tunnel outlet. Photos taken on December 12th, 2021 during base flow conditions.

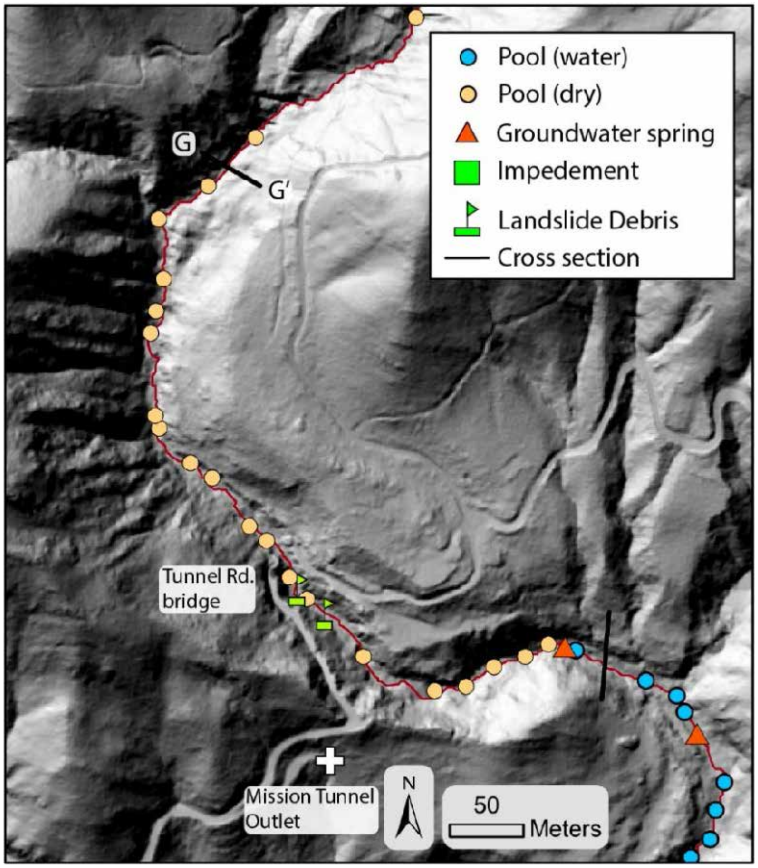
Figure 4.1.13. Large forced and plunge pools formed by boulder obstacles and bedrock steps. Photos taken on December 8, 2021 during base flow conditions.

Figure 4.1.14: Angular blocks and landslide debris deposited in the channel from SCE construction activities. View looking upstream to Tunnel Road bridge (left). View looking downstream (above) from the same spot. Photos taken on December 8, 2021, during base flow conditions.

North of Tunnel Road Bridge Survey Reach

The reach north of the Tunnel Road bridge extends for 550 m upstream with an average gradient of 9% (5°) (Figure 4.1.15). The channel is deeply entrenched/incised into the Coldwater Sandstone Formation, creating steep channel banks and narrow constrictions formed by bedrock outcrops. The channel bed upstream of the Tunnel Road bridge contains a series of small step pools with depths ranging from 0.3 – 0.5 m formed by boulders, bedrock steps, and gravel deposits, accounting for 45% of the pools along the reach (Figure 4.1.16). Upstream of the step pools, the bare bedrock channel contains boulders and sparse gravel where resistant, fractured sandstone beds create bedrock constrictions and steps that form forced pools (30%) and plunge pools (25%). Pool tail-outs are primarily composed of bedrock with boulders and sparse cobbles and gravel. Refugia are present in 25% of the pools, and no groundwater springs or surface water were present at the time of the survey.

(a)



(b)

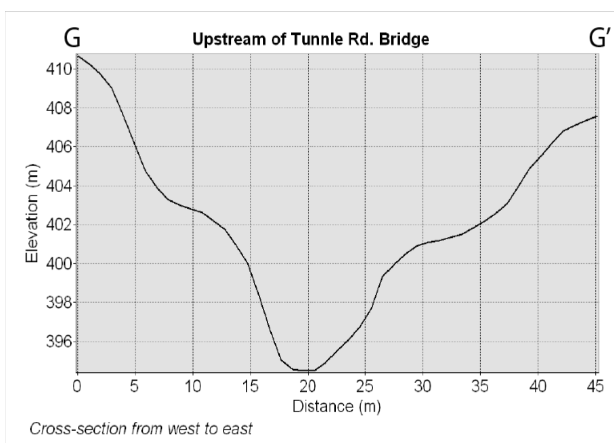


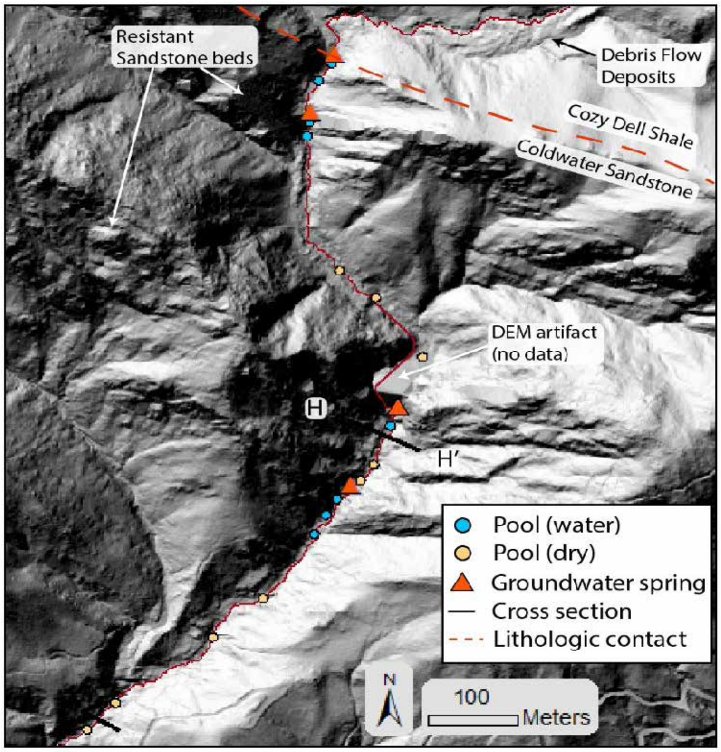
Figure 4.1.15. (a). Map of the stream reach upstream of the Tunnel Road bridge. Note the lack of surface water upstream of the Tunnel Road bridge. Green flags=location of landslide debris deposited in the channel by SCE construction activities. (b). Channel cross-section G-G′ shown.

Figure 4.1.16. Small step pools, gravel deposits, and bedrock outcrops upstream of the Tunnel Rd. bridge (left). Narrow channel and plunge pool created by fractured bedrock (right). Photos taken on December 8, 2021 during base flow conditions.

Seven Falls Survey Reach

The 7 falls survey reach extends 900 m upstream with an average gradient of 12.5% (7°) (Figure 4.1.17). The channel is deeply entrenched/incised into the Coldwater Sandstone, creating steep channel banks and narrow constrictions formed by bedrock outcrops. Plunge pools were most common along the reach (60%), and were separated by intermittent step (13%), forced (13%), and combination pools (13%) that were dry. Several resistant sandstone beds outcropping along the middle and upper portions of the reach resulted in a series of plunge pools (Figure 4.1.17). The plunge pools are typically supplied with water by groundwater springs located within channels and emanating from fractures in the sandstone beds. These pools are 1-2 m deep and likely contain water throughout the year (Figure 4.1.18). Surface water was present directly upstream and downstream of the plunge pools (for ~10 – 20 m), but the channel was dry along the rest of the reach. The steep, near-vertical faces created by several of the resistant sandstone beds that extend across the channel may be potential impediments to steelhead passage except during very high discharge events (Figure 4.1.18). Refugia were present in ~70% of the pools along this reach and tail-outs consisted mainly of boulders and gravel deposits (70%), and bedrock steps (30%).

(a)



(b)

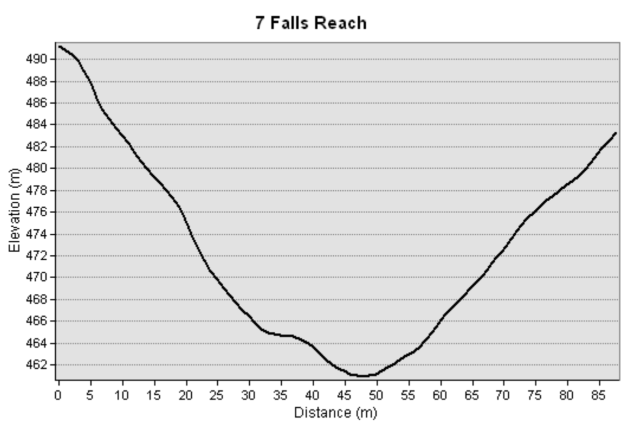


Figure 4.1.17. (a). Map of the 7 Falls stream reach. The resistant sandstone beds coincide with the locations of plunge pools containing water and groundwater springs, and the large number of debris flow deposits at the point of the Coldwater Sandstone / Cozy Dell Shale contact. (b). Cross-section (H-H') representative of the channel geometry.

Figure 4.1.18. Seven Falls Reach. Dry channel leading up to resistant sandstone beds and plunge pools (Top left). Series of plunge pools supplied by groundwater springs emanating from fractures in the sandstone beds (Top Right). Larger plunge pools with bedrock steps (lower panels). Photos taken on February 3rd, 2022, during base flows after December rains.

Upper Mission Creek Tributaries Survey Reach

This survey reach extends ~ 800 m up three main tributaries to Mission Creek that extend into the Cozy Dell Shale and Matilija Sandstone formations (Figure 4.1.19). In general, few pools were observed on the Cozy Dell Shale formation, consisting mostly of shallow step pools (~0.3 m deep) (92%) and a few forced pools (8%). The lack of pool development in these tributaries can be attributed to the high erodibility of the shale bedrock, which does not contribute boulders to the channel. There are, however, intermittent sandstone lenses within the Cozy Dell Formation that supply boulders for step and forced pools, and large dams of boulders from the Matilija Sandstone formation that were deposited by past debris flows (Figures 4.1.19 and 4.1.20). The Mission Creek Tunnel underlies and bisects the two tributaries to the east, and both did not contain surface water at the time of the survey, whereas the tributary to the far west contained nearly-continuous surface flows supplied by groundwater springs (Figure 4.1.20). Refugia were present in 33% of the pools along this reach and tail outs were underlain mainly by boulders (70%), bedrock (15%), and sparse gravel (15%).

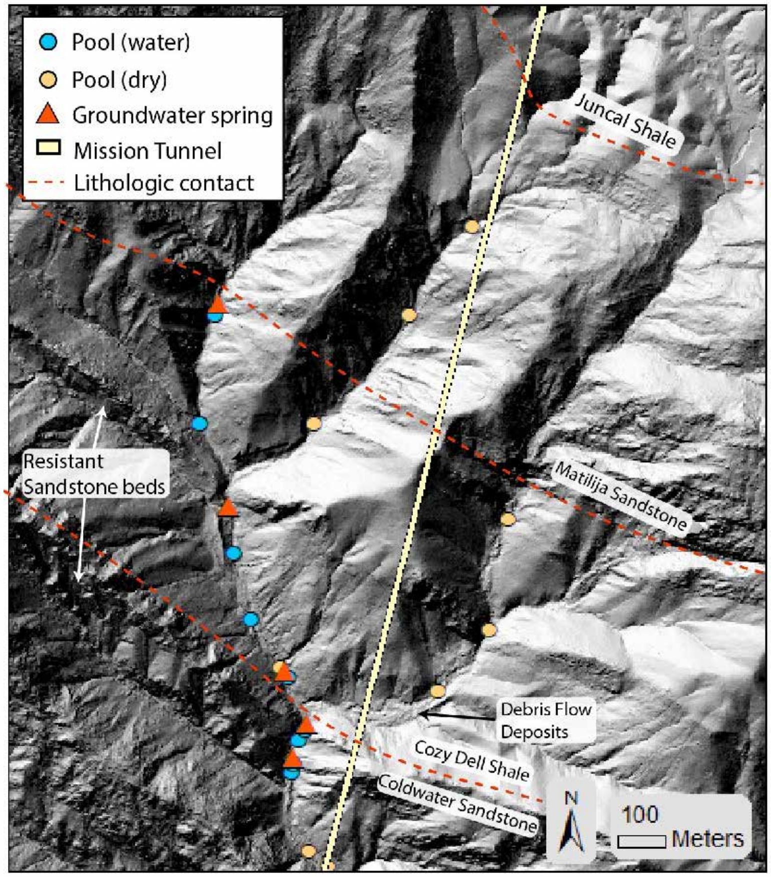


Figure 4.1.19. Map of the Mission Creek tributaries over the Cozy Dell Shale Formation. Near-continuous surface flows were present along the western-most tributary. Note locations of resistant sandstone beds and groundwater springs, and the large number of debris flow deposits where the Coldwater Sandstone / Cozy Dell Shale Formations make contact

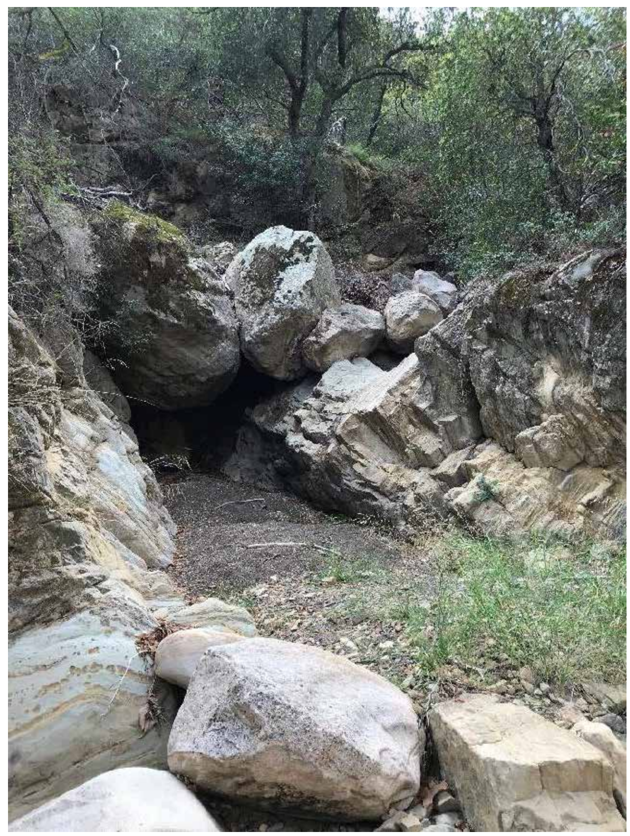
Figure 4.1.20. Continuous surface flows and step pools within the tributary to the far west (Top panels). Large debris flow deposits lining channel (bottom left) and narrow bedrock channel (bottom right) in the two dry tributaries to the east. Photos taken on February 3rd, 2022 during base flow conditions.

4.1.4 Additional Photos and Comments, Mission Creek.

Sediment deposition upstream of the Mission Canyon Rd. bridge extends for ~20 m upstream. Photo taken on December 12, 2021 during base flow conditions.

Debris flow snout in the southern reach of the Santa Barbara Botanic Gardens. Photo taken on December 12, 2021.

Deep pool downstream of the Tunnel Rd. bridge. Photo taken on December 12th, 2021, during base flow conditions.



Plunge pool created by a bedrock step located downstream of the Tunnel Rd. bridge. Photos taken on December 8, 2021 during base flow conditions.

Rattlesnake Canyon

4.1.5 Summary

Surveys were conducted along a 6.6 km section of Rattlesnake Canyon from December 15th, 2021, to May 10th, 2022, to map the distribution of pools and springs, evaluate geological influences on their development, and identify potential impediments to steelhead migration. The 2021-22 water year was anomalous in that 70% of the rain fell in December (15.9 cm), none fell in January and February, and another 3.8 cm fell in March and April. General descriptions of stream geomorphology and potential aquatic habitat, and the presence of anthropogenic features within the stream corridor, were described beginning at the confluence of Mission and Rattlesnake Creeks and extending upstream to Gibraltar Road. Data on pool type, step height, grain size in the pool tail, the presence of water, and physical habitat characteristics were collected at each pool location. Conditions at the time of the survey from the confluence of Mission and Rattlesnake Creeks upstream were representative of low flow conditions just before and after December rain events, with surveys upstream of Skofield Park being representative of base flow conditions. ~15% of the surveyed reach contained surface water supplied by groundwater springs, which is habitat sustaining steelhead trout (*Oncorhynchus mykiss*), as well as other sensitive aquatic species.

In total, 161 pools were identified within the surveyed section. Step-pools were the most common pool type, accounting for 66% of the pools, followed by forced pools (14%), combination pools (13%) (a combination of step and forced), and plunge pools (7%). Pool were formed throughout the stream course where there were boulder deposits. In general, the spatial distribution of the largest boulders (> 1 - 2 m in diameter) regulated the type, location, dimensions, and spacing of pools throughout Rattlesnake Creek. Although there was spatial variation in the presence of surface water, pools and surface flows generally had good connectivity over reach length scales of 100's of meters, but were disconnected by multiple human-made barriers including a channelized portion of the stream, concrete slabs under bridge crossings, the Las Canoas Road bridge, a debris dam and basin, and a Mission dam. These barriers likely impeded steelhead migration and instream movement. Multiple locations along the residential segments of Rattlesnake Creek also contain small private developments such as streamside benches and private trails that intrude into the riparian and stream environment, and increase the erosion of fine sediments into the stream channel.

4.1.6 Geology of the Upper Rattlesnake Canyon Watershed

The Rattlesnake Canyon watershed drains a series of alternating sandstone and shale formations that consist of steeply southward dipping and overturned beds of marine and terrestrial sedimentary rocks (Minor et al., 2009). Each unit also contains interbeds of either shale or sandstone (Minor et al., 2009). The alternating lithologies are eroded by the southward-flowing stream network into topographic zones with rugged, near vertical ridges on the sandstones and lower, smoother, convex ridges on the shales. Channels within the range are incised into the bedrock due to active fold growth and uplift of the Western Transverse Ranges (Melosh & Keller, 2013).

Channel sediments in these steep mountain drainages primarily consist of sandstone boulders sourced from the Coldwater and Matilija Sandstone Formations with sizes ranging from 0.25 – 6.0 m in diameter. Boulders >1 ~ 1.5 m in diameter are generally immobile during floods and require flows with high sediment concentrations, such as hyper-concentrated or debris flows, to be transported downstream. The distribution of boulder deposits and their characteristics within the channel network depend on (1) their lateral flux from rockfalls and landslides on hillslopes, and bank collapses along channel margins, and (2) their downstream translocation by debris flows during high-magnitude floods, particularly after wildfires. Gravel is a common substratum in the channel, but is commonly limited to occasional deposits in low gradient sediment storage sites in pools and downstream of boulder accumulations.

4.1.7 Stream and Physical Habitat Characterization

Here, we segment the stream into distinct reaches where natural breaks in channel morphology, gradient, and sediment size distributions affect hydrological conditions and pool development.

Mission and Rattlesnake Creek Confluence to Skofield Park Reach

The reach upstream of the Mission and Rattlesnake Creek confluence extends for 1.7 km to the southern portion of Skofield Park (Figure 4.1.21). The channel is entrenched into alluvial deposits with steep channel banks that are composed of silt, sand, cobbles, and increasing number of boulder-rich debris flow deposits upstream. Discontinuous fluvial terraces range from 3 - 6 m above the stream bed, and bank collapses from the undercutting of erodible channel banks supply the channel with meter scale boulders. The average channel gradient is 5% (3°). Step pools are the most common pool type (67%), followed by forced pools (18%), combination pools (11%), and plunge pools (4%). Boulder refugia are present in 37% of the pools, which infrequently contain woody debris and exposed roots from undercut banks. Pool tail-out substrata are primarily dominated by gravel, silt, and sand with sparse boulders. Boulder refugia are deeper aquatic habitats created by boulders that provide shade, escape cover, or resting areas for fish and other aquatic species.

This reach is characterized by a series of step pools with typical depths of 0.3 – 0.5 m, and tail outs primarily composed of boulders, gravel, silt, and sand (Figure 4.1.22). Low gradient (2-3%) (2°) riffles typically separate the step pools, and forced and combination pools with depths ranging from 0.5 – 1.5 m are formed by boulders that range from 1 – 4 m in diameter that partially obstruct the channel (Figure 4.1.22). Continuous surface flows connect pools during typical low flow conditions over length scales of 100’s of meters throughout most of the reach. Discontinuities in flow connectivity in this reach include a channelized section of the creek and a concrete slab for a bridge crossing (Figure 4.1.23).

At its downstream end, a pool formed by the concrete slab creates a ~1 m high jump (Figure 4.1.23). Impounded cobbles and boulders (trapped sediment) upstream of the slab create a sediment wedge extending ~50 m upstream that inhibits pool development and flow connectivity between aquatic habitats. There are also two water wells situated on the channel banks behind private residences, but it is unknown if they are drawing water (Figures 4.1.21 and 4.1.22).

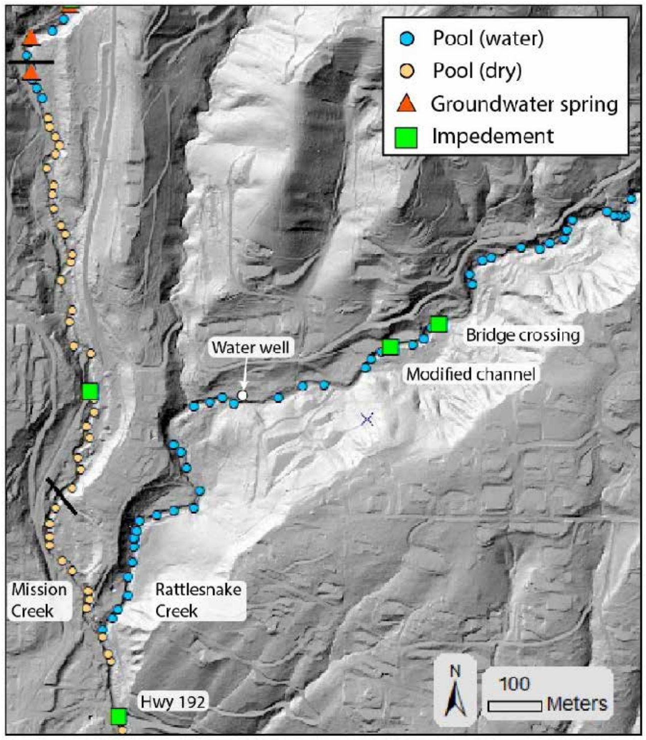


Figure 4.1.21. Map of Rattlesnake Creek upstream of the confluence with Mission Creek showing the location of pools, water wells, and impediments to fish passage. Note sparse pool development upstream of the modified channel and bridge crossing. Most of this section of Rattlesnake Creek was dry in late September, 2022.

Figure 4.1.22. Shallow step pools upstream of the Mission and Rattlesnake Creek Confluence (upper left). Note boulder-rich debris flow deposits lining the channel bank (upper right). Water well perched along the banks of the channel (below). Photos taken during low flow, Dec. 16, 2021.

Figure 4.1.23. Fish passage impediment along a channelized section of the creek (left). The scour depth of the channel bed sediments at its downstream end is ~1.5 m creating a ~3 m jump to the modified channel above (left). A pool formed below a concrete slab at a bridge crossing creates a ~1 m high jump (right). Photographs taken on December 16, 2021, during low flow conditions.

Skofield Park Reach

The Skofield Park reach extends for ~1.2 km from the southern portion of Skofield Park to a debris basin just north of the Las Canoas Road bridge and Rattlesnake Canyon trailhead (Figure 4.1.24). The channel is entrenched into alluvial deposits with steep channel banks that are composed of silt, sand, cobbles, and increasing number of boulder-rich debris flow deposits upstream. Discontinuous fluvial terraces range from 3 - 6 m above the stream bed, and bank collapses from the undercutting of erodible channel banks supply the channel with meter scale boulders. The average channel gradient in this reach is 6% (3.5°). Step pools are the most common pool type (56%), followed by forced pools (16%), combination pools (16%), and plunge pools (2%). Boulder refugia are present in 56% of the pools, which infrequently contain woody debris and exposed roots from undercut banks (Figure 4.1.25). Pool tail out substrata are dominated by gravel, silt, and sand with sparse boulders.

The relative proportion of combination and forced pools, and the frequency of pools with depths > 0.5 m, increase upstream throughout the reach, and can be attributed to increases in the number of large boulders (>2 m in diameter). The amount of in channel debris flow deposits and areas where the entire channel is lined with boulders increases in frequency upstream (Figure 4.1.25). The distribution of pools, presence of other instream physical features and refugia, and continuity of surface flows throughout this reach provide potential habitat suitable for steelhead and other aquatic species; however, there are two significant impediments to fish passage and potentially the movement of other aquatic species at the Las Canoas Rd. Bridge/Rattlesnake Canyon trailhead and at a debris basin upstream (Figure 4.1.24). At the downstream end of the Las Canoas Rd. bridge, a plunge pool formed by the concrete invert creates a ~2m high jump that may impede or prevent fish passage/migration upstream during high stream flows (Figure 4.1.26). At the downstream end of the flood control debris basin, a plunge pool formed below the culvert passing through the concrete dam creates a ~2 m high jump and the top of the debris dam is ~6 m above the water surface. Impounded/trapped cobbles and sediment upstream of the debris basin form a sediment wedge that inhibits pool development and connectivity between aquatic habitats (Figure 4.1.26).

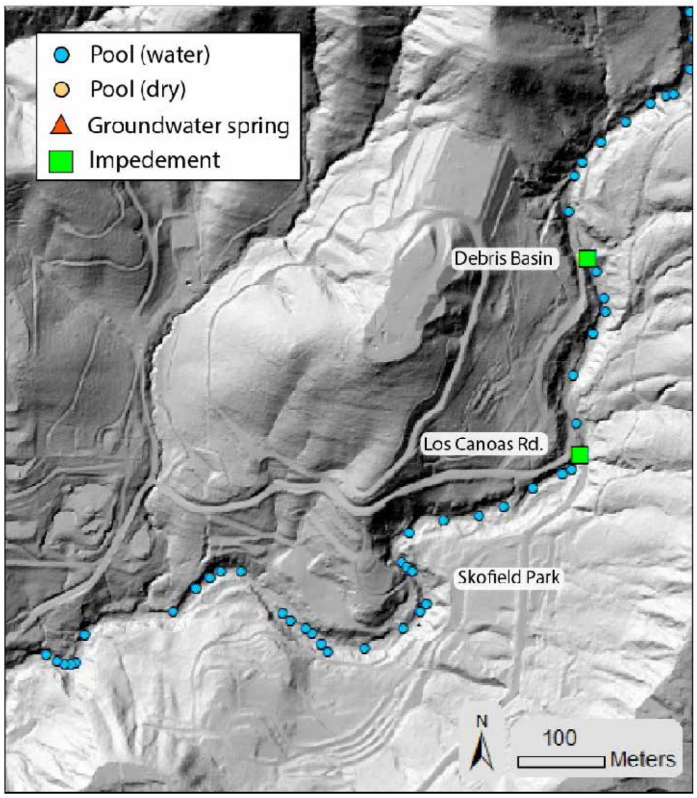


Figure 4.1.24: Map showing the location of pools, groundwater springs, and impediments to fish passage along the Skofield Park reach. Note sparse pool development upstream of the Las Canoas Rd. bridge and debris basin. Much of this reach was dry in September, 2022.

Figure 4.1.25: Combination and forced pools with boulder refugia increase in frequency upstream throughout the Skofield Park reach. Photos taken during low flow conditions on December 16th, 2021.

Figure 4.1.26. The relative proportion of large boulders (> 1-2 m in diameter) within the channel increases upstream through the Skofield Park reach (top left). View looking downstream of the concrete invert at the Las Canoas Rd. bridge (top right). A plunge pool formed by the concrete culvert creates a ~2m high jump and flow within the culvert that may impede or prevent fish passage/migration upstream during high stream flows. At the downstream end of the flood control debris basin (bottom left), a plunge pool formed below the culvert through the concrete dam creates a ~2 m high jump and the top of the debris dam is ~6 m above the water surface. Sediment deposition upstream of the dam inhibits pool development (lower right). Photos taken during low flow conditions on February 4th, 2022.

Lower Rattlesnake Canyon Park Reach

The lower Rattlesnake Canyon Park reach extends for 1.5 km upstream of the debris basin (Figure 4.1.27). The channel is deeply entrenched/incised into the Sespe and Coldwater Sandstone Formations, creating steep channel banks and narrow constrictions formed by large boulder obstacles and bedrock outcrops. Boulder-rich deposits from past debris flow events and rock fall from the side slopes supply the channel with meter scale boulders (Figure 4.1.28). The average channel gradient in this reach is 8.6% (5°). Step pools are the most common pool type (48%), followed by combination pools (27%), forced pools (20%), and plunge pools (5%). Boulder refugia are present in 77% of the pools, which infrequently contain woody debris and bedrock ledges (Figure 4.1.28). Pool tail out substrata are dominated by boulders with sparse cobbles and gravel.

In general, pools are deeper and occur more frequently along this reach relative to downstream reaches, and surface flows were nearly continuous throughout this reach at the time of the survey during low flow conditions. The relative proportions of combination and forced pools, and the frequency of pools with depths > 0.5 m also increases, and can be attributed to increases in the number of large boulders (>2 m in diameter). Increases in the number of groundwater springs and surface flows are likely due to increased bedrock outcrops and flow through fracture sets in the sandstones. The distribution of pools and springs, and the continuity of surface flows, throughout this reach provide habitat suitable for steelhead and other aquatic species; however, there is one potential impediment to fish passage at the remnants of a dam constructed as part of the Santa Barbara Mission water supply system (Figures 4.1.27 and 4.1.29).

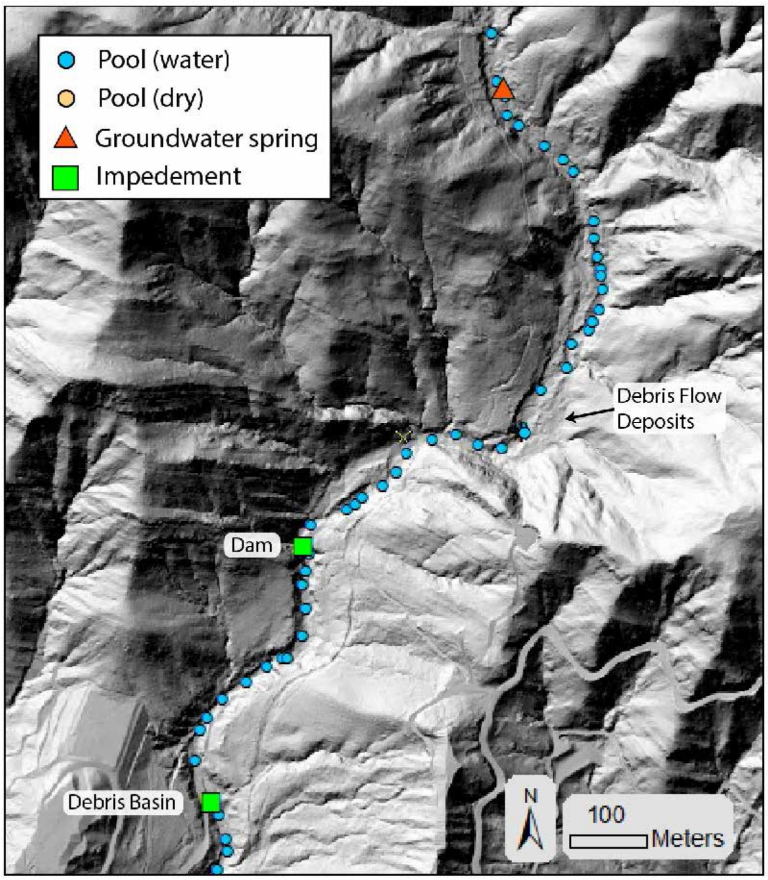


Figure 4.1.27: Map of lower Rattlesnake Canyon Park reach showing the location of pools, groundwater springs, and impediments to fish passage. Note the large number of debris flow deposits and lack of pool development where the channel makes a sharp bend.

Figure 4.1.28. Large forced and plunge pools formed by boulder obstacles and bedrock steps. Increased, continuous surface flow from groundwater springs upstream supplies deeper step, forced, and plunge pools along this reach. Photos taken on February 4th, 2022 during low flow conditions after December rains

Figure 4.1.29: Potential impediment to fish passage at the remnants of an old dam constructed as part of the Santa Barbara Mission water supply system. The pool below is ~1.5 m deep and the dam creates a 2.5 m jump (right). Photos taken on February 4th, 2022 during drought base flow conditions.

Rattlesnake Canyon Park Reach

The Rattlesnake Canyon Park reach extends for 1 km upstream of the debris basin (Figure 4.1.30). The channel is deeply entrenched/incised into the Coldwater Sandstone and Cozy Dell Shale Formations, creating steep channel banks and narrow constrictions formed by large boulder obstacles and bedrock outcrops. Boulder-rich deposits from past debris flow events, and rock fall from the side slopes, supply the channel with meter scale boulders (Figure 4.1.31). The average channel gradient is 13% (7.4°). Step pools are the most common pool type (68%), followed by combination pools (16%), forced pools (8%), and plunge pools (8%). Boulder refugia are present in 68% of the pools (Figure 4.1.31). Pool tail out substrata are dominated by boulders with sparse cobbles and gravel.

In general, groundwater springs located along resistant sandstone beds supply pools and surface flows throughout most of the reach (Figure 4.1.31). However, the pools along this reach have greater spacing and reduced size and depth relative to the next reach downstream, perhaps owing to the narrowing and steepening of the channel, and higher proportions of debris flow deposits that line the stream bed, in this reach (Figure 4.1.31).

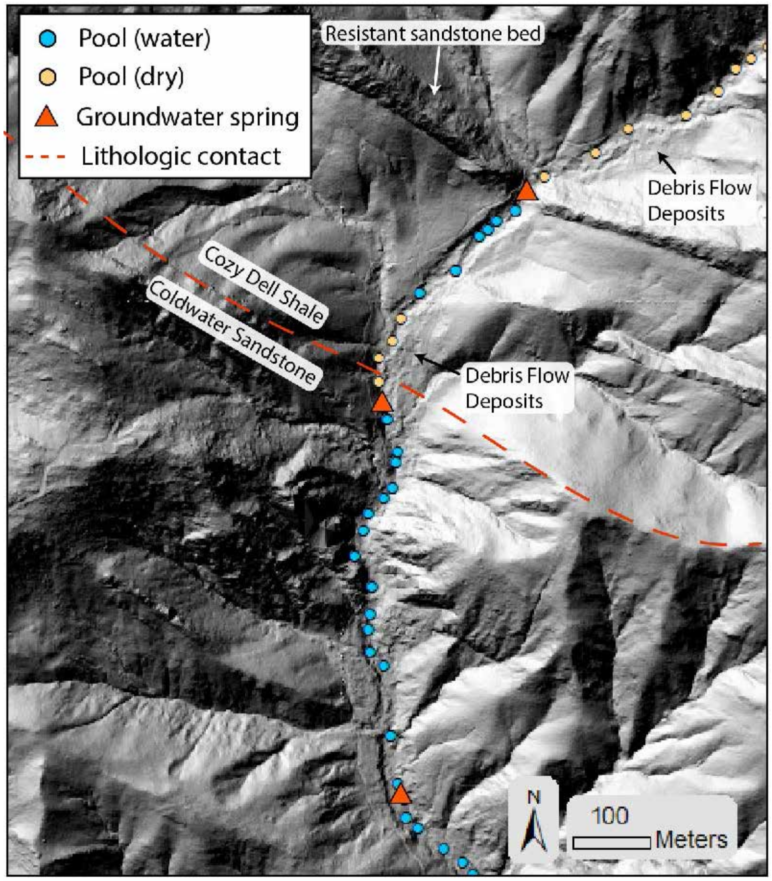


Figure 4.1.30. Map of the Rattlesnake Canyon Park survey reach showing the location of pools and springs. Note the large amount of debris flow deposits at the Coldwater Sandstone / Cozy Dell Shale contact, and upstream of the channel constriction created by a resistant sandstone bed within the Cozy Dell Shale Formation.

Figure 4.1.31. Pools and surface flows supplied by groundwater springs (top left and right). Pool development and surface flow connectivity in this reach is limited by relatively high proportions of past debris flow deposits that line the entire stream bed (bottom left and right). Photos taken on May 10th, 2022, during base flow conditions.

Upper Rattlesnake Canyon Park Reach

The upper Rattlesnake Canyon Park survey reach extends for 1.2 km upstream to Gibraltar Rd. (Figure 4.1.32). The channel is deeply entrenched/incised into the Cozy Dell Shale and Matilija Sandstone Formations, creating steep channel banks and narrow constrictions formed by large boulder obstacles and bedrock outcrops. Boulder-rich deposits from past debris flow events, and rock fall from the side slopes, supply the channel with meter scale boulders (Figure 4.1.32). The average channel gradient is 21% (12°). Step pools are the most common pool type (66%), followed by plunge pools (20%) and combination pools (14%). Boulder refugia are present in 68% of the pools (Figure 4.1.32). Pool tail out substrata are dominated by boulders with very sparse cobbles and gravel.

This entire reach was dry at the time of the survey, although there were groups of dry boulder pools, some associated with substantial waterfall drops. The steep section at the upper part of this survey reach is likely above the limits of anadromy for steelhead due to the frequency of substantial waterfall drops and the lack of evidence of any persistent flow during base flow conditions.

Large boulders and debris flow deposits line the channel within the Matilija Sandstone and Cozy Dell Shale Formations (Figure 4.1.33). Pool development and surface flow connectivity appear to be limited by the larger number of boulders that line the entire stream bed (Figure 4.1.33). In general, the boulders are supplied to the stream bed by rockfalls along stream reaches where the channel is deeply entrenched into resistant sandstone beds. The high erodibility of the Cozy Dell Shale Formation results in lower gradients and wider stream valleys, creating storage sites for debris flow deposition (Figure 4.1.32). In turn, the current distribution of boulder deposits can be attributed to the channels being loaded with sandstone boulders from rockfall over time and episodic debris flows that transport them to these lower gradient storage sites (over timescales of centuries). Large boulder accumulations from debris flow deposition also occur upstream of areas where the channel is constricted, and where the channel makes tight bends (see Figures 4.1.27, 4.1.30, and 4.1.32).

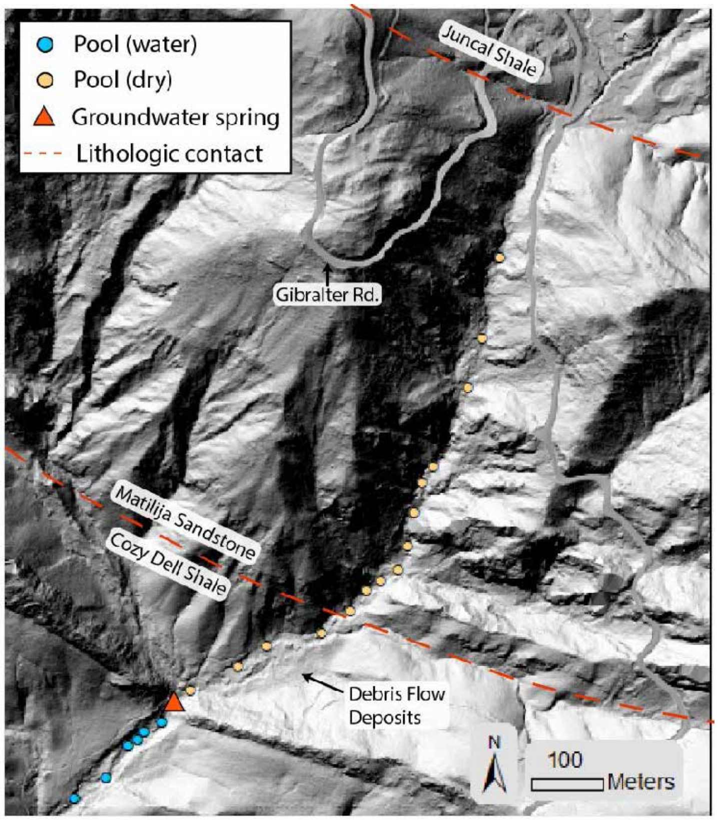


Figure 4.1.32: Map of the Upper Rattlesnake Canyon Park reach. Note the large debris flow deposits at the Matilija Sandstone / Cozy Dell Shale contact, and a decrease in pool frequency and surface flow between pools.

Figure 4.1.33. Small pools formed between boulder deposits that line the steep and narrow channels along this reach (left and right). Photos taken on May 10th, 2022 during base flow conditions.

Figure 4.1.34. Pool development and surface flow connectivity are limited by large boulder deposits that line the entire stream bed, and steep bedrock channels with substantial waterfall drops (top and bottom panels). Photos taken on May 10th, 2022 during base flow conditions.

APPENDIX 4.2

Report on Terrestrial Riparian Biota in Mission and Rattlesnake Creeks

4.2.1 Summary

We concentrated on the distribution, composition, and health of riparian woodlands in the study region because riparian zones are biodiversity hotspots, provide many ecosystem services, and support water, food resources, habitat, and migration corridors for terrestrial and aquatic animals. Within our region, deciduous riparian trees like sycamore (*Platanus racemose*), alder (*Alnus rhombifolia*), and willow (*Salix* sp.) are obligate riparian phreatophytes with shallow roots typically less than 2 to 2.5 m deep and generally require constant access to shallow groundwater (Cooper 1922, Stromberg 1993, Canadell 1996, Kibler 2021). By contrast, evergreen trees like coast live oak (*Quercus agrifolia*) and bay-laurel (*Umbellularia californica*) have much deeper roots up to 10 m deep (Cooper 1922, Canadell 1996)., are only facultative phreatophytes, and can tolerate deeper groundwater tables or sites with no accessible groundwater at all.

Figure 4.2.1: Examples of trees characteristic of riparian woodlands in our area. Left, white alder (*Alnus rhombifolia*), and right, California bay-laurel (*Umbellularia californica*).

We conducted surveys in the field and analyzed remotely-sensed data products to assess vegetation along Mission and Rattlesnake Creeks. We measured canopy cover with a densiometer and mapped surface water and riparian tree composition in fall of 2021 and 2022, at the end of the dry season when water levels were lowest and vegetation experienced maximal water stress. We used LiDAR data collected in 2018 to generate maps of terrain elevation, slope, and vegetation height across the watershed, and aggregated satellite time series imagery to build monthly maps of vegetation greenness. We compared data and maps of riparian plant vigor to geologic, topographic, and hydrologic data (particularly surface water extent mapped by Dr. Paul Alessio). We focused on relationships between plant vigor metrics and geological layers relevant to ground and surface water dynamics.

We found that canopy cover and the fraction of obligate riparian vegetation were 11% and 96% to 279% higher, respectively, near surface water sources during our surveys. In the vicinity of Mission

Tunnel's south portal, Mission Creek was consistently drier than Rattlesnake Creek at corresponding elevations within the same rock formation (the Coldwater Sandstone). All vegetation vigor metrics showed that the riparian woodland along Rattlesnake Creek at that elevation (with more extensive perennial surface flows in late summer) was healthier than that along Mission Creek (mostly dry even in spring). Riparian woodland extent was reduced in patches along Mission Creek, and chaparral or invasive annual plants had invaded dewatered sections. We suggest that differences in vegetation and summer base flows between and within Mission and Rattlesnake Creeks are due to the interception and diversion of groundwater by the Mission Tunnel with the consequent diminishment of stream flows.

We conducted bioacoustic surveys in summer 2022 to monitor riparian bird communities across the county, including along Mission and Rattlesnake Creeks. We deployed automated recording units across 27 riparian sites in the Mission Creek watershed, as well as across 118 additional riparian sites across Santa Barbara County (concentrated in the South Slopes of the Santa Ynez Mountains). We collected a total of 5600 hours of audio recordings across all sites (1053 hours at Mission and Rattlesnake Creeks). We extracted metrics of bird species composition and vocal frequency at study sites, then compared these data to information on vegetation and hydrologic conditions at each monitoring site.

