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IDENTIFYING WATERSHED AND CLIMATIC FACTORS THAT INFLUENCE HEADWATER STREAMS IN THE SAN BERNARDINO NATIONAL FOREST - A FRAMEWORK FOR ADAPTIVE MANAGEMENT AND CONSERVATION

Christine Sue Seeger

IDENTIFYING WATERSHED AND CLIMATIC FACTORS THAT INFLUENCE HEADWATER STREAMS IN THE SAN BERNARDINO NATIONAL FOREST - A FRAMEWORK FOR ADAPTIVE MANAGEMENT AND CONSERVATION

A Thesis

Presented to the

Faculty of

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In Partial Fulfillment

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by

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ABSTRACT

Headwater streams play a significant role in overall watershed condition. These streams are critical freshwater resources and are imperative for human and ecosystem health. Seasonal variability in climate patterns is becoming increasingly more common as the effects of climate change are studied. The phenomenon known as “weather whiplash,” prolonged periods of drought followed by a sudden increase in precipitation, creates additional challenges for human and ecosystem conditions. Factors adversely impacting headwater streams include climate change, drought, wildfires, and human influence. While climate change continues to be studied, little is known about how weather whiplash patterns affect headwater streams in Southern California. This study focuses on four streams in the San Bernardino Mountains: Deep Creek, Little Bear Creek, Hooks Creek, and Orchard Creek, all headwater streams of the Mojave Watershed. Each stream exhibits a unique flow pattern that navigates through various landscapes with diverse land use and cover conditions. To better comprehend these intense shifts in climate, water samples were collected for each stream at least once a month for the hydrological years 2019-2020 and 2020-2021. Water quality parameters included stream flow rate, stream temperature (c), conductivity, dissolved oxygen (DO), pH, turbidity, ammonium (NH_4^+), nitrate (NO_3^-), total coliform (TC), E. coli, and enterococcus. Water data was analyzed as a percentage of not meeting regulatory requirements. Monthly precipitation and atmospheric temperature were also assessed to examine any relationship between climate and stream health. The NLCD was applied to stream sites to explore how land use types potentially affect water quality. Findings found that nutrients had the highest regular exceedances throughout the hydrological year. After precipitation events, the limited bacteria samples collected had high exceedance rates and were primarily concentrated in catchments with higher development concentrations. Furthermore, examining current watershed management practices allowed for assessing possible ways to manage headwater streams better.

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DEDICATION

I dedicate this to my family, Katie, Natalie, and Chris. This is for you guys. I love you lots. Chris, thank you for everything through this process. This thesis is just as much yours as it is mine. Thanks for your patience along the way.

I also dedicate this to my parents, Roger and Shelly. They instilled the importance of perseverance and hard work. Watching my mom go through school while my sister and I were young gave me the encouragement and confidence to return to college. I miss you, Mom, every day, and I hope I am making you proud.

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CHAPTER ONE

INTRODUCTION

Literature Review

Freshwater resources are essential to supporting human and ecosystem health. Of the world's total water supply, approximately 2.5 percent is freshwater, with only 0.26 percent of that total found as surface freshwater in the form of lakes, reservoirs, and river systems (Shiklomanov, 1998). Hydrological systems or units (i.e., watersheds, river basins) serve as the primary conveyance system to collect and transport surface water to lakes and oceanic bodies (Alexander et al., 2007; Edwards et al., 2015; Peters and Meybeck, 2000). The beginning or headwaters of a hydrologic system are significant because adverse morphological or physiochemical impacts on these surface flows mean that downstream water resources will likely be adversely impacted (Alexander et al., 2007; Gomi et al., 2002; MacDonald and Coe, 2007)

Watersheds are an essential source of freshwater within a landscape. A watershed is defined as an area of land that channels precipitation and surface flows to a common body of water as a result of its topography and landscape, including forest, rural, agricultural, urbanized, and other land use and land cover types (CWQMC, 2023; Edwards et al., 2015; NCSU, 2023; NOAA, 2022) Several variables, including climate, watershed landscape, and human activities, influence the overall health of a watershed. Several studies indicate that human impacts are the most significant on watershed landscape and surface water quality and quantity. This may include agriculture, recreation, urbanization, and land management policies (Ahmadi and Moradkhani, 2019; Mainali and Chang, 2021; Smucker et al., 2016). Understanding the complexity of headwater characteristics, how both human and environmental factors influence headwater streams (HWS), and their role within a watershed is imperative to ensure water management practices are utilized for watershed conservation. Of growing concern to resource agencies, researchers, and communities is how these factors influence HWS in situ and downstream. This knowledge is essential to developing resilient and adaptive watershed conservation and management strategies.

Although less attention has been given to HWS regarding overall watershed management, increasingly watershed management agencies and the in situ and downstream communities that rely on headwater stream flows seek to identify what factors influence surface water quality and quantity (Alford and Mora, 2022). The lack of focus on HWS leads to uncertainty about how to adaptively manage and protect these flows along the main stem to their point of termination (Lassaletta et al., 2010; MacDonald and Coe, 2007). Central to determining impacts on HWS is understanding the landscape configurations or patterns that drain to HWS as well as how those landscapes change from the headwaters to the mouth of a watershed (Alexander et al., 2007; Dodds and Oakes, 2008; Gomi et al., 2002; Nadeau and Rains, 2007). Colvin et al. (2019)

observed that modifying or rescinding policies established to protect HWS and wetlands would critically endanger millions of acres of HWS within the United States. In the same study, Colvin et al. (2019) concluded that HWS are essential for supporting the quality and quantity of biodiversity, ecosystem habitats, natural resource tourism, and many human uses (i.e., drinking water, agriculture, manufacturing, and the like).

HWS are classified as first- and second-order, representing the highest-branched streams within a hydrological unit (Gomi et al., 2002). In the contiguous United States, HWS comprise over 70 percent of river length and account for 79 percent of stream networks within the United States, highlighting the need to understand disturbances to HWS and how such impacts impact water resources across the entire hydrological network (Colvin et al., 2019; Lassaletta et al., 2010). HWS provides both ecological and human benefits across the entire hydrological network. Ecological benefits of HWS include stream and soil health (i.e., sediment distribution in situ and downstream), sustaining ecosystems (i.e., aquatic and terrestrial habitats), riparian vegetation (i.e., flood control and pollution mitigation), and groundwater recharge (i.e., baseflow) Human benefits of HWS include safe drinking and recreational water resources that are imperative for promoting public health. In addition, surface water resources support diverse human activities, including agriculture (i.e., water for crops and livestock) and commercial uses, including retail and industrial uses (i.e., manufacturing) (Alexander et al., 2007; Dodds and Oakes, 2008; EPA, 2015c).

Although HWS serve multiple benefits, they are also subjected to spatially and temporally diverse environmental and anthropogenic factors. Dynamic shifts in drought and precipitation suddenly alter HWS and cause shifts between low flows and sudden, excessive stormwater discharge. These sudden fluctuations can negatively alter water quality and quantity, leading to ecosystem deterioration and creating difficulties for public health (Chang and Bonnette, 2016; Loecke et al., 2017). Wildfires are also of concern during droughts because they destroy substantial quantities of vegetation and soil profiles. After a wildfire, reestablishing vegetation to negatively impacted soil is difficult. Exposed soil is often transported via debris flows, causing sediment and turbidity in HWS and downstream (Smith et al., 2011). Human alteration and development of the landscape (i.e., housing, roadways, infrastructure) influence HWS significantly due to an increase in impervious surfaces (Alford and Mora, 2022). Impervious surfaces cause stormwater runoff and pollution during and after precipitation events, causing significant concern (Arnold and Gibbons, 1996; Brabec et al., 2002). Land use, such as agriculture, also impacts HWS due to water quality degradation from stormwater runoff (Danz et al., 2013; Loecke et al., 2017).

Given the significance of HWS, it is essential to consider the spatio-temporal extent to which environmental and anthropogenic factors impact the quantity and quality of headwater flows (Alexander et al., 2007; Dodds and Oakes, 2008; Rasmussen et al., 2013). This includes identifying the land use and cover within a watershed landscape, monitoring water stream flows, and considering climatic trends through interdisciplinary assessment techniques. One of the primary threats to headwater stream health is climatic changes, including unpredictable weather and drought conditions that impact stream flow and quality, as well as supporting conditions for wildfires (Ahmadi and Moradkhani, 2019). Drought negatively impacts streamflow, increases concentrations of pollution inputs and harmful algal blooms, and affects riparian health (i.e., regulating stream temperature and excessive sediment transport). Additionally, atmospheric rivers (i.e., short but severe precipitation events) can alter stream flows, accelerate soil erosion, increase sediment deposition, and alter stream morphology (Dettinger, 2013; Najafi et al., 2021; Ralph et al., 2006, 2018). Collectively, these climate “whiplash” events, transitions from drought conditions to wet seasons, cause uncertainty for natural resource and water management agencies, making water protection and management challenging (Loecke et al., 2017). The identification of HWS impacts is essential to developing adaptive conservation and resource management strategies, including best management practices, that seek to protect HWS since water quality influences numerous aspects of ecosystem and anthropogenic activities (i.e., human and environmental health, water quality, safe drinking water, recreation) (Alford and Caporuscio, 2020; Colvin et al., 2019; Delpla et al., 2009; Dodds and Oakes, 2008). Adaptive management and plans that collectively observe land use and current regulatory policies, utilize geospatial analysis, and assess biochemical and climatic data would assist in identifying the types and the extent of human-environmental relationships across the entire hydro network (Heintzman et al., 2022; Kearns et al., 2003; Riordan and Rundel, 2014). This comprehensive and interdisciplinary approach enables agencies and communities to be proactive and adaptive to emerging and unpredictable water resource management challenges, including "weather whiplash".

Impacts on Headwater Streams

Climate Change. Numerous adverse impacts on HWS have been documented and modeled across various landscapes and climatic regions, with the decline in headwater stream flows and health often linked to climatic changes (Chang and Bonnette, 2016; H. Liu et al., 2021; W. Liu et al., 2015; Underwood et al., 2018). The United Nations Framework Convention on Climate Change defines climate change as "a change of climate which is attributed directly or indirectly to anthropogenic activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." (UN, 1992). While naturally occurring climate fluctuations have been observed throughout Earth's history, anthropogenically driven climate change amplifies the effects of natural climatic patterns. Anthropogenic drivers of climate change include but are not limited to the atmospheric concentration of carbon dioxide due to the burning of fossil fuels, increased anthropogenic greenhouse gasses, and deforestation to support diverse human activities, including the development of housing, infrastructure, agriculture, and natural resource extraction for manufacturing(Houghton, 2001;

Karl and Trenberth, 2003; Solomon et al., 2007; Thom et al., 2017; Underwood et al., 2018). Specifically, the urban heat island effect in urbanized developments contributes to rising temperatures within urbanized areas. Impervious surfaces in urbanized watersheds (i.e., roads, developments, sidewalks) prevent soil infiltration, contributing to decreased groundwater recharge and increased surface runoff.

Additional threats to headwater resources include increasing surface water temperatures due to increasing global temperatures, decreased snowfall, snowpack, and cover retreating glaciers, and unpredictable precipitation patterns, including extreme weather events (Houghton, 2001). An example of erratic weather patterns is the El Niño and La Niña phenomenon. According to the National Oceanic and Atmospheric Administration (NOAA), the El Niño Southern Oscillation (ENSO) and La Niña are inversely related to extreme weather patterns that form near Earth's equator in the Pacific Ocean. During an El Niño season (i.e., northern hemisphere's fall through spring), warmer than average ocean water temperatures lead to increased evaporation, causing intensified precipitation and potentially destructive flooding in the southern United States, and warmer, dry conditions in the Midwest and northern United States (NOAA, 2020). Of concern in the southwestern United States are Atmospheric rivers, defined by the NOAA and atmospheric scientists as bands of the Earth's Atmosphere that carry an immense amount of moisture combined with high wind, producing heavy rain and snow in a short amount of time upon reaching land

(Dettinger, 2013; Kiest, 2023; NASA, 2023; Ralph et al., 2018). While El Niño and atmospheric rivers are a source of precipitation that alleviates drought conditions, they also present challenges for natural resource management. Substantial precipitation in short durations may lead to flooding, debris flows, and landslides, especially in areas where vegetation has been cleared. Stream quality is impacted as turbidity increases, transferring polluted soil and other contaminants downstream. Communities within a watershed can be affected when water reservoirs quickly reach capacity. Sudden capacity is usually caused by excessive sediment transport via debris flows or by a sudden influx of water. Local economies are adversely affected as costs related to storm damage and infrastructure repairs are often excessive. Although the rapid increase in stream flows has adverse impacts, they also recharge groundwater, enabling HWS to maintain base flows during dry periods (Duhan et al., 2018; Lamjiri et al., 2017; Ralph et al., 2018). Conversely, La Niña events are essentially the inverse of an El Niño pattern, forming during years of oceanic cooling. When a La Niña season occurs, the southern United States encounters warmer temperatures, less precipitation, potential droughts, and the potential of an amplified hurricane season, while the northern and midwest United States experiences cooler temperatures and increased precipitation (NOAA, 2015, 2023). Prolonged periods of warm, dry winters cause drought conditions during weather events such as La Niña. In contrast, La Niña conditions promote heat waves and prolonged drought. Heat waves and low surface flow from reduced precipitation impact overall stream health. Drought and heat waves contribute to reducing both surface and groundwater levels, impacting a headwater stream's ability to support riparian habitat and produce flows that support wildlife health and other ecosystem services, in addition to making it unpredictable for downstream communities to manage water resources for human uses (NOAA, 2023).

Over time, these unpredictable shifting of climatic conditions create a phenomenon scientists call climate feedback loops. The National Aeronautics and Space Administration (NASA) states that any feedback that contributes to warming is known as "positive feedback," and anything that contributes to lessening warming is known as "negative feedback" (NASA, 2023). NASA also relates climatic feedback loops to varying climate factors. This shifting climate accommodates prolonged dry or wet periods in place of previously standard weather patterns and seasons. As climate change progresses, existing monitoring and models indicate that multiple negative feedback loops will dominate ecosystems across the globe (NASA, 2023). Although impacts occur globally, some extreme examples of impacts on the quantity and quality of water resources can be observed across California. Observed negative feedback loops include changes in temperature and precipitation frequency and intensity, composition, and productivity of vegetation, increased occurrence and intensity of wildfires, increased pest outbreaks, invasive species type conversion after disturbance events, continued environmental stressors to already at-risk species of flora and fauna, expansion of grasslands, and decreased water availability (Boy et al., 2019; Candry et al., 2023; Lenihan et al., 2003; Sturrock et al., 2011).

Drought The National Integrated Drought Information System (NIDIS) defines drought as a deficiency of precipitation over an extended period of time, resulting in a water shortage (NIDIS, 2023). Because droughts can vary in type and severity, a classification system was created to manage and track the different types and the level at which they affect any given region by a joint partnership between the USDA, University of Nebraska National Drought Mitigation Center, U.S. Department of Commerce, and NOAA (USDM, 2023). The U.S. Drought Monitor was created to track weekly drought conditions and categorizes drought severity as either none (normal or wet conditions), D0 (abnormally dry), D1 (moderate drought), D2 (severe drought), D3 (extreme drought), and D4 (exceptional drought) (USDM, 2023). The United States Department of Agriculture (USDA) outlines droughts in different categories. Hydrological drought occurs when water is reduced in streams, lakes, and reservoirs. Agricultural drought adversely affects agriculture, which experiences a decrease in crop survival and productivity. Socio-economic drought reduces the supply of economic goods such as food and timber. Finally, ecological drought occurs when an ecosystem is affected by drought, leading to increased ecosystem vulnerability to other disturbances (USDA, 2017). Drought adversely affects groundwater recharge, baseflow, and surface flows. When prolonged drought occurs, groundwater recharge is severely reduced due to reduced precipitation and snowpack. Reduced groundwater recharge directly affects baseflow, the portion of stream surface water originating from groundwater. Baseflow is essential for streamflow during the dry season.

Droughts significantly threaten long-term headwater stream resiliency, especially in forested areas. Applying climate modeling to help illustrate and predict droughts' environmental effects is essential to understanding these impacts. The Coupled Model Intercomparison Project (CMIP), a climate model currently in its 6th phase, helps scientists model variables such as regional drought severity, vegetation growth, and wildfire activities (X. Li et al., 2022). One study used CMIP6 drought scenarios as a key parameter in climate modeling and observed that droughts within Southern California are expected to be more prolonged and will take longer to recover from in the future (Ahmadi and Moradkhani, 2019). Prolonged droughts create a shift in surface water chemistry, which can lead to catastrophic negative impacts on aquatic biosystems and public health within stream networks (Ahmadi and Moradkhani, 2019; Chang and Bonnette, 2016; Gómez-Gener et al., 2020). Ahmadi and Mordkhani (2019) found that drought recovery may create short-term water degradation, including increased turbidity, decreased dissolved oxygen, and water temperature recovery, adding an additional dimension to headwater stream quality. After prolonged drought, water recharge may take months for streams and their surrounding ecosystems to recover, including sustained flows and riparian health. Rainstorm events, especially after a period of drought, also led to elevated levels of turbidity (i.e., increased sediments) and organic matter (i.e., vegetation debris) as sediment is transported into water systems (Alford and Mora, 2022; USGS, 2023).

Wildfires In areas where drought conditions persist, wildfires and their impacts on hydrological systems are of great concern. Unlike prescribed burns, which are planned and managed low-intensity fire events, wildfires are high-intensity fires that occur without warning, impacting human safety and ecological integrity (Murphy et al., 2023; Smith et al., 2011; USDA, 2023c, 2023b). As previously noted, excessive heatwaves and low annual precipitation dry out landscape vegetation, where low humidity causes reduced or depleted stream base flows (i.e., groundwater-fed surface flows) and impacts the health of riparian vegetation, collectively altering the biodiversity within forested areas. Drought conditions also weaken the immune systems of forest vegetation, supporting conditions favorable for invasive vegetation to threaten and impair forest health. Furthermore, forest vegetation can also be more susceptible to diseases and invasive pests such as root rot, sudden oak death, the Goldspotted Oak Borer, and Bark Beetles, which collectively increase forest fuel loads (i.e., dead vegetation on the landscape) (Coleman et al., 2011; Lloret and Kitzberger, 2018, 2018; Sturrock et al., 2011). The mixture of wet-to-dry climate shifts, along with additional factors such as downslope winds (i.e., Santa Ana winds), anthropogenic ignition (i.e., human-caused via powerline failure, accidental ignition, etc.), or naturally occurring (i.e., lightning strikes). Tools such as the

Monitoring Trends in Burn Severity (MTSB) are critical in identifying past events and the cause of ignition. Within hydrological networks, impacts to riparian habitat are found along surface water corridors (i.e., rivers, streams, lake shorelines, and the like) (MTBS, 2023). Forest surfaces are negatively affected by wildfire by loss of vegetation and soil organic matter, decreased soil cohesion, enhanced soil water repellency, ash layer deposition, and increased water directed to the surface near surface pathways of burned watersheds (Burke et al., 2013).

A study examining the effects of soil quality following wildfire disturbances in Mediterranean climates found that wildfires, especially repeated disturbances in the same area within short intervals, significantly impact soil health, quality, quantity, organic matter, and nutrients due to increased vulnerability to erosion (Shakesby, 2011). Post-fire erosion following rainfall transports sediment yields downstream, impacting HWS health. Poor soil quality prolongs vegetation establishment, essential in preventing or reducing flooding, debris flows, and erosion, which can impact water-supply reservoirs, water quality, and drinking-water treatment processes (USGS, 2023). For example, after two succeeding wildfires in Arizona, the 2004 Nuttall-Gibson Complex and the 2017 Frye Fire, significant flooding and substantial debris flows were observed, which caused considerable ecosystem and infrastructure degradation (McGuire and Youberg, 2019). Another study examined the Station Fire which occurred in the Angeles National Forest in California (2009), observing increased levels of trace elements, including iron, manganese, lead, mercury, selenium, zinc, and nickel within surface waters during and after storm events (Burton et al., 2016). Wildfires in forested landscapes, where HWS are present, impact the quality of drinking water storage, creating public health issues for surrounding communities dependent on water catchments (Bladon et al., 2014; Smith et al., 2011). Additionally, Smith et al. (2011) found that negative water quality after wildfire events disrupted drinking water availability in some areas, costing millions to remedy while taking months to years to treat and purify back to required drinking water standards. Identifying burn intensity and burn history when studying water quality within HWS allows for a better understanding of possible influences on study outcomes.

Human Impacts

Forestry or Silviculture In addition to impacts from climate changes (i.e., drought, atmospheric rivers, and wildfires), headwater stream degradation is also adversely impacted by anthropogenic activities that are often spatially and temporally diverse. Anthropogenic deforestation, the removal of vegetation from forested regions, negatively alters water chemistry parameters in streams, notably leading to higher acidity, increased sulfates, decreased calcium ions, and overall poor stream health (Kosmowska et al., 2016). When landscapes transition from natural or undisturbed to developed (i.e., urban, agriculture), they are more susceptible to stormwater runoff due to decreased soil infiltration and increased impervious surfaces.

Urban Development Urban development and land use modifications within a watershed result from vegetation removal, soil compaction, ditching that drains soil, and the introduction of infrastructure and impervious surfaces that increase stormwater runoff (Arnold and Gibbons, 1996; Booth and Jackson, 1997; USGS, 2018a). Arnold and Gibbons (1996) demonstrate how various percentages of impervious surfaces impact watersheds and water health, such as rural (lower percentage of impervious surfaces) or urbanized (higher percentage of impervious surfaces. Urbanized landscapes see higher rates of surface water degradation due to higher stormwater runoff rates (Arnold and Gibbons, 1996; Booth and Jackson, 1997). Urbanization and population density also influence water quantity, as growing populations require water to survive (Bigelow et al., 2017). Septic systems are utilized in place of complex sewage systems in urbanized watersheds, especially those in more remote areas. Designed to leach raw waste slowly, septic systems become hotspots for micropollutants as they can leach into the soil and water table within a watershed, causing micropollutants and other harmful chemicals, such as pharmaceuticals, hormones, and personal care products, to affect watershed health adversely (Yang et al., 2016). Over time, water quality and quantity degradation within an urbanized watershed become a public health issue as humans rely on watersheds for drinking water. Delpha et al. (2009) found that the degradation of drinking water quality increases the threat of adverse health impacts, specifically after extreme precipitation events due to water quality parameters not meeting or exceeding regulatory standards. As such, agencies and communities increasingly seek BMPs to mitigate existing and emerging urban activities and their impacts on water.

