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Finding Balance in Our Managed Beaches: Policy Recommendations to Mitigate Emergency Sediment Disposal Impacts in Santa Barbara County

A Group Project submitted in partial satisfaction of the requirements for the degree of Master of Environmental Science and Management for the Bren School of Environmental Science & Management

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March 2025

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The Group Project is required of all students in the Master of Environmental Science and Management (MESM) Program. The project is a year-long activity in which small groups of students conduct focused, interdisciplinary research on the scientific, management, and policy dimensions of a specific environmental issue. This Group Project Final Report is authored by MESM students and has been reviewed and approved by:

Patricia Holden	Date

Acknowledgments

This project's success would not have been possible without the generous feedback, collaboration, expertise, and support of numerous individuals and organizations.

<u>Faculty and External Advisors</u>

We would like to thank our faculty advisor, Patricia Holden (UCSB, Bren School), and our external advisors, Andrew Raaf (SB County Flood Control District), and Summer Gray (UCSB, Environmental Studies), for their invaluable feedback and unwavering support throughout our project's development. Their guidance and expertise have been instrumental in guiding our work to success.

<u>Client and Collaborators</u>

We extend our appreciation to our client, Nate Irwin at Santa Barbara Channelkeeper, for their collaborative effort and support of a summer internship position. We would also like to thank Andrew Raaf, Stephanie Meza & Jason Johnston (SB County Environmental Health Services), and Shelby Fredickson (Numeric Solutions) for providing the data that formed our analysis. In addition to this group, we would like to acknowledge the many individuals who generously responded to our questions and offered valuable feedback and suggestions. These include but are not limited to Sarah Anderson (UCSB, Bren School), Christopher Costello (UCSB, Bren School), Heather Hodges (UCSB, Bren School), Karina Johnston (UCSB, Bren School), Nathaniel Grimes (UCSB, Bren School), Ian Walker (UCSB, Geography), Kyle Emery (UCSB, Marine Science Institute), Dan Reed (UCSB, Marine Science Instiitute), Scott Cooper (UCSB, EEMB), Jonathan Warrick (USGS), Alex Simms (UCSB, Earth Science), Lars Seifert (SB County Public Health), Jill Murray (City of Santa Barbara, Sustainability & Resilience), and Milpas Rental. Lastly, our sincere thanks to John Campanella and the James S. Bower Foundation for their generous contribution in support of this project.

<u>Land Acknowledgement</u>

The University campus and study areas are located on indigenous lands, and we acknowledge the Chumash people as the traditional custodians of this land. We recognize the deep history, culture, and enduring presence of the Chumash community and their diligent stewardship of these lands and waters. We encourage local public agencies, organizations, and research institutions to include and prioritize Indigenous perspectives and community needs in preserving, protecting, and managing this region's lands and ecological resources. We pay respect to Chumash Elders, past, present, and future, who carry this place's knowledge, traditions, and stewardship practices, which remain a center of learning for people from around the world.

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I. Project Significance

The topography of the Santa Barbara and Carpinteria landscape is typical to coastal California areas: coastal mountain ranges with steep hillslopes drain watersheds through developed plains and coastal creeks, discharging into the ocean. Rainfall runoff transports sediments downstream in creek channels, creating localized flooding hazards if not managed properly. Debris basins within watersheds are used as intermediate sediment accumulation points along the foothills. When rainfall runoff is excessively high and mountains face increased erosion – for example, after a fire has removed stabilizing vegetation - sediment and boulder transport downstream can exceed debris basin capacity, leading to catastrophic debris flows as occurred in Montecito in 2018.

Figure 1.1. San Ysidro Debris Basin in Montecito, CA

Recent flooding has encouraged the development of new plans around Santa Barbara County to increase flood protection, such as the Montecito Flood Control Master Plan (Santa Barbara Flood Control District, 2024). These plans call for the construction of new debris basins despite growing concern surrounding their long-term environmental impacts, including limiting the movement of habitat-forming sediments and acting as barriers for the passage of steelhead trout. While creek dredging and debris basin clearing are necessary to reduce flood risk, more frequent and intense storm events warrant updated permitting and environmental evaluation of emergency activities to address the near- and long-term impacts of regional debris management. The Santa Barbara Channelkeeper (SBCK) is interested in a comprehensive analysis of the current emergency permits to understand their regulatory difference from routine permits and how the increasing frequency of associated activities may impact ecological and public health at County beaches. Specifically, there is concern surrounding the disposal of upstream sediment at Goleta Beach and Carpinteria City Beach under emergency permit conditions.

The main question addressed in this project is: how should creek and debris basin sediments removed for flood control operations be managed, and is beach disposal a sustainable and equitable option, considering increasing frequency in emergency sediment removal? Our work attends to the natural and social science dimensions of this question and the legal and policy aspects that govern the implementation of wise sediment management in the future.

A current project being proposed within the SB Flood Control District is the BeachSMART program (Santa Barbara County Flood Control District, 2024; County of Santa Barbara, 2024), which aims to create more coordinated sediment management efforts in the County. The program goals include developing multi-benefit projects where both beaches and watersheds can benefit from sediment removal and deposition. Additionally, emerging research has raised concerns about equity in the ongoing use of Goleta Beach and Carpinteria beaches as receiving sites for upper watershed debris during emergency activities (Gray, 2023). The two beach sites have experienced short-term beach closures for public safety as heightened turbidity and fecal indicator bacteria levels are recorded, negatively impacting water quality (County of Santa Barbara Public Health, 2024). Public awareness of this issue may increase as deposition activities become more frequent, leading to disrupted beach access and potential health consequences. Our team's policy recommendations, research, and data analysis can provide guidance toward more equitable approaches to sediment management in the region. This project can also serve as a model for other coastal communities to understand sediment management needs for future urban flood control and beach preservation projects so that ecological and human health are protected.

II. Project Objectives

1. Inform Santa Barbara Channelkeeper and other public agencies in Santa Barbara County of potential impacts from emergency sediment disposal activities on fecal indicator bacteria concentrations at Goleta and Carpinteria beaches.
2. Evaluate the social impact and public perceptions of sediment disposal activities by conducting a beachgoer activity and demographic survey at Goleta and Carpinteria beaches.
3. Recommend potential modifications to permits that guide debris basin clearing and associated beach disposal activities to promote more environmentally and socially equitable emergency sediment disposal activities at Goleta and Carpinteria beaches.

III. Background/Literature Review

Santa Barbara is located on the central coast of California and has a Mediterranean climate characterized by mild, wet winters and warm, dry summers. The city is bordered by the Pacific Ocean to the south and the Santa Ynez Mountains to the north, making it susceptible to climate-related challenges. As a coastal city, Santa Barbara faces direct impacts from global climate change, including rising sea levels, increasing temperatures, and shifts in precipitation patterns, which pose significant risks to its residents, economy, and natural ecosystems (City of Santa Barbara, 2019). These challenges are already visible as sea level rise is accelerating beach loss and flooding in low-lying areas, threatening homes and infrastructure, while wildfires are becoming more frequent due to increased temperatures and prolonged droughts (Environmental Protection Agency, 2025).

The city's most pressing vulnerabilities include coastal erosion, water supply instability, and threats to agriculture. Coastal erosion affects beaches, infrastructure, and tourism, while drought and decreasing rainfall put stress on water systems that rely on groundwater, reservoirs, and desalination. The county has experienced significant climate-related impacts in recent years, for example, the 2017 Thomas fire burned over 281,893 acres in Santa Barbara and was followed by a deadly debris flow in Montecito in early 2018 (California State Firefighters' Association, 2024). Erosion at Goleta Beach has increased, prompting regular beach nourishment projects to maintain recreational access and infrastructure protections. These events highlight the importance of the need for coordinated proactive resilience strategies.

At the same time, responses to these challenges raise complex trade-offs. While seawalls and other hard infrastructure offer immediate protection, they often accelerate erosion elsewhere and reduce beach width over time (European Environment Agency, 2023). In contrast, nature-based solutions offer a sustainable and adaptive form of long-term protection but they require significant planning, public engagement, and adequate funding to implement effectively. As communities implement and explore options as a response to climate change impacts, it is essential to prioritize equity, as lower-income communities may have fewer resources to adapt or relocate in response to climate change-related threats.

Flood Control Operations

The primary objective of the Santa Barbara County Flood Control and Water Conservation District (SBCFCD) is to provide "flood protection and to conserve flood and surface waters for beneficial public use" (Santa Barbara County Flood Control District, n.d.). The agency is responsible for designing, constructing, and overseeing the upkeep of flood control systems in the County's active flood control zones. These systems include debris basins designed to capture sediment, rocks, vegetation, and inorganic material traveling through the watershed during wet weather events (Willardson, 2020). Regular clearing of debris basins protects infrastructure, property, and community residents located downstream from significant damage during heavy rain and flooding. Historically, the accumulated debris in the basins has been routinely disposed of by SBCFCD and placed in the upland locations of Buellton, Santa Paula, the Foothill Landfill, and other County locations. Dredged sediment from emergency debris basin clearing and other sediment management operations throughout the county has been placed at Goleta Beach County Park and Carpinteria Beach (Robertson, 2018). While dredging operations and debris basin clearing are necessary to reduce flood risk, more frequent and intense storms may warrant a review of permits overseeing routine and emergency maintenance to account for and address the near and long-term environmental and social impacts of regional debris management.

Starting in 1994, routine dredging of the Goleta Slough began as part of the corresponding Goleta Slough Management Program (Battalio et al., 2015). The SBCFCD utilizes the removed sediment for beach nourishment at Goleta Beach. In response to the devastating Montecito debris flows in 2018, SBCFCD pursued emergency permits from several agencies that sanctioned the prompt removal of debris basin material from the Montecito and Carpinteria area watersheds. The post-flood/debris flow emergency response project received authorization to dispose of sediment cleared from creeks and debris basins at Goleta Beach County Park and Carpinteria Beach (Robertson, 2018). Most recently in 2023, SBCFCD secured emergency permits again to undertake the debris removal and transportation to the same beaches aforementioned. Rising concern about the increasing need for emergency permits brings into question the viability of continuing to operate under the current permits. Regular permitting should be updated to account for weather patterns altered increasingly by climate change, and to allow SBCFCD to conduct maintenance activities by incorporating the appropriate regulations on less stringent activities that emergency permits would allow. Further implications of emergency permits entail the rapid and large movement of sediment volume to the beaches designated as disposal sites. Unlike routine maintenance permits, which typically have a longer time limit, emergency permits grant 180 days for the permittee to complete their project, which could pose challenges for maintaining efficient monitoring practices during the movement of sediments. Sediment disposal has led to short-term beach closures for public safety as elevated turbidity and fecal indicator bacteria levels are recorded, negatively impacting water quality (Santa Barbara Public Health Department, 2018). Long-term ecological impacts are also of concern where studies have shown that sediment deposition may impair coastal ecosystems by reducing species richness, abundance, and biodiversity of intertidal organisms (Manning et al., 2014; Peterson et al., 2014; Schooler et al., 2019; Wooldridge et al., 2016).

Permitting

SBCFCD operates under a series of permits to conduct emergency and routine flood control activities. The permits are granted by various federal, state, and local agencies. The United States Army Corps of Engineers (USACE) grants both routine and emergency permits. SBCFCD conducts routine maintenance activities under the USACE Department of the

Army Permit program for “Santa Barbara Flood Control Routine Maintenance and Goleta Slough Dredging Activities.” This permitted project encompasses a Debris Basin Maintenance Plan, an Annual Stream Maintenance Plan, and the Goleta Slough Dredging Project (U.S. Army Corps of Engineers, n.d.). Complementing the routine maintenance, SBCFCD performs activities in accordance with “Regional General Permit No. 63,” which allows the county to proceed with necessary repair and protection activities during emergency events (U.S. Army Corps of Engineers, 2013).

In emergency situations such as intense fire, flooding, or debris flows, conditions under the Regional General Permit (RGP) 63 govern the emergency repair and protection activities that may impact the receiving waters within Santa Barbara County. RGP 63 identifies debris basin clearing as one of these activities: “permanent or temporary discharge of dredged and/or fill material into waters… include but are not limited to: … clearing of accumulated sediment and debris from sediment, retention, detention, or debris basins…” (State Water Resources Control Board, 2023). The USACE determines the situation is an “emergency” following their definition where “there is a clear, sudden, unexpected, and imminent threat to life or property demanding immediate action to prevent or mitigate loss of, or damage to, life, health, property or essential public services (State Water Resources Control Board, 2023). Emergency debris basin clearings consequently raise the need for discharge and disposal of the dredged materials, which requires a Water Quality Certification from the State Water Resources Control Board (SWRCB). USACE is required to submit an application for a certification due to the activities that will result in sediment disposal affecting U.S. navigable waters, triggering Section 401 of the Clean Water Act (Environmental Protection Agency, 2023.). To stay in compliance with the regulations, USACE has adopted the water quality conditions outlined in the certification within permit 63. The conditions include the timeline of emergency repair start date and days of completion, construction conditions, mitigation conditions, and water quality monitoring. Within the conditions, repairs must be kept to a minimum and if minor upgrades are to be included in the project plan, they may be authorized in the Notice of Applicability (NOA) if the enrollee uses bioengineered, biotechnical, or other environmentally sensitive solutions (State Water Resources Control Board, 2023). Section 401 water quality certification provides SBCFC an exemption that allows them to discharge into waters of the United States, such as Goleta Beach. For example, the emergency response project to the 2018 Montecito flooding and debris flows mandated sediment disposal of up to 420,000 cubic yards from creeks, roads, and debris basins. The accumulated sediment was disposed of at Goleta Beach and Carpinteria Beach. The issued 2018 Certification detailed monitoring and reporting requirements as the dredged material was placed on the named beaches (Robertson, 2018).

Goleta Beach lies within a coastal zone, putting it under the jurisdiction of the California Coastal Commission (CCC) and introducing another agency into the permitting framework as SBCFC operations involve this location (Battalio et al., 2015). The CCC oversees the enforcement of the California Coastal Act of 1976, one of the statutory regulations that establishes the guidelines for SBCFC’s maintenance activities including dredging, beach nourishment, and beach raking in Santa Barbara’s designated Coastal Zone. The Coastal Commission has “original permit jurisdiction” over the beach and other creeks within the boundaries, and SBCFC is obligated to seek permission from the state agency before conducting any development activities, including sediment disposal. This is granted as a Coastal Development Permit and authorizes the county's annual desilting program for creeks within Santa Barbara (California Coastal Commission, 2021). The routine desilting is an important maintenance activity by SBCFCD in limiting sediment accumulation and lowering risk of life and property damage to the surrounding residential communities. As aforementioned, emergency situations can arise during extreme storm events, bringing about flooding and debris flows that will require another agency exemption. The CCC will issue an Emergency Coastal Development Permit Waiver for SBCFC to undertake the necessary emergency actions. In 2023, this waiver was granted as intense winter storms resulted in the buildup of sediment in creeks and debris basins. The quantity of sediment was significant enough to sanction proposed emergency action to move about 250,000 cubic yards of beach-compatible sediment to be deposited in the surf zones of Goleta Beach and Carpinteria Beach (South Central Coast District Staff, 2023).

The Beach Erosion Authority for Clean Oceans and Nourishment (BEACON) is a California Joint Powers Agency that has a role in permitting beach nourishment projects to address coastal erosion (BEACON, n.d.). As a member agency of BEACON, Santa Barbara County takes part in the Coastal Regional Sediment Management Plan: Central Coast from Point Conception to Point Mugu (CRSMP). This plan designated five beaches across Santa Barbara and Ventura County as sites to receive "beach-compatible sediments" from debris basins when approved by regulatory agencies. However, the 2023 Santa Barbara Multi-Jurisdictional Hazard Mitigation Plan notes that "it is unclear to what extent if any [beach nourishment] would slow or offset such sea level rise induced accelerated erosion"(County of Santa Barbara, 2023). Therefore, it is important to examine further scientific literature regarding sediment size and composition when making future informed policy recommendations regarding beach nourishment using creek and debris basin sediments.

Emergency Sediment Disposal Beach Sites

Goleta Beach County Park and Carpinteria City Beach are the two beaches used for emergency sediment disposal activities. They are among the most popular beaches in Santa Barbara County, with Carpinteria being the most visited beach, making the beaches significant contributors to the local economies (Beach Erosion Authority for Clean Oceans and Nourishment, 2009). In addition to economic considerations, the County identifies these sites to be ideal for disposal due to the accessibility for large sediment trucks, provided by the wide roads nearby (County of Santa Barbara, n.d.)

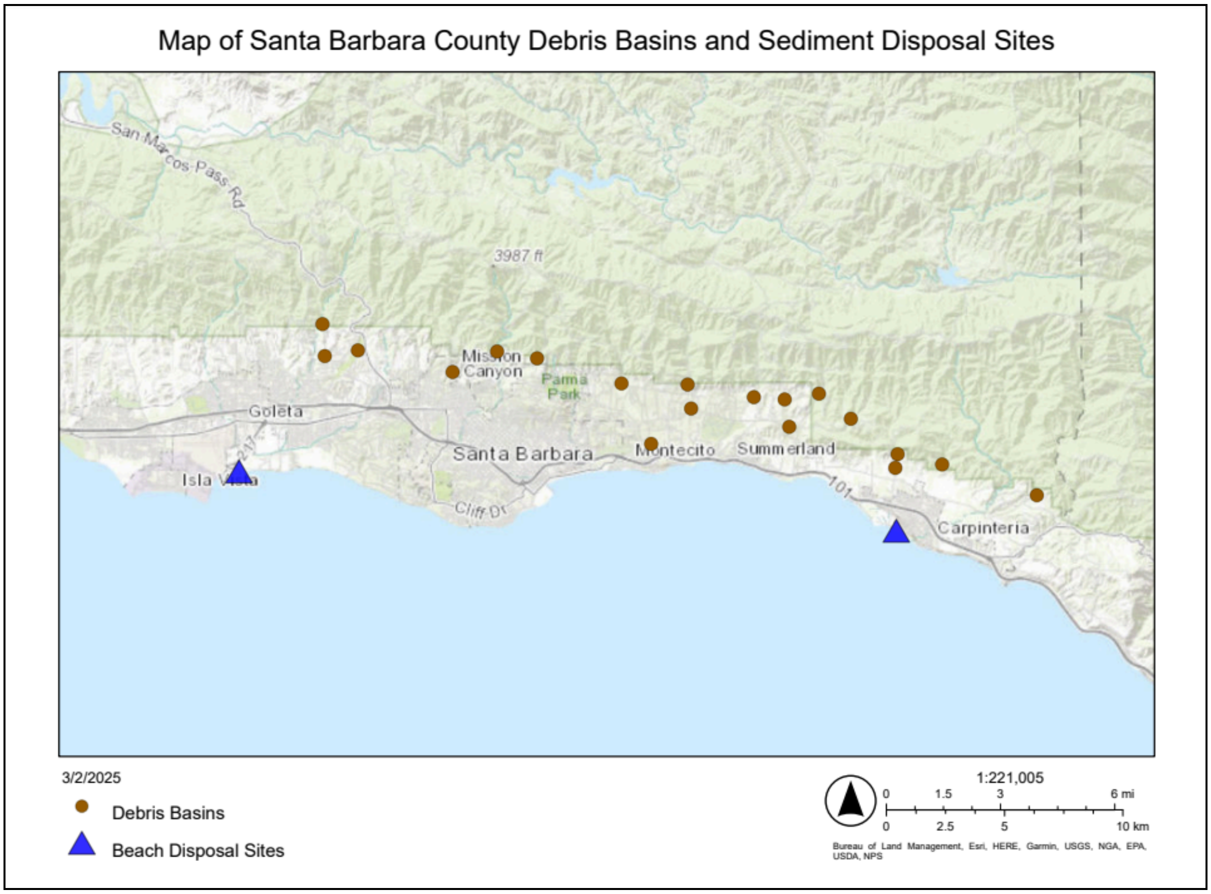


Figure 3.1. Map of Santa Barbara County Debris Basin sites (brown) and the two beach sites, Goleta and Carpinteria Beach, used for sediment disposal (blue). Location data from SBCFCD.

Disposal Site 1: Goleta Beach County Park

Goleta Beach lies adjacent to the University of California, Santa Barbara Campus off Sandspit Rd. This park boasts diverse amenities with grills, a restaurant, a fishing pier, a playground, and grassy picnic lawns (Beach Erosion Authority for Clean Oceans and Nourishment, 2009). Free parking is available for visitors from sunrise to sunset, and walking and biking trails are accessible at all hours. Fishing is among the most popular activities since no license is required at Goleta Pier. Sediment disposal at Goleta Beach occurs routinely following routine dredging from the Goleta Slough and its tributaries. In cases of emergency disposal, sediment sources include managed debris basin sites throughout the County (Figure 3.1). Goleta Beach's perimeter is 2,236 meters, as indicated by the yellow line in Figure 3.2.

Figure 3.2. Goleta Beach's length from West to East, about 2,236 meters, measured using Google Earth.

Disposal Site 2: Carpinteria City Beach

Carpinteria City Beach and Carpinteria State Beach lie between Ash Avenue and Palm Avenue in Carpinteria, California. The sandy beaches are connected, although sediment disposal occurs at the northern end of the city beach at Ash Avenue. This beach is considered one of the safest along the Central Coast, making it a popular destination for families with young children and campers (Beach Erosion Authority for Clean Oceans and Nourishment, 2009). The State beach is a popular surf spot, hosting annual surf competitions for local youth in the Winter months. Carpinteria is quite long, with a beach perimeter of about 1,908 meters across the State and City beach (indicated by the yellow line, Figure 3.3). Carpinteria beachgoer activity was noted by survey researchers to be spatially spread across the length of the beach more homogeneously than Goleta Beach.

Figure 3.3. Carpinteria Beach's length from West to East, about 1,908 meters, measured using Google Earth.

Environmental Implications of Current Sediment Management

Sediment Transport

Sediment loads in small coastal creeks that have been altered by debris basins have been examined in the past (Barnard et al. 2009, Sherman et al. 2002). However, little is known about the variation of sediment loads in relation to discharge magnitude and frequency (Warrick et al. 2015). Understanding how sediment loads are influenced by different precipitation levels can help clarify the role of debris basins in creek sediment transport and anticipated changes in creek morphology.

Debris basins can fundamentally alter sediment transport to the littoral cell by intercepting and capturing materials that would naturally flow downstream (Forgiarini et al., 2011; Fryirs, 2013; Patch & Griggs, 2007). This interruption creates a disconnection between upland erosional processes and coastal sediment supplies, potentially leading to beach erosion and habitat modification in downstream environments (Barnard et al., 2009). Further research is needed to quantify the precise volume of sediment retained by these structures in Santa Barbara and its potential contribution to coastal systems if allowed to flow naturally.

Coastal currents along the beach move primarily in a southerly direction according to seasonal patterns, though variations occur based on storm events and seasonal wave dynamics (Stevens et al., 2024). Studies by Li et al. (2020) indicate that bacterial sequences from intestinal sources found in surf zone waters showed genetic similarities with those present in both deposited sediments and sewage effluent due to association to sediment particles, distributing materials along the coastline and beyond the source area (Li et al., 2020). This transport mechanism represents a critical component of the coastal sediment budget that must be considered when evaluating sediment management practices.

Sediment quantity varies significantly based on different environmental events. Post-fire conditions typically yield higher volumes of fine-grained sediments due to reduced vegetation coverage and increased surface erosion (Florsheim et al., 2017). Flood events, particularly following extended dry periods, can transport coarser materials and larger volumes overall (Pranzini et al., 2013). These variations in sediment characteristics and quantities have different implications for both debris basin management and downstream coastal environments.

Through a visual observation method, the team inspected sediment load changes within San Ysidro Creek. Over 2000 creek bed photographs taken from a game camera supplied by Montecito Water District were used to measure changes in creek bed levels. It was determined that approximately 1.3 inches of rainfall was the minimum amount of rainfall that would trigger a noticeable change in creek bed levels. This approach provided a direct, visual assessment of how precipitation influences creek bed morphology. Although the scope of this project evolved, rendering this initial analysis inapplicable to our final objectives, the results are included in this report for reference and potential justification for subsequent research or related projects.

Sediment Quality

Sediment quality data was provided by Santa Barbara County Flood Control for 2010, 2018, 2020, and 2023 from various locations, including local debris basins, Goleta Beach, and Carpinteria Beach. Based on the Water Quality Control Plan for Enclosed Bays and Estuaries of California Sediment Quality Provisions, total metal disturbances are divided into four categories: reference (category 1), low disturbance (category 2), moderate disturbance (category 3), and high disturbance (category 4) (Beegan & Faick, 2018). The reference category suggests that a community is generally unaffected. The low disturbance category is considered to mean that a community may show an indication of stress, but it could be within measurement error of unaffected conditions. Moderate disturbance suggests confidence that a community shows evidence of physical, chemical, natural, or anthropogenic stress. High disturbance considers that the magnitude of stress is high.

The sediment sample data included total metals, such as copper, lead, mercury, and zinc. They were compared to the disturbance categories defined in the Sediment Quality Provisions Plan. All samples taken stayed in category 1 and 2 disturbance levels for the dates Santa Barbara County Flood Control provided us. Arsenic was found at very low levels, between 1-4 mg/kg. It is important to note that California does not have specific numeric sediment quality standards for most chemicals, including arsenic. Instead, the Sediment Quality Objectives (SQO) approach provides a framework for assessment rather than strict numeric criteria to account for variability in characteristics between sites and allow for discretion by region. The goal is to maintain ecological and human health, define indicators of sediment quality, outline monitoring programs, and describe actions to be taken if an objective is not met (Beegan & Faick, 2018).

The Emergency Coastal Development Permit Waiver, issued under Section 30611 of the California Coastal Act, allows for expedited action during emergencies to protect public safety and property. As outlined in the January 26, 2023, report by the California Coastal Commission, this waiver includes specific guidelines for sediment deposition during emergency beach operations. Sediment brought to the beach must not exceed 25% fine material, defined as particles passing through a U.S. Sieve #200 or smaller. The averages of fine sediment between all samples for each year were below 25% for all years except 2018 and 2023, which had major storm events. There is a wide range of fine percentages by sample per year, as sediment is heterogeneous, even when it comes from the same source. For example, samples had a range of 4-13% fines in 2010, 13-78% in 2018, 13-61% in 2020, and 1-69% in 2023.

However, slightly larger grain sizes such as those passing through sieves #170 or #120 are not restricted by percentage under this waiver. Additionally, there are no limits on the quantity of large rocks or boulders deposited during emergency operations, even though such materials can significantly alter sandy beach environments by bringing in artificial Coastal boulder deposits (CBD) (Cox et al., 2019; Oak, 2022). Operations have provided Goleta Beach with a variety of larger sediment sizes, as seen in Figure 3.4.

Figure 3.4. Goleta Beach emergency operations on January 28th, 2023. Provided by Santa Barbara County Flood Control District.

Boulders deposited on beaches can reduce the width of the back beach, which is critical for buffering wave energy and providing habitat for coastal species (Angnuureng et al., 2023). Large, hard structures like barriers or boulders can also lead to a narrowing of the beach profile over time, reducing its ability to absorb wave energy and increasing vulnerability to storm surges and sea-level rise (Pollard et al., 2022). Large non-native sized structures can also interfere with longshore sediment transport, a key process that redistributes sand along the coastline (Nawarat et al., 2024). This disruption can create sediment imbalances and localized downdrift erosion (Sanitwong-Na-Ayutthaya et al., 2023).

Grain size was also identified as a critical factor influencing steelhead trout (*Oncorhynchus mykiss*) spawning success. Fine sediments about 1 mm in diameter have been thought to clog interstitial spaces in gravel beds, reducing permeability and oxygen availability essential for egg survival (Kondolf, 2000; National Marine Fisheries Service, 2014; Wildfish, 2017). Excess fine sediment deposition has been linked to reduced egg survival rates and delayed fry emergence, posing significant risks to steelhead populations (Nicol et al., 2015; Reiser & White, 1988; Suttle et al., 2004). Additionally, there are ecological concerns from altered transport of habitat-forming sediment caused by debris basins in Santa Barbara coastal creeks, some of which have been identified as critical steelhead habitats (National Marine Fisheries Service, 2014).

Filter feeders, such as bivalves and other suspension-feeding organisms, are highly susceptible to increased suspended sediment concentrations. The clogging of their feeding structures by fine sediment particles interfered with their ability to extract food from the water column, leading to reductions in growth and overall condition (Manning et al., 2014). These impacts are particularly pronounced in environments experiencing high sediment deposition rates, where filter feeders faced both immediate physical stress and longer-term ecological consequences (Pineda et al., 2017).

Emergency sediment deposition may also have impacts on kelp population abundance (*Macrocystis pyrifera*). Kelp has critical ecological functions, including being a habitat-forming species, filtering pollutants, producing oxygen for the water column, and potentially influencing coastal dynamics depending on the system (Elsmore et al., 2024; Le et al., 2022; Miller et al., 2018). Existing research suggests that sedimentation can negatively impact kelp, particularly in its spore attachment and reproduction processes (Devinny & Volse, 1978; Geange et al., 2014). Since kelp has short lifespans, around 1 year long, and reproduce the most in the winter months, emergency sediment deposition could have a long-term effect on kelp abundance off of Goleta Beach (Gibson et al., 2007; Van Tussenbroek, 1989). This can have impacts on community composition and availability of fish for pier fishermen. To quantify the ecological impacts of emergency sediment deposition, future research could be done focus on kelp (*Macrocystis pyrifera*) as an indicator of ecosystem health. The study could utilize KelpWatch data, a collaborative remote sensing project involving UCSB, UCLA, Woods Hole Oceanographic Institution, NASA, and the Nature Conservancy. This comprehensive dataset provides quarterly kelp coverage measurements from 1984 – 2024 using Landsat satellite imagery, with 30m resolution pixels. The data allows for analysis of kelp canopy area, enabling comparison of kelp abundance before and after sediment disposal events. Additionally, Santa Barbara Coastal Long-Term Ecological Research (SB LTER) offers valuable time-series data on giant kelp forest communities within Santa Barbara County. Maintained by the University of California, Santa Barbara, the data catalog provides ongoing ecological monitoring, including two transects located offshore of Goleta Beach since 2001. These long-term datasets include 8-9 transects of 40m surveyed annually, offering a consistent, robust look at kelp ecosystem dynamics over time. While the transect data doesn't capture subsurface kelp characteristics, it provides validation for satellite imagery and offers nuanced ecological insights not captured by remote sensing alone. Key research questions could include assessing kelp coverage and density as a method to quantify long-term sediment disposal impacts. Satellite data would be helpful in identifying overall canopy abundance patterns due to factors other than sediment disposal, such as ocean currents, sea surface temperatures, nutrient availability, and storm patterns. The methodology should employ a Before-After Control-Impact Paired Series (BACIPS) approach, comparing kelp canopy areas at impacted sites like Goleta and Carpinteria Beach with control locations to detect potential sedimentation effects (Thiault et al., 2017). To go one step further, an in-situ experiment could be done by first locating the average plume direction and area covered. The researcher could then place blocks along the pipe leading from the Goleta Sanitary District's Wastewater Treatment plant to offshore, ensuring similar nutrients and temperature of the local water. The spore abundance attached to the blocks within and outside the treatment area along the plume's path could be monitored over time to determine if turbidity of the water limited the amount of sunlight and significantly impacted the number of viable kelp spores.

There are also the immediate physical impacts of sediment deposition, which include smothering of benthic organisms and habitat alteration. Excessive sediment accumulation has been observed to reduce light penetration, impair photosynthetic organisms such as algae and seagrasses, and disrupt benthic habitats critical for various marine species (Magris & Ban, 2019). In severe cases, sediment deposition can lead to the burial of organisms, which would cause suffocation and ecosystem-level disruptions (Byers & Grabowski, 2013). These changes can affect not only individual species but also the broader food web dynamics.

These impacts could have consequences on community composition near the deposition sites or have other rippling effects on ecological systems, beach erosion vulnerability, or fish availability for subsistence fishers. In-situ experiments would need to be conducted to indicate causality.

Social Implications of Sediment Disposal on Beaches

Nationally, little is known about the demographic behaviors, characteristics, and health risks of beachgoers (Collier et al., 2015). This project aims to better understand the social impact of sediment deposition operations at Goleta and Carpinteria beaches, and how the general public is affected. By conducting a beachgoer activity and demographic survey at Goleta and Carpinteria beaches, the interests and needs of beachgoers in relation to the effects of sediment deposition are assessed. Beach use during the coronavirus pandemic proved to be a haven of safety for many people, leading to unprecedented economic return (Houston, 2024). For every $1 spent on beach nourishment throughout the U.S., beachgoers generate ~$3,000 in economic output, ~$1,400 in direct spending, and ~$200 in taxes (Houston, 2024). While sediment deposition may provide economic benefits, it is important to use the best possible science to promote a beneficial balance between socioeconomic impacts as well as the ecological health of public beaches. Generally, people seek out safe and healthy beaches as a refuge for physical and mental health (Severin et al., 2022). Current demographic knowledge can inform better recommendations to Santa Barbara County around efforts to protect water quality and improve the health and safety of beach visitors.

It is important to address the concerns of beach users to inform coastal management decisions that balance the protection of beach ecosystems and user demands (Dodds & Holmes, 2019; Lucrezi & van der Walt, 2016). This project aims to assess the relationships between the effects of sediment deposition and beach use activities to identify activity groups that may benefit versus those that may be disadvantaged from sediment deposition.

Fecal Indicator Bacteria Monitoring

Assembly Bill 411 (AB411) was enacted in 1999 to protect public health at California's beaches, which were identified as critical recreational resources that attracted more than 150 million visitors annually and generated in excess of $10 billion in revenue (Monterey Bay National Marine Sanctuary, n.d.). Under this legislation, weekly bacterial testing was mandated between April 1 and October 31 at public beaches that received more than 50,000 annual visitors and were situated near storm drains that flowed during summer months. This timeframe was formally designated as the AB411 monitoring period, during which systematic and consistent water quality data was collected (California State Water Resources Control Board, 2025).

The bacterial standards established under AB411 were selected because the monitored bacteria chosen (total coliform, fecal coliform, enterococcus, and *E. coli*) were recognized as indicators of possible water contamination with organisms that could cause a spectrum of health impacts (Beachapedia, 2021). These potential health effects were documented to range from mild symptoms such as fever and flu-like conditions to more severe illnesses including respiratory infections, gastroenteritis, and hepatitis. Direct identification of actual pathogens in ocean water was considered expensive and time consuming, which justified the use of these indicator bacteria instead (Monterey Bay National Marine Sanctuary, n.d.).

In 2011, the responsibility for implementing AB411 was transferred from the California Department of Public Health to the State Water Resources Control Board through Senate Bill 482 (Beach Safety Program), maintaining the same monitoring requirements and bacterial standards. Monitoring by Santa Barbara County has been supplemented by Santa Barbara Channelkeeper, including in non-AB411 periods (Santa Barbara Channelkeeper, n.d.) Visual locations of AB411 sampling sites for Goleta and Carpinteria Beach can be found in figures 3.5-3.6.

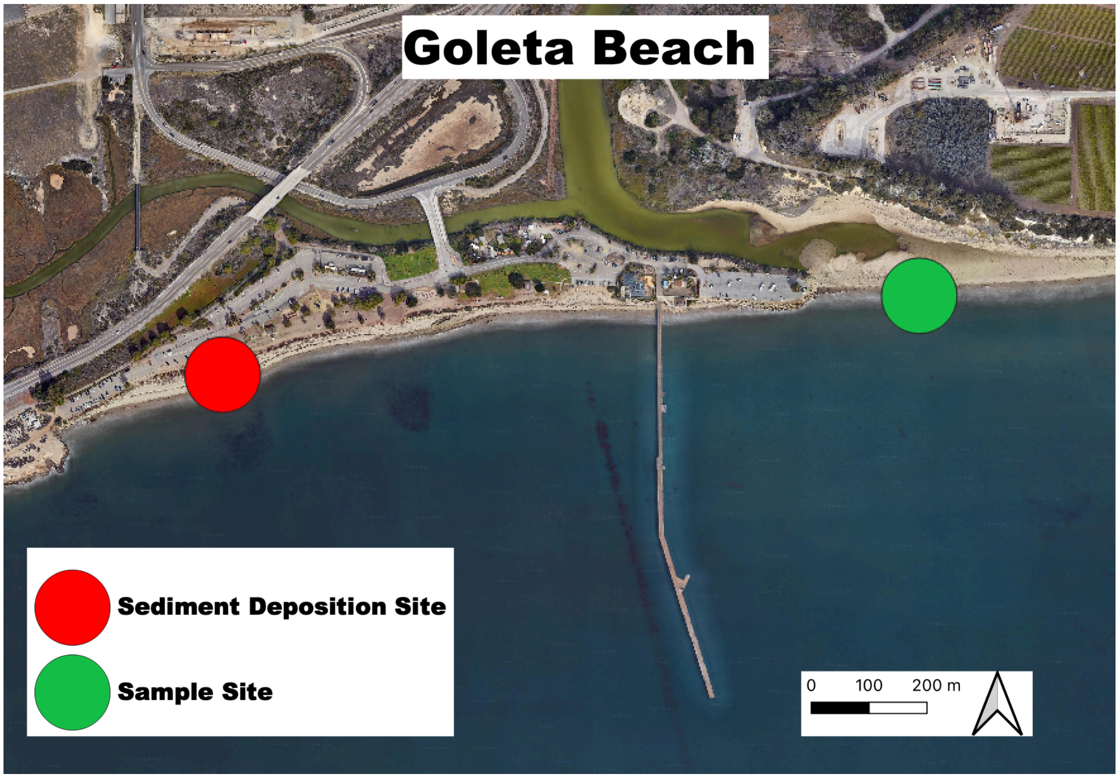


Figure 3.5. Goleta Beach AB411 site (green) and sediment deposition site (red).