Across the broader study region, we detected riparian bird species – those considered specialist breeders in riparian woodlands (Lehman 2021) – 1.8 to 26 times more frequently at sites with surface water than at sites that were dry in the dry season. By contrast, we detected oak woodland and generalist bird species more frequently along creek reaches that dried seasonally. Our results emphasize the primacy of water in dictating ecosystem health and promoting biodiversity within our riparian woodlands.

Obligate riparian-breeding bird species are almost all declining in this region and across the Western United States, and are now limited to a few select watersheds on the South Coast of Santa Barbara County (Holmgren 2020, Lehman 2021). Adequate supplies of surface and groundwater are crucial for sustaining habitats and protecting the terrestrial riparian biota associated with local streams.

4.2.2 Riparian Vegetation

Field Surveys

We estimated fractional canopy cover at 71 sites along Mission and Rattlesnake Creeks with a spherical densiometer. Densiometers allow the visual estimation of areal canopy cover using a mirrored surface and regularly gridded etch markings. The user orients the device so that the canopy overhead is visible on a mirrored surface and intersections of mirror grid cells or spaces with canopy elements are counted. We estimated cover in four directions (upstream, downstream, to the right, and to the left) at the middle of the channel, then averaged these to obtain a total cover value for each site. Partway through surveys, we began additionally estimating the fractional cover by individual deciduous phreatophyte species (sycamore, alder, willow, and cottonwood).

Canopy cover varied from 33% to 99% (mean = 77%, SD = 15%) and deciduous riparian tree cover varied from 0% to 85% (mean = 39%, SD = 26%). Overall canopy cover was greater at sites very close to pools, with sites within 5 m of surface water having an average cover of 82.2% and sites further than 5 m from surface water averaging 73.6% (independent sample t-test, $p = 0.01$, $t=2.65$, $df = 66.3$). We also found that winter-deciduous riparian phreatophytes had higher cover at wet than dry sites, averaging 48.2% within 5 m of surface water and 24.5% > 5 m from surface water (independent sample t-test, p =

0.012, t=2.72, df=22.92). Canopy cover by deciduous phreatophytes showed large differences at distances from surface water less or greater than specific thresholds (e.g., < versus > 20 m from surface water = 45.7% vs. 13.8% (independent sample t-test, p = 0.001, t=4.117, df=13.8) and < versus > 100 m = 42.9% vs. 11.3% (independent sample t-test, p=0.0003, t=4.94, df=12.13)). Although winter-deciduous phreatophytes can access shallow groundwater even when no surface flows are present, provided that the water table is within 1 to 2.5 meters of the surface (the maximal rooting depth for our winter-deciduous phreatophytes (Stromberg 1993, Kibler 2021)), we observed strong relationships between deciduous canopy cover and proximity to surface water because surface water is an expression of the water table via spring inputs to pools. Dense concentrations of deciduous woodland are concentrated along reaches containing at least some scattered surface water, reflecting the shallow depths of the groundwater table in those reaches. By contrast, the groundwater table is often at depths below the rooting depth of shallow-rooted phreatophytes where continuous reaches are dry, resulting in the absence or rarity of deciduous trees from dry reaches.

4.2.3 Remote Sensing Analysis

Data Generation and Preprocessing

We downloaded LiDAR point clouds from entwine.usgs.gov using the Point Data Abstraction Library (PDAL 2020). The source flight was conducted between May 27 and October 12, 2018 ("leaf-on" conditions, when both evergreen and deciduous riparian trees had leaves) (USGS 2019). Data were processed to create bare earth and digital terrain models using the utilities in the open-source Dirt_Or_Leaf library (McMahon 2020a). These methods extract terrain returns from LiDAR by comparing the height and local surface orientations of the cloud to those of their spatial neighbors within a 3.3 m radius, extracting points which are relatively flat and low within a neighborhood as ground returns. The following settings were used:

Decimation Factor: 5
Minima Radius: 1 m
Normals Radius: 3.3 m
Roughness Neighbors: 10
Min Veg Height: 0.5 m

Vegetation Decimation Factor: 10
Maxima Decimation Factor: 1
Normals Neighbors for Maxima: 4

Roof Distance Threshold: 1.7
Roof Smoothing Threshold: 0.5

For a detailed description of the above parameters, the methods, and source code, see the documentation for the software package.

Following extraction of terrain and canopy points, the point cloud was sampled at 1 m canopy height and terrain elevation rasters using the open source library LiDAR_Raster_Stats (McMahon 2020b). Examples of the LiDAR-based rasters for the Mission Creek watershed are show in Figure 4.2.2.

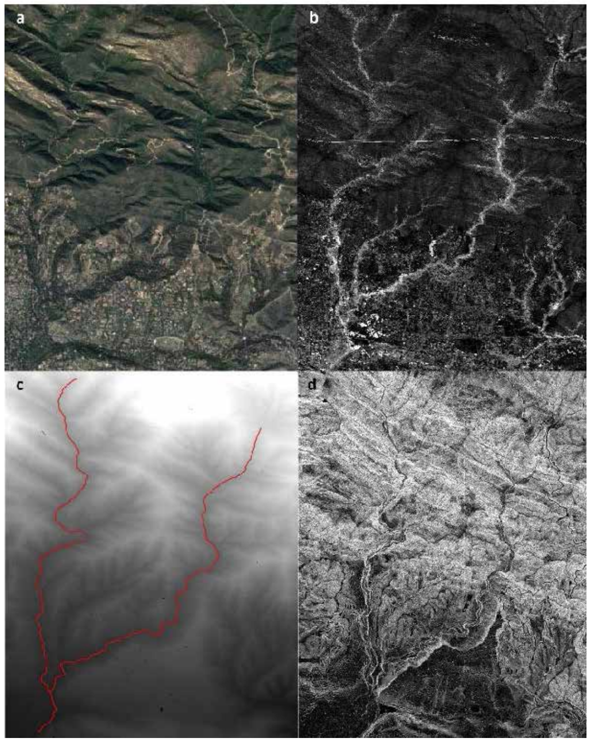


Figure 4.2.2. LiDAR products derived for the study area. (a) Google satellite image; (b) canopy height model (grayscale from 0 to 25 m); (c) terrain elevation (grayscale from 0 to 1000 m), with creek flowlines overlain in red for Mission and Rattlesnake Creeks; (d) terrain slope (grayscale from 0 to 50°).

We used the same library to build vegetation height histograms (raster products where vegetation height values are binned across 1 m height intervals within 10 m grid cells). The output is shown in Figure 2. Here, we used the following settings (again, see the package details for more information):

Field name: height
Pixel size: 10 m
Histogram min: 0 m
Histogram max: 30 m
Histogram bins: 30
Scale factor (z): 1
Scale factor (xy): 1
CRS input: EPSG:3857
CRS output: EPSG:3857

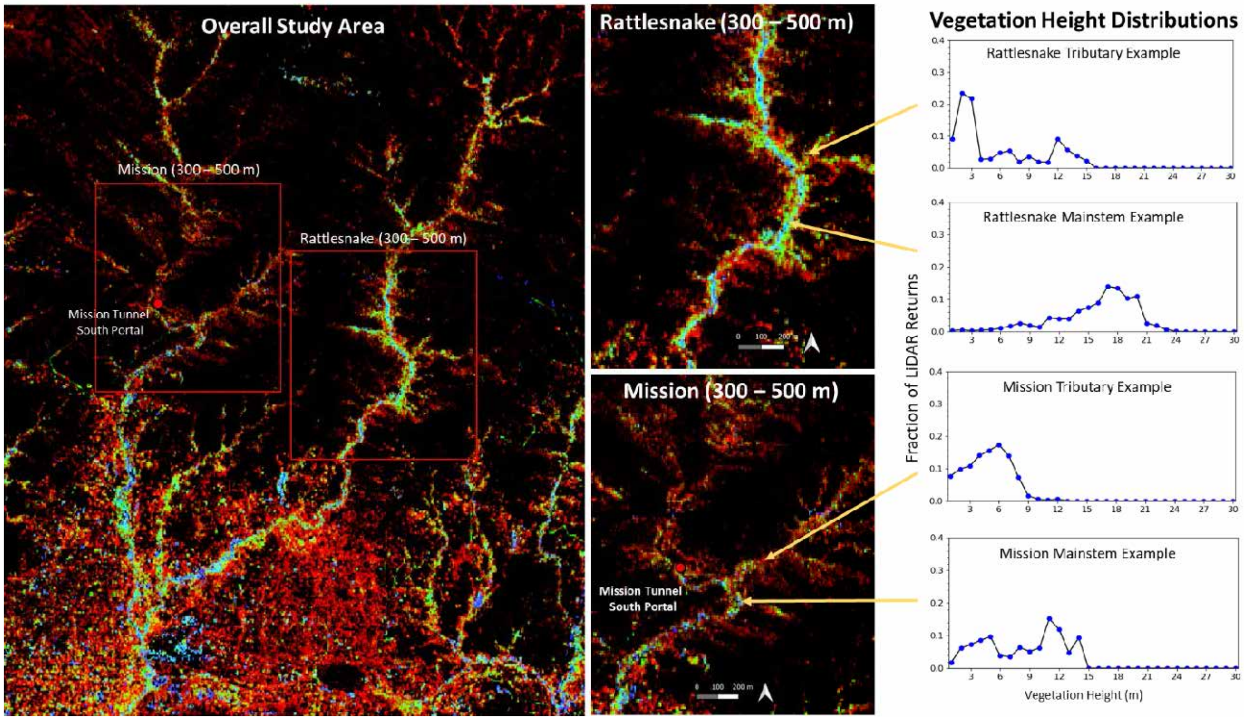


Figure 4.2.3. Vegetation height distributions mapped across the Mission and Rattlesnake Watersheds with LiDAR (left), with red rectangles indicating magnified images (center) ranging from approximately 300 to 500 m elevation along each creek. Magnified areas correspond roughly to the reaches overlying the Coldwater Sandstone Formation. In both raster images, color scale is Red: fraction of vegetation 5-10 m in height; Green: fraction 10-15 m; Blue: fraction 15+ m. The approximate location of Mission Tunnel's south portal is shown as a red dot. At right, example vegetation height distributions for select points are shown (locations indicated by yellow arrows).

Vegetative phenology maps were constructed using Google Earth Engine (Gorelick 2017) and the Sentinel-2 satellite constellation (Copernicus 2021), which maps the earth at 10 m resolution every 5 days with 12 spectral bands. Near infrared (NIR) and red (Red) bands were used to calculate the Normalized Difference Vegetation Index (NDVI) at each point on each overflight date in the archive during 2021:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

This index ranges from -1 to 1 and maps healthy green vegetation as high values (0.5 to 1), because healthy vegetation is highly absorptive to red light (used in photosynthesis) and highly reflective to near infrared light. Sparse vegetation has values ranging from 0.3 to 0.5, and bare soils have values ranging from 0.2 to 0.3.

NDVI values were filtered to remove cloudy pixels using the spectrally-based cloud product which is distributed with Sentinel-2. An additional temporal cloud filter was applied by masking pixels that were more than 0.1 NDVI unit lower than a linear temporal interpolation across the immediately preceding and following dates. Clouds have very low NDVI, so when a very low value is immediately preceded and followed by higher values, the low value is likely to have resulted from cloud cover.

After computing and filtering NDVI values, the image date was converted to a continuous day-of-year value (ranging from 1 for January 1, 2021 to 365 for December 31, 2021). Monthly phenology curves were fit using an adaptive regression routine with the following steps:

1) We generated 12 day-of-year timestamps corresponding to each month.
2) We obtained NDVI values from the Sentinel-2 timeseries for each pixel in a moving window of 30 days around each timestamp. The Sentinel-2 constellation has a return interval of 5 days, so within a 60-day window, each period had up to 12 NDVI values to use in fitting a local phenology curve (before cloud filtering).
3) We fit quadratic and linear regressions relating NDVI to day-of-the-year within each window for each pixel. Additionally, we computed the median NDVI value in each time-neighborhood.
4) Time-spans differ in the number of cloud-free scenes and consequently in the accuracy of the regression fits. This is especially problematic during portions of the year that are characterized by heavy cloud cover (e.g., "June Gloom" in Southern California). In cases when only a few NDVI values are unaffected by clouds, and when pixels that are occluded or shaded by fog, clouds, or cloud shadows are not completely removed by the automated filtering routine, higher order regressions can fit poorly. The following rules were used to decide if quadratic, linear, or median regression models produced the best fits:
    a. If the total number of images in the window was greater than 5, and the quadratic regression predicted a physically reasonable NDVI value (-1 to 1), and the absolute value of the z-score of the NDVI prediction with respect to the distribution of values in its associated time window was less than 1.5 (i.e., not a statistical outlier), a quadratic fit was used.
    b. OTHERWISE, if the total number of images was greater than 2, and the linear regression predicted a physically reasonable NDVI value (-1 to 1), and the absolute value of the z-score of the NDVI prediction with respect to the distribution of values in its associated time window was less than 1.5, a linear fit was used.
    c. OTHERWISE, the median NDVI value of the neighborhood was used.
5) This procedure was repeated for every pixel and time window to produce a phenological image stack with 12 temporal bands corresponding to monthly estimates of vegetation greenness.

An example image showing spatial variation in vegetation phenology is shown in Figure 4.2.4.

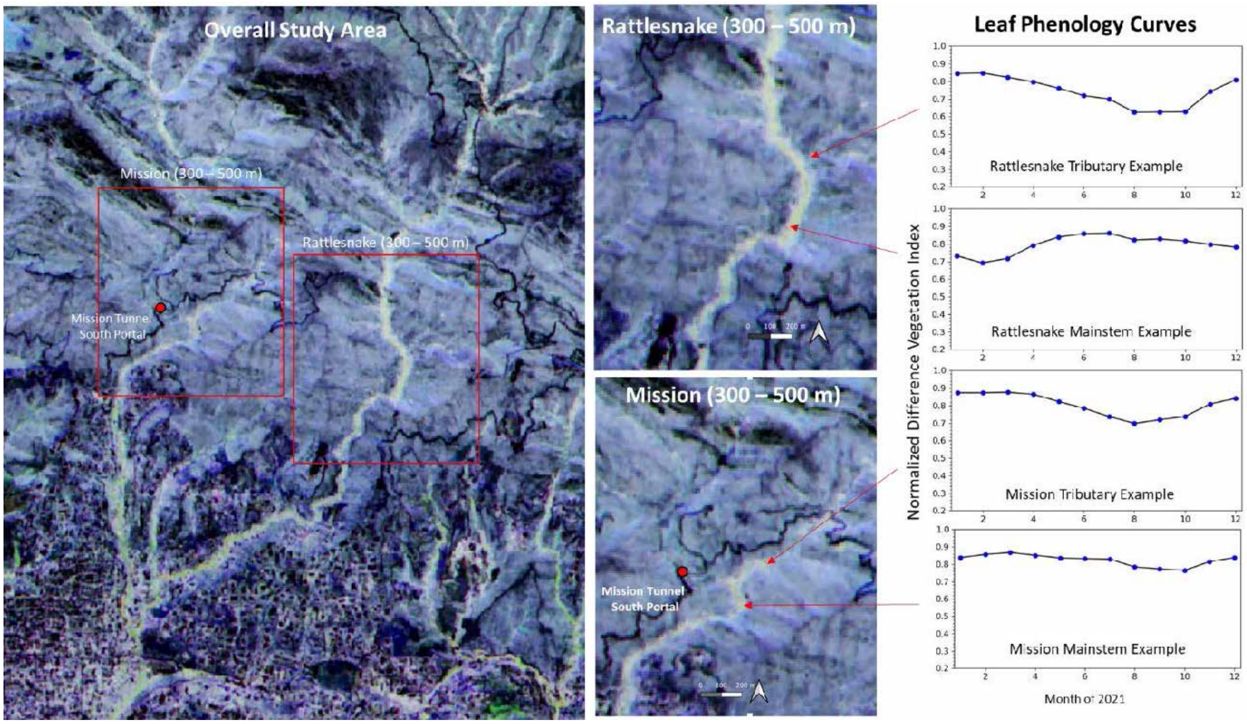


Figure 4.2.4. Greenness phenology image mapped across the study area using Sentinel-2 and Google Earth Engine (left), with red rectangles indicating cutout images (center) ranging from approximately 300 to 500 m elevation along each creek – the section overlying the Coldwater Sandstone geological formation. The approximate location of Mission Tunnel's south portal is shown as a red dot. At right, example phenological curves are mapped for select points (locations indicated by red arrows). In both color images, color scale is Red: October greenness; Green: June greenness; Blue: January greenness. With this color scale, short-lived annual plants are blue, evergreen vegetation is white, winter-deciduous trees are yellow, and chaparral is pale whitish blue (due to moderate declines in greenness in late summer for the mix of evergreen, drought-deciduous, and annual plants characteristic of chaparral). In the leaf phenology curves outlined at right, the first and third curves ("Rattlesnake Tributary Example" and "Mission Tributary Example") are characteristic of chaparral vegetation; the second curve ("Rattlesnake Mainstem Example) is typical for high elevation creeks with a mix of winter-deciduous hydroriparian phreatophytes (e.g., sycamore) and evergreen facultative phreatophytes (e.g., coast live oak, bay laurel). The lowest curve ("Mission Mainstem Example") is characteristic of purer evergreen woodland without much influence from deciduous trees.

In phenology imagery (Figure 4.2.4) for mixed woodlands of evergreen and deciduous trees, it can be difficult to visually distinguish between pure stands of evergreen woodland (white areas in Figure 4.2.4) and mixed woodlands of deciduous and evergreen trees closer to the channel (yellow in Figure 4.2.4). However, differencing winter and summer greenness renders the boundaries between the deciduous and evergreen trees quite clear, as in Figure 4.2.5 below. In this format, the close adherence of deciduous trees to the channel becomes obvious.

For upland plants like chaparral and grasses, the exact timing of greenness varies substantially between years in response to pulses of precipitation and drought, although the general pattern of annuals dying back early in spring and chaparral maintaining its greenness longer into the year tend to hold. However, the greenness phenology of riparian trees is less dynamic and is driven more strongly by a combination of integrated seasonal temperature (or 'degree days', primarily for spring leaf flush) and photoperiod (primarily for fall leaf senescence).

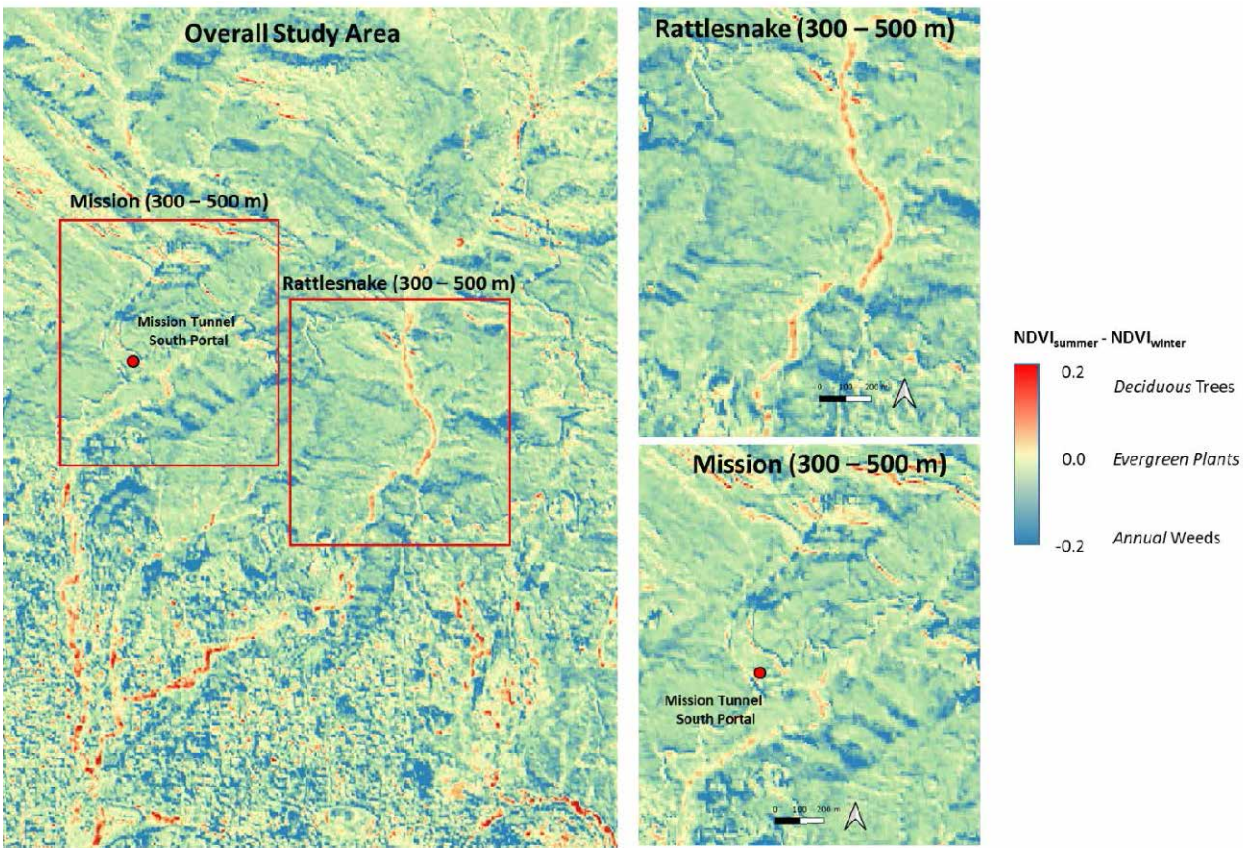


Figure 4.2.5. Map of difference in summer and winter greenness across the study area. Zoomed in regions correspond to the creek reaches over the Coldwater Sandstone Formation, from approximately 300 to 500 m in elevation. Evergreen plants – including live oak and bay-laurel – change little in greenness across the year and show up in this map as very pale beige (with difference values close to 0). Winter deciduous riparian trees are much greener in summer than in winter, and are mapped in red (difference values > 0). Areas are bright blue when dominated by grasses and herbaceous plants which green up early in the year, in response to winter rains, then die back during summer. Areas dominated by chaparral, which is typically a mixture of evergreen, drought-deciduous plants, and annual plants, are pale blue.

Vegetative Characteristics Along Channel

To assess differences in vegetation along and between the two creeks, we manually delineated flow lines for Mission and Rattlesnake Creeks and sampled evenly every 30 m to produce a network of 509 points regularly spaced along the thalweg in each creek. At every point, we estimated the terrain elevation and the lateral distance along the channel from the study area outlet (at the base of Rocky Nook Park). We assigned points to geologic formations using Diblee maps of the study area, ranging from alluvium at low elevations, upwards through the Sespe, Coldwater Sandstone, Cozydell Shale, and eventually Matilija Formations. The highest elevations in the study area are underlain by the Juncal Formation, but the combination of steep creek bed slopes, high elevations, and low contributing watershed area mean that there is almost no riparian woodland on the Juncal Formation.

We calculated the distance from each vegetation sampling point to the nearest pool containing water mapped during summer surface water surveys (Dr. Paul Alessio, see Appendix 4.1 above). We also computed distance to the nearest pool which was wet during winter/spring surveys, and distance to the nearest pool which was wet in summer surveys. We labeled points as 'summer dry' if the nearest pool during summer surveys was dry and 'winter dry' when the closest pool was dry during winter or spring. Surface water and geologic formation maps are shown in Figure 4.2.6.

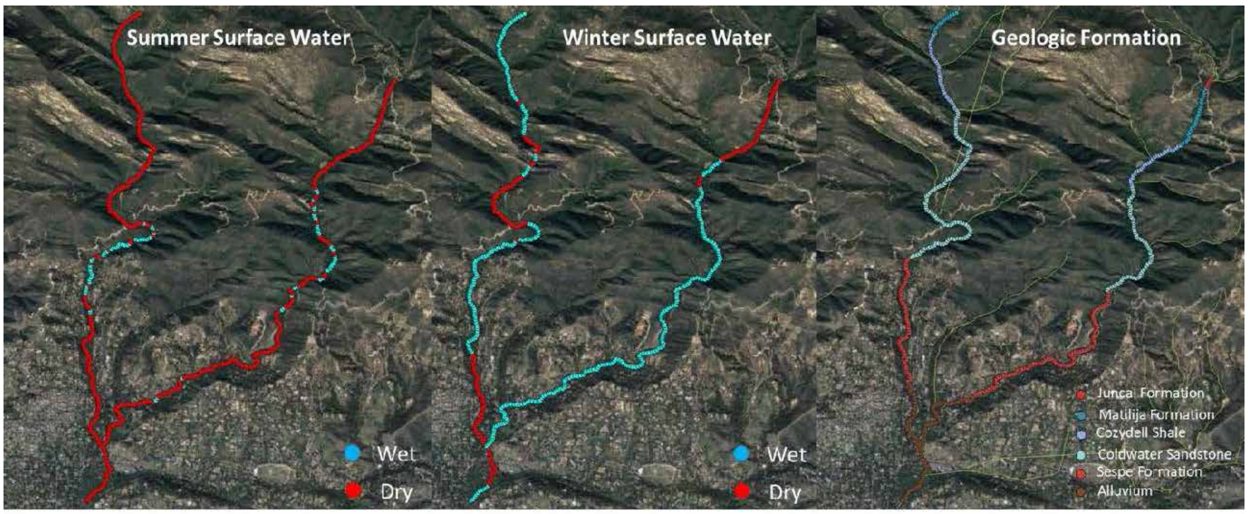


Figure 4.2.6. Presence of surface water in summer (left) and in winter (right), 2021-22, and the association of the creeks with different geologic formations.

We determined vegetative characteristics from the LiDAR and Sentinel-2 raster data by aggregating all pixels within 30 m of each thalweg point. The 30 m threshold was used based on visual inspection of the image datasets, which revealed that the riparian woodland rarely exceeded 60 m in total width (both sides of the creek) within our study area. For each group of pixels within 30 m of a thalweg point, we computed the following metrics of vegetative vigor:

1) Maximum vegetation height
2) Mean vegetation height (across all vegetative LiDAR returns)
3) Deciduous vegetation cover, estimated as the fraction of pixels for which June/July greenness was greater than January/February greenness. Note that stands of evergreen trees exhibit relatively little seasonal change in NDVI values, but were slightly greener during winter than summer due to subpixel mixing with other vegetative types (e.g. annual weeds) and drought stress during the summer. See descriptions of phenological types in Figure 4.2.4 and Figure 4.2.5.
4) Median greenness
5) Maximum greenness

Subsequently, we plotted measures of vegetative vigor for each creek against longitudinal position along the creek (from 0 m at the base of Rocky Nook Park to 8000 m at the upper end of the watershed). Locally estimated scatterplot smoothing (LOESS) regression curves were fit to the data with the R function geoms_ mooth, using a smoothing span of 0.75 to produce curves describing spatial variation in mean vigor metrics with distance up the creek. These data and curves are plotted in Figures 4.2.7 to 4.2.11 alongside cutoff points for summer water distributions and geological formations. Although the exact geological formation breakpoints differ slightly between the two creeks due to the northeast slant of formations in the Santa Ynez Mountains, we use the average position of each formation for the two creeks for clear visualization. Subsequent analysis using statistical tests used creek-specific geological formation breakpoints.

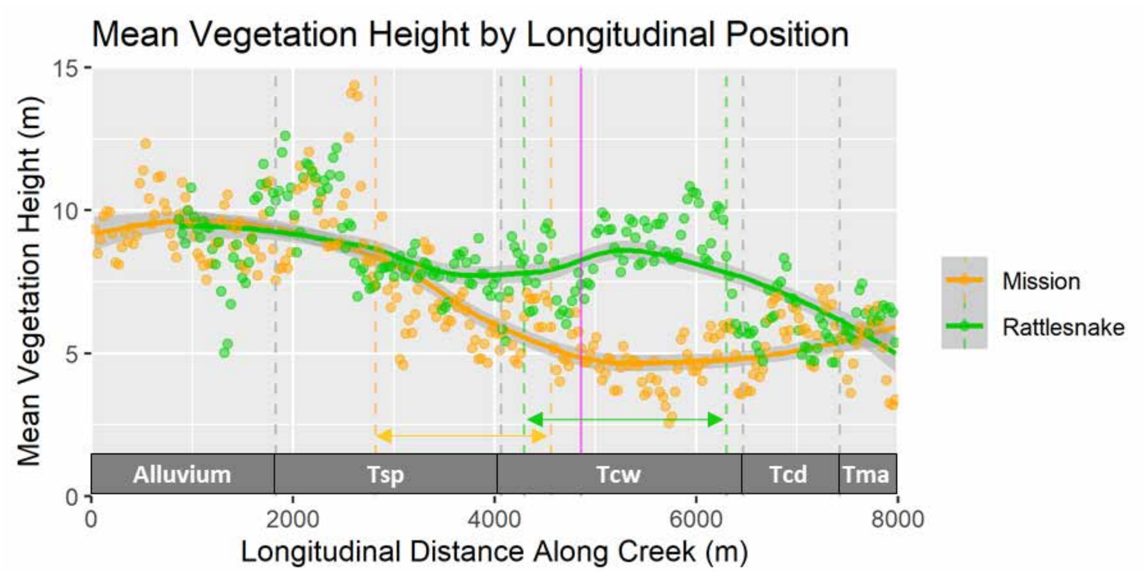


Figure 4.2.7. Mean vegetation height by distance upstream from the lowest boundary of Rocky Nook Park. We plotted separate LOESS regression curves for Mission Creek and Rattlesnake Creek, with 95% confidence intervals shown by gray bands. The pink vertical line shows the location of the Mission Tunnel's south portal. Green and orange arrows and vertical dashed lines, respectively, indicate the spatial extent of surface water during summer on Rattlesnake Creek and Mission Creek. Geological formations are indicated and labeled at the bottom of the plot and creek transitions between geologic formations are given by gray dashed lines.

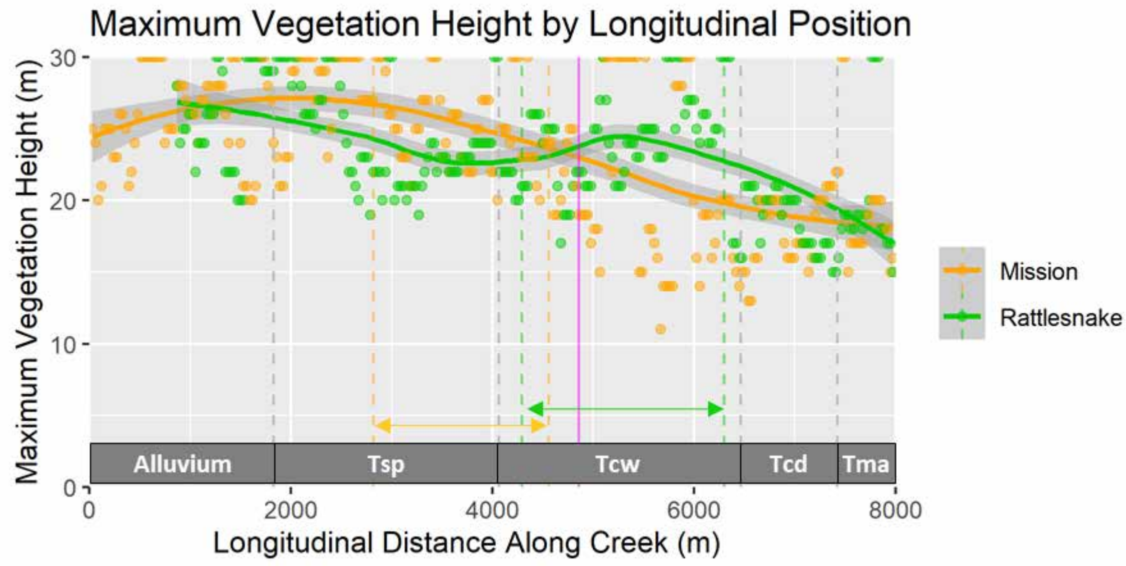


Figure 4.2.8. Maximum vegetation height by distance up the creek from Rocky Nook Park. Other designations as in Figure 4.2.7.

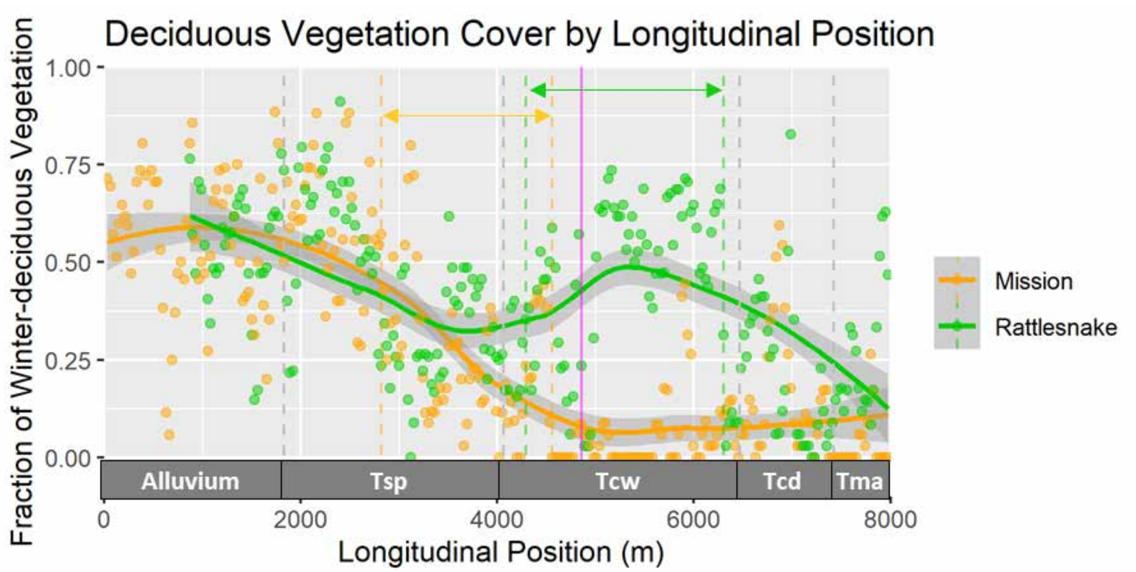


Figure 4.2.9. Mean fractional cover by winter-deciduous, obligate riparian phreatophytic trees, by distance up the creek from Rocky Nook Park. Other designations as in Figure 4.2.7.

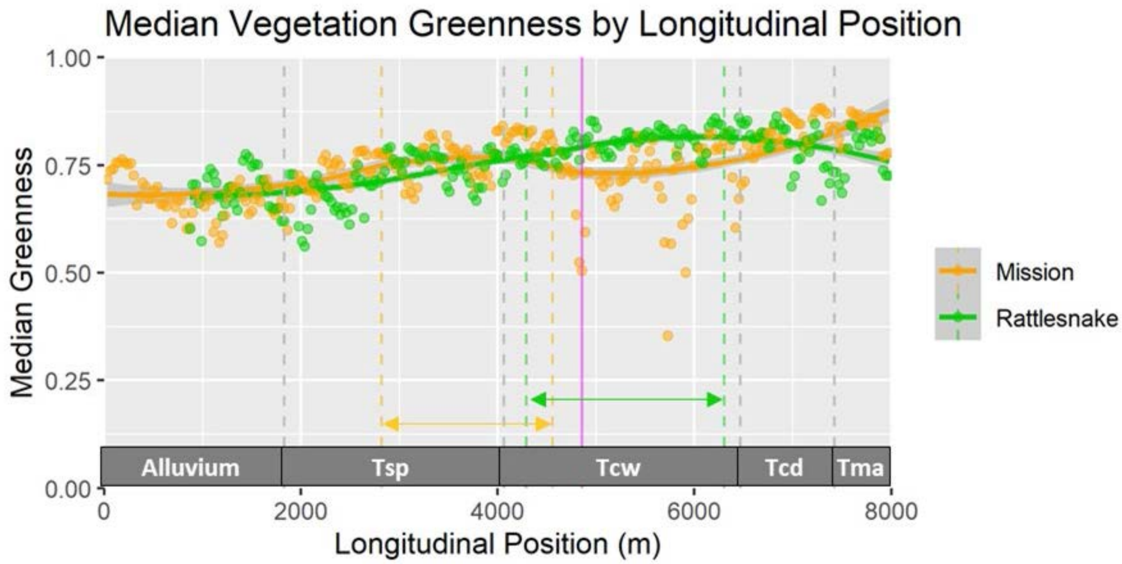


Figure 4.2.10: Median vegetative greenness (NDVI) by distance up the creek (in m) from Rocky Nook Park. Other designations as in Figure 4.2.7.

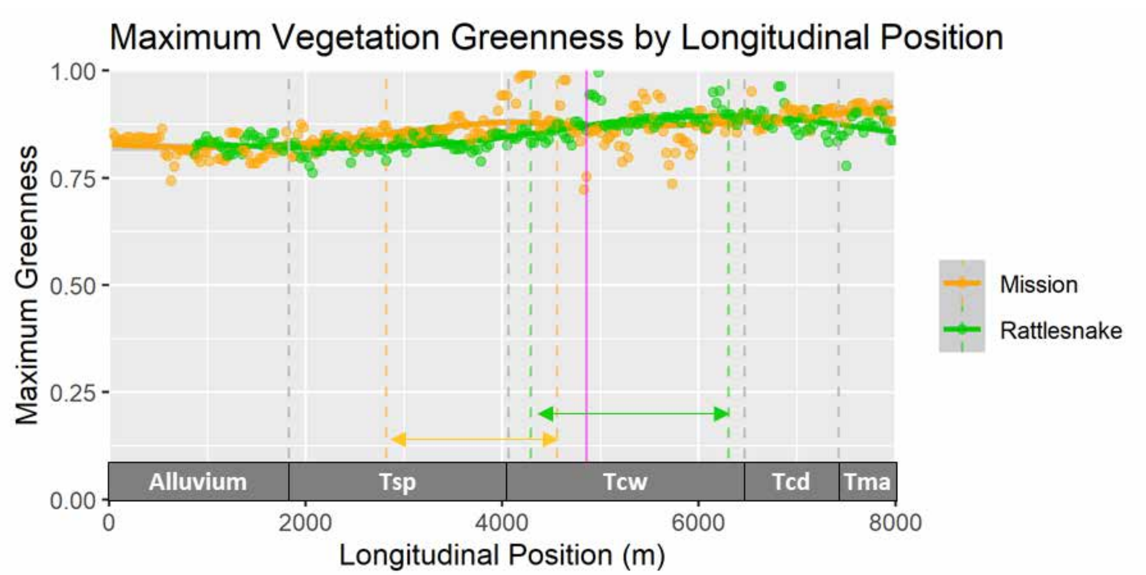


Figure 4.2.11: Maximum vegetative greenness (NDVI) by distance up the creek (in m) from Rocky Nook Park. Other designations as in Figure 4.2.7.

We integrated phenological curves and LiDAR height histograms across entire reaches within each geological formation and each creek to produce estimates of average greenness phenology and vegetation height distributions. The resulting curves are presented in Figures 4.2.12 (phenology) and 4.2.13 (vegetation height).

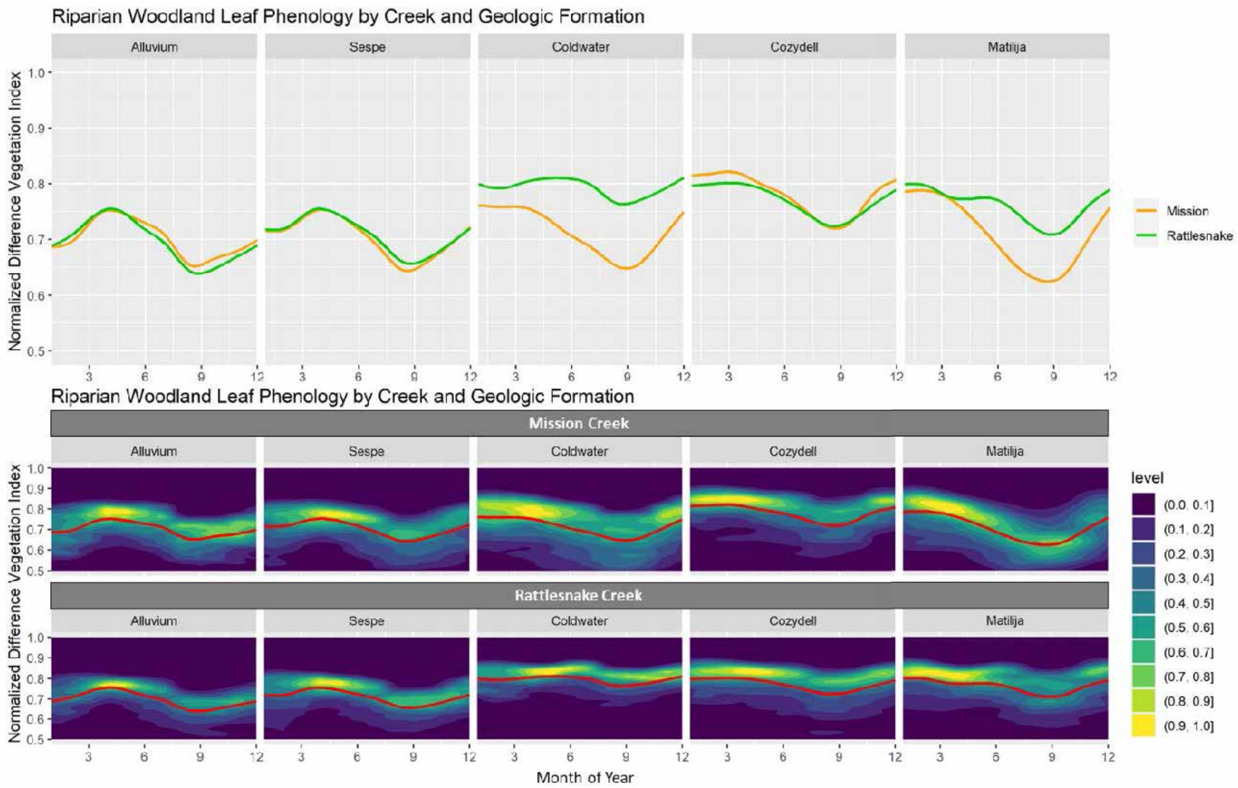


Figure 4.2.12. Average NDVI values within 30 m of the thalweg for each creek (above), as well as the distribution of NDVI values for each creek (below), across months for each geological formation. The color scale next to the lower plot shows the fraction of all points along a reach that exhibited that greenness (NDVI) value during that month and red lines show the mean NDVI value across all points within a reach for each month.

Note that levels and temporal changes in NDVI values for both creeks are quite similar for reaches flowing through alluvium, the Sespe Formation, and the Cozydell Shale Formation. By contrast, Rattlesnake Creek had higher late-summer greenness where it flowed through the Coldwater and Matilija Formations, likely due to an invasion of non-woodland vegetation types in Mission Creek on those formations (e.g., invasive annual grasses and forbs, or drought-deciduous chaparral shrubs). Overall variability in NDVI values (spread around the mean in lower portion of Figure 4.2.12) was much greater in Mission Creek than Rattlesnake Creek on the Coldwater Sandstone Formation, which is also consistent with conversion from woodland to other vegetation types in the riparian zone.