Agriculture Agriculture has several negative impacts on headwater streams. Non-point source pollution, including nutrient and bacteria overload, the introduction of harmful toxic sediment and pesticides to water resources, and increased sediment loads are extremely common adverse impacts observed in streams. Multiple studies, including Billen et al. (2001), Bradshaw et al. (2016), Haack et al. (2016), He et al. (2015) Kronvang and Bechmann (2015), observed elevated concentrations of nutrients and bacteria such as nitrates, phosphorous, and fecal indicator bacteria. Additionally, the use of pesticides in agricultural lands negatively impacts headwater streams. After rainfall, toxic pesticides such as DDT, along with other non-point source pollution, get transported to headwater streams, via stormwater runoff and contaminates water (Schreiner et al., 2016; Weston et al., 2004). Because many headwater streams are sources of drinking water for the communities nearby, this is a dangerous human health issue. Agriculture also affects stream habitat, often creating habitat fragmentation (Mullu, 2016).

Recreation HWS are often in environments ideal for outdoor recreational activities. Excessive use of an area within a watershed, including recreational use, can lead to stream degradation due to increased erosion and sediment transport. The US EPA defines a recreational area as any land that is designed, constructed, designated, or utilized for recreational purposes and includes but is not limited to activities such as hunting, fishing, biking, swimming, boating, hiking, and camping (EPA, 2019). Other outdoor recreation includes horseback riding, nature viewing, off-road vehicle trails, picnicking, and winter activities, including skiing, snowboarding, and snow play (USDA, 2024). Global studies found that the COVID-19 pandemic led to increased participation in outdoor recreation, with one study in the United States showing an estimated 69 percent of those surveyed reporting increased or significantly increased visitation to natural areas and urban forests (Fagerholm et al., 2021; Grima et al., 2020; Kiraz and Thompson, 2023; Landry et al., 2021).

Outdoor recreation presents obstacles to ensuring HWS remains free from negative impacts caused by humans. Sanecki et al. (2006) examined infrastructure and urbanization associated with ski resorts and other snow-based recreation. The authors observed that the vegetation removal required in creating resort infrastructure such as downhill ski slopes, cross-country trails, and ski lifts and increasing snow compaction during the winter months adversely affects surrounding ecosystems, particularly small wildlife (i.e., bush rats and mice). Additionally, the use of snow vehicles and other snow recreation led to increased snow compaction, which negatively affected ecosystems and small wildlife (Arlettaz et al., 2015; Sanecki et al., 2006). Increased snow compaction, even in instances of non-motorized recreation on trails such as snowshoeing and cross-country skiing, is found to increase soil erosion rates. This can increase sedimentation and turbidity within HWS once snowmelt begins (Eagleston and Rubin, 2013). In addition to snow activities, year-round recreation can also negatively influence HWS. Off-road vehicle use and multiple-use trails (i.e., hiking, biking, horseback riding) also have adverse effects such as “soil trampling” and increased erosion caused by surface runoff, which leads to increased sediment deposition into nearby streams (Cooke and Xia, 2020; Iwona et al., 2017; Kidd et al., 2014; Kuznetsov et al., 2017). Water-based recreation also creates challenges that impact a watershed. Multiple studies found that water-based recreation can influence biodiversity and water quality, including a decrease in wildlife and riparian vegetation (Berberi et al., 2024; Liddle and Scorgie, 1980; Meyer et al., 2021; Schafft et al., 2021, 2024). Strategies to decrease recreational impacts on water resources include education, rotating trail use, and vegetation restoration.

Headwater Protection and Management Strategies

Policy Legislation and policy are essential elements to ensuring water resources are protected. Strategies may include regulatory approaches such as reestablishing protected areas and educational programs. The National Environmental Policy Act (NEPA) was adopted in 1970, establishing a federal policy to protect the environment and natural resources by requiring federal agencies to consider the environmental impact proposed Federal actions have on federal lands (NEPA, 2020) Shortly after the implementation of NEPA, The United States established the Clean Water Act (CWA) in 1972, a fundamental federal water policy set to protect surface water by regulating the pollutants found in water while also regulating water quality standards (EPA, 2013). Within the CWA, conditions and discharge of pollutants in U.S. waters are regulated within the National Pollution Discharge Elimination System (NPDES) while also establishing pollution control programs that regulate wastewater standards through legal responsibility and regulatory enforcement and establishing guidelines and standards that must be followed (BOEM, 2023). For example, these federal legislative initiatives also prompted several states to develop their own environmental quality policies. Within the state of California, the California Environmental Quality Act acts much like NEPA, requiring public agencies to evaluate and inform the public about any proposed activity that could adversely affect the environment (OPR, 2023). While federal and state policies aim to protect natural resources such as water, HWS, and their protection have long been disputed due to interpretation of terminology such as “tributary, adjacency, and significant nexus” (Nadeau and Rains, 2007). Biggs et al. (2017) found that ponds, small waterbodies, and small and low-order streams lack protection as they do not fall into most freshwater science and policy making. In relation to HWS, creating framework policy, legislation, and regulatory measures to protect HWS is essential, as anything that happens within headwater and low-order streams can potentially affect anything downstream.

Over time, traditional natural resource management strategies may become obsolete in regions where climate patterns suddenly shift. As such, adaptive natural resource management strategies have been adopted to respond more proactively to landscape and climatic shift changes. The U.S. Department of the Interior identifies adaptive management as a systematic approach that improves resource management through learning from past management outcomes (DOI, 2009). Utilizing adaptive resource management is shown to improve watershed health and increase economic productivity (Ebrahimi Gatgash and Sadeghi, 2024). Adaptive resource management is most effective when efforts between researchers, land managers, policymakers, educational institutions, and stakeholders foster collaborative solutions to ensure long-term resource management (Allan et al., 2008). Additionally, promoting public outreach and education allows policymakers to implement successful solutions and management practices (M. G. Kang and Park, 2015).

Pollution, Stormwater Discharge, and Best Management Practices (BMPs)

Both point and nonpoint source pollution negatively impact headwater stream quality and alter the landscape. Point source pollution occurs from a singular source, such as industrial and wastewater pipes discharging into waterways (USGS, 2018b, 2018a). Nonpoint source pollutants include excess fertilizers, herbicides and insecticides, oil, sediments, salt, bacteria, and nutrients from livestock, pet wastes, and faulty septic systems (EPA, 2014; USGS, 2018a). Streamflow transports pollution inputs in waterways by carrying contaminants downstream, resulting in more total areas of the hydrological networks being impaired by these sources. As a result, it has become increasingly important to monitor both the quality and quantity of headwater stream quality and quantity to determine overall water quality within a watershed. One study examining pollutants and their effect on water quality within a forested landscape found that nearby ecosystems are threatened or lost when HWS are polluted or destroyed (Fritz et al., 2018) CITE. Researchers found that nonpoint source pollution is a severe issue that affects HWS and surrounding ecosystems as it degrades surface waters and aquatic ecosystems (Dodds and Oakes, 2008). An extensive amount of anthropogenic pollution results from urbanization, industrialization, or agriculture (Delpla et al., 2009).

As previously discussed, stormwater runoff occurs during and after precipitation (rain, snow, snowmelt). According to the United States Geological Survey (USGS), stormwater is concerning because it picks up and distributes pollutants such as sediment, harmful chemicals from lawn fertilizers, bacteria and from human and animal waste, pesticides used in lawns, gardens, and agriculture, metals found on roadways and urbanized developments, and petroleum by-products from (USGS, 2018b). Stormwater runoff influences surface waters in a watershed due to the transportation of pollutants from up-gradient to down-gradient within the watershed. Ahn et al. (2005) examined coastal water quality from stormwater runoff and found that after precipitation events, stormwater runoff that flows into the Santa Ana River eventually makes its way to the coast, where water quality within the surf zone becomes severely negatively impacted (Ahn et al., 2005). As a result of the spatial-temporal variability of nonpoint source pollution across the hydro network, localized and regional prevention measures are necessary to ensure overall watershed health.

Best management practices (BMPs) help combat adverse water issues such as stormwater runoff and pollution. The Clean Water Act of 1972 outlines and requires specific regulation of ground and surface water, including pollution, to improve and maintain water quality within the United States. One such example is the California State Waterboard, which outlines the criteria of BMPs and includes management practices that prevent or decrease pollution within watersheds in the United States. BMPs include structural and nonstructural controls, treatment requirements, operation and maintenance procedures, and practices to control plant site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage (CSWRCB, 2013).

Maintaining BMPs helps ensure long-term environmental health, including promoting and supporting biodiversity, providing erosion control while reducing or preventing sediment transport, and ensuring water quality standards are maintained. Implementing and maintaining BMPs are essential for safeguarding both surface and groundwaters. Reiter et al. (2009) analyzed turbidity levels in the Deschutes River Watershed in Washington State over a 30-year period. They reported that since the implementation of sediment control BMPs, turbidity levels have significantly declined in adjacent surface waters (Reiter et al., 2009). Mallin and Cahoon (2003) examined livestock-concentrated animal feeding operations and the effect of massive amounts of animal waste on both surface and groundwater within a watershed. Their study found elevated nitrogen, phosphorus, and ammonium levels within the watershed studied. The study also indicated that spreading livestock waste onto fields or pumped into waste lagoons was not federally regulated, resulting in continued pollution of surface and groundwaters (Mallin and Cahoon, 2003). Instances such as the study by Mallin and Cahoon highlight why BMPs are necessary for overall watershed health. The use of hydrologic modeling software within a watershed dramatically influences the types and extent of BMPs required to ensure short and long-term watershed health (Avay et al., 2022).

Headwater Resources and Protection in California

When considering strategies for protecting and managing HWS, California provides a unique landscape case study because of its dynamic climatic regions and landscapes. California has a unique landscape due to its vast size, extreme elevation changes, and proximity to the Pacific Ocean. The length of California spans roughly 900 miles from the northern border to the southern border, with a total area of approximately 160,000 square miles (California, 2023; Visit California, 2023). The topography and climate of California differ significantly throughout the state, containing the highest elevation – Mount Whitney (14,494 ft.) and the lowest point – Death Valley (-282 ft.) in the continental United States (CDFW, 2021; USGS, 1995). California is comprised of a variety of climates, including deserts, cool interiors, highlands, steppes, and Mediterranean climates (CDFW, 2021). The climates of Northern, Central, and Southern California vary significantly. On average, Northern California receives considerably more precipitation than Southern California. Over 70 percent of streams and water flow is located north of Sacramento, with two-thirds originating in the Sierra Nevada Mountains (DWR, 2023; WRCC, 2023). Southern California depends heavily on imported water as approximately 25 percent comes from the Colorado River Aqueduct, 30 percent is transported from Northern California from the State Water Project (SWP), and 45 percent originates from regional water resources such as HWS and watersheds originating in local mountains (i.e. San Bernardino Mountains and Santa ana Watershed), groundwater supplies that are generally recharged within a watershed, and other sources such as desalination and recycling (MWD, 2023; Sun et al., 2019; WRCC, 2023).

In contrast, Southern California experiences multiple stressors that can adversely affect watershed health. Climate variability within a diverse California landscape creates a problematic situation as there is no “one size fits all” solution to state-wide watershed management (Abatzoglou et al., 2009). Factors such as climate change, wildfire, BMP management, water quality and quantity, climate variability, and weather whiplash from long-term drought to a sudden shift in increased precipitation stemming from multiple atmospheric events within a wet season all adversely affect watershed health throughout California (Abatzoglou et al., 2009; Alford and Caporuscio, 2020; Burton et al., 2016; CSWRCB, 2013; Underwood et al., 2018). The San Bernardino mountains contain the divide of the Mojave and Santa Ana watersheds, two significant watersheds in Southern

California that millions of people rely on. If the headwater stream condition is poor, then the overall watershed condition is also inadequate, affecting anything downstream. (Alford and Caporuscio, 2020; Alford and Mora, 2022; Avay et al., 2022; Edwards et al., 2015; Mojave River Watershed Group, 2024; RCRW, 2023). While this study focuses on HWS within a Southern California watershed, it can be implemented and utilized for other arid environments beginning to see extreme shifts between droughts and atmospheric rivers.

As California continues to experience dramatic climate shifts that make water management challenging to predict, there has been an increasing need to understand the physicochemical and water quality stream flow characteristics of headwater streams. This is essential to ensure adequate and healthy water resources are available for ecological and human activities and present and future water resource needs. The Mojave River Basin is an example of a basin that relies on the health and flow of the headwater stream. While multiple studies have examined these stressors' effect on watersheds, more needs to be published exploring the impact of these stressors and BMPs on HWS within the Mojave watershed. The Mojave watershed is important because it is one of the primary drinking water sources for the California high desert.

The Mojave River is a significant water source for high desert communities, including the densely populated cities of Victorville, Barstow, and Apple Valley, among many other smaller communities within the watershed. The latest credible population statistics for the Mojave watershed came from

California Regional Waterboard Lahontan Region, which contains population statistics from 2010. It stated that the population was roughly 390,000 within watershed boundaries, and the area has an expected population growth totaling 550,000 by 2030 (LRWQCB, 2019). Additionally, it encompasses an area of 4,500 square miles within San Bernardino County(LRWQCB, 2019; Mojave Water Agency, 2016). According to a report by the Water Education Foundation, in 2020, an estimated 87 percent of the population within the Mojave Watershed boundary qualify as disadvantaged (WEF, 2020a). The California Department of Water Resources defines a disadvantaged community as a household with an income less than 80 percent of the statewide median household income (DWR, 2022).

Given the importance of Headwater Streams (HWS) in the San Bernardino National Forest (SBNF) to downstream communities, this study seeks to observe and identify relationships among climatic conditions, watershed landscape characteristics, and in situ stream water quality and quantity. More specifically, the objectives of this study are to (1) identify HWS watershed landscape characteristics, including land use and land cover, which includes vegetation and development patterns (i.e., roadways, infrastructure, residential, industrial, and commercial) within the watershed, (2) the spatio-temporal trends in the physicochemical water quality of HWS, (3) frequency that water samples exceed regulatory standards, (4) temporal trends in climatic patterns including precipitation and atmospheric temperature. This is needed to understand the relationships between climate, water quality, and water quantity.

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CHAPTER TWO

STUDY PURPOSE AND SITE

Study Purpose

The San Bernardino Mountains contain the headwaters of the Santa Ana Watershed, a major freshwater natural resource in the San Bernardino, Riverside, Orange, and a small portion of Los Angeles Counties, which encompasses over 2,400 square miles and converges into the Santa Ana River, the longest river and largest watershed drainage in Southern California (USBR, 2013; WEF, 2020b). The Santa Ana watershed flows through multiple urbanized communities with a total population of over 6 million people, ending its estimated 100-mile-long journey by draining into the Pacific Ocean between the cities of Huntington and Newport Beaches (Ahn et al., 2005; RCRW, 2023; SAWPA, 2018; WEF, 2020b). Also within the San Bernardino Mountains are the headwaters of the Mojave River Watershed. According to the Mojave Water Agency, an entity created in 1960 to address the overdraft of groundwater within the Mojave region, the Mojave River is the primary source of groundwater recharge in the Mojave Groundwater Basin. Most of the water within the Mojave River originates from precipitation in the form of rain and snow from the San Bernardino Mountains and flows about 100 miles, ending in Soda Lake(Mojave Water Agency, 2023; WRC, 2024). The Mojave River watershed is approximately 4,500 square miles and provides water for the communities of Adelanto, Apple

Valley, Hesperia, Lucerne Valley, Oak Hills, Phelan, Victorville, and Wrightwood, among many other smaller communities (Mojave River Watershed Group, 2014). The Mojave Desert averages four to six inches of rain a year, making the communities within the Mojave Watershed severely reliant on headwater stream flows from the SBNF (Lines, 1996).

The San Bernardino National Forest (SBNF) is located within the San Bernardino and San Jacinto mountains in Southern California and consists of 672,701 acres throughout two counties (Riverside and San Bernardino) and is the start of two major watersheds within Southern California (USDA, 2023a). San Bernardino National Forest Inventory provided by the United States Forest Service details various forest and terrestrial attributes, including 151,341 acres of wilderness and 156 threatened, endangered, and sensitive species of flora and fauna. Recreationally, the SBNF supports off-road vehicle (ORV) trails and hiking trails and diverse development, including private, commercial, residential, and public buildings, as well as utilities and roadways (USDA, 2023a). Big Bear, which resides in the SBNF, is noted to receive three million annual visitors each year (Big Bear, 2024). The San Bernardino Mountains contain several residential and urbanized communities, including the popular tourist destinations of Big Bear and Lake Arrowhead. Many of the San Bernardino Mountains communities rely immensely on tourism to support their local economies due to the region's popularity as a regional destination for Southern California residents. Lake Arrowhead Communities Chamber of Commerce stresses the importance of tourism on local economies by stating that ski packages, weddings, and ecotourism are the primary economic producers, bringing in 78 million dollars a year and providing 1300 jobs for local residents (LACCC, 2023).

Headwater Streams Studied

All streams studied are headwater streams within the Mojave Watershed in the San Bernardino National Forest. The streams include Deep Creek, Little Bear Creek, Hooks Creek, and Orchard Creek. Little Bear Creek and Orchard Creek drain into Lake Arrowhead, a significant source of drinking water for mountain communities. Hooks Creek ends at a confluence with Little Bear Creek east of Lake Arrowhead. Little Bear Creek continues to flow until the next stream confluence, where it meets with Deep Creek. Deep Creek flows through the SBNF before emptying into the Mojave River, where it recharges groundwater and flows through the Mojave Desert. Deep Creek is a significant water source for many high desert communities in the arid Mojave Desert.

<u>Deep Creek</u> The headwaters of Deep Creek begin at the approximate coordinates 117.0284151°W 34.2315131°N, at an elevation of roughly 6960 feet. It starts in rugged, undeveloped terrain just outside of Running Springs, California, downgradient of California Highway 18. This part of Highway 18 is where Highway 330, the most traveled route to Big Bear, ends and merges into it (Big Bear Lake, CA, 2023). As Deep Creek continues to flow, it crosses Highway 18 via an underground culvert and converges with North Fork Deep Creek. This

tributary flows through Snow Valley Mountain Resort and Snowdrift Snow Tubing Park, popular San Bernardino National Forest recreation destinations. Snow Valley Mountain Resort is Southern California's oldest continually operating ski resort. It includes year-round recreation, including 230 skiable acres, snow tubing, snow play in the winter, and 28 trails that allow hiking and mountain biking the rest of the year (Alterra Mountain Resort, 2023). Deep Creek eventually crosses Highway 18 a second time via an underground culvert near the study site. As it travels through the SBNF, several smaller streams confluence into Deep Creek until it flows into the Mojave River. However, this study only focuses on the catchment at the start of Deep Creek.

Orchard Creek Orchard Creek is the smallest headwater stream studied and begins near a low-density urbanized neighborhood north of Highway 18. It crosses California State Route 173 right after the study site via an underground culvert. Shortly after the study site, Orchard Creek converges into Lake Arrowhead. Most of Orchard Creek flows through low-to-moderate-density urbanization.

Little Bear Creek Little Bear Creek is a small headwater stream that flows adjacent to Daley Canyon Road and California State Route 189, a popular route to Lake Arrowhead. The path of Little Bear Creek flows entirely through urbanized areas. This headwater stream is of interest due to its proximity to the road. During precipitation events, stormwater becomes channelized into Little

Bear Creek, while excess snow gets plowed and stored within this stream, raising concerns about possible adverse effects.

Hooks Creek The final stream observed in this study is Hooks Creek. It starts inside the northern boundary of Skypark at Santa's Village, a year-round popular tourist destination in the San Bernardino National Forest. Consisting of 230 acres, SkyPark at Santa's Village offers outdoor recreation, including hiking and mountain bike trails, fishing, zip lining, ice- and roller-skating rink, rock climbing, amusement rides and attractions, and an RV camping resort (SkyPark, 2021, 2024). It flows through undeveloped forest until it reaches the study site, located at the base of Scout Reservation land. After the study site, Hooks Creek runs along Hooks Creek Road through an urbanized neighborhood. It eventually converges with Deep Creek, east of Lake Arrowhead.

CHAPTER THREE

METHODOLOGY

Watershed Delineation

Using ArcGIS Pro v3.2.2 and Arc Hydro, a water resource management tool created for ArcGIS Pro, and applying methods similar to Lahsaini et al. (2018), Li (2014), Tefera (2017), and Alford and Caporuscio (2020), this study maps watershed characteristics for both the SBNF and this process supports determination of watershed delineation boundaries, surface flow direction and accumulation, stream definition, drainage points (Lahsaini et al., 2018; Z. Li, 2014; Tefera, 2017). Arc Hydro is a fundamental hydrological modeling and mapping tool used to delineate and characterize watersheds while assessing spatiotemporal relationships between surface water and landscapes (ESRI, 2023; Lapides et al., 2022). Additionally, datasets provided by the United States Geological Survey (USGS), including the National Hydrography Dataset Plus High Resolution (NHDPlus HR) and Watershed Boundary Dataset (WBD), were utilized in ArcGIS Pro to assist in mapping watershed features and boundaries (USGS, 2022). The Environmental Protection Agency (EPA) WATERS (Watershed Assessment Tracking and Environmental Results System) Data for Google Earth Pro provided essential watershed information, including satellite imagery, water quality assessments, impaired water information, and measurement tools, allowing for a detailed evaluation of watershed characteristics (EPA, 2014).

Watershed Landscape Analysis

Utilizing the National Land Cover Database (NLCD) developed by the Multi-Resolution Land Characteristics Consortium, a group of federal agencies collaborating and exchanging updated land cover information, this study will analyze land cover type by percent (MRLC, 2023). NLCD data utilized throughout this study is from the year 2021, which is the latest dataset available at the time of this study. Past studies examined land cover using remote sensing methods to quantify changes over time (Ahearn et al., 2005; Homer et al., 2020; Smucker et al., 2016). This study aims to analyze and compare land cover types in the SBNF and the catchment for each stream analyzed, as outlined in the National Land Cover Database Class Legend and Description. This enables examining the relationship between stream quality land use and land cover type (MRLC, 2023). The NLCD measures land type using a 30-meter resolution. In addition to utilizing the NLCD, this study also examined wildfire history within the Santa Ana and Mojave watersheds using the Monitoring Trends in Burn Severity model to observe possible post-wildfire watershed effects using methods similar to Shaw et al. (2017) (MTBS, 2023). Google Earth Pro will assist in verifying GIS spatial data while physically examining each stream to ensure ground-truthing.

