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Impacts of Atmospheric Rivers on Communities in Northern California: Comparative Analysis of Sonoma County Hazard Mitigation Plans

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This Master's Project

Impacts of Atmospheric Rivers on Communities in Northern California: Comparative Analysis of Sonoma County Hazard Mitigation Plans

by

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Abstract

Climate change increases the frequency of extreme weather events and affects California's hydroclimate, thereby increasing flood vulnerability of all communities in Sonoma County. An example of extreme weather phenomena is atmospheric rivers (ARs), which are long narrow water vapor transported by winds across the Pacific Ocean. ARs have a history of causing major flood events that have swept through Sonoma County and negatively impacted cities along the lower Russian River, such as the unincorporated town of Guerneville, California. Major floods cause detrimental impacts to the economy. Social inequalities become evident when unincorporated communities located along floodplains are more vulnerable to floods than incorporated communities. This risk may continue to rise due to the lack of maintenance on existing infrastructure and the unpredictable extreme weather. A comparative analysis between three hazard mitigation plans (HMPs) from Sonoma County, Sonoma County Water Agency, and Sweetwater Springs Water District was conducted to determine the efficacy of ongoing flood mitigation actions established in each local government HMP. While not all evaluated mitigation actions across the three HMPs compared were effective, actions that were effective had high flood mitigation benefits.

1. Introduction

Atmospheric rivers are a common global weather phenomenon that contribute to the hydroclimates of Great Britain, East Asia, and North America (Lavers, 2012; Payne, 2020). The west coast of the United States receives approximately 50% of its total annual precipitation from atmospheric rivers (ARs) (Mascioli, 2022). ARs are narrow streams of water vapor that travel longitudinally in the lower troposphere by winds known as low-level jets (LLJ) (Lavers, 2012; Zhu & Newell, 1998). Northern California has a distinctive topography, with windward mountain ranges along its coastline tall enough to interact with ARs because they travel along at low altitudes (Lavers, 2015; Valenzuela, 2017). When ARs encounter topographic barriers, such as the West Coast Mountains in Sonoma County (Figure 1.) and the Cascades-Sierra Nevada Mountain ranges, they can transport large volumes of water vapor during landfall and cause sudden precipitation through orographic forcing (Ralph 2006; Rutz, 2013) The mountainous terrain in Northern

California features peaks that rise to heights of approximately 500-1000 meters above sea level (MSL), and the variation in topography and latitude ranges results in microclimates that intensify weather extremes (Valenzuela, 2017).

The relationship between ARs, atmospheric circulation related to El Niño–Southern Oscillation (ENSO) episodes, orographic forcing, and major flooding events on the West Coast of North America has been extensively studied (Higgins 2000; Rutz 2013). As climate change continues to alter precipitation patterns and trigger ENSO events, the impacts of atmospheric rivers (ARs) are expected to intensify (Higgins, 2000; Lavers, 2015). Climate research on atmospheric rivers (ARs) in California has focused on locations along Bodega Bay, the coastal mountains of Cazadero, and unincorporated cities in the lower Russian River (Ralph, 2006).

The Russian River watershed is the largest in Sonoma County, draining a total of 1,485 square miles from Mendocino County to the Pacific Ocean (Multijurisdictional Hazard Mitigation Plan, 2021). Nearly 90 percent of the drainage basis lies upstream of the flood-prone areas the frequency of flooding in this portion of the river causes repetitive flood losses of the lower Russian River which includes the unincorporated communities of Monte Rio, Guerneville, Rio Nido, and Forestville. Major floods have sociological and economic impacts such as loss of life, property damage, and interference with daily lives (Payne, 2020). The necessity for an adaptive approach to flood management becomes evident when considering the impacts of floods caused by ARs. The resilience of a community depends on Sonoma County's response to the stress on the environment and infrastructure (Payne, 2020).

The advent of recent technology, known as the Advanced Quantitative Precipitation Information System (AQPI), has the potential to overcome the difficulties associated with predicting AR intensity and precipitation patterns (Cifelli, 2022). AQPI is capable of measuring key characteristics of AR in real-time, offering a valuable new resource for environmental managers, research scientists, and meteorologists. AQPI can assist with understanding the temporal sequence of ARs, which can have a detrimental effect on the northern West Coast and local communities that are susceptible to flooding. ARs impact the environment by saturating soil and inundation, which causes more runoff and contributes to flooding (Payne, 2020).

This paper seeks to explain the thermodynamics of ARs and their impact on Northern California, with a specific focus on assessing the effectiveness of current flood mitigation policies in Sonoma County. A comparative analysis was conducted between hazard mitigation plans (HMPs) produced by Sonoma County, Sonoma County Water Agency, and Sweetwater Springs Water District with the objective of determining the efficacy of flood mitigation actions for each HMP.

The efficacy of the mitigation actions varied because each HMP serves different jurisdictional areas and involves different stakeholders. It was hypothesized that the Federal Emergency Management Agency (FEMA) provided the most funding for mitigation actions across all three HMPs because HMPs are funding requirements by FEMA. The findings of this study indicate that the most effective flood mitigation actions were those that offered high benefits. However, further research is necessary to determine which HMP was the most effective flood mitigation action plan.

This study also investigated the vulnerability and personal impacts of major flood events using Sonoma County resident survey data provided by the Multijurisdictional HMP Updated 2021 Volume 1 and Volume 2. Unincorporated communities, specifically Districts 4 and 5, were the most vulnerable to flood due to their location on the Russian River floodplain. The ongoing debate among Guerneville residents regarding the formation of a city council or a special district to exert more authority over infrastructure projects and community programs highlights the socio-political complexities surrounding flood management in unincorporated communities. Understanding the personal impacts of major flood events on Sonoma County residents, especially in unincorporated communities, is essential for informing effective HMPs and fostering community resilience.