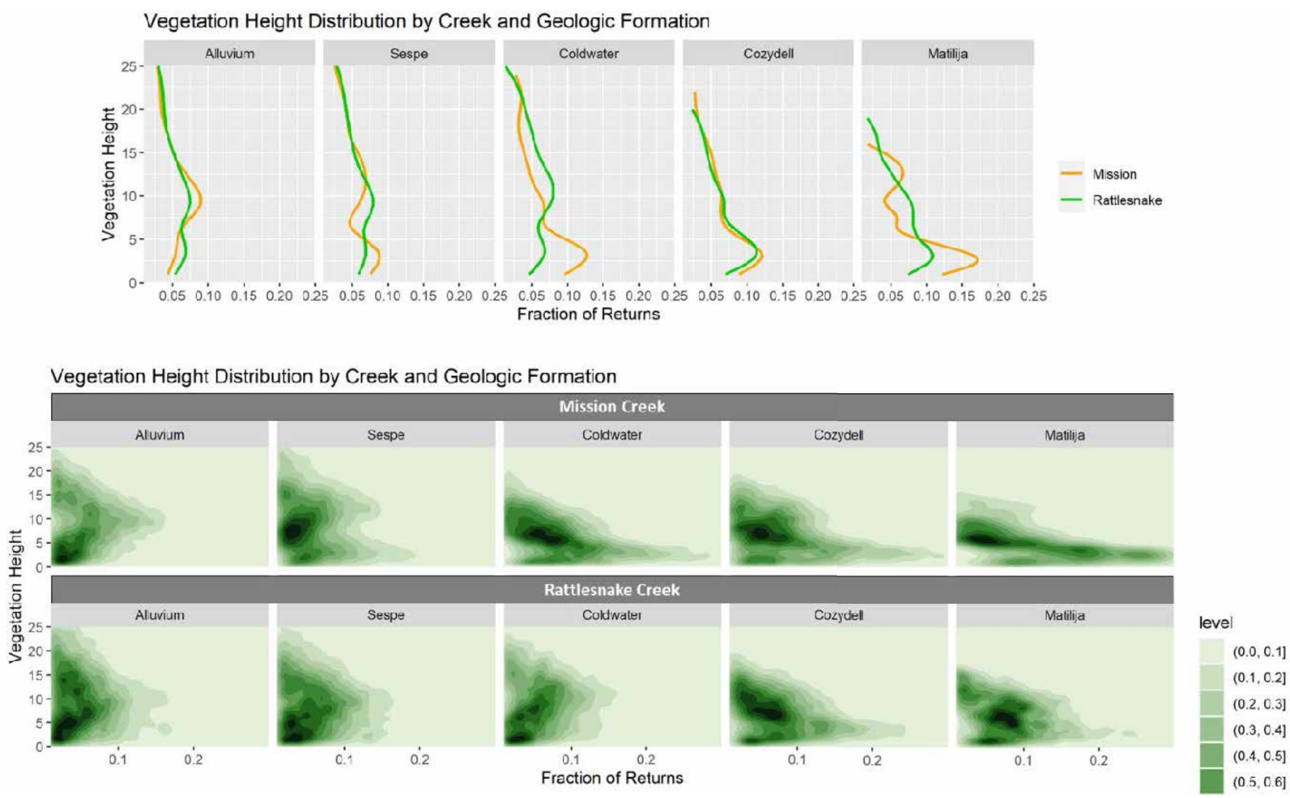


Figure 4.2.13. Vegetation height (in meters) distributions within 30 m of the thalweg for each creek (above) and variability around those mean values (below). The color scale in the lower plot shows the fraction of all vegetative LiDAR height returns along a reach at that relative height above the ground.

We found that height distributions were quite similar between Rattlesnake Creek and Mission Creek on alluvium, the Sespe Formation, and the Cozydell Shale Formation. By contrast, the Rattlesnake Creek riparian zone had more tall trees and less short vegetation than the Mission Creek riparian zone on the Coldwater Sandstone and Matilija Formations, consistent with the loss of woodland and conversion to chaparral or herbaceous vegetation along Mission Creek.

We used two-sample t-tests to compare mean vegetative metrics between the two creeks segregated by geological formation (Table 4.2.1, significant ($p < 0.05$) results are highlighted with the color indicating the magnitude and direction of the difference). During summer, the alluvium reach was wet for 5.4% of its length for Mission Creek and dry for Rattlesnake Creek; the Sespe reach was 4.6% wet on Rattlesnake Creek and 22.8% wet for Mission Creek; the Coldwater reach was 47.5% wet on Rattlesnake Creek and 22.8% wet on Mission Creek; and the Cozydell and Matilija reaches were dry for both creeks.

Table 4.2.1: Test results comparing vegetative vigor between Rattlesnake and Mission Creeks for each geological formation and vegetation variable. Results that are significant at $p < 0.05$ are indicated in light red. The Mean (RC) and Mean (MC) columns respectively show the mean values for Rattlesnake and Mission Creek in each vegetation variable. The Difference column is the difference between these two values, and the next two columns show a 95% confidence interval on the difference value. Difference values are colored to indicate the magnitude of the difference, from red (higher on Mission Creek) to green (greater on Rattlesnake Creek).

Variable	Formation	p-Value	t Statistic	Mean (RC)	Mean (MC)	Difference	Conf. Int. Low	Conf. Int. High
Mean Return Height	Alluvium	0.6817	54.5	9.249	9.371	-0.123	-0.718	0.473
Mean Return Height	Sespe	0.5638	91.8	8.487	8.680	-0.193	-0.853	0.468
Mean Return Height	**Coldwater**	0.0000	110.5	8.666	5.047	3.619	3.252	3.986
Mean Return Height	Cozydell	0.1120	54.2	6.156	5.759	0.398	-0.096	0.891
Mean Return Height	**Matilija**	0.0152	13.2	5.970	4.716	1.254	0.284	2.225
Max Return Height	Alluvium	0.5923	69.3	26.459	26.083	0.376	-1.018	1.771
Max Return Height	**Sespe**	0.0000	126.9	23.989	26.932	-2.944	-3.983	-1.905
Max Return Height	**Coldwater**	0.0006	158.0	24.475	22.079	2.395	1.047	3.744
Max Return Height	Cozydell	0.5323	60.7	19.481	19.000	0.481	-1.051	2.014
Max Return Height	Matilija	0.3402	35.0	18.852	17.833	1.019	-1.120	3.157
Deciduous Fraction	Alluvium	0.5100	84.4	0.534	0.557	-0.023	-0.092	0.046
Deciduous Fraction	**Sespe**	0.0428	113.0	0.412	0.484	-0.072	-0.142	-0.002
Deciduous Fraction	**Coldwater**	0.0000	84.4	0.489	0.105	0.384	0.327	0.441
Deciduous Fraction	**Cozydell**	0.0140	52.6	0.249	0.132	0.118	0.025	0.210
Deciduous Fraction	**Matilija**	0.0011	36.2	0.195	0.051	0.144	0.062	0.227
Median Greenness	Alluvium	0.2603	69.4	0.687	0.675	0.011	-0.009	0.031
Median Greenness	Sespe	0.1604	135.0	0.727	0.739	-0.012	-0.029	0.005
Median Greenness	**Coldwater**	0.0000	132.3	0.808	0.742	0.066	0.048	0.084
Median Greenness	**Cozydell**	0.0093	48.9	0.812	0.836	-0.025	-0.043	-0.006
Median Greenness	**Matilija**	0.0060	30.8	0.776	0.819	-0.043	-0.072	-0.013
Max Greenness	Alluvium	0.0917	94.8	0.826	0.819	0.007	-0.001	0.016
Max Greenness	**Sespe**	0.0000	121.6	0.830	0.846	-0.016	-0.023	-0.009
Max Greenness	**Coldwater**	0.0387	157.8	0.888	0.875	0.013	0.001	0.026
Max Greenness	Cozydell	0.0812	41.2	0.889	0.900	-0.011	-0.023	0.001
Max Greenness	**Matilija**	0.0001	36.5	0.870	0.901	-0.031	-0.045	-0.017

By all vegetative metrics, the riparian corridor along Rattlesnake Creek was healthier than that along Mission Creek over the Coldwater Sandstone Formation (the formation that the Mission Tunnel's south portal penetrates). This reach also was much wetter in summer on Rattlesnake (47.5% wet by length) than on Mission (22.8%) Creeks. For some vegetative vigor metrics, the difference between streams was quite large – for example, there was 365% more areal coverage by winter-deciduous woodland and a 71% increase in average vegetation height on the Coldwater Formation along Rattlesnake Creek compared to Mission Creek, although there was only a 1% difference in peak seasonal greenness between these creeks. The Coldwater Sandstone is especially important for aquatic and terrestrial wildlife which depend on surface water because of its large number of springs that feed flows even during times of severe drought (e.g., summer 2022).

By contrast, the Sespe reach was wetter in summer and had slightly higher vegetative vigor on Mission than Rattlesnake Creek. Differences were significant for maximum vegetation height (12% greater on Mission, at 26.9 m), for areal fraction of deciduous vegetation (17% higher on Mission, at 48.4%), and for maximum greenness (1.9% higher on Mission).

In higher elevation riparian zones, Rattlesnake Creek had higher deciduous vegetation fractions along both the Matilija (282% greater) and Cozydell (89% greater) reaches, as well as greater mean vegetation height along its Matilija reach (26% greater), than Mission Creek. In contrast, the riparian zone along Mission Creek had higher maximum and median greenness (3.5% and 5.4% greater) on the Matilija Formation than Rattlesnake Creek and also higher median greenness (3.0% greater) on the Cozydell Formation.

In general, differences in maximum and median greenness between creeks were a small fraction of overall variation in these metrics; however, creek differences in deciduous vs. evergreen composition were very large and differences in mean height were moderate. With regards to ecological processes, the observed differences in mean vegetation height and deciduous fraction are probably the most meaningful, because they correspond to overall woody biomass and woodland composition by obligate vs. facultative phreatophytes. In contrast, maximum vegetation height determined from LiDAR will reflect even the presence of isolated tall trees (in our area, usually sycamore or introduced redwood and eucalyptus). Given the relatively short time since the tunnel was built, it is likely that some of the tallest trees along Mission Creek predate the tunnel's construction. By contrast, the smaller trees (especially alders, which are relatively short-lived) most likely recruited and grew in the time since the tunnel was built and the hydrology of the creek was modified. As a result, the response to recent changes in hydrology should be more pronounced for the smaller height classes, which is consistent with our observations. In contrast to the tree height distribution, greenness (NDVI) values are driven by both woody and non-woody vegetation (e.g., annual grasses, invasive forbs), so these values can remain high even in cases where the woodland along the channel dies and is replaced by other vegetation types.

The two metrics most directly linked to ecological processes and riparian woodland health (deciduous fraction and mean vegetation height) were both substantially greater in Rattlesnake than Mission Creeks on the Coldwater Formation, congruent with the greater extent of dry season surface water in Rattlesnake Creek than Mission Creek. The range of elevations where Mission Creek showed both less wetted area and reduced riparian vegetation health relative to Rattlesnake Creek surrounded the point where the Mission Tunnel's south portal pierces the Coldwater Sandstone. The Rattlesnake riparian woodland along higher elevation formations, which are also pierced by the tunnel, were similarly more dominated by deciduous trees (on the Cozydell and Matilija) and showed higher mean vegetation height (on the Matilija) than Mission Creek, although these reaches dried during summer on both creeks. This pattern provides supporting evidence for the loss of groundwater to the tunnel and associated vegetative declines.

In contrast to higher elevation sites, the riparian woodland in Mission Creek's Sespe Formation reach appeared slightly healthier than Rattlesnake. The Sespe Formation is below the lowest elevation of Mission Tunnel, so its groundwater may be impacted differently than groundwater in the higher elevation formations, which are directly pierced by the tunnel. Groundwater in fractured rock systems like these are extremely complex and difficult to simulate or predict. However, regardless of the underlying hydrologic mechanism, the differences in vegetative vigor on the Sespe and Coldwater mirror differences in the extent of surface water.

Notably, the increases in in vegetative vigor in Mission's Sespe reach were much smaller than in Rattlesnake's Coldwater reach relative to the other creek's associated reach (e.g., 12% vs. 71%

difference in vegetation height, and 17% vs. 365% difference in deciduous vegetation fraction). The lower vigor on Mission Creek's Coldwater reach appeared to result from significant losses of woodland and conversions to other vegetative types. In contrast, Rattlesnake's Sespe reach was still densely wooded, although the woodland was slightly shorter and slightly more dominated by deep-rooted evergreen trees.

4.2.4 Bird Surveys

Background on Study Area Bird Communities

Across the dryland regions of the Western United States, riparian woodlands provide unique habitat to wildlife due to their lower maximum summer temperatures, persistent water availability, and lush vegetation. As a consequence, in Southern California, a unique assemblage of bird species breeds exclusively in intact riparian woodlands. Characteristic species from this group include the Yellow Warbler (*Setophaga petechia*), Wilson's Warbler (*Cardellina pusilla*), Warbling Vireo (*Vireo gilvus*), Swainson's Thrush (*Catharus ustulatus*), Yellow-breasted Chat (*Icteria virens*), Willow Flycatcher (*Empidonax traillii*), Yellow-billed Cuckoo (*Coccyzus americanus*), and Bell's Vireo (*Vireo bellii*), among others (Lehman 2020). Unfortunately, the latter three species have been largely extirpated from Santa Barbara County due to the degradation or loss of riparian habitats, and *C. ustulatus* and *I. virens* are now mostly or entirely absent from the creeks draining the south face of the Santa Ynez Mountains (Lehman 2020). Yellow Warbler, Wilson's Warbler, and Warbling Vireo remain in our area, but are isolated in highly local breeding populations in only a few creeks (Holmgren 2020).

Figure 4.2.14. Examples of bird species in the Mission and Rattlesnake Creek Watersheds. At left, an American Robin (*Turdus migratorius*) perched on a toyon (*Hetermoeles arbutifolia*), an important riparian and chaparral shrub which provides berry resources to birds. At right, a California Quail (*Callipepla californica*), a common bird of chaparral areas throughout the watershed.

Other vegetation types in the Mission and Rattlesnake Creek Watersheds are also associated with characteristic avifauna. Oak woodlands are frequented by numerous species, including Oak Titmice, California Scrub-Jay, Acorn Woodpecker, Band-tailed Pigeon, White-breasted Nuthatch, Western

Screech-Owl, Spotted Owl, Northern Pygmy-Owl, and Hutton's Vireo. Typical chaparral birds include California Thrasher, Wrentit, California and Mountain Quail, and Lesser Goldfinch. In general, most of these species are not declining regionally at the same rate as the riparian obligate breeding birds noted above (Lehman 2021).

Sampling Protocol

During summer of 2022, extensive surveys were conducted across creeks in Santa Barbara County to examine the breeding bird communities associated with riparian zones across watersheds in the Santa Ynez Mountains. In total, 145 sites were recorded along 11 creeks (Table 4.2.2).

Table 4.2.2: Distribution of audio recording stations across watersheds, and the number and percentage of sites that contained water in pools in the summer.

Creek	Total Sites	Wet Sites	Percent Wet
Rattlesnake Creek	12	6	50.0%
Mission Creek	15	4	26.7%
Atascadero Creek	15	5	33.3%
Arroyo Quemado	15	15	100.0%
Ellwood Creek	8	1	12.5%
Lake Los Carneros	8	6	75.0%
Maria Ygnacio Creek	5	0	0.0%
North Campus Open Space	8	4	50.0%
San Antonio Creek	12	2	16.7%
San Jose Creek	9	3	33.3%
Figueroa Creek	6	3	50.0%

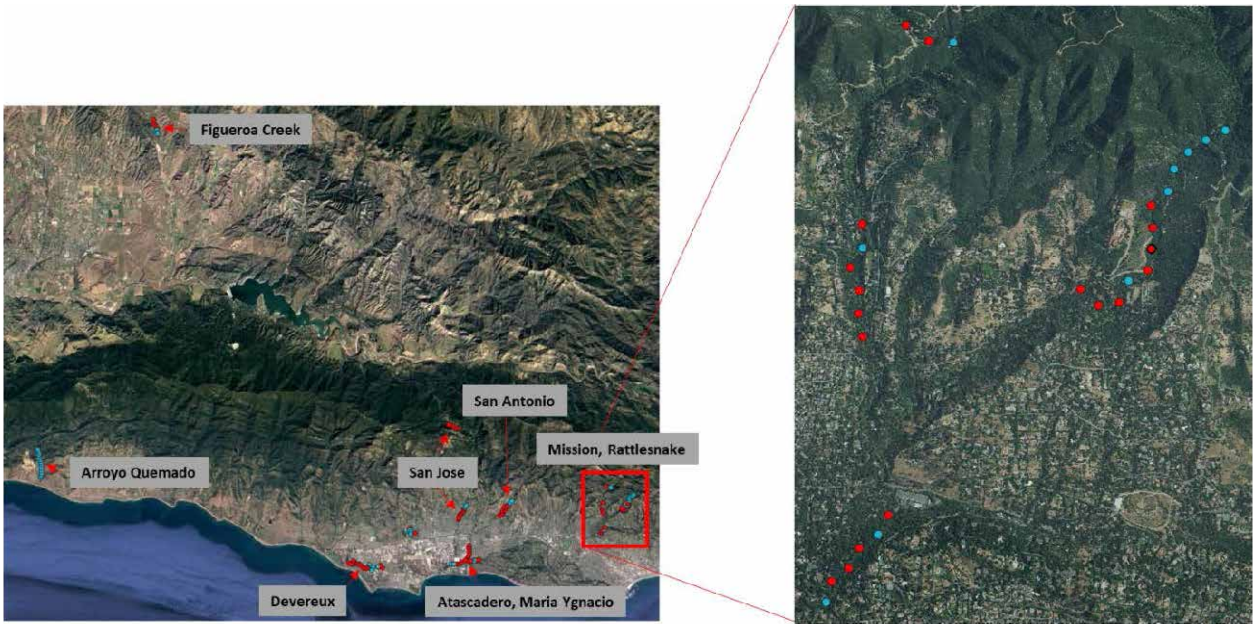


Figure 4.2.15. Distribution of acoustic monitoring sites in Santa Barbara County during summer 2022. Cutout at right shows zoomed view of monitoring sites within the Mission and Rattlesnake Creek watersheds. Points in red were dry and points in blue were wet at the time of surveys.

At each site, an autonomous recording unit (AudioMoth 1.2.0 or Wildlife Acoustics Song Meter Micro) (Hill 2019) was deployed to record bird vocalizations for at least two days. Units were programmed to record 55 out of every 60 seconds, from an hour before sunrise to an hour after sunset, every day until they were collected or ran out of batteries or storage. Additionally, bird point counts were conducted and the presence of surface water was noted at each monitoring site. During each 5 minute point count, the presence of all birds heard or seen was noted, as well as the numbers of birds present, distance from the recording device (estimated with a laser rangefinder) and whether observed birds were calling, singing, or silent.

Bioacoustics Analysis

We processed all audio data using the Cornell machine learning library BirdNET (Kahl 2019), which detects bird vocalizations and classifies them to species using a pre-existing neural network. We removed potentially spurious false positive detections by rejecting calls that BirdNET identified as having a confidence < 0.9, or species that were detected fewer than 100 total times.

At each site across the Santa Barbara County study area, the total number of detections for each species at wet versus dry sites was divided by the number of wet (49) versus dry (64) sites. We then compared bird species detections per site at dry and wet sites to determine the species that were more vocally common in one wet-dry habitat type vs. the other (Table 4.2.3).

Table 4.2.3: Differences in frequency of detection in audio analyses for wet vs. dry sites across the bioacoustics sampling domain.

More Common in Wet Sites		**More Common in Dry Sites**	
Bird Common Name	**Factor**	**Bird Common Name**	**Factor**
Purple Finch	26	White-breasted Nuthatch	4.0
American Robin	8.0	Band-tailed Pigeon	2.6
Yellow Warbler	5.0	Cooper's Hawk	2.5
Wilson's Warbler	5.0	Dark-eyed Junco	2.2
Bullock's Oriole	4.5	Allen's Hummingbird	2.0
Canyon Wren	4.0	Acorn Woodpecker	1.9
Pacific-slope Flycatcher	2.4	Orange-crowned Warbler	1.7
Scaly-breasted Munia	2.0	American Crow	1.6
Chestnut-backed Chickadee	1.8	Oak Titmouse	1.3
Song Sparrow	1.8		
Common Yellowthroat	1.4		

Strikingly, most of the species which are considered obligate breeders in riparian woodlands in our area (e.g., Yellow Warbler, Wilson's Warbler, Purple Finch, Chestnut-backed Chickadee) were much more common at wet than dry sites. Other bird species which are characteristic of, but facultative breeders in, riparian areas also were more frequently detected in wet than dry riparian habitats (e.g., Pacific-slope Flycatcher, Scaly-breasted Munia, Common Yellowthroat, Song Sparrow). Birds that were detected more frequently in dry than wet riparian habitats were mostly species considered to be generalist woodland birds or oak specialists (e.g. White-breasted Nuthatch, Band-tailed Pigeon, Cooper's Hawk, Dark-eyed Junco, Acorn Woodpecker, Oak Titmouse).

Following is a list of all (37) species detected via point count or acoustic analysis in the Mission and Rattlesnake riparian corridors:

> Acorn Woodpecker, American Crow, Anna's Hummingbird, Ash-throated Flycatcher, Band-tailed Pigeon, Bewick's Wren, Black Phoebe, Bushtit, California Scrub-Jay, California Towhee, Canyon Wren, Cooper's Hawk, Dark-eyed Junco, Hairy Woodpecker, Hooded Oriole, House Finch, House Wren, Hutton's Vireo, Lesser Goldfinch, Mourning Dove, Northern Pygmy-Owl, Nuttall's Woodpecker, Oak Titmouse, Orange-crowned Warbler, Pacific-slope Flycatcher, Red-shouldered Hawk, Red-tailed Hawk, Rock Pigeon, Scaly-breasted Munia, Song Sparrow, Spotted Owl, Spotted Towhee, Turkey Vulture, Western Bluebird, Western Screech-Owl, White-breasted Nuthatch, Wrentit.

Of these, the following are primarily riparian breeders which were found in the larger scale analysis to be associated with wet riparian environments (Table 4.2.3). Below they are listed along with the factor by which they were more frequently detected at wet than dry sites specifically within Mission and Rattlesnake Creek:

Canyon Wren (7.0), Hairy Woodpecker (5.6), Pacific-Slope Flycatcher (2.25)

The following woodland birds were detected more frequently in dry than wet riparian habitats in the Mission and Rattlesnake drainages:

Acorn Woodpecker, American Crow, Band-tailed Pigeon, Cooper's Hawk, Dark-eyed Junco, Northern Pygmy-Owl, Oak Titmouse, Red-shouldered Hawk, Spotted Owl, Spotted Towhee, Western Screech-Owl, White-breasted Nuthatch

One other species that generally nests in oak woodland, Hutton's Vireo, was still more frequently detected at wet than dry riparian sites (factor = 1.96).

Other birds that were detected in the Mission and Rattlesnake watersheds are generalists or upland species that may occasionally enter or nest in riparian environments, including:

Anna's Hummingbird, Ash-throated Flycatcher, Bewick's Wren, Black Phoebe, Bushtit, California Scrub-Jay, California Towhee, Hooded Oriole, House Finch, Lesser Goldfinch, Mourning Dove, Nuttall's Woodpecker, Orange-crowned Warbler, Red-tailed Hawk, Rock Pigeon, Scaly-breasted Munia, Song Sparrow, Turkey Vulture, Western Bluebird, Wrentit

Overall, Mission and Rattlesnake Creek had fewer of the species most strongly associated with riparian habitats (column 1 of Table 4.2.3) than did other, similar creeks in the southern County. Some bird species which nest exclusively in riparian environments were not encountered anywhere in the Mission or Rattlesnake riparian corridors, including the Yellow Warbler and Warbling Vireo, although they do occur as uncommon and localized breeders in other, nearby watersheds. Both species still nest in other high elevation sycamore-oak riparian woodlands, such as those along upper San Jose Creek. The restoration of dry season flows should help improve nesting conditions for these species, in particular the Yellow Warbler, a Bird Species of Special Concern in California, which was 5 times more likely to occur in wet than dry riparian habitats in our larger surveys.

4.3 References

Canadell, J., Jackson, R. B., Ehleringer, J. R., Mooney, H. A., Sala, O. E., and Schulze, E. D. (1996). Maximum rooting depth of vegetation types at the global scale. *Oecologia* 108: 583-595.

Cooper, W. S. (1922). The broad-sclerophyll vegetation of California: An ecological study of the chaparral and its related communities. Carnegie Institution of Washington, p. 89-92.

Copernicus Sentinel data. (2021). Retrieved from Google Earth Engine, October 2022, processed by European Space Agency.

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of the Environment, 202, 18-27, https://doi.org/10.1016/j.rse.2017.06.031

Hill, A. P., Prince, P., Snaddon, J. L., Doncaster, C. P., and Rogers, A. (2019). AudioMoth: A low-cost acoustic device for monitoring biodiversity and the environment: *HardwareX*

6, e00073. Elsevier B.V
Holmgren, M. and O'Loghlen, A. (2020). Santa Barbara County Breeding Bird Study. Santa Barbara Audubon. Accessed October 1, 2021 from https://santabarbaraaudubon.org/santa-barbara-county-breeding-bird-study/
Kahl, S. (2019). *Identifying Birds by Sound: Large-scale Acoustic Event Recognition for Avian Activity Monitoring*. PhD thesis, Chemnitz University of Technology.
Keller, E.A., Bean, G. and Best, D. (2015). Fluvial geomorphology of a boulder-bed, debris-flow—Dominated channel in an active tectonic environment. *Geomorphology*, 243, pp.14-26.
Keller, E., Adamaitis, C., Alessio, P., Anderson, S., Goto, E., Gray, S., Gurrola, L. and Morell, K. (2020). Applications in geomorphology. *Geomorphology*, 366, p.106729.
Kibler, C. L., Schmidt, E. C., Roberts, D. A., Stella, J. C., Kui, L., Lambert, A. M., and Singer, M. B. (2021). A brown wave of riparian woodland mortality following groundwater declines during the 2012–2019 California drought. *Environmental Research Letters* v. 16, 8
Lehman, P. E. (2021). *The Birds of Santa Barbara County, California*. Accessed on October 1, 2021 from http://www.sbcobirding.com/index_html_files/BOSBC.2020Spring.pdf
McMahon, C. (2020a). *Dirt Or Leaf: an open library for segmenting plant and ground returns from aerial point clouds*. Accessed https://github.com/conormcmahon/dirt_or_leaf
McMahon, C. (2020b). LiDAR Raster stats: an open library for creating raster products from LiDAR point clouds. Accessed https://github.com/conormcmahon/lidar_raster_stats
Minor, S.A., Kellogg, K.S., Stanley, R.G., Gurrola, L.D., Keller, E.A. and Brandt, T.R. (2009). *Geologic Map of the Santa Barbara Coastal Plain Area, Santa Barbara County, California* (p. 38). US Department of the Interior, US Geological Survey.
Morell, K.D., Alessio, P., Dunne, T. and Keller, E. (2021). Sediment Recruitment and Redistribution in Mountain Channel Networks by Post-Wildfire Debris Flows. *Geophysical Research Letters*, 48(24), p.e2021GL095549.
PDAL Contributors. (2020). PDAL Point Data Abstraction Library. doi:10.5281/zenodo.2556737
Stromberg, J., 1993. Root patterns and hydrogeomorphic niches of riparian plants in the American Southwest. *Journal of Arid Environments*, v. 94, p. 1–9
United States Geological Survey. (2018). USGS LPC CA SoCal Wildfires B4 2018 LAS 2019. Distributed by Open Topography. Accessed: 2021-11-01

CHAPTER 5. SOUTHERN CALIFORNIA STEELHEAD (*Oncorhynchus mykiss*) IN THE MISSION CREEK WATERSHED

5.1 Introduction

Steelhead are one of six anadromous fish species in the genus *Oncorhynchus* that are native to the North American and Asian coasts of the North Pacific Ocean (Moyle 2002, Augerot and Foley, 2005, Quinn 2018; and Spence 2019).[1] These species support important commercial and sport fisheries, and play an important role in the cultures of peoples native to the coasts and watersheds of the North Pacific Ocean, from Russia and Japan through Alaska and California (Magnuson *et al*., 1996). Pacific salmon and steelhead also play important and complex roles in their interactions with other species native to the marine and freshwater environments of the North Pacific region (Lackey *et al*., 2006).

The only native anadromous salmonid within southern California is the federally listed endangered southern California steelhead (*Oncorhynchus mykiss*)—which spawns in watersheds ranging from the Santa Maria River south to the U.S.-Mexico border. *O. mykiss* is a highly migratory species and exhibits wide variation in the time and location spent at each life history stage (Hendry and Stearns, 2004; Hayes *et al*., 2011)[2]. Although adult steelhead spend a majority of their adult life in the marine environment, its reproductive phase (migration to and from spawning areas, spawning, incubation of eggs and the rearing of juveniles) occurs in the freshwater environment. Adult steelhead enter rivers and streams draining the Coast Ranges from Point Sal to the U.S.-Mexico border during the winter and spring, when storms produce sufficient runoff to breach the sandbars at river mouths and allow fish entry and opportunities to reach upstream spawning and rearing habitats. Steelhead utilize and rely upon all portions of the watershed they enter – including the estuary, mainstem, and upper tributaries – to complete the freshwater phase of their life-history cycle. This study focuses on the two major tributaries of the Mission Creek watershed – Upper Mission Creek and Rattlesnake Creek.

Steelhead are an example of an r-selected species: a species, which makes only a small investment of resources in its progeny, but produces many young. Although progeny have a very high mortality rate before reaching sexual maturity, they tend to grow rapidly, particularly in a food rich environment. The advantage of this reproductive strategy is that if resources are limited (or their availability is uncertain or unreliable) some young will nevertheless survive to sexual maturity to reproduce. The average survival rate of steelhead, from egg to returning mature spawning adults, is only 1% – 2%.[3] By comparison the egg-to maturity survival rate of resident *O. mykiss* can be an order of magnitude higher (Moyle, 2002; Quinn, 2018).

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[1] The taxonomic status of steelhead has varied over time. Steelhead were originally placed in the genus *Salmo* with various specific names, including *mykiss* and *gairdneri*. In 1836, steelhead were classified as *Salmo gardinerii* (Richardson, 1836), but in 1988 were placed in the genus *Oncorhynchus* (*O. mykiss* Walbaum, 1792) along with the other Pacific salmon (Richardson, 1836; Smith and Stearley, 1989; Stearley and Smith, 1993; Melville, 1995; Behnke, 2002; Alagona, 2016; Spence, 2019).

[2] Other species of Pacific salmon occur in the ocean off the coast of southern California, but are not known to enter coastal watersheds to reproduce (Hubbs, 1946; Spence, 2019).

[3] A number of factors contribute to the low egg-to-sexual maturity survival rate of steelhead, including the mortality associated with frequent low-flow summer freshwater rearing conditions, the variability of prey availability on first entering the marine environment as smolts and subsequently as growing and maturing adults, and the large number of natural predators to which steelhead are exposed in the marine environment.

An important feature of the southern populations of *O. mykiss* is that they are typically composed of mixed populations of anadromous fish (steelhead) and freshwater resident fish (rainbow trout). The ratio of anadromous to non-anadromous *O. mykiss* in an individual population (or watershed) can vary considerably both geographically and temporally, depending on local conditions (Boughton *et al.*, 2006).

In 1997, the National Marine Fisheries Service (NMFS) listed the Southern California Steelhead Evolutionary Significant Unit (ESU), extending from the Santa Maria River to the Santa Monica Mountains, under the Endangered Species Act (ESA) and classified it as an endangered species (62 FR 43937). In 2002, NMFS extended the listed species' range to the U.S.-Mexico border (67 FR 21586), and in 2006 NMFS reaffirmed the listing if this species as endangered under the joint U.S. Fish and Wildlife Service/NMFS Distinct Population Segment (DPS) policy (71 FR 834. 2006). In 2005, NMFS designated critical habitat for the endangered Southern California Steelhead ESU/DPS within the areas occupied by the species at the time of its original listing[4] (70 FR 52488). Critical habitat is defined as stream habitat that contains primary constituent elements essential for the conservation of the listed species, and habitat components that support one or more of the species life-history stages (*i.e*., freshwater spawning sites, freshwater rearing sites, freshwater migration corridors, and estuarine areas). This critical habitat designation included waters within the Mission Creek watershed. See Figure 5.9.

At the time of the designation of critical habitat, NMFS' Southwest Fisheries Science Center – Santa Cruz Laboratory, had not completed its population characterization of the steelhead populations of southern California (Boughton, 2006), or mapped intrinsic potential steelhead over-summering rearing habitat. These analyses were, therefore, not reflected in the designation of critical habitat. In 2006 NMFS published a set of synoptic maps identifying potential steelhead over-summering rearing habitat in the South-Central/Southern California Steelhead Recovery Planning Domain (Boughton and Goslin, 2006). See Figures 5.6 through 5.8 and additional discussion below regarding intrinsic potential steelhead spawning and over-summering rearing habitat in the Mission Creek watershed.

5.2 Steelhead life-history and habitat requirements

The steelhead's life-history cycle involves rearing in freshwater for one to three years before migrating to the ocean, then spending from one to four years maturing in the marine environment before returning to spawn in freshwater, although there is considerable temporal and spatial variation in this basic pattern (Figures 5.1 and 5.2). The ocean phase provides a reproductive advantage because individuals that feed and mature in the ocean grow substantially larger than freshwater residents, and

[4] In addition to the native steelhead/rainbow trout (*O. mykiss*), Mission Creek supports a variety of other native aquatic species. Tidewater goby (*Eucyclogobius newberryi)*, partially armored stickleback (*Gasterosteus aculeatus microcephalus*), Coastal prickly sculpin (*Cottus asper)*, California killifish (*Fundulus parvipinnis*) are found the lower reaches of Mission Creek and the Mission Creek Estuary. The Mission Creek estuary also provides nursery habitat for a number of marine species, including, Staghorn sculpin (*Leptocottus armatus*), Starry flounder (*Platichthys stellatus*), Diamond turbot (*Hypospsetta guttulata*), California halibut (*Paralichthys californicus*), and Topsmelt (*Atherinops offinis*), as well as Coastal prickly sculpin (*Cottus asper*), which resides in the upstream reaches but descends to the estuary to breed. Striped mullet (*Mugil cephalus*) are also found in the Mission Creek Estuary; and the Mission Creek Estuary is the current northern range site for the White mullet (*M. setosus)*. California newt (*Taricha torosa*), and Two-striped garter snake (*Thamnophis hammondi*i) generally found in the upper reaches of the watershed, and of the fish species, only *O. mykiss* are found within the Study Area (Wells 1975; Ambrose 1995). A number of non-native fishes are also found in the Mission Creek watershed, including Mosquitofish (*Gambusia affinis*) and Arroyo chub (*Gila orcutti*), and a variety of Sunfish (centrarchids) (Love and Passarelli, 2020; C. Swift, pers. comm.)

larger females produce proportionately more eggs; however, the freshwater phase provides a protected rearing environment, relatively free from competitors and predators. The out-migration of juveniles to the ocean (*i.e.*, emigration of smolts) usually occurs in the late winter and spring. In some watersheds, juveniles may rear in a lagoon or estuary for several weeks or months prior to entering the ocean. A variety of factors such as photoperiod, streamflow, water temperature, and breaching of the sandbar at the river's mouth influence the timing of emigration.

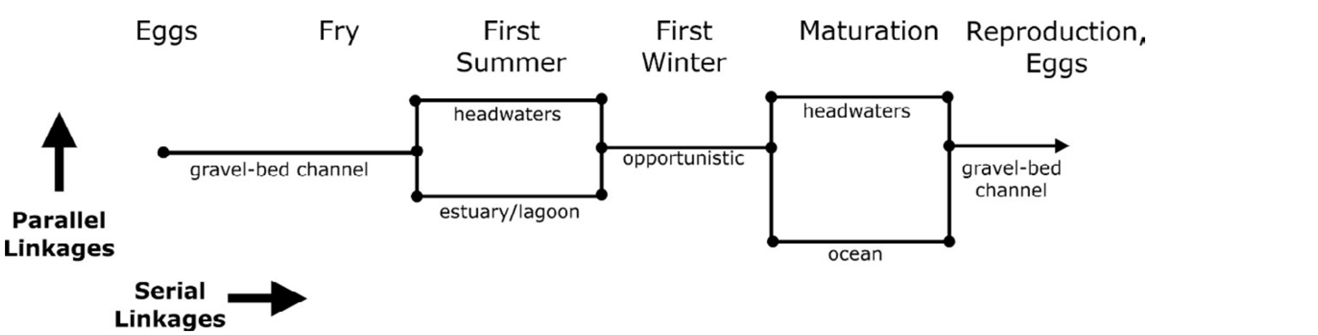

Figure 5.1. Southern California *O. mykiss* Life-History Cycle and Habitat Linkages. Parallel linkages refer to life-history phases that can occur concurrently in multiple habitat types, providing redundancy, which increases the resiliency of the species to habitat perturbations or other biological stressors. Serial linkages refer to life-history phases with distinct habitat requirements that occur sequentially and therefore create vulnerabilities for the species (relative to species with fewer distinct serial life-history phases with distinct habitat requirements). Schwing *et al.* (2010) (after Boughton et al. 2006).

The ocean phase of steelhead has not been studied extensively, but marine migration studies of other species of *Oncorhynchus* have encountered only isolated specimens of *O. mykiss*. As a result it is believed that the species does not generally congregate in large schools in the ocean like other Pacific salmon of the genus *Oncorhynchus.* Consequently, the movement patterns of steelhead at sea are poorly understood. Some anadromous salmonids have been found in coastal waters relatively close to their natal rivers, while others may range widely in the North Pacific (Moyle, 2002: Grimes *et al*., 2007; Quinn, 2018).

Returning adults may migrate from several to hundreds of miles upstream to reach their spawning grounds. The specific timing of spawning can vary by a month or more among streams within a region. In southern California adult upstream migration general occurs in winter and early spring, depending on factors such as run-off and sand bar breaching (Fukushima and Lesch, 1998). After they reach their spawning grounds, females use their caudal fin to excavate a nest (redd) in streambed gravels where they deposit their eggs. After fertilization by the male, the female covers the redd (often during construction of additional upstream redds) with a layer of gravel, where the embryos and alevins incubate. Hatching time varies from about three weeks to two months depending on water temperature. The young fish emerge from the gravel two to six weeks after hatching. Adult steelhead do not necessarily die after spawning and may return to the ocean, sometimes repeating their spawning migration more than one time. It is rare for steelhead to spawn more than twice before dying, and most that do so are females

(Shapovalov and Taft, 1954; Moyle 2002; Quinn, 2018). The frequency of repeat spawning among southern California steelhead populations has not been investigated, and it is therefore unknown how they may differ from other populations, or the role repeat spawning plays in steelhead population dynamics in southern California.

O. mykiss also can display a non-anadromous, freshwater-resident life-history. Individuals that complete their entire life-history cycle (incubating, hatching, rearing, maturing, reproducing and dying) in freshwater are commonly referred to as rainbow trout. However, this terminology does not capture the complexity of the life-history patterns exhibited by native *O. mykiss*. Individuals can complete their life-history completely in freshwater, or they can migrate to the estuary or near shore and offshore marine environments and spend varying lengths of time before returning to freshwater habitats to spawn (Figure 5.2).

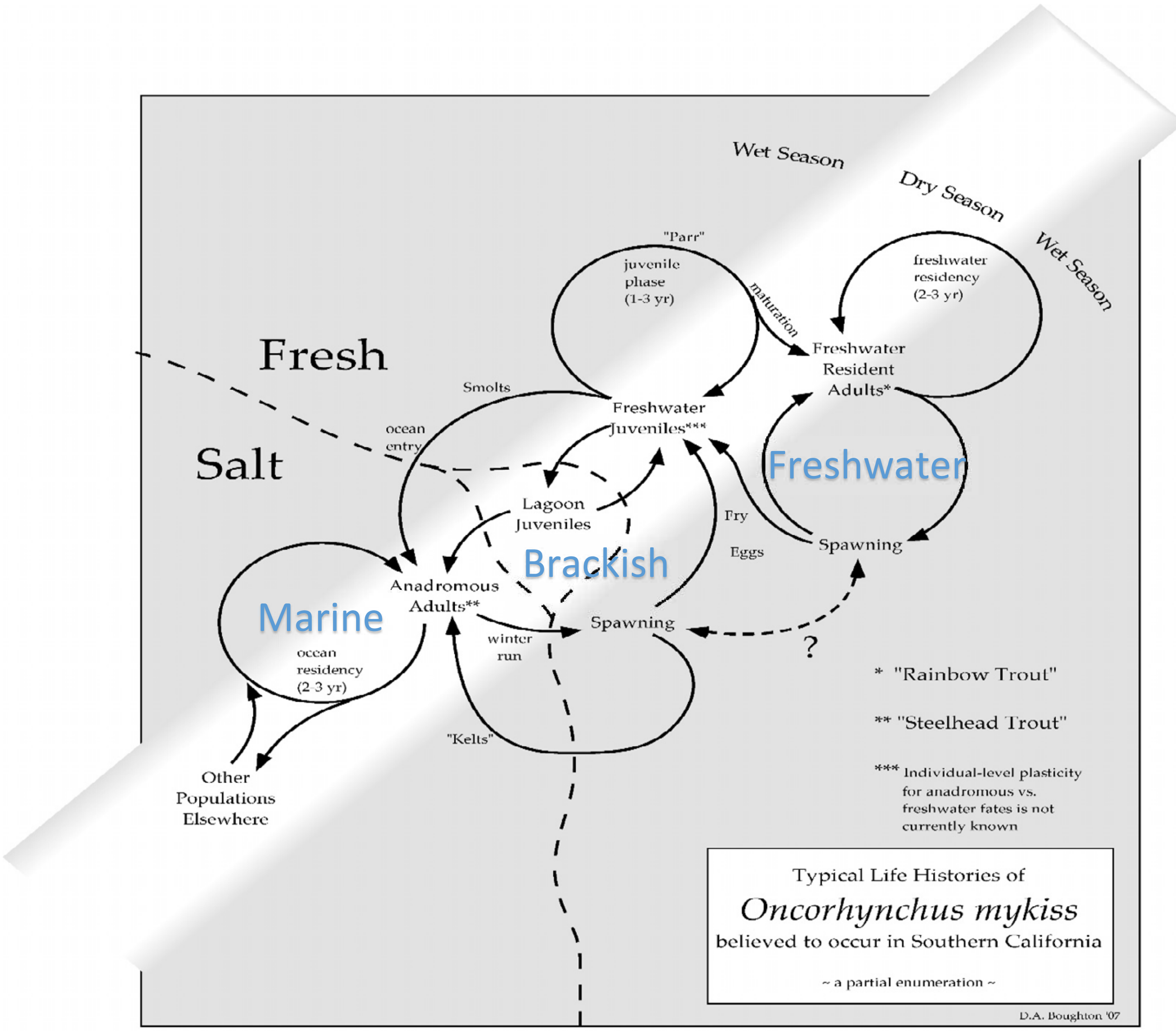

Figure 5.2. Summary of the various life history strategies exhibited by southern California *O. mykiss* and life stage terminology. The variation in the time the species (at different life-history phases) spends in different habitats (freshwater, brackish, and marine) and the variable movement between these habitats

is one of the distinctive features of this species and the key to its survival in the highly variable environment that is characteristic of southern California (after Boughton et al. 2006).

Steelhead morphological, physiological, and behavioral characteristics have been shaped by biotic and environmental influences over evolutionary time to exploit and cope with naturally varying seasonal and interannual flow conditions. Variation in instream conditions can interrupt, modify, or prevent the species from completing its life-history cycle. In particular, the over-summering period in freshwater can be challenging to juvenile steelhead survival, growth, and emigration to the estuary and ocean. Groundwater tables that are hydrologically connected to surface flows can fall owing to groundwater extraction during the dry season, reducing flows and affecting rearing individuals by reducing the depth and size (or eliminating entirely) of summer rearing pools, surface flows between pools, water quality conditions (*e.g*., dissolved oxygen levels and water temperature), and vegetative cover. (Heath, 1983; Bean, 2007; Barlow and Leake, 2012). Artificially reducing groundwater inputs would likely shrink the amount of suitable fish habitat and feeding opportunities for resident and rearing juvenile steelhead, and reduce the likelihood that juvenile steelhead would survive the low-flow period and successfully emigrate to the estuary and ocean (Fetter, 1997; Sophocleous, 2002; Glasser *et al.*, 2007; Croyle, 2009). Groundwater inputs to surface flows can also help buffer daily temperature fluctuations in streams (Brunke *et al.*, 1996; Barlow and Leake, 2012; Hebert, 2016). Physical fish passage impediments (*e.g.*, dams, flood control structures and road crossings) to both the upstream migration of returning anadromous adults and the instream movement of rearing juveniles and resident adults, even if natural instream flow patterns are maintained, can prevent the completion of the steelhead life-history cycle by preventing adults from reaching suitable upstream spawning and rearing habitats, and by inhibiting the instream movement of rearing juveniles and resident fish, which is necessary to respond to seasonal and even diurnal changes in instream conditions (*e.g*., moving between pools into riffle areas to feed, moving from riffles into pools as riffles diminish or dry, or seeking refuges from the diminishment or desiccation of pool habitats).