Table 1. National Land Cover Dataset Classification and Description.

Water	
11	**Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil.
12	**Perennial Ice/Snow**- areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	**Developed, Open Space**- areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity**- areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity** -areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity**-highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	**Deciduous Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	**Evergreen Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	**Mixed Forest**- areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
51	**Dwarf Scrub**- Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	**Shrub/Scrub**- areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.
Herbaceous	
71	**Grassland/Herbaceous**- areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling but can be utilized for grazing.
72	**Sedge/Herbaceous**- Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	**Lichens**- Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	**Moss**- Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	
81	**Pasture/Hay**-areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	**Cultivated Crops** -areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	**Woody Wetlands**- areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	**Emergent Herbaceous Wetlands**- Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

Climatic Data

Examining climate data during the study years (i.e., 2019-2020, 2020-2021), such as precipitation and atmospheric temperature, is essential in determining any correlation between weather patterns such as El Nino and El Nina. Understanding the climatic conditions during water sample collection allows for better insight into why water quality parameters vary. When connecting climate variability with water quality, one study found that “weather whiplash,” or a prompt drought-to-flood transition, severely influences water quality negatively (Loecke et al., 2017). Connecting weather conditions on sample collection dates while examining overall climate trends over the data for this study is essential in understanding short- and long-term influences weather and climate have on headwater streams' physiochemical characteristics. Using the NOAA Climate Online Dataset, weather conditions and climate trends will be examined in detail, assisting in understanding atmospheric influences on headwater streams (Kiest, 2023). Additionally, utilizing the U.S. Drought Monitor will provide insight into drought conditions within the Mojave watershed. The U.S. Drought Monitor is a partnership between the U.S. Department of Agriculture, The National Drought Mitigation Center at the University of Nebraska-Lincoln, and the National Oceanic and Atmospheric Administration, that monitors drought conditions and classifies levels of drought including none, D0: abnormally dry, D1: Moderate Drought, D2: Severe Drought, D3: Extreme Drought, and D4: Exceptional Drought (USDM, 2023).

Water Quality Sampling Data

This study will demonstrate any correlation between water quality and nearby land use by analyzing multiple water quality parameters at four sample sites; DC, HC, LBC, and OC. Water parameters collected include ammonium (mg/L), conductivity (µS/cm), dissolved oxygen (mg/L), E. coli, Enterococci, flow (m/s), pH, nitrates (mg/L), stream temperature (℃), total coliform, and turbidity (NTU). Each location has unique landscape characteristics, allowing for various conditions that may influence water quality. Water quality data was collected at least once monthly in the hydrological years 2019-2020 and 202-2019. Bacteria parameter collection varied each month due to insufficient funding. Sample data was recorded at the test sites using Vernier LabQuest 2 monitors, probes, a flow rate sensor, and ion-selective electrodes. In addition, water samples were collected in sterile, approved water jars, kept cold while in the field, and refrigerated upon arrival at the lab. All equipment was thoroughly maintained to ensure manufacturer and collection guidelines were carefully followed. Collection of data is similar to the methods observed in Alford and Caporuscio (2020), Alford and Mora (2022), Lucknow and Khatoon (2013) and Vega et al. (1998). (Alford and Caporuscio, 2020; Alford and Mora, 2022; Lucknow and Kahtoon, 2013; Vega et al., 1998)

Water Quality Regulatory Standards

Federal, state, and regional agencies regulate surface water quality. The Clean Water Act outlines quality standards on a federal level, the California State Water Resources Board regulates at a state level, and the State of California Lahontan Regional Water Quality Control Board regulates at a regional level (CSWRCB, 2024; EPA, 2013; LRWQCB, 2023a). This study will examine the water samples collected at HWS within the SBNF and compare them to federal and state water standards, outlining any discrepancies beyond regulatory standards. Using the chart in Table 2, data was audited to determine overall watershed quality and stream health. Outcomes will be examined as a percent exceedance across the water sampling period.

Table 2. Water Quality Regulatory Standards

Water Quality Metric	Standard	Source
Temperature (C)	< 25C	CA State Water Board
Dissolved Oxygen (DO) (mg/L)	>4 mg/L	CA State Water Board, Lahontan Region
pH	6.5-8.5	CA State Water Board, Lahontan Region
Turbidity (NTU)	<100 NTU	CA State Water Board (Fact Sheet)
Conductivity (uS/cm)	150-500 Range <336 ms/cm (Average)	EPA (Range) CA State Water Board (Average)
Nitrate (NO3-) (mg/L)	0.8-2.5 mg/L	San Bernardino Mountains Hooks Creek Objectives
Ammonium (NH4+) (mg/L)	0.02-0.4 mg/L	EPA Aquatic Life Criteria
Total Coliform (TC) (cfu/100mL)	1,000 cfu/100mL	CA State Water Board Objectives
e. Coli (cfu/100mL)	<126 cfu/100mL	EPA Recreational Standards
Enterococcus (cfu/100mL)	<35 cfu/100mL	EPA Recreational Standards

CHAPTER FOUR

RESULTS AND DISCUSSION

Watershed Landscape Characteristics and Site Assessment

The San Bernardino National Forest (SBNF) has a diverse landscape consisting of numerous land use land cover (LULC) patterns, including alpine meadows, evergreen forests, chaparral (i.e., shrub-scrub), urban and rural landscapes (i.e., impervious surfaces) that transition from mountain peaks to desert valleys in the Mojave Basin. First, the Mojave Watershed was mapped in ArcPro (see Figure 1). To determine physical landscape patterns across the SBNF and within specific watershed study sites, the 2021 National Landcover Database (NLCD) was imported into ArcGIS and clipped to delineated watersheds to represent each study site. Additionally, a graph comparing square meters of each delineated study site (see Figure 2) provides the context of the size of each catchment in relation to the SBNF. Combining this knowledge with the Google Earth- EPA WATERs dataset and in situ site assessments (i.e., ground truthing) allowed for a better understanding of site conditions and longitudinal landscape patterns along stream corridors. Each stream within this study has unique landscape characteristics, allowing for observations of how stream corridors and watersheds change from the headwaters to the point of monitoring or termination into a receiving waterbody (i.e., lake, ocean, river). This also allows for the identification of landscape characteristics and human activities (i.e., LULC) that influence the physicochemical and morphological attributes of headwater streams that can then be applied to similar watersheds.

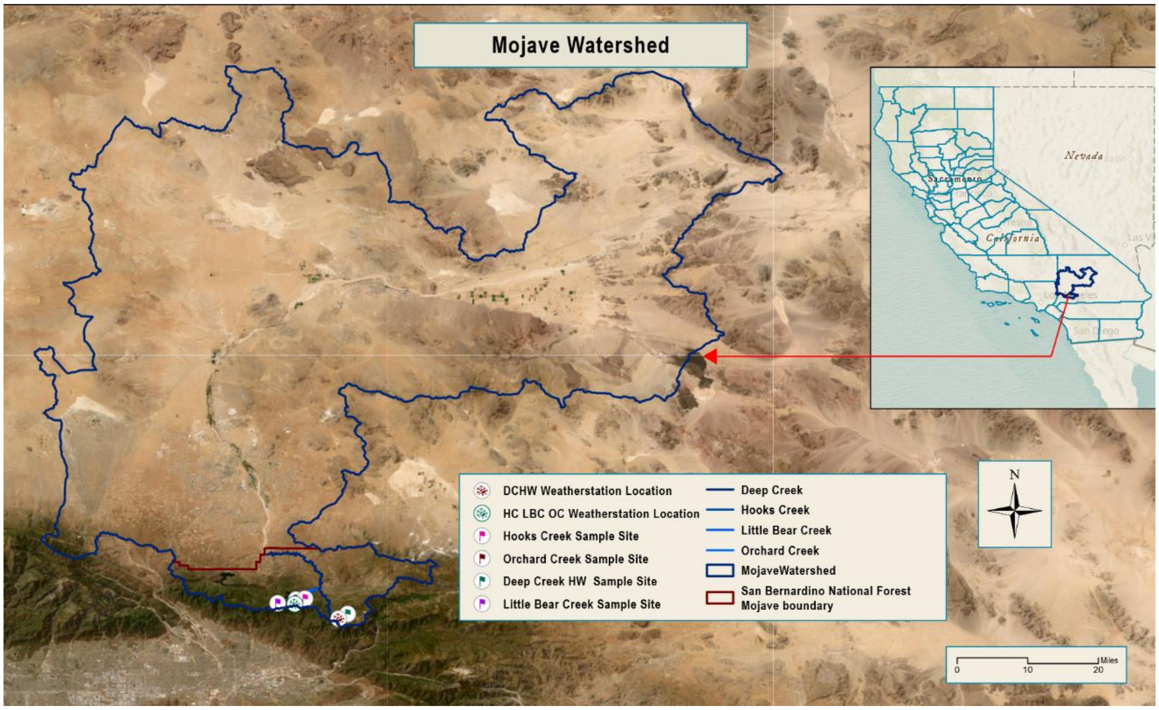

Figure 1. The Mojave Watershed.

When observing the overall landscape characteristics of the SBNF using the NCLD (Figure 2), Shrub/Scrub land (54.77%) is the most significant LULC type, followed by Evergreen Forest (22%). A smaller percentage of herbaceous wetlands (12.37%), developed open space (4.54%), mixed forest (2.64%), and developed, low intensity (1.14%) represent smaller percentages of LULC; however, they illustrate the diversity of land use types across the region.

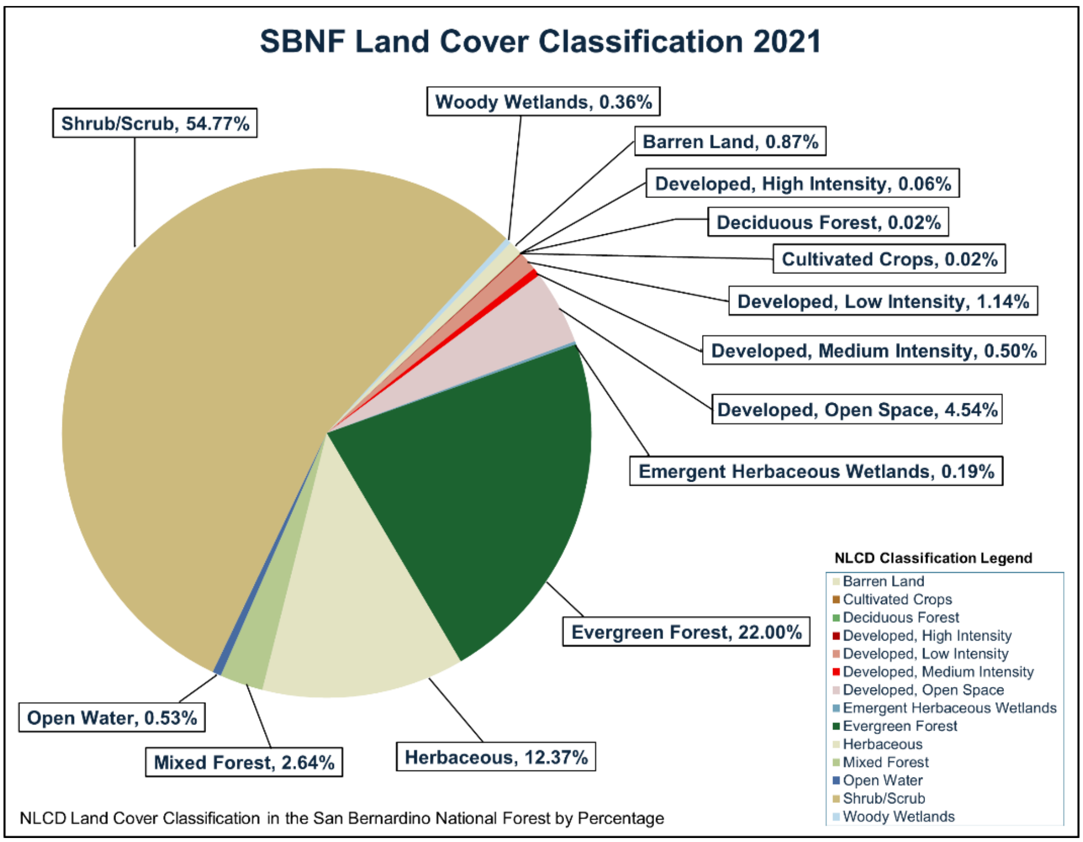

Figure 2. Land Cover Classification of the San Bernardino National Forest.

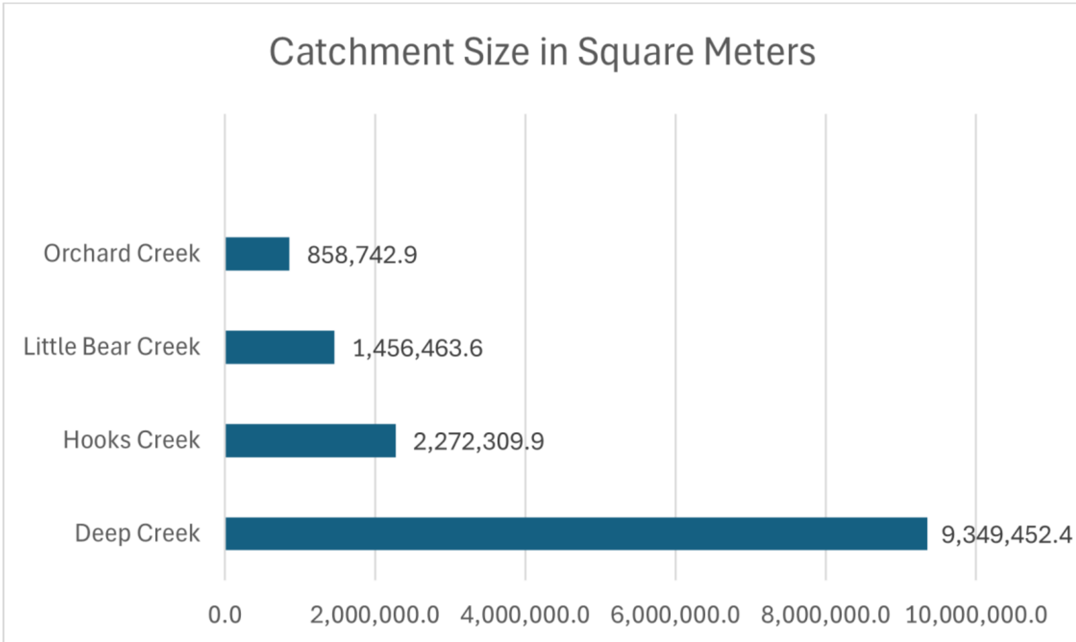

Figure 3. Sample Site Catchment Area Size.

The catchment area (i.e., drainage basin) was mapped for each study site. The catchment endpoint was the study site, so everything within the catchment was upstream from the testing location. When comparing catchment size (Figure 3), the DC catchment was the largest, comprising of 9,349,452.39 sq meters - followed by HC (2,272,309.9 sq meters), LBC (1,456,463.6) and OC (858,742.9). The steep topography of the region influences the catchment sizes. Applying the NHD dataset in ArcGIS Pro along with satellite imagery, a map was created for each site to understand streamflow and landscape characteristics.

Deep Creek

The dominant land cover of DC (see Figure 4) consists of rural landscapes. Evergreen Forest (40.81%), Shrub/Scrub (33.21%), and Mixed Forest (7.53%) comprise over 80 percent of the land cover classification. Urbanized development (developed, low intensity, medium intensity, high intensity) accounts for slightly more than 9 percent. The boundaries of Snow Valley (i.e., a popular tourist recreational destination) are within the DC catchment, contributing towards the 7.70 percent of developed, open space classification. The remaining landscape (1.65%) is split between open water, herbaceous, deciduous forest, and barren land.

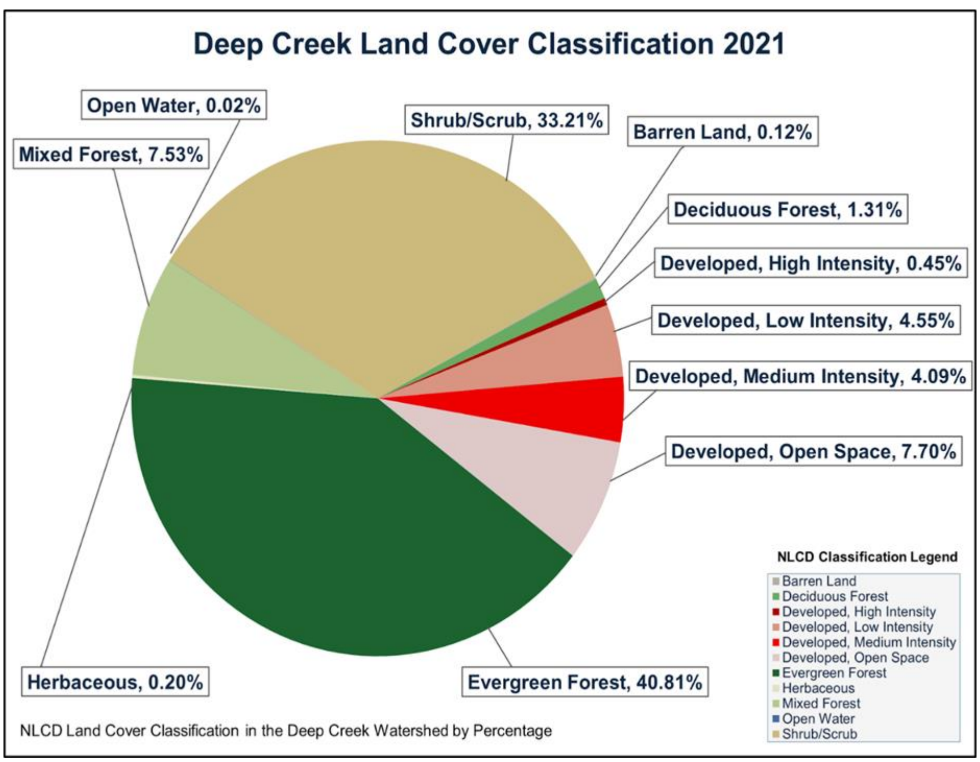

Figure 4. Deep Creek Catchment Land Cover Classification.

Following the NLCD makeup of DC, the stream begins in shrub/scrub and flows through that evergreen forest until flowing under California Highway 38. It flows through Snow Valley, classified as developed open space and medium intensity. It follows along Highway 38 until it crosses back under, where it reaches the study site. The majority of DC is rural. The developed land is mainly concentrated over Snow Valley. The data is primarily accurate; however, because of the 30m pixels, there are areas of shrub/scrub that show low intensity due to the road pixel. Figure 5 shows the delineated clip of the DC catchment, and Figure 6 is a photo taken from the sample site.

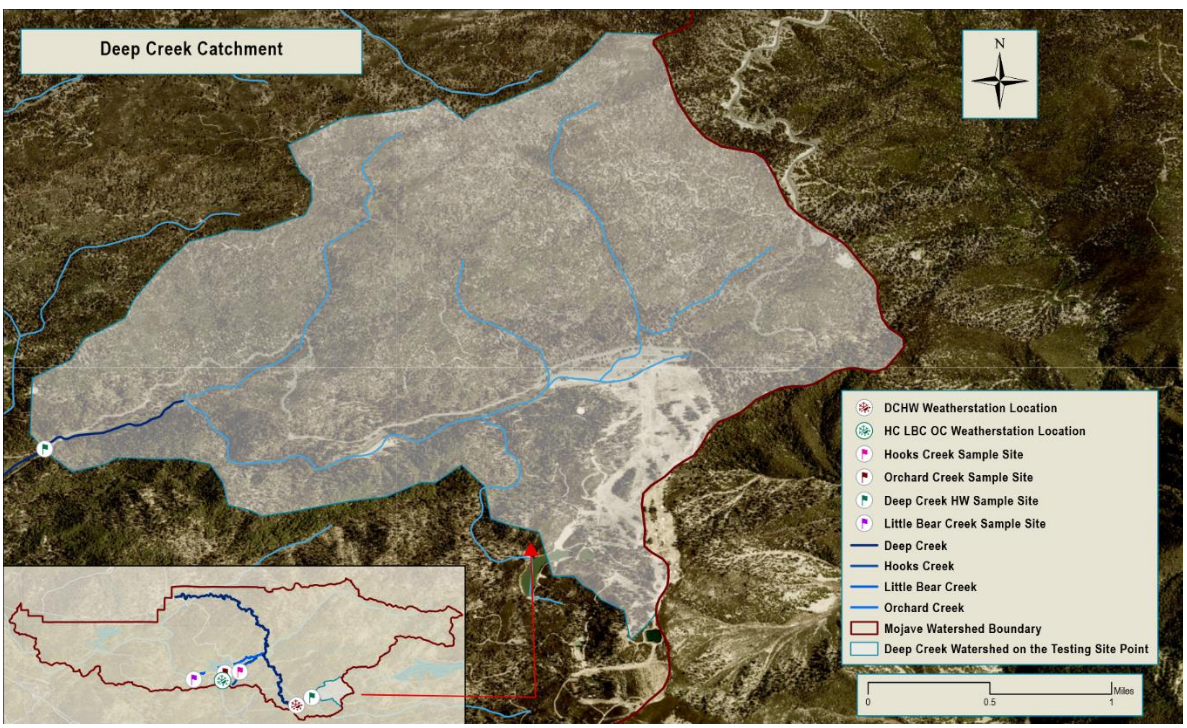

Figure 5. Deep Creek Catchment to the Study Site.


Figure 6. Photograph from the Deep Creek Study Site Looking Up at Highway 38.
Source: Christine Seeger, 2023

Hooks Creek

The NLCD classification data (Figure 7) indicate that the HC catchment is almost entirely rural. The primary land cover for HC is evergreen forest (69.20%). Shrub/Scrub (21.38%) is the secondary land cover type, followed by mixed forest (5.92%). Development (low intensity, medium intensity, high intensity, and open space) accounts for 2.98% of land cover. Barren land (0.13%) is the final land cover classification found within the HC catchment.