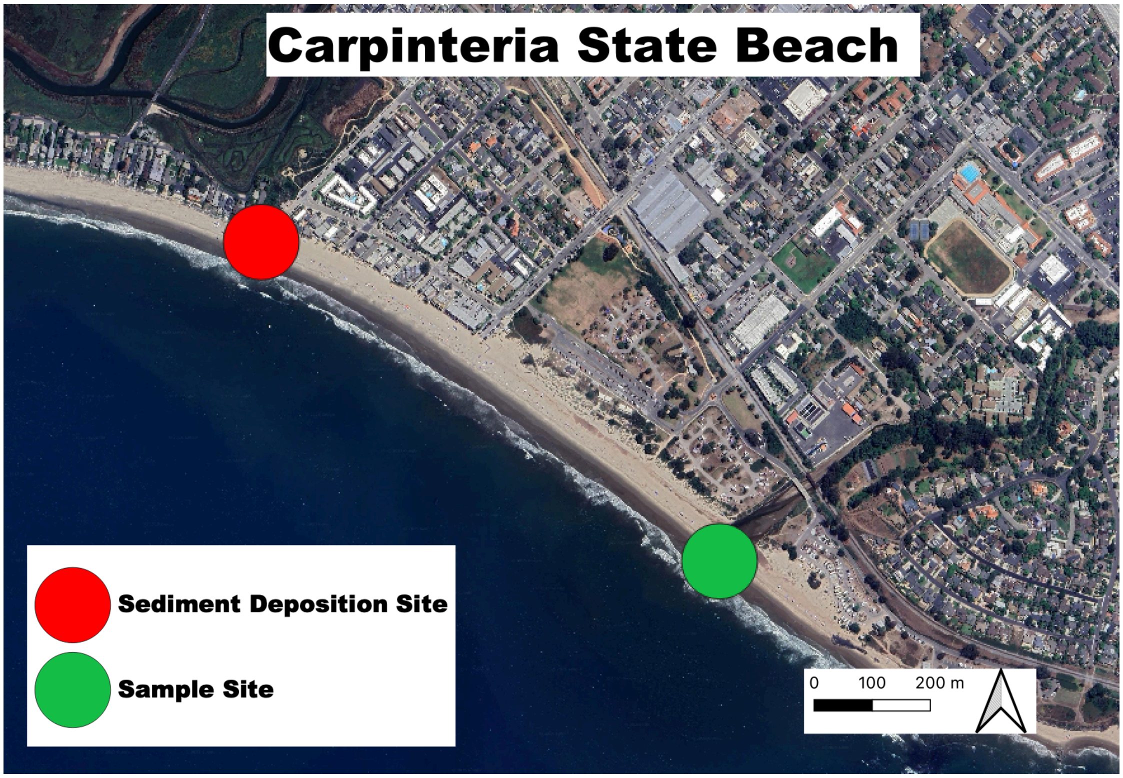


Figure 3.6. Carpinteria State Beach AB411 site (green) and sediment deposition site at the end of Ash Avenue (red).

Sediment Deposition Impact on Fecal Coliform Concentrations and Associated Beach Closures

Investigation of the beach nourishment process and application at beaches in SB County will improve an understanding of the ecological, biological, and physicochemical impacts of current sediment management on the marine environment and impacts on the beach going community due to debris relocation at Goleta Beach and Carpinteria Beach. Understanding how the water quality on a microbial and toxicological scale is affected by sediment deposition will help address potential health impacts on beachgoers as well as any species listed in the Endangered Species Act (ESA) not protected by current permitting practices.

Looking at the effectiveness of beach nourishment to address short- and long-term bacteria presence based on health concerns from published research will help create recommendations to better serve the health of the community as well as the longevity of our coastal zones. Fecal indicator bacteria (FIB) are found in animal and human waste and are highly correlated with gastrointestinal illness and infection (Rippy et al., 2013). FIB consists of total coliform, fecal coliform, *Escherichia coli*, and enterococci (Li et al., 2020) and is an ongoing issue in coastal waters used for recreation and fishing. FIB can survive in beach sand in a resilient fashion on seasonal timescales (Fuhrman et al., 2015; Whitman et al., 2014). Increased bacterial presence leads to an increased impact of risk on the ecological health and safety of our beaches. The introduction of large amounts of foreign, and perhaps contaminated, sand at Goleta and Carpinteria beaches during deposition operations may increase bacterial presence in coastal waters.

California has set health standards for FIB concentrations that include four criteria (CA State Water Resources Control Board, 2018):

- 1,000 total coliform bacteria per 100 milliliters if the ratio of fecal/total coliform bacteria exceeds 0.1; or
- 10,000 total coliform bacteria per 100 milliliters
- 400 fecal coliform/*E. coli* bacteria per 100 milliliters
- 104 enterococcus bacteria per 100 milliliters.

The California State Water Resources Control Board passed the AB411 bill in 1997, mandating local agencies to conduct weekly ocean water monitoring at state beaches between April 1 and October 31 each year (CA State Water Resources Control Board, 2025). Agencies must issue beach advisories to notify the public about a risk of illness if FIB concentrations exceed at least one of the criteria thresholds (Surfrider Foundation, 2021). Santa Barbara County conducts weekly water monitoring tests in accordance with AB411 at Goleta and Carpinteria Beach year-round (County of Santa Barbara Public Health, 2025).

In 2018, large amounts of contaminated debris flow sediments were brought from the aftermath of the January 9th Montecito debris flow and deposited at Goleta Beach with the intention of beach nourishment. As a result, there was an immediate excess in microbiological water quality disturbances; human fecal bacteria were detected in ~24% of Goleta beach samples, up from 0% the year prior (Li et al, 2022). This led to advisories and closures lasting over 200 days (Figure 3.7) and raised concerns about how sediment deposition locations may impact beachgoers at one of the counties most popular beaches. Typically, fine sediment (<63 um) associates well with FIB such as enterococcus (Rippy, 2013). Research has suggested that no more than 20% of relocated sediments deposited should consist of sediment fines, unless the grain size matches the deposition site (Rippy, 2013). While surf zone dilution typically inactivates ~60% of FIB within hours to weeks, beach wrack and sands can potentially harbor FIB to the extent of environmental regrowth, contaminating the beach many months later through storm-associated sediment resuspension (Rippy, 2013).

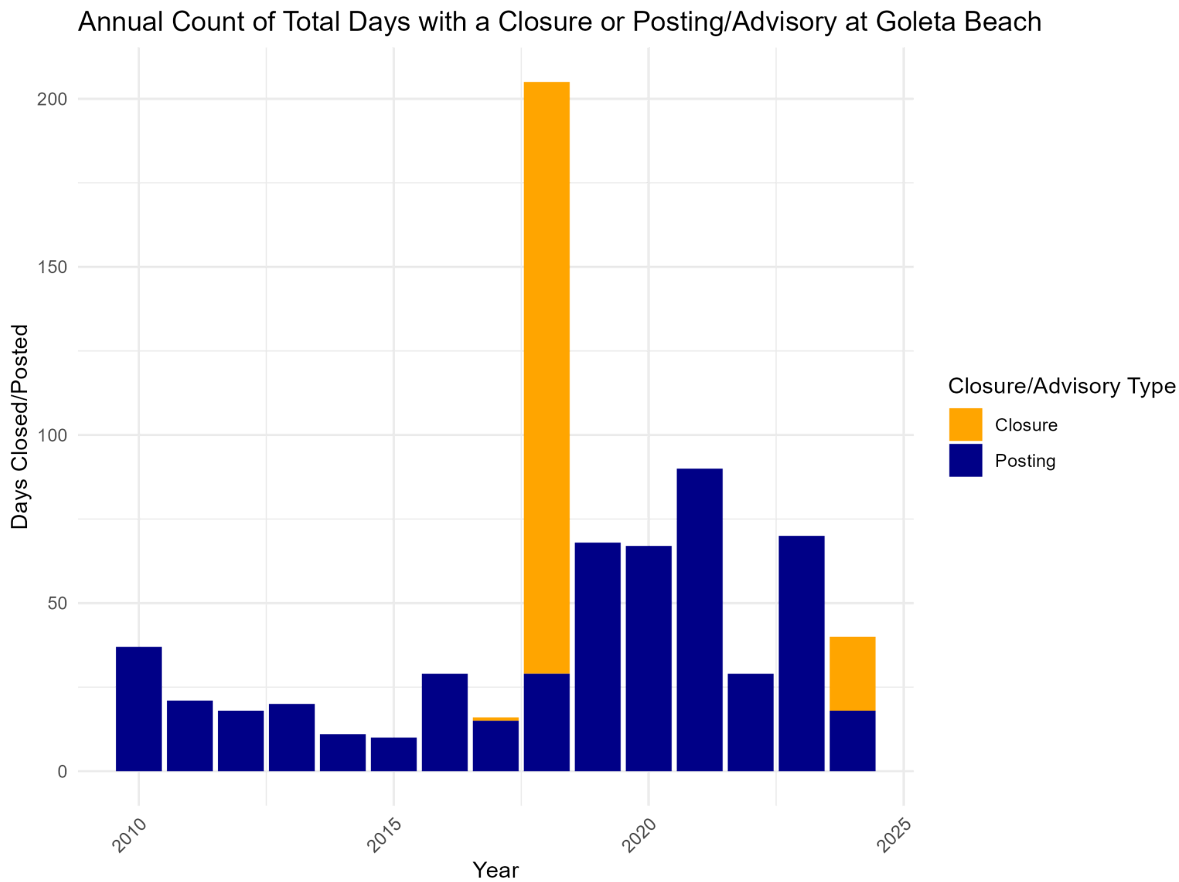


Figure 3.7. Annual count of days when there was a closure (yellow) or posting/advisory (blue) at Goleta Beach between 2010 and 2024. Data provided by the County of Santa Barbara Public Health Department.

The number of postings and closures has increased since 2018, due to various environmental factors and management actions that create instances of "Bacterial Standards Violations". Noticeably in 2018, large amounts of foreign sediment were brought to Goleta Beach following the Thomas Fire. While future years also had sediment disposal, not all scenarios led to closure. In February 2024, a sewage spill from the water treatment plant led to closures, yet the length of time was much less.

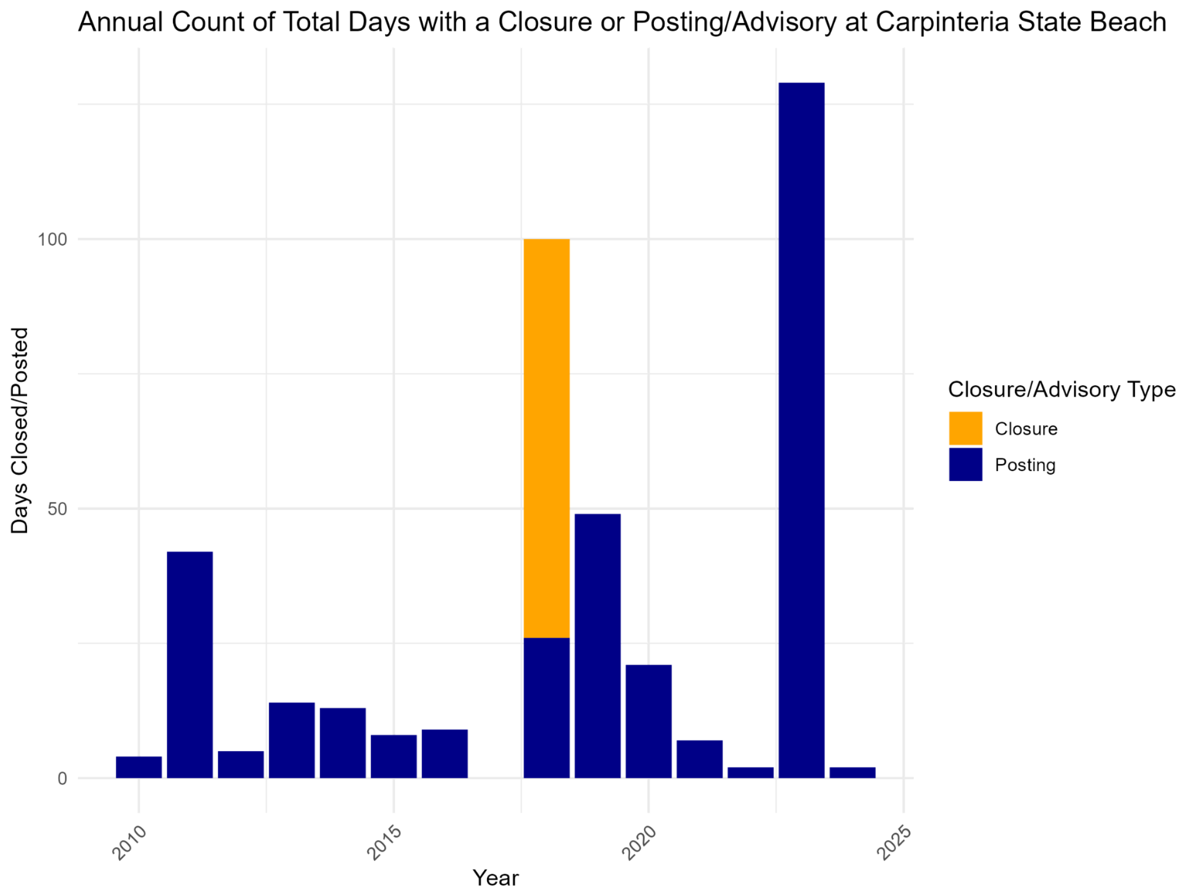


Figure 3.8. Annual count of days when there was a closure (yellow) or posting/advisory (blue) at Carpinteria State Beach between 2010 and 2024. Data provided by the County of Santa Barbara Public Health Department.

Similarly at Carpinteria State Beach, closures were greatest in 2018 (Figure 3.8). Although instances of closures and postings were generally decreasing following this event, they increased again following sediment deposition in 2023 that was triggered by large storms. A significantly larger amount of sediment was brought to Carpinteria Beach in 2023 versus in 2018, and yet no closures occurred. However, there was a larger number of advisories.

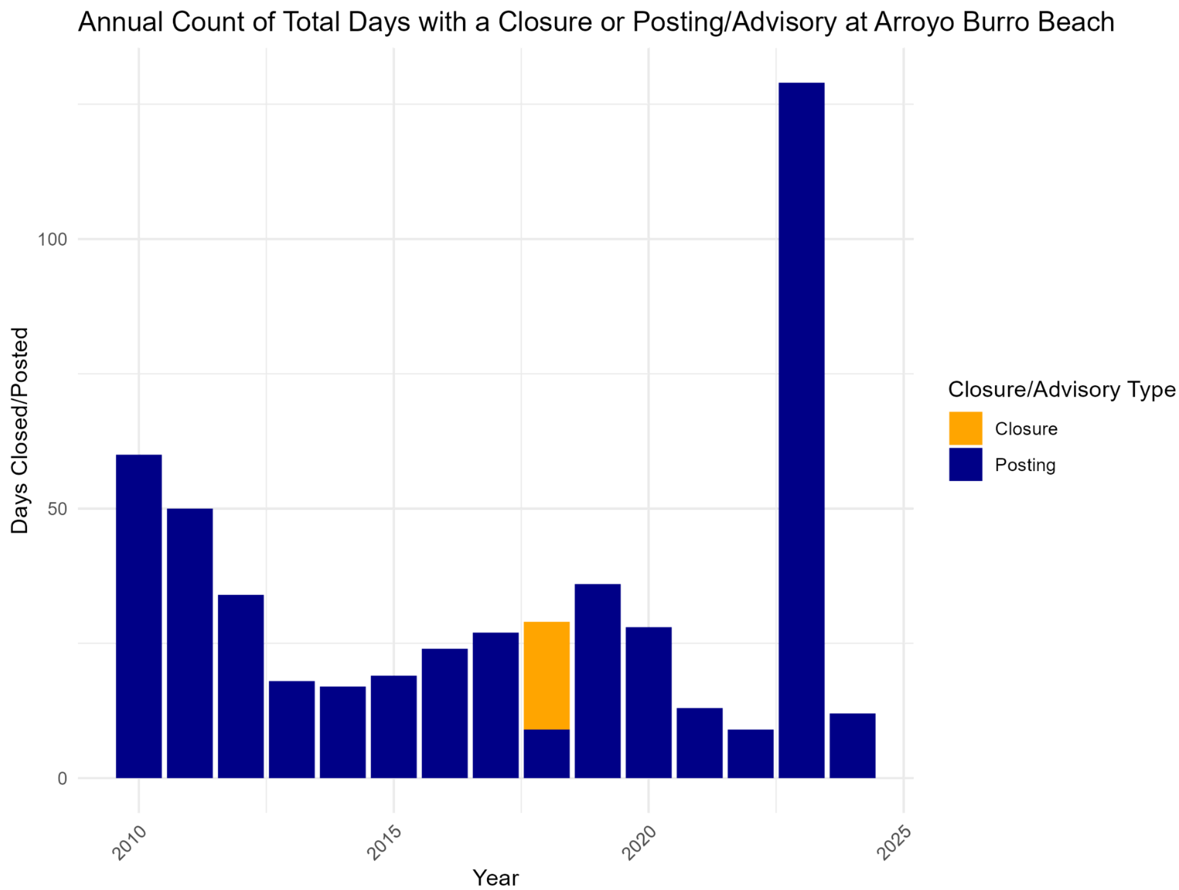


Figure 3.9. Annual count of days when there was a closure (yellow) or posting/advisory (blue) at Arroyo Burro Beach between 2010 and 2024. Data provided by the County of Santa Barbara Public Health Department.

Arroyo Burro Beach does not receive sediment from upstream creeks, but effects of fire and rain can still be seen in the beach closure and posting data. In 2018, the number of postings and closures was less than 30 days. In 2023, following large storms, the number of postings increased again, following a similar trend to Carpinteria Beach.

IV. Methods

Objective 1. Inform Santa Barbara Channelkeeper and other public agencies in Santa Barbara County of potential impacts from emergency sediment disposal activities on fecal indicator bacteria concentrations at Goleta and Carpinteria beaches.

The primary question addressed in this research was whether sediment deposition events at Goleta and Carpinteria Beaches were associated with an increased probability of bacterial contamination at levels considered hazardous to public health. This investigation was conducted to determine if beach management practices related to sediment deposition should be reconsidered or managed differently to better protect public health.

Fecal indicator bacteria measurements were utilized as the primary method by which the County determined whether Beach Advisories should be issued. Specifically, Beach Advisories or Beach Postings were triggered when at least one bacterial standard from the Ocean Water Contact Sport Standards was exceeded: 104 MPN/100mL for enterococcus, 400 MPN/100mL for *E. coli* and fecal coliform, and 1000 MPN/100mL for total coliform. When these thresholds were surpassed, warning signs were posted to inform the public about potential illness risks associated with water contact. Beach closures have different criteria depending on the situation, so they will not be considered explicitly within this objective.

For the multivariate logistic regression models, the water quality measurements were transformed into binary outcome variables based on exceedances of California state health standards. By converting the continuous bacterial measurements into binary exceedance indicators (where 1 represented an exceedance of health standards and 0 represented levels below these thresholds), the model was constructed to estimate how the log odds of a water quality exceedance were affected by sediment deposition events, considering other relevant factors such as precipitation and streamflow. This approach was determined to be particularly appropriate to evaluate public health and beach accessibility impacts, as it directly addressed whether deposition events were associated with conditions that would trigger beach advisories under California's beach safety programs.

<u>Data Description</u>

The analysis consolidates data from multiple sources to investigate the relationship between streamflow discharge, precipitation, sediment deposition, and water quality exceedances at Goleta and Carpinteria Beaches.

Streamflow discharge data for San Jose Creek (station 11120500) and Carpinteria Creek (station 11119500) were obtained from the United States Geological Survey (USGS) National Water Information System for the period 2010-2024, measured as daily average cubic feet per second (ft^3/s).

Daily precipitation data were sourced from two locations: the Carpinteria Fire Station (station 208, elevation 30 ft, latitude 34-23-49, longitude 119-31-04) through the Santa Barbara

County Flood Control Hydrology Section's County of SB Daily Rainfall records, and the Santa Barbara Airport (station USW00190, elevation 2.5 ft, latitude 34.4241, longitude -119.84249) through the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information Global Historical Climatology Network - Daily, both covering the period 2010-2024 and measured in inches.

Sediment deposition events were determined from data collected by the Santa Barbara County Flood Control District (2010-2024). Deposition events were coded in binary form, where days during sediment deposition events are labeled as "1" and all others as "0". Yearly volume amounts transported to each beach was given by SBCFCD, and divided by the number of deposition events per year to obtain a rough estimate of average volume amount of any day of deposition that year.

Water quality data, including levels of enterococcus, *E. coli*, fecal coliform, and total coliform, were acquired from the California State Water Resources Control Board for Santa Barbara County Beaches (2010-2024), measured by the Santa Barbara County Flood Control District and Santa Barbara Channelkeeper. The four fecal indicator bacteria were measured in MPN/100mL at Goleta Beach (WP0000037, Figure 4.1) and Carpinteria Beach (WP0000180, Figure 4.2). A binary variable was created to indicate exceedances of state health standards (104 MPN/100mL for enterococcus, 400 MPN/100mL for *E. coli* and fecal coliform, and 1000 MPN/100mL for total coliforms).

Arroyo Burro Beach was initially chosen as a control beach site due to its lack of sediment deposition history and similarity in composition to Goleta and Carpinteria Beach, as it also has an upstream slough that empties into the beach. However, upon further analysis of the dataset, it was determined that sufficient data existed for both deposition and non-deposition days at each individual beach location for Goleta and Carpinteria Beach. This pattern of alternating conditions at each site was recognized as providing internal control and treatment periods for the respective beaches themselves. This approach was deemed more methodologically robust than comparisons between different beach locations, as it eliminated site-specific variables that might otherwise have confounded comparisons across beach sites. Each beach was effectively used as its own control, which was considered a stronger experimental design for detecting the true impacts of deposition events on each individual beach.

Methodology

Model Overview

A preliminary graphical assessment was employed in RStudio to determine the appropriate regression approach for modeling the relationship between fecal indicator bacteria (FIB) levels and environmental covariates. The aim was to evaluate whether a multiple linear regression or a multivariate logistic regression would be more suitable for capturing the underlying dynamics. Specifically, the distribution of FIB levels over time in relation to continuous independent variables was examined, including streamflow discharge, precipitation, and lagged weekly FIB concentrations. These covariates were identified as ecologically plausible drivers of FIB concentrations at Goleta Beach.

For each FIB species, scatter plots of FIB levels versus each continuous predictor variable were generated. A locally estimated scatterplot smoothing (LOESS) curve was then overlaid to visualize the nature of the relationship. LOESS smoothing was selected as a non-parametric technique that is robust to outliers and does not assume a specific functional form, making it suitable for initial exploratory analysis. The decision rule was established as follows: If the LOESS curve suggested a predominantly linear relationship between FIB levels and a given predictor, multiple linear regression would be utilized. However, if the LOESS curve exhibited a sigmoid (S-shaped) relationship, indicative of a threshold effect, multivariate logistic regression would be favored. This preference was due to logistic regression being better suited for modeling binary exceedance outcomes.

The rationale for this approach stemmed from the fact that AB411 establishes specific threshold criteria for FIB levels. It was recognized that a standard multiple linear regression might not adequately capture the effect of predictor variables when FIB levels are clustered near these thresholds. Specifically, if a large number of samples had FIB levels just below the AB411 threshold, a binary classification approach (logistic regression) would classify these as non-exceedances, potentially masking the influence of predictor variables on FIB levels just below the threshold.

Therefore, by examining the shape of the relationship graphically, the regression approach that best represented the complex dynamics between FIB levels and environmental covariates was selected while accounting for the regulatory context of AB411. It was noted that should the scatterplots appear linear rather than sigmoid, performing a linear regression instead of a logistic one would indicate if the coefficient between deposition and FIB levels was positive, demonstrating that more deposition equaled more bacteria. A logistic regression was ultimately chosen due to the non-linear nature of FIB results against continuous predictor variables and the sigmoid relationship observed between some variables. Additionally, the use of a binary outcome variable for exceedance allowed for an interpretation of the impact relating to beach advisories.

The modeling approach encompassed the entire annual dataset rather than being restricted to only AB411 periods (April 1 to October 31) or non-AB411 periods (November 1 to March 31). This comprehensive temporal scope was selected due to the sufficient data availability across all seasons and allowed for a more complete assessment of bacterial exceedance patterns. An important temporal event captured in this analysis was the hydraulic dredging operation at Carpinteria Salt Marsh, which occurred from April 12th to June 22nd, 2023. During this dredging event, the sediment placement differed from standard protocols; rather than direct placement at Ash Avenue, the dredged material was deposited approximately 1,000 feet west at the Carpinteria Salt Marsh mouth opening. This altered deposition location increased the distance between the sediment placement and the AB411 water quality sampling site compared to typical deposition events, potentially affecting the relationship between deposition activities and bacterial concentrations at the monitoring location.

<u>Model Assumptions</u>

Statistical analysis was initiated with the verification of model assumptions. This included testing for independence of observations, ensuring there was no multicollinearity, and checking for linearity between the outcome logit and predictor variables.

The examination of multicollinearity was completed through Variance Inflation Factors (VIF) using the 'car' package in R Studio, where VIF values exceeding 5 or 10 were considered indicative of potential multicollinearity issues (Multicollinearity, n.d.). When all possible models were considered, all VIF values were below 2, with the exception of one model: the dry continuous deposition model for fecal coliforms in Carpinteria Beach, which was slightly above 5 for weekly volume and discharge (5.99 and 5.94, respectively). Considering it was still below 6, it was not deemed a concern or explicit multicollinearity.

The relationship between continuous predictors, precipitation and discharge, and log odds of the outcome was evaluated using Box-Tidwell tests and checked against empirical logit plots. The Box-Tidwell test was employed to assess whether continuous predictor variables in multivariate logistic regression models maintained a linear relationship with the logit of the outcome variable. This assumption verification process involved creating interaction terms between each continuous predictor and its natural logarithm, which were then included in the regression model. The test results were interpreted by examining the p-values associated with each predictor's interaction term after being run in a binomial model. If the p-value exceeded the chosen significance threshold ($\alpha = 0.05$), the linearity assumption was retained, implying no transformation was needed.

The Box-Tidwell assumptions were met by all variables in several models across both sampling locations. At Goleta Beach, all assumptions were met in the TC_CB_dry_c_bt (total coliforms), FC_GB_wet_b_bt, FC_GB_dry_b_bt, FC_GB_dry_c_bt (fecal coliforms), and all *E. coli* models (EC_GB_wet_b_bt, EC_GB_wet_c_bt, EC_GB_dry_b_bt, EC_GB_dry_c_bt), as well as the EN_GB_dry_b_bt (enterococcus) model. Similarly, at Carpinteria Beach, all assumptions were met in the FC_CB_dry_b_bt, FC_CB_dry_c_bt (fecal coliforms), EC_CB_wet_b_bt, EC_CB_wet_c_bt (*E. coli*), and EN_CB_dry_b_bt, EN_CB_dry_c_bt (enterococcus) models. It was noted that the EC_CB_dry_b_bt and EC_CB_dry_c_bt models did not converge due to the absence of exceedance events, as no "1"s or exceedances were recorded for *E. coli* at Carpinteria Beach during dry weeks.

All other models had one or two predictor interactions that were significant and failed to meet the Box-Tidwell test. These violations were primarily observed in the weekly rain and weekly rain interaction variables for wet season models, and in the weekly discharge and weekly volume variables for dry season models. The complete results of the Box-Tidwell test for all models are available in Appendix C.

Though there were violations to the assumption of linearity between the logit of the dependent variable and the continuous predictor variables, the transformation of these variables (e.g., log, square root, addition of quadratic terms) would have introduced multicollinearity, as was indicated by substantially increased VIF values. Since coefficient interpretation for inference rather than prediction accuracy was prioritized in this analysis, the linear specification of predictor variables was maintained. This approach was adopted to preserve the interpretability of odds ratios and effect sizes while multicollinearity issues that would have compromised the primary goal of understanding the directional relationships and significance of variables were avoided. This limitation was acknowledged and considered during the interpretation of the results.

Multivariate logistic regression analyses were conducted for each beach using the package ‘pglm’ in R, with binary FIB exceedance of AB 411 state health criteria being utilized as the dependent variable. Separate models were executed for total coliforms, fecal coliforms, *E. coli*, and enterococcus, with deposition events, precipitation, and discharge being employed as independent variables. Model diagnostics were comprised of an assessment of predictor variable significance, calculation of odds ratios to interpret variable effects on FIB exceedance and an evaluation of model fit. Comparisons of all models were done for each FIB as an outcome variable. Log likelihood values were extracted, which represented the logarithm of the probability that the observed data were generated by the model. Higher log likelihood values indicated better model fit. Delta AIC was computed as the difference between each model's Akaike Information Criterion (AIC) value and the minimum AIC value across all models. The AIC weights represented the probability that a given model was the best among the candidate set, with values closer to 1 indicating stronger support for the model.

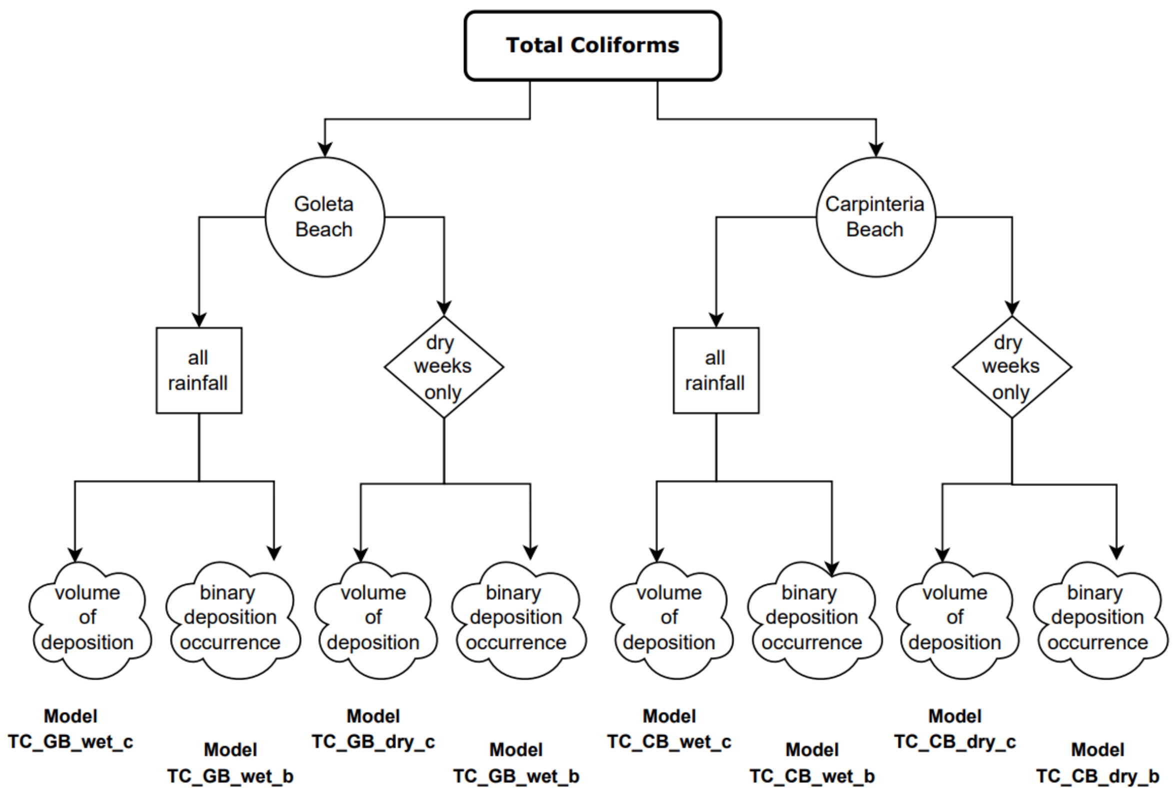


Figure 4.1. Example methodological structure of logistic regression models. This structure was employed for each fecal indicator bacteria, yielding a total of 62 models evaluated.

A total of 32 models were executed as binary logistic regressions, in which models for each FIB were separated by beach, by precipitation restrictions (none or below a summed 0.24 inches for the week), and by whether deposition was incorporated as a binary variable or utilizing a roughly estimated volume (example for total coliforms: Figure 4.1). Eight distinct models were developed for each FIB, and each of these models was subsequently rerun using "year" as an index to account for fixed effects over years, which was implemented as a robustness check to determine whether alterations in the significance or coefficient sign of predictors were observed.

Random effects models were selected over fixed effects models to preserve the ability to estimate the impact of time-invariant variables when comparing the effect of sediment deposition between Goleta Beach and Carpinteria Beach. Fixed effects estimation would have resulted in the elimination of important beach-specific characteristics such as physical geography, local hydrodynamic patterns, watershed land use, and ecological factors that remained constant throughout the study period. These inherent differences between the beaches were considered potentially significant in understanding how each site responded to deposition events. By employing random effects modeling, the time-invariant beach characteristics were retained in the analysis, allowing for a more comprehensive examination of how factors specific to each site might influence the relationship between sediment deposition and FIB exceedances at each location. This approach was deemed more appropriate for addressing the comparative research questions while still accounting for the temporal differences over the years.

Table 4.1. Names of all 62 models employed for reference to results.

Model	**Total Coliforms**	**Fecal Coliforms**	***E. coli***	**enterococcus**
1	TC_GB_wet_c	FC_GB_wet_c	EC_GB_wet_c	EN_GB_wet_c
2	TC_GB_wet_c_index	FC_GB_wet_c_index	EC_GB_wet_c_index	EN_GB_wet_c_index
3	TC_GB_wet_b	FC_GB_wet_b	EC_GB_wet_b	EN_GB_wet_b
4	TC_GB_wet_b_index	FC_GB_wet_b_index	EC_GB_wet_b_index	EN_GB_wet_b_index
5	TC_GB_dry_c	FC_GB_dry_c_firth	EC_GB_dry_c	EN_GB_dry_c
6	TC_GB_dry_c_index	NA	EC_GB_dry_c_index	EN_GB_dry_c_index
7	TC_GB_dry_b	FC_GB_dry_b_firth	EC_GB_dry_b	EN_GB_dry_b
8	TC_GB_dry_b_index	NA	EC_GB_dry_b_index	EN_GB_dry_b_index
9	TC_CB_wet_c	FC_CB_wet_c	EC_CB_wet_c	EN_CB_wet_c
10	TC_CB_wet_c_index	FC_CB_wet_c_index	EC_CB_wet_c_index	EN_CB_wet_c_index
11	TC_CB_wet_b	FC_CB_wet_b	EC_CB_wet_b	EN_CB_wet_b

12	TC_CB_wet_b_index	FC_CB_wet_b_index	EC_CB_wet_b_index	EN_CB_wet_b_index
13	TC_CB_dry_c	FC_CB_dry_c	EC_CB_dry_c	EN_CB_dry_c
14	TC_CB_dry_c_index	FC_CB_dry_c_index	EC_CB_dry_c_index	EN_CB_dry_c_index
15	TC_CB_dry_b	FC_CB_dry_b	EC_CB_dry_b	EN_CB_dry_b
16	TC_CB_dry_b_index	FC_CB_dry_b_index	EC_CB_dry_b_index	EN_CB_dry_b_index

The table above provides names for each of the 64 multiple regression models analyzing the relationship between sediment deposition and total coliform (TC) fecal indicator bacteria exceedances at two Santa Barbara County beaches (Goleta Beach [GB] and Carpinteria Beach [CB]). Models are stratified by precipitation conditions: "wet" models include all precipitation data, while "dry" models are filtered to include only periods with weekly cumulative rainfall equal to or below 0.28 inches. This was chosen because the USGS's definition of a singular "dry day" was 0.04 inches of rain or below (USGS, 2007). Sediment deposition is quantified using two approaches: binary classification (b) indicating presence/absence of deposition events, or continuous values (c) estimating sediment volume. Models labeled with "index" incorporate panel structure in the pglm regression by year to account for temporal dependencies in the data.

