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Beaver (*Castor Canadensis*) of the Salinas River:

A Human Dimensions-Inclusive Overview for Assessing Landscape-Scale Beaver-Assisted Restoration Opportunities

A Senior Project

Presented to

the Faculty of the Natural Resources Management and Environmental Sciences Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science in Environmental Management and Protection

by

Stuart C. Suplick

July, 2019

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BEAVER (*CASTOR CANADENSIS*) OF THE SALINAS RIVER:

A HUMAN DIMENSIONS-INCLUSIVE OVERVIEW FOR ASSESSING LANDSCAPE-SCALE

BEAVER-ASSISTED RESTORATION OPPORTUNITIES

by

Stuart C. Suplick

ABSTRACT

Across the western United States, researchers are increasingly working with beaver (*Castor canadensis*) for process-based stream and watershed restoration. One recently-developed geographic information system-based tool, the Beaver Restoration Assessment Tool (BRAT), analyzes opportunities for beaver-assisted restoration (BAR) at a landscape-scale. However, this tool benefits significantly from human dimensions-inclusive, basin-centralized beaver knowledge for proper interpretation. Unfortunately, this information is scattered or absent in most semi-arid and arid southern California basins. This study thus sought to gather and produce this information through an explorative, benefits-maximizing approach to landscape-scale BAR opportunities assessment in one of these basins, the Salinas River. 49.2 km of beaver dam field surveys, an emailed survey and interviews completed by 39 riparian organizations and residents, and a BRAT model run produced: an ANOVA-driven statistical determination of beaver damming hotspot areas, a beaver damming consistency range map, seven computer assisted qualitative data analysis themes, and BRAT dam capacity and management outputs. When combined, these products revealed basin beaver dam dynamics, population behavior, ecosystem impacts, and human dimensions information that, despite their high-level nature, improved the quality and applicability of assessment recommendations. Ultimately, this study demonstrates how integrating a qualitative data component in landscape-scale BAR assessments is valuable for understanding basin-specific BAR opportunities and considerations, especially for basins without extensive prior beaver research efforts. Study findings also support literature that suggests the current BAR field's focus on beaver damming, and not other beaver activities, may be too restrictive for maximizing its potential in California basins similar to the Salinas River. Perhaps most interestingly, study findings suggest that beaver may be more prevalent in southern California rivers and their tributaries than has been commonly understood. That beaver extensively utilize the Salinas River basin warrants further research efforts in this basin, in addition to surveys and studies in other major southern California basins, to better understand their prevalence and potential ecosystem tradeoffs within these hydrologic regions. To this point, in these basins where beaver need no reintroduction, California beaver advocacy groups may better promote proactive beaver management by adjusting education and communication strategies to emphasize these potential tradeoffs. In doing so, they have an opportunity to impart a healthier understanding among human communities of local ecosystem complexities.

KEY WORDS: landscape ecology, hydrologic basin, beaver, semi-arid, drought, beaver-assisted restoration, Beaver Restoration Assessment Tool, human dimensions, Salinas River, California

CASTOR (*CASTOR CANADENSIS*) DEL RÍO SALINAS:

UNA RESUMEN QUE INCLUYE LAS DIMENSIONES HUMANAS PARA EVALUAR

OPORTUNIDADES PARA LA RESTAURACIÓN CON CASTORES, A LA ESCALA DEL PAISAJE

por

Stuart C. Suplick

RESUMEN

Por todo los estados occidentales de los Estados Unidos, los investigadores están utilizando los castores (*Castor canadensis*) para lograr la restauración de quebradas y cuencas hidrográficas a través de los procesos ambientales más dinámicos y baratos. Una herramienta desarrollada recientemente que está basada en un sistema de información geográfica (SIG), la Beaver Restoration Assessment Tool (BRAT), evalua las oportunidades para esta restauración con castores a la escala del paisaje. Además, se beneficia de los conocimientos de los castores, centralizados por la dicha cuenca, especialmente si incluyen datos al respecto de las dimensiones humanas. Desafortunadamente, esta información es poco común en la mayoría de las cuencas hidrográficas áridas y semiáridas del sur de California. Por lo tanto, esta investigación tenía la intención para acumular y crear estos datos. A través de un enfoque de exploración y maximizando el descubrimiento de benefícios potenciales de los castores por unas de estas cuencas (del Río Salinas), los siguientes métodos se usaron: 49.2 km de inspecciones ribereñas para pistas de los castores y sus represas; múltiples entrevistas y una encuesta enviada por correo electrónico, llenado por 39 organizaciones y ciudadanos asociados con zonas ribereñas; y una ejecución de la BRAT. Los productos incluyeron una determinación estadística de areas claves de las represas de castores; un mapa de la extensión y consistencía del represar; siete temas producidos por un análisis de datos cualitativos con ayuda de una computadora (CAQDA, por sus siglas en inglés), y salidas de la BRAT. Cuando se combinaron, estos productos revelaron acerca de los castores de la cuenca: las dinámicas de sus represas, el comportamiento de la población, sus impactos a los ecosistemas, y información esencial que los seres humanos locales exhiben hacia ellos. Estos datos mejoraron la calidad y la aplicación de las recomendaciones evaluativas y finales, a pesar de sus niveles básicos. Últimamente, esta investigación demuestra el valor de incluir un aspecto de datos cualitativos como parte de evaluaciones de las oportunidades para utilizar castores en restauración, especialmente para cuencas en las que no hay mucha información sobre los castores que viven allí. Los hallazgos de esta investigación tambien respaldan la literatura científica que sugiere que la disciplina actual de la restauración utilizando castores se concentre demasiado en las represas, al detrimento de maximizar su potencial en las cuencas hidrográficas californianas similares a la del Río Salinas. Tal vez lo más interesante, estos hallazgos sugieren que los castores son más frecuentes en las cuencas del sur de California de lo que se ha pensado en el pasado. Que los castores usan la cuenca del Río Salinas en una manera extendida justifica más investigaciones en esta cuenca, además de las inspecciones y los estudios de otras cuencas del sur de California, para entender mejor la presencia y los intercambios derivados de los castores para los ecosistemas adentro de estas regiones. A este punto, los hallazgos recomiendan que en cualquier cuenca donde los castores estén habitando y no requieran las reintroducciones, los grupos de defensa de los castores en California podrían mejorar promoviendo el manejo sensitivo de las poblaciones de castores con nuevas estrategias educativas y comunicativas para enfatizar los intercambios entre ventajas y desventajas para los ecosistemas locales. Haciendo esto quizás ayude a fomentar una comprensión mejor y mas saludable entre las comunidades de los seres humanos sobre las complejidades de sus ecosistemas.

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This research was made possible through a United States Department of Agriculture-National Institute of Food and Agriculture (USDA-NIFA) McIntire-Stennis Capacity Grant, as well as through a generous one-time support sum from the family of Denise Dudley. I would like to highlight the patient dedication, advice, and trust that my advisor, Dr. Yiwen Chiu, has given me throughout the unexpected length of my research. Dr. Yarrow Nelson of the Civil and Environmental Engineering Department was crucial for the inception and early support of my research efforts. Meanwhile, from a broader perspective, my senior project would not have been possible without the assistance of multiple California Polytechnic State University, San Luis Obispo (Cal Poly) faculty, staff, and librarians, including Dr. Heather Smith of the Statistics Department. Deserving special mention for their assistance in the computer-modeling component of my research are Utah State University Ecogeomorphology and Topographic Analysis Laboratory (USU-ETAL) technicians and researchers; Cal Poly Kennedy Library's Data & GIS Specialist, Russ White; UC Berkeley Earth Sciences and Maps librarians; and Kate Lundquist of the Occidental Arts and Ecology Center. Field survey data collection would not have been possible without the help of Michael Moore, Jacquelyn Hancock and other staff from the California Military Department and United States Department of Defense, as well as Rava Ranch, the Porter Estate Bradley Ranch, and various riparian landholders and professionals too numerous to name.

Lastly, I owe much to the support of my parents, who made my time investment in this project possible. I must recognize the rare opportunity they afforded me as an even rarer privilege. And although I know my expression of gratitude is insufficient repayment, I hope they will find the following work, dedicated to them, to close a sliver of the immense, remaining gap. Thanks for fostering a beaver's work ethic in me.

Stuart C. Suplick

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Measurement units	
m	meters
km	kilometers
mi	miles
ft	feet
cfs	cubic feet per second
cms	cubic meters per second
afy	acre-feet per year
Q_2	2-year recurrence interval peak-flood (flow discharge with a 50% probability of occurring each year)
Q_{base}	baseflow (streamflow-delayed subsurface flow discharge, or sustained stream flow in the absence of storm events)

Other	
ANOVA	Analysis of variance
BAR	Beaver-assisted restoration
BDA	Beaver dam analogue
BRAT	Beaver Restoration Assessment Tool
Cal Poly	California Polytechnic State University, San Luis Obispo
Caltrans	California Department of Transportation
CAQDA(S)	Computer assisted qualitative data analysis (software)
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife (CDFG, post-2012)
CR	Camp Roberts
CSUMB	California State University, Monterey Bay
DWR	California Department of Water
EI	Electivity index
FHL	Fort Hunter-Liggett
GIS	Geographic information system
HU or HUC	Hydrologic unit or hydrologic unit code
LANDFIRE	Landscape Fire and Resource Management Planning Tools
LWD	Large woody debris
MCWRA	Monterey County Water Resources Agency
NHD	National Hydrography Dataset
NMFS (NOAA Fisheries)	National Marine Fisheries Service (National Oceanic and Atmospheric Administration Fisheries)
PRA	California Public Records Act
SWRCB	State Water Resources Control Board (part of DWR)
USGS	United States Geological Survey (part of US Department of the Interior)
USDA-APHIS-WS	United States Department of Agriculture - Animal and Plant Health Inspection Service - Wildlife Services
USDA-NRCS or NRCS	United States Department of Agriculture - Natural Resources Conservation Service
USFWS	United States Fish and Wildlife Service
USFS	United States Forest Service (part of USDA)
USU-ETAL	Utah State University at Logan – Ecogeomorphology and Topographic Analysis Laboratory
WWTP	Wastewater treatment plant

INTRODUCTION

The North-American beaver (*Castor canadensis*) is known as an ecosystem engineer, a term coined by Jones et al. (1994) for a species that changes the physical state of local biotic or abiotic ecosystem elements to modulate resource and nutrient availabilities to other organisms. While their non-damming activity surely contributes to their status as a geomorphological change and habitat creation agent (Meentemeyerj et al. 1998, Parish 2016), beaver generally exert their most profound and well-studied environmental benefits through dams (Naiman et al. 1988). Across a basin – defined as the fourth-level United States Geological Survey (USGS) hydrologic unit in this study (technically a "sub-basin" according to USGS hydrologic unit levels; however, "basin" is used throughout this paper to reduce confusion among readers unfamiliar with USGS catchment-coding conventions) and used interchangeably with "landscape" – beaver dams can reconnect floodplains, increase alluvial aquifer recharge, moderate or alter stream temperature, expand perennial stream reaches and baseflows, and support riparian biodiversity (Lowry 1993, Gurnell 1998, Pollock et al. 2003, Rosell et al. 2005, Westbrook et al. 2006, Pollock et al. 2007, Nyssen et al. 2011, Weber et al. 2017). Indeed, in recent years, studies demonstrating that beaver provide hydrological and ecological benefits to incised stream systems (Pollock et al. 2014, Bouwes et al. 2016) have contributed significantly to an explosion in beaver-assisted restoration (BAR) projects (Pilliod et al. 2018). These projects seek to attract or encourage beaver activity through improving their habitat and supporting their dam building activities, in order to accelerate stream function recovery, restore wetlands, or in general, add dynamism and complexity to ecosystems through active or more passive approaches (for respective examples, see Pollock et al. (2012) and Fesenmyer et al. (2018)).

However, researchers have been concerned that in too many cases, environmental feasibility assessments and human dimensions-inclusive BAR planning are conducted insufficiently to assess its suitability and potential effectiveness across basin spatiotemporal scales (Macfarlane et al. 2017, Pilliod et al. 2018). In response to this concern, the Beaver Restoration Assessment Tool (BRAT) and beaver intrinsic potential models have been developed to assist top-down, landscape-scale BAR planning processes to help managers understand risks and opportunities as they consider collaborating with beaver for restoration purposes (Macfarlane et al. 2017, Dittbrenner et al. 2018). Yet these models are primarily intended as decision-support tools, and can only be optimized and properly interpreted when a decision-maker possesses sufficient beaver knowledge for the given basin.

Unfortunately, written or published records of this relevant beaver knowledge – which can include understanding locations, dynamics, and trends of beaver populations and dams; their human dimensions; their influence on environmental processes of special importance for the specific landscape; or else an acquisition of high-level information about these topics to direct further study – are rare or nonexistent across southern California (defined in this study as California Department of Water (DWR) hydrologic regions with the majority of their spatial extents within the southern half of the state). When they do exist, a landscape-scale and beaver-focused coverage is typically lacking, as Appendix A demonstrates. Indeed, available southern California beaver knowledge that could be useful for landscape-scale BAR decisions appears largely indirect, limited to where and when beaver are judged detrimental or potentially detrimental to a single valued, threatened, or endangered species (Rohlf 1991, Brehme et al. 2004, Longcore et al. 2007, Hancock 2009, Cachuma Operation and Maintenance Board Fisheries Division 2018). This paucity of formal beaver scientific studies or monitoring can likely be attributed to the more sporadic and patchy occurrence of beaver and beaver dams in semi-arid and arid regions when compared to temperate ones (Gibson and Olden 2014), and to historical focus on beaver as beneficial from an agriculture and ranching-prioritized lens – not necessarily environmental – wherever they were not otherwise seen as a non-native fur-bearer or agricultural nuisance in California (Fountain 2014). However, regardless of cause and history, this dispersed and limited-scope of beaver knowledge is problematic for landscape-scale BAR. Primarily, without a wider spatial and temporal perspective, reach- and stream-scale limited information can misguide management decisions (Labbe and Fausch 2000). Similarly, lacking a landscape-scale perspective can make the work that Lautz et al. (2019) consider crucial for the BAR field more difficult, from landscape-scale study designs to pre- and post-restoration assessments to strategic early community involvement.

To understand which knowledge is most effective to gather for landscape-scale BAR assessments, a few studies are particularly instructive when combined with existing BAR literature. As an example, Lanman et al. (2013) focused on California historical beaver range, creating an updated range map of beaver presence with physical, reliable observational, and ethnographic evidence. However, the historical observer records used to determine that range map are limited to the time period beginning with the Spanish settlement of San Diego in 1769 and ends before 1923, when a 28-year state-wide program of beaver translocations began after a long time period when fur trappers nearly extirpated beaver. Therefore, that historical data should be regarded as a *de minimus* representation of suitable beaver habitat since it does not account for the extensive 1923-1950 translocation efforts. On the other hand, efforts to establish current range maps of California's beaver populations are based on general indicators of beaver presence, which are typically opportunistic sightings instead of regularly or systematically updated observations (see Asarian). These opportunistic sightings may not convey the full extent or dynamics of beaver home ranges, considering how beaver may disperse distances of more than 50 km using waterways and streams (Müller-Schwarze 2011), if not as much as 240 km in one extreme case noted by Chubbs and Phillips (1994). Further, BAR is only feasible in a currently beaver translocation-prohibited California if the species has reliable sourcing within, or regularly migrates into, a respective basin (Castro et al. 2018), and is likely to find a planned BAR site location. Therefore, Lanman et al.'s historical range map and Asarian's efforts provide insufficient current information for understanding a specific southern California landscape's beaver damming hotspots and dynamics. Thus, centralizing knowledge about current beaver population and damming hotspots, or if these likely persist to a greater extent in certain locations over others, can help site BAR projects within such basins.

In another example, Lundquist and Dolman (2018) sought to integrate historical and current beaver distributions, the BRAT, habitat suitability assessments, and a few human dimensions considerations to assess the BAR feasibility of select North Fork Kern River basin sites in southern California. While they ultimately identified little opportunity without beaver translocations at their client's 10 priority mountain meadow sites, their human dimensions-addressing methods were extremely conflict-avoidance focused. Namely, they conservatively suggest that most meadows' proximity to campground infrastructure outweighs the indirect recreational benefits the beaver may bring. Yet although an infrastructure flooding risk can exist, it will not necessarily materialize or be unmitigable (Macfarlane et al. 2019). This is especially true since local human population attitudes towards wildlife frequently influence management decisions or approach outcomes (Decker et al. 2001). So while Lundquist and Dolman (2018) acknowledge in their conclusion a need for an exploratory, benefits-maximizing approach by "focusing on existing populations nearby to better understand and take advantage of their impacts [which] could yield more immediate results" (pg. 15), the exploratory scope of this proposed approach is still too limiting. Benefits cannot be maximized without considering more than beaver ecology. In other words, a centralization of high-level beaver knowledge for a basin should, at the least, integrate an overview of its human attitudes towards beaver. Beginning to understand these attitudes and responses to beaver conflicts can help illuminate basin-specific, ecologically- and socially-appropriate BAR opportunities (Pilliod et al. 2018)

Centralizing high-level beaver knowledge perhaps most obviously benefits from integrating BRAT or its foundational dam capacity model, as Lundquist and Dolman (2018) attempted, since it can provide important, quantitatively-grounded insights to where BAR may be most successful across a basin. As an increasingly popular geographic information system (GIS) for landscape-scale BAR planning, BRAT first predicts stream reach dam building capacities. By integrating widely-available geospatial datasets that reflect literature-supported beaver habitat and dam building requirements, as Table 1 summarizes, it suggests where beaver damming could be most intensive across a basin (Macfarlane et al. 2017). A beaver management component can then be executed to conservatively determine where species activity can pose a risk to human infrastructure, and where it may otherwise be an opportunity.

However, since the BRAT's dam capacity model does not predict actual, current beaver population locations or dam building due to complex beaver behavior, colony dynamics, and background human influences (Leege 1968, Bergerud and Miller 1977, Baldwin 2013, Macfarlane et al. 2017), acquiring beaver dam locations and physical characteristics data for a BRAT-modeled basin can help interpret where, when, and how beaver damming occurs in the basin, and thus where it or associated beaver activity may be maintained or expanded to feasibly. Collected human dimensions data, namely of local attitudes and current management approaches toward beaver, and understanding reasons for these, can similarly assist in comprehending BAR potential within the basin.

Table 1. Input data used by the BRAT model to represent key dam building requirements and calculate stream reach dam capacities

Input data	Source name and website	BRAT function
Streams	USGS National Hydrography Dataset (NHD), http://nhd.usgs.gov/	Reliable (perennial) water sources
LANDFIRE 2014 existing vegetation	LANDFIRE land cover data, http://www.landfire.gov/	Beaver-suitable riparian vegetation extent
LANDFIRE 2014 biophysical settings	LANDFIRE land cover data, http://www.landfire.gov/	Same as previous, but for historical dam capacity calculation purposes (results not used in this study)
10 m DEM	USDA-NRCS Geospatial Data Gateway, http://datagateway.nrcs.usda.gov/	Stream gradient calculations
USGS baseflow equations	California N/A; created based upon basin-available stream gage data and USGS (2008), https://pubs.usgs.gov/sir/2008/5126/section3.html	Whether dams can be built, based upon typical hydrological environment
USGS 2-year peak flow equations	Gotvald et al. (2012), https://pubs.usgs.gov/sir/2012/5113/pdf/sir2012-5113.pdf	Whether dams can withstand typical floods

Source: adapted from Macfarlane et al. (2017)

Thus, in order to provide a centralization of high-level beaver knowledge for the Salinas River basin, beaver dam field surveys; an exploratory emailed survey and interviews, combined with a preceding historical records review; and the BRAT model were executed. The results, a preliminary understanding of basin beaver dam dynamics, population dynamics and behavior, potential ecosystem impacts, and human dimensions, were integrated to offer short-range and long-range strategy recommendations for any future BAR efforts occurring within the study area. Recommendations support literature suggesting that the BAR field's dominant focuses may be too constraining to maximize BAR in this basin and others with similar beaver and human dimensions characteristics. For the Salinas River, findings also suggest additional and perhaps more efficacious approaches to beaver education and proactive beaver management than those which California beaver advocates currently pursue. Ultimately, this study offers one approach to collect and interpret rare or formerly non-existent beaver data to maximize human dimensions-inclusive beaver benefits across a landscape while accounting for BAR-affecting, basin-specific factors.

METHODS

Study Area

Physical characteristics

Located across Monterey, San Benito, and San Luis Obispo counties, the 8622.36 km^2 semi-arid and arid Salinas River basin (USGS Hydrologic Unit Code 18060005) has a topography of gently sloped ground and rolling hills with secluded mountainous areas that reach approximately 1800 m (5905 ft) above sea level (Figure 1). The landscape receives approximately 31-127 cm (12-50 in) of precipitation annually, altitude-dependent, with a wet season generally spanning from late November through April, and a dry season from May through October. The Salinas River mainstem originates approximately 4 km east of the summit of Pine Ridge in the Los Machos Hills of the United States Forest Service (USFS) Los Padres National Forest, and is dammed approximately 45 km (28 mi) thereafter by the 1941-constructed Salinas Dam, which maintains Santa Margarita Lake (also known as Salinas Reservoir) and supplements water supply for the city of San Luis Obispo. The river then continues northwestwardly another 237 km (147 mi) through the Salinas Valley, surrounded by the Santa Lucia and Sierra de Salinas mountain ranges to the west and Gabilan and Diablo mountain ranges to the east, before emptying into Monterey Bay near the city of Marina, west of the city of Salinas. Major tributaries to the Salinas River are the Arroyo Seco, Estrella, Nacimiento, and San Antonio Rivers, with the latter two dammed in 1957 and 1965, respectively, for flood-control, irrigation, and groundwater recharge purposes. Soils underlying the Salinas River and its tributaries tend toward unconsolidated, alluvial deposits and well-drained sand. Approximately 50% of study area groundwater basin recharge begins with percolation through these streambeds, while another 40% occurs from irrigated farmland returns and 10% from other weather and subsurface inflow processes across the valley floor (MCWRA et al. 2006).

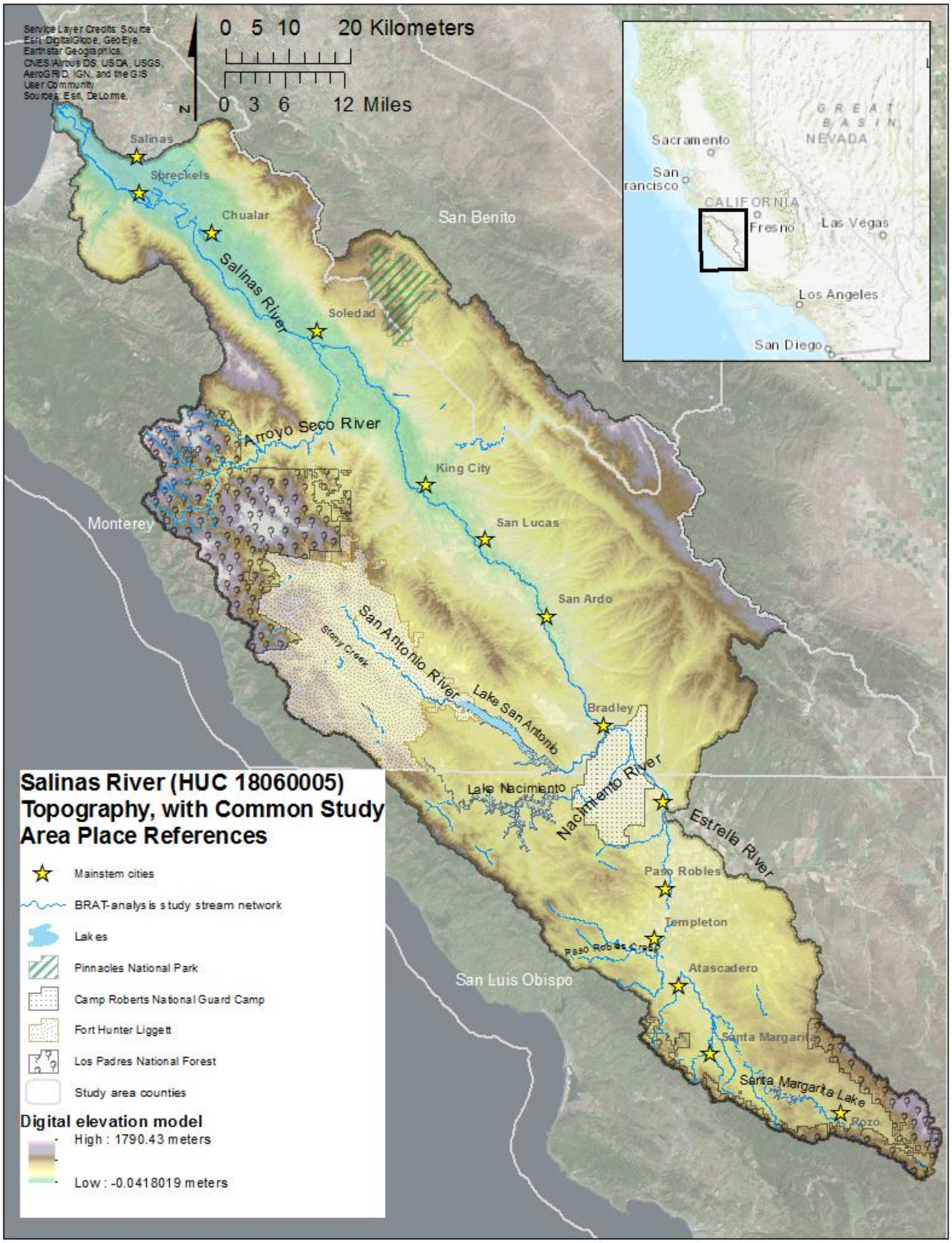

Figure 1. Study area map, showing Salinas River basin geographical, topographical, and place (hydrological and anthropological) name contexts.

For reference purposes in this report, the basin can be divided into lower and upper basins that follow the demarcation noted in Funk and Morales (2002) at the Salinas River near Bradley. Generally, the lower basin is within Monterey and southwestern San Benito counties, and is majority irrigated cropland throughout the Salinas Valley with rangeland and vineyard operations across upland areas (Worcester et al. 2000). The upper basin is within Monterey and San Luis Obispo counties, and is majority dryland farming, rangeland, and pasture land, with large amounts of acreage converted since the mid-20th century to vineyard operations or urban development (Worcester et al. 2000, Funk et al. 2004). For the study area as a whole, open space, wilderness areas, forested mountains, and protected lands account for about 81% of land cover; urban development for about 12%; and agriculture for approximately 7% of land use (LANDFIRE 2018). However, urban development and agriculture dominate the majority of the basin valley bottom, particularly agriculture within the lower basin. Urban development is heavily concentrated along the Salinas River or its tributaries, and is densest by the city of Salinas in the lower basin, and the cities of Atascadero, Templeton, and Paso Robles in the upper basin.

Selection characteristics

The Salinas River basin was selected as a study area due to its promise for landscape-scale BAR within southern California. As beaver have well-studied correlations with avian and general riparian diversity (see review in Rosell et al. 2005, Cooke and Zack 2008, Nummi and Holopainen 2014), it is conceivable that landscape-scale BAR can improve the resiliency of multiple Salinas River basin species, since historical land use changes have decreased riparian buffer widths and increased riparian-adjacent urban and agricultural density, reducing overall biodiversity (Funk et al. 2004, Beller et al. 2009, Gennet et al. 2013). These species include native endangered and threatened amphibians, birds, and fish known to inhabit basin riparian areas; the majority of these could benefit from the lentic environments that beavers engineer (see Appendix B). One of the species listed in Appendix B is the southern-central California coast steelhead trout distinct population segment (*Oncorhynchus mykiss irideus*; hereafter the population segment referred to by “steelhead trout” for in-basin references), whose habitat range extends from the

Pajaro River on the northern border of Monterey County south to Arroyo Grande Creek in San Luis Obispo County. The Salinas River basin is of special importance to steelhead trout recovery as it is the largest drainage system that this distinct population segment inhabits; thus, beginning to understand how steelhead trout and beaver may interact under basin-specific circumstances may be especially important.

Secondly, as groundwater is a major source of the drought-prone basin's agricultural water supply, aquifer recharge that can be facilitated with beaver dams or beaver dam analogues (BDAs) is appealing, even if it is quantitatively minimal (Hafen 2017).

However, the basin also exemplifies a need for understanding where and how BAR techniques may be limited, need cautious implementation, or benefit from in-depth beaver ecosystem impact studies. For instance, the lentic habitat that beaver ponds create may generate management headaches across the basin, or at least in certain areas: as Hancock (2009) notes, beaver may detrimentally affect the isolated Fort-Hunter Liggett population of endangered Arroyo toad (*Anaxyrus californicus*). And despite beaver pond inundation potentially helping with salt cedar (*Tamarix ramosissima*) eradication (Vandersande et al. 2001), it may also hinder elimination efforts of the salt-tolerant tree and other invasive species (Mortenson et al. 2008, see review in Gibson and Olden 2014, Gibson et al. 2015).

Contributions of beaver to groundwater recharge within the basin may also be minimized since percolation through major or flood-regulated rivers may preclude dam building activity due to associated width, depth, or stream power extremes (Allen 1983, McComb et al. 1990), and recharge independently of beaver dams. Even where beavers can build dams along human-perennialized reaches of the Salinas River and its tributaries, as well as other perennially-ponded areas, frequent river entrenchment and flood regulation may diminish overbank flooding frequency, which could limit this potent beaver pond-facilitated groundwater recharge mechanism (Westbrook et al. 2006).

Finally, as Baldwin (2013) highlights in his critique of beaver habitat suitability indices, current beaver absence may not only be due to poor habitat conditions, but also to historic or consistent natural predation, human hunting, and depredation. Beaver, then, may already be at their maximum extent across a given landscape due to natural and anthropogenic factors. As such, it will be difficult to determine where beaver damming or activity promotion within the Salinas River basin could be most beneficial unless the underlying causes of its presence and absence areas begin to be investigated and understood.

Additional reasons for selection of the Salinas River basin as a study area included: its proximity to Cal Poly and California State University, Monterey Bay (CSUMB); its practicality as a fourth-level hydrologic unit input for BRAT; other researchers' study interests regarding beaver ecosystem impacts within the basin (Yarrow Nelson, Department of Civil and Environmental Engineering, Cal Poly, personal communications, 23 June 2017; John Olson, School of Natural Sciences, CSUMB, personal communications, 13 January 2019); and the current, ongoing development of a comprehensive management plan for the basin (Devin Best, Upper Salinas-Las Tablas Resource Conservation District, personal communications, 18 July 2018).