See Chapter 3 “Human Alterations of the Study Area”, Chapter 4, “Geomorphology and Biology of the Study Area”, and Chapter 6 “Mission Tunnel Impacts”.

Many of the natural limiting factors affecting the freshwater life-history phase of steelhead (such as seasonal variation in rainfall, runoff, and ambient air and water temperatures) are exacerbated by the artificial modification of these freshwater spawning and rearing habitats. Assessing the influence of surface and groundwater withdrawals on this species is, therefore, of critical importance. Surface and sub-surface extractions that lower the water table or tap into springs that feed directly or indirectly into freshwater spawning, rearing, or resident habitats, in either mainstems or tributaries, can affect the timing, duration, and magnitude of surface flows essential for steelhead migration, spawning and rearing and for resident survival, growth, and reproduction (Moyle *et al*., 2008; NMFS 2012, 2022).

See the additional discussion in Chapter 6, “Mission Tunnel Impacts”, regarding the effects of the Mission Tunnel on surface flows in both Mission Creek and Rattlesnake Creek.

5.3 Mission Creek watershed

Mission Creek drains one of a series of small watersheds along the south coast of Santa Barbara County (Figure 5.3). This suite of watersheds is drained by south-flowing coastal streams, which have their headwaters in the Santa Ynez Mountains (which form part of the western Transverse Ranges) that parallels the coast, with higher elevation portions lying within Los Padres National Forest. The lower sections of these watersheds run through an uplifted and dissected marine terrace between the ocean and the coast range before discharging to the ocean through a series of small estuaries (Ferren *et al*., 1995).

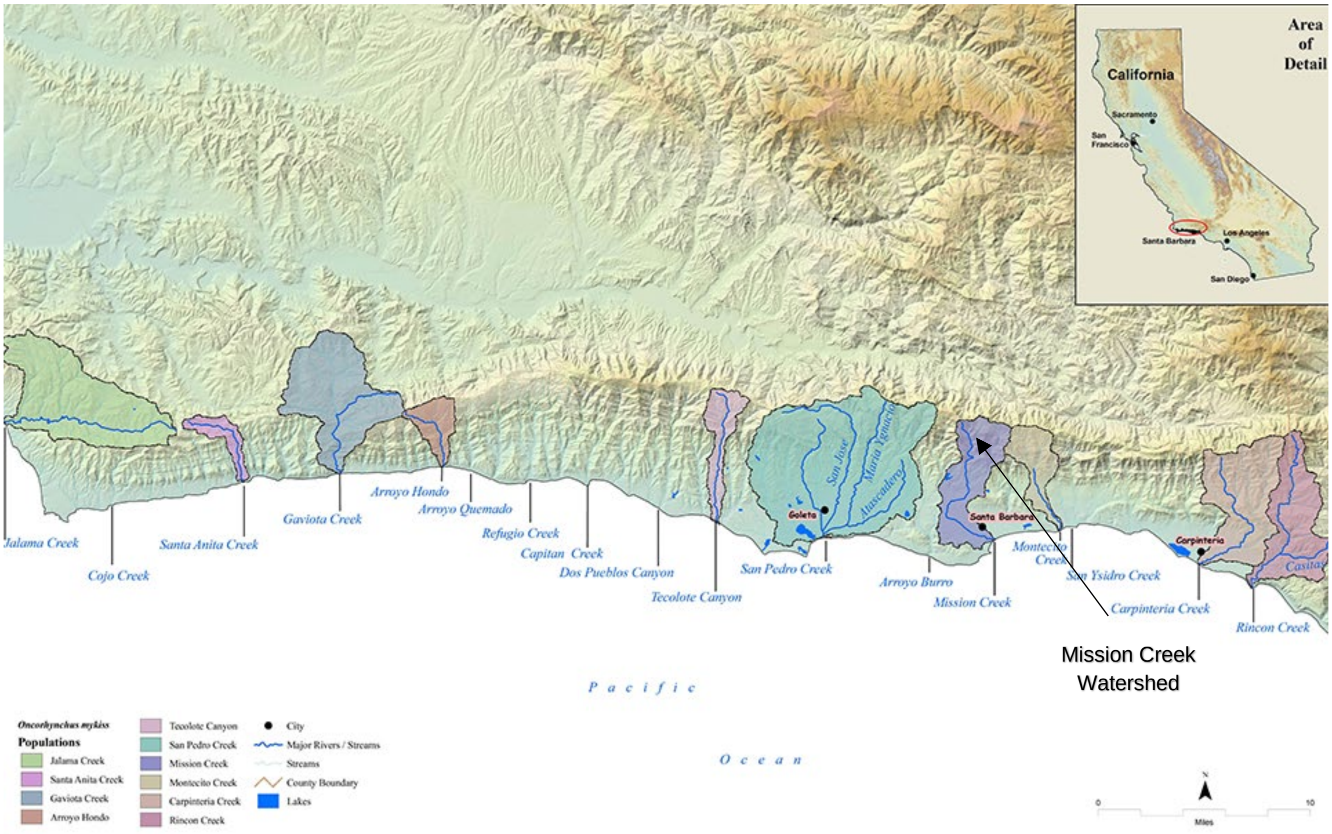

Figure 5.3. South Coast watersheds with documented *O. mykiss* populations (Conception Coast Biogeographic Population Group, NMFS, 2012).

The Mission Creek watershed encompasses approximately 12 square miles, including two major tributaries, Upper Mission Creek (2.85 square miles) and Rattlesnake Creek (3.15 square miles), with over 40 stream miles. Lower Mission Creek traverses the City of Santa Barbara (running along the north side of the Santa Barbara Mesa) and enters the Pacific Ocean near the Santa Barbara Harbor. The Mission Creek watershed is found in a Mediterranean climate, characterized by long dry summers and short, but sometimes intense cyclonic winter storms. Rainfall is restricted almost exclusively to the winter months (December through March), with the majority of the rainfall occurring in the months of January and February. There is significant variation in mean annual rainfall in the Mission Creek watershed due to the orographic effects of the Santa Ynez Mountains (Felton, 1965; Baily, 1966). Figure 5.4 shows the distribution of annual rainfall within the Mission Creek watershed. Because of the short rainfall season, summer flows in Mission Creek are dependent on groundwater and springs.

See Chapter 2, “Physical Geography and Hydrology of the Study Area”, See Chapter 3 “Human Alterations of the Study Area”, Chapter 4, “Geomorphology and Biology of the Study Area”, and Chapter 7 “Mission Tunnel Impacts”.

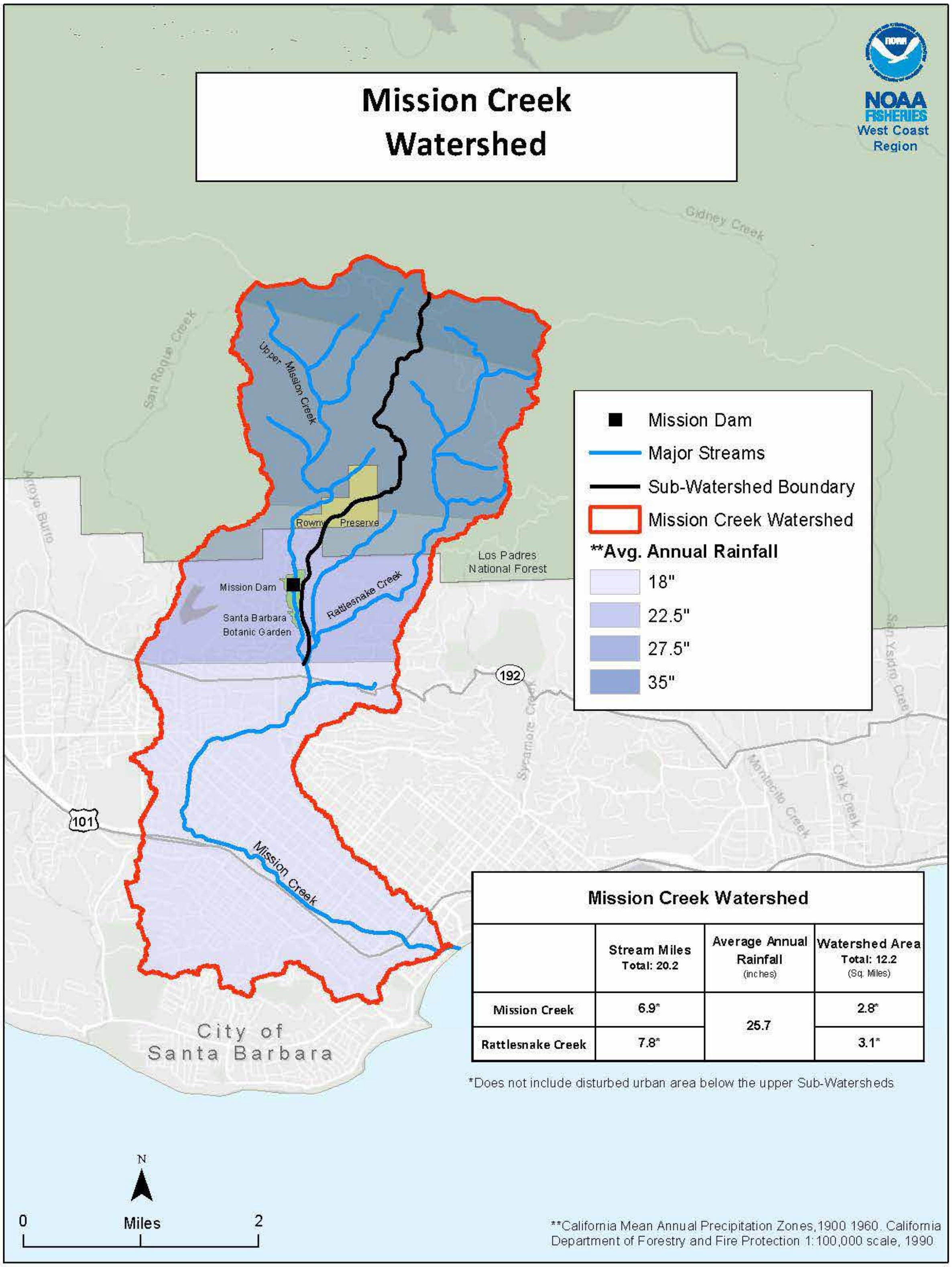

Figure 5.4. The Mission Creek watershed and the general distribution of the average annual rainfall.

5.4 The Mission Creek steelhead

Mission Creek is one of a series of small watersheds along the south coast of Santa Barbara County that provides spawning and rearing habitat for the federally listed endangered southern California steelhead[5] (Figure 5.5). The Mission Creek steelhead population is likely part of a metapopulation: a suite of interacting populations involving multiple populations from watersheds with more regular flows and appropriate spawning and rearing habitat serving as "source" populations, and other watersheds with less reliable flow or limited spawning and rearing habitat functioning as "sink" populations. The natural persistence of the Mission Creek populations is therefore likely dependent upon periodic recolonization by fish from other watersheds (i.e., other populations). The steelhead population of the Mission Creek watershed has not been extensively studied, although observations and limited surveys of steelhead have been made in the course of other investigations within the Mission Creek watershed.[6] Nor has there been systematic monitoring of adult steelhead runs or other long-term monitoring efforts of rearing *O. mykiss* populations. As a result the annual steelhead run-size, spawning distribution and reproductive success, or the extent of dispersal of adults from non-natal watersheds to Mission Creek, are unknown. Also, information is lacking about the basic autecological characteristics of the Mission Creek steelhead/resident populations, such a juvenile survival and growth rates, emigration patterns, or the relationship between the anadromous and non- anadromous forms of *O. mykiss*. A summary of the *O. mykiss* observations from the Mission Creek watershed is presented below.

Between 1982-84, 1985, and 1988 Cooper *et al*. conducted an investigation in Rattlesnake Creek that examined the effects of trout on stream invertebrate communities. This investigation involved the transfer of *O. mykiss* from pools containing *O. mykiss* to pools without *O. mykiss* as part of a controlled experiment (Hemphill and Cooper, 1984; Cooper, 1984a 1984b, 1986, 1988; Wiseman *et al*., 1994). Subsequently, Cooper et al. did streamside surveys of steelhead in reaches of Mission and Rattlesnake Creeks from 2008 through 2022, usually in June, as part of studies of the impacts of wildfire and drought on local stream communities (Cooper *et al*., 2015). Observations and analyses of these data indicated that *O. mykiss* presence was primarily related to pool depth (usually found in pools > 0.5 to 0.6 m deep) in the dry season and dry years, although *O. mykiss* were also observed to occupy shallower areas under higher flow conditions. During an August 1988 survey of Rattlesnake Creek, 84 rearing *O. mykiss* were found in 34 of the 61 pools surveyed (56%) in a 1.3 km study reach, which was 2.2 times more than were found in the same reach during a 1982 survey. The average number of fish per pool was 2.5 (ranging between 1 and 14 individuals), with a mean total length of 15.7 cm (ranging between 2 and 36.4 cm).

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[5] In addition to the native steelhead/rainbow trout (*O. mykiss*), Mission Creek supports a variety of other native aquatic species. Tidewater goby (*Eucyclogobius newberryi)*, partially armored stickleback (*Gasterosteus aculeatus microcephalus*), Coastal prickly sculpin (*Cottus asper)*, California killifish (*Fundulus parvipinnis*) are found the lower reaches of Mission Creek and the Mission Creek Estuary. The Mission Creek estuary also provides nursery habitat for a number of marine species, including, Staghorn sculpin (*Leptocottus armatus*), Starry flounder (*Platichthys stellatus*), Diamond turbot (*Hypospsetta guttulata*), California halibut (*Paralichthys californicus*), and Topsmelt (*Atherinops offinis*), as well as Coastal prickly sculpin (*Cottus asper*), which resides in the upstream reaches but descends to the estuary to breed. California newt (*Taricha torosa*), and Two-striped garter snake (*Thamnophis hammondi*i) generally found in the upper reaches of the watershed, and of the fish species, only *O. mykiss* are found within the Study Area (Wells, 1975; Ambrose, 1995). A number of non-native fishes are also found in the Mission Creek watershed, including Mosquitofish (*Gambusia affinis*) and Arroyo chub (*Gila orcutti*), and a variety of Sunfish (centrarchids).

[6] Researchers have periodically conducted fish sampling in Mission Creek and neighboring watersheds in the 1960s, 1970s, 1980s and 1990s, and some fish specimens have been curated at the Santa Barbara Museum of Natural History as well as the Los Angeles County Museum of Natural History (C. Swift, pers. comm.).

(S. Cooper, pers. comm.; Cooper, 1982; Cooper and Sasaki, 1988). The Cooper et al. (2015), investigations beginning in 2008 documented the disappearance of *O. mykiss* from study reaches in Rattlesnake and Mission Creeks during 2010 floods following the 2009 Jesusita Fire. Although the Cooper et al. studies found *O. mykiss* in 9 of 26 South Coast streams in 2008-09, *O. mykiss* had disappeared from 8 of the *O. mykiss* streams by 2022, with five populations lost during post-fire floods and three lost during the 2012-16 drought, as stream reaches were reduced to isolated pools or dried. In the latter case, *O. mykiss* disappeared from at least two of these reaches, even though surface water was present in pools; however, dissolved oxygen levels in these pools had dropped below 2 mg/L.

Figure 5.5. Southern California Steelhead over spawning reed in Mission Creek, c. 76 cm. February 16, 2008. Note small resident male *O. mykiss* (c. 20 cm) in lower right. Photo: Mark H. Capelli, National Marine Fisheries Service.

A number of other observers also have reported the presence of *O. mykiss* in Mission Creek and Rattlesnake Creek (*eg* ., Cooper et al., 1986; M. Cardenas, pers. comm.; J. Carrillo, pers. comm.; M. Capelli, pers. comm.; M. Chytilo, pers. comm.; S. Cooper, pers. comm.; C. Fusaro, pers. comm.; E. Henke, pers. comm.; E. Keller, pers. comm.; S. Sasaki, pers. comm.; M. Stoecker, pers. comm.; B. Trautwein pers. comm.; *see* Becker and Reining, 2008, and Titus *et al*. (2010) for a compilation of *O. mykiss* sighting records for the Mission Creek watershed). Additionally, Swift *et al.* (1993) reported that south of Pt. Conception there were records of steelhead in several Santa Barbara south coast streams, including Mission Creek, within the previous ten years, but did not provide estimates of numbers or specific locations.

In the summer of 1999, the California Department of Fish and Wildlife (CDFW) conducted a survey of fish in short reaches of Mission Creek and Rattlesnake Creek. The CDFW reported 15 juvenile and 3 adult (30 – 40 cm) *O. mykiss* in a pool immediately downstream of Foothill Bridge (Highway 192), and an additional 70 to 80 *O. mykiss* downstream of the Foothill Bridge. Ten deceased *O. mykiss* also were observed in an isolated pool in this as a result of low flow or drying conditions. Several age classes of *O. mykiss* also were observed in a survey of a 30 m reach of Rattlesnake Creek from its confluence with Mission Creek upstream to the first hardened road crossings (Cardenas, 1999). More recently, small numbers of adult steelhead have been observed in lower Mission Creek between 2004 and 2016 (Capelli, 2004, 2005, 2006, 2007a, 2007b, 2007c, 2007d, 2007e, 2008a, 2008b, 2008c, 2008d, 2016; Dagit *et al.* 2020; C. Fusaro, pers. comm.; M. Capelli, pers. comm.).

A survey of steelhead habitats between 1997 and 2001 within southern Santa Barbara County recorded a number of *O. mykiss* observations, including young-of-the-year, juvenile, and adult *O. mykiss* (Stoecker *et al*., 2002). E. A. Keller reported approximately 30 juvenile steelhead (likely smolts) in the Mission Creek Estuary in 2007 (E. Keller, per. comm.). In 2020, several rearing *O. mykiss* were observed in Upper Mission Creek (M. Capelli, pers. comm.; M. Chytilo, pers. comm.). A small number of rearing *O. mykiss* also were observed in Rattlesnake Creek in 2021 and 2022, and in Upper Mission Creek in 2022, confirming the continued persistence of *O. mykiss* in the Mission Creek watershed through the most recent drought and the Jesusita Fire, although a number of these fish had to be re-located because of drying conditions to more suitable habitat within the Mission Creek watershed (CDFW, 2021b, 2021c, 2021d; Evans and Sue 2021, Sue 2022a, 2022b).

The CDFW, as part of its implementation of the California Coastal Salmonid Monitoring Plan (Adams *et al.*, 2011; *see* also, Boughton *et al.*, 2021), has initiated a more systematic and larger scale steelhead monitoring effort in the Mission Creek watershed, beginning with a snorkel survey in 2019. Mission Creek has been added to the California Department of Fish and Wildlife's redd survey panel, and resident *O. mykiss* redds have been observed in the winters of 2020 and 2021, although no adult steelhead redds were observed in 2021 (CDFW, 2021; K. Evans, pers. comm.). Additionally, the U.S. Forest Service has developed a steelhead monitoring, tracking and reporting program for the Los Padres National Forest, which includes the uppermost portion of the upper Mission Creek and Rattlesnake Creek sub-watersheds. The plan includes a proposed Life Cycle Monitoring Station for the steelhead population within Mission Creek but has not been implemented (HDR Engineering, Inc., 2013).

Most recently, the CDFW has conducted a habitat assessment of 6.4 stream miles of the main channel of Upper Mission Creek as part of an investigation of unauthorized debris deposited within the upper reaches of Mission Creek (Zaragoza *et al.*, 2022; *see* also, Helix Environmental Planning, 2021; Lesage and Flores, 2021). This assessment documented the presence and condition of aquatic habitat within the stream channel at the time the surveys were conducted (June 6 and July 7, 2022). Portions of upper Mission Creek were found to contain suitable oversummering habitat for *O. mykiss*, although other reaches had been degraded by flood control alterations that likely impeded the upstream migration of steelhead or the local movement of resident fish (*see* also, Kelley, 1985). Additionally, the continuing extended drought has adversely affected instream habitat for steelhead within the Mission Creek watershed, with 60% of the surveyed channel containing no surface flows, although some of dry reach has been recently re-watered as a result the first winter rains of 2022-23 (M. Capelli, pers. comm.). Presently, the upper reaches of Mission and Rattlesnake Creeks continue to support a small number of *O. mykiss*, although all the *O. mykiss* observed within both Mission and Rattlesnake Creeks since 2019 are located upstream of fish passage impediments and are likely the remnant of a larger resident population of *O. mykiss* that has persisted without substantial input from the anadromous form of *O. mykiss* (Zaragoza et al., 2022). See Chapter 3 for a description and location of major fish passage barriers within Upper Mission Creek and Rattlesnake Creek.

The lack of adult steelhead or steelhead redds during the most recent surveys is likely the result of the prolonged drought and reduced upstream migration, spawning and rearing opportunities. The on-going drought in southern California has degraded *O. mykiss* rearing conditions (and other native species' habitats) throughout Santa Barbara County. In some cases, drying stream conditions have necessitated the rescue and relocation of *O. my*kiss from drying reaches to other portions of the watershed (or in some cases nearby watersheds) with suitable water conditions to prevent the local extirpation of individual populations. In response to the most recent drought, the CDFW has been closely monitoring the conditions in Mission Creek from the estuary to the upstream limits of anadromy[7] on a bi-weekly basis beginning in July 2021. During these regular monitoring surveys *O. mykiss* have been observed, and the CDFW has re-located a number of *O. mykiss* from drying pools to more suitable upstream habitat within the Mission Creek watershed (both upper Mission and Rattlesnake Creeks; NMFS 2019a, 2019b, Evans and Sue 2021; K. Evans, pers. comm.).

The University of California, Santa Barbara established the Santa Barbara Channel Long Term Ecological Research (LTER) program, funded by the National Science Foundation (NSF), in 2000 to better understand the ecology of coastal ecosystems (Aguilera and Melack, 2018; Goodridge *et al*., 2018). The NSF LTER program is intended to address ecological issues that could not be resolved with short-term observations, and includes sites that represent major ecosystem types and/or natural biomes. As part of the LTER program, hydro-chemical data was collected in Rattlesnake Creek from 2002 through 2015 (J. Melack, pers. comm.). See Chapter 4, for further discussion of the hydrochemistry of Mission and Rattlesnake Creeks.

The Mission Creek watershed also is included in the annual bioasessment conducted as part of the County of Santa Barbara's Project Clean Water program (Ecology Consultants, Inc., 2000-2019). This bioasessment focuses on assemblages of species, including benthic macroinvertebrates (BMIs), fish, and amphibians, to monitor and assess the biological integrity of aquatic ecosystems such as streams, rivers, and estuaries (Rosenberg and Resh, 1993; Barbour *et. al*. 1999). Because individual species have specific habitat requirements, and varying abilities to withstand or "tolerate" disturbances (*e.g*., water pollution, physical habitat alterations, introduction of non-native species, *etc*.), biological assemblages can be used as indicators of aquatic ecosystem integrity or health. Besides individual species, bioassessments such as the programs conducted by the County of Santa Barbara and the City of Santa Barbara's Creek Division, also can quantify biodiversity (*i.e*., number of species present) and characterize an assemblage's composition (*i.e.*, the types of organisms that are present). The County's annual bioasessment reports can be found at: https://countyofsb.org/pwd/sbpcw/water-quality/reports-

[7] Anadromous waters are those portions of a watershed that are within the range of the listed species and are accessible to upstream migrating anadromous salmonids, and generally limited to reaches with gradients < 12%, but may also be influenced by the local geomorphology of the stream channel.

studies.sbc#bioassessment. Bioassessments are most often applied to detect and monitor the responses of aquatic ecosystems to human influences such as waste discharges or water diversions and extractions.

The presence of a viable steelhead trout population in a stream indicates that a stream has cool, well-oxygenated waters, high-quality habitat, and a sufficient prey base to support rearing juvenile *O. mykiss*. Because *O. mykiss* is intolerant of water pollution and other habitat alterations such as increased sedimentation, low dissolved oxygen levels, and elevated stream temperatures, a viable population of steelhead is indicative of the conditions supporting other sensitive species and crucial stream processes (Frasier, 2018).

5.5 Intrinsic potential and critical steelhead habitat

As part of the steelhead recovery planning process, NMFS identified intrinsic potential steelhead spawning and over-summering habitat within core recovery watersheds. The identification of intrinsic potential habitat was used to determine the historic location, distribution and extent of suitable steelhead habitat (particularly over-summering habitat) within the species known range along the south-central and southern California coasts. The methods utilized to generate synoptic maps of this habitat were based on observed associations between fish distributions and the values of environmental factors, such as stream gradient, summer mean discharge and air temperature, valley width to mean discharge, and the presence of alluvial deposits, which are essential for steelhead spawning and egg/embryo incubation. Potential intrinsic habitat is a more inclusive term that includes habitat in the conventional sense, but also areas that are not currently suitable for supporting steelhead populations but that would be suitable under natural (unmanaged, or unimpaired) or restored conditions, providing a justification not just for protecting existing habitat but also for restoring degraded habitat (Boughton and Goslin, 2006). This method can also be considered conservative because it did not account for groundwater inputs to stream habitats, which could not be considered consistently at a landscape scale, but which can be important at specific locations in maintaining suitable over-summering habitat for juvenile steelhead and resident trout. Figure 5.6 depicts the extent and location of intrinsic potential steelhead spawning and over-summering habitat within the Mission Creek watershed, with a majority of this habitat located in Upper Mission Creek and Rattlesnake Creek.

Because steelhead require access to suitable freshwater habitat for reproduction, coastal rivers and streams are a critical component of the species' habitat. Freshwater habitats, particularly stream pools in southern California, are often spring-fed, providing suitable year-round habitat for rearing steelhead and resident trout (including important refugia during periods of drought).[8] These over-summering habitats are typically composed of boulder pools, with well-developed riparian vegetation such as found along portions of Mission Creek and Rattlesnake Creek (Chambers Consultants and Planners, 1983; Capelli and Stanley, 1984; Faber *et al*., 1998; Bean, 2007; *see* also, Chapter 4). These features provide both important sources of invertebrate food for *O. mykiss* as well as maintain suitable water temperatures, particularly during dry, warm summer months. In the development of the intrinsic potential steelhead spawning and over-summering rearing synoptic maps for the Southern California Steelhead Recovery Planning Area, the TRT drew attention to: "A positive interaction between water temperature and stream flow. High stream flow is thought to increase the food supply of the fish, which might make them more tolerant of warm water (which boosts basal metabolic rate and thus energy consumption). High stream

[8] The TRT specifically identified the important role of refuge habitat, and recommended that the recovery strategy "identify and maintain sustainable refugia against severe droughts and heat waves". Boughton *et al.*, 2007, p. 24. However, the NMFS 2022 5-year review of southern California steelhead noted that nearly all of the drought refugia that might allow steelhead populations to rebound are currently above impassable barriers (NMFS, 2022).

flow also tends to reduce diurnal fluctuations in temperature—that is, it would tend to decrease the maximum daily temperature for a stream even though it probably would have negligible effect on the mean daily temperature (Sinokrot and Gulliver 2000).” (also see Boughton and Goslin, 2006; and Boughton *et al*., 2007, p. 47).

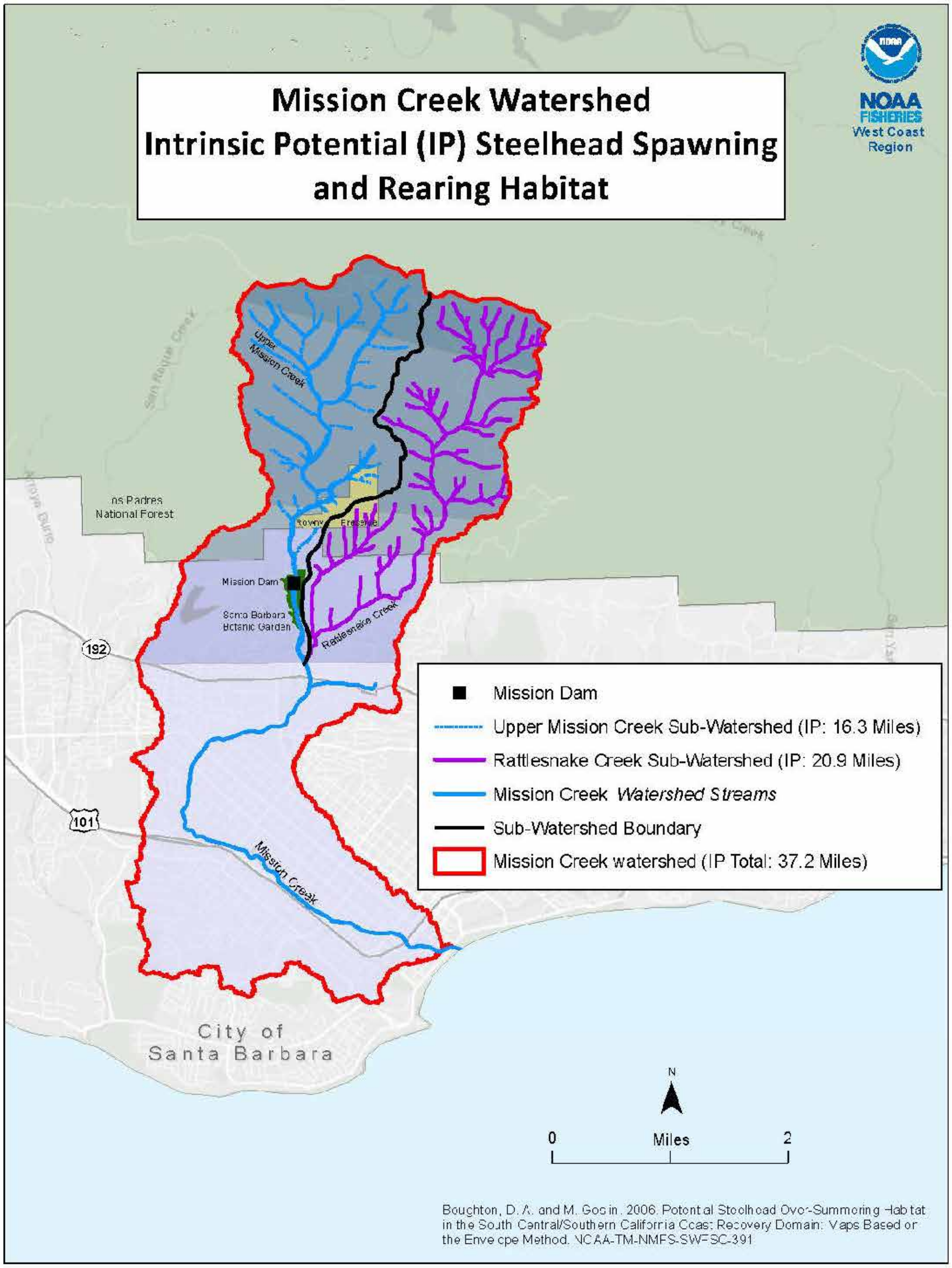

Figure 5.6. Intrinsic Potential steelhead spawning and over-summering habitat in the Mission Creek watershed. Note: the modeled intrinsic potential spawning and rearing habitat is located only in the Upper Mission Creek and Rattlesnake sub-watersheds.

A closer look at the intrinsic potential steelhead spawning and over-summering rearing habitat in both Upper Mission Creek and Rattlesnake Creek within the Study Area reveals the distribution of high and low intrinsic potential habitats within the two sub-watersheds.[9] (Figures 5.7 and 5. 8). In the Upper Mission Creek sub-watershed, 1.5 miles of high intrinsic potential habitat is identified in the *lowest* reach of the mainstem, whereas 16 miles of lower intrinsic potential habitat is identified in the *highest* reaches, including many small tributaries with only ephemeral flows and, in some cases, a series of rock outcrops that naturally impede access to higher reaches. Similarly, in the Rattlesnake sub-watershed, 2.08 miles of high intrinsic potential habitat is identified in the *lowest* reach of the mainstem, whereas 18.8 miles of lower intrinsic potential habitat is identified in the *highest* reaches, which also include many small tributaries with only ephemeral flows and, in some cases, a series of rock outcrops that naturally impede access to higher reaches. This mapped distribution of intrinsic potential habitat assumes unimpaired conditions, and as noted, did not take into account localized sources of groundwater such as the groundwater inputs from the Coldwater Formation in the upper reaches of the two subbasins. The construction and operation of Mission Tunnel has also affected groundwater input and therefore the distribution and condition of aquatic habitats conditions in (including potential steelhead rearing and over-summering habitat) within Upper Mission Creek and Rattlesnake Creek.

From the Intrinsic Potential steelhead spawning and rearing habitat maps, two things are clear: 1) most of the Intrinsic Potential steelhead habitat in the Mission Creek watershed is in the upper two subbasins (Upper Mission Creek and Rattlesnake Creek); 2) a substantial part of the Intrinsic Potential steelhead habitat is above impediments to upstream migrating fish (Figures 5.6, 5.7, and 5.8). The survey and description of pool habitat and groundwater inputs conducted as part of this study provide a more detailed characterization of potential suitable steelhead spawning and over-summering rearing habitat in Upper Mission Creek and Rattlesnake Creek (as well as important habitat for a wide variety of other species and for resident trout). See Chapter 4, “Geology and biology of the study area”, and Chapter 6, “Mission Tunnel Impacts on Creek Flows”.

As part of NMFS recovery planning process, critical habitat was designated for the anadromous waters within the Southern California Steelhead DPS in 2005 (70 FR 52488) (Figure 5.9). Critical habitat was identified for the portion of Mission Creek from its mouth at the Pacific Ocean up to the Mission Dam in the Santa Barbara Botanic Garden, and in Rattlesnake Creek from its confluence with Mission Creek up to the limits of anadromy (generally to a point where the natural stream gradient exceeds 12%, although this may not be an absolute limit depending on stream geomorphology and temporal variation in flow associated with rainfall events). Critical habitat is comprised of habitat containing essential physical and biological features that provide: (1) freshwater spawning areas with water quality and quantity, and substrate, conditions that support spawning, incubation, and larval development; (2) freshwater rearing sites with sufficient water quality and quantity, and floodplain connectivity, for creating and maintaining physical habitat conditions supporting juvenile development, growth and mobility, and providing natural cover from predators such as shading, and submerged and overhanging vegetation; and (3) freshwater migration corridors free of passage obstructions for adult and juvenile migration.

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[9] Lower intrinsic potential habitat areas are stream reaches less suitable for supporting steelhead than other areas in the same watershed, based on modeled habitat characteristics (summer air temperature, stream discharge, stream gradient, valley width relative to mean discharge, etc.). See discussion of methodology in Boughton and Goslin (2006).

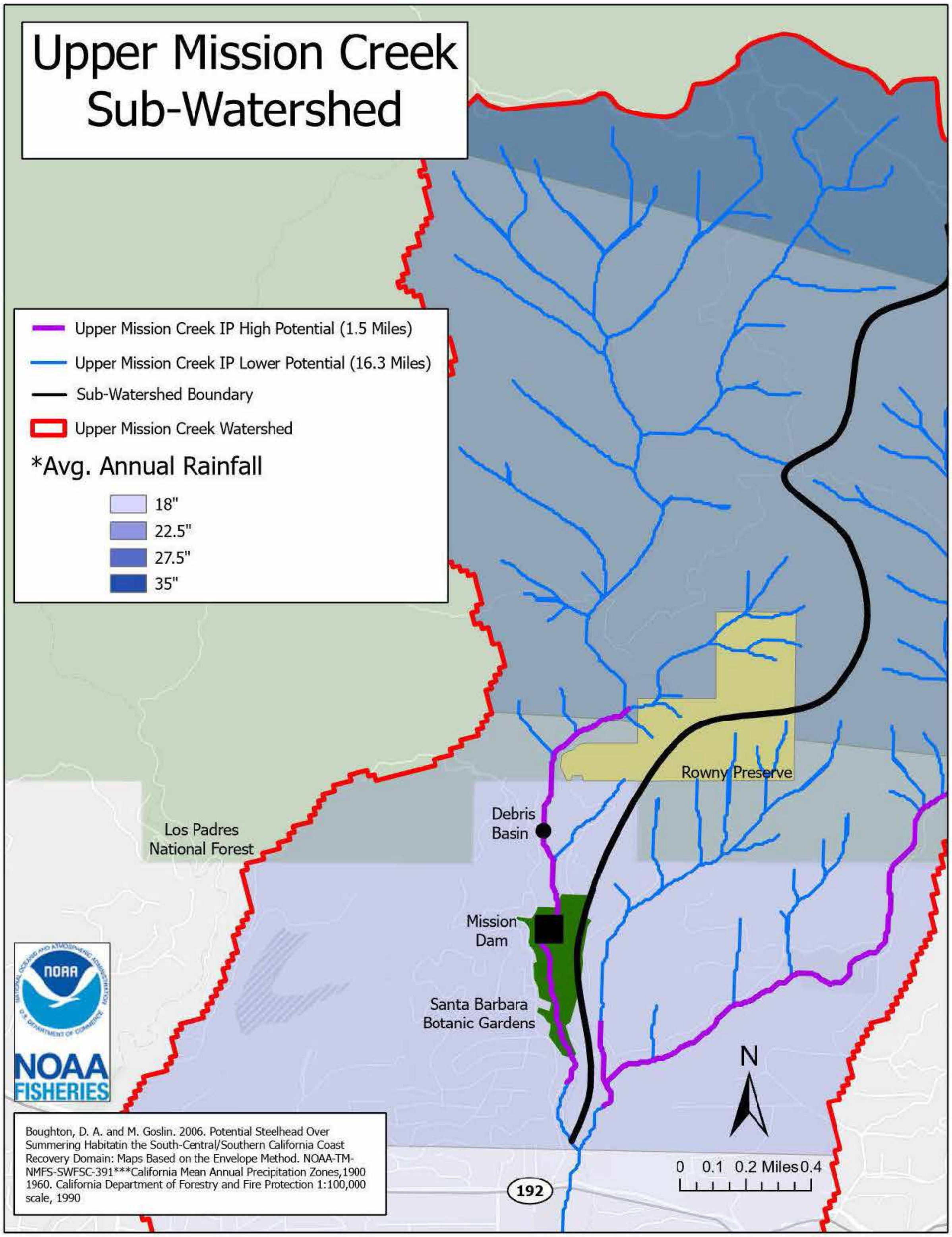

Figure 5.7. Intrinsic Potential steelhead spawning and over-summering rearing habitat within the Upper Mission Creek sub-watershed. Note: the Mission Dam and the Debris Dam present fish passage barriers that block access to over half of the High Intrinsic Potential steelhead spawning habitat within the Upper Mission Creek.

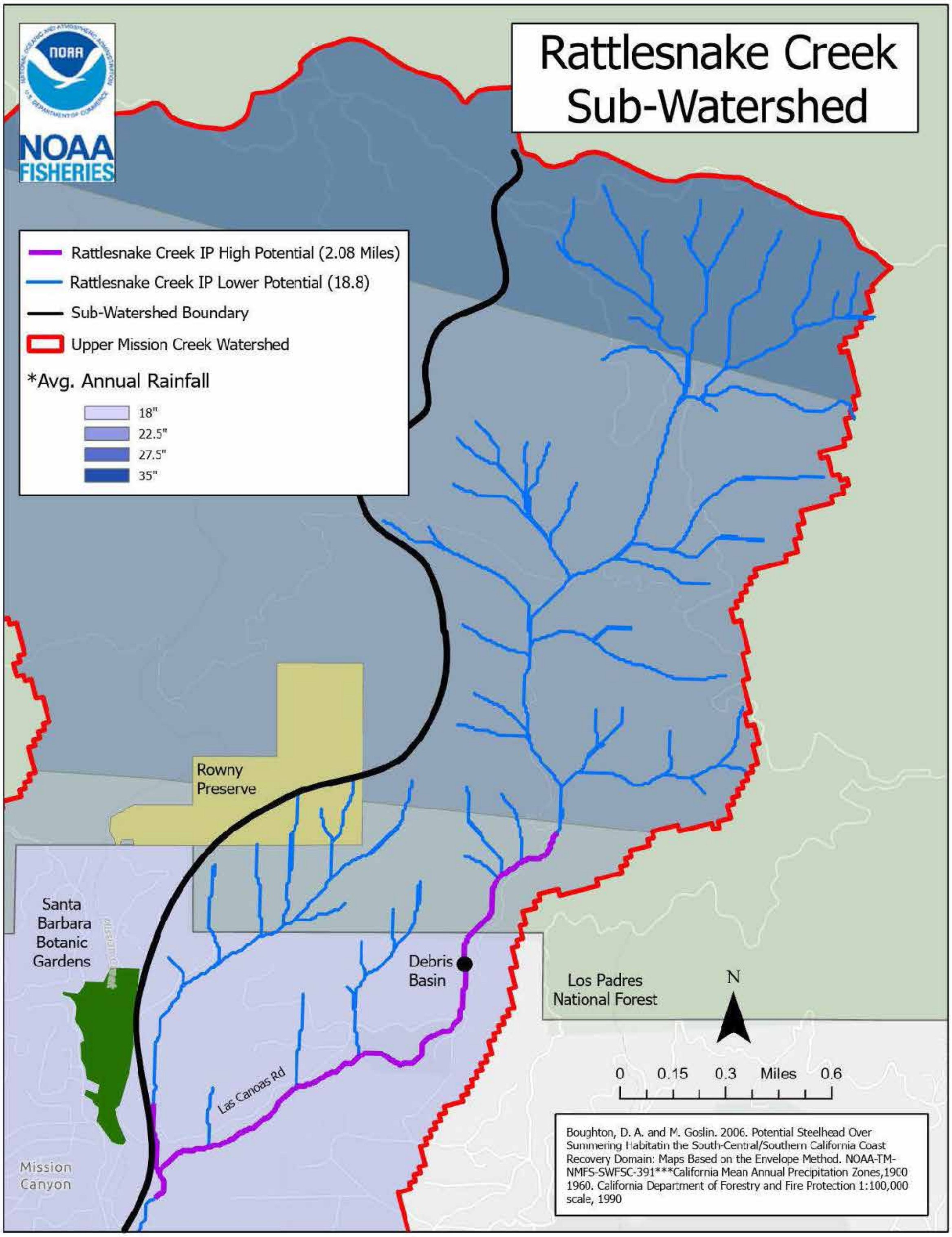

Figure 5.8. Intrinsic Potential steelhead spawning and over-summering rearing habitat within the Rattlesnake Creek sub-watershed. Note: the Debris Dam presents a fish passage barrier that blocks access to approximately one-third of the High Intrinsic Potential steelhead spawning habitat within Rattlesnake Creek.