For the analysis of fecal coliform exceedances during dry conditions (Table 4.1, fecal coliform models 5-8), the typical logistic regression model was employed. However, the dataset for dry conditions exhibited extreme class imbalance, with only 9 exceedance events (1s) compared to 570 non-exceedance events (0s). This imbalance, combined with sparse variability in some predictors, resulted in quasi-complete separation, which caused standard logistic regression to fail to converge due to instability in parameter estimation. Specifically, the Hessian matrix contained NA values at the start of the maximum likelihood estimation process. To address these challenges, Firth's bias-reduced penalized likelihood method was applied, which is reflected in the model's changed name (Puhr et al., 2017). This approach adjusts the likelihood function to reduce bias in parameter estimates and ensures convergence even in datasets with rare events or separation issues. The Firth correction was implemented using the brglmFit method from the 'brglm2' package in R. This method was deemed appropriate because it is specifically designed for logistic regression models where rare outcomes or small sample sizes lead to unstable coefficient estimates. By penalizing extreme parameter values, the Firth correction provided reliable estimates while retaining all predictors in the model.

Although Firth correction was effective for handling rare events and ensuring convergence, it does not support panel data structures due to its reliance on penalized maximum likelihood estimation rather than random or fixed effects modeling. As a result, comparisons involving indexing by year (panel structure) were not possible for dry conditions. This limitation contrasts with models for wet conditions, where panel data methods were utilized to account for temporal variability. Despite this restriction, the Firth-corrected model enabled meaningful inference by including all predictors and mitigating issues related to data sparsity and imbalance. The use of Firth correction ensured consistency in predictor inclusion across models for wet and dry conditions while providing interpretable coefficients as odds ratios. This approach facilitated robust comparisons between environmental predictors under different precipitation regimes, despite differences in methodological constraints (Puhr et al., 2017).

As the models were employed for inference rather than prediction, sensitivity, and cross-model validation techniques were not necessitated. Instead, robustness was verified through the execution of models under both normal and dry conditions, the utilization of binary and continuous sediment deposition data, and the implementation of both indexed and non-indexed approaches by year. Model summaries were subsequently compared across each FIB and beach site to ascertain whether these model modifications contributed to alterations in results.

Objective 2. Evaluate the social impact and public perceptions of sediment disposal activities by conducting a beachgoer activity and demographic survey at Goleta and Carpinteria beaches.

The second project objective focused on identifying potential populations affected by emergency sediment deposition activities that historically occurred between October and February. A "Beach Demographic and Activity Survey" was conducted to gain insight into who loses access to the beach during deposition activities and which groups are more vulnerable to the public health advisories resulting from emergency sediment deposition. Furthermore, survey questions inquired about public perception of sediment deposition activities and the social impacts of extended beach closures. The survey aimed to understand how knowledge of sediment deposition might influence future beach visits, identify primary information sources for beach closures, and examine how income and beach activities correlate with responses to poor water quality. The survey was deployed at the two beach sites, Goleta Beach and Carpinteria Beach, for a more comprehensive understanding of deposition impacts across communities with differing demographic compositions.

Survey Development

The method first referred to the U.S. Census Bureau's surveys for examples of standard demographic questions and census categories(U.S. Census Bureau, 2021). Then, 10 initial hypotheses were proposed aimed at exploring several key dimensions of beach use and social impact. Multiple hypotheses were asserted to examine various aspects of beach use, including relationships between beach visit frequency, demographic characteristics, and awareness of sediment disposal activities. These hypotheses were structured to explore potential correlations between visitor income, beach activities, closure impacts, and visitor perceptions. To test the hypotheses, the survey questions asked about the activities that beachgoers engage in during their visit and how beach advisories and closures would impact and limit their future visits. All 10 hypotheses are detailed in Table 4.1. Survey drafts were shared with three UCSB faculty members (Dr. Sarah Anderson, Dr. Heather Hodges, and Dr. Trish Holden) with expertise in survey design for feedback and accordingly improved on.

Table 4.2. Initial Hypotheses for the Beach Demographic and Activity Survey

#	Predicted Result	H_0	H_1	Questions Used
1	Visitors who indicate that they visit either Goleta or Carpinteria Beach "a few times a year," "less than once a year," or "this is their first visit," are less likely to be aware of sediment disposal at the beach site compared to those who visit the beach "Monthly" or "Weekly or more often."	There is no significant relationship between beach visit frequency and knowledge of sediment disposal.	There is a significant relationship between beach visit frequency and knowledge of sediment disposal.	Q2.9, 2.10
2	Visitors with lower household incomes will be associated most with fishing activities.	There is no significant relationship between household incomes and fishing activities.	Lower-income households will be present at the beach for different reasons than middle or high-income households.	Q2.4, Q3.4-3.6
3	Beach closures would most impact low-income individuals.	There is no significant difference between lower and higher-income households reporting that they will avoid the beach during beach advisories.	There is a significant difference in lower-income households reporting that they will avoid the beach during beach advisories compared to higher-income households.	Q2.5, 2.7, 2.11
4	There is a higher proportion of non-White visitors at Goleta and Carpinteria beaches when compared to County demographics.	There is no significant difference between the number of White respondents and the number of non-White respondents.	There is a significant difference between the number of White respondents and the number of non-White respondents.	Q3.3

5	Physical accessibility features (free parking, proximity to home, less crowded than other beaches) will be among the most popular reasons for visiting Goleta and Carpinteria Beach.	There is no significant difference between the options selected as reasons why people visit these specific beaches.	There is a significant difference between the selected options for why people visit these specific beaches.	Q2.7
6	Free parking at Goleta Beach encourages visitors with vehicles from further cities/neighborhoods in the County, increasing the spatial range of beach closure impacts.	There is no statistically significant difference between zipcode and "free parking" as a reason the respondents chose to visit this beach.	There is a statistically significant difference between zipcode and "free parking" as a reason the respondents chose to visit this beach.	Q2.14
7	Beach visitors are more likely to avoid the beach during sediment deposition activities.	There is no statistically significant difference between the number of respondents who would visit and not visit the beach during deposition events.	There is a statistically significant difference between the number of respondents who would visit and not visit the beach during deposition events.	Q2.18
8	The primary source of information for beach closures is official beach signage.	There is no statistically significant difference between the number of respondents who learn about beach advisories from beach signage and respondents who use other sources of information.	There is a statistically significant difference between the number of respondents who learn about beach advisories from beach signage and respondents who use other sources of information.	Q2.17
9	Beachgoers will be more likely to definitely not visit the beach if there is a beach advisory declared.	There is no statistically significant difference between respondents choosing "I would definitely not visit the beach" and the other options when asked how beach	There is a statistically significant difference between respondents choosing "I would definitely not visit the beach" and the other options.	Q2.16, Q3.5, Q2.5, Q2.7

		advisories would affect their decision to visit.		
10	Household income distributions will differ between Goleta and Carpinteria Beach.	The two beaches do not have statistically significant different distributions for household income.	The two beaches have statistically significant distributions for household income.	Q3.5

The final survey version has 28 questions (Appendix A), takes approximately 5-10 minutes to complete, is hosted online via Qualtrics, and is administered in person onsite by a researcher interacting with the respondent directly. The questionnaire was submitted to UC Santa Barbara's Institutional Review Board (IRB) on November 22, 2024, initially reviewed on December 6, 2024, resubmitted with corrections on December 13, 2024, and approved on January 8, 2025 (Appendix D). During the development period, 27 responses were received during four days of survey beta testing (December 17, 20, and January 6, 7) at Goleta and Carpinteria Beach. The beta testing period guided modifying the survey to include a question indicating which beach site the respondent was visiting and to make more clear questions with initially ambiguous phrasing.

Survey Deployment

The deployment of the survey via response collections onsite commenced on January 8, 2025, and ended on February 25, 2025. The survey was conducted via in-person interviews with beachgoers present at the site. RStudio was used to randomize the days, times, and beach sites for ten survey shifts per week. Each survey shift had one to two similarly trained group members at the beach for an hour and thirty minutes. Surveys were conducted daily, but a few days were omitted in February due to inclement weather. Potential surveying hours were 7 AM to 6 PM, chosen to correspond with the beaches' hours of operation (8 AM to sunset).

Survey locations included multiple areas at Goleta Beach (the pier, picnic tables, beach, and rocky shore by Henley Gate) and both Carpinteria State and City Beach. There was no distinction between Carpinteria State and Carpinteria City Beach, and survey responses at these two sites were solely recorded as "Carpinteria Beach." The participants were offered three survey options for completion: a digital QR code, a digital survey on a mobile device completed by the researcher, or a paper copy. If individuals could not complete the survey at that moment but were still interested in participating, they were offered to receive the survey via email. Translations were available in Arabic, Chinese (Traditional), Korean, Spanish, and Vietnamese. A standardized preamble script explained the survey's purpose and gained participant consent. Participants were offered the choice of self-completion or researcher assistance. The methodology emphasized capturing comprehensive demographic information, with careful attention to response tracking. Minors were excluded. At the beginning and end of each survey shift, the number of visitors was counted as a census at each site. Also recorded were the number of invitations according to individuals approached, and survey participation rates through yes and no response counts. This information was compiled into a singular document at the end of the survey period.

Data Analysis

Statistical analysis employed both inferential and descriptive techniques, with methodological guidance drawn from the reference text Exploring Complex Survey Data Analysis Using R (Zimmer et al., 2024). The comprehensive approach aims to cover a broad understanding of the social dynamics surrounding beach closures and sediment disposal activities. Once the survey period concluded, responses were graphed for visualization in RStudio to observe the data structure and trends. The first graphs depicted the results of the demographic survey portion, showing the distribution of factors such as age, gender identity, and annual household income across both beaches. After data visualizations, statistical analysis of survey results was performed to test hypotheses (Table 4.1). The statistical tests subsequently mentioned were conducted in RStudio with the program's base package.

The statistical analyses began with assessing demographic question responses to identify preliminary trends and relationships. For survey questions with numeric responses and options such as "age," the Kolmogorov-Smirnov (KS) was initially used to assess if the survey responses were likely to have a normal distribution, which would allow the presentation of the data through mean values. This test was chosen as the more appropriate method amongst other normality tests due to the larger sample size of over 50 samples (Mishra et al., 2019). Following convention, 0.05 was the selected alpha value (Zimmer et al., 2024). If the p-value (*P*) was greater than 0.05, there was a failure to reject the null hypothesis, which states that the data has a normal distribution. If *P* was less than 0.05, the null hypothesis was rejected, and it was assumed that the data were not normally distributed.

Following the KS test, if the question provided continuous numerical data results with a normal distribution, an unpaired two-sample t-test was performed (Zimmer et al., 2024). A Mann-Whitney U (also known as the two-sample Wilcoxon rank sum) test was used for datasets that were not normally distributed (Rousseaux & Gad, 2013).

A chi-square test of independence (X^2) was used to analyze the relationships between each beach and categorical demographic factors (Zimmer et al., 2024). The options for 5 out of 8 demographic questions had categorical response options. The null hypothesis (H_0) for the chi-square test is that there is no significant association between the variables of interest, and the alternative hypothesis (H_1) states that the variables of interest are associated (Franke et al., 2012). The alpha value for the chi-square test was selected to be 0.05 (Zimmer et al., 2024). The null hypothesis failed to be rejected if the calculated p-value was greater than 0.05. If *P* was less than 0.05, the null hypothesis was rejected. In conjunction with the chi-square test, the effect size, or the strength of the association between tested categories, was tested by calculating Cramer's V (Kearney, 2017). The ggbarstats function from the ggstatsplot package was used to simultaneously calculate X^2 and Cramer's V and visualize results in survey hypothesis testing. Fisher's exact test was used instead of X^2 when the dataset had expected frequency values less than 5. (Giannini, 2005).

An example regards testing the relationship between the beach site and the annual household income of beachgoers. The null hypothesis (H_0) states there is no significant association between the beach site and the mean annual household income of beachgoers, and therefore, the distribution of household income is the same across both beach sites. The alternative hypothesis (H_1) states that there is an association between the beach site and the mean annual household income of beachgoers, exhibiting different distributions of household income between beach sites.

Objective 3. Recommend potential modifications to permits that guide debris basin clearing and associated beach disposal activities to promote more environmentally and socially equitable emergency sediment disposal activities at Goleta and Carpinteria beaches.

The third objective employed recommendation modifications to permits guiding debris basin clearing and beach disposal activities, ensuring that emergency sediment disposal at Goleta and Carpinteria beaches is environmentally sustainable and socially equitable. The review of existing permits identified critical gaps in environmental projection, long-term monitoring, and community engagement. This analysis was conducted due to the increased usage of permits between 2005 through 2023.

Routine maintenance permits typically cover debris basin maintenance activities, such as vegetation removal from pilot channels, from August 1 to November 30 and beach disposal from October 15 to March 1, with frequency of maintenance varying based on vegetation growth and sediment accumulation. Long-term maintenance follows the same permit, but occurs every 3 to 4 years, or when basin capacity drops below 25%. Long-term maintenance involves excavation of debris basin sediments, which is less frequent than general maintenance. Emergency permits, issued in response to post-fire or post-storm conditions, allow for up to 180 days of project completion and are historically used between January and March. These operational timeframes shape permit analysis and helped contextualize the evaluation of sediment disposal practices across multiple years.

Permit usage data was collected to visualize the frequency of routine versus emergency permits. This analysis integrated a permit review to compare routine and emergency permits to assess limitations in sediment monitoring, disposal procedures and stakeholder involvement. Findings were summarized into categorized tables to analyze current permit structures, evaluate ecological and social impacts, and assess the feasibility and potential benefits of various modifications.

<u>Permit Content Review and Synthesis</u>

The process began with an in-depth review of existing debris basin clearing and beach disposal permits. Initially, the permits were collected and organized into a table, divided into routine and emergency categories based on the issuing agency. To evaluate the effectiveness of current permit structures, the analysis involved a comparative review of permit content across multiple agencies, including the State Water Resources Control Board, the U.S. Army Corps of Engineers, the California Coastal Commission, and the California Department of Fish and Wildlife. The review focused on key regulatory components such as sediment quality standards, environmental impact mitigation, and procedural flexibility during emergency events. This organization allowed for easier comparison of permit content between routine and emergency situations. To further analyze the permits, routine and emergency permits were compared based on permit content to identify potential gaps and limitations. From the review, findings were summarized into comprehensive tables according to ecological and social impact studies to assess the consequences of current sediment disposal practices.

They were further summarized using a two-dimensional evaluation matrix based on feasibility and impact. The matrix features a horizontal axis representing feasibility gradients, ranging from least to most feasible, and a vertical axis measuring environmental and social impact, from least to most positive. Recommendations ranged from high feasibility actions, such as improving public education, enhancing advisory signage, and expanding water quality monitoring near sediment deposition sites, to more complex measures, such as implementing nature-based solutions and modifying emergency permit language to require long-term impact studies. The feasibility of each recommendation was determined based on regulatory constraints, agency capacity, and financial considerations, ensuring proposed modifications could be integrated into sediment management practices.

Permit Synthesis for Stakeholders

Building on the regulatory review, the permit content was reformatted into distinct audience-specific tables to improve accessibility and understanding. The tables are tailored to the needs of key stakeholder groups, which include SBCFCD, Channelkeeper/nonprofit organizations, academic researchers, and the general public. Each group was identified and selected based on criteria such as relevance to sediment disposal practices, regulatory oversight, and community impacts using targeted methods, including surveys, direct contacts, and reviews of organizations. For example, SBCFCD provides operational oversight, nonprofits bring in community advocacy perspectives, academia offers analytical thoroughness, and the general public represents community interests. The table includes key information that each stakeholder will require for engagement. The list of recommendations in the table addresses concerns based on feasibility and the overall impact of the proposed modifications.

V. Results

Objective 1

Inform Santa Barbara Channelkeeper and other public agencies in Santa Barbara County of potential impacts from emergency sediment disposal activities on fecal indicator bacteria concentrations at Goleta and Carpinteria beaches.

Sediment Quantity Deposition at Goleta and Carpinteria Beach

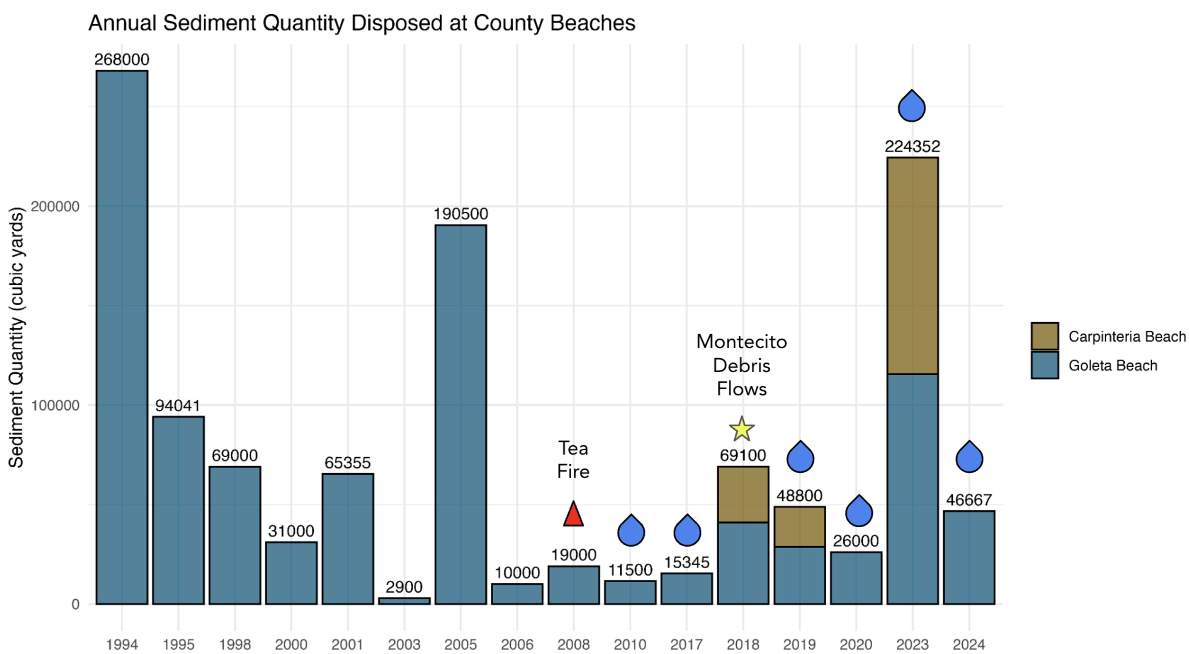


Figure 5.1. From data provided by SBCFCD, the annual sediment quantity (in cubic yards) disposed at Goleta and Carpinteria Beach from 1994 to 2024 is visualized in a bar graph. The red triangle represents a fire event, blue raindrops indicate years with heavy precipitation events, and the 2018 Montecito debris flows are signified with a yellow star.

Visual Exploration of FIB Concentrations During Deposition Events

2023 San Jose Creek Discharge vs. Goleta Beach FIB (*E. coli* and total coliforms)

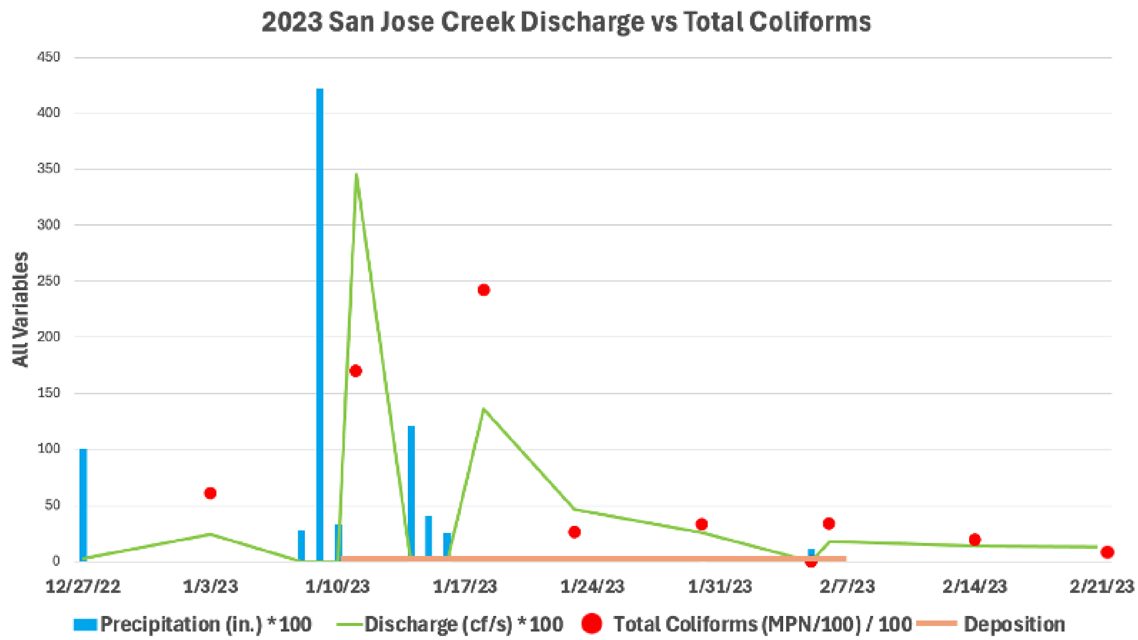


Figure 5.2. Creek discharge rates, precipitation data, and total coliform concentrations for Goleta Beach between December 2022 and February 2023. Sediment deposition activities (yellow categorical line) occurred from January 11, 2023 to February 8, 2023. San Jose Creek was used as a reference site for Goleta Beach. Unsafe levels of total coliforms per AB411 are > 10,000 MPN/100 mL (represented as 100 here because of the multiplier).

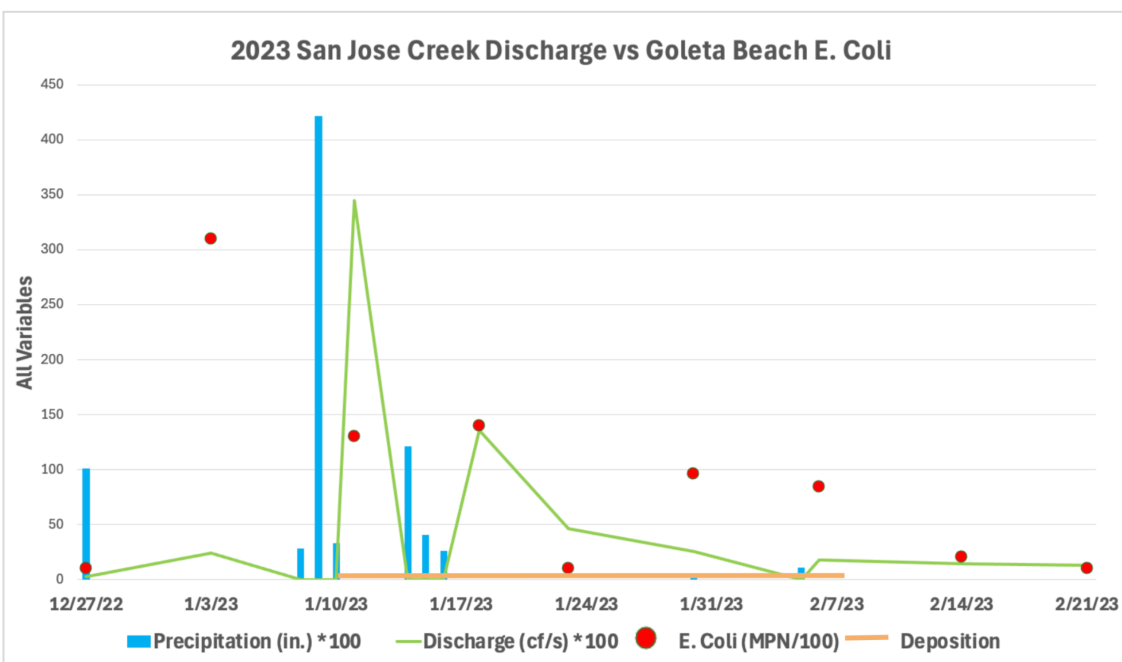


Figure 5.3. Creek discharge rates, precipitation data, and *E. coli* concentrations for Goleta Beach between December 2022 and February 2023. Sediment deposition activities (yellow categorical line) occurred from January 11, 2023 to February 8, 2023. Unsafe levels of *E. coli* are > 400 MPN/100.

For visual clarity, precipitation and discharge values are presented with multipliers, while total coliform levels are divided by 100. Any total coliform results exceeding 10,000 MPN/100 mL are considered unsafe per AB 411 and are displayed as 100 on the graph. On January 3, 2023, *E. coli* levels were elevated before the start of deposition operations but remained within safe limits, with unsafe levels defined as greater than 400 MPN/100 mL under AB 411. A 2- to 4-day lag is observed between precipitation events and discharge peaks (Figure 5.2). Total coliform levels follow a similar trend as *E. coli*, except for the January 3 sample (Figure 5.3). Notably, unsafe levels of total coliforms were recorded between January 10 and January 20, following high precipitation and discharge events during ongoing sediment deposition operations.

2023 Carpinteria Creek Discharge vs. Carpinteria Beach Total Coliforms

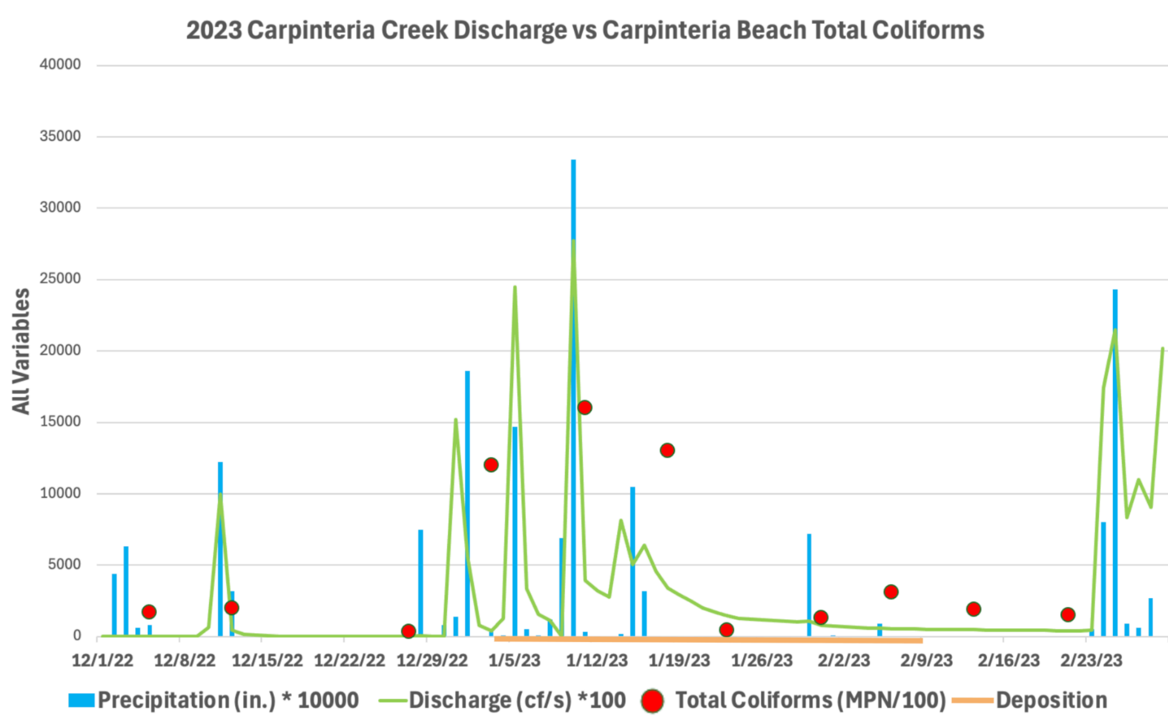


Figure 5.4. Creek discharge rates, precipitation data, and total coliform concentrations for Carpinteria Beach from December 2022 through February 2023. Sediment deposition activities occurred from January 4, 2023 to February 9, 2023. Carpinteria Creek was used as a reference site for Carpinteria Beach. Unsafe levels of total coliforms per AB411 are > 10,000 MPN/100 mL.

For visual clarity, precipitation and discharge values are presented with multipliers. During sediment deposition events between January 5 and January 19, 2023, total coliform levels exceeded 10,000 MPN/100 mL, surpassing the safe threshold established by AB 411 (Figure

5.4). This spike remained for about two weeks from multiple significant precipitation events. Additionally, a 0 to 4-day lag was observed between precipitation events and corresponding discharge peaks.

2018 San Jose Creek Discharge vs. Goleta Beach FIB (Enterococcus and Total Coliforms)

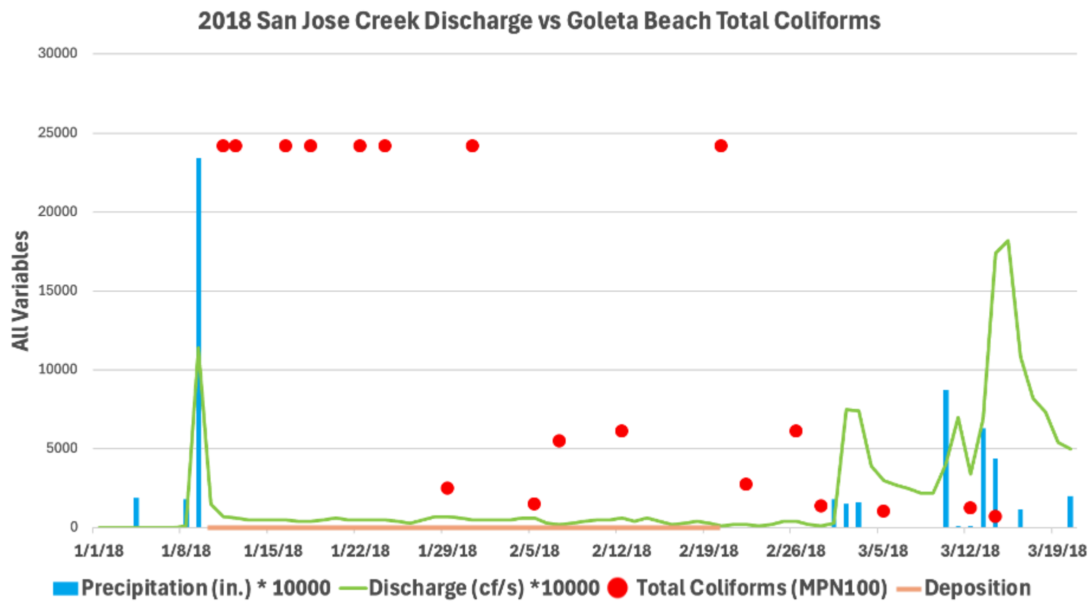


Figure 5.5. Creek discharge rates, precipitation data, and total coliform concentrations are plotted. Deposition activities occurred from January 11, 2018 to February 20, 2018 (BEACON, 2019). Unsafe levels of total coliforms per AB411 are > 10,000 MPN/100 mL.

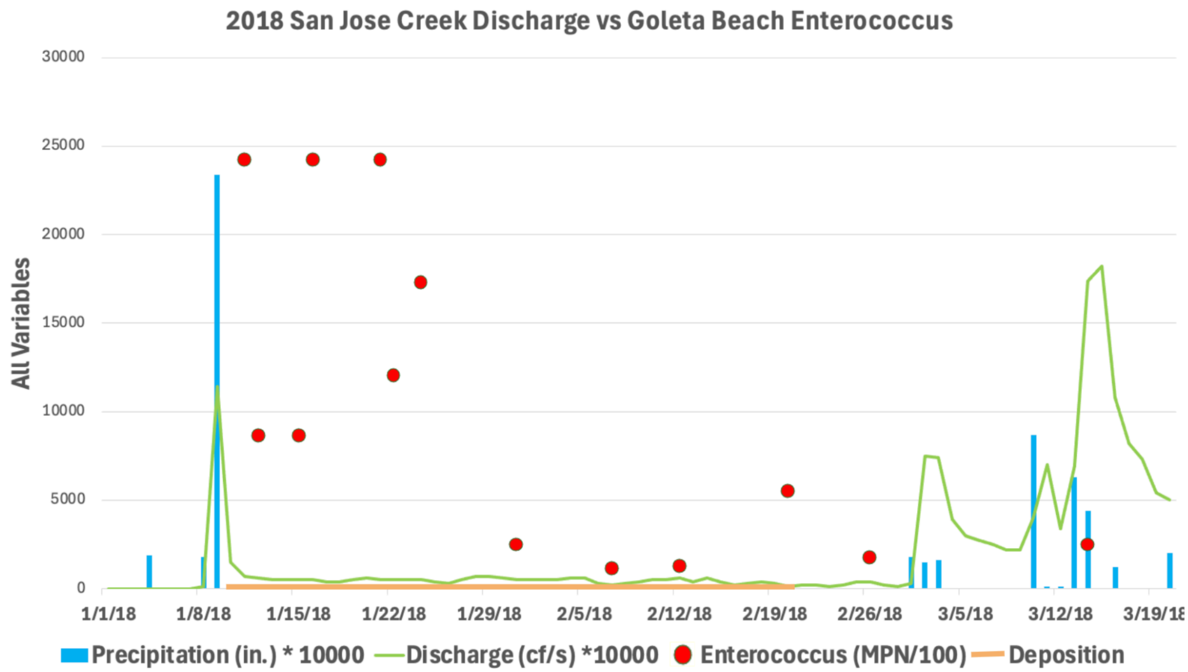


Figure 5.6. Creek discharge rates, precipitation data, and enterococcus concentrations are plotted. Deposition activities occurred from January 11, 2018 to February 20, 2018 (BEACON, 2019). Unsafe levels of Enterococcus per AB411 are 104 MPN/100 mL.

Following the Montecito Debris Flow events on January 9, 2018, which resulted in a massive deposition of debris flow material, total coliform and enterococcus levels spiked to extremely high levels, reaching approximately 25,000 MPN/100 mL (Figure 5.6). According to AB 411, the recommended safe limit for enterococcus is 104 MPN/100 mL for a single sample and 35 MPN/100 mL for a 35-day average. However, unsafe levels of enterococcus persist throughout the entire dataset. While a decrease in enterococcus levels is observed approximately three weeks after the initial sediment deposition operations, concentrations remain elevated beyond safe thresholds.

Control period: Goleta Beach

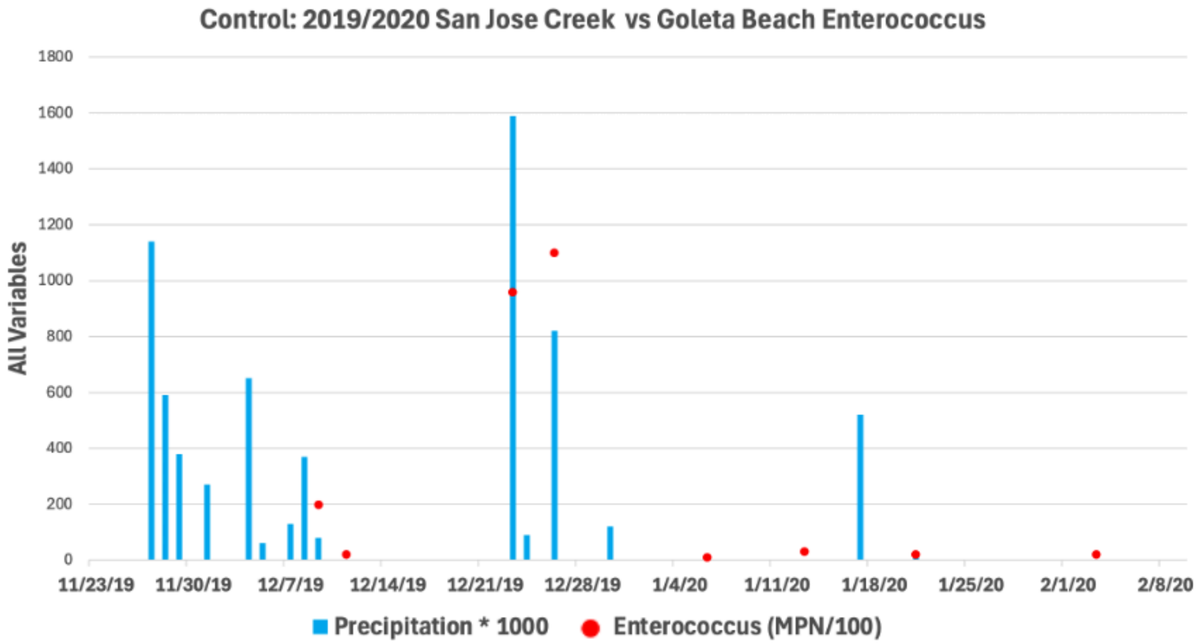


Figure 5.7. Precipitation at San Jose Creek and enterococcus concentrations at Goleta Beach are plotted. Unsafe levels are 104 MPN/100. This period did not have deposition activities at Goleta Beach. Enterococcus samples < 20 MPN/100 are not plotted. Unsafe levels of enterococcus per AB411 are 104 MPN/100 mL.