Methods Overview

Given the considerable overlap among methods for study objectives, Table 2 summarizes how they were combined.

Table 2. Summary of study methods integration.

Study goal	Objectives	Method utilized		
		Beaver dam field surveys	Historical records review, email survey and interviews	BRAT model run
Centralization of high-level beaver knowledge for basin-specific, human dimensions-inclusive BAR recommendations	Determination of beaver damming hotspot areas	X		
	Creation of beaver damming consistency range map	X	X	
	CAQDA of beaver behavior and human dimensions		X	
	Interpretation of BRAT outputs	X	X	X
	BAR recommendations	X	X	X

Because the scope of this study was being finalized as data collection occurred, almost all analytical methods were finalized post-execution, in part to accurately reflect the collected data quality and availability. Descriptions of each method's purpose, general procedures, and *a posteriori* analyses are described below.

Beaver Dam Field Surveys during Late Autumn Baseflow Conditions

Purpose

To determine current, relative beaver damming hotspot areas within the Salinas River basin, field surveys were conducted to identify sites with statistically significant dam densities and dam magnitudes (as measured by crest length and dam height). This data was included in this centralization of high-level beaver knowledge since streams with high densities of beaver dams exert greater ecological and geomorphological effects on their environments than those with few (Johnston and Naiman 1990, McKinstry et al. 2001, Cooke and Zack 2008) and streams with larger individual dams may, depending on topography, exert similarly pronounced effects through larger ponding extents and volumes than those found with smaller dams (Beedle 1991, Westbrook et al. 2006, Karran et al. 2017). Resulting information about the sites can therefore help guide development of various spatiotemporal-scale BAR or beaver ecosystem impact studies at or among the field surveyed locations. Perhaps more importantly, additional data collected on individual surveyed dams can improve understanding of basin dam dynamics.

Field surveys were also conducted to provide beaver dam locations for the beaver damming range map, and for BRAT results validation and interpretation.

Survey area selection and field protocol

Following Macfarlane et al. (2017), Google Earth was used to identify beaver dams within the study area. Historical satellite imagery that was consistently available across USGS water years 2011-2017 was used to identify potential dams, with imagery review focused over the NHD perennial stream network (USGS 2019), i.e. mostly the Salinas River and its major tributaries. Field survey area selections were then digitized in ArcMap 10.6 and modified as-needed based upon the following creation and adjustment criteria: (1) where groupings of Google Earth-identified potential dams existed; (2) where legal public access points to navigable riverbeds occurred, or where legal private property ingress and egress consent was obtained through permission-seeking letters, emails, and courtesy-notices; (3) where perennial water and substantial riparian vegetation appeared to end, based on the historical imagery; and (4) where the stream was safely traversable by foot. Several survey areas in Fort Hunter-Liggett (FHL) were also created opportunistically during survey coordination, through the FHL biologist's beaver knowledge. Traversed FHL survey areas were also significantly shortened in-field due to time and budgetary constraints, but were shortened to capture likely damming locations, again based upon the FHL biologist's beaver knowledge. All final survey areas traversed are shown in Appendix C.

Surveys were conducted November through early December while baseflow was still present. No surveys were conducted afterwards due to time, equipment, and budgetary constraints, and the greater likelihood of flood conditions after late November, which could have affected the quantity of dams measured. (For instance, Hagar (1996) notes that in late winter of water year 1995, a beaver dam near the city of Salinas treatment pond blew out during flood conditions; Hancock (2009) also explains that winter floods blow out most dams throughout FHL arroyo toad habitat. Both support that beaver dams generally have short life-spans in at least parts of the Salinas River basin, a common dam characteristic among semi-arid and arid environments (Gibson and Olden 2014).)

To obtain dam characteristics data, measurements followed Hafen (2017) with information collected on USU-ETAL staff-provided data sheets shown in Appendix D. This data focused on dam geographical locations and physical characteristics, and were later transcribed into an Excel database.

Statistical analyses

Descriptive statistics were used to summarize dam crest lengths and heights. Again based on procedures from Hafen (2017), univariate analyses of variance (ANOVA) with Tukey-Kramer Honestly

Significant Difference (HSD) tests at 95% confidence were then used to analyze dam crest length and height by survey area. Additionally, during field surveys, two survey areas appeared to have higher dam densities than the others. Stream reach dam densities for these two survey areas were analyzed against the others using a two-sample Student's t-test at 95% confidence to help determine if they were damming hotspots. All statistical analyses used alpha levels of .05 and were performed in JMP Pro 14 or Minitab Express.

Emailed Survey and Interviews of Targeted Population Segment

Purpose

To better understand basin beaver activity and their human dimensions (namely, the current status of beaver management and local attitudes toward the species), a Google Forms survey was emailed to the study area population segment who would be best able to offer valuable anecdotal data, with an alternative semi-structured phone interview offered as well. These recipients included riparian-area management organization contacts, as well as stream-adjacent private landholders that were opportunistically established during field surveys and from aforementioned organization contacts. (For details on survey questions and protocol, see Appendix E.)

As briefly discussed under *Introduction*, this exploratory approach was necessary to determine if there were beaver population behaviors, dam dynamics, ecosystem impacts, or human dimensions specific to the Salinas River basin that should be accounted for in final BRAT interpretations and BAR recommendations. These may not be of current BAR literature focus, which concentrates on beaver damming and largely excludes consideration of other beaver activity (Pollock et al. 2014, Bouwes et al. 2016, Macfarlane et al. 2017, Castro et al. 2018), which may not be the best approach to maximize beaver benefits across semi-arid and arid large river environments, given their typical seasonal damming and bank denning (Gibson and Olden 2014, Parish 2016).

Secondary objectives of the survey and interviews were twofold. First, they helped ensure as comprehensive coverage of the study area as possible for understanding beaver damming and activity extent, considering the constraints of previously described field surveys and Google Earth dam-censusing. Second, since BRAT outputs are built upon dam capacity, which is not necessarily equivalent to dam longevity or damming consistency, derived respondent observation location data supported the development of a beaver damming consistency range map to interpret these outputs more robustly.

Historical records and literature review-informed computer assisted qualitative data analysis (CAQDA)

To gather physical evidence, primary literature, grey literature and other documentation of beaver presence and activity that could contextualize, verify, or add insights to obtained survey data, a historical records search was conducted focusing on 1923-present and utilizing methods from Lanman et al. (2013): Web of Science Core Collection and Zoological Record, Google Scholar, Library of Congress-digitized historic American newspapers (https://chroniclingamerica.loc.gov/), and California Digital Newspaper Collection (https://cdnc.ucr.edu/) searches using 'California beaver,' 'California castor canadensis,' 'Salinas River beaver,' and '[study area major tributary and city names] beaver; inquiries to study area natural history libraries, county libraries, historical societies, and university libraries including their archives and vertebrate collections; United States Fish and Wildlife Service (USFWS), Department of Agriculture Animal and Plant Health Inspection Service – Wildlife Services (USDA-APHIS-WS), and California Department of Fish and Wildlife (CDFW) and Transportation (Caltrans) inquiries including Public Records Act (PRA) requests for past research, environmental planning reports, trapping records, and depredation permits; and other state, regional, and local government agency online library searches for relevant grey literature.

Additionally, to determine if there were further historical, local records or oral histories regarding beaver, Lynn and Glading (1949) beaver transplant sites were estimated within the study area utilizing ArcMap 10.6. Site elevations and literal descriptions were referenced to overlaid, online historical USGS topographic maps and to comparisons between Wieslander vegetation maps (Kelly et al. 2005) with current Google Earth satellite imagery in context of these topographic maps. An arbitrary 1 km radius was generated around each of the approximated release sites in order to constrain this additional search, in which available business and parcel data contacts were derived from various sources including Google Maps, Cal Poly (Russ White, Kennedy Library, Cal Poly, personal communications, 18 July 2018), and CSUMB (Pat Iampietro, School of Natural Sciences, CSUMB, personal communications, 6 October 2018). Contacted individuals were asked if they had information related to current beaver, historical beaver transplants, or knew of current or previous landholders who may have had this information. Contacts who knew of historical beaver transplants or activity either took the emailed survey or were in-person interviewed. The decision to in-person interview was made when: extensive knowledge of beaver historical presence could prove valuable to other researchers; and the participant did not have an email address, or it would have been more difficult to involve them in the study via emailed survey.

Emailed survey and interview data were iteratively coded using the CAQDA software, NVivo 12, with an initial deductive approach around the following information categories, or themes, prioritized by study objectives: sighting locations, persistence at the observed location(s), potential study area-specific ecosystem niches, nuisance activity and frequency, and respondent attitude toward beaver – and if there were possible spatial patterns or trends suggested at the local (reach- and stream-scale) versus landscape-scale. Final themes resulting from the coding process were treated individually for discussion, with primary or grey literature and historical records review findings supporting or questioning suggestions that arose from the qualitative data (Twining et al. 2017).

When alternative semi-structured phone interviews occurred, notes were concurrently taken to summarize information presented, due to equipment and workplace-setting limitations that prevented recording the majority of phone calls when they were conducted. In-person interviews were recorded using the iPhone application, Voice Memo, and later transcribed manually. In both cases, copies of the resulting interview notes and transcriptions were shared with the interviewees, inviting opportunity for corrections or additions (Bryman and Cassell 2006).

<u>Beaver damming consistency range map</u>

All reliable respondents' observations were combined with field survey data and other supporting data to create a beaver damming consistency range map across study area USGS sixth-field hydrologic units (sub-watersheds). The different consistency classifications shown in the range map are explained in Table 3.

To determine the survey data reliability, Frey et al.'s (2006) reliability classification scheme was modified and applied to survey respondents and interviewees based on their years of experience, whether they observed dams, or noted other convincing details supporting their observations. All respondents and interviewees were used in the beaver damming consistency range map since they all met the highest reliability classifications (see Appendix F), and because beaver are not a rare, hard-to-identify species (Frey et al. 2013).

Table 3. Consistency classification criteria for beaver damming consistency range map

Class	Characteristics
A: Consistent Damming (Year-Round or Seasonal)	Beaver damming noted or inferred as regularly occurring due to presence of year-round, perennial water conditions when paired with respondent/interviewee observations for area. Even if perennial water is present, damming may only occur seasonally due to winter high flows that cause blowouts or breaches. Since damming is present, other activity is as well.
B: Inconsistent or Unknown Damming, Other Activity	Upper basin: Beaver that can be assumed to be in the sub-watershed, but for which it is unknown how consistently they dam – perennial ponding, water-sources, and damming conditions were not sufficiently determined or inferred from respondents/interviewee responses. Lower basin: Sub-watersheds that beaver are unlikely to dam consistently, and are instead more likely to dam opportunistically. They may more commonly reside in bank dens due to deep and high flows, for instance. Many of these sub-watersheds may also function as dispersal travel paths, with marginal-habitat. Using Frey et al. (2006) inference guidelines: it would be unlikely for these to be colonized year-round, or most years, based upon Class A reliability-ranked respondent/interviewee's shared sub-watershed beaver locations, geographical knowledge, and other information.
C: Probable Activity Absence or Ephemeral Activity	Multiple respondent/interviewee's speculation but with no documentation or evidence; respondent/interviewee who conveyed a Class A-C reliability-ranked observation but placed it as ≥ 15 years ago and/or uncommon, with no other more recent observations for area; and/or habitat conditions look poor or unfavorable for both beaver and damming based upon Google Earth satellite imagery.
D: Likely Activity Absence	No records of recent existence that are known (or were noted) by a respondent/interviewee with ≥ 15 years of experience (or much longer, such as from one life-long resident who remembered local, historical beaver transplants) for ≥ 15 years.
Unknown	Sub-watersheds that are not categorized and are not highlighted in the map, typically due to an absence of (1) collected data, and (2) direct connection to a mainstem- or major tributary-stream (that is part of a Class A-B ranked sub-watershed).

Note: Map ranks sub-watersheds based on majority of anecdotal observations - i.e. a Class A-ranked sub-watershed can include spots with Class B.

BRAT Model Implementation

Purpose

To construct a quantitative foundation for study area BAR recommendations, the BRAT's dam capacity model was executed, calibrated, and validated. The final dam capacity output was then interpreted, along with the beaver management outputs produced from it, to provide a preliminary understanding of where and how BAR could be best pursued within the Salinas River basin..

Model execution: study area-specific adjustments

Procedures from BRAT documentation (Riverscapes Consortium) were followed for BRAT version 3.20 to produce the combined dam capacity model results, as well as the beaver management layer outputs. Where possible, third-party verification from a USU-ETAL staff member was obtained, such as for valley-bottom edits (Micael Albonico, USU-ETAL, personal communications, 21 August 2018). Each intermediate product from the modeling process was interrogated for consistent quality assurance. Data pre-processing and model run procedures that were basin-specific for the BRAT are noted under the next two sub-subsection points.

Streamflow network. Although beaver mostly build dams and inhabit areas with perennial flow (Slough and Sadleir 1977), intermittent streams were also included in the originally-modeled NHD stream network since they could include stable water sources that beaver depend on (Gibson and Olden 2014). Put another way, beaver have been known to inhabit perennial pools that exist near groundwater-upwellings along semi-arid and arid intermittent streams (Ffolliott et al. 1976), conditions that describe parts of the study area. For this reason, the procedural observations of Cailat et al. (2014), and the presence of many field-surveyed beaver dams occurring in perennial streams misclassified as intermittent, NHD accuracy could have excluded important BRAT validation outputs if only the perennial stream dataset was utilized. Moreover, potentially useful outputs would not have been produced: the intermittent-classified Atascadero, Paso Robles, and Trout Creeks are priority streams for local restoration projects (Devin Best, Upper-Salinas Las Tablas Resource Conservation District, personal communications, 2 August 2018), and may have seasonal beaver presence that could benefit from BAR.

However, including both perennial and intermittent streams in the analyzed landscape implies that a high number of the latter can confound analyses if they skew final stream length totals and proportions of one or more dam capacity categories (see next subsection, "Model validation: interpretation"). Plus, it is disingenuous and misleading to show BRAT outputs for intermittent and ephemeral streams where beaver usage, at least damming, is unlikely to occur (Macfarlane et al. 2017). Thus, for final analyses and results, the NHD perennial network, along with intermittent-coded streams where validation-dams occurred, were clipped into their own network. Meticulously recoding the perennial network in its entirety was considered outside the scope of this study.

Baseflow (Q_{base}) equation. While a 50-year flood (Q_2) equation was identified for the study area (Gotvald et al. 2012), no Q_{base} equations have been published for California basins or hydrologic regions. One was therefore created using a flow-duration method on available data from study area USGS gage stations, utilizing 80th-percentile annual exceedance probabilities or greater based upon monthly-averaged recorded flow discharge data (USGS, 2008; Figure 2). This Q_{base} equation was then reviewed by a USU-ETAL staff member (Scott Shahverdian, USU-ETAL, personal communications, 27 August 2018).

As seen in Figure 2, quadratic regression reveals a high coefficient of determination (R^2 = 0.8825), meaning that 88% of the variation in predicted low-flow discharge values can be explained by the equation's manipulation of drainage area. Yet this quadratic regression equation use to produce baseflow estimates in the model is inherently erroneous, as intuitively, baseflows should increase positively with drainage area, unless major surface water diversions exist. More obviously, there can be no negative discharge volumes.

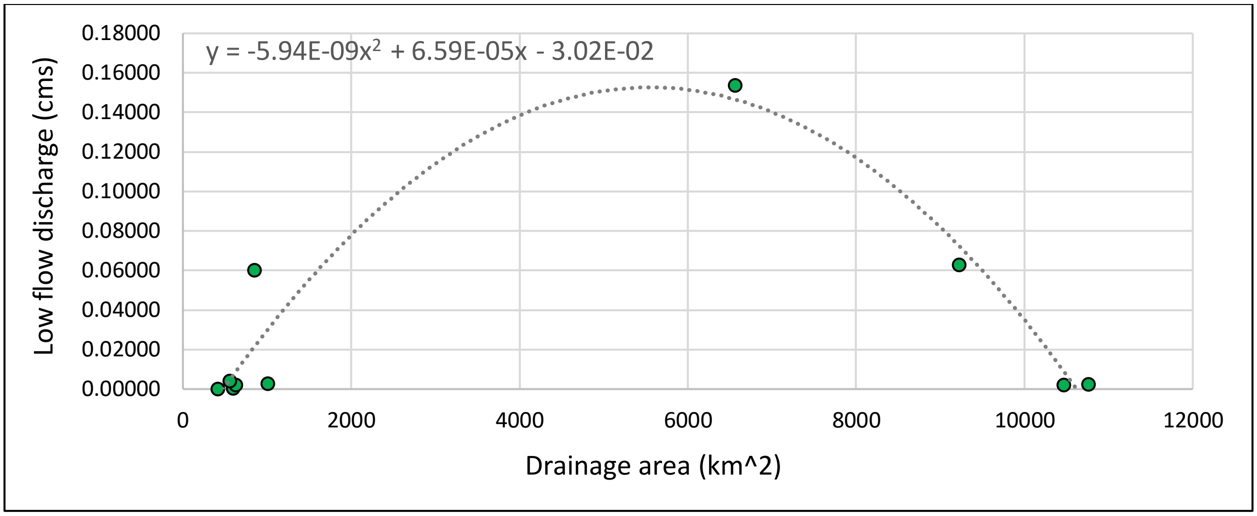

Figure 2. The baseflow equation used for BRAT modeling the Salinas River basin. The equation shows drainage area as a predictor of stream gage-measured low flow conditions with outlier low flow discharges eliminated or reduced. Of 11 stream gage datasets available, 10 were used in final equation production, as one was limited to < 25 years of data.

However, justifying the use of this Q_{base} equation were a few factors. First, all drainage areas sizes calculated by the BRAT resulted in outputs of no flow or greater. Second, only 11 gage stations exist within the Salinas River basin, which reduced data available for flow-duration calculations, particularly for the drainage areas between 1300 and 10,300 km^2. As the study area mainstem, Nacimiento River, and San Antonio River are flow regulated, low flows may be higher for their targeted, downstream operation extents or further, and thereby have affected calculations for at least USGS Gage Stations 11151700 (Salinas River at Soledad) and 111150500 (Salinas River near Bradley), which have respective drainage areas of 9228 and 6566 km^2. While excluding these data points and Gage Station 11149400 (Nacimiento River below Nacimiento Dam near Bradley) may therefore have been advisable, their exclusion would have been unrepresentative of the higher low flows caused by flow regulated portions of the Salinas River basin – where beaver appeared to exist based on field survey area selection methods. Therefore, the equation represents a compromise between the most and least flow regulated parts of the basin, albeit one that predicts a higher Q_{base} than is likely common for most of it.

In any case, baseflow data provided by a local environmental consulting firm for select parts of the study area are within the range predicted by the equation (Wydzga and Bennett 2017), and most importantly, Q_{base} equation accuracy needs for the basin's BRAT model were not strict, due to the equation's model purpose (i.e. determining where beavers cannot build dams due to overly powerful baseflows).

<u>Model validation: interpretation</u>

This step encompassed preliminary results calibration and final validation analyses of the BRAT's dam capacity model, since this output influences the beaver management outputs that utilize it. Following Macfarlane et al. (2017), only stream reaches where beaver dams were identified were used for the accuracy assessment. For this study, these dams included: field surveyed beaver dams, FHL-provided beaver dam data for 2016, and all beaver dams that had been located using Google Earth for years 2015 and 2017 (to respectively reflect lower and higher water flow for most study area streams, since 2015 was a drought year and 2017 a wet year). Only the desktop-identified dams located in non-field surveyed stream reaches were used, while for each stream reach, only dams from one source were utilized to avoid reach dam count inflation.

After field surveys, calibration focused on vegetation inputs. Specifically, after interrogating results, the following LANDFIRE existing vegetation layer classes were recoded to 'Moderately Suitable Material' or 'Suitable Material' from 'Barely Suitable Material' since they were repeatedly found in riparian vegetation areas with beaver dams and presence: 'California Mesic Chaparral,' 'Southern Coastal Sage Shrub,' 'California Central Valley and Southern Coastal Grassland,' 'Western Warm Temperate Urban Herbaceous,' and other, primarily shrub and forest-variant 'Western…Urban/Developed…' classes. The Q_2 equation precipitation value was not changed to see if it had an effect on an initial high rate of under-prediction observed, since vegetation input changes appeared to drastically reduce under-prediction by themselves. Vegetation calibrated results then indicated that the basin's dam capacity model could benefit from California-specific slope adjustments to better reflect realistic dam capacities for its steepest stream network reaches, since these are unlikely to be regularly inhabited by beaver, or useful for BDA purposes (see *Results and Discussion*'s "Predicted current dam building capacity output" sub-subsection). Indeed, while the dam capacity model's logic has been validated in Macfarlane et al. (2017) this validation was based upon Utah basins, many of which include snowpack-affected hydrologic regimes. Given spring snowmelt absence in most southern California basins with beaver, which could thus contribute to low reliability for beaver habitat and damming in low-order streams, as seen in dam monitoring results in Santa Barbara County's Santa Ynez River (Cachuma Operation and Maintenance Board Fisheries Division 2018), modifying the slope logic was supported. Therefore, Retzer et al. (1956), Beier and Barrett (1987), McComb et al. (1990), Suzuki and McComb (1998), BRAT-generated stream reach gradient data for field survey dam locations, and similar data from the Sierra Nevada BRAT project (Kristen Podolak Wilson, The Nature Conservancy, personal communications, 13 April 2019) were consulted to determine appropriate stream gradient changes to the dam capacity model's default slope logic. While the default logic allowed for the slopes between 17%-23% gradient to still be classified as marginally dam-able, the new slope logic gave this classification to 6-12% gradients, with greater slopes incapable of supporting dams.

BRAT validation analyses focused on answering error-pinpointing questions. From previous BRAT-implementation studies, it is noted that "Three forms of model verification [are] used to assess the performance of the capacity model. 1. Are spatial predictions coherent and logical? 2. How do dam densities track between predicted and actual? 3. Does the [electivity index] increase appreciably from the none to the pervasive class?" (Macfarlane et al. 2014, Macfarlane et al. 2019). For the first two questions, maps can be created showing representative stream reaches' vegetation and stream agreement or disagreement, and predicted versus actual dam numbers can be plotted against a 1:1 line of perfect agreement, to highlight differences or agreements among the input data (Macfarlane et al. 2014, Macfarlane et al. 2019). In regards to the third question: BRAT developers rely on the electivity index (EI; Pasternack 2011) to verify model runs since it is a metric that compares beaver utilization of a dam capacity category to the category's availability across the basin. In other words, Macfarlane et al. (2017) explain that

> a value less than one indicates avoidance of a particular habitat, whereas a value greater than one indicates preference for a habitat. If the capacity model is effectively segregating actual dam densities then the following would be expected: an EI close to zero for the 'none' and 'rare' classes, less than one for the 'occasional' class, greater than one for the 'frequent' class, and much greater than one for the 'pervasive' class. (pg. 83)

As part of the previous questions, calculated EIs can then be paired with chi-squared tests to identify not only how the model errs, but also the most likely error origins.

RESULTS AND DISCUSSION

Beaver Damming Hotspot Areas

Overall, 49.2 km of stream channel were traversed (with the exception of 'FHL Arroyo Toad Habitat,' as mentioned in *Methods*), with data collected for 69 dams across 10 distinct survey areas for a mean stream length dam density of 1.6 dams/km (Table 4). Table 4 shows key data collected to describe findings, by survey area and in aggregate. Five original survey areas – three among the lower basin (at Highway 68, Blanco Road, and South Davis Road), and two in the upper basin (Santa Margarita Creek by Highway 101 and Salinas River by the Blinn Ranch Trailhead in Pozo) – were excluded from final statistical analyses since no beaver dams were found, or because they were not traversable by foot.

Aggregate dam heights (*M* = 0.49, *SD* = 0.25) and lengths (*M* = 13.81, *SD* = 13.31) suggest that basin beaver dams skew to smaller heights and crest lengths (at least in higher-order streams, and assuming that the majority of small inactive dams had not significantly decreased in size since they were last active). Anderson-Darling tests (Figure 3) confirm that, inclusive or exclusive of outliers, these two dam dimensions exhibited log-normal distributions (respectively, $p = 0.5141$, $p = 0.7861$ including outliers; $p = 0.4494$, $p = 0.4508$ excluding outliers), reflecting common beaver dam metrics reported in the literature (Andersen and Shafroth 2010, Hafen 2017, Karran et al. 2017). This distribution is common in ecology since it describes low-mean distributions well and excludes negative values (Limpert et al. 2001).

Table 4. Summary of physical characteristics data used in study, from traversed or observed beaver dam field survey areas

Survey area code	Survey area description	Channel length traversed (km)	Stream length (km)*	Number of dams	% active dams	% dams within bankfull channel	% dams located on main channel or across its width	Channel length dam density (dams/km)	Stream length dam density (dams/km)	Stream length dam density outlier?
SA-1	Arroyo Seco River	5.5	5.5	7	57.1	100.0	57.1	1.3	1.3	N
SA-2	Lockwood-San Lucas NW	6.2	6.2	4	50.0	100.0	25.0	0.6	0.6	N
SA-3	FHL Stony Creek	1.1	1.1	11	54.5	100.0	90.9	10.0	10.0	Y
SA-4	FHL Arroyo Toad Habitat	8.4	8.4	7	85.7	100.0	100.0	0.8	0.8	N
SA-5	CR Lower San Antonio River	7.3	7.3	11	81.8	100.0	100.0	1.5	1.5	N
SA-6	CR Lower Nacimiento River	5.6	5.6	3	33.3	100.0	33.3	0.5	0.5	N
SA-7	CR East, Salinas River	3.2	1.9	2	0.0	100.0	100.0	0.6	1.1	N
SA-8	Paso Robles WWTP - Niblick Rd	4.8	2.0	6	16.7	100.0	66.7	1.3	3.0	N
SA-9	Highway 41 - Halcon Rd	6	3.8	16	87.5	100.0	100.0	2.7	4.2	N
SA-10	Santa Margarita Truck Trail - Salinas Reservoir	1.1	1.1	2	50.0	100.0	100.0	1.8	1.8	N
	Totals	49.2	42.8	69	63.8	100.0	81.2	1.4	1.6	N/A

*Primarily intended to distinguish survey areas where the channel length traversed did not have flowing or ponded water in significant portions. “Stream length” was measured in Google Earth by tracing the active stream from where survey area water or recorded beaver dams began (whichever came first) to where they ended, referencing GPS points taken in the field. Intended to approximate current and recent surface flow and ponding extent at the time of field surveys.

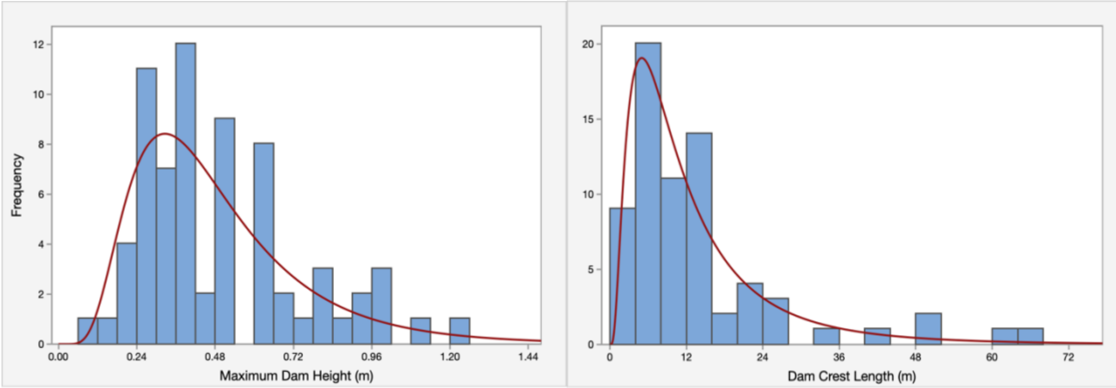

Figure 3. Aggregate beaver dam heights and lengths from 69 dams among 10 survey areas; both variables fit log-normal distributions.

ANOVAs performed on dam heights and dam lengths with survey area as an explanatory variable (Figure 4) revealed statistical significance (respectively: $f\ (9, 59) = 5.07$, $p < 0.0001$; $f\ (9, 59) = 9.22$, $p < 0.0001$), with Tukey-Kramer HSD tests showing "FHL Stony Creek" dam length differing statistically significantly from all other survey areas (all with p-values ≤ 0.0028). Dam height for this survey area only differed statistically significantly from "Arroyo Seco," "Highway 41 – Halcon Rd," "Paso Robles WWTP – Niblick Rd," "CR Lower San Antonio River," and "CR East, Salinas River" (all with p-values ≤ 0.0027). The one-tailed, two-sample t-tests (Figure 5) for the stream reach dam densities of the two noted survey areas, "Highway 41 – Halcon Rd" and "FHL Stony Creek," revealed a statistically significant difference for "FHL Stony Creek" when it was compared against all other survey area stream reach dam densities ($t = -2.38075$, $df = 39$, $p = 0.0112$). However, no statistically significant difference was detected for "Highway 41 – Halcon Rd" when it was compared against all other survey area stream reach dam densities, minus those from "FHL Stony Creek" ($t = -1.58698$, $df = 35$, $p = 0.0609$).

It is important to note how "FHL-Stony Creek" was a relative outlier compared to the other nine survey areas for this study. Specifically, that dam length was significantly different in "FHL-Stony Creek" when compared to all other survey areas, but not so for dam height, suggests an individual dam's horizontal spread in this basin may be more limited by higher-order stream environments than its vertical spread. Comparing individual survey areas to "FHL-Stony Creek" indicates a few contributing environmental factors to the noted difference. In terms of dam length, channel entrenchment or confinement can limit the maximum extent of a dam within the main channel, perhaps most apparent in “Highway 41 – Halcon Rd.” In terms of dam height, less significant variation from “FHL Stony Creek” may be due to the conditions that enable dam building in “Lockwood-San Lucas NW,” “CR Lower Nacimiento River,” and “Santa Margarita Truck Trail – Salinas Reservoir”: the few dams observed were either in side channels, proximate to river bends, in areas that received less water or experienced smaller stream powers, or were otherwise opportunistic and appeared to make use of large-woody debris that could withstand higher stream powers (Figure G-1). Though these types of dams were not unique to these streams (i.e. some were found in “CR Lower San Antonio River”), their relative prevalence among the few dams identified may be the statistical reason for no significant differences in these survey areas. In the case of “CR East, Salinas River” and “Paso Robles WWTP – Niblick Rd,” the high percentage of inactive, small dams likely contributed to the significant difference in heights, while the abundance of water and low gradient in “Highway 41 – Halcon Rd” likely led to its high number of small-stature dams.