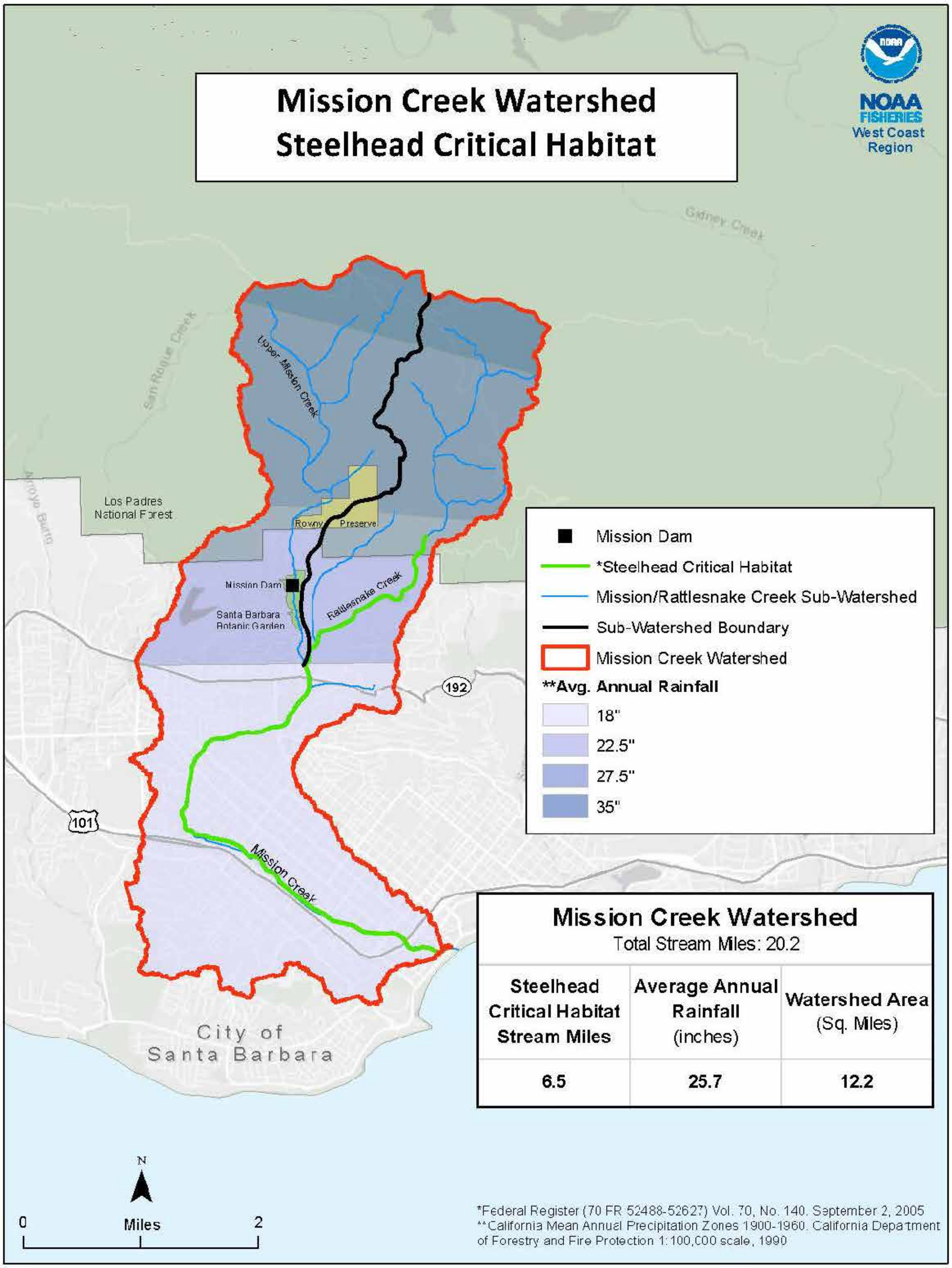

Figure 5.9. Designated steelhead critical habitat within the Mission Creek watershed.

5. 6 Systemic threats to Mission Creek and Rattlesnake steelhead habitats

The Mission Creek population is naturally highly vulnerable to periodic extirpations—as a result of droughts and catastrophic events such as debris flows. The natural vulnerability of the Mission Creek steelhead population is exacerbated by a variety of anthropogenic impacts, including fish passage impediments and depleted base flows. See Chapter 3, "Human Alterations of the Study Area" and Chapter 6, "Mission Tunnel Impacts" for a fuller discussion of these impacts.

Designated critical habitat in the Southern California Steelhead DPS has been adversely affected by the loss and modification of essential physical and biological features (substrate, water quality and quantity, channel complexity, riparian vegetation, volitional passage conditions, non-native invasive species, prey availability, *etc.*). These modifications have, as a result, hindered the ability of critical habitat to provide for the survival and ultimate recovery of the endangered Southern California Steelhead DPS.

Within the freshwater environment adult anadromous steelhead require the ability to move upstream to reach suitable spawning habitat (and also to emigrate back to the ocean as post-spawning kelts). Rearing juvenile and resident *O. mykiss* also need to move between appropriate habitats (e.g., between riffle and pool habitats or between drying and watered pools) to feed and to adjust to changing water conditions (*e.g.*, flow rates, pool depths, water temperature, dissolved oxygen levels, etc.; *see*, for example, Boughton *et al*., 2009). These essential behaviors can be inhibited or prevented by human constructions, such as dams, road crossings, and flood control structures that obstruct fish passage, and water developments that alter natural flow regimes, thereby dewatering aquatic habitat or impeding the volitional movement of fish.

As part of its recovery planning for the Southern California Steelhead DPS, NMFS conducted a threats assessment, utilizing a modified version of the Nature Conservancy's Conservation Action Plan (CAP) threats assessment methodology. The threats assessment noted "A widespread trend observed in this Steelhead Recovery Planning Area is severe to very severe degradation of habitat conditions along the mainstems of impaired watersheds, while the upper mainstem and tributaries retain relatively high habitat values for steelhead" (Hunt & Associates, 2008; Keir Associates and National Marine Fisheries Service, 2008; *see* also, Capelli 2007).

Although a wide range of anthropogenic activities have contributed to the high extinction risk of the Southern California Steelhead DPS, two types of developments and/or activities were identified as posing the principal threats to this species: (1) impediments to upstream (and downstream) fish passage, and (2) modification of natural stream flow patterns through surface water diversions and/or storage, and groundwater withdrawals. These types of developments and activities affect the freshwater life-history phases of steelhead (egg-to-smolt, smolt-to-emigration, and resident survival). As a consequence, the recovery strategy for the Southern California Steelhead DPS places a high priority on recovery actions that alleviate threats related to fish passage impediments and water management.

Mainstem and tributary habitats are affected by a variety of anthropogenic activities, including diversions, floodplain encroachment, and flood control structures, and activities that adversely affect the suitability of spawning and rearing habitats (*see*, for example, Kelley 1985; NMFS 2014). Under unimpaired conditions, some juvenile *O. mykiss* rearing in the mainstem or tributaries can move downstream and complete their juvenile rearing phase in the estuary before emigrating to the ocean

(Hayes, *et al.,* 2008; Boughton, *et al.,* 2009; Boughton *et al.,* 2006; Hayes *et al.,* 2011, 2012). In the Southern California Steelhead Recovery Plan (NMFS, 2012), roads, bridges, culverts, channelization, urban development, flood control structures, and groundwater diversions in the Mission Creek watershed (which includes Rattlesnake Creek) were identified as systemic threats to the steelhead population of Mission Creek (NMFS 2013, Table 10-2 "Threat source in component watersheds in the Conception Coast BPG region", p. 10-10).

This report provides a more detailed assessment of the adverse modification of habitats within Upper Mission Creek and Rattlesnake Creek, including modifications to riparian and aquatic habitats, through urban encroachment, flood control facilities (debris basins) and other instream structures (*e.g*., dysfunctional dams that impede or block fish movement), and the interception of groundwater that would otherwise contribute to the maintenance of natural flows in both Mission Creek and Rattlesnake Creek.

Within the Study Area, the structures that present the most serious impediments to the volitional movement (both up and downstream) of steelhead (as well as other aquatic species and resident trout) are: Mission Dam in the Santa Barbara Botanic Garden; an additional abandoned dam farther upstream on Mission Creek; a deteriorated abandoned upstream concrete rubble dam on Rattlesnake Creek; and the debris basins owned and operated by the Santa Barbara County Flood Control and Water Management District, one on Mission Creek and one on Rattlesnake Creek (Imwalle, 1996; Schott, 2005; HDR Engineering, Inc., 2010, NMFS, 2014)[10]. These instream structures impede both the upstream movement of adult steelhead, preventing them from reaching important spawning habitat, and the downstream movement of smolts, preventing them from moving in response to changing environmental conditions and emigrating to the estuary and ocean. Because sediment has accumulated above these structures, they have created reaches where base flows percolate into the accumulated sediment and create artificially dry reaches which would otherwise be surface baseflows that would allow the volitional movement of rearing juvenile up and downstream of these reaches. Dry season base flows in the Mission Watershed have been altered by periodic wildfires, alterations to vegetation, residential development, and the abstraction of groundwater resulting from the construction of the Mission Tunnel through the Santa Ynez Mountains.

See Chapter 3, "Human Alterations of the Study Area". Chapter 4, "Geology and Biology of the Study Area", and Chapter 6, "Mission Tunnel Impacts".

The Mission Creek estuary also has been highly modified by urban development and encroachment (Capelli, 2007). Development in the south coast watersheds of Santa Barbara County, including Mission Creek, has increased the rates of runoff to and sedimentation and pollution (including nutrients and other contaminants) in estuaries, modifying lagoon berm breaching patterns and the estuarine functions relevant to adult returning steelhead and rearing and emigrating juvenile steelhead (Rich and Keller, 2011, 2012).

5.7 Recent Southern California steelhead research

[10] In addition to the fish passage impediments within the study area, there are additional fish passage impediments downstream of the Study Area that impede the passage of steelhead upstream, as well as the emigration of smolts downstream to the estuary and ocean. For a comprehensive inventory of fish passage impediments in the Mission Creek watershed (including Rattlesnake Creek), see Stoecker and CCP (2002).

Effective steelhead management requires understanding the complexities of the species life history and its interaction with the dynamic marine and freshwater habitats it utilizes to complete its life-cycle. Southern California steelhead are one of the most variable animal species, whose variability has been the subject to increasingly rigorous scientific study since the fishes listing as a federally endangered species in 1997. The following summarizes some of the recent research of southern California steelhead.

Since the late 1980′s, a number of studies have elucidated the genetic structure and autecology of steelhead populations within the South-Central/Southern California Steelhead Recovery Planning Domain. Recent studies have employed molecular genetic analyses, assaying variation in mitochondrial DNA (mtDNA) sequences, and variation in tandem-repeat copy numbers of microsatellite loci. Busby *et al.* (1996) reported 51 allozyme loci in 113 *O. mykiss* populations, including 22 from California, including four from the South-Central/Southern California Steelhead Recovery Planning Domain. A high level of genetic variability was found in California *O. mykiss* coastal populations. One allele (FBALD-3) occurred either rarely, or not at all, in steelhead samples from coastal Oregon and the Klamath Mountains, but its frequency in samples increased north to south down the California coast and it was the only allele present in the southernmost *O. mykiss* sampled from Gaviota Creek and Arroyo Hondo Creek (within the Conception Coast BPG).

Busby *et al.* (1996) noted that finding an allozyme allele fixed in some *O. mykiss* populations, but entirely absent in others, is unprecedented in salmon, except when comparing *O. mykiss* populations from the extreme limits of the range of this species. Over all loci, however, there was not a clear genetic association among the southern *O. mykiss* populations. A multidimensional scaling plot showed that the two southernmost populations in the study (Arroyo Hondo Creek and Gaviota Creek) were not closely related to each other even though they were located near one another and were divergent from most other California populations. This pattern was attributed to (1) extreme and variable habitat conditions in southern California promoting local adaptation, and hence isolation, between southern steelhead populations, (2) increased freshwater residency and maturation in the south leading to increased isolation between populations, (3) small population sizes allowing genetic drift (change of allele frequencies owing to random re-assortments) to proceed more rapidly in the southern populations, and (4) the non-random, nonsystematic sampling of fish in space and time.

Further genetic analyses identified an important component of genomic variation on *O. mykiss* chromosome 5 (Martinez *et al.*, 2011; Pearse *et al*., 2014, 2019). During the steelhead's evolutionary history, a substantial portion of chromosome 5 (Omy5) underwent inversion, which is a segment of the chromosome was reversed end to end. This inversion was passed on to progeny. For fish in which one chromosome is inverted and the other is not (*i.e.*, contributed by a parent of each type), no crossing-over can occur during meiosis, so the set of genes on the inverted section of chromosome 5 are tightly linked (preventing gene exchange between the two chromosome types, or haplotypes – A and R). Pearse *et al.* (2014) surveyed the occurrence of these two haplotypes, i.e., the original and reversed versions of Omy5, in coastal populations of *O. mykiss* and found: (1) the presence of both Omy5 haplotypes in most populations; (2) strong evidence for natural selection on the set of linked genes within the inversion, and (3) dominance of one haplotype in steelhead in anadromous waters (A) and dominance of the other haplotype (R) in steelhead above impassable dams. Pearse *et al.* (2014) concluded that the two haplotypes appear to play some role in the genetic control of the expression of anadromy versus residency (steelhead versus rainbow trout) in *O. mykiss* of the California coast. Additional recent work shows that the tendency to out-migrate (versus mature in freshwater) is associated with particular juvenile body sizes, gender, the presence of a particular chromosome Omy5 "supergene", and interactions among these effects. Both variants of the strongly linked gene occur in most populations, but one variant tends to predominate in sites with connections to the ocean, and the other in populations without connections to the ocean (Pearse *et al*., 2014; Apgar *et al*., 2017; see also, Kendall, 2015). Overall, these results show that the resident and anadromous forms sometimes interbreed and are integrated at the population level (see also, Pearse, 2016).

Recent research also has documented dispersal of anadromous *O. mykiss* from their natal watersheds to non-natal watersheds (Donohoe *et al*., 2021), which has implications for steelhead recovery and management within the South-Central/Southern California Steelhead Recovery Planning Domain. A study of a small coastal stream in the central portion of the South-Central Coast Steelhead DPS (Big Creek) revealed that all seven steelhead that were sampled had dispersed from their natal watersheds to Big Creek. Three adults had originated from nearby streams (<72 km) on the Big Sur coast, whereas three had originated from more distant rivers, including the Klamath River (680 km to the north). Significantly, of the seven dispersed individuals, one was the progeny of a non-anadromous female. The rate of dispersal from natal to non-natal watersheds could not be estimated based on the small sample size, but the study did demonstrate that steelhead can disperse considerable distances and nonanadromous females can produce anadromous progeny that can disperse (thus providing genetic connectivity among widely dispersed watersheds). This phenomenon could contribute to the natural re-colonization of habitats that have been de-populated as a result of either (or both) anthropogenic modifications (*e.g*., construction of artificial barriers such as dams, diversions, or road crossings) or natural environmental perturbations (*e.g*., wildfire, debris flows, droughts, or catastrophic floods).

A recent study of the Carmel River within the South-Central/Southern California Steelhead Recovery Planning Domain sheds additional light on how steelhead populations persist, even when subjected to extremely large shifts in population size and density (Boughton and Ohms 2022). In this study, the distribution of *O. mykiss* contracted into relatively reliable, perennial habitats at high elevations, where surface flow was sustained by orographic precipitation (or groundwater fed seeps and springs) and not extracted for human use (Boughton and Ohms 2022; see also, Brunke and Gosner, 1997; Thomas and Famiglietti, 2019; Kaylor, *et al*., 2019; Kelson *et al*.; 2020). These findings suggest that populations persist even at low abundances by fish contracting into reliable drought refugia during periods of low flow, then re-expanding into more intermittent downstream habitats when rain and flows return (Boughton *et al.,* 2009).

Collectively, this body of work provides managers with a greater understanding of the way in which native steelhead and rainbow trout populations can mutually sustain each other in small watersheds such as Mission Creek, of the ongoing degradation of steelhead spawning and rearing habitats, of the un-remediated impediments to volitional steelhead migration (both upstream for adult steelhead and downstream for outmigrating smolts), and of the intra and interannual movement of steelhead, which allows the re-colonization of habitats for periodically extirpated populations and the interbreeding of the anadromous and resident forms of *O. mykiss*.

Significantly, the risk of permanently losing the anadromous phenotype (AA) of the Southern California Steelhead over the long term may be very high and likely increasing due to the lack of unobstructed migration corridors between the ocean and upstream spawning and over-summering habitats (Boughton in Southwest Fisheries Science Center, 2022).[11]

Recent findings on the genetic architecture of anadromy indicate that the anadromous phenotype can be reconstituted from populations of resident rainbow trout in drought refugia or upstream refugia above barriers, *if* their gene pool contains the Omy5 A haplotype (or from re-colonization from non-natal watersheds). Prior to the era of dam construction, and extensive water development, the periodic local extirpation and regeneration of steelhead runs occurred naturally with rainbow trout populations in headwater or spring-fed refugia (*i.e*., perennial stream reaches) emigrating downstream in years with sufficient rainfall to generate continuous flow to the ocean. If enough of these water years occurred with the right timing, returning adult steelhead could ascend streams to reproduce where they would mix and potentially interbreed with resident *O. mykiss.*

See Steelhead Appendix for a discussion of "NMFS Steelhead Recovery Planning", "Mission Creek Steelhead Recovery Actions", "California Coastal Salmonid Monitoring Program", "NMFS' 2022 Status Review", and "Southern California Steelhead Angling History '.

5.8 References

Aguilera, R. and J. M. Melack. (2018). Nutrient fluxes as a function of hydrologic variability, land cover and fires in coastal California catchments. *Journal of Geophysical Research – Biogeosciences* 123(2018):2568-2589.

Alagona, P. S., S. D. Cooper, M. H. Capelli, M. Stoecker, and P. Beedle. (2012). A History of Steelhead and Rainbow Trout (*Oncorhynchus mykiss*) in the Santa Ynez River Watershed, Santa Barbara County, California. *Bulletin of the Southern California Academy of Sciences*. 111(3):163-222.

Alagona, P. S. (2016). Species Complex: Classification and Conservation in American Environmental History. *Isis* 107(4):738-761.

Ambrose, R. F. (Ed.). (1995). *Coastal Wetland Resources of the Santa Barbara County Mainland. Final Report to the County of Santa Barbara.* Environmental Science and Engineering Program, University of California, Los Angeles. December 1995.

Apgar, T. M., D. E. Pearse, and E. P. Palkovacs. (2017). Evolutionary restoration potential evaluated through the use of trait-linked genetic marker. *Evolutionary Applications* 10(5):485-497.

[11] Apgar *et al.* (2017) estimated that the percentage of A haplotype in an isolated population loses about 5 percentage points per decade on average, although the loss would likely be faster initially and then decrease. However, when favorable conditions persist, adult steelhead would become common enough to start producing AA individuals, and genetic recombination of the anadromous genome would resume and facilitate continuing adaptive evolution of the anadromous phenotype to changing environmental conditions. Thus, even when the A haplotype is rare in a population, so that AA individuals are unlikely to occur, anadromy is still subject to natural selection due to its partial expression in AR individuals; and likewise, for freshwater-residency and the R haplotype.

Augerot, X. and D. N. Foley. (2005). *Atlas of Pacific Salmon: The First Map-Based Status Assessment of Salmon in the North-Pacific*. University of California Press.

Baily, H. P. (1966). The Climate of Southern California. University of California Press.

Bankston, S, K. Evans, and D. McCanne. (2016). *Dual-Frequency Identification Sonar (DIDSON) and Adpative Resolution Imaging Sonar (ARIS) Monitoring of Southern California Steelhead in Santa Barbara and Ventura Counties.* 2016 Annual Report for the Californa Deparment of Fishd and Wilife. Pacific States Marine Fisheries Commission. California Department of Fish and Wildlife.

Bankston, S. and K. Evans. (2018). *Sonar Monitoring of Southern California Steelhead in Santa Barbara and Ventura Counties: 2016 – 2018*. Final Report for the California Department of Fish and Wildlife Fisheries Restoration Grant No. P1550011.

Barbour, M. T., J. Gerristen, B. d. Snyder, and J. B. Stribling. (1999). Rapid bioasessment protocols for use in streams and wadeable rivers: Periphyton, benthic macroinvertebrates and fish. U. S. Environmental Protection Agency. Office of Water, Washington D.C.

Barlow, P. M., and S. A. Leake. (2012). *Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow*. U.S. Geological Survey Circular 1376.

Bean, G. S. (2007). *Geologic Controls on Channel Morphology and Low-Flow Habitat at Rattlesnake Creek, Santa Barbara, California*. A thesis submitted in partial satisfaction of the requirements of the degree of Master of Science in Geological Sciences. University of California, Santa Barbara.

Becker, G. S. and I. J. Reining. (2008). *Steelhead/Rainbow Trout (Oncorhynchus mykiss) Resources South of the Golden Gate, California.* Prepared for California State Coastal Conservancy and the Resources Legacy Fund Foundation. October 2008.

Behnke, R. J. (2002). *Trout and Salmon of North America*. The Free Press.

Boughton, D., H. Fish, K. Pipal, J. Goin, F. Watson, J. Casagrande, J. Casagrande, and M. Stoecker. (2005). *Contraction of the Southern Range Limit for Anadromous Oncorhynchus mykiss.* NOAA Technical Memorandum NMFS-SWFSC TM-380.

Boughton, D. A. and Goslin, M. (2006). *Potential steelhead over-summering habitat in the South-Central/Southern California coast recovery domain: Maps based on the envelope method. NOAA Technical Memorandum NMFS-SWFSC* 391.

Boughton, D. A., P. Adams, E. Anderson, C. Fusaro, E. A. Keller, E. Kelley, L. Lentsch, J. Nielsen, K. Perry, H. M. Regan, J. J. Smith, C. Swift, L. Thompson, and F. Watson. (2006). *Steelhead of the South-Central/Southern California Coast: Population Characterization for Recovery Planning.* NOAA Technical Memorandum NMFS-SWFSC-394.

Boughton, D. A., P. Adams, E. Anderson, C. Fusaro, E. Keller, E. Kelley, L. Lentsch, J. Nielsen, K. Perry, H. Regan, J. Smith, C. Swift, L. Thompson, F. Watson. (2007). *Viability Criteria for*

Steelhead of the South-Central and Southern California Coast. NOAA-Technical Memorandum NMFS-SWFSC-407.

Boughton, D. A., H. Fish, J. Pope, and G. Holt. (2009). Spatial patterning of habitat for *Oncorhynchus mykiss* in a system of intermittent and perennial stream. *Ecology of Freshwater Fish* 18:92-105.

Boughton, D. H. (2010a). A Forward-Looking Scientific Frame of Reference for Steelhead Recovery on the South-Central and Southern California Coast. NOAA Technical Memorandum NMFS-SWFSC-466.

Boughton, D. A. (2010b). *Some Research Questions on Recovery of Steelhead on the South-Central and Southern California Coast*. NOAA Technical Memorandum NMFS-SWFSC-467.

Boughton, D. A. and H. A. Ohms. (2022). Response of a threatened trout population to water-provisioning scenarios for the Carmel River, California. National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Boughton, D. A., H., J. Nelson, M. K. Lacy. (2022). Integration of Steelhead Viability Monitoring, Recovery Plans and Fisheries Management in the Sothern Coastal Area. *Fish Bulletin* 182. California Department of Fish and Wildlife.

Brunke, M. and T. Gosner. (1977). The Ecological Significance of Exchange Processes between Rivers and Groundwater. *Freshwater Biology* 37(1977): 1-33.

Burgner, R. L., J. T. Light, L. Margolis, T. Okazaki, A. Tautz, and S. Ito. (1992). *Distribution and Origins of Steelhead Trout (Oncorhynchus mykiss) in Offshore Waters of the North Pacific Ocean.* International North Pacific Fisheries Commission. *Bulletin* No. 51.

Busby, P. B., T. C. Wainwright, G. Bryant, L. J. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. (1996). *Status Review: West Coast Steelhead from Washington, Idaho, Oregon, and California.* NOAA Technical Memorandum NMFS-NWFSC-27.

California Department of Fish and Wildlife. (1986). Survey of Southern California Steelhead Streams. Report prepared by S. Sasaki. Region 5

California Department of Fish and Wildlife. (1992). Brief Inspection of Streams. Prepared by S. Sasaki. Region 5.

California Department of Fish and Wildlife. (1993). Steelhead Surveys of Six Southern California Coastal Streams. Report prepared by S. Engblom, G. F. Sibbald, and V. Whitman. Region 5.

California Department of Fish and Wildlife. (1999). Department of Fish and Game celebrates 130 years of serving California. *Outdoor California*. November-December 1999.

California Department of Fish and Wildlife. (2015-2022). *California Freshwater Sport Fishing Regulations, 2015-2022. Effective March 1, 2015 through February 29, 2022*. California Department of Fish and Wildlife, Sacramento, CA.

California Department of Fish and Wildlife. (2016). *Steelhead Report and Restoration Card Program: Report to the Legislature 2007-2014*.

California Department of Fish and Wildlife. (2021a). Evaluation of the Petition from California Trout to List Southern California Steelhead (*Oncorhynchus mykiss*) as Endangered University the California Endangered Species Act. Report to the California Fish and Game Commission. November 2021.

California Department of Fish and Wildlife. (2021b). Rattlesnake Creek *Oncorhynchus mykiss* Rescue and Relocation on August 10 and August 19, 2021 (with NOAA Fisheries Steelhead Pre-Rescue Data Form and Steelhead Relocation Data Form).

California Department of Fish and Game. (2021c). Rattlesnake Creek *Oncorhynchus mykiss* Rescue and Relocation on August 10, 2021.

California Department of Fish and Game. (2021d). Rattlesnake Creek *Oncorhynchus mykiss* Relocation on June 29, 2021.

California Department of Fish and Wildlife. Memorandum from Hayley Sue, Environmental Scientist, California Department of Fish and Wildlife, to Kyle Evans, Senior Environmental Scientist Supervisor, California Department of Fish and Wildlife. (2022). Re: Mission Creek Fish Rescue and Relocation of *Oncorhynchus mykiss* on September 15, 2022. August 3, 2022.

California Fish and Game Commission. (2022). Notice of Findings: Southern California Steelhead (*Oncorhynchus mykiss*). May 11, 2022.

Capelli, M. H. and S. J. Stanley. (1984). Preserving Riparian Vegetation Along California's South Central Coast. In: R. E. Warner and K. M. Hendrix (Eds.). *California Riparian Systems: Ecology, Conservation, and Productive Management*. pp. 673-686. University of California Press.

Capelli, M. H. (2004). Report Adult Steelhead Lower Mission Creek (Santa Barbara County). Technical Memo, January 20, 2005. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2005). Report adult Steelhead lower Mission Creek (Santa Barbara County). Technical Memo, October 15, 2005. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2006). Report adult Steelhead lower Mission Creek (Santa Barbara County). Technical Memo, October 20, 2006. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2007a). Memo to Elis Asarian, Keir Associates. Re: South-Central and Southern California Estuarine Estimates. National Marine Fisheries Service, California Coastal Office.

Capelli, M. H. (2007b). Report deceased adult Steelhead lower Mission Creek (Santa Barbara County). Technical Memo, March 21, 2007. Available upon request from: www. rcdsmm.org

Capelli, M. H. (2007c). Report adult Steelhead lower Mission Creek (Santa Barbara County). Technical Memo, March 31, 2007. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2007d). Report Steelhead spawning in lower Mission Creek (Santa Barbara County). Technical Memo, April 30, 2007. Available upon request from: www. rcdsmm.org

Capelli, M. H. (2007e). Report Steelhead spawning in lower Mission Creek (Santa Barbara County). Technical Memo, June 30, 2007. Available upon request from: www. rcdsmm.org

Capelli, M. H. (2008a). Observation of Steelhead, lower Mission Creek (Santa Barbara County). Technical Memo, February 21, 2008. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2008b). Report adult Steelhead, lower Mission Creek (Santa Barbara County). Technical Memo, March 30, 2008. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2008c). Observation of Steelhead, lower Mission Creek (Santa Barbara County). Technical Memo, March 30, 2008. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2008d). Observation of Steelhead, lower Mission Creek (Santa Barbara County). Technical Memo, May 30, 2008. Available upon request from: www.rcdsmm.org

Capelli, M. H. (2016). Report adult Steelhead, lower Mission Creek (Santa Barbara County). Technical Memo, January 30, 2016. Available upon request from: www.rcdsmm.org

Cardenas, M. (1999). Letter to Steve Mack, Public Works Department, City of Santa Barbara. Re: Surveys, Mission Creek. August 20, 1999.

Carmody, K., T. Redmann, and K. Evans. (2019). *Summary of 2019 Southern California Steelhead Monitoring Using Underwater Sonar (DIDSON). 2019 Annual Report.* Pacific States Marine Fisheries Commission and California Department of Fish and Wildlife. September 2019.

Chambers Consultants and Planners. (1983). Biological Resources Along Mission Creek, Santa Barbara, California. Final Report. Prepared for the U.S. Army Corps of Engineers, Los Angeles District.

Cooper, S. D. (1982). Unpublished data from Rattlesnake Creek investigation. Department of Ecology, Evolution and Marine Biology. University of California, Santa Barbara.

Cooper, S. D. (1984a). The effects of trout on water striders in stream pools: *Oecologia* 63(1984):376–379.

Cooper, S. D. (1984b). The effects of trout on water striders in stream pools: *Oecologia* 63(1984): 376–379.

Cooper, S. D, T. L. Dudley, and N. Memphill, E. A. Keller, J. Melack. (1986a). The Biolgy of Chaparral Streams in Southern California. University of California, Santa Barbara.

Cooper, S. D. (1988). The responses of aquatic insects and tadpoles to trout: *Verh. Internat. Verein. Limnol* 23(1988):1698–1703.

Cooper, S. D., Dudley, T. L., and N. Hemphill. (1986b). The biology of chaparral streams in Southern California, *in* Proceedings of the *Chaparral Ecosystems Research Conference*, Santa Barbara, CA USA, California Water Research Center 62:139–151.

Cooper, S. D. and S. Sasaki. (1988). Unpublished data from Rattlesnake Creek investigation. Department of Ecology, Evolution and Marine Biology. University of California, Santa Barbara.

Cooper, S.D., Page, H.M., Wiseman, S.W., Klose, K., Even, T., Sadro, S., Nelson, C.E., and Dudley, T.L. (2015). Physicochemical and biological responses of streams to wildfire severity in riparian zones: Freshwater Biology, v. 60, p. 2600–2619.

Croyle, Z. (2009). Analysis of Baseflow *Trends Related to Upland Groundwater Pumping for Las Garzas, San Clemente, Porter, and San Jose Creeks*. Master's Thesis. California State University, Monterey Bay.

Dagit, R., M. T. Booth, M. Gomez, T. Hovey, S. Howard, S. D. Lewis, S. Jacobson, M. Larson, D. McCanne, and T. H. Robinson. (2020). Occurrences of steelhead trout in southern California (*Oncorhynchus mykiss*), 1994-2018. *California Fish and Wildlife* 106(1):39-58.

Donohoe, C. J., D. E. Rundio, D. E. Pearse, and T. H. Williams. (2021). Straying and life history of adult steelhead in a small California coastal stream revealed by otolith, natural tags and genetic stock identification. *North American Journal of Fisheries Management* 41(3):711-723.

Ecology Consultants, Inc. (2000-2019). *Santa Barbara Streams and Estuaries Bioassement Program. Annual Reports.* Prepared for City of Santa Barbara, Creeks Division and County of Santa Barbara, Project Clean Water.

Evans, K. and H. Sue. (2021). Memo to Mary Larson, Senior Environmental Supervisor, California Department of Fish and Wildlife. Re: Mission Creek *Oncorhynchus mykiss* Monitoring 2020-21. California Department of Fish and Wildlife. October 7, 2021.

Faber, P. M., E. A. Keller, A. Sands. (1998). *The Ecology of Riparian Habitats of the Southern California Coastal Region: A Communityu Profile*. Biological Report 85(7.27). Prepared for the U.S. Departmentof Interio. Fishj and Wildlife Serivce. National Wetlans Research Center. September 1998.

Felton E. L. (1965). *California's Many Climates*. Pacific Books.

Ferren, W. R., P. L. Fiedler, and R. A. Leidy. (1995). *Wetlands of the Central and Southern California Coast and Coastal Watersheds*. Final Report Prepared for U.S. Environmental Protection Agency, Region IX. February 6, 1995.

Fetter, C. W. (1977). Statistical analysis of the impact of groundwater pumping on low-flow hydrology. *Journal of American Association* 32(4):733-74

Frazier, H. N.-B. (2018). Ecosstem prductivity and water termperatue in coastal California streams. Ph.D. Dissertation, Department of Geography, University of California, Santa Barbara.

Fry, D. H. Jr. (1973). *Anadromous Fishes of California*. California Department of Fish and Game.

Fry, D. H, Jr. (1938). Trout Fishing in Southern California Streams – instructions for the beginner. *California Fish and Game* 24(3):84-117.

Fukushima, L. and E. W. Lesch. (1998). Adult and Juvenile anadromous salmonid migration timing in California streams. *California Fish and Game* 84:133-145.

Glasser, S., J. Gauthier-Warinner, J. Gurrieri, J. Kelly, P. Tucci, P. Summers, M. Wireman, and K. McCormack. (2007). *Technical Guide to Managing Groundwater Resources.* U.S. Department of Agriculture. FS-881.

Goodridge, B. M. E. J. Hanan, E. Wetherley, R. Aguilera. Y.J. Chen, C. M. D'Antonio and, J. M. Melack. (2018). Retention of nitrogen following wildfire in a chaparral ecosystem. *Ecosystems* doi.org/10.1007/s1002-018-0243-3.

Grimes, Churchill B., R. D. Brodeur, L. J. Haldorson, and S. M. McKinnell (Eds.). (2007). *The Ecology of Juvenile Salmon in the Northeast Pacific Ocean: Regional Comparisons.* American Fisheries Society Symposium 57.

Hayes, S. A., M. H. Bond, C. V. Hanson, E. V. Freund, J. J. Smith, E. C. Anderson, A. J. Ammann, and R. B. MacFarlane. (2008). Steelhead growth in a small Central California watershed: upstream and estuarine rearing patterns. *Transactions of the American Fisheries Society* 137:114-128.

Hayes, S. A., M. H. Bond. C. V. Hanson, A. W. Jones, A. J. Ammann, J. A. Harding, A. L. Collins, J. Peres, and R. B. MacFarlane. (2011). Down, up, down and "smolting" twice? Seasonal movement patterns by juvenile steelhead (*Oncorhynchus mykiss*) in a coastal watershed with a bar closing estuary. *Canadian Journal of Fisheries and Aquatic Sciences* 68(80):1341-1350.

Hayes, S. A., C. V. Hanson, D. Pearse, M. H. Bond, R. B. MacFarlane. (2012). Should I stay or should I go? The influence of genetic origin on emigration and behavior and physiology of resident and anadromous juvenile *Oncorhynchus mykiss*. *North American Journal of Fisheries Management* 32 (2021):772–780.

HDR Engineering, Inc. (2010). *Mission Creek: Fish Passage Design Performance Evaluation.* Prepared for City of Santa Barbara. June 29, 2010.

HDR Engineering, Inc. (2013). *Los Padres National Forest Steelhead Monitoring, Tracking and Reporting Program. Final Plan.* Prepared for Los Padres National Forest. November 2013.

Heath, R. C. (1983). *Basic Ground-Water Hydrology*. U.S. Geological Survey. Water Supply Paper 2220.

Hebert, A. (2016). *Impacts to Anadromous Fish Through Groundwater Extraction.* Master's Project and Capstone. 366. University of San Francisco.

Helix Environmental Planning. (2021). *Mission Creek Habitat Restoration.* Prepared for Southern California Edison. EDS-01.10. February 2021.

Hemphill, N., and Cooper, S.D. (1984). Differences in the community structure of stream pools containing or lacking trout: *Verh. Internat. Verein. Limnol* 22(1984):1858–1861.

Hendry, A. P., T. Bohlin, B. Jonsson, and O. K. Berg. (2004). To Sea or Not to Sea? Anadromy versus Non-Anadromy. In: A. P. Hendry and S. C. Stearns (Eds.). *Evolution Illuminated: Salmon and Their Relatives*. Oxford University Press.

Hubbs, C. L. (1946). Wandering of pink salmon and other salmonids fishes into southern California. *California Fish and Game* 32(1946):81-86.

Hunt & Associates Biological Consulting Services. (2008). *Southern California Coast Steelhead Recovery Planning Area Conservation Action Planning (CAP) Workbooks Threats Assessment.* Prepared for the National Marine Fisheries Service, Southwest Region, Protected Resources Division.

Imwalle, M. H. (1996). Mission Canyon Aqueduct Project. Prepared for the Santa Barbara Botanic Garden. March 1996.

Jackson, T. A. (2007). *California Steelhead Fishing Report-Restoration Card: A Report to the Legislature*. California Department of Fish and Game, Sacramento, CA.

Kaylor, M. J., B. J. VerWey, A. Cortes, and D. R. Warren. (2019). Drought impacts to trout and salamanders in cool, forested headwater ecsystems in the wester Cascade Mountain, OR. *Hydrobiologia* 833(2019):65-80.

Keir Associates and National Marine Fisheries Service. (2008). *Fifty-Five South-Central/Southern California Steelhead DPS Conservation Action Planning (CAP) Workbooks*. Prepared for the National Marine Fisheries Service, Southwest Region, Protected Resources Division. Long Beach, CA.

Kelley, Robert. (1985). *A Century of Flooding on Mission Creek, Santa Barbara County, 1870's – 1970's: Two Histories in Conflict*. Public History Program. University of California, Santa Barbara.

Kelson, S. J. C. M. E. Power, J. C. Finlay, and S. M. Carlson. (2020). Partial migration alters population ecology and food chain length: evidence from a salmonid fish. *Ecosphere* 11(2):1-19

Kendall, N. W., J. R. McMillan, M. R. Sloat, T. W. Buehrens, T. P. Quinn, G. R. Press, K. V. Kuzischchin, M. M. McClure, and R. W. Zabel. (2015). Anadromy and residency in steelhead and rainbow trout (*Oncorhynchus mykiss*): a review of the processes and patterns. *Canadian Journal of Fisheries and Aquatic Science* 72: 319-342.

Kreider, C. M. (1948). *Steelhead*. G. P. Putnam's Sons.

Lackey, R. T., D. H. Lach, S. L. Duncan (Eds.). (2006). *Salmon 2010: The Future of Wild Coast Salmon.* American Fisheries Society.

Lentz, D. C. and M. A. Clifford. (2014). A synopsis of recent history of California's inland trout management program: litigation and legislation. *California Fish and Game* 100(4):727-739.

Lesage, J. and J. Flores. (2021). *Mission Canyon Biodiversity Project. Preliminary Invasive Survey Report. Prepared for the Santa Barbara Botanic Garden. September 2021.*

Love, M. S. and J. K. Passarelli. (2020). *Miller and Lea's Guide to the Coastal Marine Fishes of California.* University of California Press and Cabrillo Marine Aquarium.

Magnuson, J. J., F. W. Allendorf, R. L. Beschta, P. A. Bisson, H. L. Carson, D. W. Chapman, S. S. Hana, A. R. Kapuscinski, K. N. Lee, D. P. Lettenmaier, B. J. McCay, G. M. MacNabb, T. P. Quinn, B. E. Riddell, and S. E. Warner. (1996). *Up Stream: Salmon and Society in the Pacific North West*. Committee on Protection and Mangement of Pacific Northwest Anadromous Salmonds. National Acedmy Press.

Martinez, A., J. C. Garza, and D. E. Pearse. (2011). A microsatellite genome screen identifies chromosomal regions under differential selection in steelhead and rainbow trout. *Transactions of the American Fisheries Society* 140(3):829-842.

McElhany, P., M. H. Ruckelshaus, M. J. Ford, T. C. Wainwright, and E. P. Bjorkstedt. (2000). *Viable Salmonid Populations and the Recovery of Evolutionarily Significant Units*. NOAA Technical Memorandum NMFS-NWFSC-42.

Melville, R. V. (1995). *Towards Stability in the Names of Animals – A History of the International Commission on Zoological Nomenclature 1895-1995*. The International Trust for Zoological Nomenclature.

Moyle, P. B. (2002). *Inland Fishes of California.* University of California Press.

Moyle, P. B., J. A. Israel, and S. E. Purdy. (2008). *Salmon, Steelhead, and Trout in California: Status of an Emblematic Fauna.* University of Californian, Davis Center for Watershed Sciences.

Moyle, P. B., J. V. E. Katz, R. M. Quinones. (2011). *Rapid decline of California's Native Inland Fishes: A Status Assessment. Biological Conservation* 144(2011):2414-2423.

Murphy N. (2020). An Overview of Steelhead Angling for Inland Waters from 1930-1970. California Department of Fish and Wildlife, Region 5.

National Marine Fisheries Service. (2012). *Southern California Steelhead Recovery Plan.* NOAA Fisheries. West Coast Region, California Coastal Office, Long Beach, California

.

National Marine Fisheries Service (NMFS). (2014). Biological Opinion. Endangered Species Act Section 7(a)(2) Biological Opinion for Flood Control Operations including Annual Stream Maintenance, Debris Basin Maintenance, Goleta Slough Dredging and Long-term Atascadero Creek Channel Maintenance permitted by the U.S. Army Corps of Engineers, and implemented by the Santa Barbara County Flood Control District in designated waters occurring within Santa

Barbara County. NOAA Fisheries. West Coast Region, California Coastal Office, Long Beach, CA. WCRO-2020-03496. March 11, 2014.

National Marine Fisheries Service. (2019a). Steelhead Relocation Data Form. Mission Creek. September 4, 2019.

National Marine Fisheries Service. (2019b). Steelhead Relocation Data Form. Mission Creek. September 16, 2019.

National Marine Fisheries Service. (2022). *2022 5-Year Review: Summary and Evaluation of Southern California Steelhead*. National Marine Fisheries Service, West Coast Region.

Pearse, D. E., M. R. Miller, A. Abadía-Cardoso, and J. C. Garza. (2014). Rapid parallel evolution of standing variation in a single, complex, genomic region is associated with life history in steelhead/rainbow trout. *Proceedings of the Royal Society* B-Biological Sciences [online serial] 281(1783):article 2014.0012.

Pearse, D. E. (2016). Saving the spandrels? Adaptive genomic variation in conservation and fisheries management. *Journal of Fish Biology* 89(6):2697-2716.

Pearse, D. E., N. J. Barson, T. Nome, G. T. Gao, M. A. Campbell, A. Abadía-Cardoso, E. C. Anderson, D. E. Rundio, T. H. Williams, K. A. Naish, T. Moen, S. X. Liu, M. Kent, M. Moser, D. R. Minkley, E. B. Rondeau, M. S. O. Brieuc, S. R. Sandve, M. R. Miller, L. Cedillo, K. Baruch, A. G. Hernandez, G. Ben-Zvi, D. Shem-Tov, O. Barad, K. Kuzishchin, J. C. Garza, S. T. Lindley, B. Koop, G. H. Thorgaard, Y. Palti, and S. Lien. (2019). Sex-dependent dominance maintains migration supergene in rainbow trout. *Nature Ecology and Evolution* 3(12):1731-1742.

Pipal, K., M. Jessop, G. Holt, and P. Adams. (2010). *Operation of Dual-Frequency Identification Sonar (DIDSON) to Monitor Adult Steelhead (Oncorhynchus mykiss) in the Central California Coast.* NOAA Technical Memorandum NMFS-SWFSC-454.

Pipal, K. A., J. J. Notch, S. A. Hayes, and P. B. Adams. (2012). Estimating escapement for a low-abundance steelhead population using dual-frequency identification sonar (DIDSON). *North American Journal of Fisheries Management* 32(5):880-893.

Quinn, T. P. (2018). *The Behavior and Ecology of Pacific Salmon and Trout*. University of Washington Press, Seattle and the American Fisheries Society.

Redman, T. (2021). *Southern California Steelhead Monitoring Using Underwater Sonar (DIDSON) in Santa Barbara and Ventura Counties: 2019-2021*. Final Report for the California Department of Fish and Wildlife. Contract No. P1850904. Pacific States Marine Fisheries Commission.

Richardson, J. 1836. *Fauna boreali-Americana*. Part III. *The Fish*. London and Norwich.

Rich, A. and E. A. Keller. (2011). Watershed controls on the geomorphology of small coastal lagoons in an active tectonic environment. *Estuaries and Coasts* 35(2012):183-189.