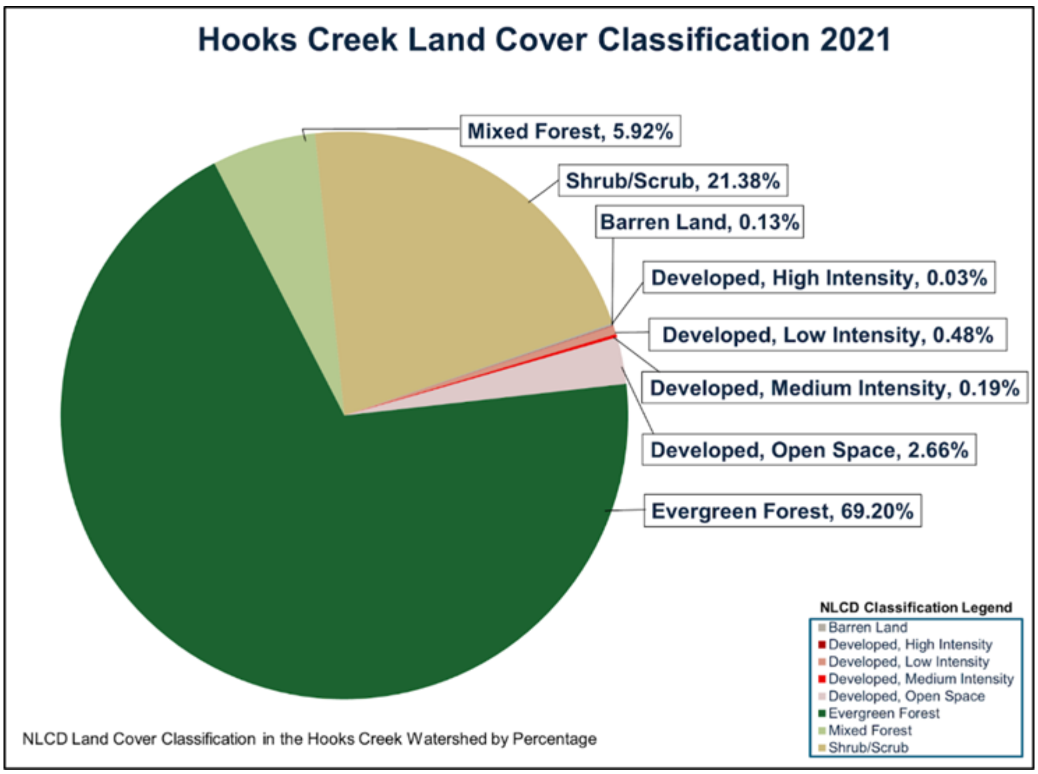

Figure 7. Hooks Creek Catchment Land Cover Total.

Examining Figure 8, the tree canopy is dense throughout most of the catchment, presenting difficulties when using satellite imagery to assess land cover. Highway 18 and Skypark Santa's Village (i.e., year-round recreation) are within the HC catchment above the HC formation. HC forms near a small pond on the Skypark property before flowing into the dense tree canopy. HC flows through the Hubert Eaton Scout Reservation. The sample site for HC is near the intersection of Deep Creek Camp Rd and Hook Creek Rd before flowing through a culvert under Deep Creek Camp Road. Figure 7 is the delineated clip of HC. The dense tree canopy can be observed throughout the catchment. Figure 9 is a photo from the sample site looking up towards Hook Creek Rd.

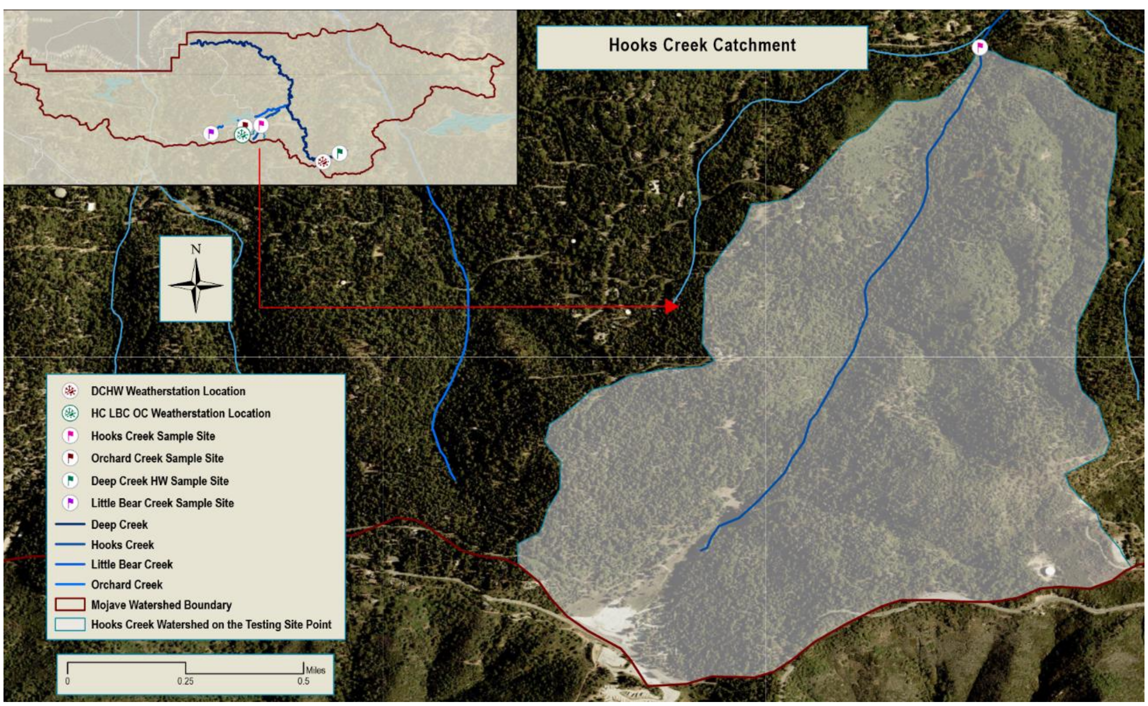

Figure 8. Hooks Creek Catchment to the Study Site.

Figure 9. Photograph from the Hooks Creek Study Site Looking Towards a Public Road.
Source: Christine Seeger, 2023

Little Bear Creek

The primary NLCD classification (see Figure 10) for LBC is evergreen forest (66.70%). A significant portion of the LBC catchment is urbanized, consisting of developed, open space (25.90%), developed, low intensity (2.98%), and developed, medium intensity (1.44%). The remaining land cover in LBC is mixed forest (2.71%) and shrub/scrub (0.27%).

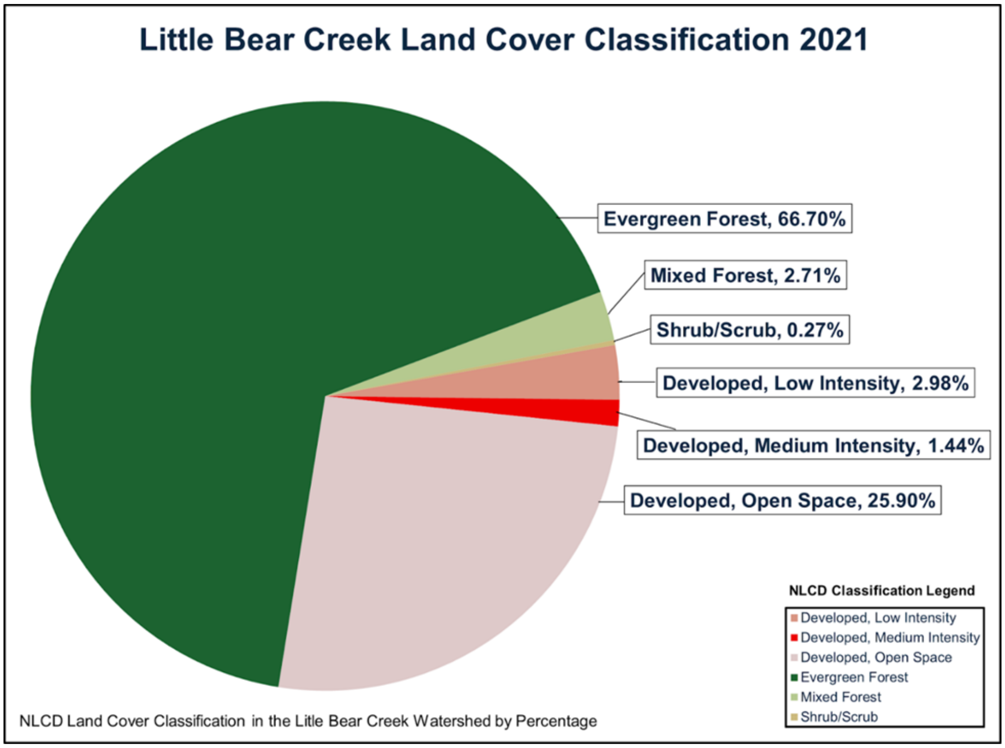

Figure 10. Little Bear Creek Catchment Land Cover Total.

The LBC catchment (Figure 11) originates in a developed landscape. The formation of LBC occurs down gradient from Highway 18, Rim of the World High School, and a retail shopping center. The path of LBC flows along a developed road until reaching the study site. Dense tree canopy presents difficulty in comprehensively analyzing LBC via satellite imagery. However, occasional breaks in tree cover indicate the presence of residential development throughout the catchment. Following along with the NLCD, the LBC catchment begins with most of the developed medium and low-intensity classifications. It flows along land cover that is considered developed, open space. It ends in an area classified as developed, open space. This information is inaccurate because this area has residential development and tree cover. Figure 12 shows a photograph from the LBC study site at California Highway 189.

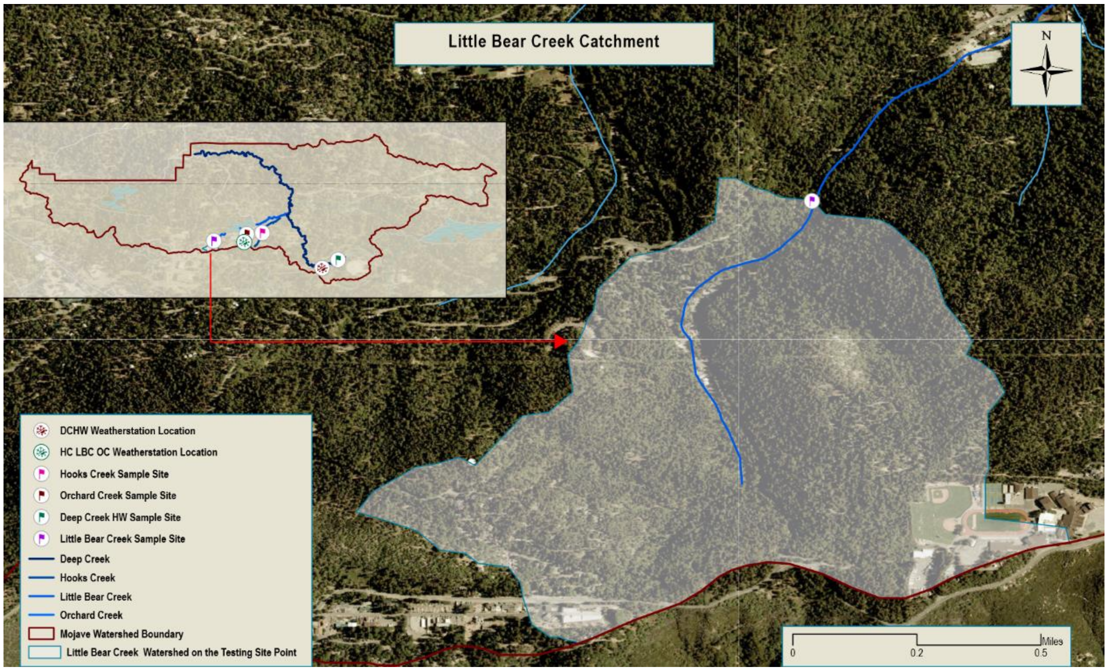

Figure 11. Little Bear Creek Catchment to the Study Site.

Figure 12. Photograph from the Little Bear Creek Study Site Looking Up at the Road.
Source: Christine Seeger, 2023

Orchard Creek

Like DC, HC, and LBC, the primary NLCD classification (see Figure 13) for OC is evergreen forest (56.29%). In contrast, OC is more developed than any other site. Developed open space (38.57%), developed high intensity (0.10%), developed medium intensity (1.11%), and developed low intensity (3.12%) compensate for 42.9 percent of total land cover. The remaining landscape within OC is shrub/scrub (0.81%).

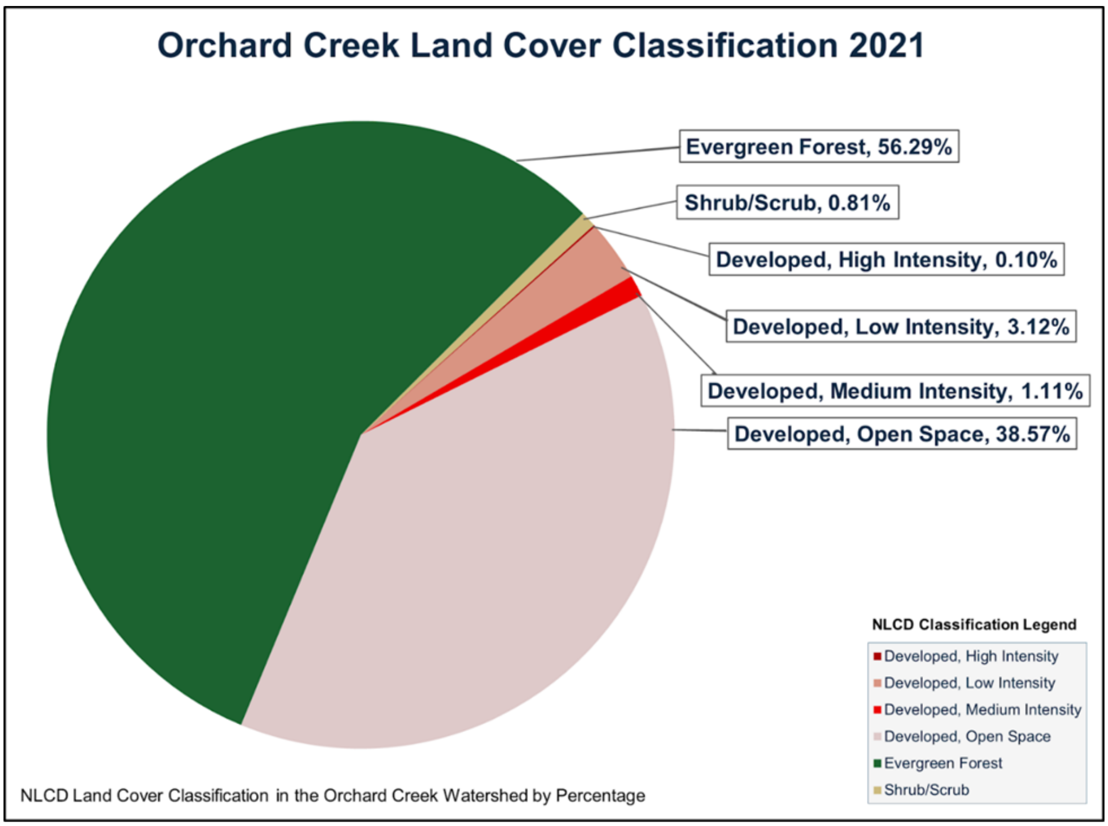

Figure 13. Orchard Creek Catchment Total Land Cover.

Much like the other test sites, OC is dominated by dense tree canopy (see Figure 14). Multiple roads indicate urbanized residential development. Unlike the other sites, OC has consistent residential urbanization throughout the entirety of the catchment. OC forms just below a residential dwelling, and the NHD flowlines show its path crossing over multiple roads. The OC basin begins as a mixture of evergreen forest and developed open space. It flows, and a majority of the NLCD shows evergreen forests. It flows through another developed open space area before ending in evergreen forest. This data is inaccurate as the whole OC catchment has residential has residential homes mixed within the evergreen forest. OC is an example of one of the limitations of the NLCD, as it was unable to detect development under dense tree canopy. Figure 15 is a photo from the test site looking at N Fremont Rd and CA-173.

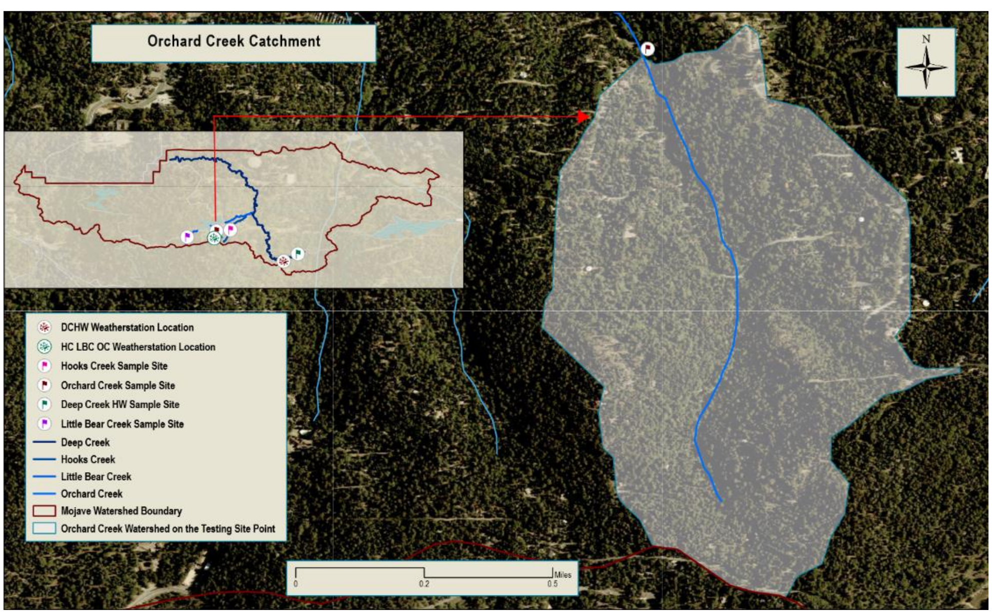

Figure 14. Orchard Creek Catchment to the Study Site.

Figure 15. Photograph from the Orchard Creek Study Site.
Source: Christine Seeger, 2023

Some discrepancies were noticed when comparing the NLCD to Google Earth Pro images and in situ assessments. Figures 10, 11, 13, and 14 demonstrate development in areas with the NLCD designated as other land cover classifications. For example, Google Earth Pro and in situ assessments revealed that residential development in areas classified as evergreen forests in LBC, HC, and OC were present. Additionally, residential developments in LBC, HC, and OC were categorized as developed, open spaces where dense development was identified instead of classifying these areas as developed low or medium insensitivity. In DC, several roads and trails are classified as shrub/scrub, evergreen forest, and mixed forest. While the NLCD is a valuable tool when assessing generalized land cover, the 30-meter resolution creates difficulty obtaining detailed, reliable data in an area with abundant tree canopy and vegetation, such as a forest (Gatti et al., 2017). Dense tree canopies also create difficulty when using Google Earth Pro since satellite images cannot view any development found under the canopy. A study by Wickham et al. (2021) noted that discrepancies further illustrate the importance of ground-truthing when analyzing land cover characteristics (Wickham et al., 2023). The NLCD is a good starting tool for landscape analysis, although additional methods should also be utilized.

Wildfire Landscape

Utilizing the Monitoring Trends in Burn Severity (MTBS) model to visualize wildfire history between 1950 and 2022, within the SBNF, 317 fires have been recorded. Figure 16 illustrates fire history in the Mojave watershed portion of the SBNF, where 63 fires were recorded in the same timeframe. Figure 17 outlines the total number of fires by decade in the SBNF and within the upper Mojave Watershed. Overall trends demonstrate increased fire frequency in the SBNF over a decade period increments since 1960, with a slight decrease in activity from 2010 to 2019. Current fire trends present concern as 32 events occurred since the beginning of this decade, which is half the total from 2010 to 2019. If current trends continue, this decade is on track to exceed last decade's total. Since the year 2000, 172 fires have occurred across the SBNF. In contrast, 145 fires occurred between 1950 to 1999. The SBNF experienced more fires in the last 24 years in less than half of the time of previous years, illustrating the need to understand how these events impact watershed landscapes and water resources flowing through and downstream of affected areas. When considering the sites observed in this study, fire history in the upper Mojave headwaters of the SBNF also presents concerning trends. Figures are not as dramatic in severity as they were for the entire SBNF. However, trends also display an overall increase in fire since 1970. Using the same 24-year to 49-year comparison, 33 events occurred since the year 2000, compared to 30 fires in the upper Mojave watershed from 1950-1999. Current trends do illustrate one divergence compared to SBNF data. Three fires have occurred in the upper Mojave watershed from 2020-2022, while the total from 2010-2019 is 14. This is less than half (21%) of the previous decade. While fire trends are trending to exceed the last decade for the SBNF, trends are currently slowing to date in the upper Mojave watershed.

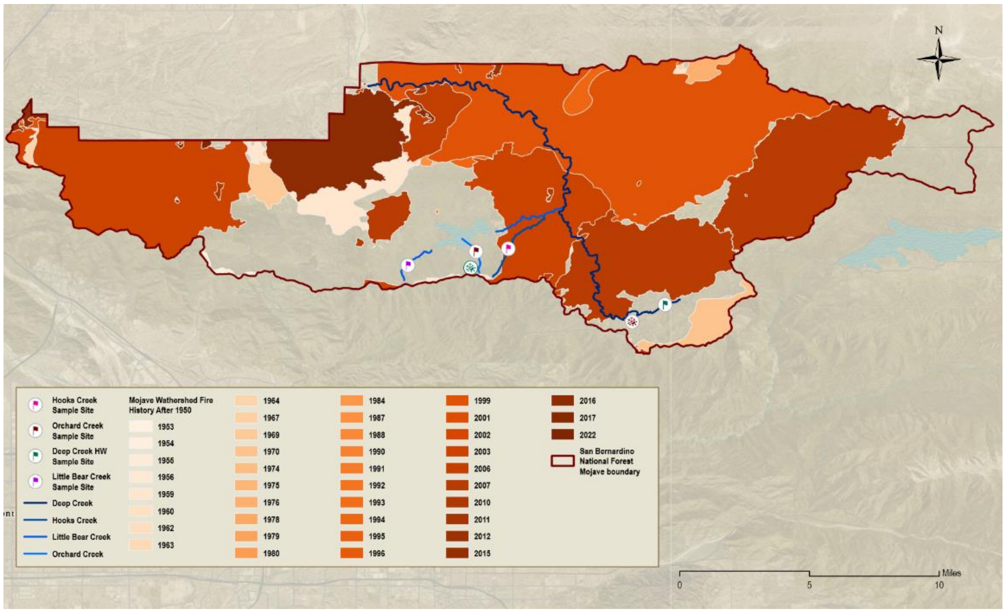

Figure 16. Burn History in the Mojave Watershed Boundary of San Bernardino National Forest from 1950 to 2022.