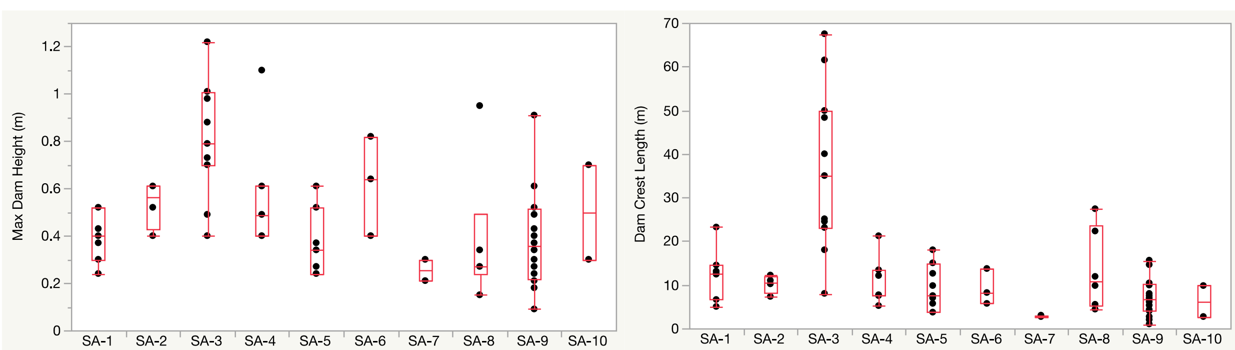

Figure 4. Box and whisker plots of beaver dam heights and crest lengths by field survey area. Heights for SA-3 differed statistically significantly from SA-1, 5, 7, 8, and 9. Lengths for SA-3 differed similarly from all other survey areas.

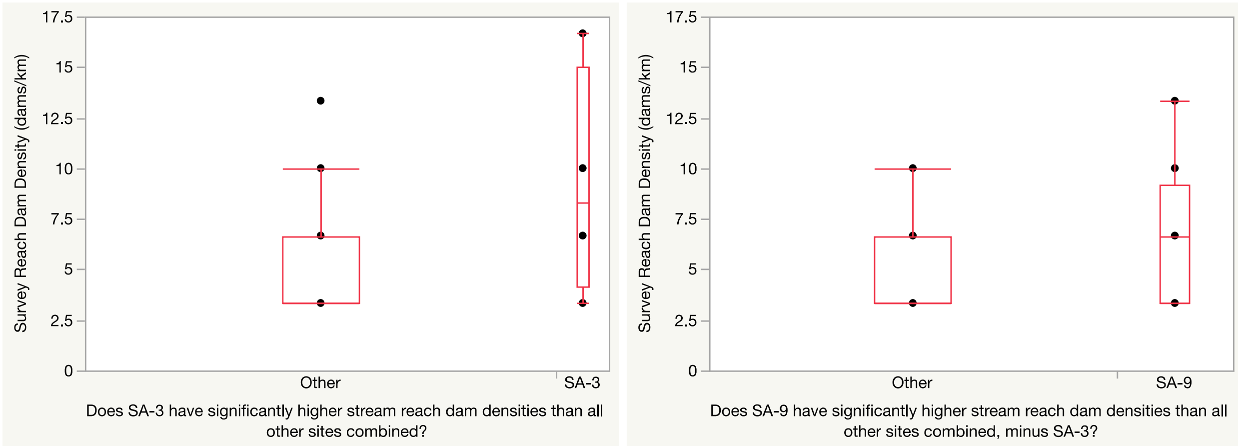

Figure 5. Box and whisker plots of beaver dam stream reach densities. Left: SA-3 exhibits a statistically significant difference after performing a one-tailed, two-sample t-test. Right: SA-9 exhibits no statistically significant difference from the same test.

It was interesting to note that despite contrary perceptions of an unusually high frequency of dams observed in the field, “Highway 41 – Halcon Rd” did not exhibit a statistically significant stream reach dam density when compared to other mainstem and major tributary survey areas. Nor was it an outlier in terms of its total survey area stream length dam density. One potential explanation lies in Table 4. It shows that compared to “Paso Robles WWTP – Niblick Rd” (which possessed a survey area stream length dam density that largely contributed to the finding of no significant difference), the number of *active* dams was significantly lower there than in the Atascadero survey area. While the number of recorded active dams at this survey area was likely greatly affected by both the late seasonal timing of the field surveys, as well as riverbed access constraints (which prevented originally planned surveying past the Paso Robles wastewater treatment plant property line – at which an unusually large dam had just been recorded, and where similarly sized dams appear in Google Earth satellite imagery), it is possible that a dearth of abundant beaver activity made this area feel comparatively isolated. Indeed, to determine if a certain location is a damming hotspot based only on dam count per unit area can be misleading, since it does not account for habitat quality to sustain damming – a factor which a dam’s activity status during late autumn only begins to reflect. Thus, it is possible that the Atascadero survey area can be considered a relative damming hotspot on the level of “FHL-Stony Creek,” since unlike its Paso Robles counterpart, it appears more abundantly dammed later into the year or year-round. Both "FHL-Stony Creek" and "Highway 41 – Halcon Rd" may therefore be good candidates for future beaver ecosystem impacts studies, especially to compare against other survey areas, or other lesser- or non-beaver dammed stream reaches.

Determining the exact reasons that "FHL-Stony Creek" (and likely "Highway 41 – Halcon Rd") was a relative damming hotspot was beyond the scope of this study, but a summary of possible reasons may be instructive. These reasons include: its location on a low-order stream at the base of a relatively small reservoir in comparison to the nine other survey areas, which were on higher-order mainstems or major tributaries with more extreme and variable stream powers (Naiman et al. 1986); its higher average-reach slope (1.11%) than all other surveyed areas, since steeper slopes may encourage greater damming densities to pond and slow water flow up to about a 4-9% gradient range (Retzer et al. 1956, Beier and Barrett 1987, McComb et al. 1990, Suzuki and McComb 1998, Macfarlane et al. 2017), as Figure G-2 would support; a relatively wide and thick riparian buffer, which provides plenty of dam building and dam maintenance material; a greater percentage of clay, silt, or loam in the riparian soil than in other survey areas within similar 'Corducci-Typic Xerofluvents, 0 to 5 percent slopes, occasionally flooded, MLRA 14' and/or 'Elder sandy loam, 0 to 2 percent slopes, MLRA 14' soil map units (USDA-NRCS), which perhaps contributed to a thicker and more stable dam composition (Butler 1989, St-Pierre et al. 2017); that it was on Fort Hunter-Liggett, which has extensive environmental protection programs in place, with rare human disturbance occurring at that specific location; and that the ANOVA was only as good as the analyzed group data. For the lattermost, it must be noted that a single year of field surveys does not account for variation in time and changing environmental conditions. Beaver dam data for surveyed sites could have been substantially different under different flow discharges. They may therefore not be representative of an average year's dam distributions in each survey area.

This lattermost point stated, it is worth noting that for mainstem and major tributary reaches (i.e. high-order streams) across the Salinas River basin, and not just in certain areas of it, the collected data in Table 4 strongly support beaver damming dynamics characteristic of semi-arid and arid environments

(Gibson and Olden 2014). Particularly, the contrast between dam activity status and main channel location categories for certain survey areas appears to confirm that seasonal damming across the mainstem occurs as winter high-flow or flood conditions recede. As seen in Figure G-3, for "CR East, Salinas River," both small and inactive dams were found in the dried-up, narrow baseflow channel, river-left along the main channel, while, as previously discussed, "Paso Robles WWTP – Niblick Rd" suggested similar dynamics. This pattern hints that during the winter or high-flow season, mainstem beaver may rely only on larger, more stable dams or established bank dens or lodges as shown in Figure G-4, if at all, and then attempt to maximize the extent of their habitat or home range with dams and canals as the dry season begins and surface flows and intermittent surface water gradually decrease and disappear (Figure G-5). Likely reasons for this behavior would be to maximize safe foraging habitat temporarily and/or otherwise alleviate population pressures that may occur as the dry season progresses due to a home range that could become more constrained and beaver-concentrated (Gurnell 1998, Baker and Hill 2003, Fischer et al. 2010). However, it is difficult to say with certainty that dry season home ranges or utilizable habitat would be more limited than during the winter, as it is unclear if mainstem dens or den-able banks with suitable vegetation and suitable stream powers would be more limited under high flows than under baseflows (which measure 0 cms, or close to it, in many Salinas River stream reaches, especially in the lower basin). Contributing to this uncertainty is Parish (2016), who found that for her large river environment study area, beavers utilized lower-order intermittent streams more during the winter than summer. Thus, during basin high flow conditions, beaver in the Salinas River basin may rely upon a different home range or utilizable habitat distribution whose degree of limitation, when compared to baseflow conditions, could not be determined from this study.

Beaver Damming Consistency Range Map

Of the 125 organizations, professionals, and private landholders contacted through the pre- and during-survey screening and referral process, 46 (36.8%) completed the survey or alternative semi-structured phone interview format. Of these participants, 36 gave affirmative responses to the analysis filter question, “Have you observed beaver or signs of beaver within the Salinas River basin?” and were considered for both: (a) obtaining beaver damming location and consistency data, and (b) CAQDA of the survey questions. (There was one exception – a Pinnacles National Park biologist who noted no beaver presence records in his jurisdiction for decades.) Additionally, information provided from three in-person interviews was considered for both purposes. Various email communications with professionals or residents, who were sent the emailed survey but did not have time to complete it, were also used for beaver damming location and consistency data, or obtaining photographed documentation for range map purposes.

The 65 sub-watersheds that were assigned observational reliability and damming consistency classifications are shown in Figure 6. Three Estrella River sub-watersheds (Pine Creek-Estrella River, Keyes Canyon-Estrella River, and Town of Estrella-Estrella River), and three Gabilan Creek sub-watersheds (Natividad Creek-Gabilan Creek, Alisal Slough-Tembladero Slough, and Elkhorn Slough) outside the study area were included to accommodate beaver activity location data points from the emailed survey, and because of their inclusion in the Salinas River basin boundaries of past studies (e.g. Worcester et al. 2000, Casagrande et al. 2003). Of these assigned sub-watersheds, 44 (67.6%) received ‘A’ and ‘B’ consistency classifications, divided equally between the two. In general, the lower-half of the Salinas River basin contains more ‘B’ than ‘A’ consistency classifications, with the ‘A’ concentrated in the area surrounding the city of Salinas, Arroyo Seco River, and San Antonio River. For the upper Salinas River basin, the opposite occurs: there are more ‘A’ consistency classifications that occur along the mainstem Salinas River below Santa Margarita Lake. In general, eastern tributaries appear to lack damming and other forms of beaver activity, with the exception of Estrella River.

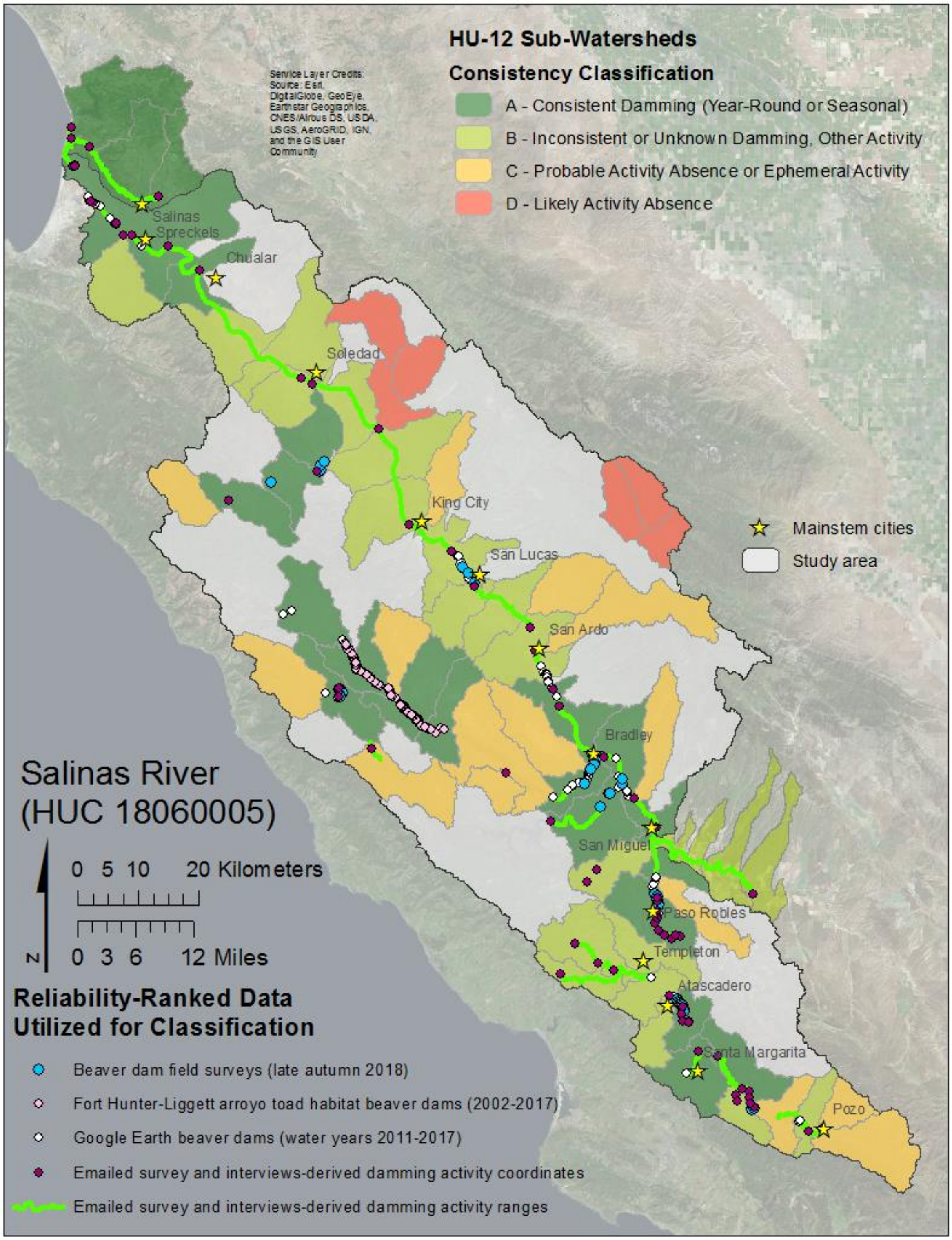

Figure 6. Beaver damming consistency range map, classified by USGS sixth-field hydrologic units with specific areas of beaver damming or other activity shown with different data categories.

These results are logical since the geographical distribution of high consistency damming appears tightly coupled with human-influenced water flow, with beaver dams occurring with flow-regulated or human-sourced water in approximately 68% of 'A' sub-watersheds. For the mainstem, these results are also not surprising since considerable lengths of the lower Salinas River are ephemeral, except where agricultural drainage and urban-runoff occurs from the Gabilan (or Reclamation Ditch) watershed (Casagrande et al. 2015). 'A' consistency classifications occurring in the upper Salinas River can be attributed to several sources. Downstream of the San Antonio and Nacimiento Rivers, along with the tributary reaches that are below their respective dams, beaver presence is influenced by perennial flow regulation of the respective rivers. Further south along the Salinas River, the following are sources of beaver damming and habitat: discharge from the Paso Robles wastewater treatment plant and other urban operations; springs with connection to the Salinas River (e.g. Franklin Hot Springs); and perennial flow regulation from Santa Margarita Lake, based on visible surface water at eight locations between the Salinas Dam and the confluence of the Nacimiento River (SWRCB 1972).

The other western tributaries with 'A' consistency-classifications are explained by their hydrology. The Arroyo Seco River is largely perennial, thus providing a reliable water source for beaver damming where geomorphological and ecological features are suitable. The different hydrological regimes of the Nacimiento and San Antonio watersheds can also help explain beaver damming frequencies upriver of the reservoirs: in the San Antonio watershed, its lower rainfall and storage in the shallow alluvial aquifer of the Lockwood basin, as opposed to the high runoff rate occurring within the Nacimiento watershed, indicates that springs along the San Antonio River provide a sufficiently reliable annual source of intermittent and perennial surface flows (Nacitone Watersheds Steering Committee and Central Coast Salmon Enhancement 2008, Hancock 2009). Downstream of these watersheds, flow release rates likely affect the relative proportion of beaver damming observed. For instance, because Nacimiento Lake receives on average three times the amount of inflow as San Antonio Lake, dam operations factors this difference into release rates, aiming to create a 3:1 ratio of empty space in reservoir storage between the two before the rainy season (MCWRA 2018). Therefore, the corresponding greater flow from

Nacimiento is probably a significant determinant of the apparent contrast in beaver damming density between these two flood-regulated rivers.

Streams within ‘B’ classified sub-watersheds (Estrella River, Paso Robles Creek, Salinas River above Santa Margarita Lake, Salinas River between Atascadero and Templeton, and Salinas River between San Ardo and Castroville) and lower-ranked ones deserve more investigation than this upper basin- and mainstem-biased study affords them. That is, inferring beaver damming conditions is prone to error when based on (a) few reliable or specific survey respondent observations and (b) the lack of observed dams through snapshot-in-time Google Earth satellite imagery for these areas. For example, respondents who noted beaver in the Estrella River indicated that there are springs at various locations throughout it. If so, and if they are springs with regular surfacing or runoff into the river, the imagery does not capture these. In any case, the lack of a positive is not equivalent to a negative. Beaver activity or damming field surveys, especially over time or in different environmental conditions, may suggest that different damming consistency classifications are more appropriate for these sub-watersheds.

CAQDA Themes: Basin-Specific Beaver Behavior and Local Human Dimensions

A final hierarchy of NVivo 12 qualitative data nodes were analyzed and categorized into seven themes, which are treated individually below and generally progress from beaver ecology and behavior to human dimensions. Topics discussed in each are generally useful to know for human dimensions-inclusive BAR planning, through better understanding basin beaver population dynamics, current beaver management, and local attitudes towards beaver.

It is acknowledged that the first four themes below would certainly be more comprehensively addressed through regular field surveys, radio-telemetry, and other techniques commonly seen in beaver biology and ecology studies (e.g. Havens 2006, Fischer et al. 2010, Müller-Schwarze 2011). Similarly, so would the fifth through seventh themes with more resource-intensive attitude surveys (e.g. McKinstry and Anderson 1999, Needham and Morzillo 2011). However, with limited resources for this study, and this study's overarching goal, the emailed survey and interviews were considered sufficient for this method's exploratory purpose.

Theme 1: beaver habitat within the basin

Largely due to emailed survey questions regarding beaver sighting locations and persistence at these locations, participants (study cases) had the opportunity to explain factors that they thought contributed to the frequency of observations at their noted sites. Unsurprisingly, the need for a reliable water source arose as a critical habitat requirement for consistent year-round activity, or at least consistent dry season activity. One study case, a CDFW warden, noted for the San Miguel area south to Atascadero that "I have observed their consistent presence in areas where there is perennial water sources or over-summer water is held in their dam areas [or where there are] perennial water areas with associated agricultural ponds." Other cases with observations further south near Santa Margarita similarly noted or suggested the necessity of a perennial water source (releases from the Salinas Reservoir) for beaver presence, including a San Luis Obispo County Parks ranger: "In the main Salinas River below the Salinas dam, activity is consistent and year around from the dam to Hwy 58 and beyond." Yet even further north, in the lower Salinas River between San Ardo and the city of Salinas, this pattern was upheld, with a city of Salinas employee noting that beaver are most visibly active in the mainstem areas during low flows and where there are islands of willow (*Salix* spp.). And a coordinator for an agriculture-cooperative river maintenance program summarized habitat requirements more broadly for the locations where she had identified beaver dams: "All these areas are low gradient…have willow forest immediately nearby and perennial water due either [to] ag drainage likely or groundwater."

In general, these responses support how a combination of human operations and springs provides the low-velocity water for beaver damming across most of the study area. However, it is unclear if human dams have augmented surface water flow that would have already been upwelling from spring location(s) downstream of these operations before the construction of these human dams. Also unclear is the extent to which beaver in relative damming hotspots such as "FHL Stony Creek" have helped create, sustain, or grow these hotspots through potential expansion of perennial-flow extent (Pollock et al. 2003). But not in the least is this ambiguity due to the lack of historical ecology or hydrology data collected and investigated for these areas during this study. As an example, as Pollock et al. (2003) show and Lautz et al. (2005) imply, whether or not beaver dams can transform nearby intermittent stream reaches into perennial ones depends on how hyporheic flow dynamics are altered for local, geologically and hydraulically complex soils.

Aside from a reliable water-source for beaver to consistently occupy an area, suitable streamside or in-river vegetation availability is a critical requirement for basin beaver populations, as the previous program coordinator and city of Salinas employee alluded to. While literature has established this notion generally (Hall 1960, Barnes and Mallik 1997, Breck et al. 2001), two Santa Margarita area residents helped paint a partial understanding of specific, preferred vegetation for upper basin beaver. In response to broad questions regarding beaver activity and signs thereof, one of these residents noted that the beaver on his property most notably feed on willow (*Salix* spp.), and graze on duckweed (*Lemna* spp.), as shown in Figure G-6, seeming to leave sycamore (*Platanus racemosa*) and oaks (*Quercus* spp.) alone. Meanwhile, the other resident, downstream of the previous, who was “a retired biologist, mostly marine and freshwater but with some terrestrial experience,” noted that “Their preferred food (here at least) is the cattail reed (*Typha* spp.)….Most of their food seems to be cattails, probably because cattails are so dense here and are easier to pull out and eat....” Indeed, willows, cattails, duckweed, along with Fremont cottonwoods (*Populus fremontii*) and other reeds and grasses were common south through the “Paso Robles WWTP - Niblick Rd” survey areas, with multiple beaver chews noted on cattail stalks, willows, and cottonwoods during field surveys. Along the Nacimiento, San Antonio, and Arroyo Seco Rivers, sycamore seemed to be utilized more (Figure G-7) in addition to willow, Fremont cottonwood, and likely other local riparian hardwoods matching known beaver preferences, such as box elder (*Acer negundo*). Yet in general, herbaceous riparian vegetation such as cattails and duckweed appeared more abundant and commonly utilized in the upper basin mainstem areas than in the survey areas further north, despite the abundance of willow throughout most observed and participant-noted beaver damming locations in the basin. If these perceived differences across the survey areas reflect the sum of upper basin beaver habitat in general, it may help explain beavers' apparent, wider-ranging mainstem occupancy and damming frequency than in the lower basin. Beier and Barrett's (1987) findings would support this notion, as they found that beaver within the Lake Tahoe basin chose herbaceous riparian vegetation over woody plants for forage when it was seasonally available.

Of course, it must be emphasized that flow discharge or stream power, land use, and other factors also contribute to beaver population and damming density, if not with greater weight than vegetation, in part since Beier and Barrett (1987) also found that riparian vegetation species added little explanatory power to their modeled beaver habitat use equations. Indeed, to say that basin beaver have a preference for any one plant species based on a few anecdotes may be confounding. After all, beaver may help promote observed herbaceous species wherever they dam, instead of vice versa (Baker and Hill 2003): most cattail and duckweed locations concentrated in the upper basin mainstem reaches would benefit from beaver ponds, which create the gentle- to no-flow conditions favorable for their growth (Hillman 1961). Since seasonal dams in most basin areas are strongly suggested, this duckweed supply may therefore be highly seasonal, as high flows would thereby diminish duckweed availability. Beavers might then shift to a higher consumption of willow and other hardwoods (Svendsen 1980, Roberts and Arner 1984). Yet even in this case, seasonal dams promoting duckweed growth would likely be more prevalent or longer-lasting in the upper mainstem and other areas with smaller drainage areas, due to the smaller floods typically associated with these reaches.

Still, these survey results add more nuance to Gordon (1996), who wrote that in the lower basin mainstem, "Its principal foods here are cottonwood and willow; the beaver seems to prefer cottonwood although the willow is much more plentiful" (pg. 189-190). With field survey areas and observations skewed toward the upper basin, when Gordon is interpreted with these and the emailed survey and interview results, it suggests that beaver food preferences and selection will vary across the basin depending on local-scale availability, ease-of-access, and predation exposure (Engelhart and Müller-Schwarze 1995). However, willow, cottonwoods, cattails, duckweed, and herbaceous riparian species can generally be considered top preferences, while box elder, sycamore, and other hardwood riparian species are likely not as preferred, but still sufficient for feeding purposes.

Theme 2: beaver behavioral adaptations to basin conditions

The contrast between a few participants offers some insight to basin beaver population dynamics. The retired biologist in Santa Margarita noted that the beaver on his property “don't occupy the den year round. They seem to migrate upstream or downstream…seem[ing] to disappear during winter and reappear in spring. Each year they birth at least one kit here.” Meanwhile, the other Santa Margarita resident, mentioned previously, responded to this question about beaver seasonal movement and behavior by explaining that beaver on his property appear to stay in their dens during winter, when there are powerful flows. As these two locations are approximately 3 km from each other and similar in vegetation, slope, and flow that runs through them, it is possible that one of these long-time residents reported an erroneous observation. But what could explain the contrast if not? As the retired biologist added to his response,

> In the cold winter months the surface freezes. Last year the ice was about one inch thick, but about ten years ago it was over three inches….Surface freezing is usually greatest in February. The sun angle is low and cannot impact the river surface due to the steepness of the hill on the south side.

Thus, although beavers are adaptable to extreme climates, it is possible that foraging or other activities under winter ice conditions at this river bend are too energetically costly when compared to other available or shareable bank denning areas (Dyck and MacArthur 1992, Fischer et al. 2010). In other words, one could speculate that nearby ice-free spots have herbaceous or hardwood riparian vegetation that would be more readily accessible, removing a food-caching need associated with ice conditions (Baker and Hill 2003). Moreover, it is worth noting that beaver returning in the spring or to give birth at the retired biologist's frontage suggests that some study area beaver may disperse during higher flows to: (a) try to find a new home, (b) temporarily expand their home range, and/or (c) let vegetation regrow in limited or different home ranges which they could be concentrated in and rely upon during drier parts of the year (Hall 1960, Bergerud and Miller 1977, Wheatley 1997).

At the opposite end of the basin, these reasons for movement or migration may also hold water. First, a USFS Los Padres National Forest ranger for the Arroyo Seco Campground revealed that he has observed beaver activity during the winter but not during the summer, especially by the Abbott Lakes region of the Arroyo Seco River (Andrew Kenner, USFS Los Padres National Forest at Arroyo Seco Campground, personal communications, 17 October 2018). As these Lakes and the Campground are located further upstream than field-surveyed areas, and not all parts of the Arroyo Seco River are perennial, this observation would at least suggest that beaver regularly disperse or migrate upstream and downstream as hydrology allows (see also Figure G-5).

Second, a city of Salinas employee and an associated agency employee discussed beaver presence in the Reclamation Ditch sub-watershed (which extends from the extreme north end of the study area) in a way that similarly suggested this hydrology-dependent home range change or dispersal. The city employee had observed beaver in the city's Reclamation Ditch over a period of at least ten years. Since he also observed beaver in the Upper Carr Lake, in the intermittent Natividad Creek, he assumed beaver moved into this part of the city's channelized stream system when it started to release retained stormwater runoff from upstream development. Echoing these observations, the related agency's employee also added that in contrast to the Salinas River's riparian forest, the dominant ditch-vegetation composition shifts to cattail, with this preferred food perhaps adding incentive for a temporary movement into Natividad Creek.

Third, a city of Soledad utilities employee who has worked regularly near the river for ten years explained that he has occasionally seen live beaver swimming in the Salinas River. He added they typically swim upstream, and qualified these sightings as occurring only when the Nacimiento and San Antonio Lakes release water, or during a high rainfall, high flow winter season. He therefore supposed the beaver were searching for additional, more reliable water sources and habitat in the Arroyo Seco River, or further upstream along the Salinas River. That mentioned, he also discussed how when the river subsides, he has observed them dam by Soledad. During the phone interview, he sounded perplexed by this behavior, expressing that he was puzzled where these beaver go or do when the Soledad area and their dams then dry up. Explaining how he thought they could die, another albeit more far-fetched possibility would be that they dig. Indeed, a USDA-APHIS-WS trapper and a local environmental history expert's responses could be interpreted this way. The former shared a story of seeing beaver come out of dens in just 2-3 inches of water by the Paso Roble's Hwy 46 bridge – though he was unclear for how long they had been staying there or remained afterwards. Meanwhile, the latter noted: "…in the summertime, when the water goes below the surface of the Salinas River, then the beavers in the river will tunnel down to the water level for water.…usually, they will go as deep as 25, 30 feet." From what could be identified in the literature, nowhere has a near-vertical well-digging behavior been noted, except with a prehistoric ancestor of North-American beaver, *Palaeocastor fossor*, in which maximum vertical burrow depths up to 2.75 m were recorded (Martin & Bennett, 1977). Of course, this literary absence raises a clear possibility that the local environmental historian's statement is exaggerated, misattributed, or wrong, especially since beaver digging or tunneling for denning purposes is typically upward oriented (Lisle 2010), and because beaver can travel overland great distances if necessary (Chubbs and Phillips 1994, Müller-Schwarze 2011). Yet when paired with the trapper and utilities employee's observations it also can be speculated that Salinas River basin beaver may use near-vertical burrows to access any existing, shallow groundwater tables of the Salinas River for water and predator protection. However, if such behavior exists, it is likely far from ideal, and is probably least energy intensive where the river channel has a close-to-surface water table, or is adjacent to surface water flow. Thus, if any near-vertical digging does occur, it would perhaps make the most sense if it is used to assist in safer overland returns to the nearest perennial surface waters. These would likely occur as surface flows begin to disappear from isolated, intermittent stream reaches by areas like Soledad.

The possibility of well-digging aside, of course, the emerging trend of regular movement and re-settlement that hydrological changes trigger would not be extraordinary. Beaver are well known generalists and opportunists, which the local environmental historian's words would certainly affirm for the Salinas River basin populations: "We found…dens along the river, various places, and [beaver would]…be in a bank of dirt, of loam there, and…when the river's up, it creates log jams – and the beavers would be in that." As discussed under the "Beaver damming hotspot areas" subsection in *Results and Discussion*, beaver dam heights on mainstem Salinas River survey sites did not differ as significantly from dam lengths when compared to "FHL Stony Creek," likely due to the nature of the fewer, opportunistic conditions that enable damming on the mainstem. This study case indicates similarly, echoing observations from Wohl (2013) on beavers frequently using large woody debris as foundational damming material (see Figure G-1). In other words, along mainstems and major tributaries, large woody debris and similar, high flow-resistant environmental features may influence where beaver dam or build bank lodges and dens after hydrology-triggered dispersals.