Rich, A. and E. A. Keller. (2013). A hydrologic and geomorphic model of estuary breaching and closure.

Geomorphology 191(2013):64-74.

Rosenberg, D. M., and V. H. Resh. (1993). Freshwater Biomonitoring and Benthic Macroinvertebrates. Chapman and Hall.

Schott, H. E. (2005). *The Santa Barbara Mission Dam: A Sturdy Construction in a Stable Environment.* Thesis. University of California, Santa Barbara, Department of Environmental Studies. September 23, 2005.

Schwing, F., S. Lindley, E. Danner, and D. Boughton. (2010). *Climate Change in California: Implications for the Recovery and Protection of Pacific Salmon and Steelhead.* NOAA Technical Memorandum NMFS-SWFSC TM-451.

Shapovalov, L. and A. C. Taft. (1954). The Life Histories of the Steelhead Rainbow Trout (*Salmo gairdneri gairdneri*) and Silver Salmon (*Oncorhynchus kisutch*) with Special Reference to Waddell Creek, California, and Recommendations Regarding Their Management. *Fish Bulletin* No. 98.

Sinokrot, B. A. and J. J. Gulliver. (2000). In-stream flow impact on river water temperatures. *Journal of Hydraulic Research* 38(5):339-349.

Smith, G. R. and R. F. Stearley. (1989). The classification and scientific names of rainbow and cutthroat trouts. *Fisherie*s 14(1):4-10.

Sophocleous, M. (2002). Interactions between Groundwater and Surface Water: The State of the Science. *Hydrogeology Journal* 10.1 (2002): 52-67.

Southwest Fisheries Science Center. (2022). *Viability assessment for Pacific salmon and steelhead listed under the Endangered Species Act: Southwest*. (T. H. Williams, B. C. Spence, D. A. Boughton, F. Cordoleani, L. Crozier, R .C. Johnson, N. J. Mantua, M. O'Farrell, K. Pipal, L. Weitkamp, and S. T. Lindley). July 11, 2022. Report to National Marine Fisheries Service – West Coast Region from Southwest Fisheries Science Center, Fisheries Ecology Division, Santa Cruz, CA.

Spence, B. C. (2019). Interpreting early species range descriptions for Pacific salmon, *Oncorhynchus* spp., in coastal California watersheds: the historical context. *Marine Fisheries Review*. 82(1):1-39.

Stearley, R. F. and G. R. Smith. (1993(. Phylogeny of Pacific trouts and salmons (*Oncorhynchus*) and genera of the family Salmonidae. *Transactions of the American Fisheries Society* 122(1):1-33.

Stoecker, M. W., and CCP (Conception Coast Project). (2002). *Steelhead assessment and recovery opportunities in southern Santa Barbara County, California*. Stoecker Ecological.

Sue, H. 2022a. Memorandum to Kyle Evans, Senior environmental Scientist Supervisor, California Department of Fish and Wildlife. (2022). Re: Rattlesnake Creek *Oncorhynchus mykiss* and Relocation – September 15, 2022. October 3, 2022.

Sue, H. 2022b. Memorandum to Kyle Evans, Senior environmental Scientist Supervisor, California Department of Fish and Wildlife. (2022). Re: Mission Creek *Oncorhynchus mykiss* and Relocation – August 24, 2022. October 3, 2022. August 30, 2022.

Swift, C. C., T. R. Hagland, M. Ruiz, and Robert N. Fisher. (1993). The Status and Distribution of the Freshwater Fishes of Southern California. *Bulletin of the Southern California Academy of Sciences* 92(3):101-167.

Thomas, B. F. and J. S. Famiglietti. (2019). Identifying Climate-Induced Groundwater Depletion in GRACE Observations. Scientific Reports. *Nature* 9(2019):1-9.

Tasi, Y.-J. and K. Carmody. (2017). *Stationary PIT Tag Arrays for the Ventura River Basin*. National Fish and Wildlife Foundation. Final Report. Prepared for the Pacific Marine Fisheries Commission Grant No.1056.16. March 2, 2017.

Titus, R. G., D. C. Erman, and W. M. Snider. (2006). History and Status of Steelhead in California Coastal Drainages South of San Francisco Bay. In draft for publication as Department of Fish and Game *Fish Bulletin*. August 2006.

Wiseman, S. W., S. D. Cooper, and T. L. Dudley. (1993). The effects of trout on epibenthic odonate naiads in stream pools: *Freshwater Biology* 30(1993): 33–145.

Wells, A. W. and J. S. Diana. (1975). Survey of the Freshwater Fishes and Their Habitats in the Coastal Drainages of Southern California. Final Written Report Submitted to the Inland Fisheries Branch, California Department of Fish and Game. Contract AB-26. Natural History Museum of Los County Count Foundation.

Zaragoza, L., R. Baruth, C. Horgan, and D. St. George. (2022) *Mission Creek Habitat Assessment Report.* California Department of Fish and Game. November 10, 2022.

Federal Register Notices

62 FR 43937. (1997). Final Rule: Endangered and Threatened Species: Listing of Several Evolutionary Significant Units (ESUs) of West Coast Steelhead.

67 FR 21586. (2002). Final Rule: Endangered and Threatened Species: Range Extension for Endangered Steelhead in Southern California.

70 FR 52488. (2005). Final Rule: Endangered and Threatened Species: Designation of Critical Habitat for Seven Evolutionarily Significant Units (ESUs) of Pacific Salmon and Steelhead in California.

71 FR 834. 2006. Final Rule: Endangered and Threatened Species: Final Listing Determinations to for 10 Distinct Population Segments (DPSs) of West Coast steelhead.

84 FR 18243. 2019. Endangered and Threatened Species Listing Recovery Priority Guidelines.

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NMFS steelhead recovery planning

The Mission Creek system is located within the Conception Coast Range Biogeographic Population Group (BPG) and its steelhead population is classified as a Core 1 population within NMFS' Southern California Steelhead Recovery Plan[12] (Figure 5.3). Core 1 populations, along with Core 2 populations, are identified as having a high priority for recovery planning, and form part of the implementation strategy necessary to meet recovery criteria for listed species, such as a minimum number of viable populations within a BPG. These core recovery populations were identified based on the following criteria:

- intrinsic potential of the population to support a viable population in an unimpaired condition (based on the amount of spawning and over-summering rearing habitat);
- the role of the population in meeting the DPS-wide population viability criteria (minimum number of viable populations per BPG, including their geographical/spatial distribution within the BPG to avoid extirpation as a result of natural catastrophic events such as wildfire);
- severity of the threats facing the population (or current condition of the population);
- potential ecological or genetic diversity of the watershed that contributes to the species overall diversity; and
- capacity of the watershed and population to respond to critical recovery actions needed to address identified threats.

See NMFS (2012), Chapter 7, "Steelhead Recovery Goals, Objectives & Criteria" and the discussion below for details.

The NMFS' Technical Recovery Team (TRT) for the South-Central/Southern California Steelhead Recovery Planning Domain published a series of Technical Memoranda that provides the scientific framework for the recovery of the two listed species in this domain: the threatened South-Central California Steelhead DPS and the endangered Southern California Steelhead DPS (see Boughton *et al*., 2005, 2006, 2007; Boughton 2010a, 2010b).

Mission Creek Steelhead Recovery actions

To meet both the DPS-Wide and Population-Level viability criteria identified by NMFS' TRT for the Southern California Steelhead Recovery Planning Area, the NMFS' Southern California Steelhead Recovery Plan identified a suite of recovery actions, including those dealing with fish passage and flows in Mission Creek and its major tributary Rattlesnake Creek. NMFS also assigned a priority number for the Southern California Steelhead DPS (1C) for the purpose of prioritizing implementation of recovery actions for this DPS. This priority number reflects the species' demographic risk (based on the listing status and species' condition in terms of its productivity, spatial distribution, diversity, abundance, and trends), and recovery potential (major threats, management actions under U.S. authority or influence to abate major threats, and certainty that actions will be effective). If the listed species is in conflict with construction or other development projects or other forms of economic activity, it is assigned a "C" and

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[12] Other Core 1 recovery populations in the Conception Coast BPG are: Gaviota Creek, Goleta Slough Complex, Carpinteria Creek, and Rincon Creek (NMFS 2012, Table 7-1 and Table 10-3).

is given a *higher* priority over those species that are not in such conflict (84 FR 18243, National Marine Fisheries Service, 2022)

The following critical recovery action was identified for the Mission Creek watershed:

> "Halt the unnatural dry-season reduction in the amount and extent of surface water to restore natural or pre-impact over-summering habitat characteristics and condition for steelhead. Physically modify channelized reaches of Lower Mission Creek, and upstream road crossing, to allow natural migration of steelhead to upstream spawning and rearing habitats and passage of smolts and kelts downstream to the estuary and the ocean. Identify, protect, and where necessary restore estuarine and freshwater rearing habits. Develop restoration and management for the Mission Creek Estuary to restore estuarine functions."

See NMFS (2012), Table 10-3, "Critical recovery actions for Core 1 populations within the Conception Coast BPG".

The NMFS Southern California Steelhead Recovery Plan also identified the following specific recovery actions to address fish passage and flows in Mission Creek (including Rattlesnake Creek):

Culverts and Road Crossings (Fish Passage Barriers):

> "MisC-SCS-3.1 Develop and implement plan to prioritize, remove and/or modify anthropogenic fish passage barriers within the watershed to allow natural rates of adult and juvenile *O. mykiss* migration between the estuary and upstream spawning and rearing habits, passage of smolts and kelts downstream to the estuary and the ocean, and reduce intrusion into the riparian corridor and restore sediment transport."

Dams and Surface Water Diversions

> "MisC-SCS-4.1 Develop and implement a water management plan to identify the appropriate diversion rates for all surface water diversion that will maintain surface flows necessary to support all *O. mykiss* life history stages, including adult and juvenile *O. mykiss* migration, and suitable spawning, incubation, and rearing habitat."

Groundwater Extraction

> "MisC-SCS-6.1 Conduct groundwater extraction analysis and assessment. Conduct hydrological analysis to identify groundwater extraction rates, effects on the natural stream pattern (timing, duration and magnitude) of surface flows in the mainstem and tributaries, and the estuary, and effects on all *O. mykiss* life history stages, including adult and juvenile *O. mykiss* migration, spawning, incubation, and rearing habitats."
>
> MsC-SCS-6.2 Develop and implement groundwater monitoring and management program. Develop and implement groundwater monitoring program to guide management of groundwater extractions to ensure surface flows provide essential support for all *O. mykiss* life history stages, including adult and juvenile *O. mykiss* spawning, incubation and rearing habitats."

See NMFS 2012, pp. 10-36, Table 10-10, "Southern California Steelhead DPS Recovery Action Table for the Mission Creek Watershed (Conception Coast BPG)".

These recovery actions are intended to provide appropriate flows for volitional fish passage and habitat for both adult and juvenile *O. mykiss* in the Mission Creek watershed to accommodate the freshwater life-history phases and migratory patterns of native *O. mykiss*. They also are intended to enable the steelhead population in Mission Creek to meet the Population-Level viability criteria identified by NMFS' TRT, and incorporated into NMFS' Southern California Steelhead Recovery Plan (including the "Biogeographic Diversity" and "Life-History Diversity" elements of the viability criteria). The recommendations in this study are consistent with those identified for Mission Creek in NMFS's Southern California Steelhead Recovery Plan (NMFS 2012) (see Chapter 7, "Recommendation to Restore the Upper Mission Creek and Rattlesnake Creek Watersheds").

NMFS identified additional recovery actions to address other systemic threats to the steelhead population in the Mission Creek watershed, including recovery actions dealing with flood control structures such as levees and channelization, debris dams, non-native species, roads, recreational facilities, and a variety of upslope activities affecting the estuary, including urban development, urban effluents, and wildfires (NMFS 2013, particularly Table 10-10. "Southern California Steelhead DPS Recovery Action Table for the Mission Creek Watershed (Conception Coast BPG)", pp. 10-36 through 10-39).

California coastal salmonid monitoring program

To rectify the dearth of demographic autecological information on South Coast steelhead populations, NMFS and CDFW developed an updated monitoring strategy for the Southern Coastal Area.

The California Coastal Monitoring Program (CMP, Adams *et al.,* 2011) was based on the viable salmonid populations framework of McElhany *et al*. (2000), which assesses salmonid viability in terms of the abundance, productivity, spatial structure, and diversity of salmonid populations. The California CMP divides the Coastal Zone of California into a North Coast Area and South Coast Area based on differences in species composition, levels of abundance, spatial distribution patterns, and habitat differences that require differing monitoring approaches.[13] California CMP data can include adult estimates based weir count or on redd count surveys of stream reaches and a statistically-valid sampling design expanded to provide adult estimates based on spawner/redd ratios. In some cases, redd surveys and estimates are not expanded to adult estimates where no spawner/redd ratio estimates are available.

In the original formulation by Adams *et al*. (2011), monitoring methods for the North Coast Area were considerably more developed than those for the South Coast Area. Key impediments to steelhead monitoring in the South Coast Area stemmed from (1) the episodic flow regime characteristic of the area's river systems; (2) the sparse distribution or "detectability" of adult steelhead; and (3) the need to distinguish rare anadromous forms from the more common resident form of *O. mykiss* (*see* Pipal *et al*. 2010, 2012; Tasi and Carmody 2017). For illustrations of these issues in field applications, *see* Bankston *et al*. (2016), Bankston and Evans (2018), Carmody *et al.* 2019), and Redman (2021).

[13] The North Coast Area extends from the Smith River in Del Norte County, south to Aptos Creek in Santa Cruz County. The South Coast Area extends from the Pajaro River in Monterey County, south to the Tijuana River in San Diego County.

An updated California CMP strategy for monitoring steelhead and the resident form of *O. mykis*s in the South Coast Area has been developed to address these issues and related methodological and analytical issues (Boughton *et al.* 2022). The modifications to Adams *et al*. (2011) include: (1) stratifying sampling by "targets of estimation" (*i.e.*, specific populations, or groups of populations such as a BPG or an entire ESU/DPS) identified in NMFS' recovery plans for the South-Central/Southern California Recovery Domain; (2) conducting electrofishing surveys instead of snorkel surveys during the low-flow season; (3) modifying the sampling frame to include "short reaches" (*i.e.*, 100 – 400 m.) for low-flow surveys; and (4) incorporating an additional stage of sampling in the low-flow season to identify the proportion of habitat that is unsuitable due to lack of surface flow (Boughton *et al*., 2022).

The new monitoring plan adds flexibility for monitoring redds, and adult and juvenile steelhead abundances, depending on what is best suited for given BPG field conditions. Increased contingent flexibility in Life Cycle Monitoring stations, where smolt production, redd surveys, and adult counts are combined, and increased guidance on how to combine fish data with life-cycle models, are also provided. Finally, explicit indicators for life-cycle diversity, including the fraction of a population that is anadromous, are identified in the updated monitoring strategy, a key need for monitoring viability and refining viability criteria for steelhead populations in the South Coast Area (Boughton *et al*., 2022).

Using the guidance from Boughton *et al*. (2022) to address these issues, NMFS has recommended obtaining the following, as soon as practicable:

- Estimates of mean 2D areal density[14] of juvenile steelhead in each monitored stream for each BPG;
- Data identifying the location, extent, and persistence of drought refugia in each BPG;
- Estimates of adult steelhead abundance in selected populations, sufficient to evaluate representation and redundancy[15];
- Estimates of adult rainbow trout abundance, sufficient to evaluate the total abundance of adult *O. mykiss* in the region;
- Estimates of smolt production and marine survival in selected populations; and
- Routine genetic monitoring, to track the frequency of occurrence of the Omy5 A haplotype[16] as an indicator of the potential for anadromy.

[14] Mean 2D areal density refers to fish per square meter of wetted channel during the low-flow season. This density metric may be a good indicator for the population density that was originally proposed but left undefined in NMFS' TRT Technical Memorandum, "Viability Criteria for Steelhead of the South-Central and Southern California Coast" (Boughton *et al.* 2007) and NMFS' Southern California Coast Steelhead Recovery Plan (NMFS 2012).

[15] Representation is the idea that species have adapted to a diverse set of habitats and prey throughout their geographic range, and so successful species protection needs to represent this diversity in a set of protected, viable populations. Redundancy is the idea that multiple redundant populations should represent each component of habitat diversity, to ensure that no catastrophe or poor water year(s) simultaneously extirpates all populations in a particular type of habitat.

[16] A haplotype is a set of closely linked alleles or other variations of DNA along a chromosome, or chromosome segment, which tend to be inherited together from a single parent.

CDFW personnel are principally responsible for implementing these monitoring activities, and have begun to develop a plan for the Mission Creek watershed to generate rigorous fishery data that allow an assessment of the status of the steelhead populations in Mission Creek and Rattlesnake Creek and, by extension, to evaluate the effectiveness of implementing the recovery actions identified in NMFS' Southern California Steelhead Recovery Plan, the NMFS 2023 5-year review, and this study (see Chapter 7, "Recommendations to Restore the Upper Mission Creek and Rattlesnake Creek Watersheds").

NMFS 2022 status review

The ESA, under Section 4(c) (2), directs the Secretary of Commerce to review the listing classification of threatened and endangered species at least once every 5 years. A 5-year review is a periodic analysis of a species' status conducted to ensure that the listing classification of a species as threatened or endangered on the List of Endangered and Threatened Wildlife and Plants is appropriate.

The 5-year review provides a:

- summary and analysis of available information on a species;
- report on a species' progress toward recovery;
- record of the deliberative process used to make a recommendation on whether or not to reclassify a species; and
- recommendation on whether reclassification of the species is warranted.

NMFS 2023 5-year review concluded that no change in the endangered listing status of the Southern California Steelhead DPS was warranted. However, the 5-year review emphasized that the most recent extended drought (coupled with extensive wildfires) have had numerous negative impacts on the Southern California Steelhead DPS, with no adult anadromous steelhead observed in many streams over the past 5 to 7 years. In streams where adult steelhead runs were actually observed, the counts have been in the single digits. During the extended drought, the anadromous adult steelhead life-history pattern has nearly disappeared (NMFS 2022). In the 2023 5-year review, NMFS identified future actions in each BPG of the Southern California Steelhead DPS to pursue over the next 5 years, although some of these recovery actions may take longer to fully implement due to technical, funding, or other constraints.

The most important recovery actions necessary to improve the status of the Southern California Steelhead DPS identified in the 5-year review include: the removal of fish passage impediments; restoration of spawning and rearing habitat, ecologically significant flows, and riparian corridors; removal and control of non-native vegetation and exotic aquatic species; identification and protection of over-summering refuge habitat; and implementation of an updated program for steelhead viability monitoring in the South Coastal Area.

Among the specific recommendations for future recovery actions for Mission Creek (including Rattlesnake Creek) are the following addressing fish passage impediments in Mission Creek and Rattlesnake Creek:

- Completion of studies and implementation of fish passage improvements at several road crossings over Mission Creek (*e.g.,* De La Vina Bridge, Mission Canyon Bridge, Highway 192 Bridge, and Las Canoas Bridge over Rattlesnake Creek) and the Mission Creek Dam on Mission Creek (NMFS, 2012a: Recovery Actions MisC-SCS-3.1).

- Implementation of NMFS Biological Opinion for the Santa Barbara County Flood Control and Water Conservations District's operations, including channel maintenance, and removal or modification of debris basins throughout South Coast watersheds including those on Mission and Rattlesnake Creeks (NMFS, 2012a: Recovery Actions MisC-SCS-5.1).

Southern California steelhead angling history

Steelhead populations traditionally supported an important recreational fishery throughout their natural range in southern California (Fry 1938, 1973; Kreider, 1948; CDFW, 1999; Alagona *et al.*, 2012). Coastal streams adjacent to urbanized areas with ready access, such as Mission Creek, where popular angling destinations for fisherpersons pursuing either steelhead or resident rainbow trout. Sport fishing for native steelhead and their non-anadromous form has been regulated by the CDFW since the early part of the 20th century (CDFW, 1999).

Between 1930 and 1970, winter angling for steelhead was limited to the tidally influenced reaches of coastal rivers (*i.e.*, the estuaries), except in a few specified watersheds. In l957, catch limits for juvenile *O. mykiss* were reduced in all waters of southern California. From 1965 to 1970, fall/winter angling restrictions limited the take of steelhead and impacts on upstream steelhead migration and spawning activity, and also prohibited angling for juvenile steelhead (*i.e*., smolts) that were emigrating out of the watershed to the ocean. During the remainder of the year, the spring/summer angling season stretching from May 1 to October 31, and related regulations, were aimed at managing the take of juvenile *O. mykiss*. A daily limit of 25 individuals or up to 10 lbs. was enforced until 1957, and these limits were subsequently reduced to 15, then 10, and finally 5 individuals at the time of the initial listing of the Southern California Steelhead ESU in 1997 (Lentz and Clifford, 2014; Murphy, 2020).

Since the early 1990s, anglers pursuing steelhead in anadromous waters of California (*i.e*., portions of rivers and streams below impassible barriers) have been required to purchase a steelhead report card. Information on the dates and locations of fishing, as well as the number of adult steelhead kept, the number of adult steelhead released, the origin of the fish caught (hatchery or wild), and the number of hours fished must be reported (Jackson, 2007; CDFW, 2016). Although anglers are required to report this information, average compliance rates are low, estimated at approximately 30 percent (CDFW, 2016). Until the ESA listing of the Southern California Steelhead ESU/DPS in 1997, recreational angling for *O. mykiss* was permitted in all coastal drainages within southern California (and continues in areas above barriers, such as major dams, which are currently impassible to fish migrating upstream).

Following NMFS' listing of populations of steelhead in California in 1997, CDFW began closing angling in anadromous waters throughout the state in 1998 but, initially, larger watersheds were excluded from this angling closure. Anadromous waters of the CDFW's Southern District (which includes the Southern California Steelhead DPS) were recommended for closure in June of 1998 as a protective measure for the recently listed steelhead. The Sisquoc River (a tributary to the Santa Maria River) remained open to angling because it was believed that steelhead were prevented from reaching the upper portions of this watershed. However, in 2011, the California Fish and Game Commission formally closed the Sisquoc River and its tributaries to all angling to protect the remnant steelhead population, including the closely related non-anadromous form of *O. mykiss* (Murphy, 2020; CDFW, 2015-2022).

Additionally, CDFW has curtailed its stocking of hatchery trout, limiting stocking to reservoirs or stream reaches above impassible barriers to upstream migrating steelhead. CDFW also expanded its use of sterile (triploid) fish to all the waters currently stocked with *O. mykiss* to prevent the interbreeding of hatchery-reared fish with native steelhead, although other entities (such as water agencies) continue to stock reservoirs in anadromous watersheds with non-native fishes, which have the potential to escape downstream into anadromous waters.

Sport and commercial harvest of steelhead in the ocean is prohibited by the CDFW (CDFW, 2015-2022) and is not believed to be a significant source of mortality for southern California steelhead populations. High seas driftnet fisheries in the past may have contributed slightly to a decline of this species in local areas, although steelhead are not targeted in commercial fisheries and reports of incidental catches are rare. Incidental ocean harvest of steelhead is also rare (Burgner *et al*., 1992), and commercial fisheries are not believed to contribute to the large declines in steelhead runs observed along most of the Pacific coast over the past several decades.

CHAPTER 6. MISSION TUNNEL IMPACTS

6.1. Introduction

The drainage of Mission Creek approximately overlies the southern part of the Mission Tunnel, which carries water from Gibraltar Reservoir, north of the Santa Ynez Range, to the City of Santa Barbara. Groundwater discharges into the Tunnel, whose water is diverted and used by the City of Santa Barbara. The tunnel was built between April 1904 and December 1912 and it is 3.7 miles (19,536 feet = 5,955 meters) long (Eckman, 1967; BCI, 1990). There are possible hydraulic connections between the Mission Tunnel and springs that discharge to Mission Creek and Rattlesnake Creek maintaining habitat for fish and other aquatic species. Inflow to the Mission Tunnel occurs in portions of the Tunnel that underlie the Creek drainage and portions that do not. Figure 6.1 shows the locations of the Mission Creek drainage and the Tunnel, as plotted on USGS topographic maps. Figure 6.2 displays the interior of Mission Tunnel with a person walking through it.

The Mission Tunnel is bored through the Santa Ynez Mountains, the westernmost east-west trending range of the Transverse Ranges (i.e., transverse to the general NW tectonic trend of California). The range comprises a south-dipping homocline (i.e., sedimentary beds with approximately uniform dip, but without a fold axis, such as a syncline or anticline would have) of Tertiary age marine sedimentary rocks. Figure 6.3 shows a geologic cross section (see the geologic description below) with shading to indicate sedimentary rock units that connect the Mission Creek and Rattlesnake Creek beds with the Tunnel. Chapter 4 provides field evidence about the association between pools that provide habitat for fish and other aquatic species and particular geologic formations.

Anecdotal evidence of impacts to Mission Creek due to the Tunnel was provided by local historian Walker Tompkins (Southern Santa Barbara County Board of Realtors, 1977):

> Mission Creek was an ever-flowing stream, and a popular hike was up the canyon to a picnic spot at Fern Falls, beyond today's Tunnel Road bridge. Above them were a series of rocky cascades known as The Seven Falls. Unfortunately, when Mission Tunnel was bored through the mountains in 1911, Mission Creek and its falls dried up except for periods of heavy rains.

This is a historian's observation, perhaps based on communication from local residents, but does not include actual measurements of stream flow. In fact, stream flow and waterfalls are continuous in early modern years through late spring or early summer. Thus, the term "dried up" should not be considered to be a rigorous hydrologic description of streamflow conditions in Mission Creek after the Tunnel was built.

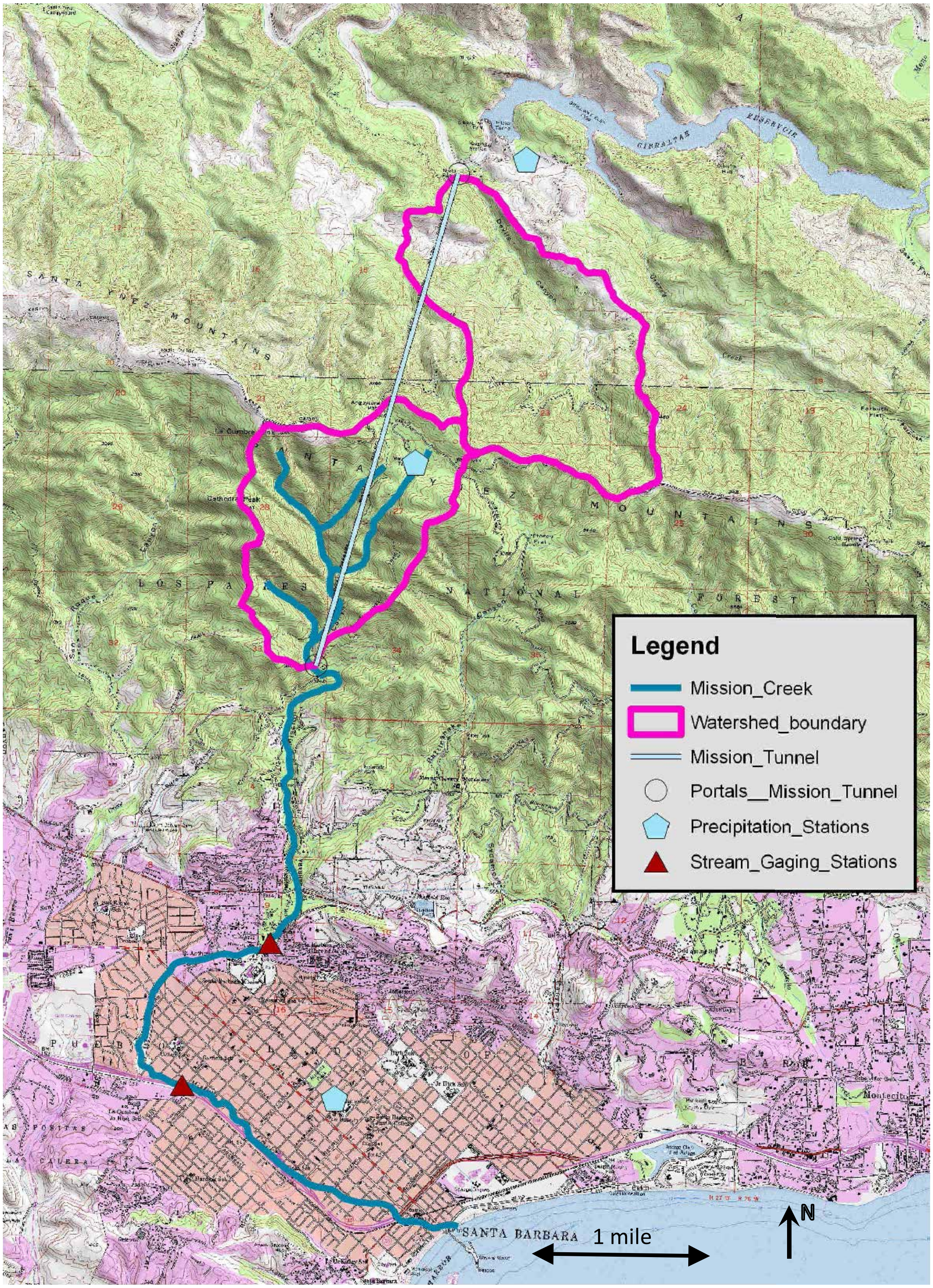

Figure 6.1. Location Map, after Brown (2003). The southwestern of the two watershed areas is the Mission Creek portion of the watershed that overlies Mission Tunnel within the upper Mission Creek watershed. Its area is approximately 2.3 square miles (5.7 km^2). The length of the tunnel within this area is 3340 m (10,960 feet). The precipitation station is within Ranch El Deseo.

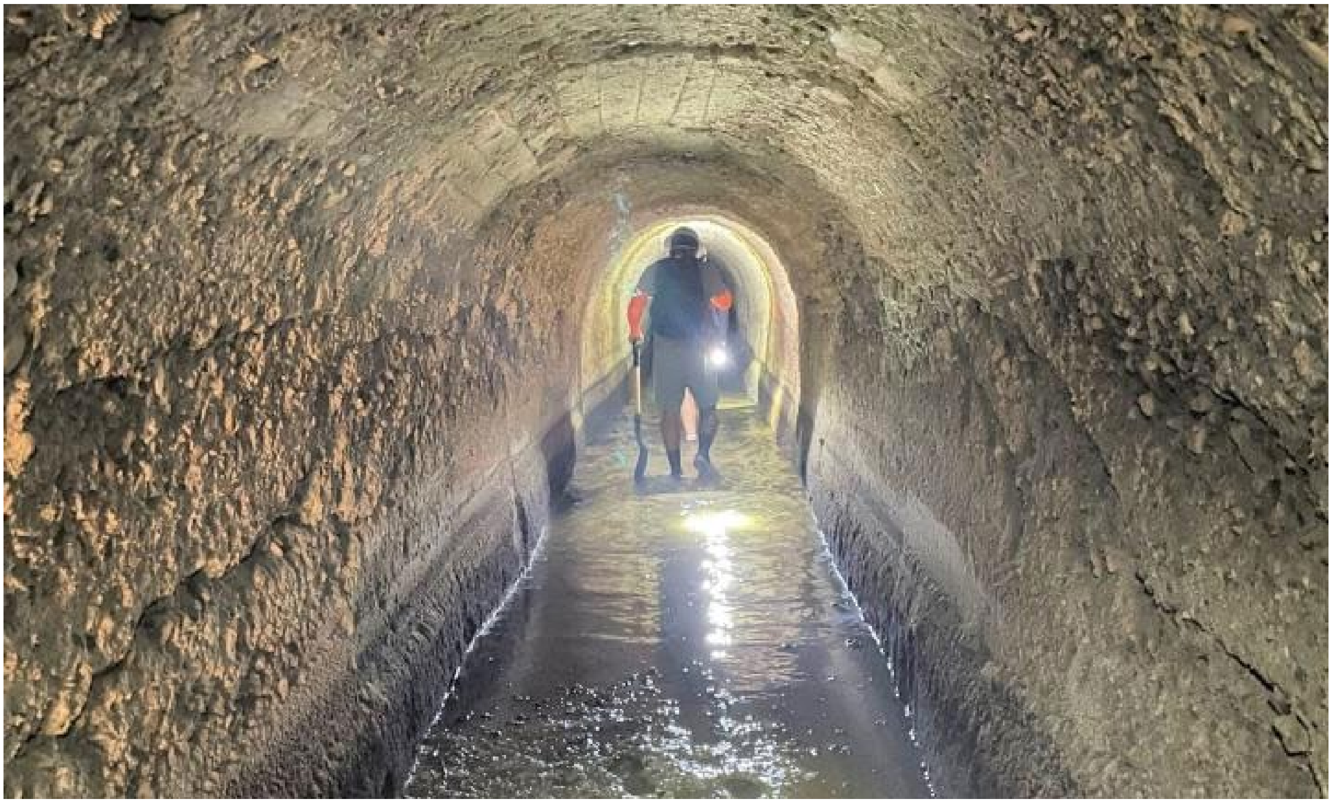

Figure 6.2. Photo of the interior of Mission Tunnel.

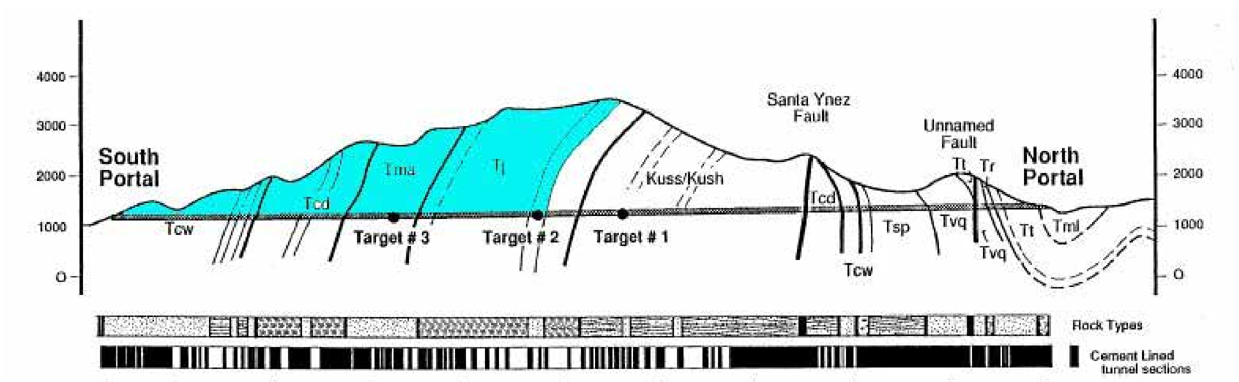

Figure 6.3. Geologic cross section of Mission Tunnel and overlying rocks (after BCI, 1990). The blue shaded beds are those within the Mission and Rattlesnake creeks' drainage area that intersect the Tunnel. Unlined tunnel sections are most common through the Juncal (Tj) and Kuss/Kush formations (unnamed marine strata (Jalama formation?), Late Cretaceous age).

6.2. Geologic and tectonic setting of the study area

The rocks of coastal California, west of the San Andreas fault (i.e., on the Pacific Tectonic Plate), have been geologically modified and transported during the past 5 million years, following subduction of the East Pacific Rise oceanic spreading center and initiation of tectonic plate motion within the continent. Some areas, including the western Transverse Ranges, have undergone clockwise rotation

(Nicholson et al, 1994), so that the present location and orientation is different from when the rocks were deposited. The present condition is most important for understanding the hydrogeologic connection between Mission Creek, Rattlesnake Creek, and the Tunnel, but the geologic history is of interest.

Dibblee (1966) noted the following regarding the Santa Ynez Range: "…the exposed stratigraphic succession for Upper Cretaceous to Upper Miocene is practically continuous, with a thickness totaling some 24,000 feet." "The Santa Ynez Mountain tectonic block…is really the northern flank of the huge trough-like Ventura sedimentary basin, of which the sunken part is submerged under the Santa Barbara Channel."

Formations through which the Mission Tunnel is bored and that underly the Mission Creek and Rattlesnake Creek watersheds are (see Figure 6.3):

Tj – Juncal Formation – shale and sandstone.

Tma – Matilija formation – sandstone, buff or gray-white or greenish white forms the most rugged, craggy, terrain.

Tcd – Cozy Dell Shale – dark gray, weathers brownish gray to olive gray.

Tcw – Coldwater Sandstone – gray-white, weathering to buff, forms rugged, rocky terrain.

Kuss and Kush – an "unnamed" Cretaceous formation, ss denotes sandstone, sh denotes shale.

<u>Depositional Environment, Lithification</u>

The dipping sedimentary rocks that connect the Mission Creek and Rattlesnake Creek watersheds with the Mission Tunnel were deposited as continental shelf sediments during the Eocene Epoch, 56 to 34 million years ago, a warm-temperature period (USGS, 2021), with deposition spanning the entire Epoch. During this time both the depth of the sea and the sources of sediments varied, influencing the character of the rocks. These rocks are generally well lithified (hardened by pressure due to burial and by cementation of grains).

The following descriptions of the depositional environment and lithification are from Dibblee (1966), based on surface outcrops. In addition to the published surface mapping of Dibblee (1966), both surface mapping and mapping of exposures within the Tunnel were reported in the BCI report (1990). As BCI noted, "Most of the tunnel walls are covered with mud, calcium carbonate, or iron staining. Samples had to be broken off the side-walls in order to see the composition of the rock. Because of this difficulty, the stratigraphy was projected from the surface to the Tunnel and only the projected contact areas were studied in detail. Bedding characteristics such as whether the rock was thin- or thick-bedded and whether inflow was identified along bedding was mapped for the entire length of the Tunnel."

Tj – Juncal "…. deposited under a moderately quiet, transgressive sea. … under conditions probably unfavorable to marine life, judging from the scarcity of fossils, presumably farther from shore, on a sea bottom subject to variations in depth and current. The sediments were probably deposited rapidly as the sea floor subsided." "..the shale is dark gray to nearly black, and disintegrates to small spheroidal fragments with blue-black manganese stains on fracture surfaces." BCI (1990) noted that the Juncal formation "(is) extremely weathered in surfaced exposures, where it commonly disintegrates into many small fragments. In contrast, [this] unit is generally competent with well-expressed bedding and fracture surfaces in the Tunnel."

Tma – Matilija "The arkosic composition of the Matilija Sandstone indicates that it was derived from a land area of granitic rocks. … apparently well sorted by submarine currents and spread out as a more or less uniform blanket of sand over the floor of the Eocene Sea as the area continued to sink." "… composed almost entirely of sandstone in beds 3 to 20 feet thick separated by shale partings." BCI (1990) noted that it "forms prominent cliffs with clearly defined bedding in [surface] exposures, but in the Tunnel bedding is very difficult to recognize."

Tcd – Cozy Dell Shale "… deposited as fine micaceous mud, probably during the time the Eocene Sea that covered the region attained its maximum transgression and depth. … adjacent land areas were probably eroded down to low relief so that they shed only fine material." …"it is well stratified and readily disintegrates into small sub-ellipsoidal to sub-platy fragments."

Tcw – Coldwater "… deposited as the sea regressed westward and became shallower" "… consists of about 80 percent arkosic sandstone and 20 percent siltstone and shale …. Beds from 2 to 150 feet thick … moderately well cemented, massive to laminated."

Also shown on geologic maps are additional symbols and rock types: Tvq denotes the Vaqueros formation; Kuss and Kush is an "unnamed" Cretaceous formation, ss denotes sandstone, sh denotes shale, and SYF denotes the Santa Ynez fault, an important regional geologic feature that is crossed by the Tunnel. The Kuss/Kush formation is shown below to be an important contributor to groundwater flow to the Mission Tunnel, in addition to the Juncal formation (see Table 6.2, Figure 6.6).

These descriptions of lithification and the conditions of fracturing and interbedding are important to groundwater flow because they can determine the bulk permeability of a rock mass for groundwater flow.

Bedrock Fracture Fabric

BCI Geonetics specialized in interpretation of surficial lineations and fracture patterns for water resources, and applied this expertise to their (1990) Mission Tunnel study. The noted that "This analysis indicates there are three major fracture sets within the bedrock in the Mission Tunnel area", with some variation in orientations across the area. The three sets are:

- Most prominent –subvertical, trending 020° (NNE). Best developed in Juncal and Coldwater formations, less well in Matilija Sandstone;
- A north-dipping, east-west trending fracture set is best expressed in the Cretaceous strata and in the Matilija Sandstone;
- A weakly developed fracture set (trending to 060° - ENE), which is evident in all of the formations.

Any of these fractures could provide a conduit for groundwater flow, but it is not clear if any are particularly important in terms of volumetric water inflow to the Tunnel. However, as discussed below, the Juncal formation is important for volumetric inflow, so this may involve the first of the three sets.

6.3 Hydrogeology

Groundwater in the Santa Ynez Mountains is recharged by infiltration of precipitation, mainly in the form of rain, but also some snow. Some of the water is discharged surficially to Mission Creek and other creeks, and some as groundwater to Mission Tunnel. Water is also discharged as groundwater underflow to the unconsolidated sediments of groundwater basins at the base of the hills, in Santa Barbara and Goleta. The eastern end of one of these basins, called Foothill Basin, lies at the base of Mission Creek where it leaves the mountains.

Rocky Nook Park, nominally the lower end of the study area for the present project is in the eastern end of the Foothill Basin. The Foothill Basin was described in the USGS study of Freckleton (1989). Although the basin extends westward of the area below Mission Creek, the latter study, which applies to the basin as a whole, noted: "…recharge to Foothill Basin includes.... subsurface inflow from weathered and fractured zones in the consolidated rocks of the Santa Ynez Mountains. … The quantity of subsurface flow that enters the Foothill basin is unknown; however, Muir (1968) estimated that about 300 acre-ft/yr enters the Santa Barbara area, which includes the Foothill Basin" …. The Santa Barbara County Water Agency's estimates of recharge lead to "… 40 to 80 acre- ft/yr of subsurface inflow to Foothill basin" … "Mission Creek upstream from the Mission Ridge fault [i.e., Rocky Nook Park area] does not recharge the ground-water basin." Chapter 2 presents a quantitative water balance in the study area, which shows that there is groundwater flow to the groundwater basins and perhaps also deeper into the consolidated rocks beneath them.

Groundwater recharge to Mission Tunnel estimated by BCI (1990)

BCI (1990) estimated groundwater recharge to Mission Tunnel on the basis of precipitation records at different elevations, stream gage records, and evapotranspiration values for southern California mountains. The recharge was calculated as being equal to precipitation minus the natural water loss (water loss due to evapotranspiration) and minus the overland runoff. The recharge was calculated for ranges of surface elevation within the Mission Creek drainage recharge area (see Table 6.1), for a total recharge of 39.6 acre-ft/yr (AFY).

Table 6.1. Groundwater recharge to Mission Creek drainage above the Tunnel calculated by BCI (1990).

Elevation zone	Precipitation (in)	RECHARGE (AFY)
800 - 1600	28.1	6.8
1600 - 2400	32.5	7.2
2400 - 3200	36.8	11.6
3200 - 4000	41.2	14
Total Recharge		39.6

The data presented in Table 6.1 are inaccurate because the calculated recharge of groundwater in the Mission Creek drainage, and, therefore, to Mission Tunnel (39.6 AFY) is much lower than the measured groundwater inflow to Mission Tunnel. The measured groundwater inflow is calculated by the City of Santa Barbara as being equal to the measured tunnel flow at the south portal minus the measured flow into the tunnel at the north portal. Figure 6.4 depicts measured groundwater seepage to Mission Tunnel from water year 1976 through water year 2021. The average annual groundwater recharge equals

1,215 AFY. The annual groundwater inflow exhibits pronounced interannual variability that reflects the variability of precipitation.