Enterococcus levels were evaluated at Goleta Beach during a period without sediment deposition. While bacteria levels generally remained within safe and normal ranges, a significant spike into unsafe levels occurred following a high-precipitation event, highlighting the impact of rainfall on water quality (Figure 5.7).

Control period: Arroyo Burro

Figure 5.8. AB411 sampling site at Arroyo Burro Beach. The adjacent lagoon is not connected to the ocean here.

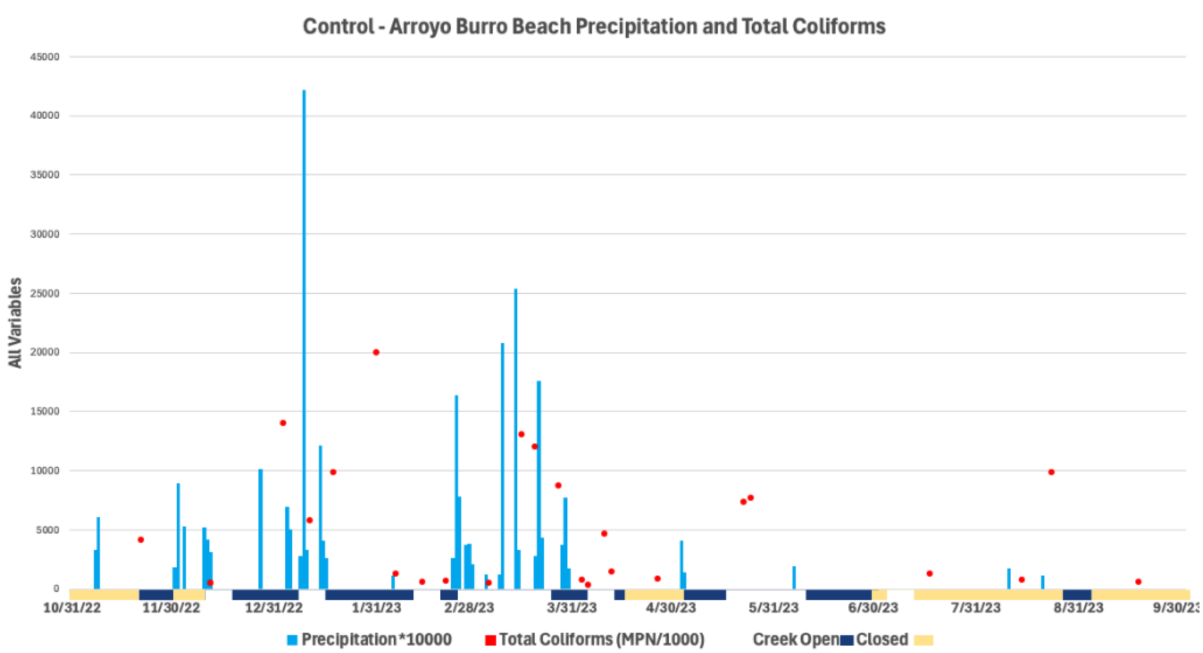


Figure 5.9. Precipitation data and total coliform concentrations are plotted for the Arroyo Burro Beach AB411 sampling site. Unsafe levels of total coliforms per AB411 are > 10,000 MPN/100 mL.

Arroyo Burro Beach, which does not receive sediment deposition, serves as an additional control site for monitoring bacteria levels. For the 2023 water year, daily satellite imagery from UCSB's Dream Lab, in partnership with Planet Satellite, was used to assess whether the adjacent lagoon was connected to the ocean, categorized as either open or closed (Figure 5.8). This analysis aimed to determine the impact of lagoon connectivity on bacterial levels. Findings indicate that total coliforms spiked to unsafe levels only in correlation with precipitation events of at least one inch, and primarily during times when the creek was connected to the ocean, except for one data point in late August 2023 (Figure 5.9).

Multivariate Logistic Regression

For all analyses, an alpha of 0.05 was used. A p-value less than 0.05 indicates significance, in which the null hypothesis is rejected. The null and alternative hypotheses for each predictor variable were as follows:

- H1: The predictor variable has a significant impact on the log odds of an exceedance event for the FIB tested.
- H0: There is no relationship between the log odds of an exceedance event and the predictor variable for the FIB tested.

The equation below modeled the log odds of total coliform exceedance as a function of weekly volume (the estimated volume of sediment brought to the beach), weekly rain (summed daily precipitation in inches), and weekly discharge (summed daily discharge in cfs), while controlling for unmeasured year-specific effects. Specifically, using TC_GB_wet_c as an example (model #1, Table___):

$$\log(P(\text{TC Exceedance}_i)/(1-P(\text{TC Exceedance}_i))) = -2.56534 + 0.00034 \times \text{Weekly Volume}_i + 0.77759 \times \text{Weekly Rain}_i - 0.00003 \times \text{Weekly Discharge}_i + u_i$$

Where $u_i \sim N(0, 0.42027^2)$ represents the random effect for observation/panel *i*.

When weekly deposition was used as a binary variable instead of weekly volume, the equation looked like this (model #3, Table___):

$$\log(P(\text{TC Exceedance}_i)/(1-P(\text{TC Exceedance}_i))) = -2.59084 + 2.88325 \times \text{Weekly Deposition}_i + 0.75761 \times \text{Weekly Rain}_i + 0.00078 \times \text{Weekly Discharge}_i + u_i$$

Where $u_i \sim N(0, 0.43632^2)$ represents the random effect for year *i*.

Using total coliform's model #3 as an example, the coefficient for weekly deposition in the binomial family panel generalized linear model was 2.88325 ($p < 0.001$). To interpret this coefficient in terms of odds ratios, the exponential transformation was applied to the coefficient value ($e^{2.88325}$), which yielded a value of 17.87. This calculation indicated that the odds of total coliform exceedance were 17.87 times higher when deposition was present compared to when it was absent. This is described as a percentage increase in the exceedance odds per unit increase in the predictor variable. Additional significant predictors in the model included weekly rainfall (coefficient = 0.75761, $p < 0.001$), while weekly discharge (coefficient = 0.00078, $p = 0.77755$) was not found to be statistically significant. The model incorporated year-specific random effects with a standard deviation of 0.43632 ($p = 0.04097$). Each model was interpreted in this manner, with an overall comparison of coefficients and significance noted within the following sections for each fecal indicator bacteria.

Total coliform

Table 5.1. Total coliform exceedance impacts, where statistically significant coefficients are bolded. A p-value of "0" represented "< 2e-16."

Table: Total coliform Logistic Regression Results with Estimates and P-values

	Model Results											
Model	**Intercept**	**P-value (Intercept)**	**Weekly Deposition**	**P-value (Deposition)**	**Weekly Volume**	**P-value (Volume)**	**Weekly Rain**	**P-value (Rain)**	**Weekly Discharge**	**P-value (Discharge)**	**Sigma**	**P-value (Sigma)**
(1) TC_GB_wet_c	-2.56534	**0**	NA	NA	0.00034	**6e-05**	0.77759	**2e-05**	-0.00003	0.99051	0.42027	0.05366
(2) TC_GB_wet_c_index	-2.56534	**0**	NA	NA	0.00034	**6e-05**	0.77759	**2e-05**	-0.00003	0.99051	0.42027	0.05366
(3) TC_GB_wet_b	-2.59084	**0**	2.88325	**0**	NA	NA	0.75761	**4e-05**	0.00078	0.77755	0.43632	**0.04097**
(4) TC_GB_wet_b_index	-2.59084	**0**	2.88325	**0**	NA	NA	0.75761	**4e-05**	0.00078	0.77755	0.43632	**0.04097**
(5) TC_GB_dry_c	-2.88572	**0**	NA	NA	0.00062	**1e-05**	-3.78495	0.44667	0.03159	0.08171	0.32923	0.2925
(6) TC_GB_dry_c_index	-2.88572	**0**	NA	NA	0.00062	**1e-05**	-3.78495	0.44667	0.03159	0.08171	0.32923	0.2925
(7) TC_GB_dry_b	-2.93186	**0**	3.36859	**0**	NA	NA	-4.15527	0.38313	0.03195	0.08493	-0.50637	0.06216
(8) TC_GB_dry_b_index	-2.93186	**0**	3.36859	**0**	NA	NA	-4.15527	0.38313	0.03195	0.08493	-0.50637	0.06216
(9) TC_CB_wet_c	-2.09021	**0**	NA	NA	0.00034	**0.00432**	0.81232	**0.00027**	0.00082	0.60024	-0.48173	**0.04743**
(10) TC_CB_wet_c_index	-2.09021	**0**	NA	NA	0.00034	**0.00432**	0.81232	**0.00027**	0.00082	0.60024	-0.48173	**0.04743**
(11) TC_CB_wet_b	-2.06979	**0**	1.36226	**0.02972**	NA	NA	0.80088	**0.00035**	0.00057	0.71389	-0.54921	**0.02654**
(12) TC_CB_wet_b_index	-2.06979	**0**	1.36226	**0.02972**	NA	NA	0.80088	**0.00035**	0.00057	0.71389	-0.54921	**0.02654**
(13) TC_CB_dry_c	-2.91241	**0**	NA	NA	0.00049	**0.0064**	4.48147	0.16089	0.01567	0.11412	-0.67198	0.09485
(14) TC_CB_dry_c_index	-2.91241	**0**	NA	NA	0.00049	**0.0064**	4.48147	0.16089	0.01567	0.11412	-0.67198	0.09485
(15) TC_CB_dry_b	-2.90310	**0**	2.52059	**0.00444**	NA	NA	4.66935	0.14273	0.01528	0.12473	-0.63105	0.11201
(16) TC_CB_dry_b_index	-2.90310	**0**	2.52059	**0.00444**	NA	NA	4.66935	0.14273	0.01528	0.12473	-0.63105	0.11201

A comprehensive analysis of total coliform exceedance was conducted using binomial family panel generalized linear models across different conditions and beach locations (Table 5.1).

For models incorporating weekly volume as a continuous predictor, positive and statistically significant relationships were consistently observed across all conditions. At Goleta Beach, during wet conditions, weekly volume was significantly associated with increased exceedance probability (coefficient = 0.00034, $p < 0.001$), with each unit increase corresponding to a 0.034% increase in exceedance odds. During dry conditions at the same location, the effect was stronger (coefficient = 0.00062, $p < 0.001$), representing a 0.062% increase in odds per unit.

Similar patterns were observed at Carpinteria Beach, where weekly volume during wet conditions was significant (coefficient = 0.00034, $p = 0.00432$) withan identical effect size to Goleta Beach. During dry conditions, the coefficient was marginally higher (coefficient = 0.00049, $p = 0.0064$), indicating a 0.049% increase in exceedance odds per unit increase. For models using binary weekly deposition as a predictor, consistently positive and significant effects were identified across all conditions and locations. At Goleta Beach during wet conditions, the presence of deposition was strongly associated with exceedance (coefficient = 2.88325, $p < 0.001$), with odds 17.87 times higher when deposition was present. During dry conditions, this effect was even more pronounced (coefficient = 3.36859, $p < 0.001$), with odds 29.03 times higher.

At Carpinteria Beach, significant but somewhat smaller effects were detected for binary deposition, with exceedance odds 3.91 times higher during wet conditions (coefficient = 1.36226, $p = 0.02972$) and 12.43 times higher during dry conditions (coefficient = 2.52059, $p = 0.00444$) when deposition was present.

Weekly rainfall was found to be a significant predictor only during wet conditions at both beaches, with positive coefficients at Goleta Beach (coefficient = 0.75761, $p < 0.001$) and Carpinteria Beach (coefficient = 0.80088, $p = 0.00035$) for the binary deposition models. Weekly discharge was not statistically significant in most models, showing only marginal significance during dry conditions at Goleta Beach.

Year-specific random effects were incorporated in all models, with standard deviations ranging from 0.32923 to 0.67198 and varying levels of significance.

Overall, the findings demonstrated consistent positive associations between deposition measures and total coliform exceedance across different conditions and locations, with particularly strong effects observed for binary deposition during dry conditions.

The comparative analysis of models for total coliform exceedances revealed that models TC_CB_dry_c and TC_CB_dry_c_index demonstrated the strongest statistical fit, as evidenced by their identical minimum AIC values of 137.7953 (Table 5.2). These models were assigned the highest AIC weight (0.2679), suggesting they were approximately 27% likely to be the best models among the candidate set. The TC_CB_dry_b and TC_CB_dry_b_index models followed closely with AIC values of 138.0826 and a

Delta_AIC of 0.2873, receiving weights of 0.2321, which indicated approximately 23% probability of being the optimal models. This is because for Tables 5.2, 5.4, 5.6, and 5.8, the difference between minimum AIC values quantified the relative information loss when using a given model compared to the best model. AIC weights were then calculated using the formula exp(-0.5 × ΔAIC) divided by the sum of exp(-0.5 × ΔAIC) across all models. These weights were interpreted as the probability that a given model was the best among the candidate set, with values closer to 1 indicating stronger support for the model.

All remaining models were found to have substantially higher AIC values with Delta_AIC exceeding 130, resulting in AIC weights of effectively zero. This pattern strongly suggested that the TC_CB_dry variants, particularly those with the '_c' parameter indicating continuous weekly volume as a predictor, were significantly better supported by the data. The log likelihood values for the best-performing models were determined to be -63.8977, which further substantiated their superior fit to the observed data. It was concluded that dry weather conditions for Carpinteria Beach provided the most reliable framework for modeling total coliform exceedances in the study area.

Table 5.2. Comparison of all models for total coliform exceedances as an outcome variable. Log likelihood values were extracted, which represented the logarithm of the probability that the observed data were generated by the model. Higher (more positive) log likelihood values indicated better model fit. Delta AIC was computed as the difference between each model's Akaike Information Criterion (AIC) value and the minimum AIC value across all models. The AIC weights represent the probability that a given model was the best among the candidate set, with values closer to 1 indicating stronger support for the model.

Model	AIC	Log_Likelihood	Parameters	Delta_AIC	AIC_Weight
(13) TC_CB_dry_c	137.7953	-63.89767	5	0.0000000	0.2679234
(14) TC_CB_dry_c_index	137.7953	-63.89767	5	0.0000000	0.2679234
(15) TC_CB_dry_b	138.0826	-64.04130	5	0.2872669	0.2320766
(16) TC_CB_dry_b_index	138.0826	-64.04130	5	0.2872669	0.2320766
(5) TC_GB_dry_c	268.0610	-129.03049	5	130.2656453	0.0000000
(6) TC_GB_dry_c_index	268.0610	-129.03049	5	130.2656453	0.0000000
(7) TC_GB_dry_b	277.0232	-133.51158	5	139.2278184	0.0000000
(8) TC_GB_dry_b_index	277.0232	-133.51158	5	139.2278184	0.0000000
(9) TC_CB_wet_c	280.8927	-135.44636	5	143.0973863	0.0000000
(10) TC_CB_wet_c_index	280.8927	-135.44636	5	143.0973863	0.0000000
(11) TC_CB_wet_b	284.1547	-137.07735	5	146.3593629	0.0000000
(12) TC_CB_wet_b_index	284.1547	-137.07735	5	146.3593629	0.0000000
(1) TC_GB_wet_c	427.6541	-208.82704	5	289.8587378	0.0000000
(2) TC_GB_wet_c_index	427.6541	-208.82704	5	289.8587378	0.0000000
(3) TC_GB_wet_b	431.7274	-210.86371	5	293.9320738	0.0000000
(4) TC_GB_wet_b_index	431.7274	-210.86371	5	293.9320738	0.0000000

Fecal coliform

Table 5.3. Fecal coliform exceedance impacts, where statistically significant coefficients are bolded. A p-value of “0” represented “<2e-16.”

Table: Fecal coliform Logistic Regression Results with Estimates and P-values

	Model Results											
Model	**Intercept**	**P-value (Intercept)**	**Weekly Deposition**	**P-value (Deposition)**	**Weekly Volume**	**P-value (Volume)**	**Weekly Rain**	**P-value (Rain)**	**Weekly Discharge**	**P-value (Discharge)**	**Sigma**	**P-value (Sigma)**
(1) FC_GB_wet_c	-4.76893	**0**	NA	NA	0.00026	**0.0219**	0.38544	0.3605	0.00122	0.77357	5.59307	**0.00254**
(2) FC_GB_wet_c_index	-4.76893	**0**	NA	NA	0.00026	**0.0219**	0.38544	0.3605	0.00122	0.77357	5.59307	**0.00254**
(3) FC_GB_wet_b	-6.49874	**6e-04**	2.17742	**0.00545**	NA	NA	0.35524	0.38286	0.00080	0.84409	2.19351	**0.0346**
(4) FC_GB_wet_b_index	-6.49874	**6e-04**	2.17742	**0.00545**	NA	NA	0.35524	0.38286	0.00080	0.84409	2.19351	**0.0346**
(5) FC_GB_dry_c_firth	-3.80588	**0**	NA	NA	0.00056	**0**	1.38535	0.88023	-0.97971	**0.00044**	NA	NA
(7) FC_GB_dry_b_firth	-3.19586	**0**	4.33401	**3e-05**	NA	NA	-28.93896	0.35759	-4.72816	0.09222	NA	NA
(9) FC_CB_wet_c	-7.95138	**0.00132**	NA	NA	-0.00001	0.97839	2.28764	**0.00028**	-0.01357	**0.01608**	2.97902	**0.01796**
(10) FC_CB_wet_c_index	-7.95138	**0.00132**	NA	NA	-0.00001	0.97839	2.28764	**0.00028**	-0.01357	**0.01608**	2.97902	**0.01796**
(11) FC_CB_wet_b	-8.35412	**0.00033**	0.32960	0.83597	NA	NA	2.57388	**0.00027**	-0.01653	**0.01836**	4.99609	**0.01306**
(12) FC_CB_wet_b_index	-8.35412	**0.00033**	0.32960	0.83597	NA	NA	2.57388	**0.00027**	-0.01653	**0.01836**	4.99609	**0.01306**
(13) FC_CB_dry_c	-5.01044	**1e-05**	NA	NA	0.00079	0.24074	3.16339	0.74254	-0.06933	0.57265	0.00000	1
(14) FC_CB_dry_c_index	-5.01044	**1e-05**	NA	NA	0.00079	0.24074	3.16339	0.74254	-0.06933	0.57265	0.00000	1
(15) FC_CB_dry_b	-5.59728	**0.00011**	4.44344	**0.02915**	NA	NA	6.01170	0.55751	-0.04945	0.46301	-0.00000	1
(16) FC_CB_dry_b_index	-5.59728	**0.00011**	4.44344	**0.02915**	NA	NA	6.01170	0.55751	-0.04945	0.46301	-0.00000	1

An analysis of fecal coliform exceedance was also conducted using binomial family panel generalized linear models across different conditions and beach locations. For models incorporating weekly volume as a continuous predictor, varying patterns of significance were observed. At Goleta Beach during wet conditions, weekly volume was significantly associated with increased exceedance probability (coefficient = 0.00026, $p = 0.0219$), with each unit increase corresponding to a 0.026% increase in exceedance odds. During dry conditions at the same location, a stronger significant relationship was observed (coefficient = 0.00056, $p < 0.001$), representing a 0.00056 unit increase in log odds per unit increase in weekly volume, or a 0.056% increase in exceedance odds per unit increase in weekly volume.

At Carpinteria Beach, weekly volume showed contrasting patterns, with no significant relationship during wet conditions (coefficient = -0.00001, $p = 0.97839$). During dry conditions, the relationship remained non-significant (coefficient = 0.00079, $p = 0.24074$).

For models using binary weekly deposition as a predictor, significant positive effects were identified in most but not all conditions. At Goleta Beach during wet conditions, the presence of deposition was significantly associated with exceedance (coefficient = 2.17742, $p = 0.00545$), with odds 8.82 times higher when deposition was present. During dry conditions, this effect was even more pronounced (coefficient = 4.33401, $p < 0.001$), with odds 76.25 times higher.

At Carpinteria Beach, binary deposition showed mixed effects, with no significant relationship during wet conditions (coefficient = 0.32960, p = 0.83597), in contrast to the strong significant relationship during dry conditions (coefficient = 4.44344, p = 0.02915), where the presence of deposition increased exceedance odds by 84.77 times.

Weekly rainfall was found to be a significant predictor of fecal coliform exceedances only during wet conditions at Carpinteria Beach (coefficient = 2.28764, p = 0.00028 for volume model; coefficient = 2.57388, p = 0.00027 for binary model), but not at Goleta Beach. Weekly discharge showed significance only at Goleta Beach during dry conditions (coefficient = -0.97971, p = 0.00044 for volume model; coefficient = -4.72616, p = 0.09222 for binary model) and at Carpinteria Beach during wet conditions (coefficient = -0.01357, p = 0.01608 for volume model; coefficient = -0.01653, p = 0.01836 for binary model).

Year-specific random effects were incorporated in most models, with standard deviations ranging from 2.19351 to 5.59307 and varying levels of significance. In models 5, 7, 13, 14, 15, and 16, standard deviation estimates were either unavailable or reached computational boundaries.

Overall, the findings demonstrated that binary deposition was a consistently stronger predictor of fecal coliform exceedance compared to continuous volume measures, particularly during dry conditions at both beaches, with effect sizes substantially larger than those observed for total coliform models.

Comparing the fecal coliform models for their ability to fit the observed data, models FC_CB_dry_b and FC_CB_dry_b_index were identified as the optimal performers, as evidenced by their identical minimum AIC values of 27.84925. These models were assigned the highest AIC weight (0.3812), indicating they were approximately 38% likely to be the best models among the candidate set examined. The FC_CB_dry_c and FC_CB_dry_c_index models were determined to be the second most supported, with AIC values of 30.18183 and a Delta_AIC of 2.332584, receiving weights of 0.1187, suggesting approximately 12% probability of being the optimal models. A substantial performance gap was observed for all remaining models, which exhibited Delta_AIC values exceeding 43 and consequently received AIC weights of effectively zero. This pattern strongly indicated that dry conditions at Carpinteria Beach, particularly those using binary weekly deposition as a parameter, were significantly better supported by the data than normal precipitation conditions or models for Goleta Beach. The log likelihood values for the best-performing models were calculated to be -8.924625, which further evidenced their superior fit to the observed data. Note that the Firth corrections used in models 5 and 7 had only four parameters, as it was implemented as a standard (non-panel) logistic regression and had no sigma coefficient to represent year-specific random effects.

Table 5.4. Comparison of all models for fecal coliform exceedances as an outcome variable. Log likelihood values were extracted, which represented the logarithm of the probability that the observed data were generated by the model. Higher (more positive) log likelihood values indicated better

model fit. The AIC weights represent the probability that a given model was the best among the candidate set, with values closer to 1 indicating stronger support for the model.

Model	AIC	Log_Likelihood	Parameters	Delta_AIC	AIC_Weight
(15) FC_CB_dry_b	27.84925	-8.924625	5	0.000000	0.3812371
(16) FC_CB_dry_b_index	27.84925	-8.924625	5	0.000000	0.3812371
(13) FC_CB_dry_c	30.18183	-10.090917	5	2.332584	0.1187629
(14) FC_CB_dry_c_index	30.18183	-10.090917	5	2.332584	0.1187629
(9) FC_CB_wet_c	70.99640	-30.498198	5	43.147145	0.0000000
(10) FC_CB_wet_c_index	70.99640	-30.498198	5	43.147145	0.0000000
(11) FC_CB_wet_b	71.75794	-30.878972	5	43.908694	0.0000000
(12) FC_CB_wet_b_index	71.75794	-30.878972	5	43.908694	0.0000000
(6) FC_GB_dry_b_firth	72.22634	-32.113168	4	44.377085	0.0000000
(5) FC_GB_dry_c_firth	79.95688	-35.978438	4	52.107626	0.0000000
(3) FC_GB_wet_b	115.52904	-52.764522	5	87.679793	0.0000000
(4) FC_GB_wet_b_index	115.52904	-52.764522	5	87.679793	0.0000000
(1) FC_GB_wet_c	124.20661	-57.103304	5	96.357356	0.0000000
(2) FC_GB_wet_c_index	124.20661	-57.103304	5	96.357356	0.0000000

E. coli

Table 5.5. E. coli exceedance impacts, where statistically significant coefficients are bolded. A p-value of “0” represented “<2e-16.”

Table: E. coli Logistic Regression Results with Estimates and P-values

	Model Results											
Model	Intercept	P-value (Intercept)	Weekly Deposition	P-value (Deposition)	Weekly Volume	P-value (Volume)	Weekly Rain	P-value (Rain)	Weekly Discharge	P-value (Discharge)	Sigma	P-value (Sigma)
(1) EC_GB_wet_c	-2.86299	0	NA	NA	0.00021	0	0.76257	3e-05	-0.00203	0.30853	-0.62237	0.00131
(2) EC_GB_wet_c_index	-2.86299	0	NA	NA	0.00021	0	0.76257	3e-05	-0.00203	0.30853	-0.62237	0.00131
(3) EC_GB_wet_b	-2.86614	0	2.69493	0	NA	NA	0.74566	5e-05	-0.00195	0.3161	0.51207	0.00591
(4) EC_GB_wet_b_index	-2.86614	0	2.69493	0	NA	NA	0.74566	5e-05	-0.00195	0.3161	0.51207	0.00591
(5) EC_GB_dry_c	-3.55383	0	NA	NA	0.00026	0.00137	-1.30049	0.78267	0.02823	0.24774	1.03130	0.00475
(6) EC_GB_dry_c_index	-3.55383	0	NA	NA	0.00026	0.00137	-1.30049	0.78267	0.02823	0.24774	1.03130	0.00475
(7) EC_GB_dry_b	-3.64403	0	3.53549	0	NA	NA	-1.50535	0.74001	0.02124	0.41179	1.05488	0.01076
(8) EC_GB_dry_b_index	-3.64403	0	3.53549	0	NA	NA	-1.50535	0.74001	0.02124	0.41179	1.05488	0.01076
(9) EC_CB_wet_c	-2.62240	0	NA	NA	0.00019	0.13715	0.89608	5e-05	-0.00051	0.65423	-0.61346	0.00978
(10) EC_CB_wet_c_index	-2.62240	0	NA	NA	0.00019	0.13715	0.89608	5e-05	-0.00051	0.65423	-0.61346	0.00978
(11) EC_CB_wet_b	-2.59159	0	0.72400	0.25846	NA	NA	0.88626	7e-05	-0.00058	0.61421	0.60042	0.01195
(12) EC_CB_wet_b_index	-2.59159	0	0.72400	0.25846	NA	NA	0.88626	7e-05	-0.00058	0.61421	0.60042	0.01195
(13) EC_CB_dry_c	-2.54521	0	NA	NA	0.00023	0.23415	-2.13286	0.63038	-0.00159	0.91509	-0.33093	0.58389
(14) EC_CB_dry_c_index	-2.54521	0	NA	NA	0.00023	0.23415	-2.13286	0.63038	-0.00159	0.91509	-0.33093	0.58389
(15) EC_CB_dry_b	-2.53704	0	1.29891	0.18573	NA	NA	-1.99104	0.65119	-0.00234	0.87177	-0.24615	0.74862
(16) EC_CB_dry_b_index	-2.53704	0	1.29891	0.18573	NA	NA	-1.99104	0.65119	-0.00234	0.87177	-0.24615	0.74862

The analysis of *E. coli* exceedance was conducted using binomial family panel generalized linear models across different conditions and beach locations. For models incorporating weekly volume as a continuous predictor, statistically significant relationships were observed only at Goleta Beach (Table __, model 1, 2). Weekly volume was significantly associated with increased exceedance probability (coefficient = 0.00021, $p < 0.001$), with each unit increase corresponding to a 0.021% increase in exceedance odds. The effect was similar for the index model. During dry conditions at Goleta Beach, weekly volume also showed a significant positive association (coefficient = 0.00026, $p = 0.00137$), representing a 0.026% increase in odds per unit.

At Carpinteria Beach, weekly volume was not statistically significant during either condition. During wet conditions, the coefficient was positive but not significant (coefficient = 0.00019, $p = 0.13715$), and similarly during dry conditions, the coefficient remained positive but did not reach statistical significance (coefficient = 0.00023, $p = 0.23415$). These results contrast with the significant associations observed at Goleta Beach.

For models using binary weekly deposition as a predictor, significant positive effects were identified only at Goleta Beach. At Goleta Beach during wet conditions, the presence of deposition was strongly associated with exceedance (coefficient = 2.69493, $p < 0.001$), with odds approximately 14.8 times higher when deposition was present. During dry conditions, this effect was even more pronounced (coefficient = 3.53549, $p < 0.001$), with odds approximately 34.3 times higher.

At Carpinteria Beach, effects for binary deposition were positive but not statistically significant, with exceedance odds 2.06 times higher during wet conditions (coefficient = 0.72400, p = 0.25846) and 3.63 times higher during dry conditions (coefficient = 1.29891, p = 0.18573) when deposition was present.

Weekly rainfall was found to be a significant predictor of both beaches during normal precipitation conditions (the wet models). At Goleta Beach, positive coefficients were observed for dry conditions (coefficient = 0.76257, p < 0.001) and wet conditions (coefficient = 0.74566, p = 0.74001), though these were not statistically significant. At Carpinteria Beach, similar positive associations occurred, in wet conditions using binary and continuous deposition variables (coefficient = 0.89608, 0.88626 respectively, p < 0.001).

Weekly discharge was not significant at either beach for any model, showing consistently negative coefficients (approximately -0.00051 to -0.00234), though there was a positive non-significant relationship at Goleta Beach during dry conditions.

Sigma values (representing year-specific random effects) were incorporated in all models, with significant year effects observed at Goleta Beach in wet condition models (sigma = -0.62237, p = 0.00131) and dry condition models (sigma = 1.05488, p = 0.01076). At Carpinteria Beach, significant year effects were observed in wet condition models (sigma = -0.61346, p = 0.00978), while year effects in dry condition models were not statistically significant.

Overall, the findings demonstrated significant positive associations between deposition measures and *E. coli* exceedance only at Goleta Beach, with particularly strong effects observed for binary deposition during both wet and dry conditions. Weekly volume also showed significant positive associations at Goleta Beach during both wet and dry conditions. Weekly rain showed positive negative relationships with exceedance probability only during wet conditions at Goleta Beach, though discharge did not have a significant impact on the log odds of an *E. coli* AB411 exceedance.

Considering all models for *E. coli* exceedances revealed that models EC_CB_dry_b and EC_CB_dry_b_index was determined to be the best performers, as evidenced by their identical minimum AIC values of 114.9516. These models were assigned the highest AIC weight (0.2649), indicating they were approximately 26% likely to be the best models among the candidate set. The EC_CB_dry_c and EC_CB_dry_c_index models followed closely with AIC values of 115.1895 and a Delta_AIC of 0.2397, receiving weights of 0.2351, which suggested approximately 24% probability of being the optimal models. A substantial performance gap was observed between these top models and all remaining candidates, with the next best models (EC_GB_dry_b and EC_GB_dry_b_index) exhibiting Delta_AIC values exceeding 96 and consequently receiving AIC weights of effectively zero. This pattern strongly indicated that dry precipitation conditions in the CB (Carpinteria Beach) configuration were significantly better supported by the data than both normal precipitation models and models using the GB (Goleta Beach) framework. The log likelihood values for the best-performing models were calculated to be -52.4758, which further substantiated their superior fit to the observed data. It was concluded that dry weather conditions with the binary weekly sediment deposition parameter (b) in the Carpinteria Beach framework provided the most reliable approach for inferring E. coli exceedances, though models using the continuous sediment deposition parameter (c) also showed strong support with only marginal differences in performance metrics.

Table 5.6. Comparison of all models for *E. coli* exceedances as an outcome variable. Log likelihood values were extracted, which represented the logarithm of the probability that the observed data were generated by the model. Higher (more positive) log likelihood values indicated better model fit. Delta AIC was computed as the difference between each model's Akaike Information Criterion (AIC) value and the minimum AIC value across all models. The AIC weights represent the probability that a given model was the best among the candidate set, with values closer to 1 indicating stronger support for the model.

Model	AIC	Log_Likelihood	Parameters	Delta_AIC	AIC_Weight
(15) EC_CB_dry_b	114.9516	-52.47578	5	0.0000000	0.2648557
(16) EC_CB_dry_b_index	114.9516	-52.47578	5	0.0000000	0.2648557
(13) EC_CB_dry_c	115.1895	-52.59476	5	0.2379723	0.2351443
(14) EC_CB_dry_c_index	115.1895	-52.59476	5	0.2379723	0.2351443
(7) EC_GB_dry_b	211.3384	-100.66918	5	96.3867960	0.0000000
(8) EC_GB_dry_b_index	211.3384	-100.66918	5	96.3867960	0.0000000
(5) EC_GB_dry_c	218.2541	-104.12706	5	103.3025566	0.0000000
(6) EC_GB_dry_c_index	218.2541	-104.12706	5	103.3025566	0.0000000
(9) EC_CB_wet_c	232.3274	-111.16372	5	117.3758856	0.0000000
(10) EC_CB_wet_c_index	232.3274	-111.16372	5	117.3758856	0.0000000
(11) EC_CB_wet_b	233.1894	-111.59471	5	118.2378591	0.0000000
(12) EC_CB_wet_b_index	233.1894	-111.59471	5	118.2378591	0.0000000
(3) EC_GB_wet_b	376.7321	-183.36606	5	261.7805663	0.0000000
(4) EC_GB_wet_b_index	376.7321	-183.36606	5	261.7805663	0.0000000
(1) EC_GB_wet_c	380.5047	-185.25234	5	265.5531235	0.0000000
(2) EC_GB_wet_c_index	380.5047	-185.25234	5	265.5531235	0.0000000

Enterococcus

Table 5.7. Total coliform exceedance impacts, where statistically significant coefficients are bolded. A p-value of “0” represented “<2e-16.”

Table: enterococcus Logistic Regression Results with Estimates and P-values

	Model Results												
Model	**Intercept**	**P-value (Intercept)**	**Weekly Deposition**	**P-value (Deposition)**	**Weekly Volume**	**P-value (Volume)**	**Weekly Rain**	**P-value (Rain)**	**Weekly Discharge**	**P-value (Discharge)**	**Sigma**	**P-value (Sigma)**
(1) EN_GB_wet_c	-2.86299	**0**	NA	NA	0.00021	**0**	0.76257	**3e-05**	-0.00203	0.30853	-0.62237	**0.00131**
(2) EN_GB_wet_c_index	-2.86299	**0**	NA	NA	0.00021	**0**	0.76257	**3e-05**	-0.00203	0.30853	-0.62237	**0.00131**
(3) EN_GB_wet_b	-2.86614	**0**	2.69493	**0**	NA	NA	0.74566	**5e-05**	-0.00195	0.3161	0.51207	**0.00591**
(4) EN_GB_wet_b_index	-2.86614	**0**	2.69493	**0**	NA	NA	0.74566	**5e-05**	-0.00195	0.3161	0.51207	**0.00591**
(5) EN_GB_dry_c	-3.55383	**0**	NA	NA	0.00026	**0.00137**	-1.30049	0.78267	0.02823	0.24774	1.03130	**0.00475**
(6) EN_GB_dry_c_index	-3.55383	**0**	NA	NA	0.00026	**0.00137**	-1.30049	0.78267	0.02823	0.24774	1.03130	**0.00475**
(7) EN_GB_dry_b	-3.64403	**0**	3.53549	**0**	NA	NA	-1.50535	0.74001	0.02124	0.41179	1.05488	**0.01076**
(8) EN_GB_dry_b_index	-3.64403	**0**	3.53549	**0**	NA	NA	-1.50535	0.74001	0.02124	0.41179	1.05488	**0.01076**
(9) EN_CB_wet_c	-2.62240	**0**	NA	NA	0.00019	0.13715	0.89608	**5e-05**	-0.00051	0.65423	-0.61346	**0.00978**
(10) EN_CB_wet_c_index	-2.62240	**0**	NA	NA	0.00019	0.13715	0.89608	**5e-05**	-0.00051	0.65423	-0.61346	**0.00978**
(11) EN_CB_wet_b	-2.59159	**0**	0.72400	0.25846	NA	NA	0.88626	**7e-05**	-0.00058	0.61421	0.60042	**0.01195**
(12) EN_CB_wet_b_index	-2.59159	**0**	0.72400	0.25846	NA	NA	0.88626	**7e-05**	-0.00058	0.61421	0.60042	**0.01195**
(13) EN_CB_dry_c	-2.54521	**0**	NA	NA	0.00023	0.23415	-2.13286	0.63038	-0.00159	0.91509	-0.33093	0.58389
(14) EN_CB_dry_c_index	-2.54521	**0**	NA	NA	0.00023	0.23415	-2.13286	0.63038	-0.00159	0.91509	-0.33093	0.58389
(15) EN_CB_dry_b	-2.53704	**0**	1.29891	0.18573	NA	NA	-1.99104	0.65119	-0.00234	0.87177	-0.24615	0.74862
(16) EN_CB_dry_b_index	-2.53704	**0**	1.29891	0.18573	NA	NA	-1.99104	0.65119	-0.00234	0.87177	-0.24615	0.74862

Enterococcus exceedance predictors were evaluated using binomial family panel generalized linear models across different conditions and beach locations. For models incorporating weekly volume as a continuous predictor, statistically significant relationships were observed at Goleta Beach in both normal (named “wet” model for easier reference) and dry conditions. At Goleta Beach during wet conditions, weekly volume was significantly associated with increased exceedance probability (coefficient = 0.00021, $p < 0.001$), with each unit increase corresponding to a 0.021% increase in exceedance odds. During dry conditions at Goleta Beach, the effect remained significant (coefficient = 0.00026, $p = 0.00137$), where each unit increase in weekly volume during dry conditions at Goleta Beach was associated with a multiplicative increase in the odds of enterococcus exceedance by a factor of 1.00026. This represented a 0.026% increase in odds per unit increase.