As noted previously, it is unclear if winter or high flows would expand or contract beaver home ranges and activities across the basin on average. However, for at least intermittent streams, activity may increase: Parish (2016) found that beaver activity specifically increased in these areas of her large river environment study area during the winter; relic beaver evidence in the intermittent Santa Margarita Creek (see Figure G-8) during one field survey could support this finding's application to the Salinas River basin. Contrarily, damming would likely decrease, on average, as it is strongly suggested under "Beaver damming hotspot areas" that dams in high-order streams are generally seasonal, highly opportunistic, and built most frequently as high flows recede.

Finally, in terms of other factors that cause regular movement, or help determine new denning or damming locations arising from it, a resource conservation district employee remembered hearing from landholders during a project site visit "that beaver continue to move around the area. Vacating a location when they are harassed." While this study case did not explain this harassment, these landholders may have meant that locals would consistently destroy beaver dams, bank lodges, or dens, or otherwise try to disrupt a recurring beaver nuisance through other non-lethal or lethal means. Another, literally human-driven deterrent may be recreation: a Paso Robles environmental consultant discussed how off-road vehicles have destroyed beaver dams in Atascadero, besides being a general detriment across Salinas River soils and habitat. He noted one memorable moment when he noticed a driver destroying a beaver dam to remove their stuck, water-logged vehicle.

However, while the latter may cause beaver to move out of other, marginally suitable habitat or damming areas, the Atascadero area mentioned may be different due to field survey-observed abundant vegetation and ongoing damming. This vegetation and damming density indicated that there are sufficient resources and unimpacted areas within these surveyed stream reaches at “Highway 41 – Halcon Rd” allowing beaver to stay and continually rebuild their dams.

Theme 3: human perceptions of beaver population change

Of course, survival underlies regular beaver movement and re-settlement across the basin, and discussion about it. When asked to rank how they perceived changes to beaver populations or activity since they began observing the aquatic rodent, from a five-point scale of ‘Large decline’ to ‘Large increase,’ with an additional option for ‘Not sure,’ study cases gave responses shown in Table 5.

Table 5. Perceptions of changes over time to beaver population numbers and activity presence, with study cases categorized by area and time extent of their observations.

Spatiotemporal knowledge category	Decrease	Unchanged	Increase	Not sure	Total (*n* = 39)
Regional-Extensive	1	4	0	6	11
	9.09%	36.36%	0.00%	54.55%	100.00%
Specific-Extensive	6	7	1	4	18
	33.33%	38.89%	5.56%	22.22%	100.00%
Regional-Minimal	0	0	0	2	2
	0.00%	0.00%	0.00%	100.00%	100.00%
Specific-Minimal	2	1	1	4	8
	25.00%	12.50%	12.50%	50.00%	100.00%

While this type of perception data and its associated anecdotal information must be interpreted with caution to understand possible population changes over time, using the perception data shown displayed in Table 5 is not unwarranted. For instance, Bevilacqua et al. (2016) found that using fishers' ecological knowledge should "not be disregarded" (pg. 14) based on the consistency of their findings with previous studies, which found agreement between scientific data and local fisher knowledge. Further, there is precedent within the Salinas River basin: a majority of historical steelhead trout knowledge comes from interviews of local families, conducted and summarized by a former science teacher (Funk and Morales 2002). However, one could still argue that beaver-observers are not the same as the fishers in these two examples, especially as many study cases noted their observations were subject to happenstance over time. (Highlighting this concern, one marine programs manager was curt: "infrequent observations cannot be used to drive population data.") Although true, this shortcoming does not negate the data's potential value if they are interpreted cautiously. Moreover, after conducting a historical records review, a glaring lack of historical records on basin beaver was apparent. This suggests that relying on remembered sightings and interactions, even if infrequent, may be the only choice for understanding possible beaver population changes from recent history to the present. Certainly, these should be triangulated with other participants, where possible, and treated critically.

Therefore, to facilitate this cautious interpretation and better understand potential cross-landscape variation in changes to beaver populations and activity persistence, the decision was made to compare perceptions by spatial and temporal extent of knowledge, as shown in Table 5. The former was defined by regional (the focus of the response or its convincing details was for more than one location over more than two HU12 sub-watersheds, or across a major tributary) or specific (for only one location or several within one or two HU 12 sub-watersheds), and the latter by extensive (greater than 15 years of experience) or minimal (less than or equal to 15 years of experience). Furthermore, assisting trend interpretation was an ensuing open-ended question that asked cases to explain their responses.

Trends from Table 5 suggested that "Specific-Extensive" observations would be the most insightful since the majority of spatiotemporal knowledge category cases, except those from this category, communicated that they were 'Not sure' of any changes. Specifically, it was interpreted that the greater variation in responses among the "Specific-Extensive" category when compared to the "Regional-Extensive" category would better inform understanding of these regional observations, since after 'Not sure,' the most frequent response among "Regional-Extensive" was 'Unchanged.' Comparing the responses between only the extensive spatial extent groups was also justified based upon reliability, since scrutinized study case responses indicated that the minimal group likely had more infrequent observations (approximately 70%) than their extensive counterparts (about 24%).

In comparing these two extensive spatial extent groups, an apparent contrast emerged, likely due to location and scale of experience. This contrast is articulated well when comparing 'Decrease' to 'Unchanged' responses (Table 6). In Table 6, located observation extents for 'Unchanged' show a bias towards areas of the basin earlier identified in this study that have reliable, perennial water (i.e. mainstem Salinas River and tributaries benefiting from flood-regulation and springs). Observations for 'Decrease' were nearly the opposite: they occurred in minor tributaries, eastern parts of the basin, or areas of the Salinas River mainstem known to receive little flow, if not dry up during significant parts of the year.

This contrast evident, three study case observations called for particular attention next. Two of these were from study cases whose "Specific-Extensive" >> 'Decrease' responses seemed to highlight the potential role of local resource consumption in reducing beaver habitat in these more water-scarce basin regions. Although it is unclear whether Rinconada Creek and Cienega Creek have experienced long periods of no-flow conditions in the past, it is concerning that these study case observations touch upon similar themes. For instance, Response 3 in Table 6, which came from a Templeton resident, conveyed that most of the wildlife on her property disappeared right after she and her husband bought the property. She described how this loss was associated with declines of instream flow, which she attributed to upstream irrigators and Whale Rock Reservoir (though the latter is dubious based on its distance and probable hydrologic disconnection to Cienega Creek, one of the creeks near her property). Meanwhile, Response 1, from a San Luis Obispo County Parks ranger, was as follows:

> I have stopped many times on my commute to the lake to look for signs of beaver in Rinconada Creek along W. Pozo Rd. I witnessed consistent activity in the creek between 2001 to 2011-ish but no activity since then.…The decline in beaver in Rinconada Creek in my observations has been large, meaning they used to be there and now they're not. Water flows in Rinconada creek between 2001 and 2011 were greater and more consistent; I assume recent droughts and ground water extraction activities on adjacent ranches may have contributed to the decline in water flows of Rinconada creek but not certain on that. It's important to note that there has been a significant decline in the density and diversity of riparian vegetation along Rinconada creek since approximately 2011; probably due to declining water flows.

These extraction activities, combined with their lack of flow regulation-based groundwater recharge and an increasing climate change-driven frequency of regional droughts (Diffenbaugh et al. 2015, He et al. 2018), can altogether make it feasible that consistent beaver population presence in these creeks and other minor tributaries have declined or are at risk for long-term decline (Persico & Meyer, 2009).

However, the third study case observation seemed to question whether this potential pattern would be limited to minor or unregulated basin streams. In Response 1 to ‘Regional-Extensive’ >> ‘Decrease,’ this Gonzales resident remarked “I've lived in the Salinas Valley all 65 years of my life. I have seen beaver habitat dwindle from areas near Nacimiento River to now only very northern areas,” suggesting beaver habitat is declining across even regulated streams. But due to groundwater extraction in the basin, it is doubtful that this observation is entirely correct. More precisely, groundwater-dependent surface baseflows along the mainstem and major tributaries are not as extensive as needed for this dwindling to occur (Howard and Merrifield 2010). Groundwater pumping changes over time also would not support the study case observation, as they have decreased instead of increased since study area dams were constructed: between 1972 and 1983 ground water pumping declined from 530,000 afy to 430,000 afy (from a high of 620,000 afy in 1962) and since then has only risen to an average of 500,000 afy for Monterey County aquifers (Brown and Caldwell 2014). With the presence of flow regulation, the increased frequency of droughts are therefore likely a bigger influence on surface water flows and beaver habitat in mainstem and major tributary streams – not localized human groundwater consumption.

Even if droughts are the main factor for understanding recent historical or future changes to beaver habitat along these higher-order streams, the changes that this third study case suggested are still likely not as extreme, noticeable, or at least as long-term as one may think based on his opinion. Principally, severe beaver population or habitat changes that might be expected from droughts could be cushioned, at least in the short-term, from flow regulation and other human flow inputs to the mainstem and large tributaries. For instance, though a National Oceanic and Atmospheric Administration (NOAA) Fisheries employee stated how "My assumption is the populations in the Salinas River basin were affected by the drought…the mainstem of the river was dry for nearly 100 miles for multiple years (2014 and 2015)," Google Earth satellite imagery for April 2015 challenges this statement in absolute (Figure 7). For when compared to June 2017, a wet year, Figure 7 shows that there appeared to be more dams in certain areas of the lower basin, which may only be explained by extended, lowered flow releases from the Nacimiento and San Antonio dams (Figure 8). The unusual relative timespan of these lower flows would perhaps have enabled beaver to dam water in more areas than under years with higher flows, or years containing more varied flow releases (Andersen and Shafroth 2010). Thus, during extreme droughts, beaver may adapt through relying more on their dam-building behavior to maximize their home ranges than under wetter conditions. (This maximization may lead to more and larger ponded surface areas along flood regulated streams during extreme droughts or short time periods during the dry season than if beaver were absent. Though not discussed in depth here or in Theme 4, such results could increase groundwater recharge along these streams during this time period – though they could also lead to conflict with downstream farmers or ranchers in terms of slowed water deliveries, whether perceived or real.)

In summary, these observations suggest that beaver may have lost regular home range over the past decades in some minor tributaries, i.e. areas where local groundwater extractions may have decreased baseflows, especially with increasing drought frequencies. However, it is unlikely that basin beaver populations as a whole decline precipitously during droughts, as beaver are a vagile species capable of traversing dozens of kilometers to reach flow regulated water (Chubbs and Phillips 1994, Müller-Schwarze 2011). Thus, at least as long as flow regulated water can be supplied, these mainstem and major tributary streams likely help basin populations weather extreme basin conditions.

Table 6. Summarized locations for spatiotemporal knowledge-categorized study case perceptions of potential beaver population changes. Shown are mainstem and major tributary vs. minor tributary, and unregulated (UR) vs regulated (R) trends for 'Unchanged' and 'Decrease,' respectively

Summarized study case response	Spatiotemporal knowledge category			
		Regional-Extensive		Specific-Extensive
Decrease	1	*Lower basin mainstem* (R)	1	*Upper basin minor western tributary* (UR)
			2	*Lower basin minor eastern tributaries* (UR)
			3	*Upper basin minor western tributary* (UR)
			4	*Upper basin mainstem, above Salinas Dam* (UR)
			5	*Upper basin mainstem, above Salinas Dam* (UR)
			6	*Eastern mainstem* [NOTE: technically, this location is outside of the study area – San Benito River in San Benito County] (R)
Unchanged	1	*Lower basin mainstem* (R)	1	*Upper basin mainstem and/or minor tributaries* (R/UR)
	2	*Upper basin mainstem* (R)	2	*Lower basin major western tributary* (R)
	3	*Upper basin mainstem; basin major western and eastern tributaries* (R/UR)	3	*Upper basin minor western tributary* (UR)
	4	*Upper basin mainstem; lower basin major western tributary* (R)	4	*Upper basin mainstem, immediately beneath Salinas Dam* (R)
			5	*Lower basin major western tributary and lower mainstem – confluence* (R)
			6	*Upper basin mainstem, beneath Salinas Dam* (R)
			7	*Upper basin mainstem, beneath Salinas Dam* (R)

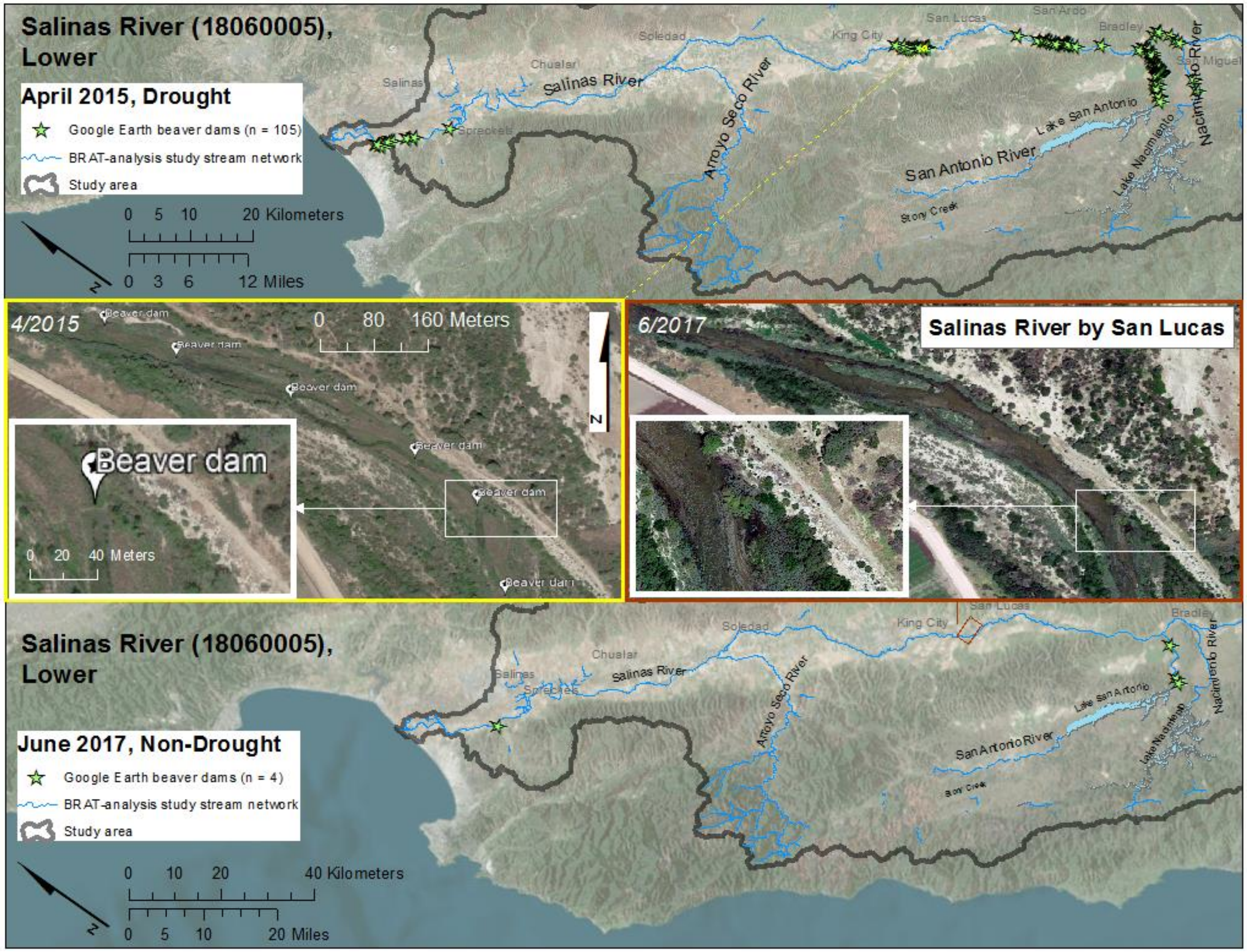

Figure 7. Beaver dam distribution differences between a drought and non-drought year, downstream from Nacimiento River, with inner frames indicating a heavily-dammed region by San Lucas during a recent drought.

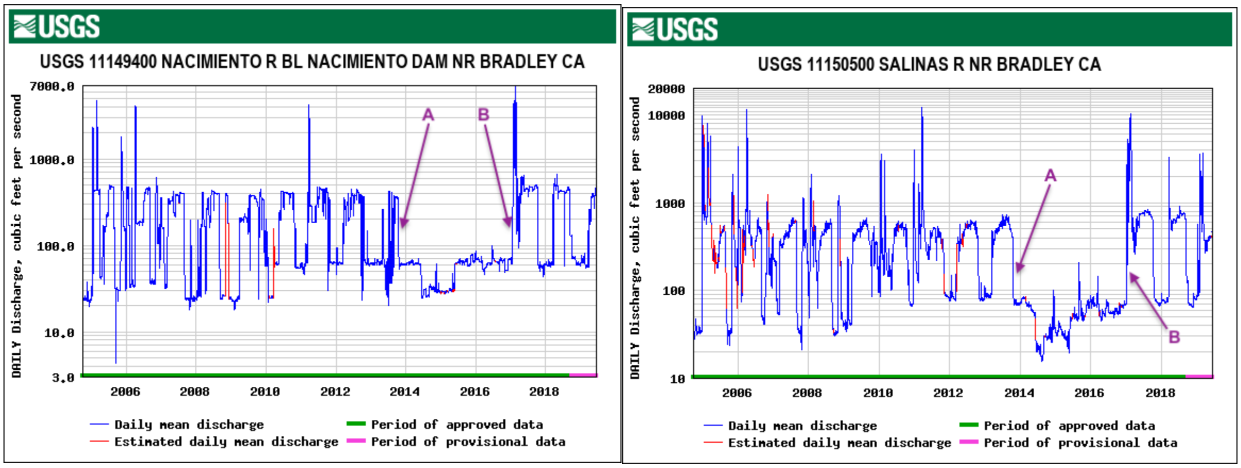

Figure 8. Daily mean flow discharge graphs (cfs) for two flood regulation-influenced lower basin USGS stream gages. Both demonstrate extended, drought-associated low flow conditions during 2014-2015, with significant peak flows occurring again in winter 2017. 11149400 (35.761389,-120.854444) is located beneath the Nacimiento Dam; 11150500 (35.930278, -120.867778) approximately bisects the Salinas River between San Ardo and Bradley. Points A and B indicate 175 cfs stream gage records. Since Anderson and Shafroth (2010) recorded most of their Bill Williams River, Arizona study dams being breached or damaged at flood pulses of this discharge, the time period they mark is likely a liberal estimate during which 4/2015 Google Earth dams were constructed, maintained, and affected mainstem and major tributary ecosystems.

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Theme 4: beaver impacts on basin riparian ecology and geomorphology

Table 7 overviews perceived beaver ecosystem impacts, as analyzed through study case responses to all questions. While it includes effects on human activity, to be referenced and discussed in ensuing themes, its “Ecology and geomorphology” part will be of focus for this subsection.

Most survey participants talked in positive terms about beaver impacts on bird, fish, and amphibian habitat. Frequently they mentioned how beaver ponds attracted “all types of wildlife,” as one Santa Margarita resident put it. The same resident also suggested an irreplaceable magnitude of beaver and beaver dams in his area, noting how they have created larger ponds and longer backwaters than a small earthen dam that his neighbors had established upstream in the 1970s. Raising the possibility of an irreplaceable dynamism created by the beaver pond and its simultaneous beaver activity, a Garden Farms resident and biologist recalled that “The beavers were active in the bank…until last year…Up until then I saw wood ducks in that area and yellow warblers, great blue herons etc. [Now] the area they were in [has] become stagnant.”

Table 7. Discussed or mentioned beaver impacts on riparian ecosystems, including humans

Beaver impact	Number of study cases (total n = 39)
Ecology and geomorphology	n = 17
Bird, fish, amphibian habitat	9
Invasive species	5
Willow or vegetation control	5
Seasonal ponding	4
Muskrat co-presence - possible den co-habitation	4
Erosion contributor	4
Steelhead migration	2
Human activities	n = 25
Associated recreation – wildlife viewing, fishing, swimming, etc.	13
Nuisance – flooding, water infrastructure, crops, ornamental trees	11
Watershed health engagement and education potential	6
Recharge and water delivery rates for agriculture	4

Meanwhile, especially in basin areas where there is less perennial water or ponding, multiple study cases indicated that beaver may offer seasonal benefits. A CDFW game warden "observed [beaver] where there [are] perennial water sources or over-summer water is held in their dam areas…[which] could provide water in summer months to wildlife in [the] Salinas River." An environmental consultant with years of stream morphology survey experience across the upper basin opined more boldly of this seasonal niche, saying that for the sandy Salinas River, which has a more modest average slope than many other rivers, perennial ponds will primarily arise from beaver, due to few bedrock channels that would otherwise more easily facilitate this process without beaver or human manipulation.

Further north in the lower basin, a USFWS biologist who works with Arroyo Seco landholders also treated seasonal water conservation as a potential benefit, writing that "beavers may contribute to preserving pools and water availability for other species including cattle, fish, and amphibians." Yet in contrast, towards the intermittent confluence of the Arroyo Seco with the Salinas River, the outlook appeared a bit bleaker, though still positive: the city of Soledad utilities employee in Theme 2 discussed that when beaver dams are built as high-flows recede, they attract wildlife and fish. Although he has noticed the fish die when these beaver ponds dry up, he considered the dams to be beneficial, thinking if nothing else these dams functioned as fish shelter, helping extend the fish's lifespans.

The benefits these study cases have noted for wildlife, especially birds, is well-recorded in the literature (see review in Rosell et al. 2005, Cooke and Zack 2008, Nummi and Holopainen 2014). The dynamism of the beaver pond is also unlikely to be exaggerated: as an example, when compared to large woody debris, Pollock et al. (Pollock et al. 2004) found that Coho salmon (*Oncorhynchus kisutch*) smolt production potential was 35-88x greater in beaver bonds than in ponds that were created by large woody debris alone. While it is easy to challenge the Soledad utilities employee's belief that the dams were beneficial for the fish – as another interpretation could be that they *trapped* the fish – the more pessimistic interpretation may not hold up to scrutiny. From one perspective, 'trapped' may be inappropriate terminology, as through beaver pond aerial surveys, Knudsen (1962) found that during severe drought years, beaver ponds were the only water sources remaining for trout across his central Wisconsin study area landscape. The hydrology of the Salinas River would also suggest that, if and when beaver begin damming in the Soledad vicinity, surface water flow would likely be diminished, returning to subsurface flow shortly downstream. Therefore, any fish still in this area by this time would be unable to reach the nearest perennial stream reaches in Arroyo Seco or near Spreckels, irrespective of whether beaver dams are present or not. Beaver dams that are present, then, appear to act as shelter in an area that would trap fish.

From another perspective, it is certainly possible that the study case's observations were of predominantly invasive species (Gibson et al. 2015), so these eventual fish deaths would be more beneficial than harmful (especially as the fish carcasses could provide an important food source for scavenger species). Supporting this possibility, the FHL biologist expressed how "[on FHL property] the greatest disadvantage to beaver is [their] positive correlation to nonnative and invasive species – water impoundments favor bullfrogs [*Lithobates catesbeianus*] and nonnative fish and crayfish [*Pacifastacus* *leniusculus*], which are threats to threatened, endangered, and sensitive aquatic species." Indeed, despite the potential of beaver dams to benefit the habitat requirements of endangered and threatened basin species (Appendix B), especially seasonally, any competition with invasive species within these seasonal beaver ponds could jeopardize potential beaver dam benefits. Nor are this biologist's observations, particularly acute on FHL property due to the endangered arroyo toad's presence (Hancock 2009), unlikely to apply to other areas of the basin, especially the few areas that may have year-round dams. As another study case, a hunter, brought up, "We have bullfrogs in [our Templeton creek,] too. We didn't have bullfrogs; this creek only ran with seasonal rains, it didn't have a native flow [before we drilled our artesian well]." Phrased more broadly, many of the study cases mentioning wildlife benefits did not name specific species. Those who did (such as the hunter) appeared unaware of whether the species were exotic or not, or minimized any ecological disruptions the beaver could contribute to (but not cause – i.e. humans have ultimately seeded many of these disruptions in the basin, e.g. the giant reed (*Arundo donax*)). In fact, at times they appeared to focus instead on the aesthetic and recreational benefits of beaver and beaver dams, and muse about educational ones (see Theme 7 and *Management Recommendations*). Thus, when taken together, the various values reflected in the study case responses about bird, fish, and amphibian habitat and invasive species support the overall conclusions of Rosell et al. (2005) and Gibson and Olden (2014). In these literature reviews, the respective researchers not only identified a need for long-term beaver ecosystem impact monitoring to better understand the effects of beaver on endangered and invasive species in semi-arid and arid environments. But they also called for reframing their detrimental and beneficial effects as tradeoffs to manage the potential significant costs of their dams appropriately.

One of these tradeoffs, then, may be a complicated picture of beaver and beaver dam effects on steelhead trout in the basin, especially its migration. Seemingly, the effects appear straightforward: neutral at the worst. The two study cases who mentioned or discussed the interactions of beaver dams with steelhead trout – the local environmental history expert and the environmental consultant – were under the impression that, due to basin steelhead trout migration waves primarily occurring during high-flow water year winter and spring seasons (NMFS 2013), it is unlikely that beaver dams are serious barrier threats to their migration. As the former put it: "the creeks where the steelhead run, there's a lot of water that comes through and will bust out the beaver dams or break them down, and flow a lot of water over them so fish can jump them." Echoing this sentiment, the latter noted from his stream geomorphology survey observations that most of the dams are small enough that they can be breached or blown out during floods; to him, other steelhead passage barriers are more prominent. Supporting these two study case opinions would also be a winter dam blow out and seasonal blowouts that Hagar (1996) and Hancock (2009) mention; all field-surveyed dams located within the bankfull channel and cumulatively skewing towards small heights (see Table 4 and Figure 2); and other studies finding that trout surmount dams more easily during higher flows associated with winter and spring (Gard 1961, Schlosser 1995).

However, basin interactions between beaver dams and steelhead trout may be more complicated during the dry season or extreme droughts, when conditions may be more favorable for extended dam-building (Figure 7). Primarily, juvenile or adult steelhead can also stay in certain basin freshwater streams throughout the year, in contrast to the anadromous migrating adult variant (NMFS 2013). Wherever these cohorts overlap with beaver dams, low flow conditions could affect them or their breeding-related activities via siltation or stream temperatures. For instance, beaver pond siltation occurring in low flow and low gradient streams may detrimentally affect steelhead redds, although redd-planting preferences for riffles between beaver ponds may negate this impact (Gard 1961, Knudsen 1962, Andersen et al. 2011, Müller-Schwarze 2011). However, this negation is not assured, as beaver pond backwaters may also inundate riffles along with other key steelhead spawning areas, as they appear to do according to accounts within Santa Barbara County's Santa Ynez River basin (Cachuma Operation and Maintenance Board Fisheries Division 2018). In the low gradient-dominated basin reaches, stream temperature may be of greatest concern (Müller-Schwarze 2011). Although small beaver dams common across field surveyed areas may not have major temperature influences (Hoffman and Recht 2013), with large frequencies they could contribute to small stream thermal changes (Andersen et al. 2011). Yet beaver pond dimensions and the local environment's degree of hyporheic exchange will ultimately influence whether individual or aggregate beaver dams increase stream temperatures or the water they impound (McRae and Edwards 1994, Westbrook et al. 2006, Pollock et al. 2007, Weber et al. 2017, Castro et al. 2018). These may interact to influence whether beaver pond thermal gradients or buffering occur, or if overall there will be downstream thermal benefits, which could outweigh any direct beaver pond temperature increases by benefitting downstream fish or species assemblages (McRae and Edwards 1994, Weber et al. 2017).

Regardless of what beaver dam tradeoffs may be during the dry season or extreme droughts, Gard (1961) highlights that these tradeoffs be better assessed through the arguably more important question of "whether [beaver dams] actually inhibit reproduction to the extent that adult populations are lowered" (pg. 239). To this end, it is important to remember that current beaver dam infrequency along the Salinas River (Table 4) during large seasonal time frames means that any tradeoffs that do occur between beaver dams and steelhead trout may therefore themselves be infrequent. Moreover, human dams and others passage barriers would almost assuredly be the more inhibiting aspect to current steelhead reproduction (Grantham et al. 2012, NMFS 2013)). Besides, as could be interpreted from Parish (2016) in her thesis exploring the dynamics between Coho salmon presence and beaver bank lodges in the Smith River, it may be more appropriate to ask whether and how beaver activities in general affect steelhead reproduction. As Parish noted that "Coho salmon and other salmonids were commonly observed utilizing burrows [dens] and woody debris piles created by beavers" (pg. 67-68) for non-natal rearing habitat during the summer – she in fact identified higher overall Coho salmon activity where beaver activity occurred – future investigative efforts looking at the interaction of beaver and steelhead trout across the Salinas River basin may be better served by taking a holistic view of beaver activity, and not just assessing their dam effects.

Interpreted study case responses suggested that beaver may contribute to localized or basin-wide geomorphological changes through these non-damming activities. One of the Santa Margarita residents observed that these collapse occasionally, while the local environmental historian estimated one episode's magnitude:

> [the cavity was] 3 or 4 feet in diameter and several feet in height…in the 1970s, [a company] was moving…a 25-ton tractor and then they got off on that, just on the edge of the black-top and they fell into the couple dens….And then there was another [tunnel: in 2018 the] county had to open it up, and fill it…

While such acute cases of beaver-induced damage appear rare (see Theme 6), this one in particular illustrates conclusions reached by Meentemeyerj et al. (1998): while beaver dens or the tunnels that lead to them may not be as erosively impactful as beaver slides or trails (Figure G-9), they can still contribute to severe erosional episodes (Figure G-10).