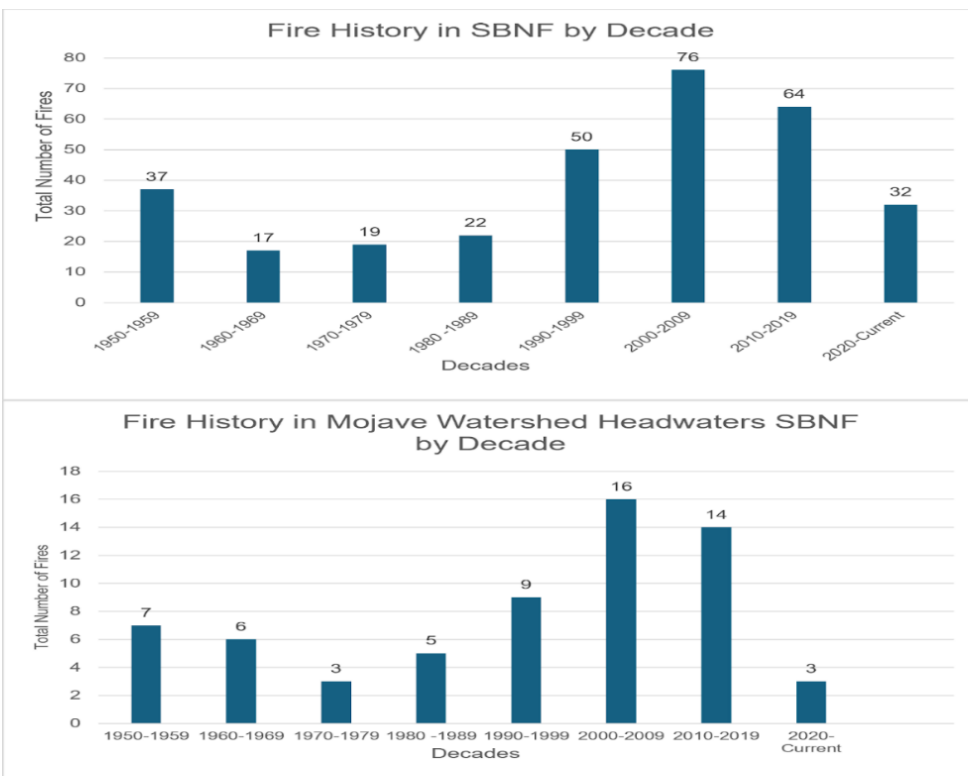

Figure 17. Fire History Total by Decade in the San Bernardino National Forest and Mojave Watershed Headwaters.

Each sampling site was analyzed using the same dataset. Figure 18 reveals four fires and the burnt acres that occurred within the catchments for DC, HC, LBC, and OC. In relation to the specific study sites, fire history reveals two fires that burned through DC, HC, and LBC and one fire in OC. The oldest fire within this dataset is the McKinley Fire, which occurred in 1956 and burned a total of 43,292,865.32 square meters (see Figure 19). The McKinley Fire burned 309,989.2 square meters in HC, 45,324.79 square meters in LBC, and 42,896.68 square meters in OC. It was also the only event that occurred in the OC catchment area. The Bear Fire burned a total of 209,041,177.9 square meters in 1970. The only catchment affected by the Bear Fire was DC, totaling 2,481,532.4 square meters. The last fire event within the DC catchment was the Slide Fire in 2007. This fire burned 2,785,856 square meters and totaled 51,674,309.7 square meters in the SBNF. In 2003, the Old Fire burned over 368,263,93 square meters. The USDC (2004) Southern California Wildfires report revealed the origin of the Old fire was anthropogenic (arson) and included six fatalities and 12 injuries, and over 1000 structures were destroyed, including 993 residential and ten commercial (USDC, 2004). The Old Fire burned 1,092,651.2 square meters (i.e., 48% of HC catchment) in HC and 44,920.106 square meters in LBC.

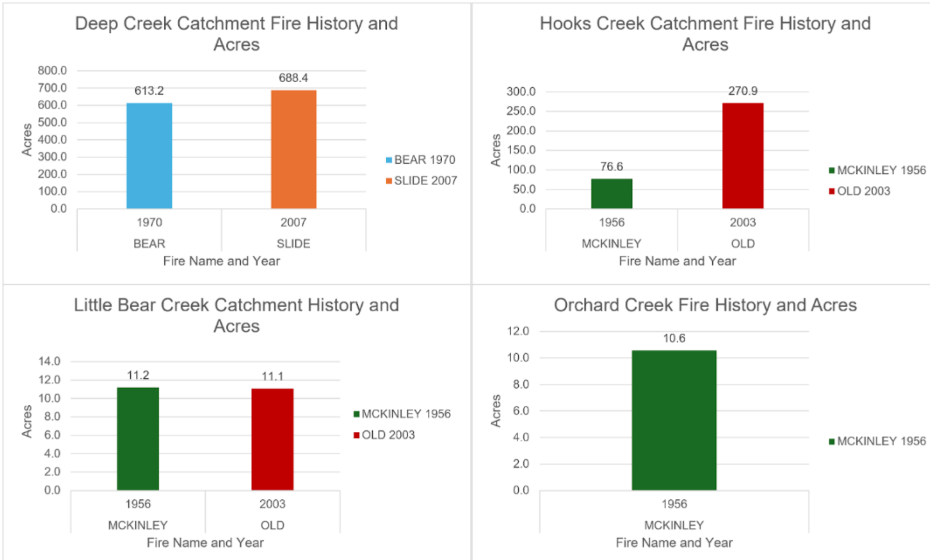

Figure 18. Fire History and Size Within Each Study Site Catchment.

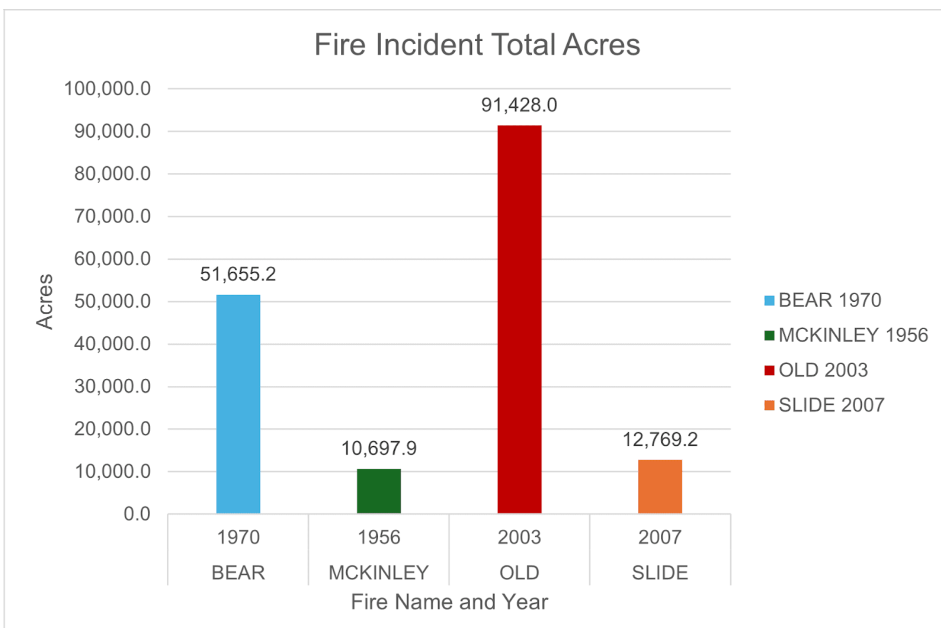

Figure 19. Fire Incident from Each Catchment Total Acres in the San Bernardino National Forest.

A visual understanding of the region's general wildfire history enables additional insight into possible influences on headwater stream quality. Bladon et al. (2014) and Holden et al. (2009) noted that knowledge of past wildfire events combined with water quality data illustrates relationships between the extent to which wildfire events may influence the physicochemical quality of surface water resources (Bladon et al., 2014; Holden et al., 2009). This further enables resource agencies to understand the importance of impact to inform restoration strategies that may include the application of best management practices in areas vulnerable to erosion and sediment transfer, as discussed by Maret et al. (2008) and Hawks et al. (2022), and MacKenzie et al. (2023) (Hawks et al., 2023; MacKenzie et al., 2024; Maret et al., 2008). This is especially important during weather whiplash events, as sudden heavy precipitation after a prolonged drought can exacerbate recently burned landscapes by transferring loose sediment and potentially harmful chemicals into nearby headwater streams.

Climatic Patterns

Precipitation and temperature trends were analyzed using data obtained from Weather Underground (Weather Underground, 2023a, 2023c, 2023b). Due to the nature of this study, acquiring weather data as close to the test location was critical, however, site-specific monitoring was beyond the scope of this study, so the nearest weather station was included in assessments.

The closest weather station to the DC sample site is located near the community of Arrowbear, California (i.e., Deep Creek Lake - Arrowbear, CA - KCARUNNI32) (Weather Underground, 2023c). The map in Figure 4 shows weather station locations relative to each study site. It is located at an elevation of approximately 1813.9 meters, whereas the elevation of the Deep Creek sample site is approximately 20374 meters. The distance between the sample site and the weather station is approximately 2 km. Locating a weather station with complete data near the LBC, OC, and HC sample sites was also challenging. There were several weather stations in the vicinity of each stream, but a majority had significant gaps in data and were missing the specific years from this study, creating limitations to observations. The only weather station in the vicinity of these three study sites identified with complete data was in Skyforest, south of Lake Arrowhead (i.e., Skyforest - KCASKYFO2) (Weather Underground, 2023b). The elevation of the weather station is approximately 5695 feet, while the elevation of the study sites at LBC is approximately 1604.8 meters, OC is approximately 1579.8 meters, and HC is approximately 1558.7 meters. The distance from the weather station to each sample site is approximately 3.6 km to LBC, 1 km to OC, and 2.3 km to HC. This clearly demonstrates just how dramatically the landscape varies within a relatively short distance in this region, as OC was less than a mile away from the weather station but had an elevation change of over 152.4 meters. While this data will help with this study, future studies can be improved by having dedicated weather stations at each test site to ensure the most precise data. Precipitation data was analyzed for the hydrological years 2019-2020 and 2020-2021 (October-September). This study defines the wet season as October-April and the dry season as May-September.

2019-2020 Precipitation data for 2019-2020 (figure 20) recorded a total of 67.72 cm at the weather station associated with DC and 45.82 cm at the weather station associated with sites HC, LBC, and OC. Most precipitation occurred during the wet season, with DC receiving 66.74 centimeters (99%) of precipitation and HC, LBC, and OC receiving 45.11 cm (98%) of precipitation. Both sites recorded less than a centimeter of precipitation throughout the dry season. Temperature data illustrates a relationship between precipitation and temperature. In months with higher totals of precipitation, the mean high and low temperatures are lower. The only exception is April, where the mean high and low temperatures began to increase at the start of the dry season, even when receiving substantial precipitation. Dry season temperatures increased significantly in comparison to the wet season.

2020-2021 The 2020-2021 hydrological year recorded a total precipitation of 10.06 cm at the weather stations associated with DC and 14.66 cm at the HC, LBC, and OC, respectively. During the wet season, DC received 6.23 cm (62%) of total precipitation, while HC, LBC, and OC received 13.07 cm (89%). The dry season recorded 3.83 cm (36%) of precipitation in DC, and HC, LBC, and OC received 1.59 cm (11%) of precipitation. The relationship between temperature and precipitation was not as defined in 2020-2021 compared to the previous year. While some months experienced a drop in mean temperature during months with precipitation, this was not always the case. For example, in February, both weather station data sets recorded a slight increase in temperature, even though it recorded precipitation.

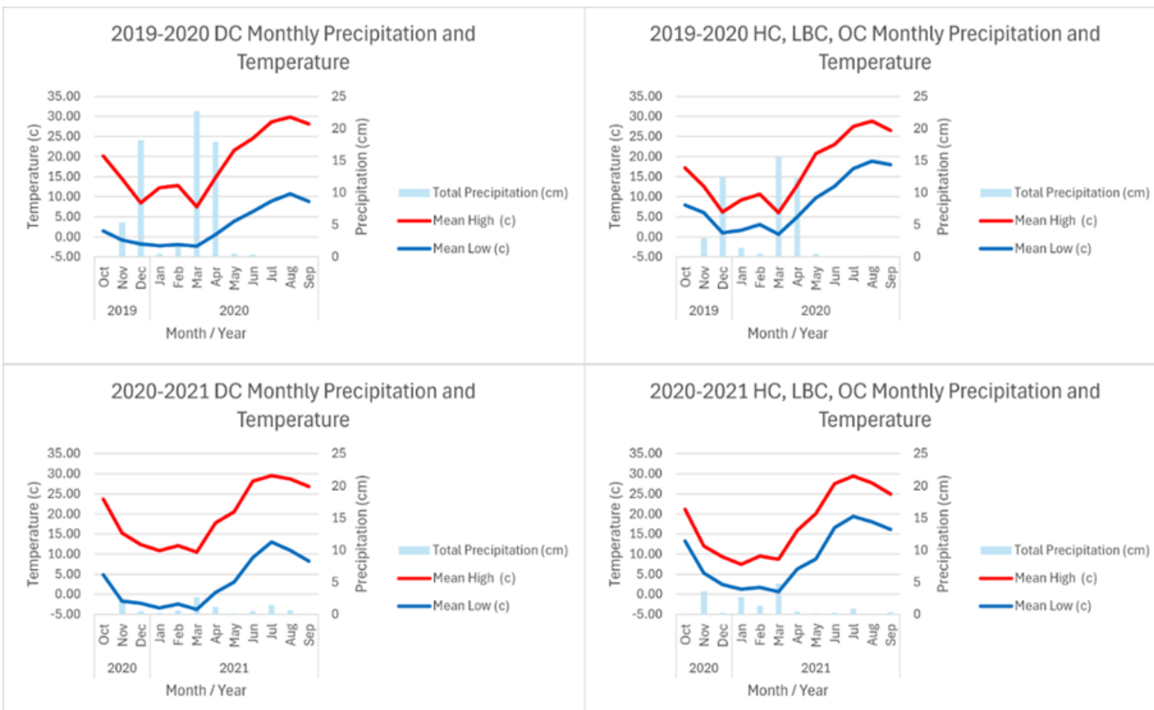

Figure 20. Mean Monthly High and Low Temperature and Total Precipitation.

Finally, drought conditions for the Mojave watershed were retrieved from the U.S. Drought Monitor dataset to illustrate how defined drought levels relate to study sites. Figure 21 combines the 2019-2020 and 2020-2021 hydrological years and charts drought conditions within the Mojave Watershed. Since all four study sites are headwater streams of the Mojave Watershed, classifying drought conditions within the Mojave Watershed grants insight into the relationship between precipitation trends and drought. Moreover, combining both hydrological years in the U.S. Drought Monitor's drought condition graph presents a visual representation of a wet-to-dry weather whiplash scenario. The 2019-2020 data presents normal or wet conditions in approximately seven months of the year, three months of abnormally wet conditions, and three months of moderate drought during the dry season. This aligns closely with the precipitation trends noted above for the same year. The 2020-2021 data presents drought conditions every month of the year, recording just over one month of severe drought and eleven months of extreme drought.

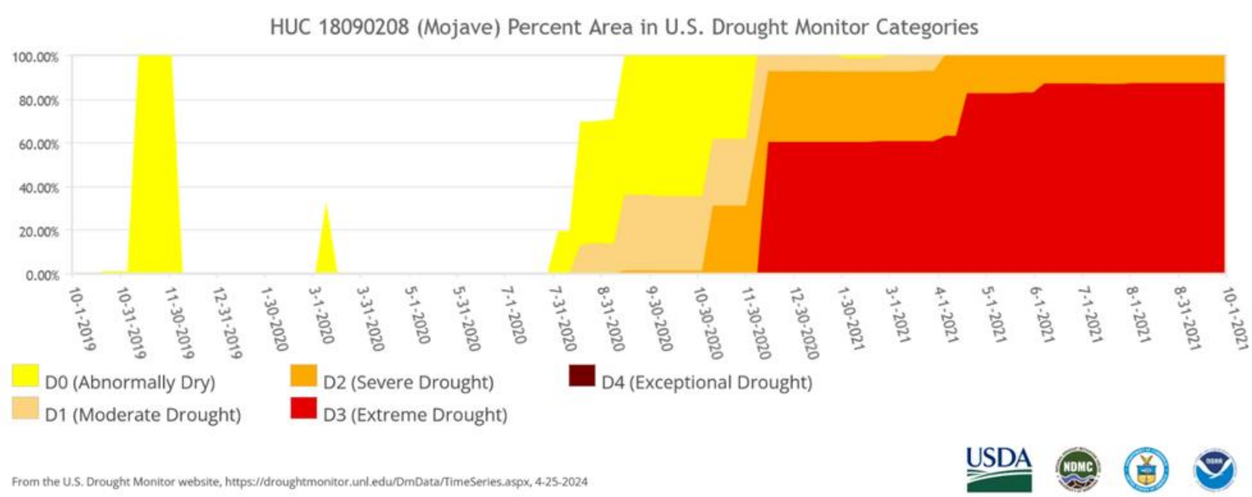

Figure 21. United States Drought Monitor Conditions in the Mojave Watershed 2019-2021.
Source: USDM, 2024.

The trends in Figure 19 illustrate dramatic shifts from significant precipitation in 2019-2020 to little precipitation in 2020-2021. Precipitation was significantly less at both sites in 2020-2021; however, the total distribution throughout the year was slightly more uniform. Data from 2019-2020 into 2020-2021 presents a sudden increase in temperature at the end of the wet season and essentially no precipitation. Prolonged high temperatures and little to no precipitation are conducive to drought conditions. These sudden shifts in climate (i.e., precipitation and temperature) observed in this study indicate the conditions defined as weather whiplash (Francis et al., 2022; Loecke et al., 2017; Swain et al., 2018). Precipitation trends also indicate the possible presence of atmospheric rivers (Dettinger, 2013; Ralph et al., 2006, 2018). Instances were observed where monthly totals came from large amounts of precipitation in a short period of time. For example, November 2019 recorded its monthly total between a period of six days, with 87 percent of the monthly total falling in a 24-hour period. Similar trends were also observed in March 2020, when 5.18cm of precipitation was recorded in a 24-hour, and 7.32cm was recorded over a 72-hour.

Water Quality and Climatic Trends

The 2019-2020 study period was wet, recording considerably greater precipitation totals than the 2020-2021 study period. The following year, precipitation totals diminished, impacting stream flows and physicochemical characteristics. Water testing at stream sites occurred monthly, with additional sampling occurring after precipitation events. Drought conditions hindered the ability to sample as stream flows ceased. However, these observations meet the study objectives, so trends are discussed.

Water Quality Exceedances

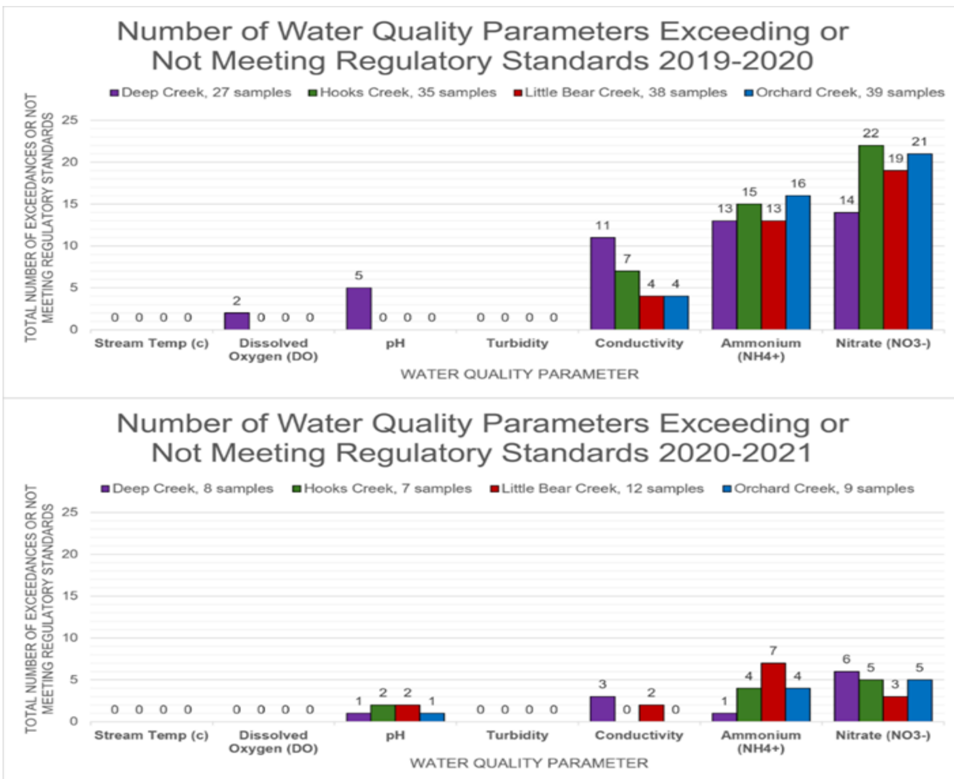

Figure 22. Number of Water Quality Parameters Failing to Meet Regulatory Standards by Site and Year.

Figure 22 illustrates trends in the number of samples meeting or exceeding regulatory standards for each site. Monitoring samples collected from 2019 to 2020 include 28 samples for DC, 35 samples for HC, 38 for LBC, and 39 for OC. In 2020-2021, when drought conditions were present, eight samples were collected for DC, 7 for HC, 12 for LBC, and 9 for OC.