At Carpinteria Beach, weekly volume was not statistically significant during either condition. During wet conditions, the coefficient was positive but not significant (coefficient = 0.00019, $p = 0.13715$), and similarly during dry conditions (coefficient = 0.00023, $p = 0.23415$).

For models using binary weekly deposition as a predictor, significant positive effects were identified only at Goleta Beach. During wet conditions at Goleta Beach, the presence of deposition was strongly associated with exceedance (coefficient = 2.69493, $p < 0.001$), with odds approximately 14.8 times higher when deposition was present. During dry conditions, this effect was even more pronounced (coefficient = 3.53549, $p < 0.001$), with odds approximately 34.3 times higher.

At Carpinteria Beach, effects for binary deposition were positive but not statistically significant, with exceedance odds 2.06 times higher during wet conditions (coefficient = 0.72400, $p = 0.25846$) and 3.63 times higher during dry conditions (coefficient = 1.29891, $p = 0.18573$) when deposition was present.

Weekly rainfall was not found to be a significant predictor in any of the models, with p-values well above the 0.05 threshold across all conditions and locations. Negative coefficients were observed at Goleta Beach for dry conditions (coefficient = -1.30049, $p = 0.78267$) and wet conditions (coefficient = -1.50535, $p = 0.74001$), as well as at Carpinteria Beach, though none reached statistical significance.

Weekly discharge was statistically significant only in models for wet conditions at Goleta Beach, showing consistently negative coefficients (approximately -0.00203 to -0.00195) with p-values < 0.05. At Carpinteria Beach, discharge coefficients were also negative but did not reach statistical significance.

Sigma values (representing year-specific random effects) were incorporated in all models, with significant year effects observed at Goleta Beach in wet condition models (coefficient = -0.62237, $p = 0.00131$) and dry condition models (coefficient = 1.05488, $p = 0.01076$). Year effects were also significantly observed at Carpinteria Beach during normal precipitation models for binary (coefficient = -0.61346, $p = 0.00978$) and continuous (coefficient = 0.60042, $p = 0.01195$) deposition variables.

Overall, the findings demonstrated significant positive associations between deposition events and enterococcus exceedance only at Goleta Beach, with particularly strong effects observed for binary deposition during both wet and dry conditions. Weekly volume also showed significant positive associations at Goleta Beach. Weekly rain showed significant positive relationships with exceedance probability only during wet conditions at both beaches.

The comparison of models to infer impacts on enterococcus exceedances demonstrated that models EN_CB_dry_b and EN_CB_dry_b_index were identified as the optimal performers, as shown by their identical minimum AIC values of 114.9516. These models were assigned the highest AIC weight (0.2649), indicating they were approximately 26% likely to be the best models among the candidate set examined. The EN_CB_dry_c and EN_CB_dry_c_index models were determined to be the second most supported, with AIC values of 115.1895 and a Delta_AIC of 0.2398, receiving weights of 0.2351, suggesting approximately 24% probability of being the optimal models. A substantial performance gap was observed for all remaining models, with the next best models (EN_GB_dry_b and EN_GB_dry_b_index) exhibiting Delta_AIC values exceeding 96 and consequently receiving AIC weights of effectively zero. It was strongly indicated that dry precipitation models within Carpinteria Beach were significantly better supported by the data than both wet-weather models and models for Goleta Beach. The log likelihood values for the best-performing models were calculated to be -52.4758, reaffirming their fit to the observed data. It was concluded that dry weather conditions with the binary weekly deposition parameter (b) at both beaches provided the most reliable approach for inferring enterococcus exceedances (Table 5.8).

Table 5.8. Comparison of all models for enterococcus exceedances as an outcome variable. Log likelihood values were extracted, which represented the logarithm of the probability that the observed data were generated by the model. Higher (more positive) log likelihood values indicated better model fit. Delta AIC was computed as the difference between each model's Akaike Information Criterion (AIC) value and the minimum AIC value across all models. The AIC weights represent the probability that a given model was the best among the candidate set, with values closer to 1 indicating stronger support for the model.

Model	AIC	Log_Likelihood	Parameters	Delta_AIC	AIC_Weight
(15) EN_CB_dry_b	114.9516	-52.47578	5	0.0000000	0.2648557
(16) EN_CB_dry_b_index	114.9516	-52.47578	5	0.0000000	0.2648557
(13) EN_CB_dry_c	115.1895	-52.59476	5	0.2379723	0.2351443
(14) EN_CB_dry_c_index	115.1895	-52.59476	5	0.2379723	0.2351443
(7) EN_GB_dry_b	211.3384	-100.66918	5	96.3867960	0.0000000
(8) EN_GB_dry_b_index	211.3384	-100.66918	5	96.3867960	0.0000000
(5) EN_GB_dry_c	218.2541	-104.12706	5	103.3025566	0.0000000
(6) EN_GB_dry_c_index	218.2541	-104.12706	5	103.3025566	0.0000000
(9) EN_CB_wet_c	232.3274	-111.16372	5	117.3758856	0.0000000
(10) EN_CB_wet_c_index	232.3274	-111.16372	5	117.3758856	0.0000000
(11) EN_CB_wet_b	233.1894	-111.59471	5	118.2378591	0.0000000
(12) EN_CB_wet_b_index	233.1894	-111.59471	5	118.2378591	0.0000000
(3) EN_GB_wet_b	376.7321	-183.36606	5	261.7805663	0.0000000
(4) EN_GB_wet_b_index	376.7321	-183.36606	5	261.7805663	0.0000000
(1) EN_GB_wet_c	380.5047	-185.25234	5	265.5531235	0.0000000
(2) EN_GB_wet_c_index	380.5047	-185.25234	5	265.5531235	0.0000000

Goleta Beach Results Summary

At Goleta Beach, significant positive associations were observed between sediment deposition and bacterial exceedances across all fecal indicator bacteria (FIB) tested. Binary weekly deposition was found to be a consistently stronger predictor of exceedances compared to continuous weekly volume measurements. For total coliform bacteria, the presence of deposition was associated with 17.87 times higher odds of exceedance during wet conditions and 29.03 times higher odds during dry conditions. Similar patterns were detected for fecal coliform, where exceedance odds were 8.82 times higher during wet conditions and 76.25 times higher during dry conditions when deposition was present. For *E. coli*, deposition presence was linked to approximately 14.8 times higher exceedance odds during wet conditions and 34.3 times higher odds during dry conditions. Enterococcus exceedances were similarly impacted, with odds approximately 14.8 times higher during wet conditions and 34.3 times higher during dry conditions when deposition was present. Weekly rainfall was determined to be a significant predictor primarily during wet conditions, while weekly discharge exhibited limited significance across most models. Overall, stronger positive associations between deposition events and bacterial exceedances were consistently observed during dry conditions compared to wet conditions at Goleta Beach, suggesting that the impact of sediment deposition on beach water quality was most pronounced during periods with minimal rainfall.

Carpinteria Beach Results Summary

At Carpinteria Beach, variable associations were observed between sediment deposition and bacterial exceedances across the fecal indicator bacteria (FIB) tested. For total coliform, significant positive relationships were identified with both weekly volume and binary deposition measures. The presence of deposition was associated with 3.91 times higher odds of exceedance during wet conditions and 12.43 times higher odds during dry conditions. For fecal coliform, contrasting patterns were detected, with no significant relationship found between weekly volume and exceedance during either wet or dry conditions. However, binary deposition showed a strong significant relationship during dry conditions, where exceedance odds were increased by 84.77 times, while no significant effect was observed during wet conditions. For both *E. coli* and enterococcus, weekly volume was not determined to be statistically significant during either condition. While the effects of binary deposition were positive (2.06 times higher odds during wet conditions and 3.63 times higher during dry conditions), these associations did not reach statistical significance. Weekly rainfall was found to be a significant predictor during wet conditions for total coliform and *E. coli*, while weekly discharge showed significance primarily during wet conditions for fecal coliform. Notably, models for dry conditions at Carpinteria Beach consistently demonstrated superior statistical fit across all FIB types compared to other models, as evidenced by their consistently lower AIC values and higher AIC weights.

Objective 2

Evaluate the social impact and public perceptions of sediment disposal activities by conducting a beachgoer activity and demographic survey at Goleta and Carpinteria beaches.

The demographic survey received 188 total responses, comprised of 88 respondents from Goleta Beach and 100 respondents from Carpinteria Beach. Survey field notes recorded a total number of 290 respondents who agreed to participate in the survey and 74 individuals who declined, with a response rate of 79.6%. The response rates for each survey site were 82.6% for Carpinteria Beach and 76.4% for Goleta Beach. Of the 290 individuals recorded who stated that they would participate in the survey, only 64.8% of the responses were fully completed and usable for analysis.

Survey question 2.17 (“Considering what you now know about sediment deposition activities at this beach, how do you think this will impact your future visits to this beach? (Will your visits become more or less frequent and why?)” was the only free-response question. A list of responses to this question is provided in Appendix B in lieu of graphical visualization or statistical analysis. Graphical visualizations were conducted for the survey's demographic questions (Appendix A, Q3.1-3.5 & Q3.7).

Age Distribution by Survey Site

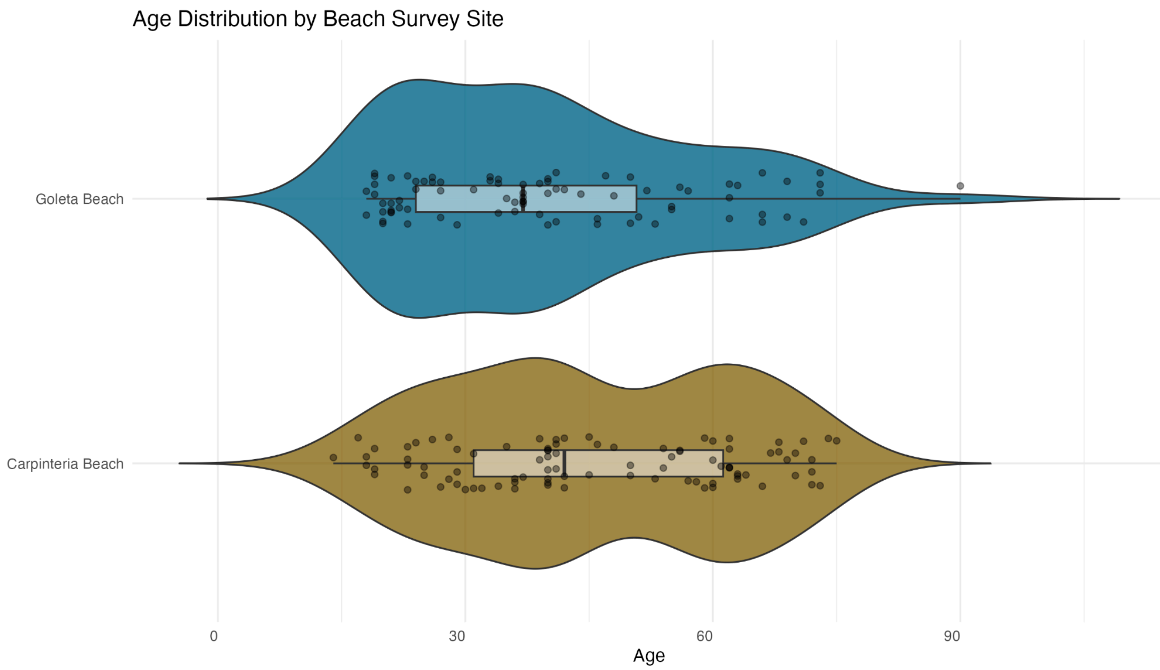


Figure 5.10. Violin plot of age distribution by beach survey site.

The age distribution for Goleta Beach visitors is skewed to the right (Figure 5.10). Carpinteria Beach exhibited a distribution with data clustered towards the ends. The mean age for Carpinteria respondents was 45 years old and 39 years old for Goleta respondents (Table 5.9). The maximum ages differed between the beaches where the oldest respondent from Carpinteria was 75 and the oldest at Goleta was 90. Other summary statistics for age distribution are shared in Table 5.9.

Table 5.9. Summary statistics for age distribution by beach survey site.

Beach Site	Min	Max	Median	Mean	Q1	Q3	SD
Carpinteria	18	75	42	45	31	61.25	17.07
Goleta	18	90	37	39	24	50.75	17.23

Gender Identity by Survey Site

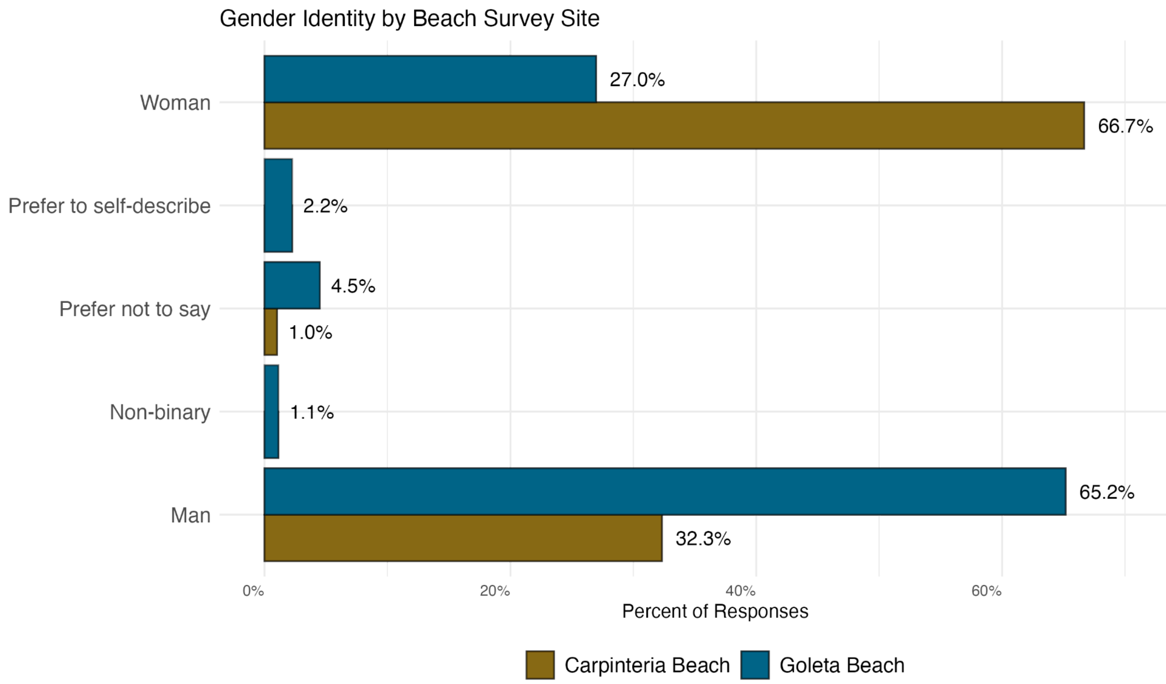


Figure 5.11. Bar plot of respondents' gender identity by beach survey site.

At Goleta Beach, more men (65.2%) took the survey than women (27%). Carpinteria Beach saw the opposite trend, with more women than men participating in the survey (Figure 5.11). No respondents indicated that they identified as non-binary or preferred to self-describe at Carpinteria Beach. Four respondents preferred not to share their gender identities.

Race/Ethnicity by Survey Site

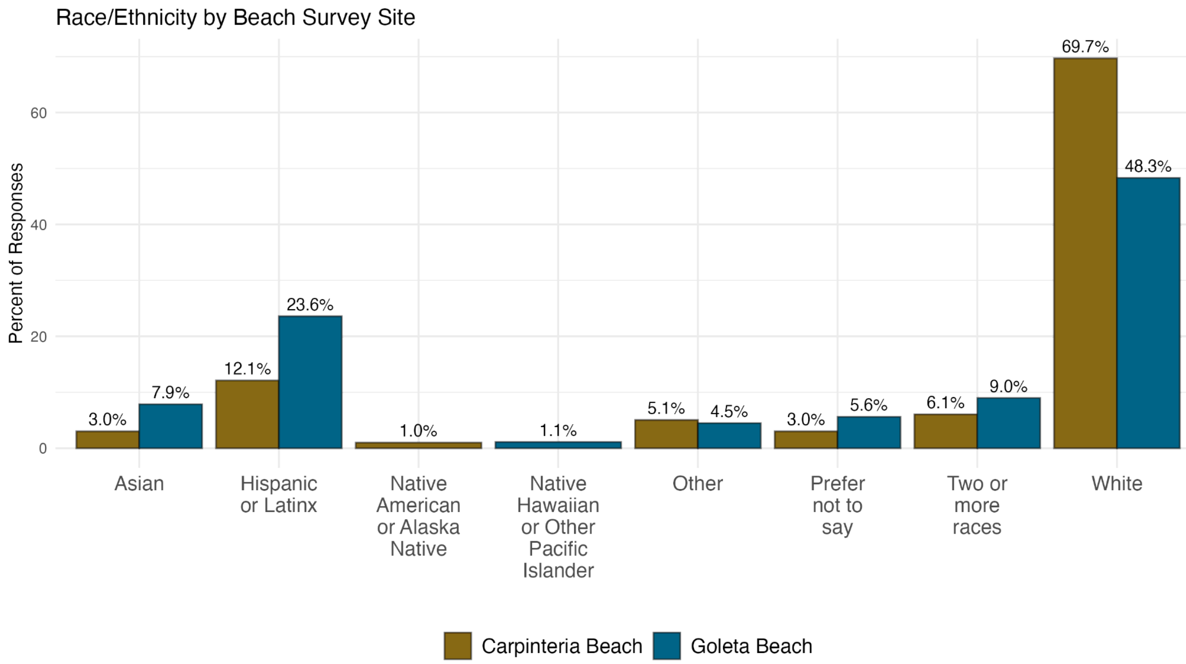


Figure 5.12. Bar plot of respondents' race/ethnicity by beach survey site.

Most respondents at each survey site indicated that they were White, with 69.7% at Carpinteria and 48.3% at Goleta Beach (Figure 5.12). No respondents identified as Native American or Alaska Native at Goleta Beach, and no respondents identified as Native Hawaiian or Other Pacific Islander at Carpinteria Beach. Five respondents preferred not to identify their race/ethnicity.

Household Income Distribution by Survey Site

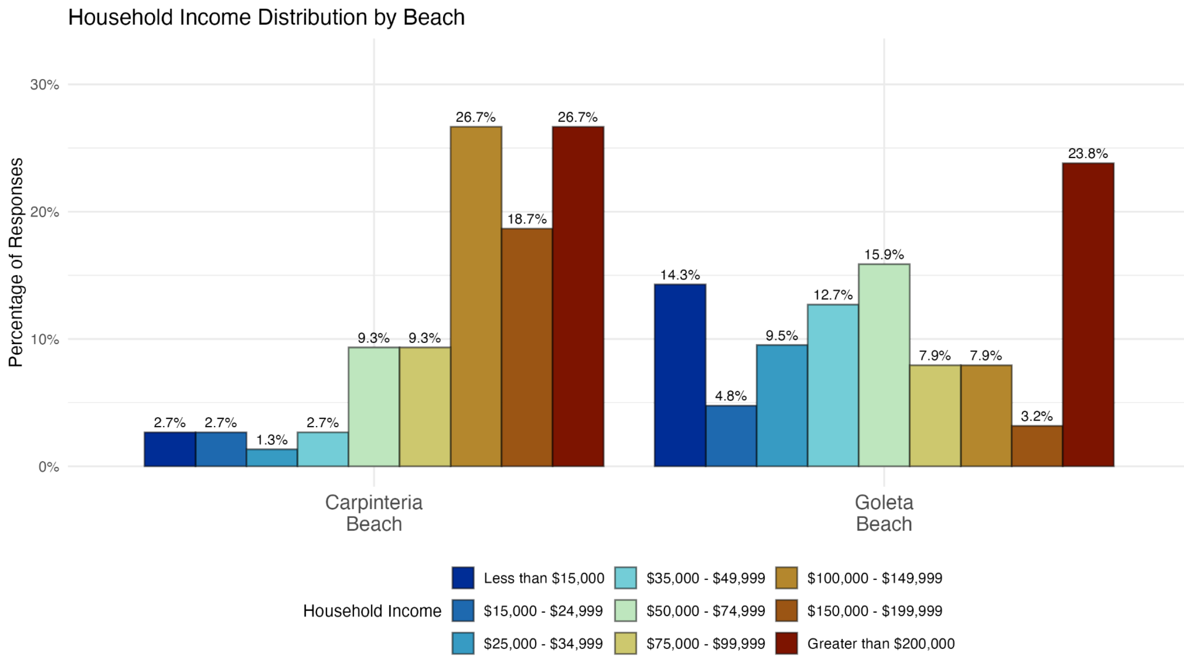


Figure 5.13. Household income distribution for each survey site.

Carpinteria Beach exhibited a left-skewed distribution, and Goleta Beach had a less skewed distribution with higher tails (Figure 5.13). Compared to Carpinteria Beach, Goleta Beach had a higher percentage of respondents with incomes less than $15,000 and from the range of $15,000 to $74,999. Carpinteria Beach had a higher proportion of visitors with household incomes over $75,000. Not included in Figure 5.13 were 34 individuals who preferred not to share their income and 15 people who were not sure.

Employment Status by Survey Site

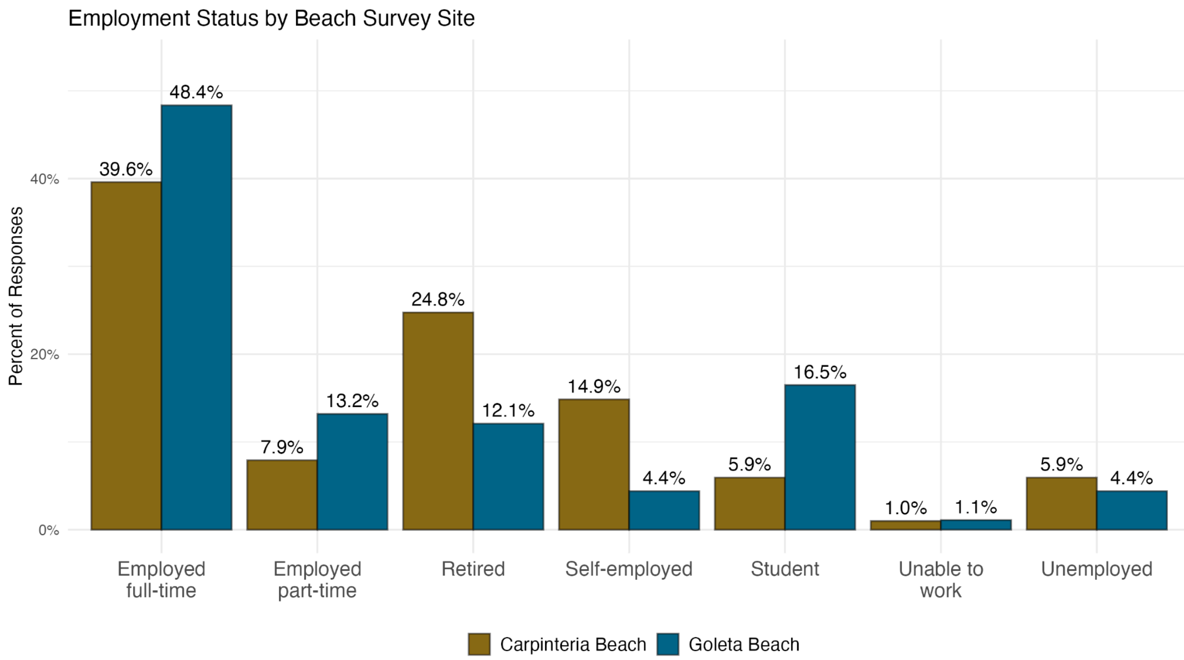


Figure 5.14. Bar plot of respondents' employment status by beach survey site.

Most respondents at both survey sites were employed full-time (Figure 5.14). Employed full-time, retired, and self-employed were the top three employment statuses for respondents at Carpinteria Beach. In comparison, Goleta Beach had visitors who were employed full-time, employed part-time, and students as the three highest employment statuses.

Languages Spoken by Respondents, Separated by Survey Site

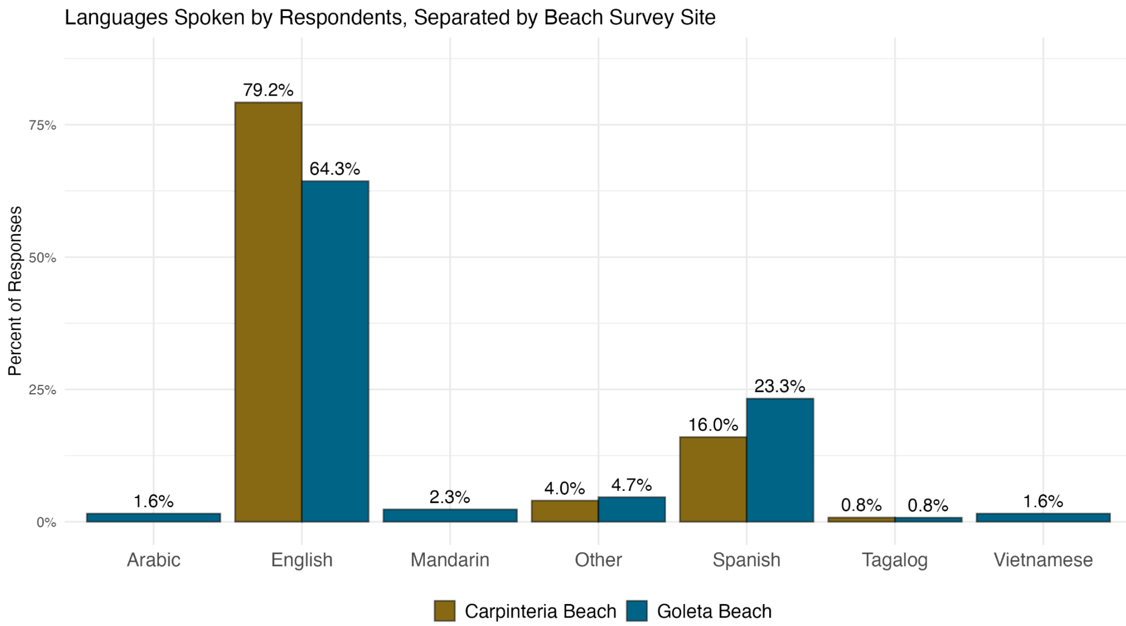


Figure 5.15. Bar plot of languages spoken by respondents, distinguished by beach survey site.

The most spoken language at both beaches was English, followed by Spanish. 79.2% of respondents at Carpinteria and 64.3% at Goleta spoke English. No visitors spoke Arabic, Mandarin, or Vietnamese at Carpinteria Beach (Figure 5.15). Other languages spoken by respondents included French, Italian, Quechua, Hebrew, Japanese, German, Punjabi, Romanian, and Russian.

Hypothesis Testing for the Beach Demographic and Activity Survey

Hypothesis 1

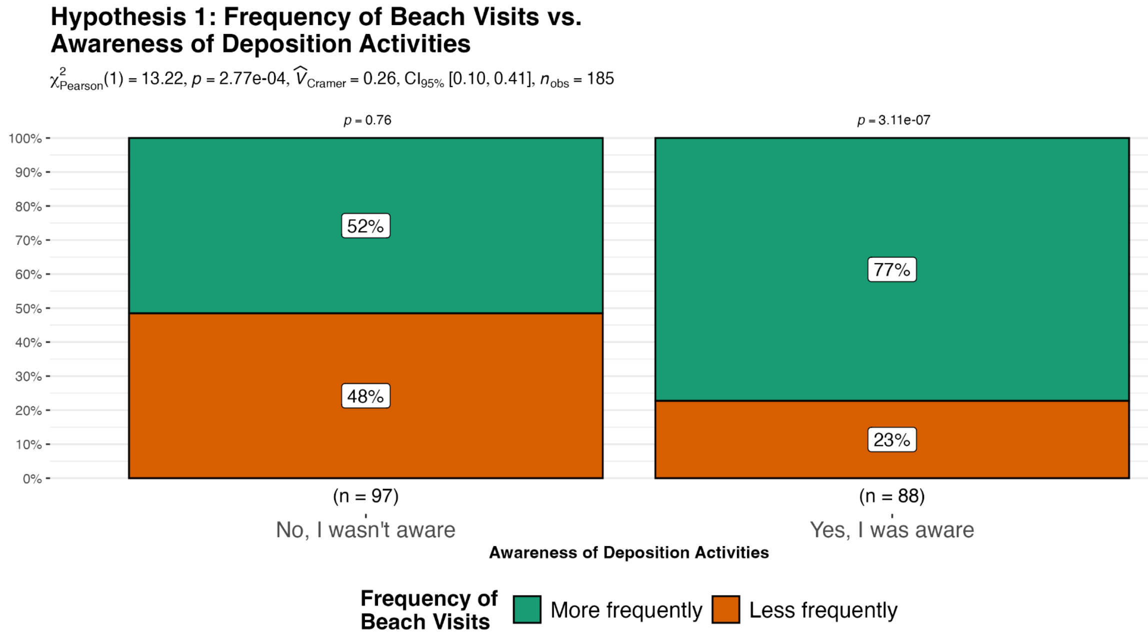


Figure 5.16. Responses for survey questions that asked about frequency of beach visits and awareness of deposition activities. Chi-square and Cramer's V test was performed. "Survey responses as 'This is my first visit', 'Less than once a year', and 'A few times a year' were categorized as 'Less frequently'. Responses as 'Monthly', 'Weekly or more often' were categorized as 'More frequently.'"

The predicted result was: "Visitors who indicate that they visit either Goleta or Carpinteria Beach "a few times a year," "less than once a year," or "this is their first visit," are less likely to be aware of sediment disposal at the beach site compared to those who visit the beach "Monthly" or "Weekly or more often." For hypothesis 1, the X^2 was 13.22 with a P equal to 2.77e-04. Cramer's V is 0.26, indicating a weak association between the categories (Figure 5.16). Within each response group for awareness of deposition activities, $P = 0.76$ for visitors who were not aware and $P = 3.11e-07$ for those who were aware.

Hypothesis 2

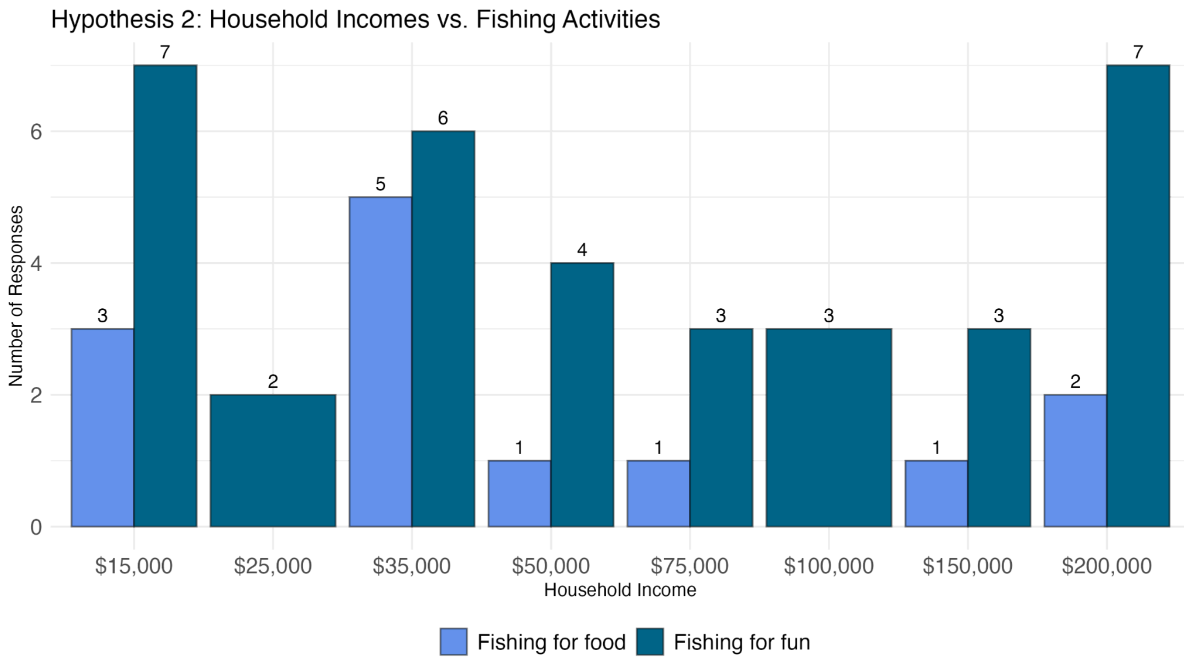


Figure 5.17. Responses that indicated visitors engage in fishing for food and for fun are plotted in correlation to their household incomes.

The predicted result for hypothesis 2 was that lower-income visitors are more associated with fishing activities at the beach. 49 respondents indicated that they visited the two survey sites to fish for fun or for food (Figure 5.17). For this analysis, lower-income groups were designated as those who make under $100,000 a year, regardless of household size. In Santa Barbara County, the Area Median Income in 2024 was $119,000 for a family of 4 (Kirkeby, 2024). For a single person, the low-income threshold is $91,200. U.S. Census income categories used in the survey did not provide the granularity to distinguish incomes between $100,000 and $150,000. Therefore, any responses under the $100,000 threshold were considered to be low-income, regardless of household size. The p-value was 0.37, with a correlation of -0.13. There is no statistical significance in income among beach visitors who choose to fish. Our analysis did not include a test of significance to evaluate the median incomes of fishermen to the median income of overall beach visitors.

Hypothesis 3

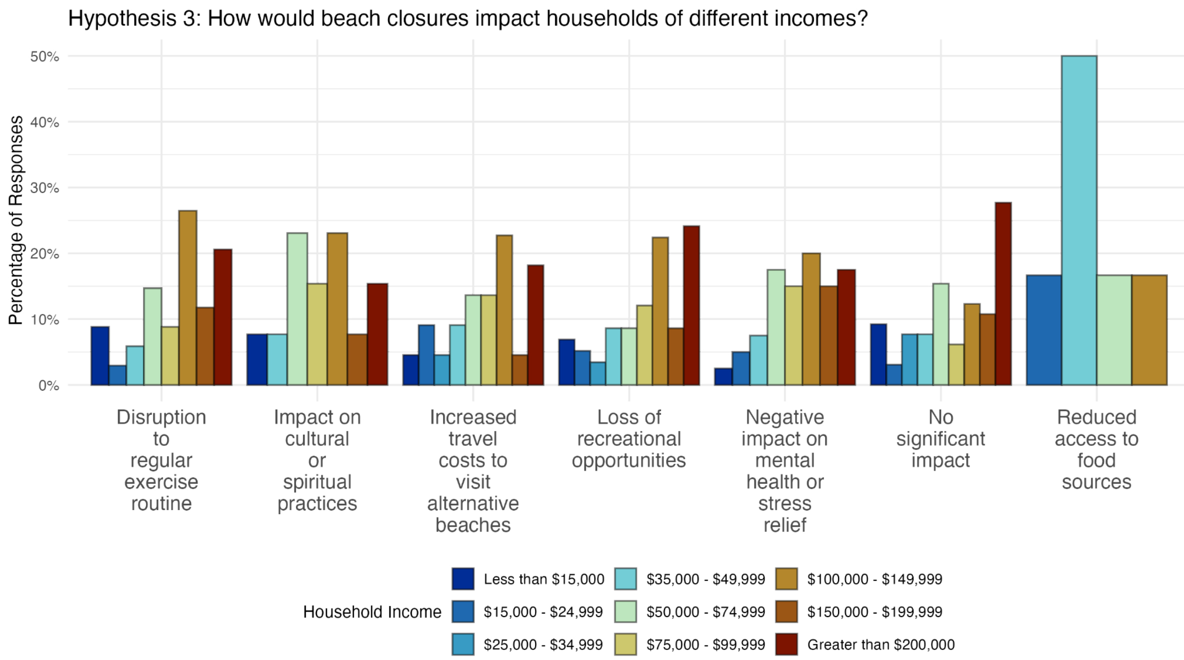


Figure 5.18. Responses for survey questions that asked for respondents' household incomes and how beach closures would impact their visits. Visit impacts were classified by household income. Percentages across each 'impact option' equals to 100% for one household level income.