But to return to beaver dams: these are also likely to affect basin geomorphology through at least three different ways. The first is dampening erosive effects of the first high flow season floods, by acting as speed bumps, attenuating channel erosion (Parker et al. 1985) – though many dams' seasonal nature indicates this attenuation may be limited in basin high-order streams. Yet beaver dams may also concentrate erosion: a resource conservation district employee recalled that "We were invited to [a] vineyard off [in Templeton] to assess the erosion caused by the beavers in a pond onsite, blocking the spillway. Erosion took place during and after storm events." Her observation suggests that beaver dams interfacing with urban or agricultural infrastructure can cause sharper or more obvious erosion than in other basin areas, perhaps due to how they affect concentrated flows where perennial water already exists (a CDFW game warden had written for the same vicinity that "Problems have occurred during…heavier flow periods…due to perennial water in the system"). In contrast, the local environmental historian's earlier comments on opportunistic beaver damming along the Salinas River, along with common infrequency and longevity of beaver dams, supports how most geomorphological changes may be more subtle but nonetheless important for many of the high-order basin streams. That is, from applicable studies within semi-arid and arid environments, it appears that the formation of significant beaver meadows – sediment-filled and plant-colonized beaver ponds – are unlikely to occur, given dam longevity requirements (Butler and Malanson 2005). But frequent beaver dam failures in the Salinas River may still have potent effects: Demmer and Beschta (2008) and Westbrook et al. (2011) report that following dam failures in their study areas, overall channel complexity increased, both in-channel and on affected stream terraces for high-order streams. For instance, stream habitat increased through created pools and riffles (Figure G-11), added channel sinuosity, and new large-woody debris, while valley bottom terraces in areas with expansive floodplains were scoured, with sediment deposition occurring. Demmer and Beschta also observed that prior to failure, beaver dams in their eastern Oregon study area's more entrenched sites helped laterally erode banks, widening the local floodplain and creating additional habitat in this manner. Meanwhile, even with frequent dam failures, it is conceivable that some sediment behind breached or blown-out Salinas River beaver dams could remain and contribute to streamside or island willow growth along intermittent Salinas River reaches (Butler and Malanson 2005).

One geomorphology-related surprise from the emailed survey was that at least three independent study cases thought that the species helps counter willow and general riparian vegetation overgrowth, particularly for the benefit of riparian property flood mitigation. As one San Benito County resident enthusiastically explained, "we loved the beavers. Because they kept the rivers cleaned out and open, so the river ran freely! And now [after local extirpation] it doesn't; it's so built up that the river [takes] whatever course it takes when it comes down." Though this study case's experience was technically outside of the study area, the other mentioning study cases indicate it can apply to the Salinas River basin. The Soledad utilities employee in the lower basin explicitly mentioned that beaver do not cause any infrastructure damage, and if anything help cut back vegetation. Meanwhile, in the upper basin, two Pozo residents were convinced that an invasive subspecies of willow, brought in with translocated beaver, quickly grew out of control and clogged the river in areas. They implied that the situation was perhaps aggravated where beaver abandoned these original transplant sites or else areas where the willow flourished due to poor beaver habitat conditions. As one of the residents, who had noted beaver presence "until several years ago" saw it:

> With all of the regulations we have been unable to keep up with clearing out the waterways. The beavers used to keep it clear and the channel was deep and strong....We feel that they were a definite benefit to the ecosystem and the maintenance of the river that runs through our ranch.

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However, so the role of beaver in vegetation control is not taken out of context or exaggerated, the other study case, a retired USFS employee, later mentioned the obvious: that “it'd take 10,000 of [reintroduced beaver] to try to clean [this] river.” Further, the San Benito resident had mentioned that her father would help control non-native vegetation. She thus implied, as this former USFS employee did, that the cause of vegetative overgrowth is far from a matter of only beaver absence, though this absence could contribute. Phrased alternatively, a large confounding factor on these study case observations was historic private-landholder vegetation management, which under local and modern environmental policies has been complicated or prohibited. In fact, supporting that beaver may not be as much as a control as these study cases express, Baker et al. (2005) conducted a study on beaver-elk herbivory whose results are evidence of a beaver-willow mutualism, with willow growth reported as more vibrant and healthier under beaver grazing than under an interaction with large ungulate grazing. But it must be remembered that beaver tend to forage preferred vegetation that is within or besides the stream closest to their dens, dams, or food caches (Baker and Hill 2003), and exhaust these in a rotating manner (Hall 1960). Therefore, it is still possible that basin beaver populations help control willow and other preferred vegetation in some reaches. They could thus potentially help mitigate flood risk for riparian-adjacent human structures as they simultaneously promote overall riparian forest growth and health, though this may be too optimistic considering the complexities of basin beaver vegetation consumption and activity patterns.

<u>Theme 5: types and frequency of nuisance activity</u>

Overall, the most common type of nuisance activity discussed by study cases was flooding or water conveyance infrastructure damage, followed by crops damage. Ornamental tree damage and road undermining were also discussed but to a far lesser extent. A PRA request submitted to CDFW for past depredation records yielded a similar frequency order (Table 8). In Table 8, depredation permit issuances for study area counties that were recorded in CDFW regional or headquarter offices from 2001-2018 (with the exception of one depredation permit obtained from the Cal Poly Roest Vertebrate Biology Collection) were compared against study case data. While admittedly flawed due to incompleteness of both data sources, the nuisance activity frequency order is unlikely to change much with more complete data, due to basin valley bottom characteristics and how the first two activities are generally among the most common categories of beaver-human conflict (Castro et al. 2018).

Table 8. Nuisance activity frequency comparison between emailed survey respondents and depredation records obtained for study area counties from PRA request

Nuisance activity	Study cases mentioning, *n* = 11*	Depredation record reason listing, *n* = 17**
Flooding or water conveyance infrastructure damage	9	11
Crops damage	5	8
Ornamental trees damage	3	-
Road undermining	2	-

* If a study case mentioned distinct nuisance events within the same activity category, these were counted as separate mentions.

** A few records descriptions were ambiguous and could have belonged to both categories, and were counted as such

The study cases who mentioned nuisance activity occurring, and elaborated upon it during the respective survey question, conveyed that beaver only occasionally pose a significant or acute threat that requires depredation (nuisance beaver take). The opinions among CDFW and USDA-APHIS-WS biologists, wardens, and trappers who responded to the survey or were phone interviewed overlapped on this matter. One of the USDA-APHIS-WS employees said that in his 17 years with the agency, he could recall only three years or distinct times when they had beaver problems. Alluding to this rarity, a second USDA-APHIS-WS employee, in discussing his respect for beaver, concluded by saying that unfortunately “[beaver] occasionally tend to find trouble with the ag folks” in the basin, while a CDFW game warden noted that “Between 1986 and present I issued one permit for depredation….” Though both of these wildlife professionals mentioned many locations where, respectively, they had assisted beaver depredations or observed the species, each of their 30-plus years of experience combined with their responses' frequency qualifiers strongly suggests a rarity in official nuisance beaver take. This plausibility becomes more apparent after considering Table 9, adapted from Michael Baker International (2017). Briefly, it shows the number of beavers that USDA-APHIS-WS trappers depredated on behalf of depredation permittees for Monterey County (since CDFW does not depredate beaver itself) over the past two decades, and compares these numbers to the top nuisance mammals taken. Table 9 reflects the paraphrased words of the first USDA-APHIS-WS employee: beaver is such a minute part of their work because they typically deal with feral swine (*Sus scrofa*) and coyotes (*Canis latrans*) instead. Or to summarize one perspective of a retired Monterey County Parks employee who worked by San Lorenzo Park (King City) and San Antonio Lake for over 26 years, he and his coworkers were more concerned by the omnipresent nuisance activity of deer (*Odocoileus hemionus*) than beaver. They rarely observed beaver and considered them "more of a novelty."

When asked if there was any consistent pattern about the year or occurrence of these beaver nuisance episodes, the first USDA-APHIS-WS employee clarified that there appeared to be no association with particularly dry or wet years from his perspective. He did say, though, that they may get called in if a beaver makes its way up to a man-made ditch or irrigation pond area. Perhaps adding insight to this USDA-APHIS-WS employee's response, the CDFW game warden wrote that "I have had a couple of calls over the years of a beaver in an unusual location due to flooding, but observations only that were called in by the public," which suggests, in the words of the other USDA-APHIS-WS employee, "Just because I'm not being called out to trap [beaver] doesn't mean they aren't there."

Table 9. Comparison of selected USDA-APHIS-WS reported mammal species taken through its technical assistance to CDFW depredation permit holders in Monterey County, 1997-2016

Year	Mammal			
	Coyote (*Canis latrans*)	Squirrel, ground or other (*Otospermophilus beecheyi*)	Feral swine or hog (*Sus scrofa*)	Beaver (*Castor canadensis*)
1997	393	0	0	0
1998	700	0	0	6
1999	581	0	6	9
2000	725	0	12	5
2001	464	0	29	11
2002	305	252	83	0
2003	318	103	33	0
2004	225	220	0	0
2005	183	0	81	0
2006	202	0	11	0
2007	228	0	25	0
2008	243	50	45	0
2009	316	20	30	0
2010	301	23	26	0
2011	296	0	0	0
2012	226	0	0	0
2013	177	0	3	0
2014	112	0	2	0
2015	67	0	4	0
2016	70	0	18	0
Total number	6262	668	408	31
Rank of 16 species reported	1	2	3	10

Source: Michael Baker International (2017)

Of course, the relative paucity of beaver depredation does not communicate whether beaver populations are currently experiencing significant annual losses from CDFW-permitted commercial fur or recreational trapping, as this category is classified differently and is not included in the previous metrics. Neither does it communicate population losses from licensed hunting during the November 1st to March 31st open season. However, sustained significant losses from these sources appear improbable based on available CDFW commercial fur and recreational trapping statistics (Table 10), an estimate of beaver existing throughout the basin, and nuanced human attitudes towards basin beaver.

Table 10 indicates that from 68 years of trapper reports, in only 11 were beavers trapped for fur, with the last being over 20 years ago. Thus, based on where the trappings occurred relative to Figure 6 (i.e. there were few in San Luis Obispo County, where lots of consistent activity was identified), and the low beaver numbers trapped in an average year, it would appear that official trapping of beaver for commercial fur or recreation purposes would have a negligible effect on basin beaver populations.

A 1970s beaver population study conducted by CDFW (then the Department of Fish and Game, or CDFG), south of Chualar, indirectly strengthens this view. Mentioned second-hand in Gordon (1996), this study estimated a beaver population of 12 per km, or 20 per mile, wherever there was good habitat, i.e. willow or cottonwood riparian forest. If applied to all stream reaches that were surveyed and had active dams (roughly 26) as a proxy for active dens and colonies, a conservative population estimate of at least 93 beaver would result. While paltry for the Salinas River basin, this number would not be for the basin, but only for the stream reaches surveyed that had dams, excluding other stream reaches of survey areas that may have active dens and colonies. With many more beaver to add, too, based upon 'A' and 'B' classified sub-watersheds' stream reaches in Figure 6, this number is especially a severe population underestimate. Nevertheless, even with this underestimate, if the average depredation and trapping numbers from Monterey County were subtracted from it, there would still be plenty of beaver remaining to rebuild the overall population. Moreover, because field surveying and Figure 6 identified multiple, stable beaver source areas, many of which are within hard-to-access private properties or military lands, it is extremely unlikely that annual beaver trapping or hunting occurs across each of these areas. In fact, inside and outside these areas, Table 9 would suggest that coyotes and other predators may exert a larger control upon basin beaver populations than humans.

Lastly, a nuanced attitude that one study case shared indicated that while licensed beaver hunting (which CDFW does not record, unlike licensed trapping or depredation permitting) certainly occurs in the basin during the open season, it is likely done sensibly and rarely. This subject is discussed in the next theme.

Table 10. Years when a licensed commercial fur or recreation trapper took beaver within study area counties, 1950 – 2018

Trapping season	Study area county and number of beavers taken		
	Monterey	San Benito	San Luis Obispo
1976-1977	6	0	0
1977-1978	2	0	2
1979-1980	2	1	0
1980-1981	2	0	2
1981-1982	4	0	0
1982-1983	1	0	1
1985-1986	3	0	0
1986-1987	8	0	6
1989-1990	30	0	0
1990-1991	17	0	0
1995-1996	2	0	0

Note: it was unable to be determined what accounted for the high trapping season numbers of 1989-1991
Source: CDFWb

Theme 6: attitudes towards beaver nuisance activity and its frequency

Some insight into the mindset of regional wildlife agencies and landholders with respect to beaver was best summarized by the first USDA-APHIS-WS employee mentioned in the preceding theme. He emphasized it is often the dam and not the beaver that poses a threat. He believes most landholders they have worked with have the attitude: "If you can live with [beaver], why not?…just enjoy it if it's not hurting nothing." To this degree, when inquired if they try to use pond-levelers and other non-lethal beaver co-existence tools that have emerged in recent years, he added that they typically assess the situation to see if a pond-leveler could indeed work, as it is typically the better win-win option in the long-run. Though he notes general living-with-beaver strategies are their recommended approach where possible, he concluded this point by saying that they only offer informational material about them, and otherwise do not get involved with their implementation. Thus, the selected approach for a nuisance beaver is ultimately up to the landholder.

While CDFW as a statewide agency has recently added a page to their website that promotes this beaver coexistence (CDFWa), based on the limited extent of survey questions, it was unable to be concluded from CDFW study cases if their departmental region operates like USDA-APHIS-WS when it comes to beaver, by investigating or recommending these strategies first. However, it appears unlikely. For one, a CDFW game warden communicated with his response that he interprets the law as obliging his department to issue depredation permits, especially as fish and game law enforcement favors agriculture when non-endangered species damage crops. Thus, when beaver interfere, if an applicant provides all required permit application information satisfactorily (though it is unclear what counts as satisfactory for regional game wardens and biologists, and if they have the same shared standards, since any of them can issue depredation permits), CDFW issues a permit because they currently have no compelling or legal reason not to. Secondarily, as one of the CDFW biologists indicated by writing that he “would like to see more evidence of whether this was historic range or not,” there may be understandable skepticism to any beaver take prevention need within the departmental region, as the species’ historical and current ecosystem role may still not be seen as native (but see *Management Recommendations*). Combined with beaver prevalence and beaver depredation rarity expressed in Theme 5, there would thus be a powerful rationale for CDFW to not rigorously evaluate or concern themselves about each requested beaver depredation permit. Especially if USDA-APHIS-WS incorporates lethal-need assessments to some extent, and that CDFW likely has greater ongoing priorities in the basin, if Table 9 is any indicator.

Concerning other local agencies, study cases currently or formerly belonging to them indicated a strong theme of flexibility or non-lethal adaptation to beaver nuisance activity. Reflecting this theme were the responses of a Paso Robles and a Salinas wastewater treatment plant employee to the open-ended question asking them to describe nuisance activity. According to the former, “some people don’t like the dams [while] others like me don’t care; I see it as routine maintenance.” Similarly, the latter stated that beaver led to routine maintenance needs, but they were not causing harm since he and other employees "just had to stay on [top of dam removals]" though he added these were “a pain-in-the-butt.” Other agencies that are not affected by the dams but by beaver tree-felling also appear aware of and implement tree-protection strategies, at least in the lower basin. As NOAA Fisheries employee wrote, “At the Salinas River Lagoon, we had to cage young riparian trees that were planted as a restoration project to avoid destruction by beaver,” while a draft environmental impact report’s mitigation measures for a Davis Road bridge replacement project stipulated fencing for to-be-planted riparian trees as a beaver deterrent method (Caltrans and Monterey County 2015). By no means a definitive representation of how all local basin agencies handle nuisance beaver, these responses appear to expand the aforementioned USDA-APHIS-WS employee's opinion on openness to beaver coexistence to encompass local agencies.

Possible reasons for this coexistence willingness include beaver benefits that are not necessarily environmental (Table 7). In fact, in Table 7, these benefits, such as 'Associated recreation,' are actually mentioned more frequently than ecological ones among study cases. Based upon private landholders or local agencies that reported nuisance activity experiences, seeing beaver or their dams probably breaks up job monotony for some: a Salinas Dam operator, explaining that beaver dam up a critical piece of water-release or measurement infrastructure immediately downstream of the reservoir, wrote that he "Totally enjoy[s] beaver presence even if they cause a little extra work." Similarly, although she could not remember having any past nuisance activity, the environmental consultant for the San Ardo oil fields explained "field crews do a good job watching and tracking the beaver," later adding that these crews become excited over them.

Implied respect was an underlying key component that connected these cases, in some outright stated, such as for the second USDA-APHIS-WS employee mentioned in Theme 5. For one case, it was reflected in beaver trapping: the study case explained that they can occasionally be a nuisance to the structural integrity of small human dams set up on his property's creek. Intended to control spring water-flow for his cattle, these dams have washed out in the past due to beaver dams blocking their spillway flow. Conveying that they choose to hunt beaver instead of try pond leveling devices (though it appears some of his neighbors try to use these pond-leveling mechanisms, see Figure G-12), he elaborated:

> You just handle it yourself, because they're there, beavers. You can, you can trap [and hunt] them in beaver season…And that's when their pelts are really nice and rich….But no, no, we didn't try to transplant them…I know our neighbors contacted Fish and Game and Fish and Game sent a trapper out; he'd just trap them and throw the carcass out on the side…we found three or four

> dead beavers, you know, at different colonies that they'd been trapped out of…And I took the skulls to school, and looked at the teeth and everything, and – I do have a beaver pelt, too, that I use[d] in my classroom, that kids [would] feel…

To translate, as a hunter, the study case indicates that he sees more efficiency and utility in exercising his trapping and hunting skills than applying for depredation permits through CDFW, perhaps repeatedly over time, to deal with nuisance beaver. By contrasting his experience with how USDA or private trapping companies handle these nuisance beaver for their depredation permit-holding clients, and how he responded, he also implies a high-level of respect for beaver, especially for the ones he takes. That is, he does his best to make the most of the beaver, for personal pelt-use or educating others. (Beaver carcass use appears generally prohibited under beaver depredation permitting, due to public health concern; however, the carcasses are still not necessarily "wasted" since they may become food for scavenger species.) He appeared to emphasize this respect by later stating:

> There's…just a lot of beavers. I was thinking last night…I'm sure there's more than a dozen beavers in our little creek here….I mean, I think [they] are real positive, except when they overpopulate, and then become a nuisance, and then you have to get rid of some, but they seem to spread out, they go down the creek, and go up other creeks with water so, you know, I don't think they're a nuisance now, not really. So just a very slight, very slight nuisance [overall].

Having lived on his property for decades, the hunter portrays himself as an observant population control agent, knowledgeable of local population dynamics, who only takes beaver when necessary. Thus, in regards to the question raised in Theme 5 about beaver hunting and trapping outside of depredation permitting as a beaver population loss factor: where and when it does occur in this basin, it may be minimal or infrequent, to control these local overpopulations and prevent property damage. Preventing this damage may be too maintenance-laden for these landholders' tastes if approached with living-with-beaver strategies (if these can be applied), especially if they enjoy hunting. But while current beaver depredation law may also contribute to some hunters choosing to control beaver populations independently, hunters are unlikely to cause local extirpations if they realize environmental and recreational benefits from the beaver that outweigh perceived environmental and human infrastructure costs, as with this study case.

Then again, as can be suggested under Theme 4's discussion on beaver and invasive species, hunter interests in regards to not extirpating beaver for other hunting, fishing, or aesthetic interests may unwittingly propagate detrimental aspects of basin beaver populations. This consideration would be supported with this study case's opinion toward bullfrogs, mentioned in Theme 4. To this extent, Holsman's (2000) critical inquiry into the classic hunter-as-environmental-steward perception – where he highlights how historically, hunter education and knowledge tends toward game species management and not necessarily towards more resilient ecosystem management – would appear applicable.

Theme 7: overall attitudes towards beaver

In an effort to visualize quantitatively the full range of study case opinions on beaver, participants were asked to rank how they would characterize their overall attitudes toward them (Table 11). In Table 11, it is apparent that over half the participants had extremely favorable attitudes toward beaver, while a little less than half were more moderated in their opinions, with only one study case having a decidedly negative attitude toward beaver.

Table 11. Study case responses to "Lastly, how would you characterize your current overall attitude towards beaver?"

Likert scale ranking	Number of study cases (total *n* = 39)
1 - Extremely negative	1
2 - Negative	0
3 - Neutral	6
4 - Positive	12
5 - Extremely positive	20

Note: four study cases did not directly reply to this question, so a score was estimated based on their other responses, resulting in a 1-0-1-1-1 distribution.

When examined more closely, "Neutral" ranking reasons included: admitting to little beaver experience ("As there are no more beavers [east of King City], don't have an attitude."), experience-informed or cautious environmental management ("My attitude toward beaver are neutral – I view them as part of the natural ecosystem and manage the land accordingly" and "[I] would like to see more evidence of whether this was historic range or not."), and routine maintenance indifference ("Some people don't like the dams; others like me don't care, I see it as routine maintenance.").

"Positive" rankings were predictably affected by experience as well: seven came from water resource or wildlife management-involved study cases who had tangible experience and knowledge of beaver nuisance activity, as expressed through their responses. Meanwhile, the other five may not have expressed this experience, but their decision not to select the higher scale option suggested an awareness to it, or to other beaver activity uncertainties ("My understanding is that there is a debate as to whether or not beavers are native to the Salinas. In any case, I also understand that their behavior enhances complexity which improves habitat for species across the food chain…"). Their decision not to select the lower scale option perhaps reflected more positive than negative experiences for a limited spatial area, all while acknowledging a knowledge scarcity for study area beaver ("In this area beavers may contribute to preserving pools and water availability for other species including cattle, fish, and amphibians.").

Finally, "Extremely positive" was filled by study cases who had more limited spatial-extent experiences with beaver – such as 11 with more-or-less backyard perspectives. Other traits for this rank's study cases included at least 14 who possessed little to no basin wildlife management experience that encompassed beavers specifically. At least nine mentioned, if not focused on, non-environmental benefits of beaver (for example, "Neighbors and myself enjoy their presence and view them in evening hours," "Totally enjoy beaver presence even if they cause a little extra work," "Workers were very excited to see the beaver and looked for it frequently"), while two believed that the environmental benefits outweighed any detrimental effects of beaver.

One unexpected similarity between a "Extremely negative" and an "Extremely positive" study cases was beaver symbolism. A study case with a doctorate in environmental science and the "Extremely positive" attitude explained: "I see beaver presence along the Salinas River as a wonderful symbol of the persistence of nature in Central Coast streams despite unreasonable anti-holistic riparian destruction by private agricultural operators." This exuded enthusiasm for beaver contrasted with its symbolism to the "Extremely negative" study case, the former USFS employee, who expressed his opinion as follows:

> And [beaver] were not native here anyhow! So why did they bring them here? I think what they said in those days was that they put them there to build ponds and stuff for the fish. Well, we had ponds and stuff before the beaver that the fish lived in. And these were rock quarries and swimming holes that we'd build and stuff like that. And all of that's gone now. And to me, I'd say that's because of the beaver. Because of mismanagement by the federal and state agencies of not taking care of our streams the way they should be.

In both cases, beaver represents a distinct means of affirming core values and beliefs. For the doctor of philosophy in environmental sciences, it is part of the resistance against environmental degradation due to human activity; for the former USFS employee, it is ammunition to be used against environmental stewardship that excludes humans, which he feels has limited beneficial community involvement, such as in riparian vegetation management. Yet a potential warning lies in both extremes. First, as Theme 4 shows, though detrimental beaver effects may be minimal, they may also be significant under certain conditions, especially when invasive species competition is considered. Under basin conditions, beaver may not be as unwaveringly beneficial a keystone species as many study cases assume them to be. Second, although it may seem unfair and inappropriate to scapegoat beaver for general resource management grievances, this frustration is not unusual where local communities feel that decision makers are prioritizing other environment components without adequately considering their needs or perspectives (e.g. Kideghesho et al. 2007). Rather than dismissing the former USFS employee's perspective, decision makers should interpret it as further evidence that community involvement for any potential BAR project is critical (Castro et al. 2018, Charnley 2018).

In short, study cases were biased toward pro-beaver, benefits-outweigh-costs individuals despite best efforts to obtain responses from a diverse range of riparian organizations and individuals, including ranching and agricultural groups who commonly conflict with beaver. Yet notwithstanding this caveat, it is unsurprisingly clear that broader wildlife-management experience or detrimental beaver effects knowledge contributed to more moderated beaver opinions. This trend has educational and strategic implications for BAR throughout the basin, as will be discussed under *Management Recommendations*.

BRAT Model Outputs and Interpretation

<u>Predicted current dam building capacity output</u>

Figure 9 shows the Existing Dam Building Capacity layer of BRAT, including a bar graph summarizing relative stream reach dam density category abundance. (This output is specified as "Existing" because the BRAT model produces another dam building capacity output to reflect "Historic" conditions, i.e. an output that uses the LANDFIRE 2014 biophysical settings layer, which reflects pre-European settlement vegetation. This BRAT output was not utilized due to study objectives, and due to its assumptions that pre-human dam basin stream types would be similar to current stream types.)

General patterns observed include higher dam capacities in the study area's western tributaries, its southern stream reaches above Bradley, and its far northern stream reaches from Spreckels to Monterey Bay. 'Pervasive' categories occurred in the highest stream reaches of tributaries to the Arroyo Seco River and Nacimiento Lake, as well as in Paso Robles Creek and Santa Margarita and Pozo area stream reaches. The lower Salinas River mainstem, between Bradley north to Spreckels, was almost uniformly 'Rare' and 'Occasional' categories.

The validation of this output, based on the three forms of model verification overviewed in *Methods* from Macfarlane et al. (2014) and Macfarlane et al. (2019), is discussed below, with formatting and analyses closely following these two publications. The analyses are then followed by an overall output interpretation.

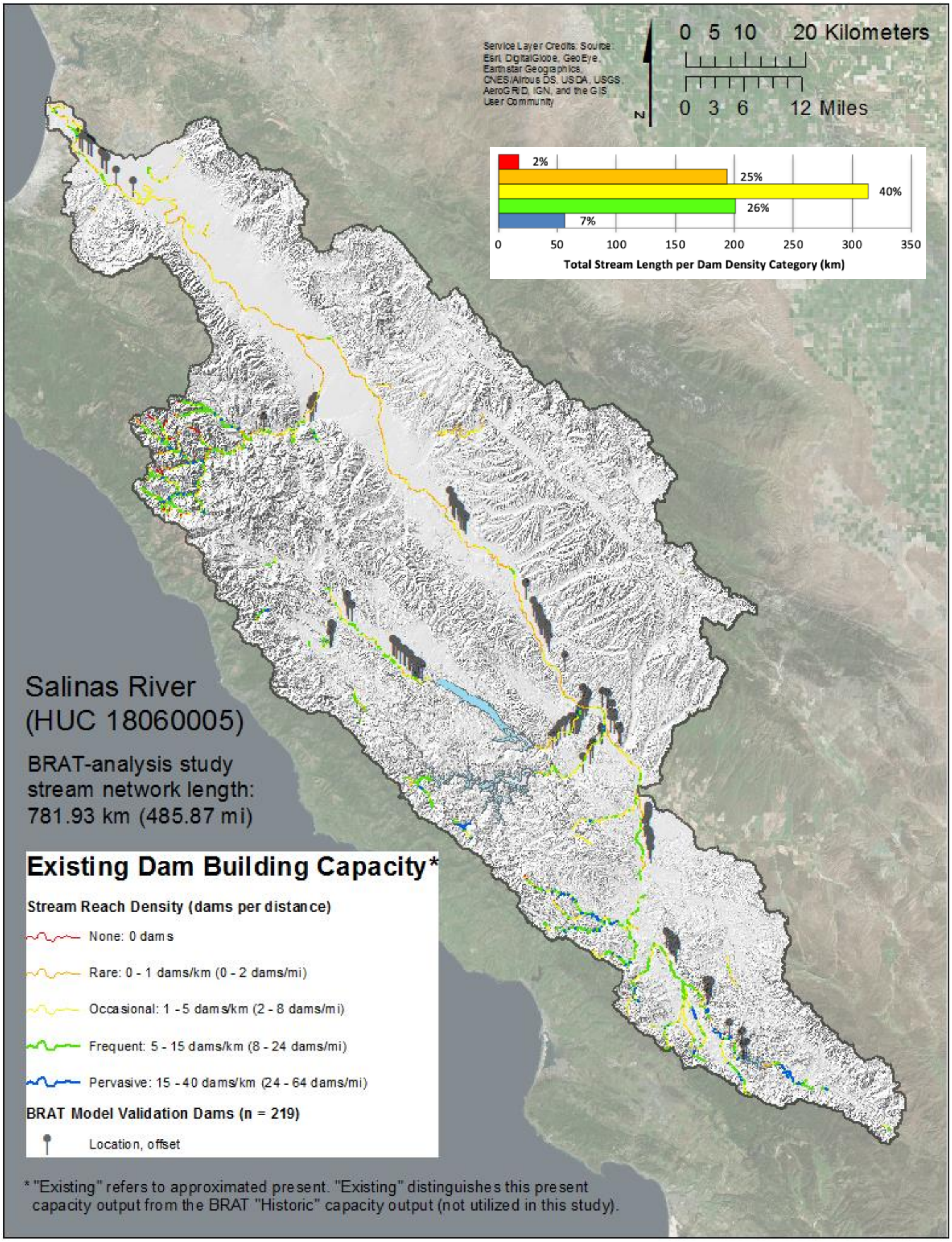

Figure 9. Foundational BRAT model output showing basin dam building capacity, analyzed by stream reach lengths of mostly 300 m, with model validation dam locations from three sources. Cartographic format similar to maps created by Chalese Hafen (see Macfarlane et al. 2019)

1. “How do dam densities track between predicted and actual?”

Figure 9 also shows locations of the 219 validation beaver dams across the BRAT-analyzed stream network from the three sources identified under *Methods*. Altogether, these dams occurred on 145 stream reaches, representing 43.21 km (5.52%) of the 781.93 km modeled stream network, with no dams occurring on the 2.19% of stream network modeled as ‘None.’ Of these dam-occurring stream reaches, 36 (24.83%) were found to under-predict the number of dams identified, while 35 (24.13%) overpredicted and 74 (51.03%) perfectly predicted the number of dams identified (Figure 10). As Figure 10 shows, the under-predicted validation stream reaches are positioned above a 1:1 line, while perfectly predicted reaches intersect this line and over-predicted reaches lay below it. Red data points represent model output inaccuracies, while green represents otherwise correct predictions. Since overpredictions can in reality be unrealized upper dam capacity limits due to unaccounted-for anthropogenic constraints, they are not counted as BRAT modeling inaccuracies per se. Hence, the data colors in Figure 10 represent how underpredictions are of highest concern for BRAT validation. The relative amount of green versus red data points helps show the overall trend for plotted validation dam reaches: that the majority of these reaches (75.16%) track well between predicted and actual dam densities.