It is also pertinent to understand how climatic conditions impact flows in relationship to stream physicochemical trends. Figures 23, 24,25, and 26 detail the relationship between stream flow rate versus precipitation within 72 hours of the sample time and expected streamflow usually increased after precipitation. All four sites had consistent streamflow through the 2019-2020 year. In 2020-2021, streamflow drastically decreased and had inconsistent flows at all four sites. HC had the most variable flow data, as only one reading was recorded over the hydrological year. From December 2020 through February 2021, HC had a visible flow; however, stream flow and water quantity were below the threshold required for a flow rate sensor to record reliable data measurements.

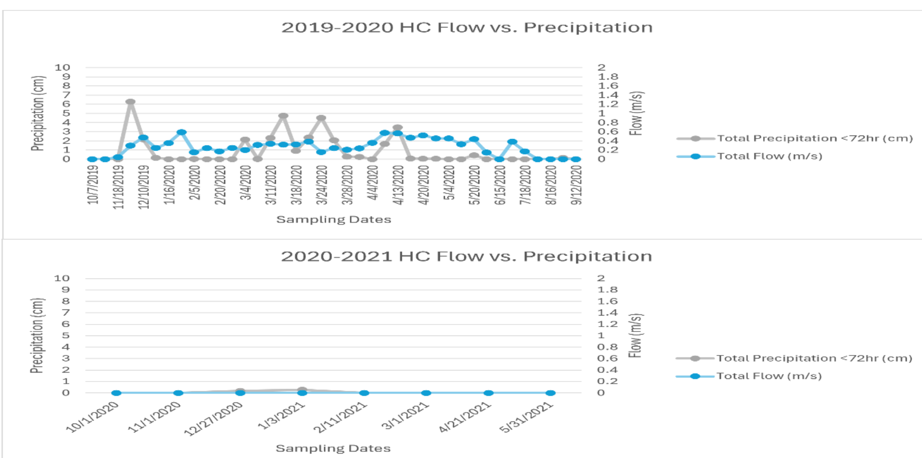

Figure 23. Hooks Creek Flow Vs. Precipitation Both Study Years.

Because of low flows that the flow meter could not measure, HC flow data for most months was recorded as “0.” HC was dry from October through November 2020 and stopped flowing in June through the end of the hydrological year. LBC had flows too low to measure from October 2020 through January 2021 and May 2021 and stopped flowing overall in July 2021.

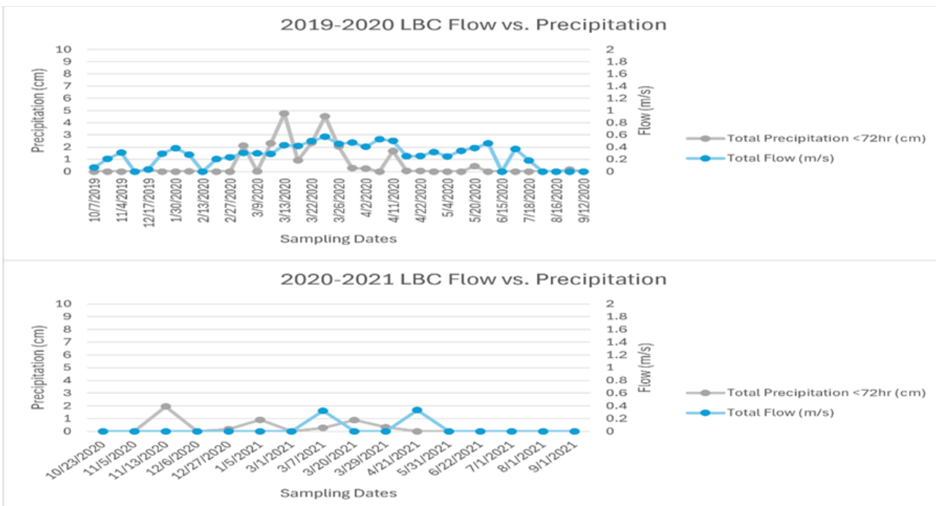

Figure 24. Little Bear Creek Flow Vs. Precipitation Both Study Years.

When flows are compared to exceedances (i.e., data exceeding requirements) or not meeting regulatory requirements (i.e., data lower than regulatory requirements), 2019-2020 water quality issues observed seem to trend more towards not meeting regulatory requirements, and 2020-2020 water quality issues trend more towards exceedances.

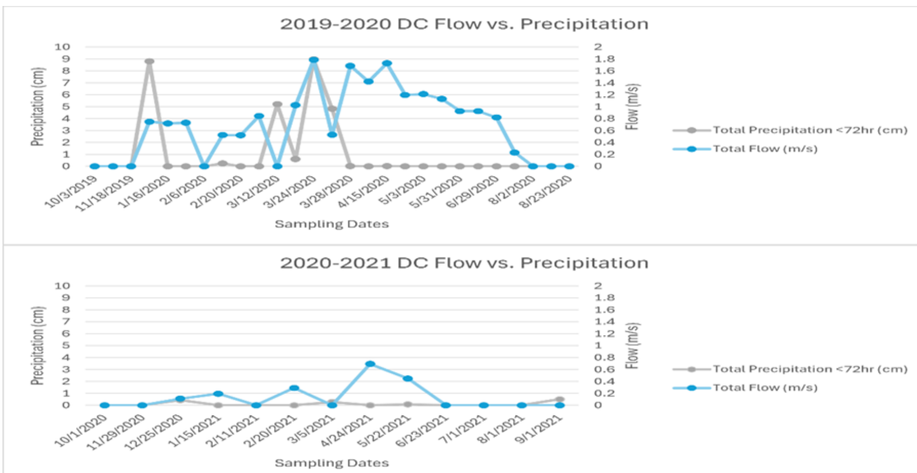

Figure 25. Deep Creek Flow Vs. Precipitation Both Study Years.

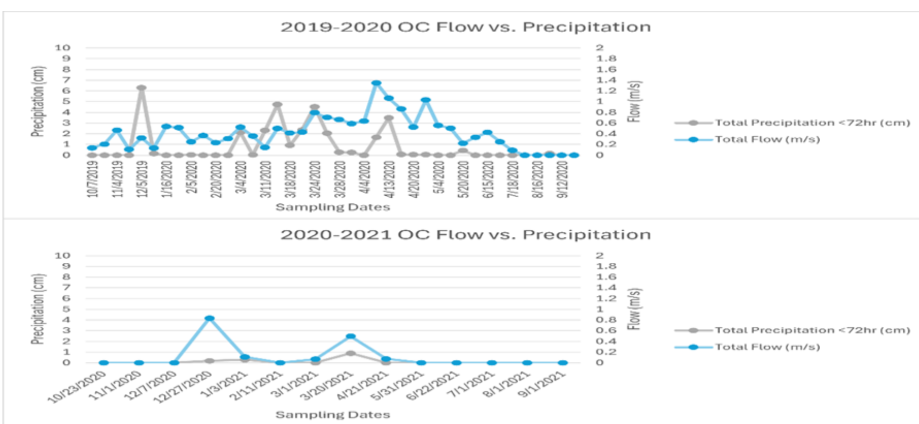

Figure 26. Orchard Creek Flow Vs. Precipitation Both Study Years.

<u>Nutrients</u> In both study years, every site had at least one water quality parameter reaching 50 percent or more of the collected samples that did not meet regulatory standards, with nitrate having the highest percentage of exceedances across both years. In 2019-2020, every site had at least or more than 50 percent of samples that failed to meet regulatory standards for Nitrate, including HC (63%), OC (54%), DC (52%), and LBC (50%). These failures to meet were uniform throughout each year for each site regardless of whether there was precipitation indicating that it. DC and LBC had more samples falling below regulatory standards than HC and OC. HC and OC both had a higher number of exceedances with all of them occurring from January 2020 through June 2020. In 2020-2021, the sites that failed to meet regulatory standards for nitrate included DC (75%), HC (71%), and OC (55%). The highest concentration of nitrate for each season was: DC (1.4 mg/l, October), HC (5.9 mg/l, May), LBC (4.3 mg/l, February), and OC (5.7 mg/l, April). Two occurred during the wet season, and two occurred during the dry season, but each of the highest readings happened after precipitation.

From 2020 to 2021, a more significant number of exceedances did not meet regulatory standards. The first precipitation event of the hydrological year occurred at the end of November, and each site except HC failed to meet regulatory standards in December. All four sites exceed March, the month with the most precipitation. Nitrate in LBC was 8.1 mg/l on March 1, and OC was 10.8 mg/l on March 20. Unfortunately, water quality parameter data was not recorded on March 20 at LBC due to plowed snow stacked on top of the test site (see Figure 27). For 2020-20201, nitrate exceedances happened more frequently in the wet season and spiked after precipitation. For example, every site had exceedances in March 2021, the wettest month of the year. The highest exceedances for each site occurred during the wet season: DC (3.8 mg/l, April), HC (4.8 mg/l, March), LBC (8.1, March), and OC (10.8 mg/l, March). The sites with the highest readings are both within the highest developed catchments.

Figure 27. Little Bear Creek Study Site Covered in Dirty Snow from Snowplows. Source: Jennifer Alford, 2023

Ammonium Ammonium was another nutrient that failed to meet regulatory standards requirements; However, exceedances were less frequent than nitrate. While no sites exceeded 50 percent or more in 2019-2020, three sites (DC, HC, and OC) all recorded total exceedances between 40 and 49 percent. In 2020-2021, LBC (58%) and HC (57%) were the only sites surpassing 50 percent for ammonium. The majority of exceedances in ammonium for both years spiked after precipitation events during the wet season. Much like nitrate, the highest exceedances occurred in catchments with urban developments.

Bacteria Bacteria parameters, including total coliform (TC), E. coli, and enterococcus, were collected intermittently at each site each year due to funding limitations and limited access to reagents during COVID. TC has an allowance of up to 1000 cfu/100ml, E. coli has a range of under 126 cfu/100ml, and enterococcus has a cfu of under 35 cfu/100ml. The IDEXX sampling regents allow for a 1:1 comparison of colony-forming units (cfu) to the most probable number (MPN) for ease of understanding of how lab results link to regulatory standards (IDEXX, 2024).

From 2019 to 2020, LBC exceeded most of the fecal bacteria parameters. Enterococci had the highest percentage of samples with exceedances, recording 69 percent, followed by E. coli with 48 percent of exceedances, and TC with 22 percent. TC had two readings that were higher than the recordable limit of 2419.9 MPN/100ml, recorded in March and June 2020. The March exceedance had a 72-hour precipitation of 4.75cm. However, the sample in June was taken during a dry period. E. coli and enterococci had an alarming number of exceedances well above regulatory requirements. Exceedances were variable throughout both the wet and dry seasons.

In 2020-2021, LBC had an 88 percent exceedance out of nine samples for enterococcus but only had .125 percent for E. coli and had no exceedances for TC. OC had three exceedances of enterococcus, and HC had one exceedance of TC 2419.9 cfu/100ml, which was the highest detectable limit. LBC, HC, and OC flow through urbanized areas, whereas DC flows through a more rural path. Due to land use types, the detection of fecal bacteria at LBC, HC, and OC is the likely reason due to similar findings by Kang et al., 2010 (J.-H. Kang et al., 2010). The high number of bacteria in LBC and HC is a potential public health issue as both streams flow into Lake Arrowhead, which is used for drinking water and recreation.

Additional Parameter Trends Conductivity recorded a small number of regulatory exceedances. However, DC was the only site with over 20 percent each year, recording 41 percent in 2019-2020 and 37 percent in 2020-2021. The last parameters that failed to meet standards were DO, and pH, but the percentage of total failures to meet was much lower than the 50 percent or higher threshold each year. DO had two readings, both in 2019 and 2020, that fell below 4 mg/l. In October, it had a reading of 3.72 mg/l, and in August, it had a reading of 3.46 mg/l. For pH, the failures recorded were all below regulatory standards.

Stream temperature and turbidity were the only parameters never to record an exceedance.

Identifying Factors that Influence Monitoring

Trends Factors contributing to fluctuating sample data in this study include the forest closures, the COVID-19 pandemic, limited funding needed to purchase sample collection reagents, and accessibility to study sites after heavy snow. The USFS enacted forest closures in 2020 and 2021 due to elevated risks of wildfire throughout the state of California (USDA 2020; 2021). Additionally, stay-at-home orders due to the COVID-19 pandemic prevented access to parts of the SBNF and created inventory issues, affecting the ability to purchase reagents necessary for bacteria collection. Additional barriers to reaching monitoring streams included the fact that San Bernardino County employees clear public roads using snowplows after snowstorms. It is not uncommon for excess snow to end up stacked in and around study sites, including LBC, HC, and OC. Substantial volumes of stacked snow may take weeks to melt, prolonging collection. The large piles of accumulated snow also present unsafe conditions when collecting data samples, preventing a safe route to the respective study sites.

Referring to Figure 21 above, nitrate and ammonium are the two water quality parameters that regularly fail to meet regulatory standards at all four sites. This data closely correlates to precipitation trends. Precipitation was more significant in 2019-2020 than in 2020-2021, with most occurring throughout the wet season. Frequent precipitation events positively impact prolonged streamflow. Since 2019-2020 was a wetter year, there were more months of steady streamflow, and parameters such as nitrate and ammonium could dilute, impacting the ability to meet regulatory standards. In 2020-2021, precipitation was significantly less than the previous year, and more extended periods between precipitation events occurred.

The sites with the highest total number of failures to meet regulatory standards for 2019-2020 were LBC and HC. LBC is in a highly urbanized catchment. HC is not as urbanized; however, it is downhill from Skypark Santa's Village. The sites with the highest recorded exceedances across all parameters were LBC and OC. Both catchments are within the most densely urbanized watersheds. While it is beyond the scope of this study to identify specific reasons for regulatory data not being met, further studies are warranted to investigate these findings.

Best Management Practices (BMPs)

Water quality trends show that all four sites struggled with nutrients (i.e., nitrate and ammonium). Multiple studies have outlined how to manage BMPs, including Avay et al. (2022), Bdour et al. (2022), Gautam et al. (2010), and Lee et al. (2013). Pollutants concentrate near streams until precipitation events flush them downstream. OC and LBC flow through densely urbanized areas, while DC flows along one of the most traveled routes in the SBNF and crosses into a popular year-round recreational destination. The source of nutrient pollution in surface water can originate from several causes, including wastewater, stormwater runoff from agriculture and urban causes, failing septic systems, and industrial discharge (EPA, n.d.). Land use most likely influenced nutrient exceedances, as multiple studies observed similar data under similar circumstances (Hsu et al., 2023; J.-H. Kang et al., 2010; Kincaid et al., 2020). BMPs, such as creating riparian buffers of at least 10m from a stream, help mitigate numerous problems at once, as seen in the study by Clinton (2011) (Clinton, 2011). Further studies are recommended to correctly identify and recommend site-specific BMPs, as they are beyond the scope of this study.

Adaptive Management

Adaptive management, the practice of using BMPs and strategies that may change over time depending on the landscape, results, new science, and effectiveness, is ideal when managing a large watershed (Clinton, 2011; DOI, 2009). However, it must be done correctly in order for it to work. For adaptive management to be successful, all parties involved in managing a watershed must be in contact with one another and agree to solutions to benefit the watershed as a whole. Adaptive management strategies can be as simple as changing the behavior of management implementation, helping residents in an area understand the reasoning for conservation methods, or even creating guidelines for more frequent water monitoring.

Conceptual Adaptive Watershed Model for the SBNF

Watershed management poses complex challenges that require a multifaceted approach. In a landscape like SBNF, headwater streams flow through multiple communities and jurisdictions, often creating knowledge gaps unidentified by all affected. Due to the complexity of managing HWS and the numerous issues that affect watersheds and the communities within (i.e., climate change, weather whiplash, drought, wildfire, and human impact), adaptive management should be utilized to address issues proactively. Adaptive management only works if partnerships promote trust and collaboration in the community. Fostering community involvement is crucial; it's the backbone of our efforts because many components necessary to maintain a healthy watershed begin at local communities within the headwaters. Engagement and education must be at the forefront of watershed planning, and once that is in place, management strategies fall into place. The recommendations presented in this discussion cater to the SBNF; However, the interdisciplinary approach can be applied to any watershed.

Often, multiple agencies are involved in HWS protection and watershed management. For example, HWS within the SBNF is managed by several agencies ranging from local volunteer organizations and community groups to federal agencies. The chart in Figure 28 illustrates the hierarchy of agencies involved. Watershed management in the SBNF must begin at the community level (i.e., community residents, non-profit organizations, and resource conservation districts). The first agencies involved are local retailer agencies (i.e., Crestline Water District and Running Springs Water District). Regional agencies and water wholesalers are at the next level (i.e., San Bernardino Valley Municipal Water District, Mojave Water Agency). State agencies (i.e., State Water Board, Department of Water Resources) oversee watersheds from a regulatory standpoint. Finally, the SBNF has an additional agency level since many HWS flow through National Forest lands (i.e., USFS). DC is an example of the jurisdictional complexity in the SBNF. It begins on a National Forest (i.e., federal: USFS), flows through a high-volume ski and recreation resort (i.e., community: Snow Valley), crosses through multiple culverts under California Highway 38 (i.e., state: Caltrans), flows back on USFS land, meets up with Silverwood Lake (i.e. state: California State Parks), and then eventually recharges the Mojave Basin, managed by Mojave Water Agency (i.e. regional: water wholesaler). DC is just one example of many HWS in the SBNF that flow within multiple watershed management jurisdictions.

Figure 28. Visual Relationship of the Many Agencies Managing the San Bernardino National Forest.

Having multiple agencies involved in watershed management can be helpful, but often, little to no communication between agencies and local communities creates disconnection at every level. Each agency has different objectives and roadblocks when it comes to watershed management. For example, when a local or regional agency is developing a yearly watershed management plan, how does their decision-making affect neighboring communities and agencies, and are neighboring agencies considered in management annual land plans? Communication and collaboration are not just essential; they are the keys to success in any watershed where multiple agencies and communities coexist. Communication with one another not only promotes collaboration between agencies but also promotes trust and transparency in the community/agency relationship. This is why programs such as the Local Headwaters Resiliency Partnership, formed by the San Bernardino Valley Municipal Water District, are cutting-edge programs that offer proactive solutions to complex watershed management issues. The Headwaters Resiliency Partnership is a first-of-its-kind program designed to address watershed management issues within the headwaters of the SBNF while promoting collaboration between local, regional, state, and federal agencies, along with community stakeholders (SBVMWD, 2021).

Engagement between the community and watershed agencies promotes discussions to identify the communities' strengths and needs in watershed management issues. It needs to be multifaceted, engaging the community through multiple outlets. Investing in K-12 education is fundamental as it enables agencies to engage with younger community members to teach watershed stewardship early on. Community outreach events, including engagement with decision-makers, board meetings, and interactive activities that educate and promote water resiliency, can earn community trust while learning about their needs. Citizen science models promote transparency and involve the public in water monitoring. Survey modes such as Water Talks, a community-facing program intending to generate and increase community involvement in LA and Ventura counties, created and analyzed needs assessment surveys to identify community needs that can be easily implemented in the SBNF (Watertalks, 2024).

Creating a knowledge hub is essential for the different levels of agencies to exchange data, knowledge, and expertise. Sometimes, local-level agencies do not have the resources to get the latest information, but regional, state, and federal levels have a surplus of knowledge, scientists, and experts. Higher agency levels, such as state and federal, are typically hundreds of miles away from the locations they serve and are disconnected from community needs. This is where local agencies are essential in getting the public involved. Information sharing allows for practicality at all levels. Each agency has strengths and weaknesses; therefore, working collaboratively and sharing data is critical. Agencies must assimilate with the community to build trust and identify needs while listening to their expertise. This must be a continual learning process, and the structure of each partnership is different; therefore, getting to know the local community is fundamental. This process will take time and involve lots of trial and error, but it starts with baseline data, community trust, and agency communication. It’s a necessity for adaptive management to work. If not, we are managing from a reactive model instead of a proactive one.

Past literature does not consider headwater streams, which is why it should be included; so many people are disjointed, and anything that happens upstream affects downstream (Lassaletta et al., 2010; Nadeau and Rains, 2007; Rasmussen et al., 2013). If we do not manage headwaters, the whole watershed is in trouble. We need to eliminate disjointed to implement adaptive management strategies successfully.

CHAPTER FIVE

CONCLUSION

This study utilized an interdisciplinary approach to examining and understanding influences on headwater streams, including landscape characteristics, spatio-temporal trends in the physicochemical water quality, and temporal trends, including precipitation and atmospheric temperature, to examine the effects on headwater stream quality and quantity. It also investigated effective land management strategies to recommend practices that can better protect headwater streams in mixed-use watersheds. It utilized data collected over a two-year period, one during a year that experienced high precipitation, followed by a year that experienced low precipitation and drought conditions, a common trend that occurs in the SBNF, and identified samples that did not meet regulatory compliance standards. The findings of this research suggest that land use characteristics and climatic trends such as precipitation and temperature influence water quality and quantity. When examining water quality data, nitrate (NO_3^-) had the highest number of samples, followed by ammonium (NH_4^+), which did not meet regulatory requirements. Findings for both nutrients suggest that land use influences exceedances, and the highest readings were found in catchments with higher development percentages after precipitation events. It also examined bacteria in water samples. While bacteria sample data was limited, there was a relationship between land use type and exceedances.

Catchments with higher development had samples that consistently exceeded regulatory requirements. Exceedances were observed during both the wet and dry seasons, suggesting that landscape influences bacteria more than climate.

The findings of this study have significant implications for land management strategies. It underscores the importance of adaptive management and collaborative relationships between community members and the agencies that serve them in ensuring watershed resiliency. The study points to programs like the Watershed Resiliency Partnership, organized by the San Bernardino Valley Municipal Water District, as the future of headwater stream management. These findings provide a clear roadmap for policymakers and community members to follow in their efforts to protect headwater streams.

While this study primarily focuses on the SBNF, the findings can be applied to any watershed. An interdisciplinary approach to watershed management is crucial as it combines the science and policy of headwater stream management to protect headwater streams better. With climate change, weather whiplash, wildfire, and the threat of human activities, headwater stream protection is more critical than ever. Anything downstream in a watershed relies on everything upstream. If headwater streams are not adequately managed, the health of the whole watershed is in jeopardy.

REFERENCES

Abatzoglou, J. T., Redmond, K. T., & Edwards, L. M. (2009). Classification of Regional Climate Variability in the State of California. *Journal of Applied Meteorology and Climatology*, *48*(8), 1527–1541.