Hypothesis 3 predicted that beach closures would most impact low-income individuals. The X^2 test returned a p-value of 0.26. Data visualization revealed that respondents who selected "Reduced access to food sources" as an impact were from incomes only ranging between $15,000-$150,000, compared to the other categories that ranged across all groups (Figure 5.18).

Hypothesis 4

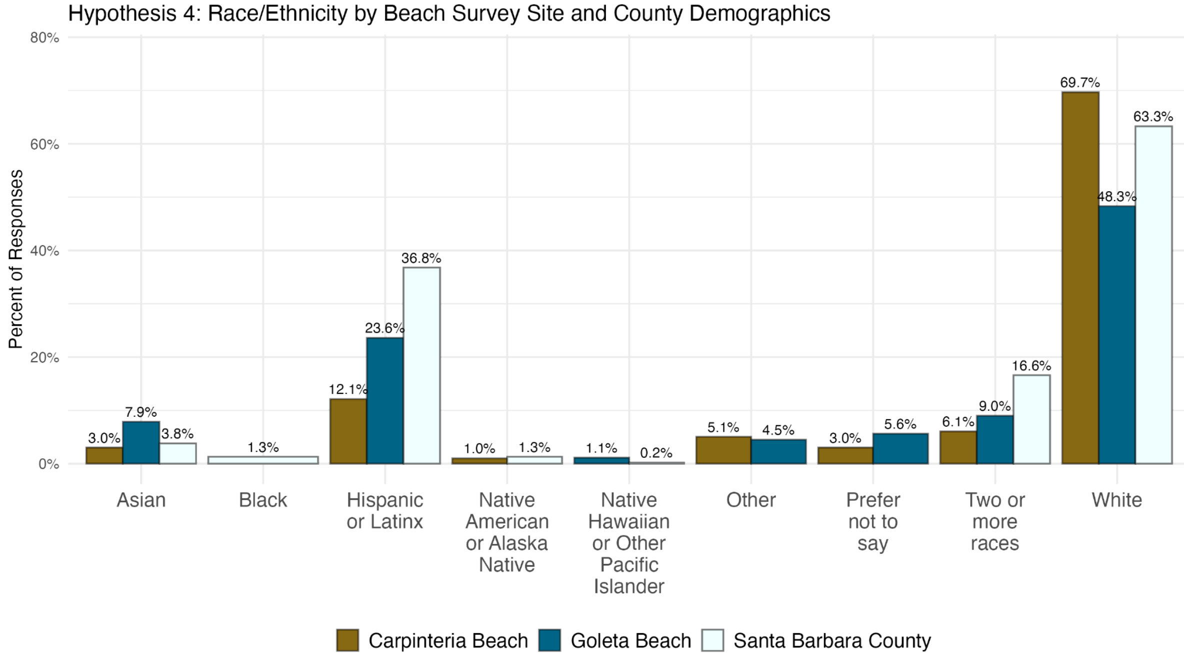


Figure 5.19. Race/ethnicity separated by each beach site. Santa Barbara County demographics were added, with data retrieved from the U.S. Census Bureau.

Hypothesis 4 predicted that there was a higher proportion of non-White visitors at Goleta and Carpinteria beaches when compared to County demographics. Survey results showed that of non-White respondents, individuals identifying as Asian (7.9%) or Native Hawaiian or Other Pacific Islander (1.1%) at Goleta Beach were the only groups with a higher proportion than the broader Santa Barbara County (Figure 5.19). There were no Black respondents at either survey site and no Native Hawaiian or Other Pacific Islanders at Carpinteria Beach. Compared to County demographics, the proportion of Hispanic or Latinx respondents wwaslower at Goleta Beach by about 13.2% and 24.7% at Carpinteria Beach. There was a higher percentage of White respondents at Carpinteria Beach (69.7%) compared to Santa Barbara County (63.3%).

Hypothesis 5

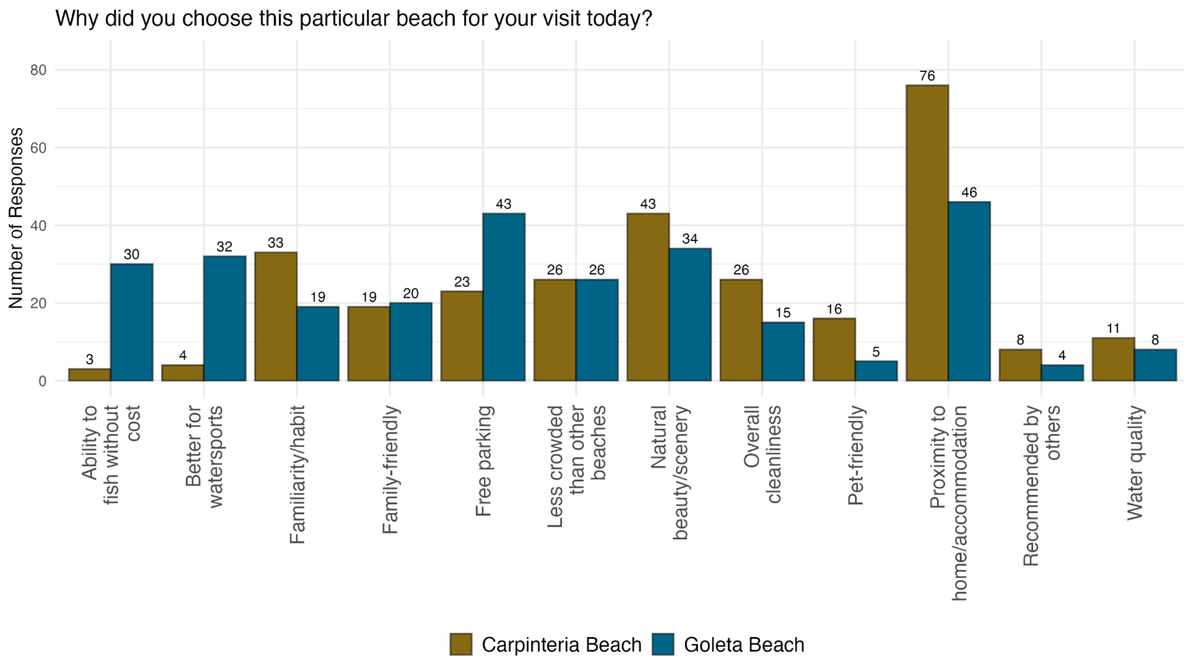


Figure 5.20. Responses, separated by beach site, for a survey question that asked, "Why did you choose this particular beach for your visit today?"

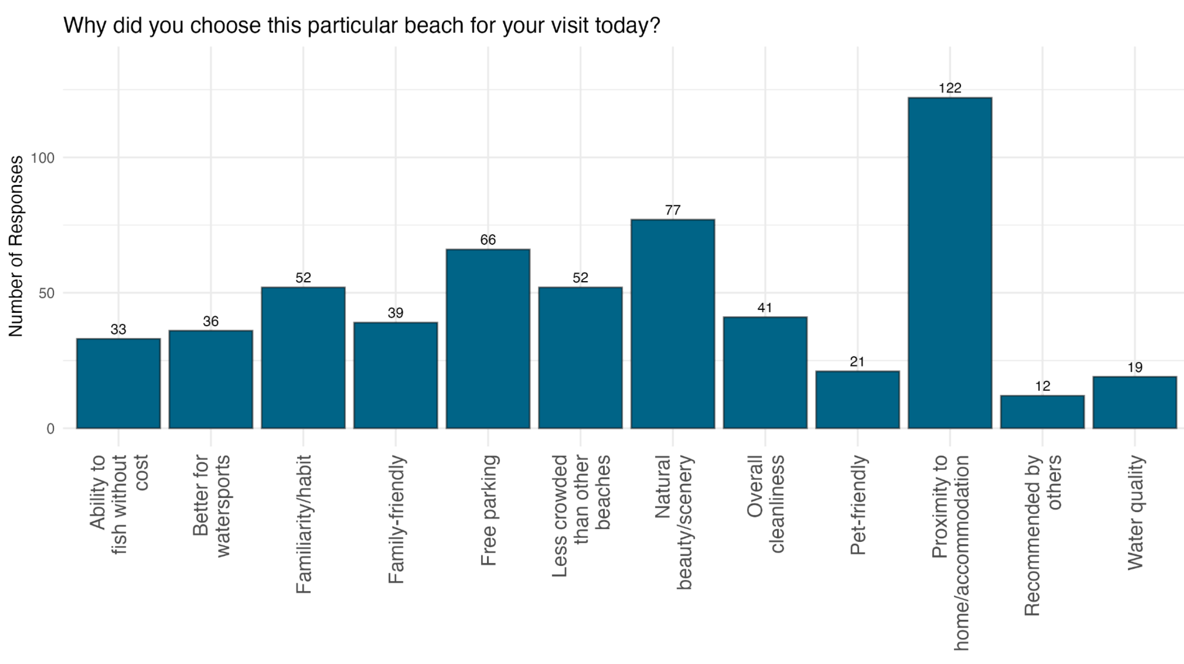


Figure 5.21. Responses, combined across both survey sites, for a survey question that asked, "Why did you choose this particular beach for your visit today?"

Hypothesis 5 predicted that the accessibility features of free parking, proximity to home, and fewer crowds are among the most popular reasons for visiting either beach. A factor is considered among the most popular if it is one of the three most selected answer choices. Proximity to home/accommodation was the most selected reason for responses separated by beach and combined from both sites (Figure 5.20). Free parking was the second most-selected factor for Goleta Beach, but not in the top three for Carpinteria Beach. "Less crowded than other beaches" was not among the most popular reasons for either beach. The third most selected option for Carpinteria was familiarity/habit and natural beauty/scenery for Goleta. Combined responses from both beaches have proximity to home, natural beauty/scenery, and free parking as the most popular reasons for visiting either beach (Figure 5.21).

A significant relationship exists between beach site and reason of visit among the respondents. The X^2 test returned a p-value of 3.87e-11, which is less than the 0.05 significance level. By looking at the contributions from the statistical analysis, the two largest contributors to the difference in reasons for visitation to each beach were "Ability to fish without cost" and "Better for water sports."

Hypothesis 6

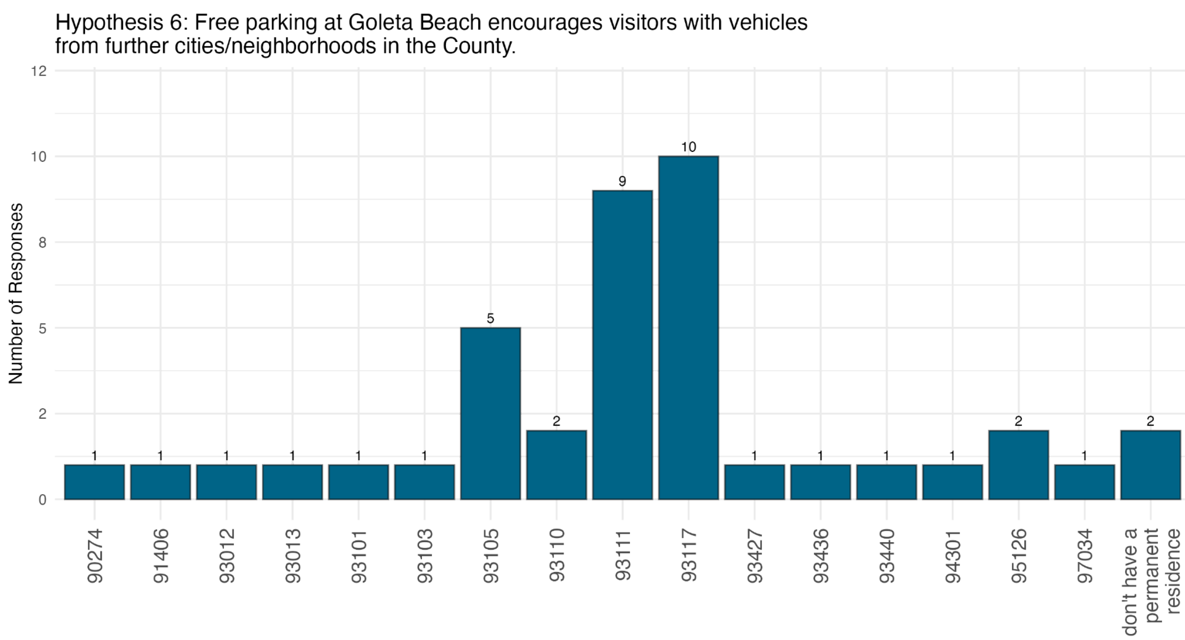


Figure 5.22. Responses that indicated free parking was a reason for choosing either Goleta or Carpinteria Beach were selected. The counts of zip codes of respondents were plotted.

Hypothesis 6 predicted that free parking at Goleta Beach encourages visitors with vehicles from further cities/neighborhoods in the County, increasing the spatial range of beach closure impacts. For this hypothesis, we define "further cities and neighborhoods" from Goleta

Beach as zip codes that are not located in the city of Goleta. Respondents from the two Goleta zip codes were recorded the most at 19 counts (Figure 5.22). There were 41 respondents who selected "free parking" as a reason why they chose to visit Goleta Beach. There were 16 different zip codes correlated with each response, with two participants indicating that they do not have a permanent residence. The zip code with the most respondents that chose Goleta Beach for its free parking is 93117, followed by 93111 and 93105.

The zip codes correspond with the following counties and regions:

- Los Angeles County: 90274, 91406
- Ventura County: 93012, 93013
- Northern Santa Barbara (SB) County: 93427, 93436, 93440
- Southern SB County: 93101, 93103, 93105, 93110
- SB County, City of Goleta: 93111, 93117
- Santa Clara County: 94301, 95126
- Clackamas County, Oregon: 97034

Hypothesis 7

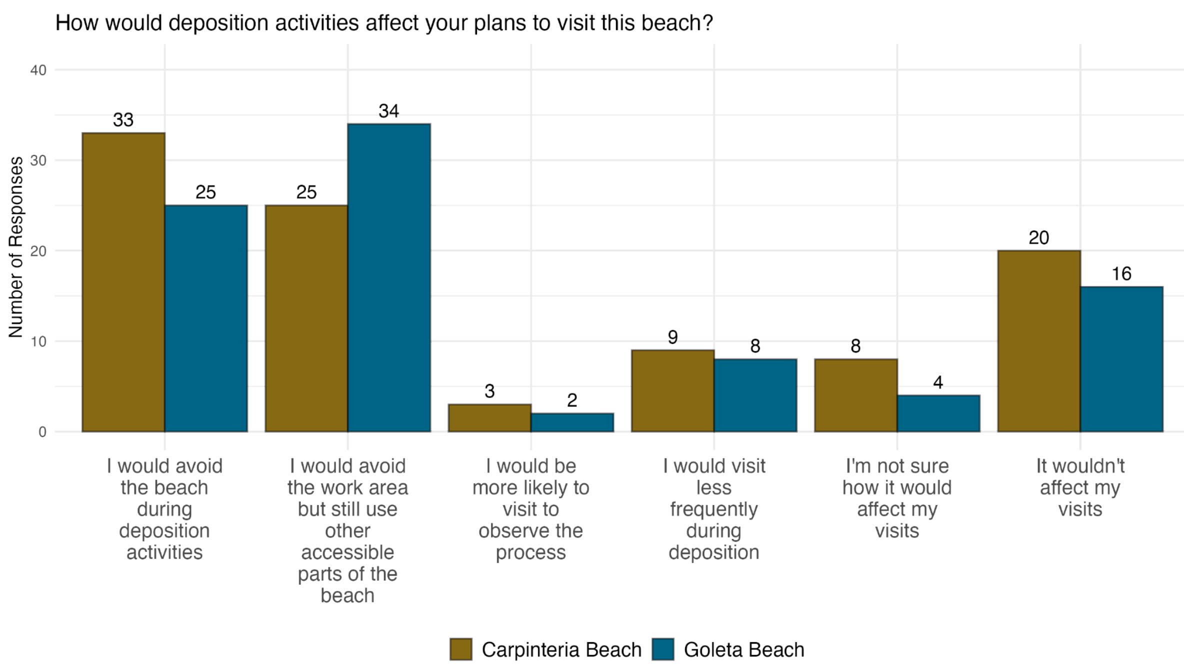


Figure 5.23. Survey responses for the question that asked, "How would deposition activities affect your plans to visit this beach?" Responses were separated by survey sites.

From both survey sites combined, there were 58 responses that selected "I would avoid the beach during deposition activities" when asked how deposition activities would affect their plans to visit the survey site. At Carpinteria, most respondents reported that they would avoid the beach during deposition activities while Goleta respondents selected that they would avoid the work area but still use other accessible parts of the beach the most (Figure 5.23).

Hypothesis 7 predicted that beach visitors are more likely to avoid the entire beach during sediment deposition activities. There is a significant difference between visitors who would avoid the beach and people who would visit less frequently, are more likely to visit to observe the process, and those who are unsure how it would affect their visits (Table 5.10). There is no significant difference when compared to people who would avoid the work area but still access other parts of the beach and those whose beach visits would not be affected. When testing responses that stated "I would avoid the beach during deposition activities" against all other categories combined, the X^2 coefficient = 26.96 with P = 2.08e-07.

Table 5.10. X^2 coefficients, P-values, and response counts for comparison of survey respondents who would avoid the beach during deposition activities to those who selected a different response.

Future beach visit impacts	**I would avoid the work area but still use other accessible parts of the beach**	**Would visit less frequently**	**Wouldn't affect my visits**	**I'm not sure how it would affect my visits**	**I would be more likely to visit to observe the process**
X^2 Coefficient	1.44e-30	16.01	2.99	22.49	34.91
P-value	1	6.28e-05	0.08	2.12e-06	3.45e-09
Response counts	59	17	36	12	5

Hypothesis 8

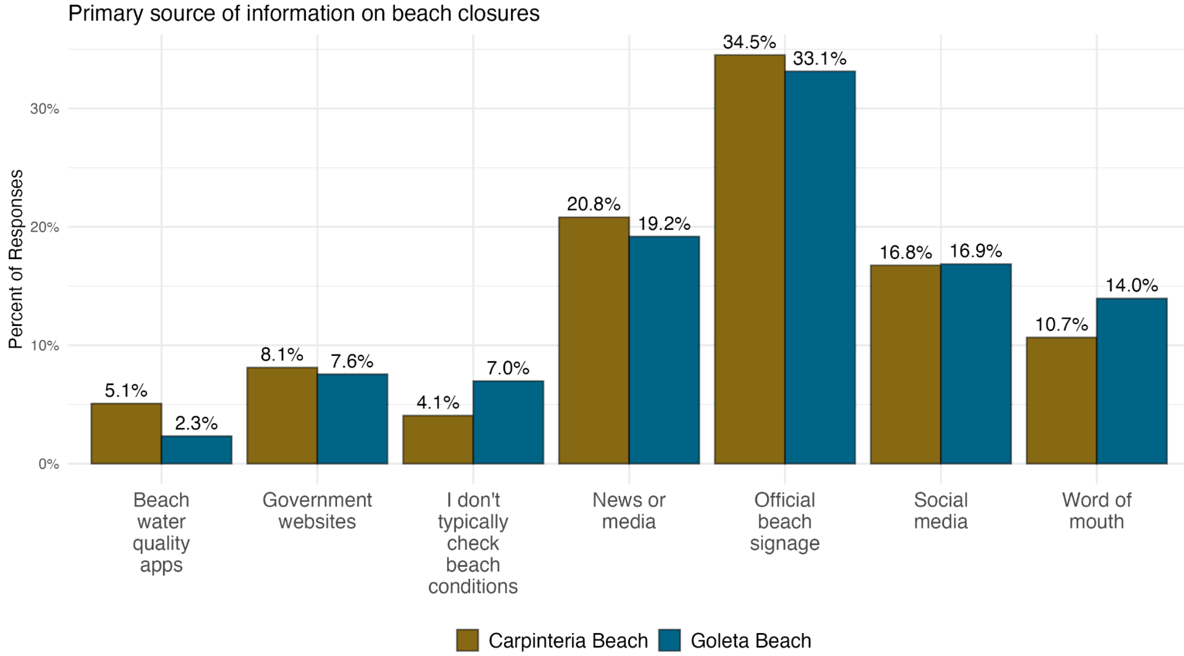


Figure 5.24. Responses for the survey question that asked "If you learned about a beach advisory, what would be your primary source of information about the safety conditions?" Responses are differentiated by beach site.

125 respondents indicated that they receive information about beach advisories from official beach signage. Official beach signage was the most selected source of information with 34.5% of responses at Carpinteria and 33.1% at Goleta Beach (Figure 5.24). Using an alpha-value of 0.05, all sources of information are significantly different from official beach signage (Table 5.10). Beach water quality apps and government websites have the highest X^2 values for beach advisory information sources other than official beach signage.

Table 5.11. X^2 coefficients, P-values, and response counts for comparison of "Official beach signage" against "other categories."

Source of Information	**Beach water quality apps**	**Government Websites**	**News or media**	**Social Media**	**"I don't typically check beach conditions."**
X^2 coefficient	68.85	44.01	7.81	13.53	57.82
P-value	1.06e-16	3.25e-11	0.005	2.34e-4	2.87e-14
Response counts	14	29	74	62	20

Hypothesis 9

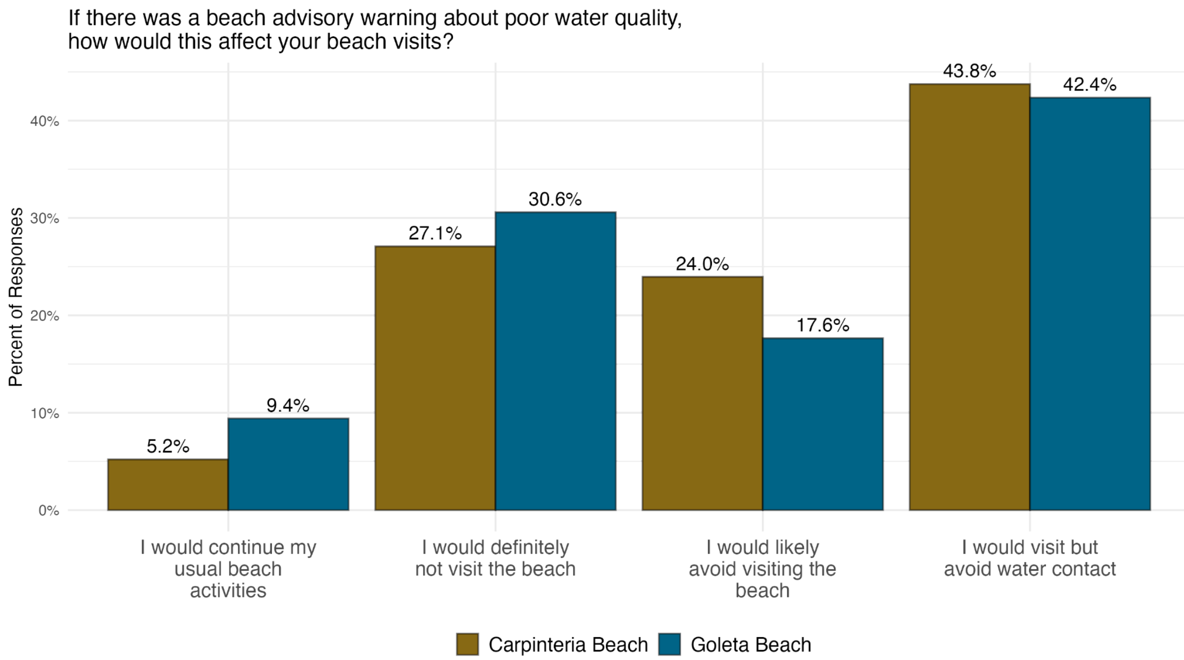


Figure 5.25. Responses for the survey question that asked "If there was a beach advisory warning about poor water quality, how would this affect your visit?" Response percentages are differentiated by beach site.

The predicted result for hypothesis 9 was that "beachgoers will be more likely to definitely not visit the beach if there is a beach advisory declared." 52 respondents combined across both survey sites indicated that they would definitely not visit the beach during a beach advisory. At both beaches, most respondents reported that they would still visit the beach, but avoid water contact (Figure 5.25). When comparing this response to the other responses listed in table 5.12, there was a statistically significant difference among beachgoers who would continue usual beach activities during a beach advisory. There was no statistically significant difference between "definitely not visit" and the other two choices where beachgoers would "likely avoid visiting the beach" and "would visit but avoid water contact."

Table 5.12. X^2 coefficients, P-values, and response count for comparison of responses indicating "I would definitely not visit the beach" and "other categories." Calculated values are from all responses across both beaches.

Future beach visit impacts	Would continue usual beach activities	Likely avoid visiting the beach	Would visit but avoid water contact
X^2 coefficient	17.40	1.17	1.93

P-value	3.03e-05	0.28	0.17
Response counts	13	38	78

In a second X^2 test where the other three responses ("Would continue usual beach activities, likely avoid visiting the beach, would visit but avoid water contact") were combined into one category of "other categories" to compare to "definitely not visit the beach," the p-value was 1.04e-08 with a X^2 coefficient of 32.76. There is a significant difference between respondents who reported they would definitely not visit and the other categories combined.

Hypothesis 10

Hypothesis 10 predicted that household income distributions would differ between Goleta and Carpinteria Beach. Results of the Fisher's test of significance returned a p-value 0.00011, which is under the 0.05 threshold. The null hypothesis was rejected, revealing a significant difference in distributions among the two beach study sites. Carpinteria Beach had a significantly higher income compared to Goleta Beach, whose median income was around $50,000 to $74,999. The Cramer's V analysis for effect size returned 0.41, implying that the beach site had a moderate effect on the income distribution.

Objective 3

Recommend potential modifications to permits that guide debris basin clearing and associated beach disposal activities to promote more environmentally and socially equitable emergency sediment disposal activities at Goleta and Carpinteria beaches.

The analysis of routine and emergency permits worked to identify limitations in sediment monitoring, disposal procedures, and stakeholder engagement. The findings from this review are summarized in the following tables, which categorize current permit structures, analyze ecological and social impacts, and assess feasibility and impact levels for potential modifications.

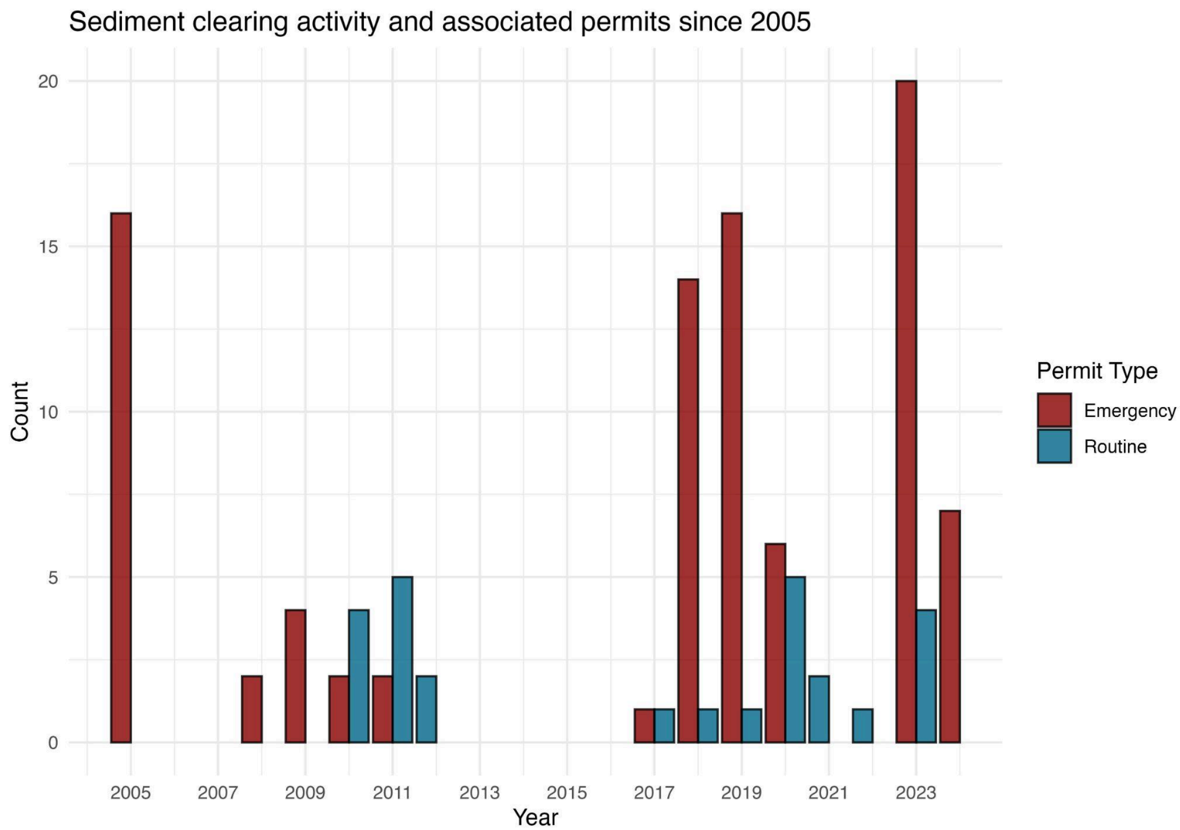


Figure 5.26. Trends in sediment clearing activity and associated permits since 2005, categorized by permit type (Emergency vs. Routine). An increase in reliance on emergency permits is shown, particularly after 2017.

Between the eighteen-year period, there was a sharp increase in emergency permits after 2017, with notable peaks in 2019, 2021, and 2023 (Figure 5.26). This trend suggests that sediment deposition events require urgent intervention due to extreme emergency events. The reliance on emergency permits indicates that sediment disposal activities are primarily reactive, addressing crises as they arise rather than following a long-term management plan.

Permit Review and Identified Gaps

Table 5.13. A comprehensive table of permits that SBCFCD operates under during routine and emergency sediment disposal activities.

Agency	State Water Resources Control Board	U.S. Army Corps of Engineers	California Coastal Commission	California Department of Fish and Wildlife
Routine	Central Coast RWCB – Water Quality	Flood Control Routine Maintenance and Goleta	Coastal Development Permit	Lake or Streambed Alteration Agreement

	Certification	Slough Dredging Activities		
Emergency	Emergency Water Quality Certification (For Permit Number 63)	Permit Number 63 for Repair and Protection Activities in Emergency Situations	Emergency Coastal Development Permit Waiver	Lake or Streambed Alteration Program – Notice of Emergency Work

Table 5.14. Permit Analysis of routine and emergency permits gaps with the inclusion of ecological and social impacts.

Permit	**Gaps**	**Ecological Impacts**	**Social Impacts**
Central Coast RWCB - Water Quality Certification	Strict limit and sediment characteristics (fine grain percentage, volume)	Sediment quality standards help protect coastal ecosystems, but rigid requirements may not account for all natural sediment variation.	Transparent standards build trust, but deviations could lead to concerns over environmental impact.
Emergency Water Quality Certification (For Permit Number 63)	A compressed timeline of 180 days may be restrictive and overlook cumulative impacts over time.	Provides water quality protection, though a shortened timeline risks missing gradual or environmental effects.	Enables a quick response to water quality, but residents might question the thoroughness of long-term environmental protection.
Flood Control Routine Maintenance and Goleta Slough Dredging Activities	Rigid reporting and maintenance schedules may limit adaptive responses and delays in updating procedures in response to ecological changes.	Routine maintenance helps preserve aquatic habitats. Limits on adaptive responses may hinder ecological adjustments when conditions change.	Structured reporting promotes accountability, but delays may reduce public confidence in prompt sediment management.
Permit Number 63 for Repair and Protection Activities in Emergency Situations	Tight timeframes may limit thorough environmental review and allow for relaxed precautionary measures.	Rapid interventions help mitigate damage but might not fully address longer-term ecological restoration needs.	Action supports community safety, but the process can be seen as a bypass for environmental standards.
Coastal	Focused on routine	Regular monitoring	Maintains

Development Permit	operations with periodic testing that does not address emergency events.	supports long-term coastal health.	operations.
Emergency Coastal Development Permit Waiver	Limited detail on follow-up monitoring after emergency action.	Rapid action may bypass comprehensive environmental assessment, risking incomplete sediment evaluation and habitat impacts	Quick response benefits communities during emergency events but may raise concerns about reduced monitoring
Lake or Streambed Alteration Agreement	Protective measures for wildlife could be vague and may not incorporate the latest biological monitoring data.	The purpose is to protect species and habitats, but vague guidelines can result in insufficient protection.	Designed to protect communities' natural resources, but imprecise measures may raise concerns.
Lake or Streambed Alteration Program – Notice of Emergency Work	This may reduce stakeholder engagement and delay community input.	Facilitates immediate response during emergencies but may limit ecological assessments.	Expedites work during emergency events but reduce upfront transparency.

Evaluation of Feasibility and Impact of Recommended Permit Modifications

Table 5.15. Two Dimensional Evaluation Matrix

	Highly Feasible	Moderately Feasible	Less Feasible
High Impact	● Improve public education and outreach programs. ● Ensure proper placement of advisory signage. ● Expand AB 411 monitoring closer to deposition sites.	● Including/moving an AB411 site close to the deposition sites ● Strengthen follow-up water quality monitoring requirements ub emergency permits. ● Require clear post-disposal impact assessments for all emergency events.	● Develop a Sediment holding and processing facility. ● Implement nature-based solutions such as beach dunes for sediment retention. ● Modify emergency permit language to require long-term impact studies.
Moderate Impact	● Implement standardized SOPs for routine and emergency	● Enhance operational protocols through targeted training	● Require a 5-year review annual review to refine

	sediment disposal. ● Increase the frequency of site monitoring for water and sediment quality.	sessions. ● Implement additional testing for contaminants in deposited sediment. ● Increase community involvement in decision-making for emergency disposal activities.	sediment disposal practices. After an initial 5-year review and comprehensive data collection, review annually. ● Adjust permit language to include ecological concerns to minimize long-term impacts.
Low Impact	● Update communication and notification methods to reduce delays for shorter notice periods (e.g., emergency events)	● Incorporate community engagement in advisory sign placement. ● Develop reporting that makes sediment disposal activities more transparent and accessible to the public.	● Establish incentive programs for alternative sediment reuse (e.g., construction material)

Stakeholder-Specific Recommendations and Engagement

Table 5.16. Stakeholder-Specific Content

Stakeholder Group	Key Information	Engagement Approach	Recommendation Actions
SBCFD	● Operational feasibility and cost considerations ● Emergency response timelines and monitoring expectations	● Direct communication with regulatory agencies. ● Technical workshops for sediment disposal staff. ● Water quality monitoring and data sharing.	● Implement standardized SOPs for routine and emergency disposal. ● Increase staff training on improved monitoring and documentation protocols. ● Expand AB 411 monitoring stations.
Channelkeeper/ Non-profits	● Community engagement, advocacy	● Joint monitoring effort, advocacy meetings.	● Strengthen follow-up monitoring requirements in emergency permits ● Assist in improving

			public transparency and access to real-time monitoring data
Academia	• Sediment transport studies, ecological impact assessments	• Research partnerships, data sharing agreements	• Conduct pilot studies on alternative sediment reuse, such as habitat restoration or construction applications • Evaluate the feasibility of nature-based solutions • Assist in improving data collecting and reporting standards.
General Public	• Beach access and environmental concerns	• Public forums and online resources	• Stay informed on beach advisories through government websites and local newsletters • Engage in public meetings/hearings

VI. Discussion

Deposition Impacts on FIB Concentrations

<u>2023 San Jose Creek Discharge vs. Goleta Beach *E. coli* and Total Coliforms</u>

E. coli presence showed nearly equal spikes regardless of precipitation events, as seen when comparing early January with early February. Although *E. coli* levels remained within the AB 411 recommended safe range of less than 400 MPN/100 mL, the trend suggests a response to deposition events. Peaks in both *E. coli* and total coliform concentrations corresponded with discharge peaks and declined when sediment deposition operations ceased, though they still aligned with discharge data on February 14 and February 21. However, no data was available on the quantity of sediment deposition.

2023 Carpinteria Creek Discharge vs. Carpinteria Beach Total Coliforms

Even at 1,000 and 5,000 MPN/100 mL, there remains a low but present risk (1-7% per AB 411), which was observed following all but two deposition and precipitation events. A noticeable uptick in total coliforms toward the end of deposition operations on February 7, 2023, is unlikely to be linked to the previous precipitation event over a week prior. Other data suggest that total coliform levels tend to recover within a few days, as seen in the 2023 San Jose Creek vs. Total Coliforms graph. However, this interpretation remains flexible, as results can vary significantly based on precipitation and deposition amounts. Overall, total coliform trends suggest an influence from both sediment deposition and precipitation/discharge, exemplified by a ~200% increase in total coliforms on February 9 compared to a similar precipitation event on December 1.