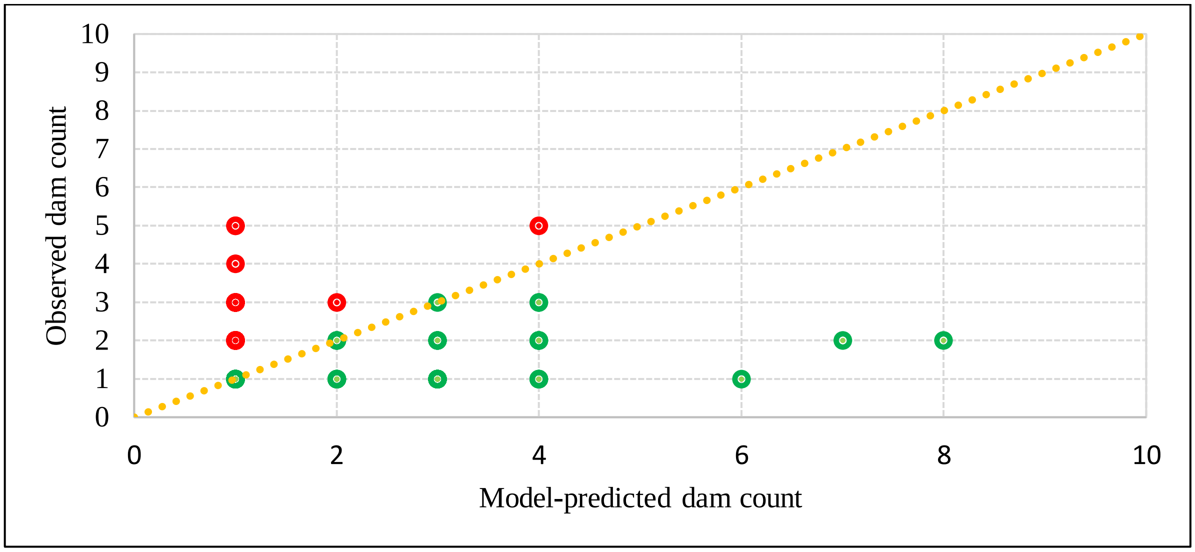

Figure 10. BRAT dam capacity output-predicted dam numbers versus observed dam numbers (from Google Earth (2015 and 2017), FHL (2016), and late autumn field surveys (2018) beaver dam data) for 145 stream reaches containing the observed (validation) beaver dams. 1:1 line shown in dotted orange, demarcating accurate (green) from inaccurate (red) model predictions.

2. "Are spatial predictions coherent and logical?"

To determine more precisely how the underpredicted results erred, a chi-squared goodness-of-fit test was conducted next. This statistical test showed that among the 142 'Rare', 'Occasional', and 'Frequent' categories (with 'Pervasive' validation dam reaches excluded since they did not meet the test's frequency conditions), the BRAT model-predicted distribution exhibited a statistically significant difference from the observed distribution of these stream reach categories, $X^2(2, N = 142) = 8.03$, $p < 0.05$ (Figure 11 and Table 12). As shown in Figure 11 and Table 12, the 'Rare' and 'Frequent' categories contributed most to this significant difference, indicating that the BRAT model tended to misclassify certain 'Frequent' validation dam reaches as 'Rare.'

Table 12. Chi-squared goodness-of-fit test counts for BRAT dam capacity model validation, with 142 of 145 validation dam reaches utilized

Dam density category	Predicted frequency count	Actual frequency count
1 - Rare (>0-1 dams/km)	38	24
2 - Occasional (>1-4 dams/km)	66	70
3 - Frequent (>5-15 dams/km)	38	48

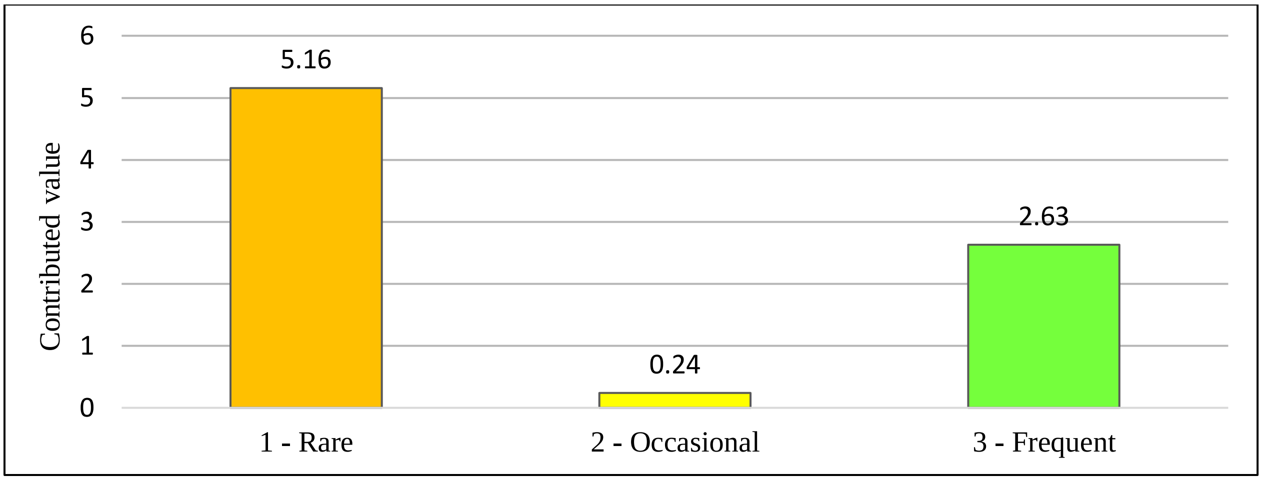

Figure 11. Contributions to chi-squared goodness-of-fit test's final chi-squared value, by BRAT dam density category (visual). 'Rare' and 'Frequent' categories exert large influences in the test.

To determine reasons for this occurrence, the underpredicted stream reaches were examined. In general, though in some cases the original NHD shapefile was misaligned with the actual network, in most instances this misalignment appeared to be minimal or induce little change in the modeled 30 m and 100 m buffer vegetation content. Instead, where the underpredicted reaches occurred – primarily near San Ardo and San Lucas – it appeared that landcover cell resolution was the principal causal factor (e.g. LANDFIRE 2014 'Open water' attribute encompassed multiple cells where field surveys showed preferred vegetation where damming could occur (Figure 12)). As Figure 12 shows, there is plenty of riparian forest canopy and aquatic vegetation that is not captured through the BRAT vegetation coding scheme. Thus, while in general the spatial predictions were sufficiently coherent and logical, for modeled stream reaches similar to the San Lucas and San Ardo riparian areas they were not.

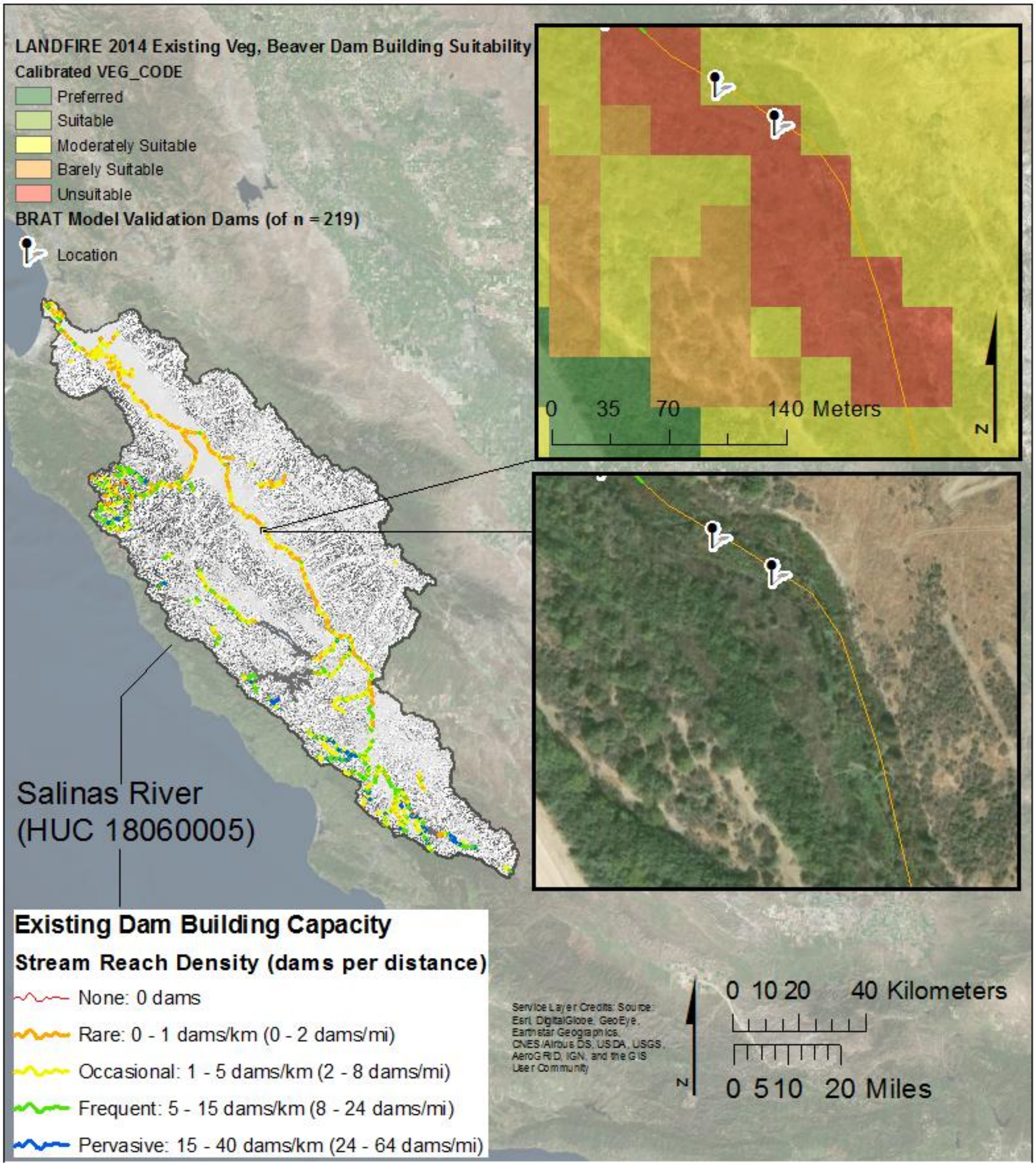

Figure 12. Example of a stream reach where LANDFIRE 2014 raster cell resolution (30 m) contributed to reach dam density under-prediction. Here, 'Unsuitable' was associated with 'Open water' landcover cell designations, despite clear riparian vegetation presence. The corresponding 300 m reach was classified as 'Rare' instead of 'Frequent,' in large part due to this error.

Because the Q_2 stream power equation resulted in an intermediate that increased logically with greater drainage area throughout the basin, it was not rigorously investigated as a causal factor of inaccuracy, especially since stream power extremes do not appear to limit consistent dam building within the far northern areas of the lower basin (Figure 6 and Figure 9). Stream slope was considered a non-factor due to the extremely low average gradients correctly calculated among validation dam reaches.

3. “Does the [electivity index] increase appreciably from the none to the pervasive class?”

EIs for each dam capacity category or segment type are shown in Table 13. As Table 13 communicates, EIs did not increase appreciably from the none to the pervasive class. However, it is conceivable that this pattern could occur from the none to the frequent category after accounting for the aforementioned spatial resolution and vegetation coding errors. As the Google Earth and field survey dam locations were biased towards high-order and minimally-canopied stream reaches and the easier-to-access private properties located there, it is also conceivable that many stream reaches with ‘Frequent’ and ‘Pervasive’ category dams were undercounted. A perfect dam census could therefore have increased the EIs of these categories, and led to an appreciable increase from none to pervasive.

Combined interpretation. To interpret the BRAT Existing Dam Building Capacity layer, especially in context of the three validation methods: first, it is suggested that dam capacity is higher among study area ‘Rare’ stream reaches that are similar in spatial resolution errors (inherently inaccurate vegetation coding) to the erroneous validation dam reaches. In other words, when and where damming occurs in these areas, which are primarily concentrated in the lower basin, it may be more abundant than can be expected from the model outputs alone. However, this damming abundance may only occur during extreme droughts or dry seasons, or otherwise be inconsistent (Figure 6 and Figure 7).

Table 13. Electivity index calculations for BRAT existing dam capacity model validation.

Segment Type	Stream Length	% of Drainage Network	Google Earth & Field Surveyed Dams	BRAT Estimated Capacity	Average Actual Dam Density	Average BRAT Predicted Capacity	% of Modeled Capacity	Electivity Index
	km	*%*	*# of dams*	*# of dams*	*dams/km*	*dams/km*	*%*	
None	17.13	2.19%	0	0	0.00	0.00	0%	0
Rare	193.65	24.77%	59	674	0.30	3.48	8.75%	1.09
Occasional	313.65	40.11%	95	1078	0.30	3.44	8.81%	1.08
Frequent	200.80	25.68%	60	2109	0.30	10.50	2.84%	1.07
Pervasive	56.71	7.25%	5	1229	0.09	21.67	0.41%	0.31
Total	781.93	100.00%	219	5090	0.28	6.51	4.30%	NA

Note: table adapted from USU-ETAL-provided Excel spreadsheet format (Margaret Hallerud, USU-ETAL, personal communications, 20 March 2019)

Another key point is that because the predicted current dam capacity is estimated at only 4.30% of its theoretical maximum (the sum of predicted dams across the stream network), it is unlikely that beaver will regularly dam and inhabit stream reaches of Arroyo Seco River and upper Nacimiento River tributaries, Paso Robles Creek, and Santa Margarita creeks that are greater than 2 or 3% slope. Only in situations where beavers have few to no population growth constraints (i.e. near modeled capacity) would they expand into these steeper stream gradients (Müller-Schwarze 2011), which are generally devoid of human development and have dense surrounding vegetation across this study area. Thus, since these reach slopes in these streams mostly received 'Occasional,' 'Frequent,' and 'Pervasive' categorizations, even after adjustments to the model's Python script slope logic, they may be better interpreted as 'None' under current beaver population and damming densities.

Finally, it must be remembered that the Existing Dam Building Capacity layer reflects only dam capacity and not dam longevity or damming consistency, though the three are interrelated. Understanding the locations, longevity, and recurrence likelihood (consistency) of current beaver dams within a stream network is crucial for strategic BAR recommendations. To understand how the three can affect BAR recommendations, this BRAT output is interpreted with the other BRAT outputs and Figure 6 under the next sub-subsection.

Conservation and restoration management outputs

As part of the BRAT model, three beaver management outputs were produced, each incorporating various logic combinations of the model intermediates and dam capacity outputs (these combinations are outlined in BRAT documentation; see Riverscapes Consortium). These outputs were: (1) an unsuitable or limited dam building opportunities layer (Figure 13), which helps describe the main limiters of dam building across the stream network; (2) a potential risk areas layer (Figure 14), which conservatively highlights stream reaches with varying degrees of human activity or infrastructure conflict; and (3) a potential conservation and restoration opportunities layer (Figure 15), which attempts to quantify and categorize efforts required for effective and low-risk BAR.

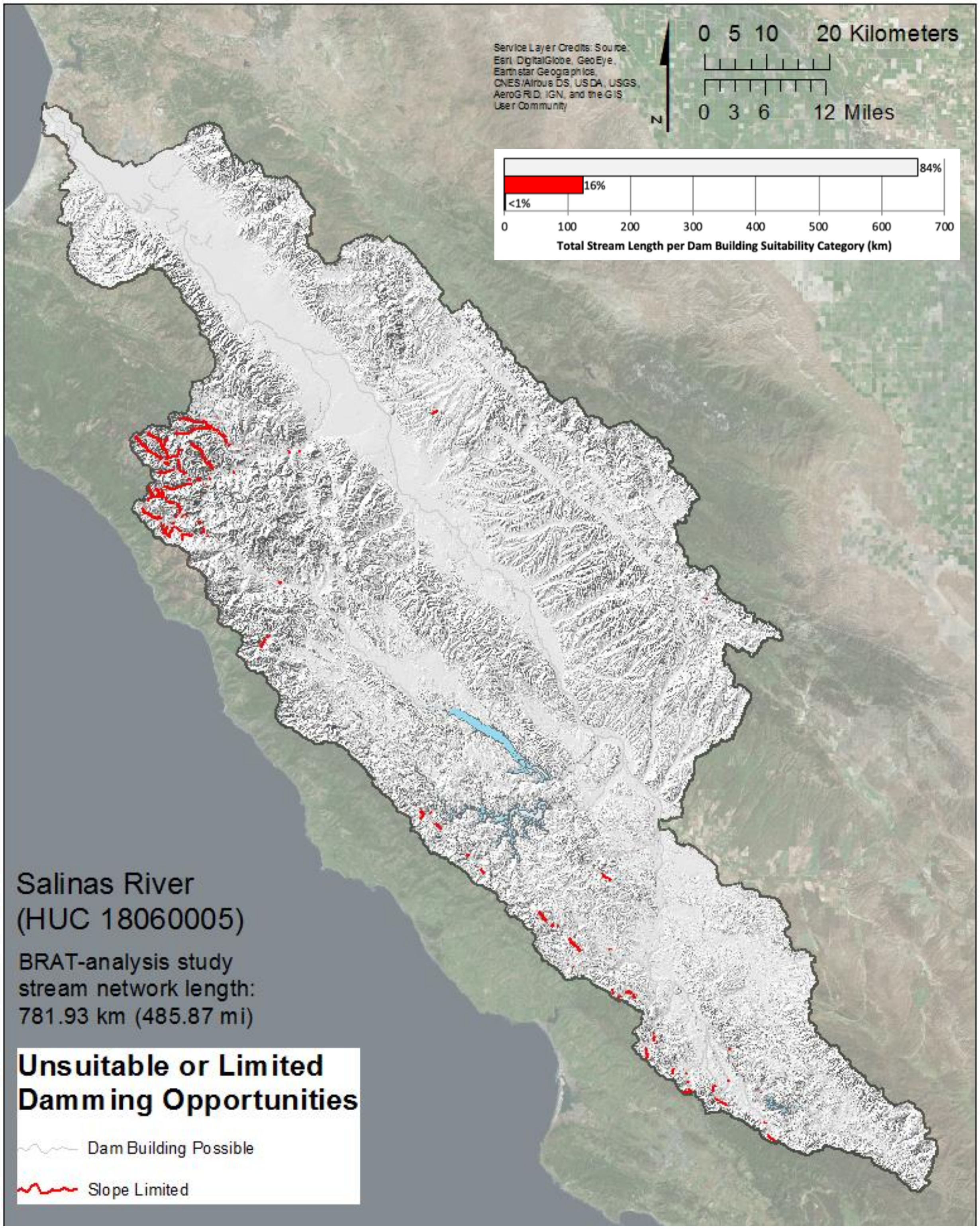

Figure 13. The first of three management layers: BRAT model output showing main limiting factors for beaver damming by stream reach across the study area. It excludes limiting factors that were < 1% of the stream network. Cartographic format similar to maps created by Chalese Hafen (see Macfarlane et al. 2019)

As Figure 13 shows, stream gradient limits approximately 16% of the modeled stream network from dam building, while the rest of the stream network has no dam building impediments of slope, stream power, vegetation or other characteristics that were tested for. However, this layer reflects the implications of current dam capacity, as discussed in the previous subsection. In other words, modeling logic for this layer was adjusted from interpreting stream reaches > 23% to > 3% as 'Slope Limited.' While this logic change to > 3% may appear extreme, if not flawed, as it was based primarily upon the maximum stream reach gradients identified for beaver dams during the low slope-biased field surveys, it creates no problems for later interpretation. Principally, when these 'Slope Limited' reaches are clipped from the potential conservation and restoration opportunities layer, only areas that would benefit least from BAR are removed – i.e. regions where beaver are extremely unlikely to disperse to or inhabit regularly, or regions which are already well-stewarded environmentally.

Perhaps unsurprisingly, Figure 14 shows that beaver and beaver dams within heavily urbanized and agricultural upper basin areas between Santa Margarita Lake and Paso Robles exhibit 'Some Risk' to 'Considerable Risk' to urban and agricultural infrastructure, with a greater number of these stream reaches belonging to the latter category. In the lower basin, stream reaches north of Spreckels and within the far upper reaches of the Arroyo Seco River and its tributaries are higher risk areas for similar reasons, although the categorization is less severe, in favor of 'Some Risk.' Still, despite these concentrations of higher-risk areas, the majority of the stream network (68%) is 'Minor Risk' and 'Negligible Risk' area. This layer suggests that dams built or encouraged in these stream reaches are unlikely to cause beaver-related problems, most likely due to: sufficiently wide riparian buffer areas, private property fences set up between agricultural fields and rivers, stream entrenchment, or other human or geomorphological farm-river barriers observed during field surveys.

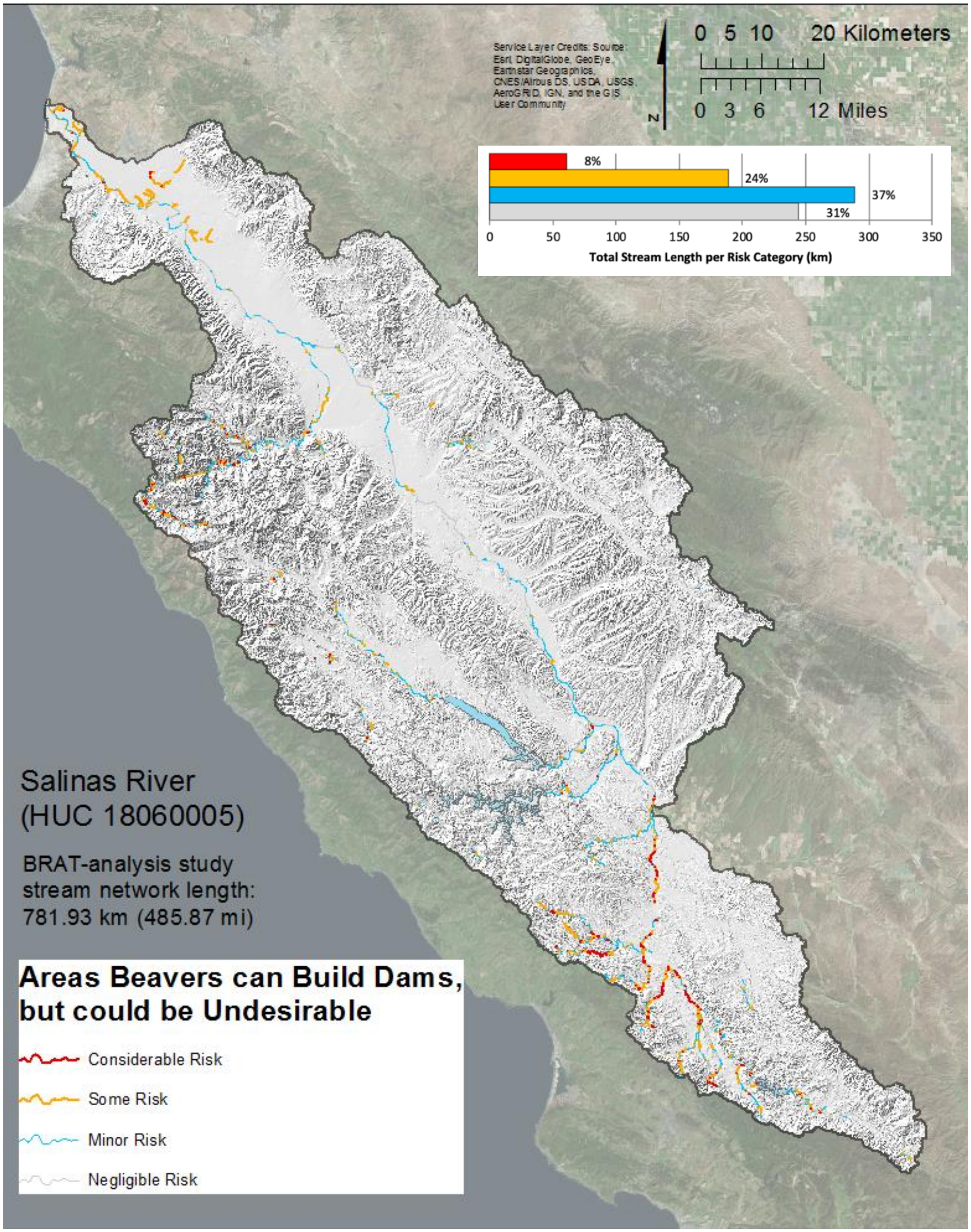

Figure 14. The second of three management layers: BRAT model output conservatively showing risk to human infrastructure (canals, roads, railroads, developed land within the basin valley bottom) from beaver damming, by study area stream reach. Cartographic format similar to maps created by Chalese Hafen (see Macfarlane et al. 2019)

In a culminating manner, Figure 15 suggests that there are more immediate beaver conservation and restoration opportunities in the upper basin than the lower basin, with more long-term opportunities concentrated in the lower basin. This interpretation comes from a combination of the dam capacity model outputs, Figure 6, and documentation for the conservation and restoration opportunities layer, in which each category's logic is summarized as follows:

> i) 'easiest - low hanging fruit' has capacity, just needs beaver if beaver are not there yet, ii) 'straight forward - quick return' is currently occasional capacity but [according to the historical dam capacity model] was higher capacity, iii) 'strategic' is currently degraded condition with historically higher capacity. These areas typically need long-term riparian recovery before beaver can be introduced (e.g. grazing management), and [iv] 'other' is for streams that do not fall into the above categories. (Riverscapes Consortium)

The first three categories are also stream reaches that are categorized as 'Negligible Risk' or 'Minor Risk' in Figure 14. Meanwhile, the fourth category is typically of the two higher risk categories. However, upon interrogation of this fourth category, approximately 73% of the stream network, it became apparent that many areas that had been classified as 'Minor Risk' had been included within the 'Other' conservation and restoration category. But because the 'Other' category is not necessarily synonymous with avoidance for BAR purposes – only that BAR strategies for these areas may not be as obvious, and require more effort and careful approaches (Joseph Wheaton, USU-ETAL, personal communications, 26 September 2018) – these 'Minor Risk' stream reaches were paired with the other study products for proper interpretation.

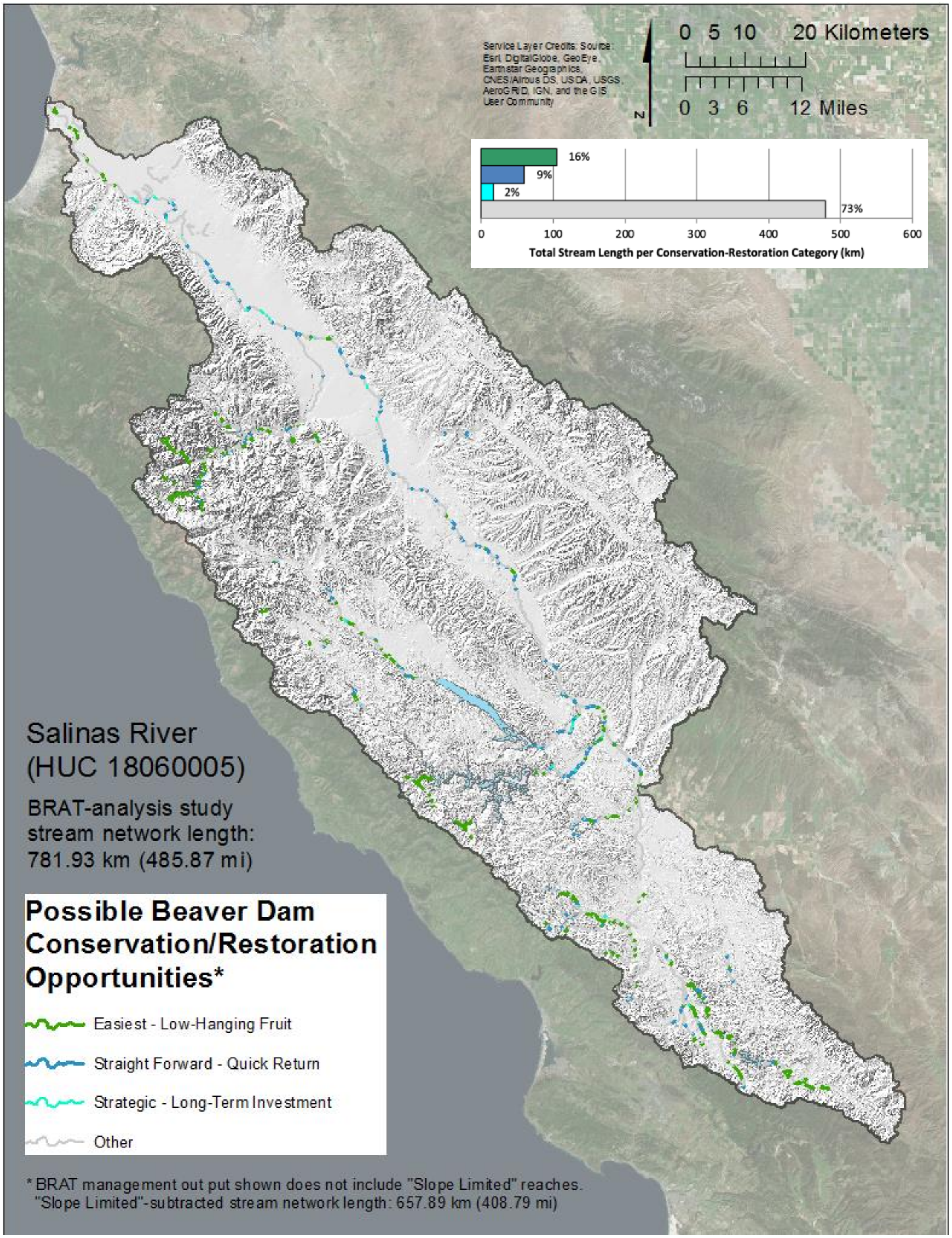

Figure 15. The third of three management layers: BRAT model output showing opportunities for beaver damming and BAR, by study area stream reach. Essentially, it is a composite of all previous BRAT outputs. Cartographic format similar to maps created by Chalese Hafen (see Macfarlane et al. 2019).