Ahearn, D. S., Sheibley, R. W., Dahlgren, R. A., Anderson, M., Johnson, J., & Tate, K. W. (2005). Land use and land cover influence on water quality in the last free-flowing river draining the western Sierra Nevada, California. *Journal of Hydrology*, *313*(3), 234–247. https://doi.org/10.1016/j.jhydrol.2005.02.038

Ahmadi, B., & Moradkhani, H. (2019). Revisiting hydrological drought propagation and recovery considering water quantity and quality. *Hydrological Processes*, *33*(10), 1492–1505. https://doi.org/10.1002/hyp.13417

Ahn, J. H., Grant, S. B., Surbeck, C. Q., DiGiacomo, P. M., Nezlin, N. P., & Jiang, S. (2005). Coastal Water Quality Impact of Stormwater Runoff from an Urban Watershed in Southern California. *Environmental Science & Technology*, *39*(16), 5940–5953. https://doi.org/10.1021/es0501464

Alexander, R. B., Boyer, E. W., Smith, R. A., Schwarz, G. E., & Moore, R. B. (2007). The Role of Headwater Streams in Downstream Water Quality1. *JAWRA Journal of the American Water Resources Association*, *43*(1), 41–59. https://doi.org/10.1111/j.1752-1688.2007.00005.x

Alford, J. B., & Caporuscio, E. (2020). Effectiveness of Stormwater Best Management Practices in Headwater Streams to Mitigate Harmful Algal Blooms: A Case Study of the San Bernardino National Forest, California. *Case Studies in the Environment*, *4*(1), 1233521. https://doi.org/10.1525/cse.2020.1233521

Alford, J. B., & Mora, J. A. (2022). Factors influencing chronic semi-arid headwater stream impairments: A southern California case study. *AIMS Geosciences*, *8*(1), 98–126.

Allan, C., Curtis, A., Stankey, G., & Shindler, B. (2008). Adaptive Management and Watersheds: A Social Science Perspective1. *JAWRA Journal of the American Water Resources Association*, *44*(1), 166–174. https://doi.org/10.1111/j.1752-1688.2007.00145.x

Arlettaz, R., Nusslé, S., Baltic, M., Vogel, P., Palme, R., Jenni-Eiermann, S., Patthey, P., & Genoud, M. (2015). Disturbance of wildlife by outdoor winter recreation: Allostatic stress response and altered activity–energy budgets. *Ecological Applications*, *25*(5), 1197–1212. https://doi.org/10.1890/14-1141.1

Arnold, C. L., & Gibbons, C. J. (1996). Impervious Surface Coverage: The Emergence of a Key Environmental Indicator. *Journal of the American Planning Association*, *62*(2), 243–258. https://doi.org/10.1080/01944369608975688

Avay, R., Parajuli, P. B., & Link to external site, this link will open in a new tab. (2022). Evaluation of the Impact of Best Management Practices on Streamflow, Sediment and Nutrient Yield at Field and Watershed Scales. *Water Resources Management*, *36*(3), 1093–1105. https://doi.org/10.1007/s11269-022-03075-7

Bdour, A. N. (2022). Arid Lands Flood Evaluation and Mitigation Measures Using HEC-HMS Model and Best Management Practices (BMPs). *Global NEST Journal*, *24*(4), 621–628. https://doi.org/10.30955/gnj.004221

Berberi, A., Guay, J. D., Bulté, G., Cooke, S. J., Davy, C. M., & Nguyen, V. M. (2024). Interactions between inland water-based recreation and freshwater turtles: A review. *Aquatic Conservation: Marine and Freshwater Ecosystems*, *34*(2), e4088. https://doi.org/10.1002/aqc.4088

Big Bear. (2024). *Sustainable Tourism & Stewardship* | *Big Bear Lake, CA*. Big Bear Lake, CA. https://www.bigbear.com/care-for-big-bear/

Bigelow, D. P., Plantinga, A. J., Lewis, D. J., & Langpap, C. (2017). How Does Urbanization Affect Water Withdrawals? Insights from an Econometric-Based Landscape Simulation. *Land Economics*, *93*(3), 413–436.

Billen, G., Garnier, J., Ficht, A., & Cun, C. (2001). Modeling the response of water quality in the Seine River estuary to human activity in its watershed over the last 50 years. *Estuaries*, *24*(6), 977–993. https://doi.org/10.2307/1353011

Bladon, K. D., Emelko, M. B., Silins, U., & Stone, M. (2014). Wildfire and the Future of Water Supply. *Environmental Science & Technology*, *48*(16), 8936–8943. https://doi.org/10.1021/es500130g

BOEM. (2023). *Clean Water Act (CWA) | Bureau of Ocean Energy Management*. https://www.boem.gov/environment/environmental-assessment/clean-water-act-cwa

Booth, D. B., & Jackson, C. R. (1997). URBANIZATION OF AQUATIC SYSTEMS: DEGRADATION THRESHOLDS, STORMWATER DETECTION, AND THE LIMITS OF MITIGATION1. *JAWRA Journal of the American Water Resources Association*, *33*(5), 1077–1090. https://doi.org/10.1111/j.1752-1688.1997.tb04126.x

Boy, M., Thomson, E. S., Acosta Navarro, J.-C., Arnalds, O., Batchvarova, E., Bäck, J., Berninger, F., Bilde, M., Brasseur, Z., Dagsson-Waldhauserova, P., Castarède, D., Dalirian, M., de Leeuw, G., Dragosics, M., Duplissy, E.-M., Duplissy, J., Ekman, A. M. L., Fang, K., Gallet, J.-C., … Kulmala, M. (2019). Interactions between the atmosphere, cryosphere, and ecosystems at northern high latitudes. *Atmospheric Chemistry and Physics*, *19*(3), 2015–2061. https://doi.org/10.5194/acp-19-2015-2019

Brabec, E., Schulte, S., & Richards, P. L. (2002). Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. *Journal of Planning Literature*, *16*(4), 499–514. https://doi.org/10.1177/088541202400903563

Bradshaw, J. K., Snyder, B. J., Oladeinde, A., Spidle, D., Berrang, M. E., Meinersmann, R. J., Oakley, B., Sidle, R. C., Sullivan, K., & Molina, M. (2016). Characterizing relationships among fecal indicator bacteria, microbial source tracking markers, and associated waterborne pathogen occurrence in stream water and sediments in a mixed land use watershed. *Water Research*, *101*, 498–509. https://doi.org/10.1016/j.watres.2016.05.014

Burke, M. P., Hogue, T. S., Kinoshita, A. M., Barco, J., Wessel, C., & Stein, E. D. (2013). Pre- and post-fire pollutant loads in an urban fringe watershed in Southern California. *Environmental Monitoring and Assessment*, *185*(12), 10131–10145. https://doi.org/10.1007/s10661-013-3318-9

Burton, C. A., Hoefen, T. M., Plumlee, G. S., Baumberger, K. L., Backlin, A. R., Gallegos, E., & Fisher, R. N. (2016). Trace Elements in Stormflow, Ash, and Burned Soil following the 2009 Station Fire in Southern California. *PLOS ONE*, *11*(5), e0153372. https://doi.org/10.1371/journal.pone.0153372

California. (2023). *Request Free California Official Visitor's Guide Service Details | www.ca.gov*. https://www.ca.gov/service/?item=request-free-california-official-visitor%27s-guide

Candry, P., Abrahamson, B., Stahl, D. A., & Winkler, M.-K. H. (2023). Microbially mediated climate feedbacks from wetland ecosystems. *Global Change Biology*, *29*(18), 5169–5183. https://doi.org/10.1111/gcb.16850

CDFW. (2021). *Atlas of the Biodiversity of California* (2nd ed.).

Chang, H., & Bonnette, M. (2016, November 24). *Climate change and water-related ecosystem services: Impacts of drought in california, usa* | *Ecosystem Health and Sustainability*. https://spj.science.org/doi/full/10.1002/ehs2.1254

Clinton, B. D. (2011). Stream water responses to timber harvest: Riparian buffer width effectiveness. *Forest Ecology and Management*, *261*(6), 979–988. https://doi.org/10.1016/j.foreco.2010.12.012

Coleman, T. W., Grulke, N. E., Daly, M., Godinez, C., Schilling, S. L., Riggan, P. J., & Seybold, S. J. (2011). Coast live oak, Quercus agrifolia, susceptibility and response to goldspotted oak borer, Agrilus auroguttatus, injury in southern California. *Forest Ecology and Management*, *261*(11), 1852–1865. https://doi.org/10.1016/j.foreco.2011.02.008

Colvin, S. A. R., Sullivan, S. M. P., Shirey, P. D., Colvin, R. W., Winemiller, K. O., Hughes, R. M., Fausch, K. D., Infante, D. M., Olden, J. D., Bestgen, K. R., Danehy, R. J., & Eby, L. (2019). Headwater Streams and Wetlands are Critical for Sustaining Fish, Fisheries, and Ecosystem Services. *Fisheries*, *44*(2), 73–91. https://doi.org/10.1002/fsh.10229

Cooke, M. T., & Xia, L. (2020). Impacts of Land-Based Recreation on Water Quality. *Natural Areas Journal*, *40*(2), 179–188. https://doi.org/10.3375/043.040.0209

CSWRCB. (2013). *NATIONAL POLLUTANT DISCHARGE ELIMINATION SYSTEM (NPDES) STATEWIDE STORM WATER PERMIT WASTE DISCHARGE REQUIREMENTS (WDRS) FOR STATE OF CALIFORNIA DEPARTMENT OF TRANSPORTATION* (2012-0011-DWQ).

CSWRCB. (2024). *Laws and Regulations* **|** *California State Water Resources Control Board*. https://www.waterboards.ca.gov/laws_regulations/

CWQMC. (2023). *My Water Quality: Aquatic Ecosystem Health—Streams, Rivers & Lakes*. California Water Quality Monitoring Council. https://mywaterquality.ca.gov/eco_health/streams/landuse2.html

Danz, M. E., Corsi, S. R., Brooks, W. R., & Bannerman, R. T. (2013). Characterizing response of total suspended solids and total phosphorus loading to weather and watershed characteristics for rainfall and snowmelt events in agricultural watersheds. *Journal of Hydrology*, *507*, 249–261. https://doi.org/10.1016/j.jhydrol.2013.09.038

Delpla, I., Jung, A.-V., Baures, E., Clement, M., & Thomas, O. (2009). Impacts of climate change on surface water quality in relation to drinking water production. *Environment International*, *35*(8), 1225–1233. https://doi.org/10.1016/j.envint.2009.07.001

Dettinger, M. D. (2013). Atmospheric Rivers as Drought Busters on the U.S. West Coast. *Journal of Hydrometeorology*, *14*(6), 1721–1732.

Dodds, W. K., & Oakes, R. M. (2008). Headwater Influences on Downstream Water Quality. *Environmental Management*, *41*(3), 367–377. https://doi.org/10.1007/s00267-007-9033-y

DOI. (2009). *Adaptive Management The U.S. Department of the Interior Technical Guide*.

Duhan, D., Pandey, A., & Srivastava, P. (2018). Rainfall variability and its association with El Niño Southern Oscillation in Tons River Basin, India. *Meteorology and Atmospheric Physics*, *130*(4), 405–425. https://doi.org/10.1007/s00703-017-0525-x

DWR. (2022). *Disadvantaged Communities Nomenclature Within the State of California: Findings and Conclusions—A Recommendation Document*.

DWR. (2023, December 8). *Delta Conveyance*. https://water.ca.gov/Programs/State-Water-Project/Delta-Conveyance

Eagleston, H., & Rubin, C. (2013). Non-motorized Winter Recreation Impacts to Snowmelt Erosion, Tronsen Basin, Eastern Cascades, Washington. *Environmental Management*, *51*(1), 167–181. https://doi.org/10.1007/s00267-012-9963-x

Ebrahimi Gatgash, Z., & Sadeghi, S. H. (2024). Comparative effect of conventional and adaptive management approaches on watershed health. *Soil and Tillage Research*, *235*, 105869. https://doi.org/10.1016/j.still.2023.105869

Edwards, P. J., Williard, K. W. J., & Schoonover, J. E. (2015). Fundamentals of Watershed Hydrology. *Journal of Contemporary Water Research & Education*, *154*(1), 3–20. https://doi.org/10.1111/j.1936-704X.2015.03185.x

EPA. (2019, April 10). *Definition of recreational area for determining offsite impacts in RMP* [Overviews and Factsheets]. https://www.epa.gov/rmp/definition-recreational-area-determining-offsite-impacts-rmp

EPA. (2015c). *Urbanization—Overview* [Collections and Lists]. https://www.epa.gov/caddis-vol2/urbanization-overview

EPA, O. (2013, February 22). *Summary of the Clean Water Act* [Overviews and Factsheets]. https://www.epa.gov/laws-regulations/summary-clean-water-act

EPA, O. (2014, November 26). *WATERS (Watershed Assessment, Tracking & Environmental Results System)* [Data and Tools]. https://www.epa.gov/waterdata/waters-watershed-assessment-tracking-environmental-results-system

ESRI. (2023). *Arc Hydro GIS for Water Resources* | *Tools for Watershed Management*. https://www.esri.com/en-us/industries/water-resources/arc-hydro

Fagerholm, N., Eilola, S., & Arki, V. (2021). Outdoor recreation and nature's contribution to well-being in a pandemic situation—Case Turku, Finland.

Urban Forestry & Urban Greening, *64*, 127257. https://doi.org/10.1016/j.ufug.2021.127257

Francis, J. A., Skific, N., Vavrus, S. J., & Cohen, J. (2022). Measuring "Weather Whiplash" Events in North America: A New Large-Scale Regime Approach. *Journal of Geophysical Research: Atmospheres*, *127*(17), e2022JD036717. https://doi.org/10.1029/2022JD036717

Fritz, K. M., Schofield, K. A., Alexander, L. C., McManus, M. G., Golden, H. E., Lane, C. R., Kepner, W. G., LeDuc, S. D., DeMeester, J. E., & Pollard, A. I. (2018). Physical and Chemical Connectivity of Streams and Riparian Wetlands to Downstream Waters: A Synthesis. *JAWRA Journal of the American Water Resources Association*, *54*(2), 323–345. https://doi.org/10.1111/1752-1688.12632

Gatti, M., Garavani, A., Vercesi, A., & Poni, S. (2017). Ground-truthing of remotely sensed within-field variability in a cv. Barbera plot for improving vineyard management. *Australian Journal of Grape and Wine Research*, *23*(3), 399–408. https://doi.org/10.1111/ajgw.12286

Gautam, M. R., Acharya, K., & Stone, M. (2010). Best Management Practices for Stormwater Management in the Desert Southwest. *Journal of Contemporary Water Research & Education*, *146*(1), 39–49. https://doi.org/10.1111/j.1936-704X.2010.00390.x

Gómez-Gener, L., Lupon, A., Laudon, H., & Sponseller, R. A. (2020). Drought alters the biogeochemistry of boreal stream networks. *Nature*

Communications, *11*(1), 1795. https://doi.org/10.1038/s41467-020-15496-2

Gomi, T., Sidle, R. C., & Richardson, J. S. (2002). Understanding Processes and Downstream Linkages of Headwater Systems. *BioScience*, *52*(10), 905. https://doi.org/10.1641/0006-3568(2002)052[0905:UPADLO]2.0.CO;2

Grima, N., Corcoran, W., Hill-James, C., Langton, B., Sommer, H., & Fisher, B. (2020). The importance of urban natural areas and urban ecosystem services during the COVID-19 pandemic. *PLOS ONE*, *15*(12), e0243344. https://doi.org/10.1371/journal.pone.0243344

Haack, S. K., Duris, J. W., Kolpin, D. W., Focazio, M. J., Meyer, M. T., Johnson, H. E., Oster, R. J., & Foreman, W. T. (2016). Contamination with bacterial zoonotic pathogen genes in U.S. streams influenced by varying types of animal agriculture. *Science of The Total Environment*, *563–564*, 340–350. https://doi.org/10.1016/j.scitotenv.2016.04.087

Hawks, E. M., Chad Bolding, M., Michael Aust, W., & Barrett, S. M. (2023). Best Management Practices, Erosion, Residual Woody Biomass, and Soil Disturbances Within Biomass and Conventional Clearcut Harvests in Virginia's Coastal Plain. *Forest Science*, *69*(2), 200–212. https://doi.org/10.1093/forsci/fxac050

He, T., Lu, Y., Cui, Y., Luo, Y., Wang, M., Meng, W., Zhang, K., & Zhao, F. (2015). Detecting gradual and abrupt changes in water quality time series in response to regional payment programs for watershed services in an agricultural area. *Journal of Hydrology*, *525*, 457–471. https://doi.org/10.1016/j.jhydrol.2015.04.005

Heintzman, R., Balling Jr., R. C., & Cerveny, R. S. (2022). Desert Climate Regionalization for Joshua Tree National Park and Surrounding Areas Using New Climate Network Observations. *Journal of Applied Meteorology & Climatology*, *61*(1), 13–23. https://doi.org/10.1175/JAMC-D-21-0061.1

Holden, Z. A., Morgan, P., & Evans, J. S. (2009). A predictive model of burn severity based on 20-year satellite-inferred burn severity data in a large southwestern US wilderness area. *Forest Ecology and Management*, *258*(11), 2399–2406. https://doi.org/10.1016/j.foreco.2009.08.017

Homer, C., Dewitz, J., Jin, S., Xian, G., Costello, C., Danielson, P., Gass, L., Funk, M., Wickham, J., Stehman, S., Auch, R., & Riitters, K. (2020). Conterminous United States land cover change patterns 2001–2016 from the 2016 National Land Cover Database. *ISPRS Journal of Photogrammetry and Remote Sensing*, *162*, 184–199. https://doi.org/10.1016/j.isprsjprs.2020.02.019

Houghton, J. T. (John T. (2001). *Climate change 2001: The scientific basis: Contribution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Hsu, T.-T. D., Yu, D., & Wu, M. (2023). Predicting Fecal Indicator Bacteria Using Spatial Stream Network Models in A Mixed-Land-Use Suburban Watershed in New Jersey, USA. *International Journal of Environmental*

Research and Public Health, *20*(6), 4743. https://doi.org/10.3390/ijerph20064743

IDEXX. (2024). *IDEXX Water Testing Solutions—IDEXX US*. https://www.idexx.com/en/water/

Iwona, M.-P., Natalia, P., & Marcin, P. (2017). Impact of recreation and tourism on selected soil characteristics in the Lisia Góra Nature Reserve area (south-east Poland). *Soil Science Annual*, *68*(2), 81–86. https://doi.org/10.1515/ssa-2017-0009

Kang, J.-H., Lee, S. W., Cho, K. H., Ki, S. J., Cha, S. M., & Kim, J. H. (2010). Linking land-use type and stream water quality using spatial data of fecal indicator bacteria and heavy metals in the Yeongsan river basin. *Water Research*, *44*(14), 4143–4157. https://doi.org/10.1016/j.watres.2010.05.009

Kang, M. G., & Park, S. W. (2015). An Adaptive Watershed Management Assessment Based on Watershed Investigation Data. *Environmental Management*, *55*(5), 1006–1021. https://doi.org/10.1007/s00267-014-0442-4

Karl, T. R., & Trenberth, K. E. (2003). Modern Global Climate Change. *Science*, *302*(5651), 1719–1723. https://doi.org/10.1126/science.1090228

Kearns, F. R., Kelly, M., & Tuxen, K. A. (2003). Everything Happens Somewhere: Using WebGIS as a Tool for Sustainable Natural Resource Management.