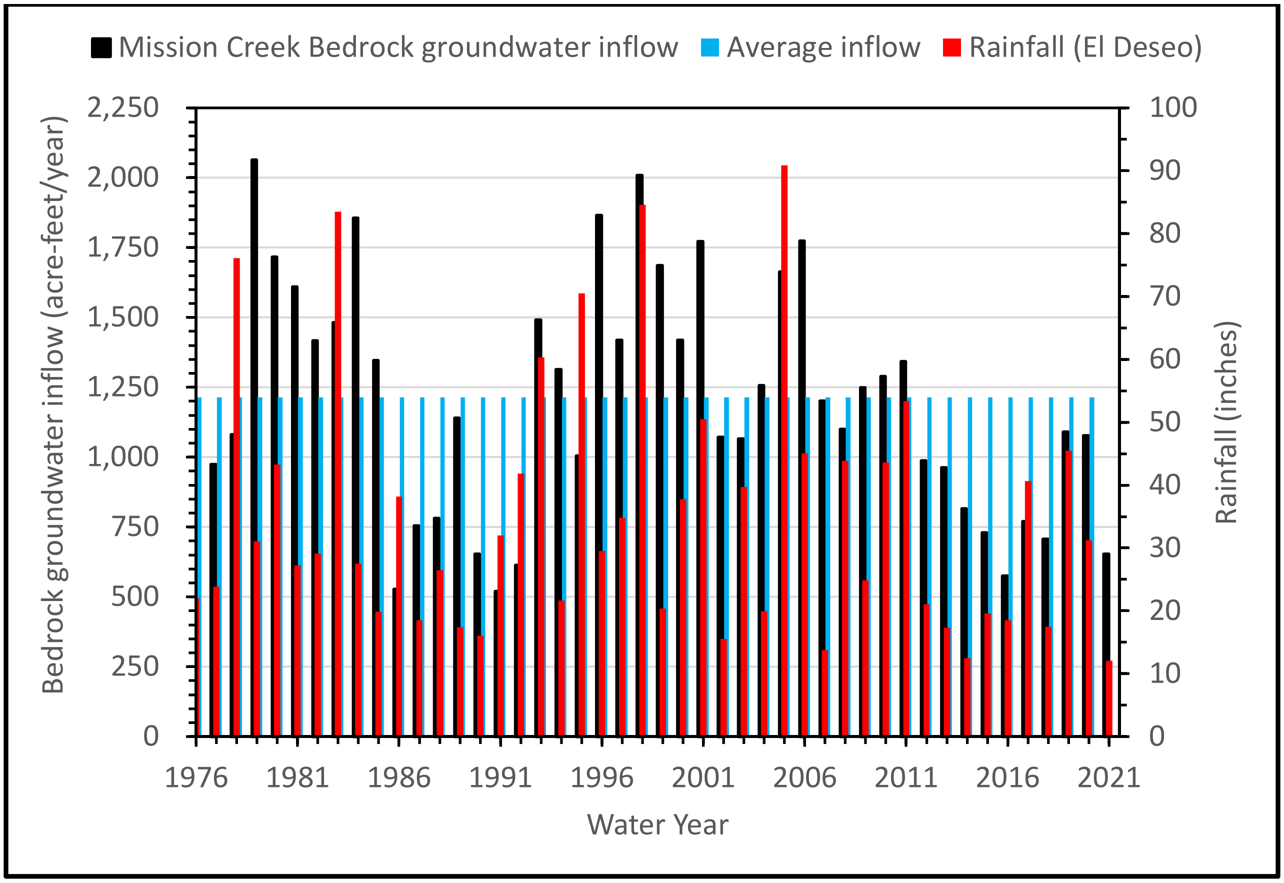

Figure 6.4. Annual groundwater inflow to Mission Tunnel and annual rainfall at El Deseo station (see location in Figure 6.1). The average groundwater inflow equals 1215 AFY. (Source: City of Santa Barbara's Water Resources Division).

The discrepancy between the Mission Creek drainage recharge estimated by BCI (1990) and the tunnel inflow obtained by outflow minus inflow measurements may be caused by one or more of the following: (1) the Tunnel inflow is depleting bedrock groundwater storage, (2) the recharge area supporting the Tunnel inflow is significantly larger than the Mission Creek drainage area used by BCI (1990) to calculate groundwater recharge, (3) the water balance method applied by BCI (1990) did not correctly estimate the partitioning of precipitation into creek flow, evapotranspiration, groundwater recharge, and changes in soil moisture. If the first alternative were true, the resource might have dried up by now, which is clearly impossible given the data displayed in Figure 6.4. The second and third alternatives are the likely explanation of the discrepancy between the BCI calculations and the measured groundwater inputs to the Tunnel, although errors in precipitation used by BCI (1990) may also contribute to it. Rademacher et al (2003) reported the presence of water without bomb tritium in some seeps, indicating that the water was older than 45 years (as of 2003) and thus was sourced from long-term storage encompassing a substantial distance from the Tunnel, thus implying a recharge area larger than that used in BCI (1990). Chapter 2 presents an analysis of precipitation, evapotranspiration (water that is transpired by vegetation plus water that is evaporated from soils and from vegetation following rainfall, Crippen, 1965), creek flow, soil moisture, and bedrock ground water storage in the drainage area upstream of the confluence of Mission and Rattlesnake creeks in a more realistic manner than the simplified analysis presented in BCI (1990). Chapter 2 documents high interannual variability in groundwater storage and subsurface flow from the study area. The Chapter 2 findings are in contrast with the subsurface flow proposed by Muir (1968), who estimated it to be about 300 acre-feet annually. Muir (1968) and other authors who investigated the bedrock aquifers of the Santa Ynez Mountains of Santa Barbara County (e.g., Miller and Rapp, 1968) erroneously assumed zero change of bedrock groundwater storage over a water year in their estimate of groundwater recharge.

Measurements of inflow in Mission Tunnel

As noted above, the long-term average groundwater inflow into Mission Tunnel, measured as the average annual difference between water leaving the south portal and that entering the north portal equals 1,215 acre-ft/yr (AFY) based on measurements made from water years 1976 through 2019 (a water year is defined by the City of Santa Barbara as the time elapsing between October 1st of a given year and September 30th of the following year). In April of 1990 BCI geologists measured inflows at various locations within the tunnel using a cutthroat flume, a device that channels water flow on the floor of the tunnel and measures the depth of water flowing over a blockage. In spite of some difficulties using the flume within the confines of the Tunnel the flows listed in Table 6.2 were measured. These are instantaneous flow rates measured in gallons per minute (gpm) and can be compared with long term flow rates using the conversion factor 1 gpm =1.61301 AFY.

Table 6.2. Measured inflow to Mission Tunnel by geologic formation.

No.	Distance from North portal (ft)	Geologic Formation (preceding interval)	Flow (gpm) at this station	Flow (gpm) increase since last station	Flow (AFY) increase since last station
1	1980	Tvq	18	18	29.03
2	4100	Tcw/Tcd	18	0	0.00
3	7144	Kush/Tcd, SYF	21	3	4.84
4	9750	Kush/Kuss	78	57	91.94
5	10600	Tjss/Tjsh	180	102	164.53
6	11995	Tjsh	215	35	56.46
7	14038	Tjsh/Tma	252	37	59.68
TOTAL			252		406.48

The total measured flow of 252 gpm, if extrapolated to an entire water year, is equivalent to 406 AFY, which is much lower than the long-term average of 1,215 AFY. This discrepancy may have been due to leakage around the measurement flume, or that the measurements were made in a period of anomalously low inflow. There was a severe drought in the study area in the years 1987-1991 (see Chapter 2), which encompassed the time when the BCI study was conducted. The measured Tunnel inflow in the water year 1990 (October 1, 1989- September 30, 1990, was 653 AFY (see Figure 6.4) or about one half of the annual average equal to 1,215 AFY).

Importance of the unnamed formation Kuss/Kush and the Juncal formation to discharge in Mission Tunnel

Only the final three measurements (i.e., 5, 6, and 7 in Table 6.1) correspond to the part of the Tunnel beneath the Mission Creek watershed. These total 281 (= 164.53+56.46+59.68 rounded to 281) AFY, about 70% of the total measured inflow to the Tunnel segments beneath the Mission Creek drainage basin during this measurement period. If groundwater inputs by geologic formations to the Tunnel in 1990 are characteristic of the long-term average inflow, then the highest part of the Mission Creek drainage, underlain by the unnamed formation Kuss/Kush and the Juncal formation (Tjss/Tjsh), corresponds to the area of highest inflow to the Tunnel.

The Mission Creek drainage where it overlies Tj is shown in Figure 6.5. This relatively flat area may be conducive to recharge via infiltration of precipitation, particularly because it is at high elevation with heavy rainfall (see Table 6.1). High infiltration would be consistent with the large volume of discharge to the Tunnel. The area of Tj at high elevation continues to the east-southeast and west-northwest of Mission Creek drainage. It is unknown at this time whether this area of Mission Creek drainage overlying Tj contains significant fish habitat, although reduction of flow in this reach of the creek would diminish flow downstream in areas where fish habitat is known to occur. El Deseo Ranch is located in this area (in Figure 6.5 where the label “Water Tank” is shown near the upper end of the eastern stream channel, and see also Figure 6.1). This is the location of the highest-elevation rain gauge used in the BCI (1990) study.

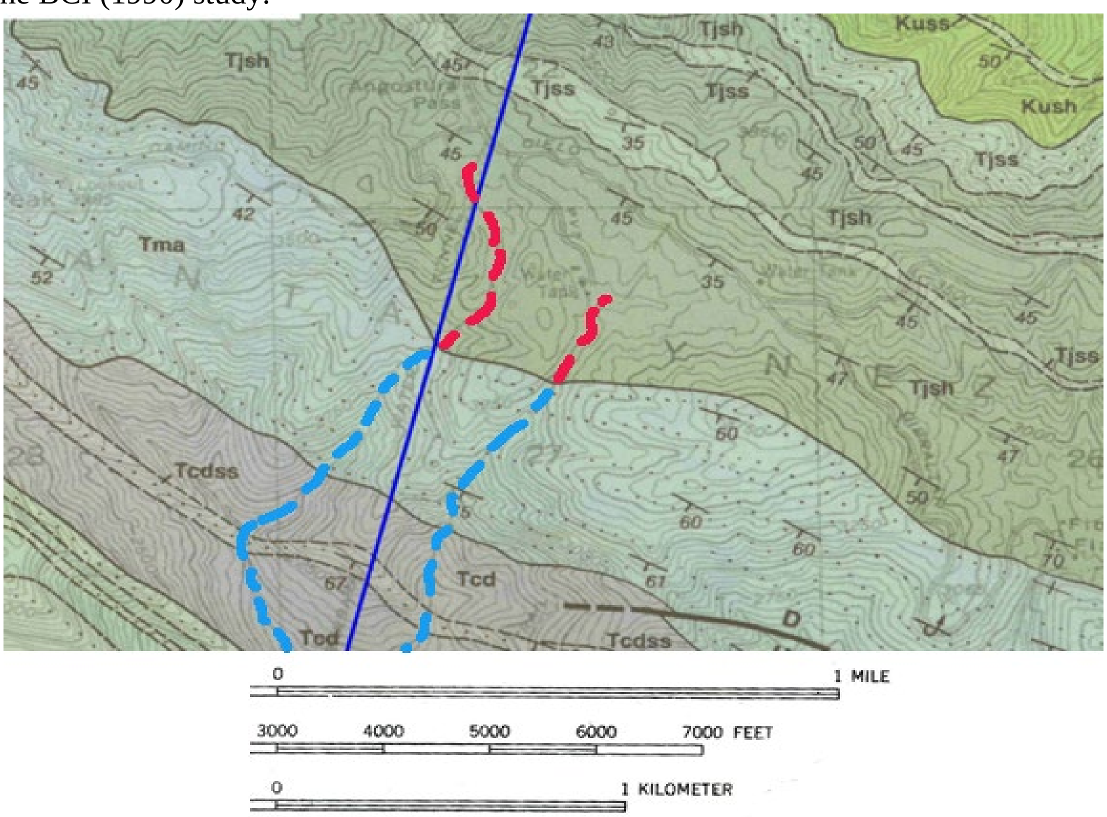

Figure 6.5. Bed of Mission Creek (two branches, with the upper sections overlying Juncal formation (Tj) shown in red, lower sections in blue). The upper sections are relatively flat, compared with lower portions. Base map is Dibblee Foundation #DF-06 with Tunnel location (blue line) as plotted by Brown (2009).

The El Deseo Ranch rain gauge location is depicted in Figure 6.1. Anecdotal testimony by a former resident of the ranch (Susan Hummels, personal communication 2022) indicates that a shallow well dried up when the tunnel was built. This resident was not alive at that time, so this information was orally handed down. The relatively large Tunnel inflow contributions of the Juncal formation (T_j) and the Kuss/Kush formation are shown in Figure 6.6.

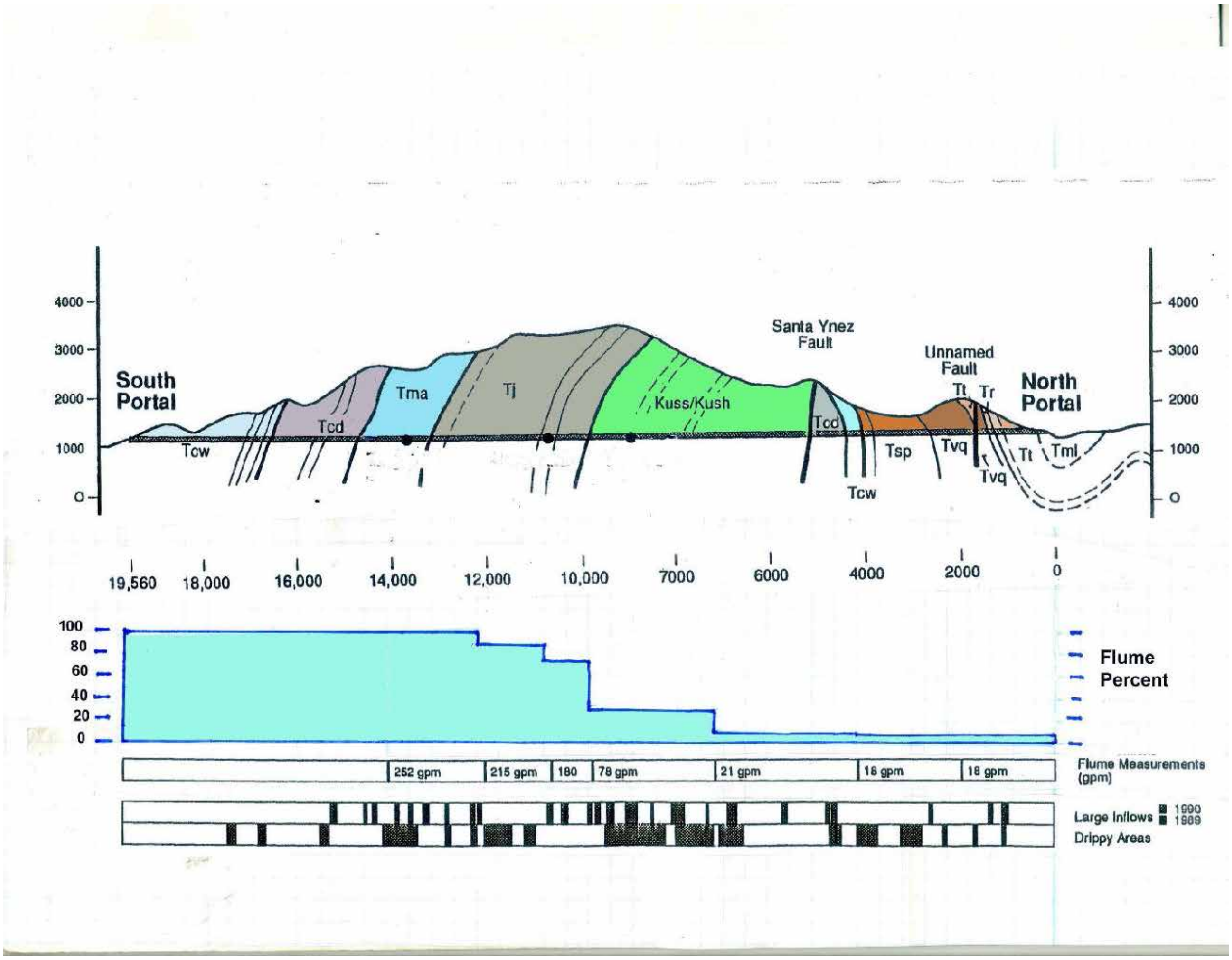

Figure 6.6. Mission Tunnel cross section with cumulative percentage of tunnel flow (light-blue area) increasing from north to south, with the largest increases through the unnamed Kuss/Kush rocks and the Juncal formation. An unknown additional contribution occurred downstream of the last measurement, still over a mile shy of the tunnel outlet. The large increase does not appear to correlate well with locations noted as "Large Inflows", which may be individual open crack conduits. Modified from BCI (1990) Figure 3, #DF-05 and #DF-06.

It is seen in Figure 6.6 that:

- A significant volume of water inflow to the Tunnel occurs where the Tunnel crosses the unnamed Kuss/Kush formation and the Juncal formation (Tj);
- It appears that Tunnel inflow is recharged from a larger area than just the Mission Creek and Rattlesnake Creeks watersheds, so adjacent high elevation areas of Tj north of the topographic divide probably contribute as well. To the WNW, the highest elevation area is underlain by

younger Eocene rocks, particularly the Matilija formation, which had smaller inflow in the BCI (1990) study.

- The Tj formation is continuous for several miles to the ESE of Mission Creek drainage, but to the WNW it is partially truncated within a few miles by the Santa Ynez fault.
- The BCI (1990) tunnel flow measurements were made during a year of drought (1990), and it is possible that those measurements did not capture groundwater recharge contributions that may occur during average or above-average precipitation.

6.4 Conceptual site model (CSM)

Numerical models are often used in modern aquifer studies, particularly the USGS- developed MODFLOW program, and its combined surface/groundwater GSFLOW model. This and similar models are appropriate for aquifers in geologic materials with primary permeability, such that groundwater moves through interconnected pore spaces. In such aquifers, groundwater elevation can be interpreted as hydraulic head, a measure of energy per unit of weight of groundwater that drives groundwater flow. However, this kind of modeling does not apply to fractured bedrock systems, such as those surrounding the Mission Tunnel. Instead of flow through pore spaces, flow is through fractures, whose size, orientation, connectivity, direction, location, and density vary greatly. Groundwater elevation may provide an index of hydraulic head driving flow or represent the isolated filling of unconnected void spaces that do not result in significant groundwater flow.

Nevertheless, some approaches to modeling can help understand the physical processes that function in the real hydrogeologic setting of Mission Creek and Tunnel. Here we start with a descriptive model, then develop a simplified numerical approach to a simplified aquifer configuration, which we then extend to the real dimensions of the Mission Creek/Rattlesnake Creek/Tunnel system.

General Setting

As discussed above, the geologic setting of the Mission Tunnel and Mission Creek drainage constitute a steeply south-dipping homocline of Tertiary sedimentary rocks. However, in terms of hydrogeology, the situation is more complex, characterized by secondary fracture porosity and potential bedding plane and fault surface conduits, and, as noted, not amenable to conventional numerical description. A Conceptual Site Model (CSM), both descriptive and numerical, is useful in understanding the real situation.

Brief descriptions of the basic characteristics of the geologic setting from the published geologic literature are presented below:

Rademacher et al (2003):

> “The tunnel passes through a nearly vertically dipping sequence of fractured sandstones and shales. The water table is not well defined in this fractured bedrock aquifer and is controlled by topography and heterogeneities in permeability. In a few areas in the tunnel, water appears to enter under pressure, suggesting that the water table is above the tunnel. However, in most areas, it appears that the water table is below the tunnel.”

Brown (2009):

"… layered sandstones and shales now oriented near vertical … Because most of the principal bedrock groundwater flowpaths are likely to be contained within certain strata, or along the boundaries between sedimentary units, migration of groundwater will preferentially occur within these approximately vertical features."

Descriptive Conceptual Model

This chapter postulates a conceptual geologic setting with one single relatively permeable fractured sandstone bed enclosed in material of lower permeability, such as shale or fractured sandstone. The conceptual geologic setting is intended to explain the relationship between the Creek and Mission Tunnel. In reality, there are numerous such relatively permeable beds, but this simple model should help understand the basic situation. The conceptual model herein proposed employs permeable bed discharges to a spring in the bed of Mission Canyon and also to the Tunnel below, as shown in the conceptual representation of Figure 6.7.

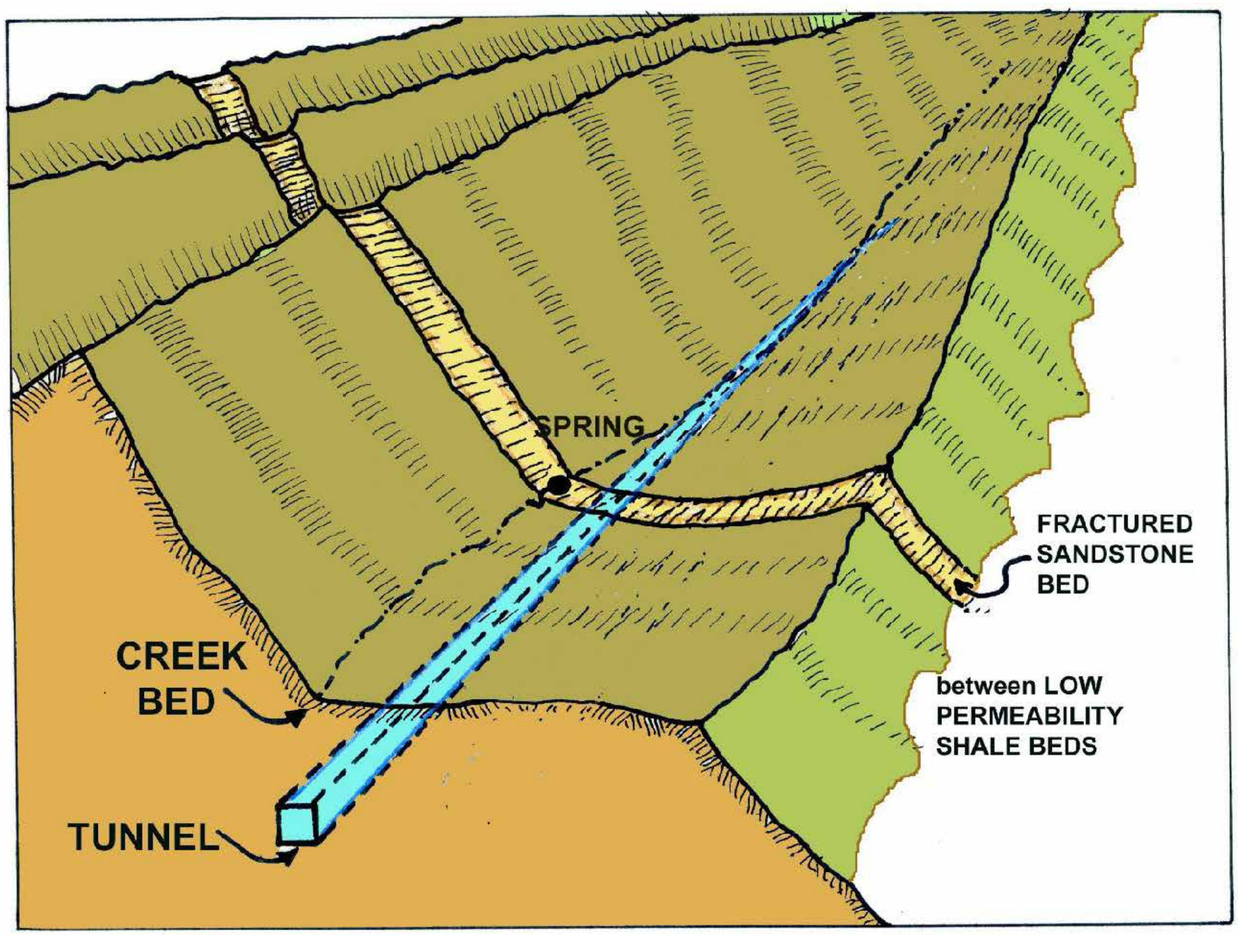

Figure 6.7. Conceptual Site Model (CSM). As shown in this graphic the simplified configuration has one relatively permeable fractured sandstone bed interstratified with less permeable shale beds, such that groundwater discharge to Mission Creek (at SPRING) and the Tunnel occurs in this bed.

Equivalent Porous Media (EPM) flow characterization

The descriptive conceptual model is used to formulate a simplified numerical model. The Equivalent Porous Media (EPM) approach to modeling fractured rock aquifers allows the use of mathematical flow models that have been developed for primary permeability aquifers, particularly "Darcy's Law" (which is an empirical formula developed from experiments, see, e.g., Fetter, 2001). It is noteworthy that the network of fractures and fissures in the bedrock where Mission Tunnel was constructed is 3-dimensional and interconnected, thus creating a bedrock aquifer saturated with groundwater. This hydrogeologic setting justifies the EPM approach and the application of Darcy's law as done below.

We postulate a vertical slab aquifer, 1 m wide (see Figure 6.8). The aquifer discharges to a 1 m^2 face in the creek bed and to a 1 m^2 face in the wall of the Tunnel. The top of the aquifer is originally at elevation h_1. The Creek discharge face is at elevation h_{2C}, and the Tunnel discharge face is at elevation h_{2T}. The schematic model as shown represents only one side of the Creek bed and Tunnel In reality the other side would be contributing as well, and the recharge area could extend beyond the first ridge on each side. This configuration is very similar to that used for modeling of proposed lateral drill holes by BCI (1990 – their Figure 4).

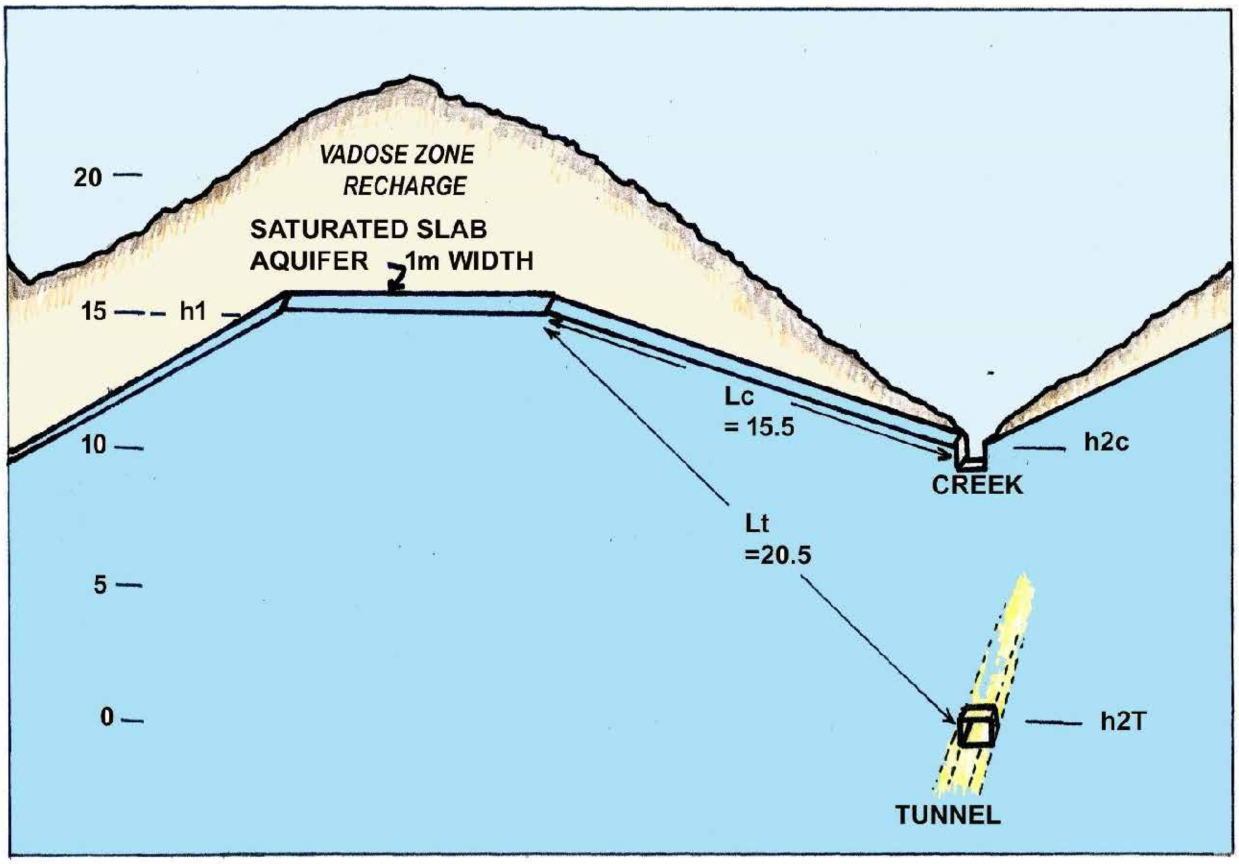

Figure 6.8. Schematic diagram of hydrogeologic parameters used to calculate nominal numerical values for the EPM version of the conceptual site model (CSM). Lengths in meters. Note that this includes only the left (in reality, that would be the west) side of the Creek bed, whereas in actuality flow to both the Creek and Tunnel would occur from both sides (see Figure 6.9).

Darcy's law is written as follows (see, e.g., Freeze and Cherry, 1979; Fetter, 2001; Sterret, 2007):

$$Q \; = \; K \; [\frac{(h_1 - h_2)}{L}] \; A \tag{6.1}$$

where Q and K denote the volumetric discharge per unit cross sectional area of aquifer and the hydraulic conductivity, respectively, the latter being a parameter related to permeability that is used for groundwater flow calculations (see, e.g., Fetter, 2001). K is a parameter that properly applies to porous media, so the EPM approach employs an approximate equivalent value. A nominal numerical value is used below; h_1 and h_2 denote the elevations shown in Figure 6.8, and L represents the flow length as shown in Figure 6.8; A represents the cross-sectional area (1 m^2 at both Creek and Tunnel). The term $\frac{(h_1 - h_2)}{L}$ is called the hydraulic gradient, often denoted by "i"

In the pre-Tunnel configuration, the discharge to the Creek (Q_C) (spring flow) would have been (see the geometry depicted in Figure 6.8):

$$Q_C = 2\,K \;\; [\frac{(h_1 - h_{2C})}{L_C}] \; A \tag{6.2}$$

where the 2 on the right-hand of equation (6.2) establishes baseflow (groundwater discharge to the spring) from both sides of the creek's canyon. In this configuration the spring discharge and the recharge due to infiltration through the vadose zone would have been part of a regime in long-term balance, including underflow to groundwater basins below the mountains, as noted above. The regime would have been subjected to interannual variations, and perhaps others at different time scales.

After the Tunnel was excavated the groundwater discharge to the Tunnel (Q_T) is, again with the factor of 2 to include both sides (see the geometry depicted in Figure 6.8):

$$Q_T = 2\,K \;\; [\frac{(h_1 - h_{2T})}{L_T}] \; A \tag{6.3}$$

Notice that an area A of 1 m^2 is assumed in equations (6.2) and (6.3). Nominal numerical values are used below, but it is apparent that the hydraulic gradient for flow to the Tunnel discharge is significantly larger than that for the Creek for the geometry depicted in Figure 6.8.

Nominal Numerical Values

The dimensions shown in the schematic diagram of Figure 6.8 are used to calculate nominal numerical values of the Creek and Tunnel discharge. These dimensions are much less than those that actually exist in the parts of the Tunnel and Creek of interest, but the results are thought to be illustrative. Flow areas and hydraulic gradients that correspond to measured values of creek and tunnel flows are presented below.

For the Creek discharge in the pre-Tunnel configuration:

$$Q_C = 2\,K \;\; [\frac{(h_1 - h_{2C})}{L_C}] \; A \tag{6.4}$$

Values used in the calculation are:

K = 1 m/day (Sterret, 2007 Figure 2.11 for friable sandstone). This choice of K is in the middle of the range of values given by Sterret (2007). Its choice is supported by studies of groundwater recharge by Todd (1978, p. 40), and Freckleton (1989, p. 16) in the Foothill Groundwater Basin of Santa Barbara.

The latter stated that "Much of the precipitation runs off as surface flow, is consumed by plants, or is lost by evaporation; however, some percolates downward through subsurface formations and flows toward the lowlands. Some of the water emerges as springs or as seepage along stream channels or as seepage along stream channels. The various pathways and rates of flow, and outflow points for this subsurface flow are unknown. However, the subsurface flow seems to be relatively direct and rapid, as evidenced by the flow regime of local springs (Todd, 1978, p. 40)". Rantz (1961; 1962) studied springs in the Santa Ynez Mountains about 10 miles west of the Mission Creek watershed, and observed short lag times between precipitation and spring discharge. Dr. Brad Newton, P.G., and Dr. Hugo A. Loaiciga, P.E., P.H., D.WRE, P.H. measured flow in the Barker Adit of Montecito (an adit is a nearly horizontal borehole with one portal only), about one mile east of Mission Tunnel, in multiple occasions. They observed that the hydrograph of captured bedrock groundwater peaked a few days (usually less than 10 days) after heavy rainfall, demonstrating the relatively high speed with which water moves through fractured sandstone in this area (Newton, 1997). Using the geometry of Figure 6.8:

h_1 = 15 m; h_{2C} = 10 m; L_C = 15.5 m; A = 1 m^2.

Therefore, the groundwater contribution to creek flow, or baseflow, prior to tunnel construction is (with K = 1 m/d):

Q_C = 2 x 1 x [(15 – 10) / 15.5] x 1 m^3 / day = 6.45 x 10^{-1} m^3 /day (6.5)

This equals 645 liters per day under the geometry of Figure 6.8 and a flow area A equal to 1 m^2.

For the Tunnel discharge:

$$Q_T = 2\,K\ [\frac{(h_1 - h_{2T})}{L_T}]\ A \qquad (6.6)$$

Values are:

K = 1 m/day (Sterret, 2007, Figure 2.11 for friable sandstone)

h_1 = 15 m; h_{2T} = 0 m; L_T = 20.5 m; A = 1 m^2.

Therefore, the groundwater discharge to the tunnel, is:

Q_T = 2 X 1 x (15 / 20.5) x 1 = 14.64 X 10^{-1} m^3 /day (6.7)

This equals 1,464 liters per day for the geometry of Figure 6.8 and per unit of flow area A = 1 m^2.

Change due to the Mission Tunnel

The discharge volume to the Mission Tunnel calculated with the simple numerical model is more than twice the Creek discharge, so the total discharge from the slab aquifer would be 645 liters per day compared with 1,464+645 = 2,109 liters per day (or slightly over three times the original Creek discharge. This would have the effect of dewatering the aquifer, so that the top of the saturated zone, previously in long-term balance with recharge through the vadose zone, would start to decline to a lower elevation.

A key aquifer parameter governing the decline of the phreatic surface (or water table) is the specific yield, which is the percentage of a volume of porous rock from which water drains due to gravity (as free water, i.e., not held in suspension by capillary forces). For fractured sandstone, Driscoll (1986) indicates a specific yield of 10%, as compared to a total porosity of 30 – 40 %. We use this value for the actual secondary permeability condition. The balance of the water would be retained by capillary forces or trapped in unconnected pores.

The flat top of the water table in the slab aquifer shown in Figure 6.8 is 10 m long, so the total volume of the top 1 m of aquifer is about 10 m^3. This means that when 10 % of the volume of the top part of the water table has drained, the water table elevation will decline accordingly, that is, by 1 m, in other words, a 1 m decline in the water table would correspond to 1 m^3 of discharge. At the combined discharge rate of 2,109 liters/day = 2.109 m^3/day a 1 m decline of the water-table elevation would take less than one day. This value is illustrative only because the dimension of the saturated zone is a nominal value; yet, it is indicative of the mechanism of dewatering.

The most significant impact of this water table decline would be a lower hydraulic head difference between the water table and the Creek. The 1 m decline in the water table would mean a 20% decline in $h_1 - h_{2C}$ (see Figure 6.8), and thus the 20% decline in the hydraulic gradient (the small change in L_C is ignored) would result in a Creek discharge of approximately 516 L/day. The reduced gradient to the Tunnel would lower the groundwater input to the Tunnel, but from a qualitative point of view the main impact of Tunnel installation is lowered Creek (spring) discharge Q_C. The resulting values are shown in Table 6.3.

Table 6.3. Nominal Numerical Value Results for Simplified Equivalent Porous Media (EPM) Model. Because the parameters used are only nominal, these results should not be considered to be actual, but indicative of how the installation of the Tunnel could reduce the discharge to the Creek.

All Values in L/day			
Discharge to Creek		Discharge to Tunnel	
Original	After drawdown. Approximate	As first installed	After drawdown, approximate
645		1464	
	516		1464

Goodman et al. (1965) presented an analytical solution for flow into a tunnel that used the theory of image wells. The solution is based on the assumption that the phreatic surface (or "water table") does not change when groundwater is captured by the tunnel. Meiri (1985) presented a numerical solution to the problem of groundwater captured by a tunnel. The solution imposes constant-head boundary conditions at known distance from the tunnel. The Goodman et al. (1965) and Meiri et al. (1985) solutions propose field conditions that are not met in the Mission Tunnel situation because the position of the phreatic surface and the boundary conditions cannot be specified with certainty.

The principles presented in this section are applied in the next section, which employs measured bedrock groundwater and stream data to evaluate the impact of the Mission Tunnel on Mission Creek and Rattlesnake Creek flow.

6.5 Estimation of Mission Tunnel effect on Mission and Rattlesnake Creeks' flows

Pre-tunnel Groundwater Conditions

The discussion that follows relies on the model depicted in Figure 6.9. It is seen in Figure 6.9 that without the tunnel (pre-1912 condition) Mission Creek received natural groundwater from both sides of its canyon (and so did Rattlesnake Creek across the topographic divide). With the tunnel (post 1912) Mission Creek receives groundwater from the western area of its canyon, and reduced groundwater flow for the eastern area of its canyon because of flow capture by the tunnel. Likewise, Rattlesnake Creek's flow is also impacted by Mission Tunnel as shown in Figure 6.9(b). It must be kept in mind that the Mission Tunnel's capture of bedrock groundwater is 3D (three-dimensional), with possible contribution of groundwater originating from below the tunnel. Therefore, the 2D model of bedrock-groundwater capture herein presented most likely underestimates the amount of groundwater captured by the tunnel. The average groundwater inflow to the tunnel (equal to Q_T = 1,215 AFY ≅ 1,500,000 m^3/year ≅ 4,100 m^3/day, see Figure 6.4), the length of tunnel within the upper Mission Creek watershed (10,958 feet = 3,340 m), an area of groundwater flow into the tunnel equal to A_T = 2.5 m x 3,340 m = 8,350 m^2 considering the dimensions of the tunnel's borehole or shaft, and a hydraulic conductivity K = 1 m/day are applied to calculate the hydraulic gradient that drives groundwater into Mission Tunnel. Solving from Darcy's law for the hydraulic gradient I_T:

$$I_T = Q_T / (K \cdot A_T) = 4{,}100/(1 \times 8{,}350) \cong 0.50 \quad (6.8)$$

This hydraulic gradient provides an approximation to the pre-tunnel hydraulic gradient that drove groundwater to Mission Creek (see Figure 6.9). The pre-tunnel hydraulic gradient was probably smaller than 0.50 because the absence of Mission Tunnel would be to reduce the hydraulic gradient as depicted in Figure 6.9. Guided by this reasoning a hydraulic gradient equal to I_{C0} = 0.30 is used instead of 0.50. The reasonableness of this assumption is evaluated below. The pre-tunnel groundwater contribution to Mission Creek (Q_{C0}) in the study area is estimated as follows:

$$Q_{C0} = 2\,K \cdot I_{C0} \cdot A_C \quad (6.9)$$

in which A_C denotes the area of flow into the creek, which is approximately 3,000 m long in the area overlying the tunnel in the upper Mission Creek watershed (see Figure 6.1). Therefore, A_C = 3,000 x 1 = 3,000 m^2. Applying Darcy's law:

$$Q_{C0} = 2 \times 1 \times 0.30 \times 3{,}000 = 1{,}800 \text{ m}^3/\text{day} \quad (6.10)$$

A similar baseflow contribution was made to Rattlesnake as displayed in Figure 6.9(a). Based on these calculations the average pre-tunnel contribution of groundwater flow to upper Mission Creek flow was probably about 1,800 m^3/day (≅ 530 AFY), which means that the average pre-tunnel contribution to Mission Creek and Rattlesnake Creek in the tunnel-impacted area is estimated to be 2 x 530 = 1,060 AFY. It is noteworthy that the average annual flow within the upper Mission Creek watershed overlying Mission Tunnel, which has an area of 2.3 mi^2 (see Figure 6.1), equals 585 AFY. The latter value was obtained by adjusting the average annual measured Mission Creek flow at the USGS Rocky Nook Park station (= 1,680 AFY) by the ratio of the drainage area (2.3 mi^2) to the drainage area upstream of the USGS station (6.6 mi^2), in other words 585 AFY = 1,680 AFY x 2.3/6.6. Twice this value is used to obtain the post-tunnel flow in the areas of Mission Creek and Rattlesnake Creek affected by the Tunnel (see Figure 6.9) to obtain 2 x 585 = 1,170 AFY. The creek flow in the pre-Tunnel era was most likely larger than 1,170 AFY because the USGS station measures creek flow in the post-tunnel era (i.e., flow measurements since 1983), when the tunnel affected creek flow. The implication from these calculations is that the groundwater contribution to Mission Creek and Rattlesnake combined flow in the area impacted by the tunnel is estimated at 1,060 AFY, or, about 90% (= (1,060/1,170) x 100) of the post-tunnel creek flow. This percentage would be smaller with respect to the pre-tunnel creek flow because the creek flow was larger in the pre-tunnel area than that measured at the USGS station at Rocky Nook Park. That is because the station measures creek flow whose flow has been reduced by the capture of groundwater by the tunnel. The account by historian Walker Tompkins cited above concerning the ever-flowing nature of Mission Creek prior to tunnel operation suggests that groundwater was a substantial contributor to creek flow in the absence of rainfall.

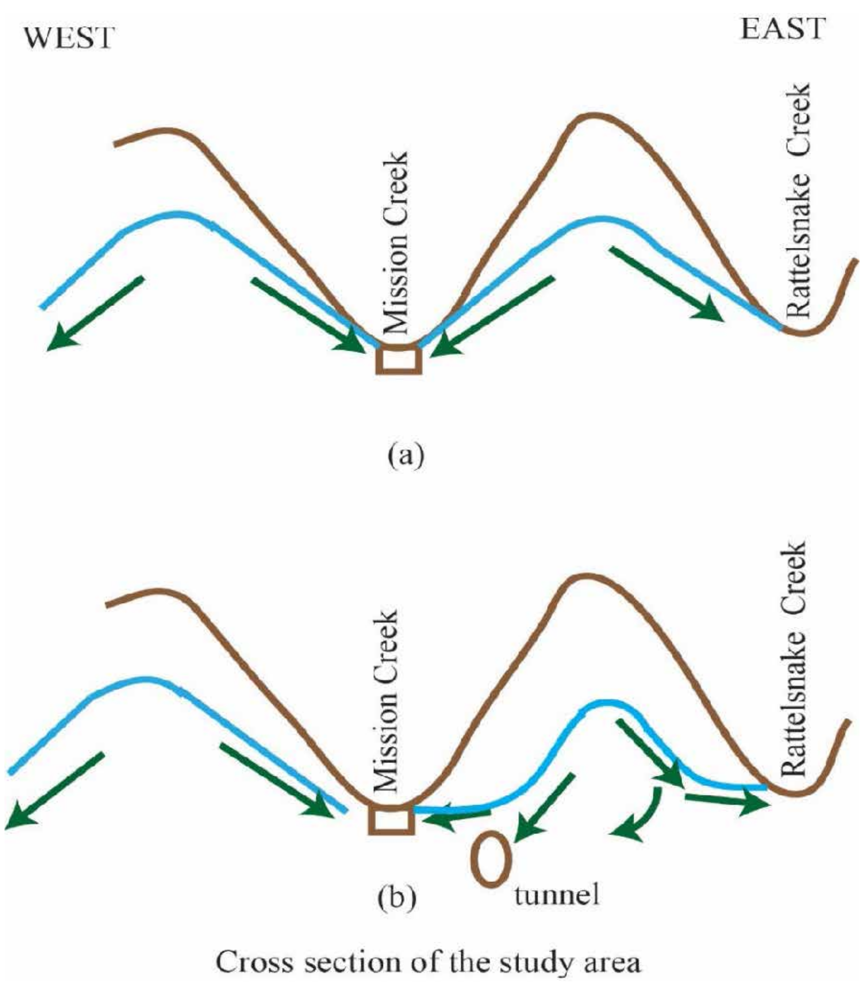

Figure 6.9. Conceptual representation of groundwater discharge to Mission Creek and Rattlesnake Creek: (a) without the tunnel (a), (b) and with the tunnel in operation. Not drawn to scale.