2018 San Jose Creek Discharge vs. Goleta Beach Enterococcus and Total Coliforms

The graphs for this time period illustrate the impacts of the Montecito mudslide sediment transport and deposition event at Goleta Beach. Following a high-level precipitation event combined with extensive sediment deposition operations, both total coliforms and enterococcus showed no recovery for nearly a month. A mild recovery in total coliforms appeared after approximately three weeks, only to spike again at the conclusion of sediment deposition operations. These events highlight an extreme case in which sediment deposition operations prolonged the period of unsafe and elevated bacterial levels beyond what would likely be the typical recovery time frame following a precipitation event.

Control periods: Goleta Beach

Enterococcus only reaches unsafe levels >104 once after the 0.4 inches precipitation event on 12/8/19 and after the 1.6 in. precipitation event on 12/22/20 and is fully recovered by 1/7/20. It is worth noting that natural recovery may have happened even earlier than 1/7/20, as that was our earliest available sampling.

Control period: Arroyo Burro

The sample site is located directly where the creek periodically connects the lagoon to the ocean, a connection that appears to correlate with elevated precipitation events. Unsafe levels of total coliforms are observed when precipitation reaches at least one inch, suggesting a strong link between rainfall and bacterial contamination. Conversely, bacterial levels decrease when the creek is not connected to the ocean, indicating that the hydrological connection plays a key role in influencing water quality.

Multivariate Logistic Regression

The analysis revealed distinct patterns in how environmental factors influence bacterial contamination at Goleta and Carpinteria Beaches, with notable differences between the two locations. At Goleta Beach, all 30 models indicated a positive significant relationship between sediment deposition events and fecal indicator bacteria odds of exceedance. By running each of these models, the influence of sediment deposition could be teased out. The first layer was running the model in normal weather conditions, without filtering precipitation in any way. This was done to understand the overall system, and determine how other environmental factors known to impact water quality were acting within each beach. In unfiltered precipitation models for Goleta Beach ("wet" conditions), weekly rain was a significant predictor of increased log odds of exceedances for total coliforms, *E. coli*, and enterococcus. However, fecal coliform exceedances were not significantly increased by the presence of rain. This could be because total coliforms include both environmental and fecal-associated bacteria. Rainfall has been shown to mobilize sand-dwelling bacteria like *Enterobacter* (which comprises >40% of coliforms after rainfall) into water, increasing total coliform counts without requiring fresh fecal contamination (Tamai et al., 2023). Alternatively, fecal coliforms are a subset of total coliforms specifically linked to warm-blooded animals (Kenneth Schiff et al., 2005; Richiardi et al., 2023). Their absence of increase suggests that rainfall at Goleta Beach primarily redistributes existing environmental bacteria, such as those already within the sand, rather than introducing new fecal matter from sewage, pets, or wildlife. Additionally, *E. coli* and enterococcus thrive in moist sand, where rainfall temporarily creates favorable growth conditions, and declines rapidly as sand dries, indicating transient growth cycles tied to water content (Tamai et al., 2023). A study on the effects of rainfall on *E. coli* concentrations in Wisconsin showed that *E. coli* counts surged from ~290 MPN/100 mL to greater than 2419.6 MPN/100mL within 24 hours of rain (Kleinheinz et al., 2009). Fecal coliforms on the other hand (e.g., *Klebsiella*, an *E. coli* associated with humans) may require direct fecal input, and the results at Goleta Beach reflected that (Guentzel, 1996).

When considering dry models for Goleta Beach, sediment deposition was a significant variable increasing the log odds of an exceedance for all fecal indicator bacteria, regardless of whether binary or volumetric data was used for depositions. In these dry models, precipitation was not a significant variable for any fecal indicator bacteria, reaffirming the validity of the results. Discharge was only significant for fecal coliforms, likely due to wildlife within the Goleta Slough. Out of all Goleta Beach models, those that used limited precipitation were always better fits to the data than the "wet" models at Goleta Beach, as indicated by their AIC and Log Likelihood values. Therefore, there was compelling evidence that deposition events could highly impact the safety of the beach for beachgoers. In this analysis, since FIB data was weekly or less frequent, all data was aggregated by week. Future analyses should consider modeling using a time lag to determine whether this result could have longer lasting effects on microbiological conditions and, therefore, safety.

Carpinteria Beach's fecal indicator bacteria predictors varied greatly from Goleta Beach. Though deposition was a significant predictor with a positive increase in log odds of an exceedance for total coliforms and fecal coliforms, it was not for *E. coli* and enterococcus. This was surprising, as enterococcus is known for its ability to persist in the water column longer than other fecal indicator bacteria, often due to its association with particles and sediments, in both turbid and stable conditions alike (Graves et al., 2023; Mote et al., 2012). Discharge was only a significant parameter contributing to the decrease in log odds of a fecal coliform exceedance within the unfiltered precipitation models, which could speak to an intrinsic different in currents along Carpinteria Beach versus Goleta Beach. It may also be that Carpinteria Creek's flow dispersal moves faster offshore, as it is much further North from the AB411 site than the Goleta Slough output from its respective sample site. A more northern AB411 sample location near the mouth of the Carpinteria Salt Marsh and near where deposition takes place off of Ash Avenue would be beneficial to obtain more accurate local impacts to beach quality (see Objective 3 Discussion, and Figure 6.1).

Figure 6.1. Carpinteria Salt Marsh and active deposition event, circled in red. Turbidity coming downstream through the creek mouth is highlighted during the simultaneous beach

operation. Photo from SBCFCD. Additional recommended AB411 sample site represented by the blue cross (see Objective 3 Discussion).

Rain significance between wet and dry models for Carpinteria Beach were also supportive of the model's accuracy, as weekly rain remained a positive coefficient and was significant for all FIBs at Carpinteria Beach when precipitation was unfiltered. Coupled with the fact that the dry models for Carpinteria Beach were the best fit out of all models (including Goleta Beach), there was persuasive evidence that the models are robust for inference purposes.

For all models, indexing by year was done as a robustness check to determine if yearly variations accounted for changes in the relationship between deposition and bacteria exceedances. Significant year-specific random effects were observed at both beaches, confirming that temporal factors beyond the measured predictors influenced exceedance patterns. At Goleta Beach, significant negative year effects were detected during wet conditions for *E. coli* (sigma = -0.62237, p = 0.00131), suggesting that unmeasured yearly factors tended to reduce E. coli exceedance rates relative to model predictions. Conversely, during dry conditions at the same location, significant positive year effects were identified (sigma = 1.05488, p = 0.01076), indicating that yearly factors tended to increase exceedance rates beyond what was expected based on the fixed predictors alone. At Carpinteria Beach for *E. coli,* significant negative year effects were observed only during wet conditions (sigma = -0.61346, p = 0.00978), with a similar dampening effect on exceedance rates. These findings, among other significant sigma values for total coliforms, fecal coliforms, and enterococcus during dry models underscore the importance of accounting for temporal variations when modeling bacterial exceedances in coastal environments, as year-specific factors such as changing management practices or climate patterns may significantly influence water quality outcomes. Variations should be further investigated in future studies on these legacy emergency beach operation sites.

It is essential to remember that there were limitations to key assumptions for certain model configurations, concerning the assumption of linearity between predictor variables and the logit of the outcome. As mentioned within the methodology section, transformations were explored but ultimately deemed unsuitable due to the introduction of multicollinearity, which was indicated by inflated VIF values. Thus, the linear specification was maintained to prioritize the interpretability of odds ratios for inference.

Despite these acknowledged limitations, the validity of the inferences drawn should still be considered robust, as evidenced by the consistency of the positive relationship between sediment deposition events and FIB exceedances at Goleta Beach across binary, continuous, wet and dry model formats. Additionally, each model was indexed by year and did not see changes to the sign or significance of the coefficients. Carpinteria and Goleta Beach models also displayed accuracy through rain significance between wet and dry models. The primary goal of understanding directional relationships and variable significance was achieved, though the potential impact of non-linearity on the magnitude of effects should continue to be carefully considered during the interpretation of individual coefficients.

These findings have important implications for SBCFCD's beach choice for sediment deposition and public health protection. The strong relationship between deposition events and bacterial exceedances at Goleta Beach suggests that it is crucial for attention to be paid to water quality monitoring during and after events at this location. For Carpinteria Beach, the results indicate that rainfall events may be a more crucial factor in predicting potential water quality issues, and deposition may not present as much of a public health risk. However, this result could be marred by the distance from the AB411 site and nearshore water currents, dampening the potential impact of deposition on nearby beach water quality. If that is the case, it would be in the County's best interest to include another monitoring site to capture the area of Carpinteria City Beach, rather than just the Carpinteria State Beach.

Beach Demographic and Activity Survey Findings

The Beach Demographic and Activity Survey provided a broad understanding of beachgoer population, public perception, and potential social impacts of deposition activities at Goleta and Carpinteria Beach.

Qualitative Survey Observations

At Goleta Beach, researchers noted across multiple survey shifts that there was more beachgoer activity in the area surrounding the pier compared to the sandy shore. It was observed that many visitors also remained in their cars at the parking lots and did not physically access the rest of the beach. These individuals were not approached for the survey to respect their privacy. During the survey period, the researchers briefly spoke with two park rangers who had prior experience and knowledge of deposition activities. One ranger commented on how the heavy traffic of dump trucks from the 2018 Montecito debris flows "ruined $150,000 of new pavement" for the Goleta Beach parking lot. On the other hand, the other ranger described how after the 2018 debris flows operations, a new bridge was constructed, the parking lot was repaved, and asphalt thickness was increased to accommodate more frequent machinery operations in future deposition activities. Further conversations and interviews with park staff would be beneficial by providing an additional perspective and first-hand accounts of how deposition activities are operated at the disposal sites.

For both beaches, it was difficult to approach visitors who were on the move, such as running or biking. This may have created an unintentional bias and excluded a proportion of beachgoers who rely on the beach for their routine exercise. The survey did not capture the population of beachgoers who did not speak English well, due to language barriers between the researcher and beachgoer. Even though Qualitrics provided survey translations to languages other than English and Spanish, the surveyors were unable to properly verbally explain the survey's purpose and consent notice so that the visitor would be comfortable participating.

Demographic Data from Beach Survey Results

The age distribution visualizations showed that Goleta Beach is frequented by a younger demographic than Carpinteria Beach. 16.5% of Goleta respondents indicated their employment status as students, which was the second-highest chosen status. Goleta Beach's proximity to UC Santa Barbara reflects this higher proportion of student visitors. However, the mean age for Goleta respondents was 39 with a median of 37, which reflects a more middle-aged visitor population. For the distribution of gender identities across both beaches, there are no clear theories as to why there were more men at Goleta Beach and more women at Carpinteria Beach.

At both beaches, most respondents identified as White, which correlates with census data that reports the majority of Santa Barbara County residents are White (U.S. Census Bureau, 2024). The second largest population is Hispanic/Latinx for both the County population and survey respondents. From the bar plots, there was a different distribution visually of household incomes between both beaches. Carpinteria Beach's left-skewed distribution shows that there are more visitors with higher incomes, which could be attributed to a smaller student population and a higher proportion of retirees. Goleta Beach served more visitors with household incomes from $15,000 to $74,999. Languages spoken by beach visitors were predominantly English, but the survey results also showed that there is a notable proportion of Spanish-speakers with 16% at Carpinteria and 23.3% at Goleta. This highlights the need to consider language accessibility through translations for public beach advisories and other communication materials.

Analysis of Results from Hypotheses Testing

Hypothesis 1: With a p-value of 2.77e-04, the null hypothesis was rejected. There is a statistically significant relationship between beach visit frequency and knowledge of sediment disposal. For respondents who indicated that they were aware of deposition activities, it is more likely that they visit the beach monthly, weekly, or more often (P = 3.11e-07. This suggests that beachgoers who frequent Goleta and Carpinteria Beach more often are more likely to be aware that deposition activities occur at that site. On the other hand, there is no significant difference between beachgoers who visit more or less frequently if they do not know about deposition activities ($P = 0.76$). This leads to the conclusion that the predicted result was not seen through the survey results.

Hypothesis 2: It was predicted that lower-household income visitors would be more likely to visit the beach for fishing due to the absence of an on-site fishing fee. The statistical analysis failed to reject the null hypothesis, concluding that there is no significant difference between fishing and other activities for beachgoers with lower household incomes. From the graphical visualization of this hypothesis, there is no distinct trend between increases or decreases in incomes and fishing activities. Across all incomes, it was seen that more beachgoers fish for fun than for food.

Hypothesis 3: The p-value was calculated to be 0.26, failing to reject the null hypothesis. There is no significant relationship between the impacts of beach closure on a visitor and their income. Through data visualization, it was worth noting that 50% of individuals with a household income of $35,000 – $49,000 would have reduced access to food sources. The distribution of respondents' household income across the other options of possible beach closure impacts did not have outstanding trends.

Hypothesis 4: The predicted result stated that there would be a higher proportion of non-White visitors at Goleta and Carpinteria beaches compared to County-wide demographics. There were more Asian beachgoers at Goleta Beach (7.9%) compared to the County population, but less at Carpinteria Beach (3.0%). For the Hispanic or Latinx population, there were fewer visitors at both beaches than the County population percentage. There was a higher percentage of 1.1% Native Hawaiian or Other Pacific Islander respondents compared to the 0.3% County population, but with these low values, it is possible that this is skewed by the smaller survey sample size. With the different comparison results across non-White races, it is difficult to conclude if the proportion of all non-White visitors was higher than County demographics. Hypothesis 4 could have been better formulated to specify and distinguish between non-White races/ethnicities.

Hypothesis 5: Data visualizations for hypothesis 5 indicated that our predicted result did not occur for either beach. The prediction was correct in identifying proximity to home/accommodation as a popular reason for choosing to visit the two specific beaches. The highest number of responses for this option and all other options was at Carpinteria Beach, possibly due to the residential neighborhoods that are located directly adjacent to the beach. Familiarity/habit was the third most-selected at Carpinteria Beach and further underscores the beach's appeal to beachgoers who live nearby. There were eight times more respondents at Goleta Beach who chose "Better for watersports" compared to Carpinteria Beach, which is notable as Carpinteria is known more for surfing and occasionally hosts surfing competitions. Goleta Pier's social value was highlighted by how many more respondents at Goleta Beach chose the ability to fish as a reason for visiting compared to Carpinteria.

Hypothesis 6: It was predicted that there would be more visitors at Goleta Beach from cities and neighborhoods further from its location in the city of Goleta. However, most respondents who indicated that they chose to visit Goleta Beach for free parking were from Goleta zip codes. There were still beachgoers from other parts of Santa Barbara County outside of Goleta. Visitors also came from counties farther away, including Ventura, Los Angeles, Santa Clara, and even from Oregon. As a public beach with no entrance or parking fees, it is not surprising that visitors from other counties and states would choose to visit Goleta Beach.

Hypothesis 7: It was predicted that people are more likely to avoid the beach during sediment deposition activities. There was a significant difference (P = 2.08e-07) between people who would avoid the beach and the combined options for people who would still visit the beach in varying conditions. However, it has to be taken into consideration the response counts for each category where 58 respondents indicated "I would avoid the beach" and 129 people selected the other options. The significant difference here suggests that fewer people are certain that they would avoid the beach deposition activities, in contradiction to the predicted result. The difference between the most selected option between Goleta ("I would avoid the work area but still use other accessible parts of the beach") and Carpinteria Beach ("I would avoid the beach") can be attributed to Goleta Pier, offering another recreational area for Goleta visitors even if there is no access to the shore. Further analysis of potential demographic drivers to responses can be investigated using data from the survey.

Hypothesis 8: The predicted result was that the primary source of information for beach closures is official beach signage. X^2 tests found that out of all information sources that respondents turn to for beach advisory updates, official beach signage was the most referred to and supports the prediction. This suggests that beach signage is the most important source of information about beach advisories and possibly the most effective. SBCFCD and other supervising agencies can prioritize maintaining and improving public beach signage to better inform the public about beach advisories and closures. Improvements to public beach signage can include placing them in visible and high-traffic locations and translations to languages other than English. Adding a QR code to direct visitors to the County website for resources on beach advisories and closures can open up avenues for education and more effective information distribution.

Hypothesis 9: It is not certain that beachgoers are more likely to definitely not visit the beach if there is a beach advisory declared. There was a statistically significant difference between "definitely not visit" and "would continue usual beach activities." By looking at the response counts for each of these two options, it is more likely that people will definitely not visit during an active beach advisory. However, there is no difference when compared to those who would only be likely to avoid and those who would still visit and avoid water contact. Most respondents at both beaches indicated that they would still visit but avoid water contact. It is possible that many beachgoers highly value their beach visits and would not change their routine or that there is no serious concern around a beach advisory for beachgoers.

Hypothesis 10: The null hypothesis was rejected to conclude that there is a significant difference between the household income distributions at Goleta and Carpinteria Beach. The median income among Goleta Beach beachgoers who participated in the survey was between $50,000 and $75,000, whereas for Carpinteria Beach the median income ranged from $100,000 to $149,999 (Figure 5.x). Compared to the U.S. Census Data, the median household income in the City of Goleta was $118,039 in 2023 (U.S. Census Bureau, 2023). Median income household among Goleta Beach visitors appears to be about half of the average of the city. At Carpinteria, the median income of beachgoers closely aligns with the median income of the rest of the City of Carpinteria, $104,233. Graphical visualization of household income distribution shows that there are more beachgoers with higher household incomes at Carpinteria Beach than at Goleta Beach. When considering the impacts of deposition activities between both beaches, the household income distributions suggest that more lower-income households will be impacted at Goleta Beach. Therefore, it is important to consider how the social and monetary costs associated with deposition impacts, such as travel costs to another beach without construction activities or loss of recreational opportunities, can disproportionately affect Goleta beachgoers.

VII. Recommendations

Effective sediment management is essential for balancing flood mitigation, water quality, and coastal resilience. While emergency sediment disposal practices during emergency events play a critical role in protecting infrastructure and communities, their environmental and social impacts require thoughtful planning. The following recommendations provide actionable strategies for organizations and agencies to enhance current sediment disposal practices, improve monitoring efforts, and explore sustainable alternatives. By adopting these measures, decision-makers can minimize long-term ecological harm, protect public health, and ensure equitable access to safe and clean coastal environments.

Sediment Deposition Operations and Monitoring

AB 411 and Additional Bacteria Monitoring at Closer Deposition Sites

Water quality monitoring should be improved by placing monitoring stations at locations closer to actual deposition sites, both during and outside deposition periods. Specifically, monitoring should occur near the block of homes at Carpinteria Beach to ensure bacterial contamination is consistently tracked where sediment is being deposited. This will provide a more accurate data set for assessing impacts on water quality. Additionally, AB 411 sample sites should be placed directly at the deposition location to ensure that FIB data is collected right next to where the sediment is placed, improving public health protection and regulatory compliance.

Standard Operating Procedures (SOPs) for Routine and Emergency Situations

Developing SOPs for both routine and emergency situations will ensure consistent sampling and data collection. Standardizing sampling frequency will provide a clearer understanding of water and sediment quality changes over time, as well as long-term shifts in beach sand composition. Project managers should follow uniform procedures and avoid making case-by-case decisions on sampling frequency. SOPs should also outline parameters for evaluating sediment deposition, including pile size, number of piles, and specific sampling methods for sediment quality assessments (e.g., sediment composition and chemical analysis). Additionally, establishing seasonal baselines will allow the county to compare trends over multiple years.

Documenting SOPs will help standardize and improve future practices. Developing training programs will enhance preparedness for the increasing frequency of emergency permits and ensure proper emergency handling practices. Implementing these measures will strengthen sediment management efforts and establish consistent sediment testing requirements. Rigorous documentation of disposal activities will allow staff to analyze trends and assess long-term impacts effectively.

Potential Alternative: A Sediment Holding Facility

As an alternative to direct beach disposal during emergency events, the County should explore the feasibility of developing a sediment-holding facility. A holding facility would provide temporary storage for sediment removed from debris basins, allowing for additional time for testing, analysis, and planning before final placement. This approach would reduce the urgency that currently drives immediate beach dumping and would help minimize environmental and social impacts, particularly at sensitive sites like Goleta and Carpinteria beaches. A holding facility could also support the beneficial reuse of sediment for habitat restoration, construction, or agricultural applications aligning with long-term sustainability and sediment management goals. To advance this concept, the County can identify potential sites, conduct a cost-benefit analysis, and initiate interagency coordination to assess permitting pathways and funding opportunities.

Public Engagement and Education

Public Engagement and Outreach

Expansion of public engagement and outreach efforts to raise awareness will be valuable in raising awareness about sediment disposal and environmental impacts. In general, the number of public advisories and postings have increased at both Goleta and Carpinteria Beach, and public education on the harmful consequences of increased FIB concentrations should be increasing alongside this trend. Partnerships between public agencies such as SBCFCD with community organizations like Santa Barbara Channelkeeper can work to make outreach efforts more inclusive and accessible. The free-response survey question that asked "Considering what you now know about sediment deposition activities at this beach, how do you think this will impact your future visits to this beach? (Will your visits become more or less frequent and why?)" can provide some guidance on topics for further public education. For example, one respondent stated, "All the rocks and sludge were dropped on dirty beach from all the rich areas, leaving sharp boulders where the junior lifeguards run and have their beach camp… so Montecito and Summerland don't have to deal with it." There may be a gap in public understanding about the importance of routine and emergency deposition activities. A collaboration between SBCFCD and a local community organization can develop simple resources such as a webpage, a flyer, or even an ArcGIS Story Map to inform County residents on why deposition is done at Goleta and Carpinteria Beach. This can also be an opportunity to better understand community perceptions of beach inequities between cities, especially when taking into account that sediment has historically been transported from Montecito to Goleta Beach, which is approximately a 15-minute drive.

Beach Clean-Ups for Non-Organic Contaminants

Future public events for beach clean-ups after sediment disposal can provide opportunities to receive community support and engagement in removing non-organic contaminants like plastics. While SBCFCD conducts visual inspections during sediment deposition, continuing clean-ups in the following weeks after disposal events will ensure a thorough contamination assessment and remediation. However, clean-ups may pose exposure to hazards, ample planning, providing proper personal protective equipment (PPE), and training are necessary to ensure that these events are safe. There may be age limits set in place to protect the health of younger individuals. County staff and/or volunteer groups can partner to lead targeted clean-up efforts at Carpinteria and Goleta Beaches. Extending these efforts will help reduce environmental and social concerns related to sediment disposal. These clean-up events can be utilized for public education opportunities where County staff provide short talks about the value of deposition activities during the clean-up and provide time for participants to ask questions and create a sense of stewardship.

Advisory Signage Messaging

While current advisory signs are visible from regular footpaths, messaging clarity and accessibility can be enhanced. To improve communication and public health awareness, signage should be updated with additional options such as a large, clearly labeled QR code and a short, visible URL code linking to daily updates and uses on beach conditions and alerts. The link should be easy to find and be accompanied by a call-to-action (e.g., "Scan for Daily Water Quality Info"). To improve accessibility and inclusivity for diverse beachgoers, it is recommended that the county include additional language options on signage and QR codes using clear and concise messaging. This approach supports equitable access to important public health and safety information. The county should also consider adding educational resources regarding advisory warnings to inform the public about sediment disposal processes and other environmental impacts on beach water quality. Messaging improvements will help ensure visitors are informed and able to make sound decisions before, during, and after emergency events.

Nature-Based Solutions

Nature-Based Solutions for Reducing Flood Risk

Integrating nature-based solutions offers a sustainable and ecologically resilient approach to flood risk reduction. While large-scale infrastructure, such as debris basins like Randall Road provide immediate protection during storm events, these structures trap significant amounts of sediment, disrupting natural sediment transport processes that are essential to maintaining downstream ecosystems and coastal resilience. Nature-based solutions such as floodplain reconnection and green stormwater infrastructure allow sediment to move through the system in a more natural, controlled manner. These methods not only reduce flood risk but also enhance ecosystem services such as groundwater recharge, habitat restoration, and carbon sequestration. Evaluating alternative flood mitigation strategies reduces reliance on hard infrastructure, supports long-term sediment balance, and provides co-benefits for ecological health and community resilience.

Nature-Based Solutions to Protect Eroding Beaches

To address ongoing beach erosion, particularly near sediment disposal sites, the County is recommended to prioritize the use of nature-based solutions. These approaches offer a sustainable alternative to hard infrastructures such as seawalls and revetments, which often accelerate erosion in adjacent areas and disrupt natural sediment dynamics. Research by Johnston et al. (2023) demonstrates that restoring dunes on urban beaches enhances coastal resilience by promoting sand accretion, increasing elevation, and supporting vegetation growth over time. Coastal dunes serve as a sediment storage system, buffering against sea level rise, storms, and erosion while maintaining beach morphology (Johnston et al., 2023). An example of a nature based approach is the Carpinteria Living Shoreline Project, which received $1.62 million in state funding to design a vegetated dune and cobble system along Carpinteria City Beach (Fausey, 2024). While nature based solutions may vary by location, this project demonstrates how sustainable, nature based solutions can enhance shoreline resilience, reduce erosion, and protect vulnerable coastal neighborhoods without relying on hard infrastructure.

Areas for Additional Research

Sediment Transport in Debris Basin-altered Creeks

Through a visual observation method, the team inspected sediment load changes within San Ysidro Creek. Over 200 creek bed photographs were used to measure changes in creek bed levels. It was determined that approximately 1.3 inches of rainfall was the minimum amount of rainfall that would trigger a noticeable change in creek bed levels. This approach provided a direct, visual assessment of how precipitation influences creek bed morphology. Although the scope of this project evolved, rendering this initial analysis inapplicable to our final objectives, the results are included in this report for reference and potential justification for subsequent research or related projects.

Conclusion

This project took an interdisciplinary perspective to assess the environmental, ecological, public health, and social impacts of sediment deposition activities on local communities in Santa Barbara County. With 19 debris basins for flood control, sediment management of these structures is a complex and delicate process to balance protection of urban communities and natural resources. After routine and emergency clearing of the debris basins, the excess material is permitted to be disposed of at designated sites, such as Goleta and Carpinteria Beach. These deposition activities are completed to preserve recreational value for Goleta and Carpinteria Beach in the face of continual coastal erosion. However, both beaches are frequented by a diverse population and many visitors indicated that ongoing deposition activities would deter them from future visits. In consideration of this, the County should consider possible disproportional burdens on beachgoers' health and accessibility at each deposition site in long-term planning. Analysis of FIB concentrations at each disposal site has shown unsafe, elevated levels for weeks to months during precipitation and sediment deposition events, and significant positive relationships between sediment deposition and FIB exceedances for both beaches. While debris basins are currently one of the more effective flood control and sediment management strategies for Santa Barbara County, proactive consideration and research into alternative nature-based solutions are recommended for more sustainable and climate-resilient outcomes for the County's coastline and communities.

References

Angnuureng, B. D., Adade, R., Chuku, E. O., Dzantor, S., Brempong, E. K., & Mattah, P. A. D. (2023). Effects of coastal protection structures in controlling erosion and livelihoods. *Heliyon*, *9*(10), e20633. https://doi.org/10.1016/j.heliyon.2023.e20633

Barnard, Revell, Warrick, & Draut. (2009). *Coastal processes study of Santa Barbara and Ventura Counties, California: U.S. Geological Survey Open-File Report 2009-1029, 904 p.* https://pubs.usgs.gov/of/2009/1029/

Battalio, B., Behrens, D., Couch, R., Divita, E., Hubbard, D., Lowe, J., Revell, D., & Saley, P. (2015). *Goleta Slough Area SLR and Management Plan*.

Beach Erosion Authority for Clean Oceans and Nourishment. (2009, January). *Coastal Regional Sediment Management Plan: Central Coast from Pt. Conception to Pt. Mugu*. https://beacon.ca.gov/wp-content/uploads/2021/03/CRSMP.pdf

Beachapedia. (2021, December 7). *State of the Beach/State Reports/CA/Water Quality*. Beachapedia. https://beachapedia.org/State_of_the_Beach/State_Reports/CA/Water_Quality

BEACON. (n.d.). *Who We Are | BEACON*. Retrieved March 21, 2025, from https://beacon.ca.gov/who-we-are/

Beegan & Faick. (2018). Water Quality Control Plan for Enclosed Bays and Estuaries of California Sediment Quality Provisions. *California State Water Resources Control Board*. https://www.waterboards.ca.gov/water_issues/programs/bptcp/docs/sediment/sed_qual_provs.pdf

Byers, J. E., & Grabowski, J. H. (2013). *Soft-Sediment Communities*. https://jebyers.ecology.uga.edu/wp-content/uploads/2016/10/byers-grabowski-soft-sediment-20131.pdf

California Coastal Commission. (2021). *Coastal Development Permit*.

California State Firefighters' Association. (2024, December 13). The Thomas Fire December 2017. *CSFA - California State Firefighters' Association*. https://www.csfa.net/the-thomas-fire-december-2017/

California State Water Resources Control Board. (2025, January 28). *State Water Boards Bacterial Objectives*. https://www.waterboards.ca.gov/bacterialobjectives/

City of Santa Barbara. (2019, August). *City of Santa Barbara Local Coastal Program Coastal Land Use Plan*. https://santabarbaraca.gov/sites/default/files/documents/Services/LCP%20Update/City%20of%20Santa%20Barbara%20Complete%20Certified%20Coastal%20LUP.pdf

Collier, S. A., Wade, T. J., Sams, E. A., Hlavsa, M. C., Dufour, A. P., & Beach, M. J. (2015). Swimming in the USA: Beachgoer characteristics and health outcomes at US marine and freshwater beaches. *Journal of Water and Health*, *13*(2), 531–543. https://doi.org/10.2166/wh.2014.095

County of Santa Barbara. (2023). *2022 Hazard Mitigation Plan Update | Santa Barbara County, CA*. https://www.countyofsb.org/510/2022-Hazard-Mitigation-Plan-Update

County of Santa Barbara Public Health. (2024, February 22). *Ocean Water Monitoring Program*. https://www.countyofsb.org/2263/Ocean-Water-Monitoring-Program

Cox, R., O'Boyle, L., & Cytrynbaum, J. (2019). Imbricated Coastal Boulder Deposits are Formed by Storm Waves, and Can Preserve a Long-Term Storminess Record. *Scientific Reports*, *9*(1), 10784. https://doi.org/10.1038/s41598-019-47254-w

Devinny, J. S., & Volse, L. A. (1978). Effects of sediments on the development of Macrocystis pyrifera gametophytes. *Marine Biology*, *48*(4), 343–348. https://doi.org/10.1007/BF00391638

Dodds, R., & Holmes, M. R. (2019). Beach tourists; what factors satisfy them and drive them to return. *Ocean & Coastal Management*, *168*, 158–166. https://doi.org/10.1016/j.ocecoaman.2018.10.034

Elsmore, K., Nickols, K. J., Miller, L. P., Ford, T., Denny, M. W., & Gaylord, B. (2024). Wave damping by giant kelp, Macrocystis pyrifera. *Annals of Botany*, *133*(1), 29–40. https://doi.org/10.1093/aob/mcad094

Environmental Protection Agency. (2023). *Clean Water Act Section 401: State Certification of Water Quality*.

Environmental Protection Agency, O. (2025, February 4). *Climate Change Indicators: Coastal Flooding* [Reports and Assessments]. https://www.epa.gov/climate-indicators/climate-change-indicators-coastal-flooding

European Environment Agency. (2023). *Seawalls and jetties*. https://climate-adapt.eea.europa.eu/en/metadata/adaptation-options/seawalls-and-jetties

Fausey, C. (2024, May 4). Carpinteria's Living Shoreline Project Gets $1.62 Million to Protect Coast from Climate Change. *The Santa Barbara Independent*. https://www.independent.com/2024/05/04/carpinterias-living-shoreline-project-gets-1-62-million-to-protect-coast-from-climate-change/

Florsheim, J. L., Chin, A., Kinoshita, A. M., & Nourbakhshbeidokhti, S. (2017). Effect of storms during drought on post-wildfire recovery of channel sediment dynamics and habitat in the southern California chaparral, USA. *Earth Surface Processes and Landforms*, *42*(10), 1482–1492. https://doi.org/10.1002/esp.4117

Forgiarini et al. (2011, September 1). *Quantifying the geomorphologic and urbanization influence on coastal retreat under sea level rise*. ResearchGate.

https://www.researchgate.net/publication/336601405_Quantifying_the_geomorphologic_and_urbanization_influence_on_coastal_retreat_under_sea_level_rise

Franke, T. M., Ho, T., & Christie, C. A. (2012). The Chi-Square Test: Often Used and More Often Misinterpreted. *American Journal of Evaluation*, *33*(3), 448–458. https://doi.org/10.1177/1098214011426594

Fryirs, K. (2013). (Dis)Connectivity in catchment sediment cascades: A fresh look at the sediment delivery problem. *Earth Surface Processes and Landforms*, *38*(1), 30–46. https://doi.org/10.1002/esp.3242

Fuhrman, J. A., Cram, J. A., & Needham, D. M. (2015). Marine microbial community dynamics and their ecological interpretation. *Nature Reviews Microbiology*, *13*(3), 133–146. https://doi.org/10.1038/nrmicro3417

Geange, S. W., Powell, A., Clemens-Seely, K., & Cárdenas, C. A. (2014). Sediment load and timing of sedimentation affect spore establishment in Macrocystis pyrifera and Undaria pinnatifida. *Marine Biology*, *161*(7), 1583–1592. https://doi.org/10.1007/s00227-014-2442-6

Giannini, E. H. (2005). CHAPTER 6—DESIGN, MEASUREMENT, AND ANALYSIS OF CLINICAL INVESTIGATIONS. In J. T. Cassidy, R. E. Petty, R. M. Laxer, & C. B. Lindsley (Eds.), *Textbook of Pediatric Rheumatology (Fifth Edition)* (pp. 142–173). W.B. Saunders. https://doi.org/10.1016/B978-1-4160-0246-8.50012-7

Gibson, R. N., Atkinson, R. J. A., & Gordon, J. D. M. (2007). *Oceanography and Marine Biology: An annual review. Volume 45*. CRC Press.

Graves, G. M., Vogel, J. R., & Tanner, R. S. (2023). Investigation of environmental factors on Enterococcus survival in Oklahoma streams. *Aquatic Sciences*, *85*(2), 1–13. https://doi.org/10.1007/s00027-023-00933-3

Gray, S. (2023). Flows of Injustice: Linking Disaster Waste and Uneven Recovery to the Social Implications of Climate Disruption. *Environmental Justice*, *16*(4), 321–327. https://doi.org/10.1089/env.2021.0123

Guentzel, M. N. (1996). Escherichia, Klebsiella, Enterobacter, Serratia, Citrobacter, and Proteus. In S. Baron (Ed.), *Medical Microbiology* (4th ed.). University of Texas Medical Branch at Galveston. http://www.ncbi.nlm.nih.gov/books/NBK8035/

Houston, J. R. (2024). The economic value of America's beaches. *Shore & Beach*, *92*(2), 33–43. https://doi.org/10.34237/1009225

Johnston, K. K., Dugan, J. E., Hubbard, D. M., Emery, K. A., & Grubbs, M. W. (2023). Using dune restoration on an urban beach as a coastal resilience approach. *Frontiers in Marine Science*, *10*. https://doi.org/10.3389/fmars.2023.1187488

Kearney, M. W. (2017). Cramér's V. In *The SAGE Encyclopedia of Communication Research Methods* (pp. 290–290). SAGE Publications, Inc. https://doi.org/10.4135/9781483381411

Kenneth Schiff, John Griffith, & Gregory Lyon. (2005, August 18). *Microbiological Water Quality at Reference Beaches in Southern California During Wet Weather*. Southern California CoastalWater Research Project. https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/448_reference_beach.pdf

Kirkeby, M. (2024, May 9). *2024 State Income Limits*. Division of Housing Policy Development. https://www.hcd.ca.gov/sites/default/files/docs/grants-and-funding/income-limits-2024.pdf

Kleinheinz, G. T., McDermott, C. M., Hughes, S., & Brown, A. (2009). Effects of Rainfall on E. coli Concentrations at Door County, Wisconsin Beaches. *International Journal of Microbiology*, *2009*, 876050. https://doi.org/10.1155/2009/876050

Kondolf, G. M. (2000). Assessing Salmonid Spawning Gravel Quality. *Transactions of the American Fisheries Society*, *129*(1), 262–281. https://doi.org/10.1577/1548-8659(2000)129<0262:ASSGQ>2.0.CO;2

Le, D. M., Desmond, M. J., Buschmann, A. H., Pritchard, D. W., Camus, C., Hurd, C. L., & Hepburn, C. D. (2022). Reproduction, hatchery and culture applications for the giant kelp (Macrocystis pyrifera): A methodological appraisal. *Applied Phycology*, *3*(1), 368–382. https://doi.org/10.1080/26388081.2022.2086823

Li, D., Van De Werfhorst, L. C., Dunne, T., Devarajan, N., Ayala, T. G., & Holden, P. A. (2020). Surf zone microbiological water quality following emergency beach nourishment using sediments from a catastrophic debris flow. *Water Research*, *176*, 115733. https://doi.org/10.1016/j.watres.2020.115733

Lucrezi, S., & van der Walt, M. F. (2016). Beachgoers' perceptions of sandy beach conditions: Demographic and attitudinal influences, and the implications for beach ecosystem management. *Journal of Coastal Conservation*, *20*(1), 81–96.