Frontiers in Ecology and the Environment, *1*(10), 541–548. JSTOR. https://doi.org/10.2307/3868165

Kidd, K. R., Aust, W. M., & Copenheaver, C. A. (2014). Recreational Stream Crossing Effects on Sediment Delivery and Macroinvertebrates in Southwestern Virginia, USA. *Environmental Management*, *54*(3), 505–516. https://doi.org/10.1007/s00267-014-0328-5

Kiest, K. (2023, January 12). Atmospheric Rivers: What are they and how does NOAA study them? *NOAA Research*. https://research.noaa.gov/2023/01/11/atmospheric-rivers-what-are-they-and-how-does-noaa-study-them/

Kincaid, D. W., Seybold, E. C., Adair, E. C., Bowden, W. B., Perdrial, J. N., Vaughan, M. C. H., & Schroth, A. W. (2020). Land Use and Season Influence Event-Scale Nitrate and Soluble Reactive Phosphorus Exports and Export Stoichiometry from Headwater Catchments. *Water Resources Research*, *56*(10), e2020WR027361. https://doi.org/10.1029/2020WR027361

Kiraz, L., & Thompson, C. (2023). How Much Did Urban Park Use Change under the COVID-19 Pandemic? A Comparative Study of Summertime Park Use in 2019 and 2020 in Edinburgh, Scotland. *International Journal of Environmental Research and Public Health*, *20*(21), 7001. https://doi.org/10.3390/ijerph20217001

Kosmowska, A., Żelazny, M., Małek, S., Siwek, J. P., & Jelonkiewicz, Ł. (2016). Effect of deforestation on stream water chemistry in the Skrzyczne massif (the Beskid Śląski Mountains in southern Poland). *Science of The Total Environment*, *568*, 1044–1053. https://doi.org/10.1016/j.scitotenv.2016.06.123

Kronvang, B., & Bechmann, M. (2015). Agriculture and stream water quality – future challenges for monitoring. *Acta Agriculturae Scandinavica, Section B — Soil & Plant Science*, *65*(sup2), 139–143. https://doi.org/10.1080/09064710.2015.1012321

Kuznetsov, V. A., Ryzhova, I. M., & Stoma, G. V. (2017). Changes in the properties of soils of Moscow forest parks under the impact of high recreation loads. *Eurasian Soil Science*, *50*(10), 1225–1235. https://doi.org/10.1134/S1064229317100052

LACCC. (2023). Economy. *Lake Arrowhead Communities Chamber of Commerce*. https://www.lakearrowheadchamber.com/economy/

Lahsaini, M., Tabyaoui, H., Mounadel, A., Bouderka, N., & Lakhili, F. (2018). Comparison of SRTM and ASTER Derived Digital Elevation Models of Inaouene River Watershed (North, Morocco)—Arc Hydro Modeling. *Journal of Geoscience and Environment Protection*, *6*(9), Article 9. https://doi.org/10.4236/gep.2018.69011

Lamjiri, M. A., Dettinger, M. D., Ralph, F. M., & Guan, B. (2017). Hourly storm characteristics along the U.S. West Coast: Role of atmospheric rivers in extreme precipitation. *Geophysical Research Letters*, *44*(13), 7020–7028. https://doi.org/10.1002/2017GL074193

Landry, C. E., Bergstrom, J., Salazar, J., & Turner, D. (2021). How Has the COVID-19 Pandemic Affected Outdoor Recreation in the U.S.? A Revealed Preference Approach. *Applied Economic Perspectives and Policy*, *43*(1), 443–457. https://doi.org/10.1002/aepp.13119

Lapides, D., Sytsma, A., O'Neil, G., Djokic, D., Nichols, M., & Thompson, S. (2022). Arc Hydro Hillslope and Critical Duration: New tools for hillslope-scale runoff analysis. *Environmental Modelling & Software*, *153*, 105408. https://doi.org/10.1016/j.envsoft.2022.105408

Lassaletta, L., García-Gómez, H., Gimeno, B. S., & Rovira, J. V. (2010). Headwater streams: Neglected ecosystems in the EU Water Framework Directive. Implications for nitrogen pollution control. *Environmental Science & Policy*, *13*(5), 423–433. https://doi.org/10.1016/j.envsci.2010.04.005

Lee, J. G., Selvakumar, A., Alvi, K., Riverson, J., Zhen, J. X., Shoemaker, L., & Lai, F. (2012). A watershed-scale design optimization model for stormwater best management practices. *Environmental Modelling & Software*, *37*, 6–18. https://doi.org/10.1016/j.envsoft.2012.04.011

Lenihan, J. M., Drapek, R., Bachelet, D., & Neilson, R. P. (2003). CLIMATE CHANGE EFFECTS ON VEGETATION DISTRIBUTION, CARBON, AND

FIRE IN CALIFORNIA. *Ecological Applications*, *13*(6), 1667–1681. https://doi.org/10.1890/025295

Li, X., Chen, Z., Wang, L., & Liu, H. (2022). Future projections of extreme temperature events in Southwest China using nine models in CMIP6. *Frontiers in Earth Science*, *10*. https://www.frontiersin.org/articles/10.3389/feart.2022.942781

Li, Z. (2014). Watershed modeling using arc hydro based on DEMs: A case study in Jackpine watershed. *Environmental Systems Research*, *3*(1), 11. https://doi.org/10.1186/2193-2697-3-11

Liddle, M. J., & Scorgie, H. R. A. (1980). The effects of recreation on freshwater plants and animals: A review. *Biological Conservation*, *17*(3), 183–206. https://doi.org/10.1016/0006-3207(80)90055-5

Lines. (1996). *Ground-water and surface-water relations along the Mojave River, southern California*. https://doi.org/10.3133/wri954189

Liu, H., Kong, F., Yin, H., Middel, A., Zheng, X., Huang, J., Xu, H., Wang, D., & Wen, Z. (2021). Impacts of green roofs on water, temperature, and air quality: A bibliometric review. *Building and Environment*, *196*, 107794. https://doi.org/10.1016/j.buildenv.2021.107794

Liu, W., Wei, X., Liu, S., Liu, Y., Fan, H., Zhang, M., Yin, J., & Zhan, M. (2015). How do climate and forest changes affect long-term streamflow dynamics? A case study in the upper reach of Poyang River basin. *Ecohydrology*, *8*(1), 46–57. https://doi.org/10.1002/eco.1486

Lloret, F., & Kitzberger, T. (2018). Historical and event-based bioclimatic suitability predicts regional forest vulnerability to compound effects of severe drought and bark beetle infestation. *Global Change Biology*, *24*(5), 1952–1964. https://doi.org/10.1111/gcb.14039

Loecke, T. D., Burgin, A. J., Riveros-Iregui, D. A., Ward, A. S., Thomas, S. A., Davis, C. A., & St. Clair, M. A. (2017). Weather whiplash in agricultural regions drives deterioration of water quality. *Biogeochemistry*, *133*(1), 7–15.

LRWQCB. (2019). *Beneficial Use changes for the Mojave River watershed and other minor revisions*. https://www.waterboards.ca.gov/rwqcb6/water_issues/programs/basin_plan/docs/mojave_river/drft_rpt_mjve.pdf

LRWQCB. (2023a). *Home Page | Lahontan Regional Water Quality Control Board*. https://www.waterboards.ca.gov/lahontan/

Lucknow, & Kahtoon. (2013). Correlation Study For the Assessment of Water Quality and Its Parameters of Ganga River, Kanpur, Uttar Pradesh, India. *IOSR Journal of Applied Chemistr*, *5*(3), 80–90. https://doi.org/10.9790/5736-0538090

MacDonald, L. H., & Coe, D. (2007). Influence of Headwater Streams on Downstream Reaches in Forested Areas. *Forest Science*, *53*(2), 148–168.

MacKenzie, K., Auger, S., Beitollahpour, S., & Gharabaghi, B. (2024). The Role of Stream Restoration in Mitigating Sediment and Phosphorous Loads in

Urbanizing Watersheds. *Water*, *16*(2), Article 2. https://doi.org/10.3390/w16020363

Mainali, J., & Chang, H. (2021). Environmental and spatial factors affecting surface water quality in a Himalayan watershed, Central Nepal. *Environmental and Sustainability Indicators*, *9*, 100096. https://doi.org/10.1016/j.indic.2020.100096

Mallin, M. A., & Cahoon, L. B. (2003). Industrialized Animal Production: A Major Source of Nutrient and Microbial Pollution to Aquatic Ecosystems. *Population and Environment*, *24*(5), 369–385.

Maret, T. R., MacCoy, D. E., & Carlisle, D. M. (2008). Long-Term Water Quality and Biological Responses to Multiple Best Management Practices in Rock Creek, Idaho1. *JAWRA Journal of the American Water Resources Association*, *44*(5), 1248–1269. https://doi.org/10.1111/j.1752-1688.2008.00221.x

McGuire, L. A., & Youberg, A. M. (2019). Impacts of successive wildfire on soil hydraulic properties: Implications for debris flow hazards and system resilience. *Earth Surface Processes and Landforms*, *44*(11), 2236–2250. https://doi.org/10.1002/esp.4632

Meyer, N., Schafft, M., Wegner, B., Wolter, C., Arlinghaus, R., Venohr, M., & von Oheimb, G. (2021). A day on the shore: Ecological impacts of non-motorised recreational activities in and around inland water bodies.

Journal for Nature Conservation, *64*, 126073. https://doi.org/10.1016/j.jnc.2021.126073

Mojave River Watershed Group. (2014). *Permit Year 1 Annual Report*. https://www.mojaveriver.org/files/managed/Document/174/14-10-15%20MRWG%20Annual%20Report%20Final.pdf

Mojave River Watershed Group. (2024). *What Is The Problem? : Mojave River Watershed Group*. https://www.mojaveriver.org/app_pages/view/209.html

Mojave Water Agency. (2016). *2015 Urban Water Management Plan for Mojave Water Agency*. https://www.mojavewater.org/wp-content/uploads/2022/04/UWMP_Report_Final_Adopted20160609.pdf

Mojave Water Agency. (2023). *Local Sources*. Mojave Water Agency. https://www.mojavewater.org/basin-management/water-supply/local-sources/

MRLC. (2023). *National Land Cover Database Class Legend and Description* | *Multi-Resolution Land Characteristics (MRLC) Consortium*. https://www.mrlc.gov/data/legends/national-land-cover-database-class-legend-and-description

MTBS. (2023). *Home* | *MTBS*. https://www.mtbs.gov/

Mullu, D. (2016). *A Review on the Effect of Habitat Fragmentation on Ecosystem*.

Murphy, S. F., Alpers, C. N., Anderson, C. W., Banta, J. R., Blake, J. M., Carpenter, K. D., Clark, G. D., Clow, D. W., Hempel, L. A., Martin, D. A., Meador, M. R., Mendez, G. O., Mueller-Solger, A. B., Stewart, M. A., Payne, S. E., Peterman, C. L., & Ebel, B. A. (2023). A call for strategic water-quality monitoring to advance assessment and prediction of wildfire impacts on water supplies. *Frontiers in Water*, *5*. https://www.frontiersin.org/articles/10.3389/frwa.2023.1144225

MWD. (2023). *MWD | How We Get Our Water*. https://www.mwdh2o.com/your-water/how-we-get-our-water/

Nadeau, T.-L., & Rains, M. C. (2007). Hydrological Connectivity Between Headwater Streams and Downstream Waters: How Science Can Inform Policy1. *JAWRA Journal of the American Water Resources Association*, *43*(1), 118–133. https://doi.org/10.1111/j.1752-1688.2007.00010.x

Najafi, S., Sadeghi, S. H., & Heckmann, T. (2021). Analysis of sediment accessibility and availability concepts based on sediment connectivity throughout a watershed. *Land Degradation & Development*, *32*(10), 3023–3044. https://doi.org/10.1002/ldr.3964

NASA. (2023, March 17). *Precipitation Piles on in California* [Text.Article]. NASA Earth Observatory. https://earthobservatory.nasa.gov/images/151107/precipitation-piles-on-in-california

NCSU. (2023, May 23). What is a Watershed? *College of Natural Resources News*. https://cnr.ncsu.edu/news/2023/05/what-is-a-watershed/

NEPA. (2020). *NEPA | National Environmental Policy Act*. https://ceq.doe.gov/

NIDIS. (2023). *Drought Basics* | *Drought.gov*. https://www.drought.gov/what-is-drought/drought-basics

NOAA. (2015, July 1). *El Niño and La Niña* | *National Oceanic and Atmospheric Administration*. https://www.noaa.gov/education/resource-collections/weather-atmosphere/el-nino

NOAA. (2020). *Are humans causing or contributing to global warming?* | *NOAA Climate.gov*. http://www.climate.gov/news-features/climate-qa/are-humans-causing-or-contributing-global-warming

NOAA. (2023). *What is La Niña?* | *El Nino Theme Page—A comprehensive Resource*. https://www.pmel.noaa.gov/elnino/what-is-la-nina

NOAA, N. (2022, April 26). *What Is a Watershed?* | *NOAA Fisheries* (New England/Mid-Atlantic). NOAA. https://www.fisheries.noaa.gov/new-england-mid-atlantic/habitat-conservation/what-watershed

OPR. (2023). *California Environmental Quality Act (CEQA) Review*. https://wildlife.ca.gov/Conservation/Environmental-Review/CEQA

Peters, N. E., & Meybeck, M. (2000). Water Quality Degradation Effects on Freshwater Availability: Impacts of Human Activities. *Water International*, *25*(2), 185–193. https://doi.org/10.1080/02508060008686817

Ralph, F. M., Dettinger, M. D., Cairns, M. M., Galarneau, T. J., & Eylander, J. (2018). DEFINING “ATMOSPHERIC RIVER”: How the Glossary of Meteorology Helped Resolve a Debate. *Bulletin of the American*

Meteorological Society, *99*(4), 837–839. https://doi.org/10.1175/BAMS-D-17-0157.1

Ralph, F. M., Neiman, P. J., Wick, G. A., Gutman, S. I., Dettinger, M. D., Cayan, D. R., & White, A. B. (2006). Flooding on California's Russian River: Role of atmospheric rivers. *Geophysical Research Letters*, *33*(13). https://doi.org/10.1029/2006GL026689

Rasmussen, J. J., McKnight, U. S., Loinaz, M. C., Thomsen, N. I., Olsson, M. E., Bjerg, P. L., Binning, P. J., & Kronvang, B. (2013). A catchment scale evaluation of multiple stressor effects in headwater streams. *Science of The Total Environment*, *442*, 420–431. https://doi.org/10.1016/j.scitotenv.2012.10.076

RCRW. (2023). *Santa Ana Watershed and Water Quality*. Riverside-Corona Resource Conservation District. https://www.rcrcd.org/santa-ana-watershed-and-water-quality

Reiter, M., Heffner, J. T., Beech, S., Turner, T., & Bilby, R. E. (2009). Temporal and Spatial Turbidity Patterns Over 30 Years in a Managed Forest of Western Washington1. *JAWRA Journal of the American Water Resources Association*, *45*(3), 793–808. https://doi.org/10.1111/j.1752-1688.2009.00323.x

Riordan, E. C., & Rundel, P. W. (2014). Land Use Compounds Habitat Losses under Projected Climate Change in a Threatened California Ecosystem. *PLOS ONE*, *9*(1), e86487. https://doi.org/10.1371/journal.pone.0086487

Sanecki, G. M., Green, K., Wood, H., & Lindenmayer, D. (2006). The implications of snow-based recreation for small mammals in the subnivean space in south-east Australia. *Biological Conservation*, *129*(4), 511–518. https://doi.org/10.1016/j.biocon.2005.11.018

SAWPA. (2018). OWOW IRWM Plans. *SAWPA - Santa Ana Watershed Project Authority*. https://sawpa.org/owow/owow-irwm-plans/

SBVMWD. (2021). *News and Press Releases* | *San Bernardino Valley Municipal Water District*. https://www.sbvmwd.com/Home/Components/News/News/1229/14

Schafft, M., Nikolaus, R., Matern, S., Radinger, J., Maday, A., Klefoth, T., Wolter, C., & Arlinghaus, R. (2024). Impact of water-based recreation on aquatic and riparian biodiversity of small lakes. *Journal for Nature Conservation*, *78*, 126545. https://doi.org/10.1016/j.jnc.2023.126545

Schafft, M., Wegner, B., Meyer, N., Wolter, C., & Arlinghaus, R. (2021). Ecological impacts of water-based recreational activities on freshwater ecosystems: A global meta-analysis. *Proceedings of the Royal Society B: Biological Sciences*, *288*(1959), 20211623. https://doi.org/10.1098/rspb.2021.1623

Schreiner, V. C., Szöcs, E., Bhowmik, A. K., Vijver, M. G., & Schäfer, R. B. (2016). Pesticide mixtures in streams of several European countries and the USA. *Science of The Total Environment*, *573*, 680–689. https://doi.org/10.1016/j.scitotenv.2016.08.163

Shakesby, R. A. (2011). Post-wildfire soil erosion in the Mediterranean: Review and future research directions. *Earth-Science Reviews*, *105*(3), 71–100. https://doi.org/10.1016/j.earscirev.2011.01.001

Shiklomanov, I. A. (1998). *World water resources: A new appraisal and assessment for the 21st century; 1998*.

SkyPark. (2021). *SkyPark at Santas Village Media Kit*. https://skyparksantasvillage.com/content/uploads/2022/04/SkyPark-at-Santas-Village-Media-Kit-2021.pdf

SkyPark. (2024). Media Kit | SkyPark at Santa's Village—Skyforest, CA. *SkyPark at Santa's Village*. https://skyparksantasvillage.com/media/media-kit/

Smith, H. G., Sheridan, G. J., Lane, P. N. J., Nyman, P., & Haydon, S. (2011). Wildfire effects on water quality in forest catchments: A review with implications for water supply. *Journal of Hydrology*, *396*(1), 170–192. https://doi.org/10.1016/j.jhydrol.2010.10.043

Smucker, N. J., Kuhn, A., Charpentier, M. A., Cruz-Quinones, C. J., Elonen, C. M., Whorley, S. B., Jicha, T. M., Serbst, J. R., Hill, B. H., & Wehr, J. D. (2016). Quantifying Urban Watershed Stressor Gradients and Evaluating How Different Land Cover Datasets Affect Stream Management. *Environmental Management*, *57*(3), 683–695. https://doi.org/10.1007/s00267-015-0629-3

Solomon, S., Intergovernmental Panel on Climate Change, & Intergovernmental Panel on Climate Change (Eds.). (2007). *Climate change 2007: The* *physical science basis: contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.

Sturrock, R. N., Frankel, S. J., Brown, A. V., Hennon, P. E., Kliejunas, J. T., Lewis, K. J., Worrall, J. J., & Woods, A. J. (2011). Climate change and forest diseases. *Plant Pathology*, *60*(1), 133–149. https://doi.org/10.1111/j.1365-3059.2010.02406.x

Sun, F., Berg, N., Hall, A., Schwartz, M., & Walton, D. (2019). Understanding End-of-Century Snowpack Changes Over California's Sierra Nevada. *Geophysical Research Letters*, *46*(2), 933–943. https://doi.org/10.1029/2018GL080362

Swain, D. L., Langenbrunner, B., Neelin, J. D., & Hall, A. (2018). Increasing precipitation volatility in twenty-first-century California. *Nature Climate Change*, *8*(5), 427–433. https://doi.org/10.1038/s41558-018-0140-y

Tefera, A. H. (2017). Characterization of Beles River Basin of Blue Nile sub-Basin in North-Western Ethiopia using Arc-Hydro tools in Arc-GIS. *International Journal of Water Resources and Environmental Engineering*, *9*(5), 113–120. https://doi.org/10.5897/IJWREE2016.0708

Thom, D., Rammer, W., Dirnböck, T., Müller, J., Kobler, J., Katzensteiner, K., Helm, N., & Seidl, R. (2017). The impacts of climate change and disturbance on spatio-temporal trajectories of biodiversity in a temperate forest landscape. *Journal of Applied Ecology*, *54*(1), 28–38. https://doi.org/10.1111/1365-2664.12644

UN. (1992). *UNITED NATIONS FRAMEWORK CONVENTION ON CLIMATE CHANGE*.

Underwood, E. C., Hollander, A. D., Flint, L. E., Flint, A. L., & Safford, H. D. (2018). Climate change impacts on hydrological services in southern California. *Environmental Research Letters*, *13*(12), 124019. https://doi.org/10.1088/1748-9326/aaeb59

USBR. (2013). *Summary Report Santa Ana Watershed Basin Study*. https://www.usbr.gov/watersmart/bsp/docs/finalreport/SantaAnaWatershed/SantaAnaBasinStudySummaryReport.pdf

USDA. (2017, July 31). *Drought*. US Forest Service. https://www.fs.usda.gov/managing-land/sc/drought

USDA. (2024). *San Bernardino National Forest—Recreation*. https://www.fs.usda.gov/recmain/sbnf/recreation

USDA. (2023c). *Management to Improve Forest Resilience and Reduce Wildfire Risk*. https://www.fs.usda.gov/research/understory/management-improve-forest-resilience-and-reduce-wildfire-risk

USDA. (2023a). *San Bernardino National Forest—About the Area*. https://www.fs.usda.gov/wps/portal/fsinternet3/cs/main/sbnf/about-forest/about-area

USDA. (2023b). *Wildfire* | *USDA Climate Hubs*. https://www.climatehubs.usda.gov/taxonomy/term/398

USDC. (2004). *Southern California Wildfires October 20 to November 3, 2003*. https://www.weather.gov/media/publications/assessments/Signed-Wildfire.pdf

USDM. (2023). *What is the USDM?* | *U.S. Drought Monitor*. https://droughtmonitor.unl.edu/About/WhatistheUSDM.aspx

USGS. (1995). *Elevations and Distances*. https://pubs.usgs.gov/gip/Elevations-Distances/elvadist.html

USGS. (2018a). *Impervious Surfaces and Flooding* | *U.S. Geological Survey*. https://www.usgs.gov/special-topics/water-science-school/science/impervious-surfaces-and-flooding

USGS. (2018b). *Runoff: Surface and Overland Water Runoff* | *U.S. Geological Survey*. https://www.usgs.gov/special-topics/water-science-school/science/runoff-surface-and-overland-water-runoff

USGS. (2022). *USGS National Hydrography Dataset Plus High Resolution National Release 1 FileGDB* [dataset]. [object Object]. https://doi.org/10.5066/P9WFOBQI

USGS. (2023). *Wildfires and Water Quality* | *U.S. Geological Survey*. https://www.usgs.gov/centers/california-water-science-center/science/science-topics/wildfires-and-water-quality

Vega, M., Pardo, R., Barrado, E., & Debán, L. (1998). Assessment of seasonal and polluting effects on the quality of river water by exploratory data analysis. *Water Research*, *32*(12), 3581–3592. https://doi.org/10.1016/S0043-1354(98)00138-9

Visit California. (2023). *California Geography Essentials* | *Visit California*. Visit California. https://www.visitcalifornia.com/experience/california-geography-essentials/

Watertalks. (2024). *WaterTalksCA.org – Home of the WaterTalks Program*. https://watertalksca.org/

Weather Underground. (2023a). *About Us* | *Weather Underground*. https://www.wunderground.com/about/our-company

Weather Underground. (2023c). *Personal Weather Station Dashboard* | *Weather Underground*. https://www.wunderground.com/dashboard/pws/KCARUNNI32/graph/2019-10-31/2019-10-31/monthly

Weather Underground. (2023b). *Personal Weather Station Dashboard* | *Weather Underground*. https://www.wunderground.com/dashboard/pws/KCASKYFO2/graph/2020-10-31/2020-10-31/monthly

WEF. (2020b). *Santa Ana River*. WEF. https://www.watereducation.org/aquapedia/santa-ana-river

WEF. (2020a). *Solving Water Challenges in Disadvantaged Communities: A Handbook to Understanding the Issues in California and Best Practices for Engagement*. https://www.watereducation.org/sites/main/files/file-attachments/daci-handbook-ada.pdf

Weston, D. P., You, J., & Lydy, M. J. (2004). Distribution and Toxicity of Sediment-Associated Pesticides in Agriculture-Dominated Water Bodies of California's Central Valley. *Environmental Science & Technology*, *38*(10), 2752–2759. https://doi.org/10.1021/es0352193

Wickham, J., Stehman, S. V., Sorenson, D. G., Gass, L., & Dewitz, J. A. (2023). Thematic accuracy assessment of the NLCD 2019 land cover for the conterminous United States. *GIScience & Remote Sensing*, *60*(1), 2181143. https://doi.org/10.1080/15481603.2023.2181143

WRC. (2024). *Mojave River*. Western Rivers Conservancy. https://www.westernrivers.org/projects/ca/mojave-river

WRCC. (2023). Western Regional Climate Center. https://wrcc.dri.edu

Yang, Y.-Y., Toor, G. S., Wilson, P. C., & Williams, C. F. (2016). Septic systems as hot-spots of pollutants in the environment: Fate and mass balance of micropollutants in septic drainfields. Science of The Total Environment, 566–567, 1535–1544. https://doi.org/10.1016/j.scitotenv.2016.06.043