This collective examination showed that although some of these areas can cautiously be considered among the first two conservation and restoration categories, many within the lower basin are more likely categorized as the ‘Strategic’ or ‘Other’ categories with their more limited BAR prospects. Specifically, BAR approaches that involve BDAs may be rendered infeasible or impractical by a flashy flow regime, inconsistent beaver damming dynamics, and land use suitability or private property access difficulties, all of which may suggest installation and maintenance headaches. Instead, passive BAR techniques, namely willow or other preferred vegetation planting as part of broader restoration activities, would appear more feasible options to encourage intermittent or opportunistic flow damming and general beaver activity in this region.

‘Easiest – Low Hanging Fruit’ and ‘Straight Forward – Quick Return’ reaches in the upper basin may be worth greater, initial investigation at the reach- and stream-scale for both active and passive BAR techniques. Respectively, these techniques could include BDAs (even if they would only function with intermittent flows) or targeted community educational efforts with existing beaver and damming activity (see *Management Recommendations*). In any case, when compared with the lower basin, greater efforts to involve local urban and agricultural populations would appear critical (Figure 14) to determine and execute the best approaches.

Finally, it should be noted that the ‘Easiest – Low Hanging Fruit’ and ‘Straight Forward – Quick Return’ reaches throughout FHL arroyo toad habitat may not benefit from BAR efforts, at least not in an obvious manner. FHL management goals here prioritize arroyo toad, whose oviposition sites conflict at times with constructed beaver dams, due to the bullfrog activity and vegetative occlusion that these dams tend to promote along incised channels (Hancock 2009). Efforts to use BAR in this part of the basin, such as for desired sediment deposition through BDAs, would therefore require close collaboration with FHL biologists and staff. However, perceived or real tradeoffs between beneficial and detrimental effects that these projects could bring may make them a non-starter. With decades of experience managing the arroyo toad habitat on FHL, the military installation’s biologists and staff may have optimized non-lethal beaver management already, along with less tradeoff-intensive means to obtain desired restoration goals.

MANAGEMENT RECOMMENDATIONS

Recommendations Overview

Core study suggestions and findings from each study objective are summarized in Table 14. Each study suggestion and finding is organized by the high-level beaver knowledge area that it is most appropriately associated with, to facilitate better understanding of each one in context of this study's overarching goal. A listing of the study objective results that support each suggestion or finding is also included. Recommendations based upon these suggestions or findings are then divided and discussed by "Long-Range Strategy" and "Short-Range Strategy" subsections. Sub-subsections of the former describe long-term data collection needs and rationale, while those of the latter discuss more concrete study insights for maximizing beaver collaboration opportunities, BAR or otherwise. Split in this manner to facilitate recommendations discussion, they should not be misinterpreted as mutually exclusive. Instead they should be seen as synergetic: given the multiple uncertainties regarding beaver ecosystem impacts, "Short-Range Strategy" would be best understood as one means to gather valuable information for long-term interpretation (decades). "Long-Range Strategy" would be best understood as long-range guidance for any beaver collaboration efforts that are conducted or begin to be planned within shorter time-scales (years).

Table 14. Summary matrix of key study findings, for reference during recommendations discussion

Basin Beaver Knowledge Area	Key Study Suggestions and Findings		Supporting Study Objective Results									
	Code	Description	BDHA	BDCRM	CAQDA1	CAQDA2	CAQDA3	CAQDA4	CAQDA5	CAQDA6	CAQDA7	BRAT
Dam Dynamics	DD-1	Seasonal, within-bankfull channel characteristics are common among mainstem and major tributary reach dams	X	X				X				
	DD-2	Human-influenced and perennial flows are strongly associated with damming locations and consistency	X	X	X							
	DD-3	Drought flow regulation regimes may cause different or enhanced dam distributions and ecosystem impacts					X					
Population Behavior	PB-1	Vegetation feeding preferences are more varied than previous sources indicate			X							
	PB-2	Seasonal movements, migrations, or home range changes among perennial stream reaches, or between perennial and intermittent ones, appear common	X			X						

Note: BDHA = beaver damming hotspot areas, BDCRM = beaver damming consistency range map, CAQDA# = computer assisted qualitative data analysis theme number, BRAT = BRAT model outputs

Table 14 (continued). Summary matrix of key study findings, for reference during recommendations discussion

Basin Beaver Knowledge Area	Key Study Suggestions and Findings		Supporting Study Objective Results									
	Code	Description	BDHA	BDCRM	CAQDA1	CAQDA2	CAQDA3	CAQDA4	CAQDA5	CAQDA6	CAQDA7	BRAT
	PB-3	Drought and local human groundwater consumption has perhaps reduced dry season or year-round beaver habitat in small unregulated streams, but overall population numbers appear steady if not thriving, based upon abundance of perennial, reliable, hard-to-access habitat areas (rarity of depredation and trapping) and occasional local overpopulations		X			X		X	X		
Ecosystem Impacts	ECOI-1	Areas of strongest probable damming ecosystem impacts among selected stream reaches	X									
	ECOI-2	Areas of strongest probable damming ecosystem impacts at the landscape-scale		X								X
	ECOI-3	Most noticeable damming ecosystem impacts likely occur during the dry season					X	X				

Note: BDHA = beaver damming hotspot areas, BDCRM = beaver damming consistency range map, CAQDA# = computer assisted qualitative data analysis theme number, BRAT = BRAT model outputs

Table 14 (continued). Summary matrix of key study findings, for reference during recommendations discussion

Basin Beaver Knowledge Area	Key Study Findings and Suggestions		Supporting Study Objective Results									
	Code	Description	BDHA	BDCRM	CAQDA1	CAQDA2	CAQDA3	CAQDA4	CAQDA5	CAQDA6	CAQDA7	BRAT
	ECOI-4	Dams may detrimentally affect juvenile or freshwater steelhead trout, but are unlikely to affect adult migrations. Yet how dams *and* general beaver activity overall affect the species' survival and stream community assemblages is arguably more important	X					X				
	ECOI-5	Endangered and threatened species may currently benefit less than anticipated from beaver ponds, due to competition with invasive species						X				
	ECOI-6	Beaver riparian vegetation use may contribute to vegetation and flood control in streams that they occupy, though it could be insignificant						X				

Note: BDHA = beaver damming hotspot areas, BDCRM = beaver damming consistency range map, CAQDA# = computer assisted qualitative data analysis theme number, BRAT = BRAT model outputs

Table 14 (continued). Summary matrix of key study findings, for reference during recommendations discussion

Basin Beaver Knowledge Area	Key Study Findings and Suggestions		Supporting Study Objective Results									
	Code	Description	BDHA	BDCRM	CAQDA1	CAQDA2	CAQDA3	CAQDA4	CAQDA5	CAQDA6	CAQDA7	BRAT
	ECOI-7	Generally, passive restoration techniques would be best for promoting opportunistic and seasonal beaver activity in the lower basin, while passive and active conservation techniques are best for encouraging seasonal and year-round beaver activity in the upper basin		X								X
Human Dimensions	HD-1	Non-lethal or minimal lethal adaptations to beaver nuisance activity appear frequent; benefits-outweigh-costs attitudes and respect for beaver among managers or landholders appears to drive coexistence inclinations								X		
	HD-2	Knowledge of nuisance activity or potential detrimental effects tempers positive attitudes toward the species								X	X	
	HD-3	Early community involvement is important, especially in upper basin urban areas				X					X	X

Note: BDHA = beaver damming hotspot areas, BDCRM = beaver damming consistency range map, CAQDA# = computer assisted qualitative data analysis theme number, BRAT = BRAT model outputs

Long-Range Strategy

Principal research areas

Areas were identified at the local- and landscape-scale where beaver activity, specifically beaver damming, may be exerting significant ecosystem impacts (ECOI-1 and ECOI-2). These may be useful to know for planning more in-depth and rigorous studies to test how beaver dams and activities are affecting the environments of these areas. As this study shows, there are several particular research areas that may be most interesting and informative to pursue at various spatiotemporal scales. Perhaps most pressingly, there is the question of how beaver ponds in the Salinas River basin affect survival rates between invasive and endangered or threatened species: do these ponds aggravate an ecological problem originally seeded by humans more than they provide benefits (ECOI-5)? And would these impacts vary or be similar across the landscape, or could they be concentrated in certain locales, such as in Templeton or FHL? More broadly, especially in the lower basin, understanding the effects of general beaver activity on survival rates or life histories of various fish, amphibians, and mammals can prove insightful for better understanding the scope of beavers' ecological influence in the basin, especially for steelhead trout (ECOI-4) and muskrat (*Ondatra zibethius*). (Though not formally discussed in this paper, Table 7 shows that multiple emailed survey and interview study cases noted presence of muskrat in beaver bank dens. Knudsen (1962) noted that muskrats and their houses were prevalent within Wisconsin beaver ponds, but it is unclear if beaver ponds would be a primary muskrat shelter in the Salinas River, or if muskrats contribute meaningfully to any basin ecosystem process.) Although it can likewise be studied from an ecological perspective, the riparian vegetation use of beaver would also be beneficial to assess from a geomorphological one, as there is a possibility that beaver can contribute to controlling vegetative overgrowth and thus to flood control and river form (ECOI-6) – though in context of existing human flood and erosion control measures, it is likely insignificant. And while Figures 7 and 8 are not proof that beaver damming increases across the study area during extreme droughts, particularly in the lower basin such as along the lower San Antonio River, the possibility that it may translates to drought-state ecosystem impacts that remain uncertain and should not be brushed aside (DD-3, ECOI-3). If natural resource managers wish to minimize the environmental costs of Nacimiento, San Antonio, and Salinas dam operations, or maximize the environmental benefits of current operations, considering these beaver damming dynamics and ecosystem impacts factors woul be beneficial.

Monitoring need

To best benefit the suggested priority research areas, developing a basin-coordinated long-term beaver activity monitoring scheme could prove useful. Supporting this need is the literature and historical records review, as well as the emailed survey and interview results, which confirmed that rigorous beaver activity study over time and at larger than the stream-scale is lacking. In other words, monitoring could help build an important database moving forward because currently there are minimal data on the role of beaver in historical ecology and the basin ecosystem.

For instance, where valuable localized anecdotal information was identified, it was time- and scope-limited, and was at risk of loss, or appeared already lost: three study cases possessing knowledge of historical beaver transplants and one with long-term, general beaver activity knowledge were septuagenarians to octogenarians at their youngest; meanwhile, one of the Santa Margarita study cases added in her responses that "A neighbor…kept track of [the beaver]. Unfortunately he passed away in 2016;" and a San Ardo ranch manager noted that there could have been long-time residents who knew about local beaver with greater depth and breadth than she, but that the one she immediately remembered had recently died. Perhaps identifying and talking with more of these longtime residents could be beneficial and instructive. However, time investments required to find them within the hard-to-contact agricultural and ranching communities may be prohibitively expensive, especially considering the limited information that these surviving residents may recall.

The few basin-applicable and beaver-related documents identified additionally suggest that regional natural resource agencies have not prioritized rigorous beaver ecosystem impacts study, records-keeping or knowledge-sharing among staff. Suggesting this would be the 1970s study that CDFG conducted on beaver colonies south of Chualar, which Gordon (1996) mentioned second-handedly, and Lynn and Glading's (1949) noting of beaver releases occurring near the Pozo ranger station, presumably the modern day USFS Los Padres National Forest station by Pozo Road. A PRA request to CDFW, a search through the USFS online documents library, along with regional office and staff inquiries to both agencies, did not yield the CDFG study or similar ones, nor any USFS documentation on transplants or related follow-up. Yet these recordings would have been crucial for assessing transplant success: mentioned under Theme 7, the former USFS Los Padres National Forest employee believed that the CDFG staff coordinated beaver transplants to help create fish habitat. But despite this plausible local reason (Tappe 1942, Hensley 1946, Light 1969, Fountain 2014), that regional CDFG staff did not follow-up on the multiple basin beaver transplants and their consequent ecosystem impacts (fish habitat or otherwise) nor preserve their findings in written or oral format is particularly dismaying with concerns to our lack of basin beaver knowledge today. Especially since caution should not have been a new concept: in urging CDFG to develop a sensible state-wide beaver management plan, Hensley emphasized responsibility for beaver transplant outcomes and beaver management in general, suggesting that good intentions were insufficient for beaver status across the state in the mid-1940s.

Obviously, it must be acknowledged that with CDFG's limited budget and multiple responsibilities, which are unlikely to have differed historically from those which CDFW balances today, that they were likely unable to coordinate or prioritize doing ideal, in-depth beaver study on larger than reach- or stream-scales. This is especially true as this time period was before the landscape ecology field emerged, or wildlife management began to integrate adaptive management approaches. But if true, limited time and budget would be instructive. It would build the case for coordinated planning among multiple stakeholders within public agencies, the private sector, and the interested public to share responsibility, costs, and resources for what is currently a low priority among most public agencies. Nor would these resources or monitoring to assist long-range research need to be particularly elaborate, though they should be well-planned: sustained assessments of beaver dams and colonies over time, as Demmer and Beschta (2008) and Smith and Tyers (2012) respectively conducted across Bridge Creek in

Central Oregon and Yellowstone National Park, helped them and others understand key ecosystem recovery processes, from clarifying that beaver benefitted heavily grazed and incised riparian areas, to the effects of wolf reintroduction on riparian plants and stream health. In the case of Demmer and Beschta, their diligent work also contributed considerably to BDA development, as Pollock et al. (2012) pioneered these post-assisted beaver dam structures with the help of Demmer and Beschta's observed dam locations and Bridge Creek-specific dam dynamics. With low flows and the lack of flood pulses during drought likely benefiting mainstem and major tributary dam building activity (DD-3), especially in the lower Salinas River basin, it is not unlikely that a basin-wide beaver activity monitoring scheme could play a similar role to Demmer and Beschta or Smith and Tyers. Even if it is constrained to select streams or reaches, it would help provide a more robust understanding of basin beaver activity than the only current, regular beaver dam monitoring in the study area, which occurs across FHL Arroyo toad habitat on the upper San Antonio River (Jacquelyn Hancock, Fort Hunter-Liggett Environmental Division, personal communications, 23 January 2019).

Of course, it is understandable that basin natural resource managers may be hesitant to adopt BAR measures for reasons besides time or money. For one, the beaver ecosystem impact uncertainties, which this study overviewed and sought to prioritize for future research, could be magnified under these BAR measures, raising legal concerns with existing environmental policies. Second, as one of the CDFW biologists had noted, he "would like to see more evidence of whether this [basin] was historic range or not," implying that Lanman et al. (2013) provided insufficient historical ecological evidence to inform whether native flora and fauna were adapted to beaver, and thus whether promoting beaver could overall do more good than harm.

Yet both these points may not pass scrutiny. To address the second: certainly, the three pieces of evidence that Lanman et al. (2013) provide for the Salinas River basin and its northeastern San Benito River neighbor were limited to indirect sources and included no physical evidence. Corney and Alexander (1896) could have misidentified an otter as a beaver, and a San Benito County study case identified Beaver Dam Fire Station as referring to a local 1940s or early 1950s transplant ("Because my dad leased the land to the state of California for the fire station…when they were talking about names…we wanted to call it the Beaver Dam Fire Station, so that's eventually what it was called."). Furthermore, although Heizer (1974) identified a Rumsen Costanoan word, *sur-ris*, that could imply beaver were in the lower-most Salinas River basin at best, or otherwise within the Carmel River system (Monterey County Historical Society 2010), the upstream prospects are not satisfying. One contacted Salinan tribe administrator said none of their current members knew of pre- or post-1923 historical beaver activity on their lands, which cover the majority of the basin. Neither could she find a Salinan word for beaver (Patti Dunton, personal communications, Salinan Tribe of San Luis Obispo and Monterey Counties, 17 February 2019).

Still, this is not proof that beaver are an introduced species. The Salinan tribe could have referred to beaver as another name or phrase, as Lundquist and Dolman's (2018) recounting of the Tubatulabal "mud-diver" legend would suggest. Additionally, Lanman et al. (2013) provided a wealth of additional ethnographic information that supports beaver presence in other southern California basins close to the Salinas River. Those authors also found museum specimens collected in the Ventura River drainage system and reliable historical observer records of beaver in coastal basins further south. In addition, Codding et al.'s (2010) findings of a beaver fossil within a coastal San Luis Obispo County archaeological study site supports prehistoric beaver presence in that nearby basin, and thus may support historical beaver presence, too. It would thus seem more conceivable than not that pre-1923 beaver existed within the Salinas River basin, despite the uncertainties that admittedly still exist (i.e. that this study identified no new or direct evidence of basin beaver as native, historically or prehistorically).

In any case, although well-intentioned and illuminating to know for management purposes, whether beaver were native or introduced is perhaps a moot question in context of this study's findings. For while native status is critical for planning beaver translocations or reintroductions, it seems less critical for the Salinas River basin when translocations or reintroductions are unnecessary: beaver damming and activity has grown widespread since transplants occurred in the 1940s. Beaver persistence thereby indicates that the species has been influencing the Salinas River basin ecosystem for decades.

Understanding their current ecosystem impacts, then, seems more pressing than knowing whether they are native to this particular basin. Thus, to address the concern of doing more harm than good with implementing BAR measures: in the long-term, more good than harm would likely come from BAR pilot project insights for proactive basin beaver management in general, especially after considering that these projects currently require rigorous designs (e.g. Yokel et al. 2018) and are adaptive management compatible, both of which utilize local agency knowledge to minimize potential ecosystem costs. Still, if BAR pilot projects are deemed too risky or convoluted given the current uncertainties of beaver ecosystem impacts, this sentiment only strengthens the need to implement beaver activity monitoring and research as soon as possible.

Short-Range Strategy

Human-influenced flow association, with three implications

That beavers rely largely upon human-influenced flows for more stable, consistent, and frequent damming and activity across the study area (DD-2, PB-3) translates to several key implications for potential, future BAR. One of these is that sourcing beaver for BAR across these areas is generally not a problem, since human-influenced flows affect large swaths of the Salinas River basin mainstem and major tributaries throughout the year. Neither is it a problem for unregulated and intermittent streams near or connecting these areas, which, if they possess suitable geomorphology and vegetation, probably exhibit beaver activity during the high flow season (PB-2). Hence, focusing on assessing this suitability from a reach- and stream-scale perspective may optimize site planning and selection for active BAR techniques. Assessments would ideally focus on geomorphology similar to Scamardo and Wohl (2019), or understanding whether the habitat is, or could be modified to be, attractive for at least seasonal beaver utilization. To this extent, three additional sources can help prioritize particular stream reaches for greater time and resource investment: results from the BRAT and other parts of this landscape-scale study; local or regional ecological restoration goals and constraints; and early community involvement (HD-3), especially important in the upper basin due to historical nuisance activity and urban development's proximity to many tributaries in this area. As an example, among the intermittent upper basin tributaries, Paso Robles Creek is of Upper-Salinas-Las Tablas Resource Control District interest. In tandem with long-range research efforts, BAR pilot projects conducted carefully here could expand where seasonal damming or denning occurs, with seasonal benefits and minimal or manageable tradeoffs (ECOI-3, ECOI-5).

However, this specific type of planning may not be as necessary in the lower basin or the upper basin mainstem. In the latter, as with lower basin flood-regulated major tributaries, there is likely little value to promoting more damming and denning with active BAR techniques than that which currently and prevalently occurs (ECOI-7). But when appropriate in the lower basin, BAR could be used opportunistically to replace giant reed after extermination efforts, through knowledge of beaver vegetative preferences (PB-1). For instance, willow could help stabilize channel banks while providing beaver habitat or forage, and encourage denning activity, even if in intermittent reaches the willow is only utilized seasonally. Müller-Schwarze (2011) proposes using knowledge of preferred beaver food to discourage or encourage beaver occupancy, which together with common non-lethal beaver management techniques such as chicken wire-wrapped or sand-latex painted trees, can be used around the basin to mosaic beaver activity and absence strategically.

While its feasibility and details depend on better understanding beaver ecosystem impacts within the basin, another important implication of beaver reliance on human-influenced flows is climate change planning. BAR planning efforts may be able to strategize around beaver use of human-influenced flow, and their likely susceptibility to local groundwater consumption in unregulated minor tributaries (PB-3), in anticipation of a more arid, future Salinas River basin (Diffenbaugh et al. 2015, He et al. 2018). In other words, since beaver are unlikely to create and sustain their dammed environments alone during extreme droughts (Persico and Meyer 2009), but they may offer meaningful, local climate change-mitigation benefits in areas they can still inhabit (Baldwin 2015, Hafen 2017), current beaver habitat areas could be prioritized for protective measures (e.g. through groundwater pumping moratoria or limits, voluntary community use restrictions) based upon these area which exhibit (1) the best tradeoffs among the sum of their ecosystem impacts, and (2) the most stable water supply or human flexibility to accommodate beaver habitat protection during droughts. Alternatively, beavers could be incorporated into other climate change plans to an ancillary extent, rather than as a focus: recharge basins, groundwater-pumping moratoria, or strategic land retirement or restoration initiatives may be able to use nearby beaver habitat or occupancy sites as a placement decision factor, or for compensation calculations.

A final implication of beaver benefitting from human influenced flows in the basin may be unexpected partnership opportunities. For streams with mainstem or major-tributary connections: where non-point source pollution concentrates, regulatorily-permitted discharge or urban or agricultural runoff occurs, or development plans would result in concentrated stream input, it is possible that they could attract beaver, which could create habitat for other species in turn. To be clear, this implication is not an endorsement of floodplain development, and it is unlikely a sufficient California Environmental Quality Act mitigation by itself, especially with current beaver ecosystem impact uncertainties. But its possibility still should not be dismissed. From a contaminant perspective, beaver ponds have been known to benefit point and non-point source pollution, acting as retention ponds for excess nutrients, facilitating denitrification and other pollutant reduction in both urbanized and agricultural watersheds (Maret et al. 1987, Naiman et al. 1988, Bollinger and Conklin 2012, Morse and Wollheim 2014, Lazar et al. 2015, Puttock et al. 2018). And from a social perspective, developers or operations management could have an interest in supporting local environmental education opportunities that may arise from any new resident beavers.

Beaver integration with local environmental education efforts

To explain the previous point, California watershed advocates have often seen beaver as an important species for ecosystem education, as they frequently engage children and recreationists (Müller-Schwarze 2011, Dolman and Lundquist 2016). Indeed, at least six study cases alluded to beaver as an important education and engagement tool, with two ruminating in direct context of the Salinas River basin when asked as interviews ended if they had anything else they wanted to share. A Paso Robles environmental consultant mentioned “There is a conception of ‘Why worry about [the Salinas River bed] if it’s nothing but sandy desert…?’” elaborating that despite the presence of beaver and other organisms, many watershed residents are oblivious to them or their benefits. (One Atascadero family, talked to opportunistically during SA-9 surveys, indicated that beaver ponds made the Salinas River adjacent to their house “gross” – though homeless encampments, off-road vehicles, and non-point runoff may be responsible for any pollution in these ponds. See previous sub-subsection about beaver ponds generally reducing pollution.) Similarly, a Santa Margarita resident thought education would be worth mentioning, explaining that, although there have been ongoing efforts to improve education with better methods, many residents still do not understand the Salinas River basin’s importance and how we can manage its multi-county extent better. While both did not explicitly state that beaver would be an educational panacea, that another study case confirmed their classroom absence and lack of publicity (“I don’t know any other teachers that talked about it, I taught school here 38 years of my life and I never…it’s just…I don’t even know if a lot of people even know there are beavers here!”) suggests that the shock factor of their existence, combined with the intrigue of their ecosystem impact uncertainties within basin environments, may assist substantially with watershed education efforts.

However, study results indicate that thought should be devoted to how basin environmental education programs developed in the short-term portray the species. Currently, California beaver advocates’ educational efforts appear to emphasize their potential benefits (Dolman and Lundquist 2016). But within the Salinas River basin, as well as across other similar southern California basins, such in the Santa Ynez River where beaver appear to detrimentally affect steelhead trout (Cachuma Operation and Maintenance Board Fisheries Division 2018), such an approach risks disingenuousness unless beavers’ real, possible detrimental effects are also emphasized. Thus, in context of this study and the absence of basin beaver ecosystem impacts research, it seems that including explanations and discussions of potential beaver tradeoffs, such as those discussed in Theme 4, would help create more appropriate and invaluable local ecology lessons.

Although attitudes towards beaver would likely be tempered from this small shift in how beavers are discussed (HD-2), study results indicate that from a human dimensions perspective, beaver are unlikely to become a new favorite for hunting and trapping, especially with larger game species abundant in the basin. Indeed, human captivation with the species appears unlikely to change due to the respect that the species garners and the associated recreation opportunities that it provides (HD-1).

Moreover, though it would be good to identify stakeholders with capacity to facilitate preventative versus reactionary non-lethal beaver coexistence education, the seemingly few beaver takes that occur in the basin likely help control local overpopulations – something that living-with-beaver approaches may not address. At the least, this beaver take and nuisance rarity along with the sum basin beaver population size (PB-3) suggests that at first, spending extensive resources on take prevention would not be the wisest strategy. Especially for a basin whose demographics may contain a high proportion of hunters, many of who may do their best to be observant and respectful population-control agents, time may be better devoted first to changing how regional CDFW staff administer fish and game depredation regulations. Primarily, there exist clear opportunities to enhance depredation permit data collection regionally and assist with beaver-incorporating environmental education. For depredation data, regional biologists and game wardens rarely appear to communicate with each other about the beaver depredation permits that each issues. One organizational improvement would include creating shared data collection standards for staff-issued beaver depredation permits, since this change could benefit nuisance beaver activity understanding – and thus understanding how or where to concentrate non-lethal beaver coexistence education or efforts, if deemed appropriate. For environmental education, environmental educators could utilize the skins of depredated beavers, thus providing the maximum possible utility from these taken individuals. However, since skinning or carcass use of a depredated beaver is generally prohibited under current CDFW regulations for public health reasons, these regulations would first need to be modified or assessed.

Overall, despite complexities associated with beaver education efforts, particularly those implemented before we would know more about their ecosystem impacts in detail, that the species can be an important environmental education curriculum addition is powerful when combined with the examples of unexpected BAR partnership opportunities discussed previously. For because both would represent opportunities for community collaboration and engagement, and because beaver activity extends across the basin, BAR and beaver education could thus reach communities that Stanford et al. (2018) classify as restoration funding neglected. Beaver may thereby be an unexpectedly promising means to integrate basin social equity and justice concerns with its ecological ones.

CONCLUSION

This study sought to produce initial recommendations for potential, future BAR efforts within the Salinas River basin from a landscape perspective, through centralizing high-level basin beaver knowledge. In particular, incorporating a qualitative data analysis component proved beneficial, as unlike other BAR feasibility assessments (Lundquist and Dolman 2018, Macfarlane et al. 2019), this human dimensions-inclusive component enabled a more explorative or benefits-maximizing approach to BAR planning, revealing highly basin-specific opportunities and considerations. The BRAT model alone would not have detected or suggested these due to its scope.

Some of these opportunities and considerations are uncertain and require further investigation to verify or understand how to optimize them for BAR or beaver management (such as beaver feeding activity, which could reduce Salinas River vegetation overgrowth and thus flooding severity, benefitting humans). But their possibility questions the current BAR field's focus on damming, or increasing dam longevity and frequency, and not necessarily on beaver itself (Pollock et al. 2014, Bouwes et al. 2016, Macfarlane et al. 2017, Castro et al. 2018). For at least in semi-arid and arid environments like the Salinas River, where seasonal damming and bank-dwelling populations occur, ecosystem species may be better adapted to these large river or intermittent flow regime-associated beaver activities (Levick et al. 2008, NMFS 2013, Gibson and Olden 2014) than to long-lasting or large dams. For example, though this study highlighted a large association between current beaver damming locations and damming consistency with human-influenced flow, results show that across the basin, it is highly likely that many of these dams are destroyed or damaged and are rebuilt after winter high flows or managed flood pulses occur (Andersen and Shafroth 2010, MCWRA 2018). Prior to flow regulation on three of the basin's major rivers, any existing beaver would likely have had to rebuild dams more frequently than they do currently due to increased flooding severities and frequencies, too (Beller et al. 2009). Thus, with this historical likelihood and current presence of seasonal damming, along with bank-dwelling and other common basin beaver activities which may benefit ecosystem species (Parish 2016), but with currently unknown tradeoffs across various spatiotemporal scales (Labbe and Fausch 2000), one key study suggestion is to first focus any BAR pilot projects and beaver ecosystem impacts research around this current beaver activity status quo. That is, to cautiously promote seasonal damming and denning activity if and where it may be most beneficial, and least risky, while simultaneously integrating ecosystem impacts research. BRAT model outputs provide an relatively accurate and instructive means to help decide where to concentrate these efforts, while CAQDA of study case beaver attitudes supports a need to incorporate early community involvement, similar to Charnley (2018) and Castro et al. (2018) However, CAQDA suggests that this community involvement should extend beyond those who are traditionally weary or critical of government agency-involved restoration projects (but see Charnley (2018) about government-resident interaction minimization in BAR). That is, communicating the species' potential tradeoffs with residents who see little to no harm from beaver may be valuable for spurring an increased Salinas River basin ecosystem awareness, if not obtaining their interest, support or help with project or research implementation.

Among other interesting results, through using relatively simple and low-cost methods to extensively survey the Salinas mainstem and its key tributaries, beaver were found to be pervasive throughout the Salinas River basin. This finding contrasts starkly with Lanman et al. (2013) historical records of beaver as well as current lay and scientific understanding of beaver prevalence in this southern California basin. In addition, the beaver studied during the survey period persisted and thrived through the worst drought in modern California history, demonstrating that habitat for beaver is quite suitable in at least the Central Coast hydrologic region's rivers despite frequent intermittent and ephemeral flows. Although anthropomorphic sources of water in the lower basin likely facilitated their survival, it can be postulated that the vagile nature of beaver, which use streams, other waterways, and even overland movements to travel significant distances, may have enabled them to survive this drought by moving to and concentrating themselves nearest these human-influenced perennial water sources. Hence, other contemporary surveys based on techniques employed herein, if deployed in other southern California basins, could help better understand (1) southern California beaver population prevalence and adaptation to likely worsening drought conditions in the state (Snyder et al. 2004, Seager et al. 2007, Diffenbaugh et al. 2015, He et al. 2018), (2) their current ecosystem impacts in these basins, and (3) how droughts change or may change these populations' impacts.