Magris, R. A., & Ban, N. C. (2019). A meta-analysis reveals global patterns of sediment effects on marine biodiversity. *Global Ecology and Biogeography*, *28*(12), 1879–1898. https://doi.org/10.1111/geb.12990

Manning, L., Peterson, C., & Bishop, M. (2014). Dominant macrobenthic populations experience sustained impacts from annual disposal of fine sediments on sandy beaches. *Marine Ecology Progress Series*, *508*, 1–15. https://doi.org/10.3354/meps10870

Miller, R. J., Lafferty, K. D., Lamy, T., Kui, L., Rassweiler, A., & Reed, D. C. (2018). Giant kelp, Macrocystis pyrifera, increases faunal diversity through physical engineering. *Proceedings of the Royal Society B: Biological Sciences*, *285*(1874), 20172571. https://doi.org/10.1098/rspb.2017.2571

Monterey Bay National Marine Sanctuary. (n.d.). *Beach Closures and Microbial Contamination*. Retrieved March 21, 2025, from https://montereybay.noaa.gov/resourcepro/beach_plan.html

Mote, B. L., Turner, J. W., & Lipp, E. K. (2012). Persistence and Growth of the Fecal Indicator Bacteria Enterococci in Detritus and Natural Estuarine Plankton Communities. *Applied and Environmental Microbiology*, *78*(8), 2569–2577. https://doi.org/10.1128/AEM.06902-11

National Marine Fisheries Service. (2014). *Biological Opinion for Flood Control Operations including Annual Stream Maintenance, Debris Basin Maintenance, Goleta Slough Dredging and Long-term Atascadero Creek Channel Maintenance permitted by the U.S. Army Corps of Engineers, and implemented by the Santa Barbara County Flood Control.*

Nawarat, K., Reyns, J., Vousdoukas, M. I., Duong, T. M., Kras, E., & Ranasinghe, R. (2024). Coastal hardening and what it means for the world's sandy beaches. *Nature Communications*, *15*, 10626. https://doi.org/10.1038/s41467-024-54952-1

Nicol, C. L., Smith, D. P., & Watson, F. G. R. (2015). Exploring Particle Density Effects on Partial Mobility of Steelhead Spawning Gravels. *River Research and Applications*, *31*(1), 62–69. https://doi.org/10.1002/rra.2726

Oak, H. L. (2022). *Boulder beaches: A sedimentological study* [Thesis, Macquarie University]. https://doi.org/10.25949/19438427.v1

Patch & Griggs. (2007). *Development of Sand Budgets for California's Major Littoral Cells*. https://scholarworks.calstate.edu/downloads/1r66j718n

Peterson, C. H., Bishop, M. J., D'Anna, L. M., & Johnson, G. A. (2014). Multi-year persistence of beach habitat degradation from nourishment using coarse shelly sediments. *Science of the Total Environment*, *487*, 481–492.

Pineda, M.-C., Strehlow, B., Sternel, M., Duckworth, A., Haan, J. den, Jones, R., & Webster, N. S. (2017). Effects of sediment smothering on the sponge holobiont with implications for dredging management. *Scientific Reports*, *7*(1), 5156. https://doi.org/10.1038/s41598-017-05243-x

Pollard, J. A., Christie, E. K., Spencer, T., & Brooks, S. (2022). Gravel barrier resilience to future sea level rise and storms. *Marine Geology*, *444*, 106709.

Pranzini, E., Rosas, V., Jackson, N. L., & Nordstrom, K. F. (2013). Beach changes from sediment delivered by streams to pocket beaches during a major flood. *Geomorphology*, *199*, 36–47. https://doi.org/10.1016/j.geomorph.2013.03.034

Puhr, R., Heinze, G., Nold, M., Lusa, L., & Geroldinger, A. (2017). Firth's logistic regression with rare events: Accurate effect estimates and predictions? *Statistics in Medicine*, *36*(14), 2302–2317. https://doi.org/10.1002/sim.7273

Reiser, D. W., & White, R. G. (1988). Effects of Two Sediment Size-Classes on Survival of Steelhead and Chinook Salmon Eggs. *North American Journal of Fisheries Management*, *8*(4), 432–437.

https://doi.org/10.1577/1548-8675(1988)008<0432:EOTSSC>2.3.CO;2

Richiardi, L., Pignata, C., Fea, E., Bonetta, S., & Carraro, E. (2023). Are Indicator Microorganisms Predictive of Pathogens in Water? *Water*, *15*(16), Article 16. https://doi.org/10.3390/w15162964

Rippy, M. A., Franks, P. J. S., Feddersen, F., Guza, R. T., & Warrick, J. A. (2013). Beach Nourishment Impacts on Bacteriological Water Quality and Phytoplankton Bloom Dynamics. *Environmental Science & Technology*, *47*(12), 6146–6154. https://doi.org/10.1021/es400572k

Robertson, J. M. (2018). *Water Quality Certification Number 34218WQ03 For the 18STORM1 Emergency Response Project, Santa Barbara County.*

Rousseaux, C. G., & Gad, S. C. (2013). Chapter 30—Statistical Assessment of Toxicologic Pathology Studies. In W. M. Haschek, C. G. Rousseaux, & M. A. Wallig (Eds.), *Haschek and Rousseaux's Handbook of Toxicologic Pathology (Third Edition)* (pp. 893–988). Academic Press. https://doi.org/10.1016/B978-0-12-415759-0.00030-3

Sanitwong-Na-Ayutthaya, S., Saengsupavanich, C., Ariffin, E. H., Ratnayake, A. S., & Yun, L. S. (2023). Environmental impacts of shore revetment. *Heliyon*, *9*(9), e19646. https://doi.org/10.1016/j.heliyon.2023.e19646

Santa Barbara Channelkeeper. (n.d.). *Water Quality Field Work*. Retrieved March 21, 2025, from https://www.sbck.org/our-work/field-work/

Santa Barbara County Flood Control District. (n.d.). *Flood Control | Santa Barbara County, CA*. Retrieved March 21, 2025, from https://www.countyofsb.org/2155/Flood-Control

Schooler, N. K., Dugan, J. E., & Hubbard, D. M. (2019). No lines in the sand: Impacts of intense mechanized maintenance regimes on sandy beach ecosystems span the intertidal zone on urban coasts. *Ecological Indicators*, *106*, 105457. https://doi.org/10.1016/j.ecolind.2019.105457

Severin, M. I., Raes, F., Notebaert, E., Lambrecht, L., Everaert, G., & Buysse, A. (2022). A Qualitative Study on Emotions Experienced at the Coast and Their Influence on Well-Being. *Frontiers in Psychology*, *13*, 902122. https://doi.org/10.3389/fpsyg.2022.902122

South Central Coast District Staff. (2023). *Deputy Directors Report Memo: Memo for Item W10, South Central Deputy Director's Report, 30611 Emergency Permit Waiver No. G-4-23-0001-W (Santa Barbara County Flood Control District) for the Commission Meeting of February 8, 2023*.

State Water Resources Control Board. (2023). *Water Quality Order WQ 2023-0095-DWQ Clean Water Act Section 401 Water Quality Certification for Regional General Permit 63 for Emergency Repair and Protection Activities.* https://www.waterboards.ca.gov/water_issues/programs/cwa401/docs/2023/2-RGP%2063-Certification%20MainBody.pdf

Stevens, A. W., Ruggiero, P., Parker, K. A., Vitousek, S., Gelfenbaum, G., & Kaminsky, G. M. (2024). Climate controls on longshore sediment transport and coastal morphology adjacent to engineered inlets. *Coastal Engineering*, *194*, 104617. https://doi.org/10.1016/j.coastaleng.2024.104617

Suttle, K. B., Power, M. E., Levine, J. M., & McNeely, C. (2004). How Fine Sediment in Riverbeds Impairs Growth and Survival of Juvenile Salmonids. *Ecological Applications*, *14*(4), 969–974. https://doi.org/10.1890/03-5190

Tamai, S., Shimamoto, H., Nukazawa, K., & Suzuki, Y. (2023). Growth and Decay of Fecal Indicator Bacteria and Changes in the Coliform Composition on the Top Surface Sand of Coastal Beaches during the Rainy Season. *Microorganisms*, *11*(4), 1074. https://doi.org/10.3390/microorganisms11041074

Thiault, L., Kernaléguen, L., Osenberg, C. W., & Claudet, J. (2017). Progressive-Change BACIPS: A flexible approach for environmental impact assessment. *Methods in Ecology and Evolution*, *8*(3), 288–296. https://doi.org/10.1111/2041-210X.12655

U.S. Army Corps of Engineers. (n.d.). *Department of the Army Permit: Santa Barbara Flood Control Routine Maintenance and Goleta Slough Dredging Activities*.

U.S. Army Corps of Engineers. (2013). *Department of the Army Regional General Permit Number 63 for Repair and Protection Activities in Emergency Situations.*

U.S. Census Bureau. (2021, November 23). *Decennial Census of Population and Housing Questionnaires & Instructions*. Census.Gov. https://www.census.gov/programs-surveys/decennial-census/technical-documentation/questionnaires.html

USGS. (2007). *US Rain/Dry Days Readme | Early Warning and Environmental Monitoring Program*. https://earlywarning.usgs.gov/usraindry/rdreadme.php

Van Tussenbroek, B. I. (1989). The life-span and survival of fronds of *Macrocystis pyrifera* (Laminariales, Phaeophyta) in the Falkland Islands. *British Phycological Journal*, *24*(2), 137–141. https://doi.org/10.1080/00071618900650131

Whitman, R., Harwood, V. J., Edge, T. A., Nevers, M., Byappanahalli, M., Vijayavel, K., Brandão, J., Sadowsky, M. J., Alm, E. W., Crowe, A., Ferguson, D., Ge, Z., Halliday, E., Kinzelman, J., Kleinheinz, G., Przybyla-Kelly, K., Staley, C., Staley, Z., & Solo-Gabriele, H. M. (2014). Microbes in Beach Sands: Integrating Environment, Ecology and Public Health. *Re/Views in Environmental Science and Bio/Technology*, *13*(3), 329–368. https://doi.org/10.1007/s11157-014-9340-8

Wildfish. (2017). *The impact of excess fine sediment on invertebrates and fish in riverine systems*. https://wildfish.org/wp-content/uploads/2022/05/WildFish-Sediment-Literature-Review-2017.docx-1.pdf

Willardson, B. (2020). Sustainable Debris Basins for Post-Fire Protection. *2020*

Intermountain Engineering, Technology and Computing (IETC), 1–6. https://doi.org/10.1109/IETC47856.2020.9249179

Wooldridge, T., Henter, H. J., & Kohn, J. R. (2016). Effects of beach replenishment on intertidal invertebrates: A 15-month, eight beach study. *Estuarine, Coastal and Shelf Science*, *175*, 24–33. https://doi.org/10.1016/j.ecss.2016.03.018

Zimmer, S. A., Powell, R. J., & Velásquez, I. C. (n.d.). *Exploring Complex Survey Data Analysis Using R*. Retrieved January 23, 2025, from https://tidy-survey-r.github.io/tidy-survey-book/

Appendix

Appendix A: Beach Demographic and Activity Survey

Beach Demographic and Activity Survey

Start of Block: Opening

Q1.0 Consent Notice: This survey is part of a student research project. This is a one-time survey, completed in one session. The only personal information we will be collecting from you is your email address, and we will only contact you through email if you are the winner of the raffle. Your answers will not be tied to the provided email address and your identity will remain anonymous. There are no foreseeable risks to you by completing this survey. This research is voluntary and you may refuse to answer, participate, or choose to withdraw at any time. By choosing to participate in this survey, you are providing your consent.

Q1.1 What is the name of this beach?

o Goleta Beach

o Carpinteria Beach

Q1.2 Have you already participated in this survey?

o No

o I don't know

o Yes

End of Block: Opening

Start of Block: Beach Activities

Q2.1 How often do you come to this beach?

o This is my first visit

o Less than once a year

o A few times a year

o Monthly

o Weekly or more often

Q2.2 How long do you expect to be at the beach today?

o Less than 1 hour

o 1-2 hours

o 2-4 hours

o 4-6 hours

o More than 6 hours

Q2.3 What was your transportation method to get here?

o Personal vehicle

o Carpool

o Public transportation

o Bicycle

o Walking

o Other: ____

Q2.4 What activities do you plan to engage in during your visit to this beach? (Select all that apply):

▢ Fishing for fun

▢ Fishing for food

▢ Resting

▢ Swimming/wading

- ▢ Sunbathing
- ▢ Walking/jogging
- ▢ Water sports (surfing, boogie board, kayaking, etc.)
- ▢ Dog walking
- ▢ Picnicking/grilling
- ▢ Beach sports (horseshoes, frisbee, etc.)
- ▢ Wildlife/nature viewing
- ▢ Other: ____

Q2.5 Why did you choose this particular beach for your visit today? (Select up to three main reasons):

- ▢ Proximity to home/accommodation
- ▢ Ability to fish without cost
- ▢ Free parking
- ▢ Water quality
- ▢ Overall cleanliness
- ▢ Better for watersports (e.g., surfing, swimming, kayaking)
- ▢ Family-friendly
- ▢ Less crowded than other beaches
- ▢ Familiarity/habit
- ▢ Natural beauty/scenery
- ▢ Pet-friendly
- ▢ Recommended by others
- ▢ Other: ____

Q2.6 Who are you visiting the beach with today? (Select all that apply)

- ▢ Alone
- ▢ Partner/Spouse

- ▢ Family
- ▢ Children
- ▢ Friends
- ▢ Pet
- ▢ Organized group (e.g., tour, school, club)
- ▢ Other: ____

Q2.7 Which of the following factors, if any, have prevented you from visiting this beach? (Select all that apply)

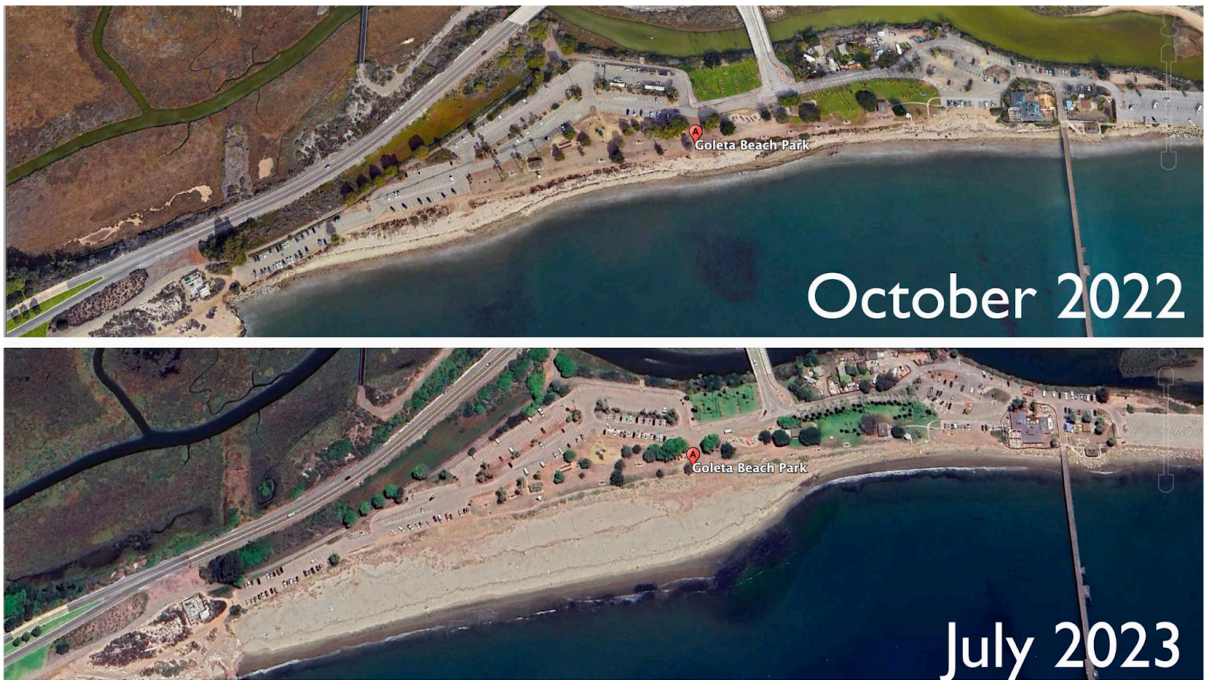
- ▢ Lack of transportation
- ▢ Beach accessibility issues
- ▢ Overcrowding
- ▢ Poor water quality
- ▢ Beach advisories/closures
- ▢ Construction activities
- ▢ Excess litter or pollution
- ▢ Cost (e.g., parking fees, equipment rental)
- ▢ Weather
- ▢ None of the above
- ▢ Other: ____

Q2.8 Are you familiar with the practice of importing sediment to beaches to increase beach width?

- o Yes, I'm familiar
- o I've heard of it but don't know much about it
- o No, I'm not familiar with it

Q2.9 **Sediment deposition as a practice:**

Human activities (such as dams and development) have limited the natural movement of sand to beaches, creating concerns about long-term beach width. Santa Barbara County has been delivering inland sediment (including sands, gravels, and boulders) to Goleta and Carpinteria Beach to maintain beach width. The sediment is brought from upstream creeks and placed on the beach. This practice is intended to protect buildings near the coast from erosion, give organisms more space to live, and ensure adequate space for recreation on the beach (National Park Service). Typical operations in Santa Barbara County for emergency sediment deposition take place during the months of October to February.



https://www.countyofsb.org/3711/Emergency-Beach-Operations

Q2.10 Before today, were you aware that sediment from inland areas is brought to this beach on occasion?

o No, I wasn't aware

o I had heard something about it, but wasn't sure of the details

o Yes, I was aware

Q2.11 Imagine you're planning a beach visit and learn that sediment deposition activities are scheduled to take place. During this time, sections of the beach will have heavy equipment like bulldozers spreading new sand, creating a construction-like setting. The active work area would be closed to the public, though nearby sections of beach remain open. Given this situation, how would these deposition activities affect your plans to visit this beach?

o I would avoid the beach during deposition activities o I would avoid the work area but still use other accessible parts of the beach

o I would visit less frequently during deposition

o It wouldn't affect my visits

o I'm not sure how it would affect my visits

o I would be more likely to visit to observe the process

Q2.12 How important are the following beach features to you? (Rate each on a scale from 1 to 5, where 1 is Not at all important and 5 is Extremely important)

- Opportunity to fish:
- Lack of trash and plastics:
- Safety:
- Free parking:
- Ecological health of the beach environment:
- Aesthetic appearance of the beach:
- Opportunities for nature observation (e.g., birds, marine life):
- Water quality:
- Less frequent beach advisories/closures:

Q2.13 Imagine that this beach was closed for an extended period (e.g., for several weeks). How would it affect you or your family? (Select all that apply)

▢ No significant impact

▢ Reduced access to food sources (e.g., from fishing or gathering)

▢ Loss of recreational opportunities

▢ Negative impact on mental health or stress relief

▢ Loss of income or job opportunities (e.g., from beach-related work)

▢ Increased travel costs to visit alternative beaches

▢ Disruption to regular exercise routine

▢ Impact on cultural or spiritual practices

- ☐ Other: ____

Q2.14 Are there other beaches in Santa Barbara County that you prefer to visit?

- o If yes, which other beaches do you visit?: ________________
- o No

Q2.15 If there was a beach advisory warning about poor water quality, how would this affect your beach visits?

- o I would definitely not visit the beach
- o I would likely avoid visiting the beach
- o I would visit but avoid water contact
- o I would continue my usual beach activities
- o It would depend on the type of advisory (please explain): ________________

Q2.16 If you learned about a beach advisory, what would be your primary source of information about the safety conditions? (Select all that apply)

- ☐ Official beach signage
- ☐ News or media
- ☐ Social media
- ☐ Word of mouth
- ☐ Government websites
- ☐ Beach water quality apps
- ☐ I don't typically check beach conditions
- ☐ Other: ____

Q2.17 Considering what you now know about sediment deposition activities at this beach, how do you think this will impact your future visits to this beach? (Will your visits become more or less frequent and why?):

____

____

End of Block: Beach Activities

Start of Block: Demographics Block

Q3.1 What is your age?: ____________________

Q3.2 Which best describes your gender identity?

- ▢ Man
- ▢ Woman
- ▢ Non-binary
- ▢ Prefer to self-describe: ____________________
- ▢ Prefer not to say

Q3.3 Which of the following best describes your race/ethnicity? (Select all that apply)

- ▢ Black or African American
- ▢ White
- ▢ Hispanic or Latinx
- ▢ Asian
- ▢ Native American or Alaska Native
- ▢ Native Hawaiian or Other Pacific Islander
- ▢ Other: ____
- ▢ Prefer not to say

Q3.4 What is your current employment status? (Select all that apply)

- ▢ Employed full-time
- ▢ Employed part-time
- ▢ Self-employed

- ▢ Unemployed
- ▢ Student
- ▢ Retired
- ▢ Unable to work
- ▢ Prefer not to say

Q3.5 What is your annual household income before taxes?

- o Less than $15,000
- o $15,000 - $24,999
- o $25,000 - $34,999
- o $35,000 - $49,999
- o $50,000 - $74,999
- o $75,000 - $99,999
- o $100,000 - $149,999
- o $150,000 - $199,999
- o More than $200,000 (Please specify): ____________________
- o I'm not sure
- o Prefer not to say

Q3.6 Including yourself, how many people live in your household?

- o Please enter a number. _______________________

Q3.7 What are the languages spoken in your home? (Select all that apply)

- ▢ English
- ▢ Spanish
- ▢ Mandarin
- ▢ Tagalog

- ▢ Vietnamese
- ▢ Arabic
- ▢ Other: ____
- ▢ Prefer not to say

Q3.8 What is the zip code of your primary residence? [Text Entry Box for 5-digit zip code]

- o Enter zip code here: ____________________
- o I don't have a permanent residence
- o I don't know my zip code
- o I live outside the United States
- o Prefer not to say

END OF SURVEY

Appendix B: Response List for Q2.17 of the Beach Survey

Q2.17 of the Beach Demographic and Activity Survey asked: "Considering what you now know about sediment deposition activities at this beach, how do you think this will impact your future visits to this beach? (Will your visits become more or less frequent and why?)"

The written responses to this free-response question are listed below. Responses have only been edited for spelling mistakes and translated from Spanish where needed. Fifty-one (51) respondents stated that there would be no change in their decision to visit the beaches. Response submissions that responded only "stay the same," "N/A", "no," "no impact," or "no effect" is not included below. Responses with additional comments were kept.

1. I will continue regular usage. Sediment deposits are part of managing life in our area. I trust it's being done wisely
2. I'll still come here as much as I can, probably daily
3. I would avoid it if they determine it's contaminated but this is my place of stress, exercise and leisure.
4. Not affect it except for the dates when they are working
5. It might not come for a while.
6. Yes less frequent
7. When the work is being done, we come less frequently. Respecting the process.
8. He would come back more to activities and continue enjoying the beach
9. I think my visits would become less frequent during deposition
10. No - similar amount of visits. The beach in carp is already small width in some areas and that sand is needed to protect the houses and condos here.
11. Less frequent
12. Probably no change unless equipment or trucks are present
13. I dislike the deposition while it is happening (it's ugly) but I love the way the deposits capture enough sand to build a beautiful recreational beach. I find it easy to avoid being downstream of the sediments that erode from the deposits.
14. Sorry but I find this to be bullshit! All the rocks and sludge were dropped on dirty beach from all the rich areas, leaving sharp boulders where the junior lifeguards run and have their beach camp. To me this is just "dump crap on a smaller beac": so rich towns like Montecito and Summerland don't have to deal with it.
15. Not if there are accessible areas.
16. No meaningful impact. Avoidance of construction zones. I have definitely noticed increased beach width here in the last few years. Wasn't sure how much of this was ongoing engineering vs debris deposition from the Montecito mudslides
17. A little

18. I don't know
19. No it would not make my visits less frequent, I am aware of it. Can see how water is affected. Have seen people go in when they do it and others that don’t. People are warned about quality of beach. Have also seen signs warning people. Not as clear as it normally is
20. Less
21. Still come, interesting about inland instead of beach sand.
22. We walk the beach each morning and we would miss being able to do so
23. Won't. Appreciate the fact that there needs to be more education, lots of resentment about dump trucks coming to this beach versus others.
24. I’m not sure
25. Yes
26. No, we have observed the construction but have continued to come. It’s nice to be fully informed as to where the sand is coming from and what months of the year the project is most affected.
27. No change unless I'm not allowed to visit.
28. Generally the material imported is from some other disaster area so it is nasty. Fishing on the pier dies when they deposit stuff on the beach
29. I will visit anyway
30. Less during deposition times
31. If it is to improve the life of the community, you have to be patient.
32. Not sure.
33. Reduce visits
34. They will stay the same
35. Yes I'd avoid during activity
36. About the same at this point
37. No effect unless I cannot fish
38. Less, for deposition reasons
39. Less frequent I don't want to be around construction at a beach
40. If there are sediment deposition activities I would not visit the beach
41. Keep coming, favorite beach
42. Being more aware of making sure beach is safe and clean for kids
43. They would want to know more about it and make their decision based on that.
44. Not at all. This is my favorite beach.
45. Wouldn’t change it.
46. These activities don’t impact our enjoyment of the beach and we will continue to visit weekly. With kids, the construction vehicles are actually exciting!
47. More frequent because there is more beach area and fishing grounds.
48. No impact, fishing not interrupted
49. They will be the same. We visit once or twice a year.

50. Neutral. Although I am bummed to see this breach this way since I grew up going to this beach.
51. Will stay the same but not go to areas where they're doing dumping
52. Less
53. I want to find out more information about why there was so many rocks brought to this specific beach and not a dirt lot or a different beach
54. Be more aware of what's going on and research before going
55. It's complicated. It won't affect our visits but there is a give and take. There's no good solution. But it is important to give time for the beach to recover.
56. I am in support of beach renourishment provided that peak seasons for breeding/rearing of sensitive bird and fish species is observed and the deposited sediment has been spot-tested for toxins/pollutants. Less concerned about grain size compatibility and temporary effects on turbidity
57. They would become less frequent. I would want to know the safety facts about what was in the sediment before letting my dog, my kids, even my own feet run on the beach and play in the water.
58. Noticed a decrease in marine life such as crabs since 1970s; county doesn't care about Goleta beach they should take it to canyon for agricultural use or whatever; it is not natural; sediment dumping shocks the ocean; definitely negative impact
59. They will stay the same unless there is a major work area.
60. It would not affect much, but we would be aware of the conditions of the beach in case there is a warning regarding the deposition of sediments.
61. Less during construction
62. Only when active
63. No impact, would like to understand the effects that sediment deposition activities create.
64. I don't think it will impact them
65. They would be the same because I would get the same things I want from the beach
66. Yes, water quality. The more nature is untouched, the better. Noise pollution might affect and air pollution and water.
67. During the construction, less frequent visits. I don't want to be around the construction-like setting. Noise pollution will bother me.
68. No, the same. Great beach to fish on
69. Frequency will remain the same
70. Not much, but maybe a tiny bit
71. The same as long as fishing and surfing is good.
72. Skip too cold
73. I would still come, I like the beach and visiting for the water
74. would affect me.
75. Does not affect me; just wouldn't use the beach during deposition activities

76. I will be more aware
77. I think I will continue to visit this beach as it is very convenient, but I will probably avoid it if there is construction.
78. We view the beach as an opportunity to decompress and if there are bulldozers we would not frequent the beach as much.
79. Likely not much impact since I only visit a few times a year.
80. Once they're done, I would visit more often.
81. More
82. I tend to avoid this beach when I see a lot of heavy equipment because the full route isn't long enough
83. Unsure
84. Maybe about the same. If it doesn't affect the pier it doesn't affect me since I usually just fish when visiting the beach.
85. Same habits
86. It would increase in frequency. It would be good.
87. More, we have small children that prefer to play on the sand.
88. No impact, if it makes the beach better then it's good.
89. Less frequent
90. I will still run by the beach

Appendix C: Objective 1

Variance Inflation Factor (VIF) Results

Total coliforms:

- Goleta Beach:
  - TC_GB_wet_b_bt: **none failed to meet assumptions**
  - TC_GB_wet_c_bt: **none failed to meet assumptions**
  - TC_GB_dry_b_bt: **none failed to meet assumptions**
  - TC_GB_dry_c_bt: **none failed to meet assumptions**
- Carpinteria Beach:
  - TC_CB_wet_b_bt: **none failed to meet assumptions**
  - TC_CB_wet_c_bt: **none failed to meet assumptions**
  - TC_CB_dry_b_bt: **none failed to meet assumptions**
  - TC_CB_dry_c_bt: **none failed to meet assumptions**

Fecal coliforms:

- Goleta Beach
  - FC_GB_wet_b_bt: **none failed to meet assumptions**
  - FC_GB_wet_c_bt: **none failed to meet assumptions**
  - FC_GB_dry_b_bt: **none failed to meet assumptions**
  - FC_GB_dry_c_bt: **none failed to meet assumptions**
- Carpinteria Beach
  - FC_CB_wet_b_bt: **none failed to meet assumptions**

- FC_CB_wet_c_bt: **none failed to meet assumptions**
- FC_CB_dry_b_bt: **none failed to meet assumptions**
- FC_CB_dry_c_bt: **none failed to meet assumptions,** but were slightly above 5 for weekly volume and discharge (5.99 and 5.94, respectively).

E. coli:

- Goleta Beach
  - EC_GB_wet_b_bt: **none failed to meet assumptions**
  - EC_GB_wet_c_bt: **none failed to meet assumptions**
  - EC_GB_dry_b_bt: **none failed to meet assumptions**
  - EC_GB_dry_c_bt: **none failed to meet assumptions**
- Carpinteria Beach
  - EC_CB_wet_b_bt: **none failed to meet assumptions**

- EC_CB_wet_c_bt: **none failed to meet assumptions**
- EC_CB_dry_b_bt: **none failed to meet assumptions**
- EC_CB_dry_c_bt: **none failed to meet assumptions**

Enterococcus:

- Goleta Beach
    - EN_GB_wet_b_bt: **none failed to meet assumptions**
    - EN_GB_wet_c_bt: **none failed to meet assumptions**
    - EN_GB_dry_b_bt: **none failed to meet assumptions**
    - EN_GB_dry_c_bt: **none failed to meet assumptions**
- Carpinteria Beach
    - EN_CB_wet_b_bt: **none failed to meet assumptions**

- EN_CB_wet_c_bt: **none failed to meet assumptions**
- EN_CB_dry_b_bt: **none failed to meet assumptions**
- EN_CB_dry_c_bt: **none failed to meet assumptions**

Box-Tidwell Results

Total coliforms:

- Goleta Beach:
  - TC_GB_wet_b_bt: weekly rain, weekly rain interact
  - TC_GB_wet_c_bt: weekly rain, weekly rain interact, weekly volume (weekly_volume_interact was not significant, so it did not violate the assumption for weekly_volume)
  - TC_GB_dry_b_bt: weekly_discharge, weekly_discharge_interact
  - TC_GB_dry_c_bt: weekly_discharge, weekly_discharge_interact
- Carpinteria Beach:
  - TC_CB_wet_b_bt: weekly rain, weekly rain interact
  - TC_CB_wet_c_bt: weekly rain, weekly rain interact
  - TC_CB_dry_b_bt: weekly_discharge
  - TC_CB_dry_c_bt: **none failed to meet assumptions**

Fecal coliforms:

- Goleta Beach
  - FC_GB_wet_b_bt: **none failed to meet assumptions**
  - FC_GB_wet_c_bt: weekly volume, weekly_volume_interact
  - FC_GB_dry_b_bt: **none failed to meet assumptions**
  - FC_GB_dry_c_bt: **none failed to meet assumptions**
- Carpinteria Beach
  - FC_CB_wet_b_bt: weekly_rain, **none failed to meet assumptions** (no interact term was significant)

- FC_CB_wet_c_bt: weekly_rain, **none failed to meet assumptions** (no interact term was significant)
- FC_CB_dry_b_bt: **none failed to meet assumptions**
- FC_CB_dry_c_bt: **none failed to meet assumptions**

E. coli:

- Goleta Beach
  - EC_GB_wet_b_bt: **none failed to meet assumptions**
  - EC_GB_wet_c_bt: **none failed to meet assumptions**
  - EC_GB_dry_b_bt: **none failed to meet assumptions**
  - EC_GB_dry_c_bt: **none failed to meet assumptions**
- Carpinteria Beach
  - EC_CB_wet_b_bt: **none failed to meet assumptions**

- EC_CB_wet_c_bt: **none failed to meet assumptions**
- EC_CB_dry_b_bt: algorithm did not converge**,** there were no “1”s or exceedances for carpinteria in weeks that were dry for *E. coli*
- EC_CB_dry_c_bt: algorithm did not converge**,** there were no “1”s or exceedances for carpinteria in weeks that were dry for *E. coli*

Enterococcus:

- Goleta Beach
  - EN_GB_wet_b_bt: weekly_rain, weekly_rain_interact
  - EN_GB_wet_c_bt: weekly_rain, weekly_rain_interact, weekly_volume, weekly_volume_interact
  - EN_GB_dry_b_bt: **none failed to meet assumptions**
  - EN_GB_dry_c_bt: weekly_volume, weekly_volume_interact
- Carpinteria Beach
  - EN_CB_wet_b_bt: weekly_rain, weekly_rain_interact

- EN_CB_wet_c_bt: weekly_rain, weekly_rain_interact
- EN_CB_dry_b_bt: **none failed to meet assumptions**
- EN_CB_dry_c_bt: **none failed to meet assumptions**

The algorithm was not converged for Carpinteria's dry season *E. coli* models due to absence of exceedance events. This convergence failure was attributed to insufficient positive cases in the dataset.

Appendix D: IRB Human Subjects Approval Letter

UNIVERSITY OF CALIFORNIA

BERKELEY • DAVIS • IRVINE • LOS ANGELES • MERCED • RIVERSIDE • SAN DIEGO • SAN FRANCISCO • SANTA BARBARA • SANTA CRUZ

SANTA BARBARA
FWA#00006361

1/8/2025

VERIFICATION OF ACTION BY THE UCSB HUMAN SUBJECTS COMMITTEE

RE: HUMAN SUBJECTS PROJECT NUMBER 6

FROM: UCSB HUMAN SUBJECTS COMMITTEE

PROTOCOL NUMBER 6-24-0772

TYPE: NOTICE OF EXEMPT DETERMINATION

TITLE(S):
GOLETA BEACH DEMOGRAPHIC AND BEACH ACTIVITY SURVEY

INVESTIGATOR(S):
Patricia Holden
Roxana Lagunas
Janiece Luu
Letty Aguilar
Tali Cook
Sophia Lecuona

The above identified project may commence on 1/8/2025. Exempt protocols do not expire.

The research activities under this submission qualify as Exempt from the Federal Regulations at 45 CFR 46.104(d) under the following Categories: 2

Although your study qualifies as exempt research, investigators are expected to adhere to UCSB policies and conduct their research in accordance with the ethical principles of Justice, Beneficence, and Respect for Persons as described in the Belmont Report.

AMENDMENTS/MODIFICATIONS/CHANGES:
Any change in the design, conduct, or key personnel of this research must be reviewed by the UCSB HSC prior to implementation. This includes changes to the study procedures and/or documents (e.g., protocol, consent form, recruitment materials, addition of data points, addition or change of research sites) and changes to the research team. If you are unsure whether your changes constitute a protocol modification, contact the HSC for guidance.

UNANTICIPATED PROBLEMS/ADVERSE EVENTS
If any study subject experiences an unanticipated problem involving risk to subjects or others, and/or a serious adverse event, the UCSB HSC must be informed promptly. An e-mail or phone call must be received within 7 days. Further reporting requirements will

be determined by the UCSB HSC at that time.

RECORDS RETENTION REQUIREMENTS
Please remember that signed consent forms must be maintained for a minimum of three years after the end of the calendar year in which the research is completed. Additional requirements may be imposed by your funding agency, your department, or other entities.

If you have any questions about the above, please contact the UCSB Human Subjects Committee Coordinator at: (805) 893-3807; (805) 893-2611(fax); hsc@research.ucsb.edu

For more details on this protocol, go to the ORahs website: https://orahs.research.ucsb.edu/

HSC approval does not include evaluation or approval of COVID-19 related safety procedures. You are expected to follow all applicable COVID-19 safety requirements to include, but not limited to, institutional, local, state, and government requirements, during the conduct of this research. It is the responsibility of the Principal Investigator to be informed of and follow the research policies and guidelines found here: https://www.research.ucsb.edu/human subjects/covid-19-impact-human-subjects-research.