A similar baseflow contribution was made to Rattlesnake as displayed in Figure 6.9(a). Based on these calculations the average pre-tunnel contribution of groundwater flow to upper Mission Creek flow was probably about 1,800 m^3/day (≅ 530 AFY), which means that the average pre-tunnel contribution to Mission Creek and Rattlesnake Creek in the tunnel-impacted area is estimated to be 2 x 530 = 1,060 AFY. It is noteworthy that the average annual flow within the upper Mission Creek watershed overlying Mission Tunnel, which has an area of 2.3 mi^2 (see Figure 6.1), equals 585 AFY. The latter value was obtained by adjusting the average annual measured Mission Creek flow at the USGS Rocky Nook Park station (= 1,680 AFY) by the ratio of the drainage area (2.3 mi^2) to the drainage area upstream of the USGS station (6.6 mi^2), in other words 585 AFY = 1,680 AFY x 2.3/6.6. Twice this value is used to obtain the post-tunnel flow in the areas of Mission Creek and Rattlesnake Creek affected by the Tunnel (see Figure 6.9) to obtain 2 x 585 = 1,170 AFY. The creek flow in the pre-Tunnel era was most likely larger than 1,170 AFY because the USGS station measures creek flow in the post-tunnel era (i.e., flow measurements since 1983), when the tunnel affected creek flow. The implication from these calculations is that the groundwater contribution to Mission Creek and Rattlesnake combined flow in the area impacted by the tunnel is estimated at 1,060 AFY, or, about 90% (= (1,060/1,170) x 100) of the post-tunnel creek flow. This percentage would be smaller with respect to the pre-tunnel creek flow because the creek flow was larger in the pre-tunnel area than that measured at the USGS station at Rocky Nook Park. That is because the station measures creek flow whose flow has been reduced by the capture of groundwater by the tunnel. The account by historian Walker Tompkins cited above concerning the ever-flowing nature of Mission Creek prior to tunnel operation suggests that groundwater was a substantial contributor to creek flow in the absence of rainfall.

Effect of Mission Tunnel on creek flows

The question of how much baseflow to Mission Creek and Rattlesnake Creek is captured by the Mission Tunnel is addressed in this section. Figure 6.9(b) depicts the effects of the tunnel on Mission Creek flow. The tunnel captures wholly or in part bedrock groundwater in the eastern area of Mission Creek's canyon, and also in the western area of Rattlesnake Canyon. If there is total capture of flow this means that the groundwater contribution to upper Mission Creek is reduced by one half of that calculated in equation (6.10):

$$Q_{CT} = 1 \times 0.30 \times 3{,}000 = 900 \text{ m}^3/\text{day} \qquad (6.11)$$

which amounts to 265 AFY. A similar reduction is likely to have occurred at Rattlesnake Creek, as depicted in Figure 6.9(b) which means a reduction of baseflow at the confluence of Mission Creek and Rattlesnake Creek of at least 2 x 265 = 530 AFY by the operation of Mission Tunnel under the conditions underlying equation (6.11). This is likely an underestimate of baseflow reduction because (i) the tunnel receives groundwater in a three-dimensional (3-D) flow domain (possibly including upwelling of deep groundwater from below the Mission Tunnel) rather than in a 2-D flow domain as implied by the schematic shown in Figure 6.9, and (ii) the Tunnel may capture groundwater flow from both sides of the Mission Creek and Rattlesnake Creek canyons.

The findings by Rantz (1961) concerning the drying of a spring (named 110b) in the vicinity of Tecolote Tunnel are pertinent to our study of Mission Tunnel. Tecolote Tunnel brings water under the Santa Ynez Mountains from Cachuma Lake to the Corona del Mar Treatment in western Goleta, about 10 miles west of Mission Tunnel. The large volume of bedrock groundwater discharging into the tunnel indicates that a large bedrock aquifer is tapped. The chemical quality of the bedrock groundwater suggests that it originates from deep infiltration of precipitation (i.e., it is of meteoric origin). Tecolote Tunnel was constructed between March 1950 and January 1956. Spring 110b is located 1.8 miles east of Tecolote Tunnel with water that is chemically similar to bedrock groundwater that seeps into the tunnel. Water temperatures at spring 110b ranged from 105°F to 112°F, equaling the bedrock water temperatures observed in the tunnel. Although the elevation of spring 110b is 400 feet above the tunnel, tunnel groundwater inflows were under a static (or equilibrium) hydraulic head of about 500 feet, thus making it possible that both spring and tunnel are supplied from the same aquifer. The flow of spring 110b was first measured in July 1954 and a discharge of 29 gallons per minute was observed. The discharge receded rapidly, and by March 1955 the spring was dry. Rantz (1961) concluded that "All evidence indicates that the failure of spring 110b was a result of seepage into Tecolote Tunnel". The hydrologic processes described by Rantz (1961) closely parallel those that govern the interaction between Mission Tunnel and upper Mission and Rattlesnake creeks. Both tunnels are located in the same type of geologic formations, in regions of similar rainfall, vegetation, and topography.

Monthly reduction of creek flow by Mission Tunnel

The Water Resources Division of the City of Santa Barbara provided monthly discharge data for Mission Tunnel for water years (Oct 1 – Sep 30) 1998-2021. These data permit calculating the approximate monthly reduction of creek flow by Mission Tunnel. Figure 6.10 depicts the average monthly discharge for Mission Tunnel.

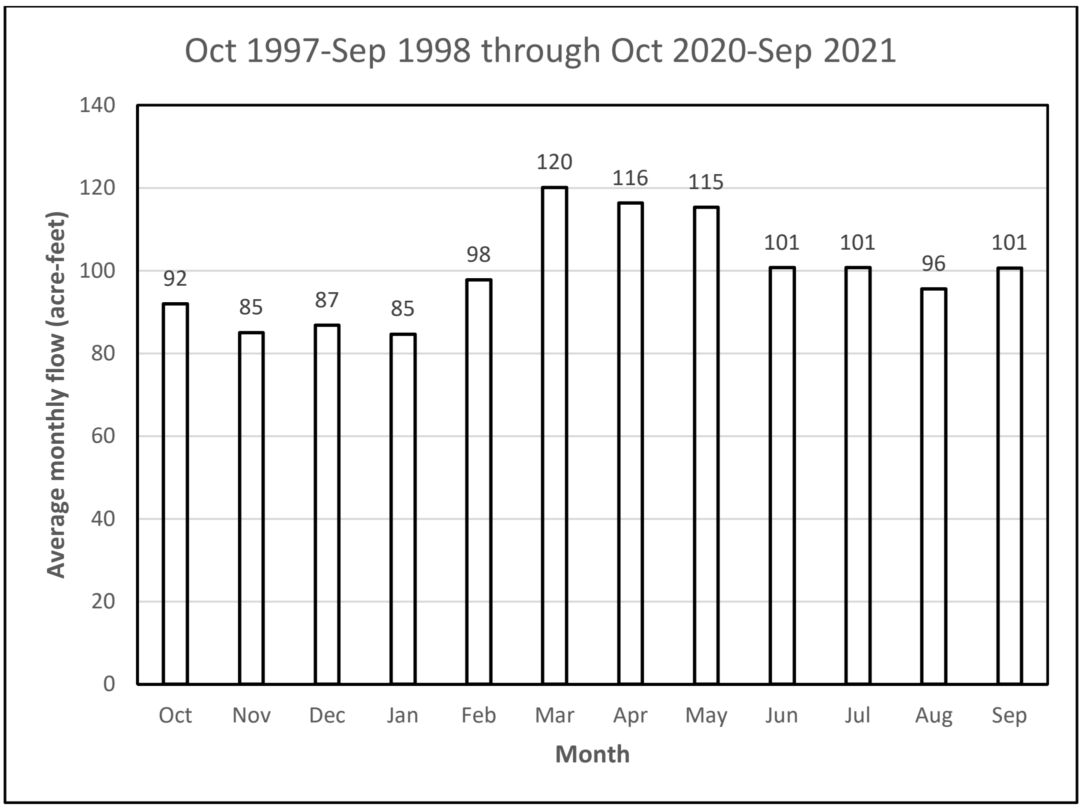

Figure 6.10. Average monthly discharge by Mission Tunnel (1998-2021). Source: calculated from data provided by the Water Resources Division of the City of Santa Barbara.

The next step in calculating the monthly depletion of creek flow by Mission Tunnel was to convert the data displayed in Figure 6.10 to data representing the fraction of the Tunnel's annual discharge corresponding to every month. Figure 6.11 displays the monthly fractional amounts.

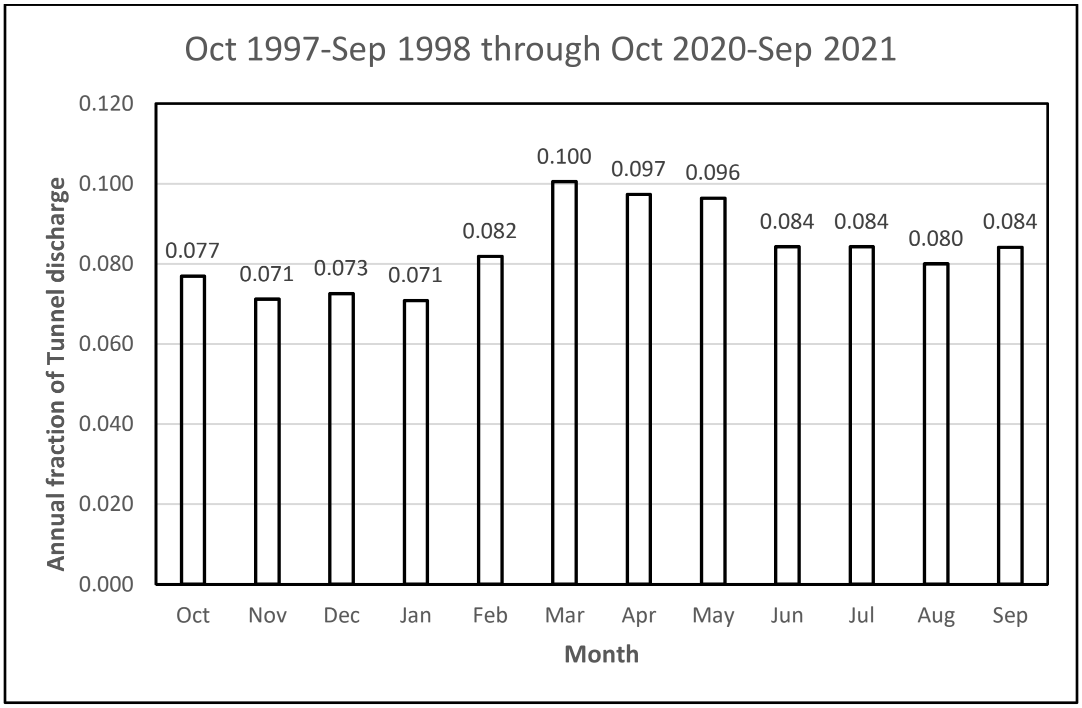

Figure 6.11. Annual fraction of Tunnel discharge corresponding to every month.

It is assumed dynamic equilibrium between tunnel discharge and baseflow reduction. In this instance the fraction of the annual tunnel discharge corresponding to any given month equals the fraction of the annual creek-flow reduction caused by the tunnel in the same month. The creek-flow reduction was estimated to be about 530 AFY. The fractions plotted in Figure 6.11 were applied to the 530 AFY rate of creek-flow depletion to calculate the monthly effects of Mission Tunnel on creek-flow depletion. Figure 6.12 depicts the estimated average monthly creek-flow reduction caused by Mission Tunnel.

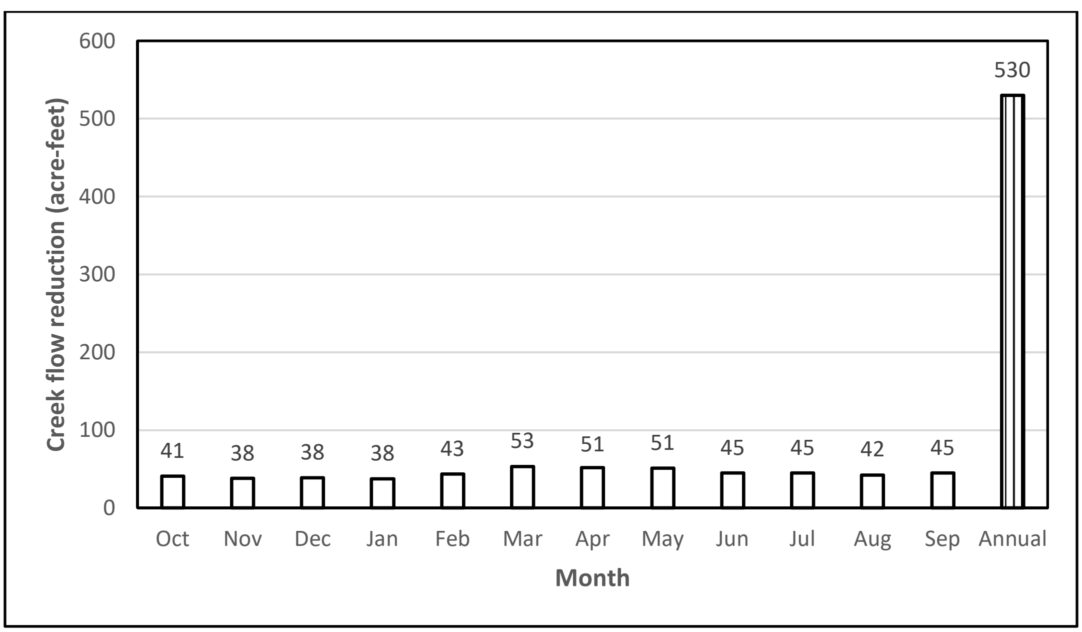

Figure 6.12. Average monthly creek-flow reduction by Mission Tunnel.

The monthly reductions graphed in Figure 6.12 constitute recommended targets for creek-flow restoration. Creek flows should be restored in the study area following a monthly schedule as shown in Figure 6.12. The volume of flow restoration required in the Upper Mission Creek watershed (area = 2.85 squared miles) and the Rattlesnake Creek watershed (area = 3.15 squared miles) is proportional to their fractional area with respect to the area of the total upstream watershed (=2.85 + 3.85 = 6.0 squared miles). Therefore, for instance, in the month of May the volume of flow restoration in the Upper Mission Creek and the Rattlesnake Creek watersheds should be respectively 51 x 2.85/6.0= 24.23 acre·feet and 51 x 3.15/6.0 =26.77 acre·feet.

6.6 Summary

Mission Tunnel was built to convey water impounded at Gibraltar Reservoir on the Santa Ynez River to the City of Santa Barbara. The Tunnel crosses from north to south beneath the Santa Ynez Mountains, through two different tectonic provinces, separated by the Santa Ynez fault. The Tunnel is approximately 19,536 feet long (5,955 meters). The southern segment of the Mission Tunnel (approximately 10,958 ft long) underlies the upper parts of the Mission Creek and Rattlesnake Creek watersheds. Previous studies have indicated that the area of recharge for inflow into Mission Tunnel is larger than the overlying Mission Creek watershed, that precipitation available for surface recharge is significantly heavier at high elevation, and that a major part of the Tunnel inflow occurs where the Tunnel crosses the unnamed Kuss/Kush formation and the Juncal formation (mainly shale - map symbol Tj). Groundwater seeps into the Tunnel provide an average annual groundwater supply of 1,215 acre-ft/yr (AFY) to the City of Santa Barbara, additional to (i) that transported from Gibraltar Lake via Mission Tunnel; (ii) Santa Ynez River water conveyed from Cachuma Lake via the Tecolote Tunnel, (iii) groundwater from the alluvial aquifers (Martin, 1984), (iv) seawater desalination, (v) State Water Project water delivered via Cachuma Lake and Tecolote Tunnel, (vi) use of treated municipal sewage (water reuse), (vii) water-demand reduction by conservation, and (viii) block-rate pricing of municipal water (Water Resources Division, 2022).

A central question addressed by this study is the extent to which discharge of groundwater to the Tunnel may have affected the flow regime and the riparian habitat of the upper watershed of Mission Creek and of the Rattlesnake Creek watershed.

The analysis and calculations presented above indicate that the reduction of stream flow at the confluence of Mission Creek and Rattlesnake Creek caused by the operation of the Mission Tunnel is about 530 AFY, and it is most likely larger than this volume. This estimate provides a reasonable reference for the purpose of establishing restoration measures. It is useful for comparison purposes to report that the total water delivery from Gibraltar Reservoir in water year 2021 was 1,235 acre·feet. The projected long-term average annual water supply from Gibraltar Reservoir is 4,330 acre·feet under Pass-Through Operations (Stetson Engineers Inc., 2013, Water Resources Division, 2022). The Pass-Through Operations established by the 1989 Upper Santa Ynez River Operations Agreement (USYROA) means that the City of Santa Barbara may “pass through” Santa Ynez River water from Gibraltar Reservoir to Cachuma Lake for delivery through South Coast by the Tecolote Tunnel. The City of Santa Barbara receives credit for water diverted from Gibraltar Reservoir to Cachuma Lake up to an amount calculated according to a base-operations scenario defined in the USYROA. The Pass-Through Operations raise the possibility of decommissioning the Mission Tunnel to restore the hydrologic system in the Santa Ynez Mountains affected by its operation. The Santa Ynez River water that would be otherwise conveyed through the Mission Tunnel would be allowed to flow to the Cachuma Lake, and the city would divert the Gibraltar Reservoir "pass-through" water from Cachuma lake, in addition to its established annual allotment from Cachuma Lake. Furthermore, decommissioning the Mission Tunnel would end the role of Gibraltar Reservoir as a water storage and diversion structure. Gibraltar Reservoir is a relic of a century-old inter-basin water transfer scheme that nears obsolescence by reservoir sedimentation. Tunnel decommissioning means sealing off the tunnel's north and south portals (that is, plugging each terminus to avoid seepage of bedrock groundwater towards the exterior) and discontinue maintenance of the tunnel so that it will cave in over time. A volume of bedrock groundwater would fill the tunnel, and that volume would be equal to the cross-sectional area of the tunnel (about 30 feet square) times the length of the tunnel (19.536 feet) for a volume equal to 30 x 19536 = 586 000 cubic feet = or about 13.5 acre-feet. Overtime, the cross-sectional area of the tunnel would fill with rock debris and the amount of stagnant water in the tunnel will diminish. The decommissioned tunnel would cease to act as a groundwater sink.

Chapter 7 makes recommendations concerning the feasibility of decommissioning the Mission Tunnel and discontinuing the operation of Gibraltar Reservoir. Chapter 7 also evaluates the option of conveying Gibraltar Reservoir's water diversions and Devils Canyon Creek flow to the City of Santa Barbara via a pipe to be constructed within the Mission Tunnel.

It is noteworthy that the City of Santa Barbara has released water from Mission Tunnel into Mission Creek to induce groundwater recharge by stream seepage, rather than to enhance habitat for fish and other aquatic species. Data provided by the City's Water Resources to these authors show that Mission Tunnel's releases to Mission Creek in the eleven-year period 2000-2010 ranged from three acre-feet in 2005 to 141 in 2009, with an eleven-year annual average value equal to 67 acre-feet. This report estimates that the reduction of baseflow to Mission Creek and Rattlesnake Creek caused by the operation of the Mission Tunnel (i.e., 530 AFY) is much more than past annual water releases from the Tunnel into Mission Creek.

This work recommends a schedule of water releases to Mission Creek from the Mission Tunnel at its south portal as listed in Table 6.4.

Table 6.4. Monthly creek-flow restoration (acre-feet).

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Flow	38	43	53	51	51	45	45	42	45	41	38	38	530

6.7 References

BCI Geonetics. (1990). Investigation of the Feasibility of Increasing Groundwater Inflow to the Mission Tunnel, Santa Barbara, California. For Santa Barbara Water District

Brown. N. (2009). Framework for Evaluating the Relationship of Mission Tunnel Infiltration and Mission Creek Streamflow. For City of Santa Barbara.

Crippen, J.R. (1965). Natural water loss and recoverable water from mountain basins in southern California. U.S. Geological Survey Professional Paper 417-E, United States Government Printing Office, Washington, D.C.

Dibblee Foundation. #DF-05. 1986. Geologic Map of the Little Pine Mountain Quadrangle. #DF-06.1986. Geologic map of the Santa Barbara Quadrangle.

Dibblee, T.W. Jr. (1966). Geology of the Central Santa Ynez Mountains, Santa Barbara County, California. California Division of Mines and Geology. Bulletin 186.

Driscoll, F.G. (1986). Groundwater and Wells. Johnson Screens, St. Paul, Minnesota.

Eckman, J. (1967). The Search for Water in The South Coastal Area of Santa Barbara County. Noticias, 13(3) Summer: 1-44.

Fetter, C.W. (2001). Applied Hydrogeology, 4^{th} ed., Prentice Hall, NJ.

Freckleton, J. (1989). Geohydrology of the Foothill Ground-water Basin Near Santa Barbara, California. USGS Water-Resources Investigation Report 89-4017.

Freeze, R.A., Cherry, J.A. (1979). Groundwater. Prentice Hall, NJ.

Goodman, R.F., Moye, D.G., van Schaikwyk, A., Javandel, I. (1965). Groundwater inflow during tunnel driving. Bulletin of the International Association of Engineering Geologists, 2(1), 39-56.

Martin, P. (1984). Groundwater Monitoring at Santa Barbara, California: Phase-2 Effects of Pumping on Water Levels and on Water Quality in the Santa Barbara Ground-Water Basin. U.S. Geological Survey Water-Supply Paper 2197, U.S. Government Printing Office, Washington, D.C.

Meiri, D. (1985). Unconfined groundwater flow calculation into a tunnel. Journal of Hydrology, 82, 69-75.

Miller and Rapp. (1968). Reconnaissance of the groundwater resources of the Ellwood-Gaviota area, Santa Barbara, County, California. U.S. Geological Survey Open File Report 68-182. Menlo Park, California.

Muir, K.S. (1968). Ground -Water reconnaissance of the Santa Barbara-Montecito area, Santa Barbara County, California. U.S. Geological Survey Water Supply Paper 1859-A. U.S. Government Printing Office, Washington, D.C.

Newton, B.E. (1997). Safe yield of a bedrock aquifer in the Santa Ynez Mountains. University of California at Santa Barbara. Master Thesis. June 1997.

Nicholson, C., Sorlien, C. C., Wysession, M., Crowell, J., & Luyendyk, B. (1994). Microplate capture, rotation of the western Transverse Ranges, and initiation of the San Andreas transform as a low-angle fault system. *Geology*, 22, 491-495.

Rademacher, L., J. Clark, J. Boles. (1993). Groundwater residence times and flow paths in fractured rock determined using environmental tracers in the Mission Tunnel, Santa Barbara County, California, USA. Environmental Geology. 43:557-567.

Rantz, S.E. (1961). Effect of tunnel construction on flow of springs and small stream in the Tecolote Tunnel area of Santa Barbara County, California. United States Geologic Survey Professional Paper 424-C, C-360-C-361.

Rantz, S.E. (1962). Flow of springs and small streams in the Tecolote Tunnel area of Santa Barbara County, California. U.S. Geological Survey Water Supply Paper 1691-R. U.S. Government Printing Office. Washington, D.C.

Santa Barbara Board of Realtors, (1980). Tompkins, Walker A. Mission Canyon History – Santa Barbara. https://www.davidcharlesallen.com/mission-canyon-history-santa-barbara

Sterret, R.J. (2007). Groundwater and Wells, 3rd ed., Johnson Screens, New Brighton, MN.

Stetson Engineers Inc. (2013). Hydrologic Analysis of the Pass-Through Operations at Gibraltar Reservoir. Prepared for the City of Santa Barbara. July 2013.

Todd, D.K. (1978). Groundwater basin data: Status and needs, a report to the City of Santa Barbara, California. David Keith Todd Consulting Engineers, Berkeley, California

USGS (United States Geologic Survey). (2021). Trek Through Time - Cenozoic. https://www.usgs.gov/science-support/osqi/youth-education-science/cenozoic

Water Resources Division. (2022). Water Supply Management Report Water Year 2021-2022. Public Works Department, City of Santa Barbara.

CHAPTER 7. RECOMMENDATIONS TO RESTORE THE STUDY AREA

7.1. Introduction

Chapters 2, 3, 4, 5, and 6 present a study of the hydrogeologic, climatic, geomorphologic, biologic, and geographic conditions in the Upper Mission Creek and Rattlesnake Creek watersheds (the study area) in compliance with the acknowledgement of responsibilities to perform a supplemental environmental project (SEP) agreed upon between the County of Santa of Barbara's Office of the District Attorney and the Santa Barbara Urban Creeks Council (UCC). The study provides summaries of existing information plus new analyses and identifies means and methods for enhancing aquatic habitat in the upper non-urban watershed of Mission Creek (the study area) and for restoring the natural hydrologic and biologic conditions in the study area. This chapter makes recommendations to restore the natural hydrologic, geomorphologic, and ecologic processes and functions that have been adversely modified by human intervention in the study area. The recommendations address the key adverse impacts that have been identified by this study. Specifically, the recommendations target: (1) the Mission Tunnel inflow, which reduces flows in both creeks, (2) infrastructure (i.e., dams, debris basins, bridges) that has adversely altered the natural streamflow and sediment transport regimes in the study area, and impedes migration of fish and other aquatic species, (3) roads and trails, which increase fine sediments deposition in the stream channel adversely affecting spawning and invertebrate production, (4) residential landscaping, which introduced no-native plant species into the riparian corridor, and (5) miscellaneous obstructions in the streams and their riparian corridors, which disrupt instream movement of fish and other aquatic species and the movement of terrestrial species, and (6) gaps in knowledge about the geomorphology and biology in the study area.

7.2. The Mission Tunnel and the Gibraltar Reservoir river-water diversions

The reduction of the bedrock aquifer in the study area by the Mission Tunnel and the associated decline in creek flow was documented in Chapters 2 and 6. The Mission Tunnel has adversely altered the flow regime, and reduced baseflows which sustain fish and other species during the dry season, and especially during droughts. The Tunnel's main impact has been the modification of aquatic habitat in Mission Creek and Rattlesnake Creek by reducing streamflow and altering the sediment regime in Mission Creek and Rattlesnake Creek. Four possible remedies were considered in this study with respect to the Mission Tunnel. They are:

(1). ***Releasing water from the Tunnel at its south portal into Mission Creek***. The City of Santa Barbara has released tunnel water to Mission Creek in past years. Those releases were less than the 530 AFY (acre feet/year) that were calculated as the tunnel-induced reduction in creek flow in Chapter 6. This remedy does not effectively address impacts to streamflows (particularly base flows) in the upper reaches of Mission Creek upstream of the south portal and in Rattlesnake Creek. Also, water releases at the south portal do not remedy the drying of springs and private wells caused by the operation of the Mission Tunnel.

(2). ***Lining of the Tunnel along its entire length to prevent seepage into it from the surrounding rocks***. This would be a recurrent activity whose cost might well exceed the value of the water gained from seepage into the tunnel. Moreover, the effectiveness of fully containing seepage into the tunnel is questionable, given the weathering of the lining over time and the fracturing that the Tunnel is subjected to by rock movement and tectonism.

(3). ***Construct a pipe within the Mission Tunnel that would convey Gibraltar Reservoir's water diversions and Devils Canyon Creek flow to the City of Santa Barbara***. This option would require maintaining the integrity of Mission Tunnel to ensure the long-term functioning of a conveyance pipe within it. Furthermore, the tunnel would have to be sealed at its south and north portals to preclude the leaking of groundwater to the tunnel's exterior. This option may be of temporary usefulness, however, because its effectiveness would depend on how much longer Gibraltar Reservoir would have sufficient storage capacity to allow the diversion of Santa Ynez River streamflow as is currently practiced.

(4). ***Decommissioning the Mission Tunnel***. This remedy is likely to improve aquatic habitats in the study area, and would require the City of Santa Barbara to divert its share of the Santa Ynez River water and Devils Canyon Creek water to Cachuma Lake (accounting for conveyance losses) where these waters would be conveyed to the South Coast through the Tecolote Tunnel. The institutional framework for implementing the recommended diversion of water from Gibraltar Reservoir to Cachuma Lake and crediting that diversion to the city already exists and is operational through the 1989 Upper Santa Ynez River Operations Agreement (USYROA), commonly referred to as the "Pass-Through Agreement". The USYROA established that the City of Santa Barbara may "pass through" Santa Ynez River water from Gibraltar Reservoir to Cachuma Lake for delivery to the South Coast through the Tecolote Tunnel. The city receives credit for water diverted from Gibraltar Reservoir to Cachuma Lake up to an amount calculated according to a base-operations scenario defined in the USYROA. The USYROA would have to be modified to accommodate the decommissioning of the Mission Tunnel. Tunnel decommissioning means sealing the tunnel's north and south portals (that is, plugging each terminus to avoid seepage of bedrock groundwater towards the exterior) and discontinue maintenance of the tunnel so that it will cave in over time[1]. A volume of bedrock groundwater would fill the tunnel, and that volume would be equal to the cross-sectional area of the tunnel (about 30 feet square) times the length of the tunnel (19.536 feet) for a volume equal to 30 x 19536 = 586 000 cubic feet = or about 13.5 acre-feet. Overtime, the cross-sectional area of the tunnel would fill with rock debris and the amount of stagnant water in the tunnel will diminish. The decommissioned tunnel would cease to act as a groundwater sink.

The decommissioning of the Mission Tunnel as a conduit for water stored in Gibraltar Reservoir could be the first step in the removal of Gibraltar Dam. The dam and reservoir are a relic of a century-old, inter-basin water transfer scheme that is becoming obsolete by reservoir sedimentation. Gibraltar Reservoir was completed in 1920 with a storage capacity of 14,500 acre·feet. Its storage capacity has been reduced to 4,693 acre·feet by early 2022 due to sedimentation (Water Resources Division, 2022). The amount of water diverted from Gibraltar Reservoir to the City of Santa Barbara in water year 2021 via the Mission Tunnel was 1,235 acre·feet (Water Resources Division, 2022) down from the average 3,600 AFY in the 15-year period 1996-2010 (Stetson Engineers Inc., 2013; U.S. Bureau of Reclamation, 2016). It was an unexpected realization by this study's authors that remedying the adverse impacts of the Mission Tunnel might involve discontinuing the operation of Gibraltar Reservoir, in which case the demolition of Gibraltar dam would be a possible consequential implication with benefits arising from restoring the Santa Inez River from the reservoir site to the Cachuma Lake. The demolition of the Gibraltar dam would not be the first of its kind given that many dams in the United States are approaching the end of their service life, and are being planned for removal as part of river-restoration efforts (The Heinz Center, 2002, The Aspen Institute, 2002). The removal of Matilija Dam in Ventura County as part of the Matilija Dam Ecosystem Restoration Project is a regional example of such ongoing river and watershed restoration activities. Dam removal could be performed in phases over a period of time following a careful environmental assessment of downstream impacts and benefits. Some view Gibraltar Reservoir as a sediment trap that reduces the sedimentation of Cachuma Lake. The effect of removing Gibraltar Reservoir on downstream sediment deposition deserves careful analysis.

Decommissioning the Mission Tunnel would reduce the current water supply to the City of Santa Barbara by an average annual amount of 1,215 AFY. However, it would also save the costs of operating and maintaining the Tunnel, and it would contribute to the restoration of the upper Mission Creek and the Rattlesnake Creek watersheds. Foregoing the1,215 AFY of water could be compensated by a

[1] The City of Santa Barbara has repaired the Mission Tunnel in the past due to damage caused by wall and roof collapse.

combination of managed municipal use and increased reliance on more reliable, long-term, local water sources such as seawater desalination and sewage recycling. The data portrayed in Figure 7.1 show the 12-month moving water production in the city from 1985 through 2021 (source: Water Resources Division, 2022). Figure 7.1 indicates that water use in the city was 17,400 acre-feet in 1985, and reached a low of 8,600 acre-feet in 2018, and was 11,908 acre-feet in the 2021 water year. The decline in water use in the city is the result of a number of factors:

(i) transitioning from a flat water-pricing schedule to an increasing block- pricing scheme that discourages wasteful use (Loaiciga and Renehan, 2000),

(ii) water education that encourages reduced domestic landscape irrigation, and

(iii) adoption of water-use reducing plumbing fixtures by water customers.

The water-use reduction in the City of Santa Barbara between 1985 (17,400 acre feet) and 2018 (i.e., 8600 acre feet) amounts to 8,800 acre-feet. The city would be able to reduce its water use, which was 11,908 acre-feet in water year 2021, by the 1,215 AFY reduction that would be caused by shutting off the Mission Tunnel. Significantly, seawater desalination is planned to increase in the city from 3,150 AFY to 5,000 AFY (Water Resources Division, 2022), which will provide an additional, long-term, reliable source of water to the City of Santa Barbara (City of Santa Barbara 2011, 2021).

Figure 7.1. 12-month moving water production in the City of Santa Barbara, 1985-2021. Source: Water Resources Division (2022).

The decline of water use in the City of Santa Barbara has occurred while its population has leveled off (see Figure 7.2), and the measures that provoked the reduction in water use were an adaptation to recurring droughts.

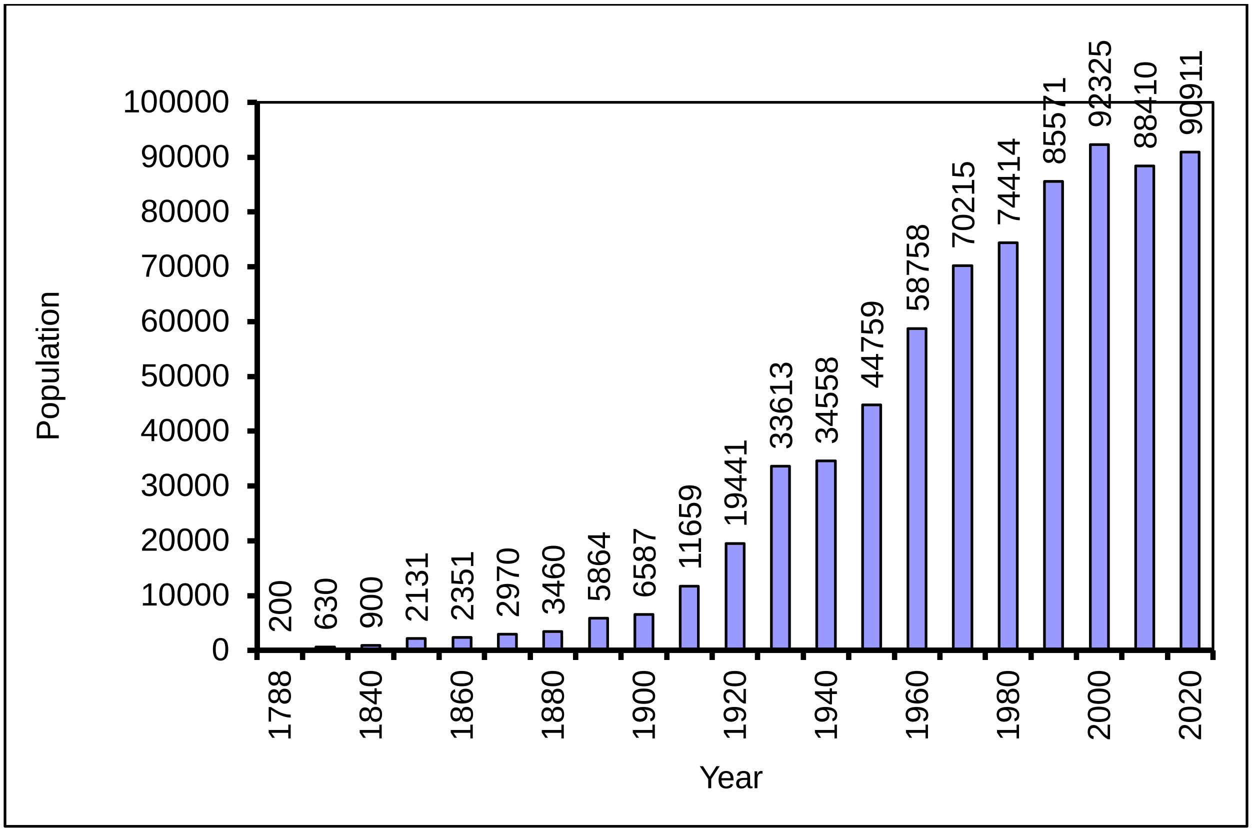

Figure 7.2. Population of the City of Santa Barbara. The pre-1900 data do not include the indigenous population. Source: U.S. Census Bureau, Santa Barbara Historical Museum (Loaiciga, 2001).

7.3. Dams, debris basins, and bridges.

The structures considered in this section are Mission Dam in Mission Creek (Figure 3.1), two debris basins and their dams (one in Mission Creek (Figure 3.3 in chapter 3), and one in Rattlesnake Creek (Figure 3.20 in chapter 3), one masonry dam in Rattlesnake Creek (Figure 3.19 in chapter 3), and the following bridges:

(1) Foothill Road bridge over Mission Creek,

(2) Mission Road bridge over Mission Creek in Skofield Park,

(3) Mission Canyon Road bridge over Mission Creek (Figure 3.7), and

(4) Las Canoas Road bridge over Rattlesnake Creek (Figure 3.17).

These structures constitute significant obstructions to fish passage (both upstream and downstream), and they have altered the flow and sediment transport and deposition regimes of Mission Creek and Rattlesnake Creek, thus impacting aquatic habitat and riparian corridor habitat in these streams. Items (1) and (2) are downstream of the confluence of Mission Creek and Rattlesnake Creek, and were therefore not covered in Chapter 3. However, allowing upstream fish passage to the important spawning and rearing habitats (as well as downstream passage) would necessitate effective restoration of upper Mission Creek and Rattlesnake Creek and should include taking action on items (1) and (2) to ensure the full realization of the habitat benefits from the removal or modification of the upstream fish passage impediments (3) and (4). A proposal for conducting additional studies study is being written by some of this report's authors to evaluate the feasibility of removing and/or modifying the debris basins, dams, and bridges cited above.

7.4. Road and trails

Chapter 3 documented that road and trails in the study area are sources of erosion and sediment loading to Mission Creek and Rattlesnake Creek. It is recommended that erosional areas on the roads and trails be mapped, and that corrective work be performed to stabilize them. Stabilization would involve the construction of water bars along trails, filling in gullies, stabilizing unstable slopes formed by road cuts, and providing suitable drainage along trails and roads following site inspection and design (Helix Environmental Planning, 2021). These actions would require coordination and cooperation with the Santa Barbara Trails Council.

7.5. Residential landscaping in the riparian corridor

This issue can be addressed by implementing a public-education campaign to inform owners of riparian parcels that certain types of landscaping and earth-moving work (filling, cutting) can be prone to erosion and become a source of undesirable sediment loading to the streams. This educational campaign should also highlight ways to reduce or eliminate the use of biocides and fertilizers near creeks. Planting non-native species can also introduce inappropriate exotic species into the riparian corridor, and Mission Canyon more generally (Lesage and Flores, 2021). Residents should be encouraged to use native plants in residential landscaping, which are readily available from the Santa Barbara Botanic Garden. The armoring of creek banks should be reviewed and permitted by the pertinent local, county, state and federal agencies (Santa Barbara County Flood Control & Water Conservation District, the US Army Corps of Engineers, the National Marine Fisheries Services, the California Department of Fish and Wildlife, and the City of Santa Barbara as city, county, state, and federal ordinances, regulations, and laws mandate it). The Urban Creeks Council, through its network of volunteers and community relationships, is uniquely well-positioned to undertake this educational task.

7.6. Miscellaneous obstructions in the streams and their riparian corridors

Abandoned pipes, rock debris and trash (e.g., tires, large metal rubbish) dumped in the creeks must be safely removed and disposed of. The Urban Creeks Council in coordination with the City of Santa Barbara's Creeks Division and the County of Santa Barbara Clean Water Project is well-positioned to undertake this work with the support of volunteers and city staff.

7.7. Gaps and knowledge and future research

There remains a significant lack of information on relations among groundwater, surface water, riparian vegetation, and wildlife in the Upper Mission Creek watersheds. More research on where and how riparian areas can be restored would benefit aquatic and riparian habitats and species. Additional studies and efforts to remove or modify barriers, such as dams and road crossings, are needed to restore steelhead to their former levels. This study revealed some of the limitations on the distributions and abundances of sensitive species, e.g., the Southern California Steelhead, such as inadequate and intermittent flows, shallow pools, and restricted breeding or spawning habitat. Even if water supplies are adequate, however, barriers to steelhead migration will prevent the restoration of steelhead stocks.

7.8. References

City of Santa Barbara. (2021). Enhanced Urban Water Management Plan. June 29, 2021.

City of Santa Barbara. (2011). Long Term Water Supply Plan. 2011.

Helix Environmental Planning. (2021). Mission Creek Habitat Restoration Plan. Prepared for Southern California Edison. EDS-01.10. February 2021.

Lesage, J., Flores, J. (2021). Mission Canyon Biodiversity Project. Preliminary Invasive Species Survey Report. The Santa Barbara Botanic Garden, Santa Barbara, California, September 2021

Loaiciga, H.A. and Renehan, S. (1997). Municipal water use and water rates driven by severe drought: A case study, Journal of the American Water Resources Association, 33(6), 1313- 1326. h ttps://doi.org/10.1111/j.1752-1688.1997.tb03555.x

Loaiciga, H.A. (2001). History of water development in Santa Barbara, California. Pacifica, Spring Issue, p. 1-13, with Figure addendum.

https://ucsb.box.com/s/jlmbsk5pfpdwev7npvw5w44iiwy7l23j

National Marine Fisheries Service (NMFS). (2014). Biological Opinion. Endangered Species Act Section 7(a)(2) Biological Opinion for Flood Control Operations including Annual Stream Maintenance, Debris Basin Maintenance, Goleta Slough Dredging and Long-term Atascadero Creek Channel Maintenance permitted by the U.S. Army Corps of Engineers, and implemented by the Santa Barbara County Flood Control District in designated waters occurring within Santa Barbara County. NOAA Fisheries. West Coast Region, California Coastal Office, Long Beach, CA. WCRO-2020-03496. March 11, 2014.

The Aspen Institute. (2002). Dam Removal: A New Option for a New Century. The Aspen Institute. Program on Energy, the Environment, and the Economy.

The Heinz Center. (2002). Dam Removal: Science and Decision Making. The H. John Heinz Center for Science, Economics, and the Environment.

Stetson Engineers Inc. (2013). Hydrologic Analysis of the Pass-Through Operations at Gibraltar Reservoir. Prepared for the City of Santa Barbara. July 2013.

U.S. Bureau of Reclamation. (2016). Storage and Conveyance of the City of Santa Barbara's Gibraltar Reservoir Pass Through Water in and Through Cachuma Project Facilities. FONSI-12-086, South-Central California Area Office, Fresno, California, January 2106.

Water Resources Division. (2022). Water Supply Management Report Water Year 2021-2022. Public Works Department, City of Santa Barbara.