Similarly, this study underscores that in basins where beaver are omnipresent, California beaver advocates' educational and BAR focuses may benefit from a strategy adjustment. To-date, extensive effort has been spent showing natural resource agencies and the public that beaver are almost assuredly native to most of California's hydrologic regions, including montane ecosystems in the Sierra Nevada to coastal streams, to perennial river in southeastern deserts (James and Lanman 2012, Lanman et al. 2013). Present beaver advocacy efforts emphasize this native status and focus on species benefits, or what ecosystems may lose by not having beaver in their basins (Dolman and Lundquist 2016). These efforts are valuable and should continue for encouraging beaver stewardship, especially among the public. However, the findings of this study suggest that, especially for basins where beaver are prevalent, integrating discussion of consequences, or what we lose by not fully understanding their basin-specific ecosystem impacts, may be just as if not more important. Among natural resource agencies and organizations, this approach may better advance proactive beaver management initiatives or BAR pilot projects, especially if they can be coupled with research that would ultimately benefit these groups' missions or duties.

While this study provided clearer research directions and human dimensions-inclusive BAR recommendations for the Salinas River basin than would have possible without any one component of this project, procedurally there are improvements that can be made to each method. For the beaver dam field surveys: early collaboration with multiple agencies or organizations, or recruiting multiple experienced surveyors to collect data from different basin areas, would have allowed for more efficient and less biased dam location collection; i.e. there would be more time available to travel to bridge or stream overlooks by lower order streams or streams to search for dams or beaver evidence. Historically, since a common beaver transplant strategy may have been to release beaver and dump beaver food at these stream-access areas (see Theme 4), these efforts may be worth the extra work. Also, if dam locations are most important, and not other dam physical characteristics, drone-based documentation should be explored.

While Puttock et al. (Puttock et al. 2015) found drones effective for repeat monitoring of beaver-influenced environmental changes for a small area at a 0.01 m resolution, less-fine drone imagery may help identify dams in minimally-canopied channels more rapidly and cost effectively than ground traverses.

For the emailed survey: perhaps as could be expected, phone calls and in-person interviews revealed more information than study cases tended to write in the survey. Along with recording and transcribing these phone interviews, more effort and focus invested in the interview format, instead of the survey response, may also reduce a potential results-reporting bias, away from the greater amount of detailed-information shared in and reviewable from the transcribed interviews. And in terms of study case composition, to better diversify shared perspectives and information, PRA requests should be submitted early. Obtained information may be useful for contacting basin residents with negative beaver experiences, or associated individuals. Local environmental consulting companies should also be included in the outreach phase in general. They may have beaver-knowledgeable staff, or possess unpublished and useful environmental impact reports and biological surveys.

And as for the BRAT model: as with Macfarlane et al. (2019) a more precise perennial stream network, including frequently perennially-ponded or spring-fed stream reaches, would have been useful to provide a more accurate BRAT assessment. In similar semi-arid and arid southern California basins, slope logic and LANDFIRE 2014 existing vegetation coding may need to be adjusted, similar to in this study, to account for regional beaver population and hydrological regime characteristics that differ from those in Utah, the BRAT model's development state.

Lastly, this study's high-level nature means that most of its findings have a higher degree of uncertainty and speculation than is common among dedicated beaver population, behavior, or habitat suitability index studies conducted between the reach- and basin-scale. In an attempt to reduce uncertainty, key findings were therefore typically grounded in more than one method (Table 14). Nevertheless, study findings should be treated and used cautiously, as they do not fully explain the respective aspects of their associated beaver knowledge area for the Salinas River basin.

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APPENDICES

Appendix A. California beaver studies with a multi-basin, basin, or close-to-basin (landscape) investigative spatial scope, out of 46 studies identified involving or mentioning beaver using search terms of 'California' and 'beaver,' or 'California' and 'castor canadensis' in Google Search, Google Scholar, Web of Science (Core Collection and Zoological Record), Agricola, and Treesearch (all: within first 100 results), along with reviewing the literature references of results. Grey literature and masters theses identified opportunistically, or which project contacts provided, were also included in this number of identified studies.

Study reference	Study location (DWR hydrologic region)	Primary investigative purpose
Ayers (1997)	North Lahontan	Geographic distribution
Baldwin (2015)	North Coast, North Lahontan	Beaver-assisted restoration
Beier and Barrett (1987)	North Lahontan	Biology or ecology
Beier and Barrett (1989)	North Lahontan	Geographic distribution
Cachuma Operation and Maintenance Board Fisheries Division (2018)	**Central Coast**	Monitoring or other study focus
Charnley (2018)	North Coast	Beaver-assisted restoration
Hensley (1946)	All	General management
Lanman et al. (2013)	All	Geographic distribution
Light (1969)	**South Coast**	General management
Lundquist and Dolman (2018)	**Tulare Lake**	Beaver-assisted restoration
Parish (2016)	North Coast	Biology or ecology
Tappe (1942)	All	Management

Note: **Bold** indicates southern California hydrologic regions

Appendix B. Salinas River basin riparian species that are endangered, threatened, or of concern, with potential effect of beaver activity based upon literature where available, otherwise on described habitat preferences.

Type	Common name	Scientific name	Federal/State/ Other status	Required or preferred habitat	Current range or known sightings within basin	Potential effect of beaver and dams*	Effect sources**
Amphibian	Arroyo toad	*Anaxyrus californicus*	FE/--/SSC	Intermittent streams with low gradients and sandy and gravelly substrate. Typical vegetated cover preferences include cottonwood, sycamore, and willow trees. Mates and lays eggs at the quiet margins of shallow streams and pools from March through July.	Presence is limited to above Lake San Antonio in the San Antonio River	-	1, 2
Amphibian	California red-legged frog	*Rana aurora draytonii*	FT/--/SSC	Perennial pools at least eight inches deep with sandy substrate. Preferably with little or no flow, emergent and overhanging support vegetation such as willows. Typically breeds from November through March.	Salinas River near Paso Robles, Atascadero Creek, Salinas River headwaters	+	3
Amphibian	Coast range newt	*Taricha torosa torosa*	--/--/SSC	Prefers valley-foothill hardwood forest with nearby freshwater or riparian areas. Prefers vernal pools for breeding, but stream pools are bred in typically after winter floods have subsided, beginning in March and lasting as late as July.	From San Diego through San Luis Obispo County; three bridges area of Atascadero Creek.	+	0
Amphibian	Southwestern pond turtle	*Actinemys pallida*	--/--/SSC	Pools three feet or greater in depth with underwater cover features and basking sites. Prefer upland terrestrial habitat. Mates from April through May.	Salinas River downstream of Santa Margarita Lake	+	4, 5

Note: "Required or preferred habitat" descriptions from http://www.californiaherps.com/, http://www.fws.gov/, http://www.wildlife.ca.gov; "Current range…" descriptions from same sources, Funk and Morales (2002), Funk et al. (2004), and/or sources listed below.

* + beneficial, - detrimental, • neutral or undetermined from sources

** [0] No species-specific beaver-association sources identified – based upon habitat description and similar species described in Castro et al. (2018); [1] Brehme (2004); [2] Hancock (2009); [3] Alvarez (2013); [4] Lovich (2012); [5] Alvarez (2006)

Appendix B (continued). Salinas River basin riparian species that are endangered, threatened, or of concern, with potential effect of beaver activity based upon literature where available, otherwise on described habitat preferences.

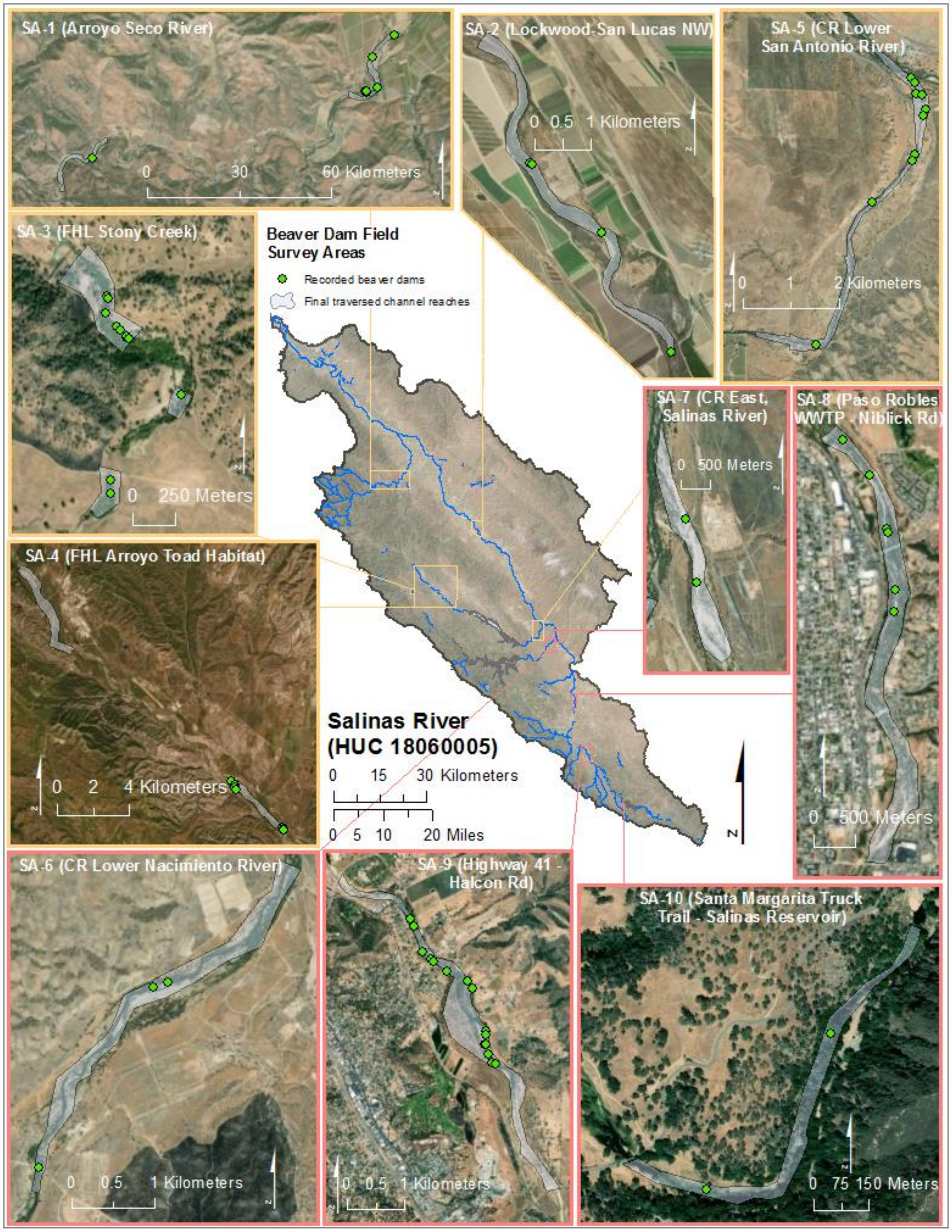
Type	Common name	Scientific name	Federal/State/ Other status	Required or preferred habitat	Current range or known sightings within basin	Potential effect of beaver and dams*	Effect sources**
Bird	Least Bell's vireo	*Vireo bellii pusillus*	FE,MBTA/ SE/CH	Riparian habitat, preferably willow-dominated with a dense understory for nest-building and near-nest-foraging purposes. Typically breeds from March through July.	Mostly in San Diego County, but smaller populations from Ventura to San Luis Obispo Counties	+	6
Bird	Swainson's hawk	*Buteo swansoni*	MBTA/ST/--	Open desert, grassland, cropland with alcoves of trees. Species typically flies through Salinas Valley, but does not nest in either county.	Eastern part of San Luis Obispo County, especially riparian habitats	•	0
Fish	Southern steelhead (South-Central California Coast Steelhead Distinct Population Segment)	*Oncorhynchus mykiss irideus*	FT/--/--	Clear, cool stream, river, and lake pools. Abundant in-stream cover such as vegetation, large woody debris preferred, clean and loose gravel with 1:1 pool-to-riffle ratio typically required. Eggs are laid in riffle sections in the spring. For migrations, fast or moderate velocity (≥1.5 ft/s) water flows are needed. Adults migrate to the ocean between March and July, while juveniles may stay within the freshwater streams year-round.	Santa Margarita Creek, Tassajara Creek, Atascadero Creek, Hale Creek, Paso Robles Creek, Jack Creek, Arroyo Seco River	•	7, 8, 9, 10, 11

Note: "Required or preferred habitat" descriptions from http://www.californiaherps.com/, http://www.fws.gov/, http://www.wildlife.ca.gov; "Current range…" descriptions from same sources, Funk and Morales (2002), Funk et al. (2004), and/or sources listed below.

* + beneficial, - detrimental, • neutral or undetermined from sources

** [0] No species-specific beaver-association sources identified – based upon habitat description and similar species described in Castro et al., 2018; [6] see discussion in Longcore (2007); [7] Gard (1961); [8] Kemp et al. (2012); [9] NMFS (2013); [10] Bouwes et al. (2016); [11] Cachuma Operation and Maintenance Board Fisheries Division (2018)

Appendix C. Final beaver dam field survey areas that were foot-traversed through the river channel, with the exception of the western-most portion of "FHL Arroyo Toad Habitat," which was mostly bank-observed via foot or vehicle. Recorded dams shown in each area. Lower basin survey areas are noted in mango extent indicators and leader lines, while upper basin survey areas are noted in pink extent indicators and leader lines.



Appendix D. Main beaver dam field survey data collection sheet used in study (page 1/2), provided by and used with permission from Utah State University's Ecogeomorphology and Topographic Analysis Laboratory.

BEAVER **DAM COMPLEX** MONITORING FORM - ADVANCED

UtahStateUniversity RESTORATION CONSORTIUM

OBSERVATION INFO

Observer Name: ______________________

Site ID: ______________________

Observation Date: ______________________

Beaver Built Dams?

- o Beaver-only Built Dams
- o Beaver Dam Analogue (manmade)
- o Mix of beaver-built and manmade

Complex Type:

- o Single Dam only
- o Primary + One or More Secondary
- o Multiple Possible Primaries + One or More Secondary

Observation Chronology

- o New Observation of New Complex
- o First Observation of Existing Complex
- o First Observation of Relic Complex
- o Repeat Observation of Existing Complex

Status

- o Active
- o Abandon
- o Historic/Relic

Confidence in Status

- o Certain - Documented Evidence
- o Probable - Strong Evidence
- o Possible - Anecdotal or Inconclusive Evidence
- o Unsure - Just a guess

Flow Condition

- o Baseflow
- o Spring runoff
- o Flood
- o Post Flood

POSITIONAL ATTRIBUTES

Location of Primary Dam

GPS UTM Easting: ______________________

GPS UTM Northing: ______________________

Complex Location Relative to Channel(s)

- □ On Main Channel
- □ On Right Side Channel(s)
- □ On Left Side Channel(s)
- □ On Left Floodplain
- □ On Right Floodplain

Complex Size

Number of Primary Dams: ______________

Number of Secondary Dams: ______________

Position of Dams

Primary Dam Location: □ Top □ Bottom □ In-between

Number of Secondary Dams Upstream of Primary: _______

Number of Secondary Dams Downstream of Primary: _______

DAM COMPLEX ATTRIBUTES AT TIME OF SURVEY (IF APPLICABLE)

Primary dam max height (m) +/- 0.1 m __________

Primary pond max depth (m) +/- 0.1 m __________

Dam height range (m) +/- 0.1 m ______________

Pond depth range (m) +/- 0.1 m ______________

Primary water surface drop (m) (m) +/- 0.1 m __________

Primary dam crest length (m) (m) +/- 1 m __________

Side Channels

NOW:	@ HIGH(ER) TYPICAL FLOOD:
□ None	□ None
□ Single Left	□ Single Left
□ Multiple Left	□ Multiple Left
□ Single Right	□ Single Right
□ Multiple Right	□ Multiple Right
□ None	□ None

Lateral Valley Bottom Extent of Complex

- o Limited to within one bankfull channel
- o Occupying multiple bankfull channel
- o Occupying single channel & partial valley bottom w. %____
- o Occupying multiple channels & partial valley bottom % ____
- o Impacting entire valley bottom width

Streamwise Extent of Complex

o < 25 m	o 50 - 100 m	o 25 - 50 m
o 100 -250 m	o 250 - 500 m	o > 500 m

Floodplain Inundation

- □ During Extreme Floods - River Right
- □ During Extreme Floods - River Left
- □ During Seasonal Floods - River Right
- □ During Seasonal Floods - River Left
- □ Year Round Inundation - River Right
- □ Year Round Inundation - River Left

Dam Materials Used (Circle Dominant)

- □Woody branches > 15 cm diameter
- □ Woody branches < 15 cm diameter
- □ Mud
- □ Grass / Reeds
- □ Other organic
- □ Cobble or Boulders

Appendix D (continued). Main beaver dam field survey data collection sheet used in study (page 2/2), provided by and used with permission from Utah State University's Ecogeomorphology and Topographic Analysis Laboratory.

Estimated Complex Age

○ < 1 year ○ 1-3 years
○ 3-5 years ○ 5 -10 years
○ > 10 years

Evidence (optional):

DAM CONDITIONS (IF APPLICABLE)

Flow Types Present (of what dams)

Flow Over Top	□ Primary	□ Secondary
Basal Flow	□ Primary	□ Secondary
Throughflow	□ Primary	□ Secondary
Flow Around Left	□ Primary	□ Secondary
Flow Around Right	□ Primary	□ Secondary

Primary Dam Breach or Blowout

○ Intact
○ Minor breach (< 25 cm height) on left
○ Minor breach (< 25 cm height) on right
○ Minor breach (< 25 cm height) on center
○ Minor basal breach
○ Major breach (> 25 cm height) on left
○ Major breach (> 25 cm height) on right
○ Major breach (> 25 cm height) on center
○ Major basal breach
○ Blowout (whole height of dam breached)

Primary Pond Capacity

○ Clean ○ Minor Sedimentation
○ Partial Filling (up to 50% of original pond capacity)
○ Major Filling (50% to 95% of original pond capacity)
○ Full of sediment (no longer a pond)

RECENT BEAVER MAINTEANCE OF COMPLEX:

Dam Expansion

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Dam Construction

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Dam Maintenance

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Scent Mound

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Canal Digging

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Pond Excavation

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Dam Notching

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Draining/Flushing

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Corn on the Cob (Foraging)

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Felling of Trees

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Harvesting of Branches

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Skid Trail Usage

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity
○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Primary Wood Harvested

○ Aspen ○ Cottonwood
○ Willow ○ Other Hardwoods
○ Conifers ○ No active harvesting

Above Ground Lodge Maintenance or Construction

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Bank Lodge Maintenance or Construction

○ Certain - Documented Evidence ○ Probable - Strong Evidence
○ Possible - Anecdotal or Inconclusive Evidence
○ Unsure - Just a guess ○ No Evidence of Activity

Appendix E. Emailed survey questions. Questionnaire was also used for semi-structured phone and in-person interviews. Protocol for emailed survey response-seeking also shown through example email.

Emailed survey question	Question type	Categorical data type	General purpose
Section 1: Contact information			
Email address	Open-ended	Nominal	Follow-up; compensation
Name	Open-ended	Nominal	Follow-up
Phone number	Open-ended	Nominal	Follow-up
Affiliation	Open-ended	Nominal	Follow-up
Have you observed beaver or signs of beaver within the Salinas River watershed?	Yes/No	Nominal	Proceeds to next section if "Yes," otherwise skips it
If yes, what is the address or detailed description of your property, business, and/or field work location(s) where beaver or beaver activity was observed?	Open-ended	Nominal	Location(s) for beaver damming consistency range map (BDCRM); spatial extent of study case knowledge
Section 2: Information on your observations			
1. Please specify the signs of beaver you have observed in this location(s).	Multiple answer	Nominal	Data reliability classification assistance for BDCRM
2. If "Nuisance activity" was selected, describe what they affect and how.	Open-ended	Nominal	Human dimensions - nuisance activity
3. Choose the beaver activity frequency option that most accurately represents your observations.	Multiple choice	Nominal	Frequency classification assistance for BDCRM
4. Please explain your answers to the previous questions.	Open-ended	Nominal	Greater detail or information for data interpretation
5. How long have you lived, worked, and/or frequented the location?	Multiple choice	Ordinal	Data reliability classification assistance for BDCRM; temporal extent of study case knowledge
6. How would you describe changes in beaver populations or activity since you have lived, worked, and/or frequented this location?	Multiple choice (Likert scale, with 'Not sure')	Ordinal	Beaver population dynamics
7. Please explain your answer to Questions #5 and 6.	Open-ended	Nominal	Greater detail or information for data interpretation

Appendix E (continued). Emailed survey questions. Questionnaire was also used for semi-structured phone and in-person interviews. Protocol for emailed survey response-seeking also shown through example email.

Emailed survey question	Question type	Categorical data type	General purpose
Section 2: Information on your observations			
8. Do you have any photos or recorded evidence of beaver in the location(s) that you can share with me?	Yes/No	Nominal	Data reliability classification assistance for BDCRM; beaver population dynamics
9. Lastly, how would you characterize your current overall attitude towards beaver?	Multiple choice (Likert scale)	Ordinal	Human dimensions - general attitudes
10. Please explain your answer to Question #9.	Open-ended	Nominal	Greater detail or information for data interpretation
If you have any other thoughts or ideas that you would like me to know, please use the below space to communicate them.	Open-ended	Nominal	Allows study case to • provide different opinions or information than asked • elaborate on any previous information they gave
Section 3: Distribution of survey to one or more acquaintances			
Do you know of other friends, neighbors, coworkers, or locals who may be aware of beaver activity within the watershed, or may have observed it?	Yes/No	Nominal	Chain referral • better reach targetted study area population • increase survey response rate via acquaintances or obtained references • improve diversity or range of final study cases
Will you forward my survey to them, and ask for them to complete it on my behalf?	Yes/No	Nominal	
Regardless of your previous answer, will you be able to share their contact information with me?	Yes/No	Nominal	
Their contact information.	Open-ended	Nominal	
Would you like to receive a copy of my thesis, when finished?	Yes/No	Nominal	Compensation

Note: Survey was linked within an initial email that aimed to be as brief as possible, explaining purpose of email and survey, its length, who should take it, and compensation. The emailed survey's introduction included a link to additional details about how submitted survey responses would be used. The survey was open for one month, with reminder emails and phone calls made to each original recipient or their referred contacts, as needed, one to two times per week after the distribution email was sent.

Appendix F. Frey et al. (2006)-modified reliability classification criteria for survey and interviews respondents, with summaries of number of respondents ranked within each.

Study reliability class	Approximate Frey et al. (2006) class-equivalent	Study class characteristics	Number of study cases (n = 39)
A: Consensus and/or evidence-verified	A: Verified	• Study case’s observations have convincing detail • Other independent study cases of ≥ 15 years’ experience (largest option in Question 5, Appendix E) support their observations • Primary data, grey literature, photographs, depredation permit(s), Google Earth-identified dams, or other evidence of dams or beaver presence supports their observations, whether they provide these themselves or these are obtained through the historical records and literature review	30
B: Highly probable or probable	B: Highly probable, C: Probable	• Study case’s observations have convincing detail • These are from only one study case with no others mentioning, or much evidence	5
C: Possible, or possible inference	D: Possible	• Single study case’s speculation(s) with little to no evidence, but Google Earth-identified dams or other study cases with similar speculations would support these speculations; or • Class A/B-status study case may be classified as C if another study case offers a different perspective for the same area yet does not necessarily invalidate the first observer's response, or some response details cause reliability doubt	4
D: Questionable or unlikely; unlikely inference	E: Questionable, F: Highly Questionable, G: Erroneous	• Study case’s observations have insufficient detail; and/or • Single study case’s speculation(s), with no evidence or consensus-driven support; and/or • Historical transplant occurred in area but there are no data of current existence found or collected; and/or • Conflicting accounts from different study cases invalidate each study case’s observations	0

Note: Study case generally refers to relevant (riparian)-experienced professionals or long-time residents. For speculations: these had to come from a study case with a relevant-experienced professional background.

Appendix G. Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-1. (a) SA-2, looking downstream, arrow indicates active dam contributing to backwatering in side channel, (previous main channel dam extent appeared blown out); (b) SA-2, downstream, inactive dam in side channel; (c) SA-2, upstream, inactive dam in side channel; (d) SA-5, downstream, potential large woody debris (LWD) collection against fallen willow tree – although not recorded as a beaver dam, it may act as an anchor for dam building or promote beaver activity during high flows or as high flows recede; (e) SA-6, downstream – also not recorded as beaver dam, but arrows indicate potential LWD anchors used for building a prior dam; (f) SA-6, upstream, active dam with arrows indicating various LWD or felled trees to build or reinforce dam structure.

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-2. Two beaver dams within SA-3, the second (crest delineated in orange) immediately downstream of and connected to the first (crest delineated in red). Though the willow tree as a stable foundation contributor and as a convenient food source could have influenced the decision to link the second to the first and at the given location, among other factors such as the plethora of building materials in SA-3, it is also possible that a steeper reach gradient than in most other SA reaches contributed as well.

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-3. (a) SA-7, looking downstream, dam or remainder of one in dried up, river-left baseflow stream within main channel; (b) SA-7, downstream (view, and relative to previous), same as previous; (c) SA-8, upstream, two dams or remainder of them in dried up, river-left baseflow stream within main channel; (d) SA-8, upstream (view, but downstream of previous, and upstream of WWTP input to Salinas River), showing a beaver pond that was still present but drying up. A probable explanation for these observed dams is that they were constructed to maximize home range as soon as high flow season began (if the intermittent flow was not substantial in these reaches), or otherwise when it was possible from receding high flows. While possible that off-road vehicle use in the Salinas River bed or high flows could have diminished the heights and lengths of these dams, it may not be a considerable factor – no off-road vehicle tracks or heavy vehicular use signs were evident where the dams were found, though some were observed along other parts of SA-7. Due to the extremely low slope of the Salinas River, and without perennial water flow, dams not much larger than in (a)-(c) would make sense for this area (Macfarlane et al., 2017) especially based upon (d). (d) and another, similar beaver pond upstream of (c) showed a lack of maintenance in these dams – indicating that these beaver ponds rely on local topography at this seasonal time period to stay filled with water, since they were otherwise drying up. Together, these observations support the plausibility of this seasonal beaver home range expansion and contraction (see also Figure G-5 and G-8).

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-4. SA-5 bank lodges. Top: active, downstream of other bank lodge. Bottom: appeared inactive; leveling rod shows relative size, with top of rod at 4.5 ft. Though bottom could be an agglomeration of LWD, its proximity to the bank (seen in background), similarity to the other bank lodge, and general intricacies of how each branch and piece of wood was positioned indicates it is the work of beaver.

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-5. Beaver canals help maximize home range during late autumn baseflows by making it easier for beaver to transport food or dam building material from forage areas to their ponds, lodges or dens – additionally, some of these canals may have been dredged from the bottom of former ponds or intermittent flows, in anticipation of the drier seasonal conditions or drought, to concentrate the water that remains. Passage can thereby continue between still-existing ponded areas, or ponds and forage areas (Müller-Schwarze, 2011). (a)-(b) SA-9, looking upstream; (c) SA-1, panorama of upstream (left) to downstream (right); (d) SA-1, downstream view at the end of this SA-1 canal; (e) dry channel inactive dam downstream of (d); (f) canal near San Lucas in 2016, photo courtesy of E. Zefferman.

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-6. Duckweed or similar herbaceous vegetation was commonly seen floating at the top of SA-9 beaver ponds – one example seen here (left) with leveling rod showing dam size (top of rod is 4.5 ft). Right: beaver grazing on or swimming through duckweed in Santa Margarita beaver pond, closer to S-10; photo provided courtesy of N. Fortune.

Figure G-7. Sycamore use along SA-6 (left) and SA-1 (right) for bank denning purposes. Different trees are likely used as well for bank denning within the study area, as trees in general help stabilize den roofs with their root structure (Baker and Hill, 2003).

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-8. Relic beaver foraging evidence (note characteristic incisor chew marks on branch) within the intermittent Santa Margarita Creek near Highway 101. Suggests that beaver may disperse into some intermittent streams during the high flow season.

Figure G-9. Bank slides (trails) seen by beaver ponds in SA-8 (left) and SA-9 (right), as indicated with arrows.

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-10. Study case demonstrating size and erosive impact of a former bank den by the Spanish Lakes neighborhood in Templeton, San Luis Obispo County. The county filled in the den and rebuilt the road after it collapsed recently, due to the beaver activity.

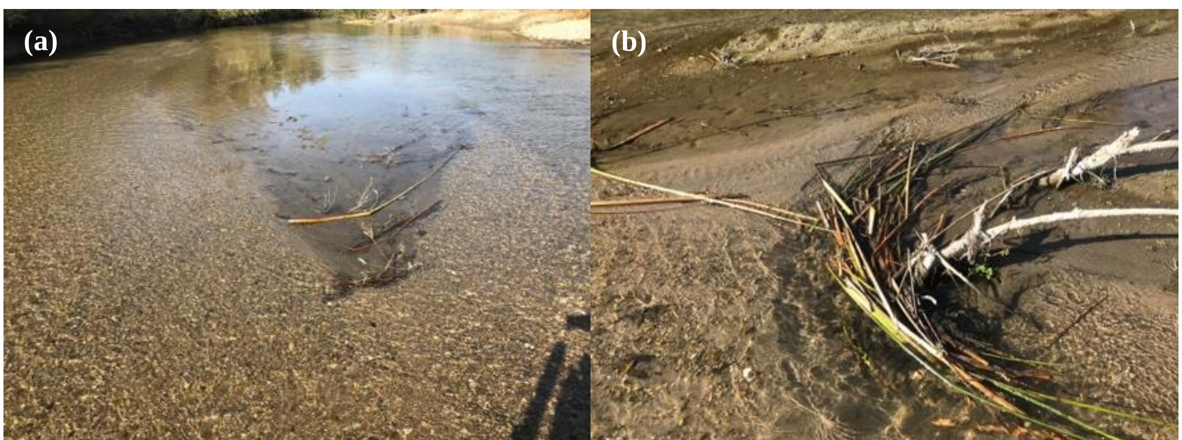


Figure G-11. Examples of beaver foraging activity and blown out dams within SA-2 that may contribute to temporary stream microhabitat creation, if not contribute to long term, small riffle and pool formations. (a)-(b) Beaver foraged food temporarily stored or caught within streambed; (c) an arrow indicates what could have been the remainder of an inactive dam.

Appendix G (continued). Beaver dam field survey photos illustrating points made in their respective *Results and Discussion* sections.

Figure G-12. Improvised pond leveling mechanisms (white pipes) seen positioned through a beaver dam (obscured by tall grass) within Franklin Creek by the Spanish Lakes neighborhood in Templeton, San Luis Obispo County.

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