Flood Control Zones
Sonoma County, California

Figure 1. The map displays Sonoma County flood control zones (1A through 9A) within the Russian River Watershed. The areas shaded in gray represent incorporated cities. The remaining areas of Sonoma County are unincorporated. Source: Sonoma County Water. https://www.sonomawater.org/flood-protection-zones

2. Atmospheric Rivers

2.1. Characteristics

The formation of water vapor from tropical sources in the Pacific Ocean can be a potential AR traveling thousands of kilometers along pre-frontal low-level jets (LLJs) in the troposphere toward the west coast of Northern California (Cordeira, 2013). LLJs are bands of wind that travel horizontally in the troposphere and usually hold larger volumes of water vapor (Ralph, 2005). Approximately 90% of the longitudinal water vapor transport conducted by ARs is concentrated in only ten percent of the hemisphere's circumference; this is roughly twice the mean annual discharge found at the mouth of the Amazon River (Payne, 2020; Zhu and Newell, 1998). The components that create ARs are thermodynamic interactions with warm air temperatures from the tropics, increased atmospheric moisture (water vapor), and high winds from an eddy-driven jet traveling longitudinally across the Pacific Ocean (Payne, 2020; Ralph, 2005; Rutz, 2014). The eddy-driven jet stream that can create atmospheric rivers forms in between the cool and warm layers of the atmosphere (Payne 2020. Wind extremes are associated with 25% or more of ARs (Waliser 2017). The mid-latitude (Northern California) coastlines are affected by ARs on average 40 or more days per year, with a greater frequency observed during the winter months (Waisler, 2017). The occurrence of extreme winds, with speeds exceeding 15-20 m/s, has been identified as a factor contributing to the deterioration of coastal areas (Waliser, 2017). The longitudinal water vapor transport occurs primarily in the lower troposphere. In California, the longitudinal direction of the LLJ and the narrow width of an AR are clues to predict where an AR landfall will occur along the coastline (Payne, 2020). The measures of thermodynamic variables (wind and water vapor) of ARs can find the intensity and the scale of impact that will be following during the landing.

2.2. Water Vapor

Water vapor transport grows along the North Pacific jet stream and stretches along the Pacific Ocean for hundreds of kilometers (Cordeira 2013). ARs are identified through radar, satellite imagery, weather devices like radiosondes, and wind profilers (Ralph 2006, 2019). Radiosondes can measure integrated water vapor (IWV), which is the moisture content volume from a section of an AR (Ralph, 2006). IWV is also referred to as precipitable water because it is the measurement to quantify the volume of water vapor as a vertical profile in centimeters (Ralph 2006, 2018). IWV is the quantity of water that would result from the condensation and precipitation of all water vapor present in an atmospheric river, and for which a depth could be measured (Ralph, 2018). The IWV threshold to identify an AR is 2 cm (Ralph, 2006). In February 2024, Northern California was subjected to a series of atmospheric rivers, which were monitored in real-time by the global IWV system. Live monitors of global IWV are available through the Cooperative Institute for Meteorological Satellite Studies webpage and can be used for verifying AR conditions (Figure 2.)

Past developments of predicting, identifying, and measuring the intensity of ARs have evolved into the metric integrated water vapor transport (IVT) (Cordeira 2013) (Figure 3.). IVT incorporates wind speeds and moisture content volumes in the atmosphere to find the total mass of water vapor traveling through a cross-section of an AR column (Ralph 2018). IVT is measured in units of kg m-1s-1. For a water vapor formation to be classified as an AR, the IVT must be 250 kg m-1s-1 or greater (Ralph 2018). Another defining characteristic of ARs, in addition to their substantial water vapor content, is their narrow width (Payne 2020).

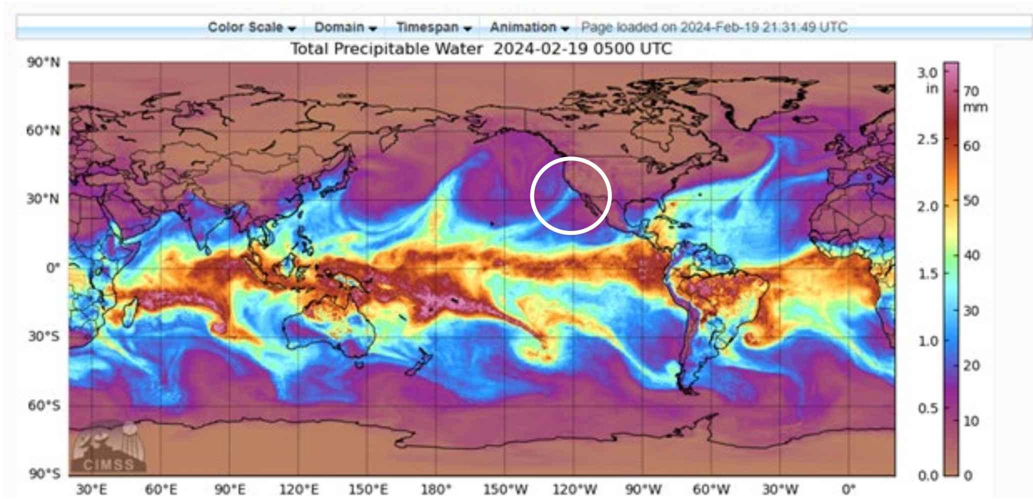


Figure 2. Satellite image of the global spatial distribution of longitudinal IWV. A series of ARs made landfall in February 2024 in Northern California. On February 19, 2024, an AR is striking the San Francisco Bay Area (white circle). Source: CIMSS. 2024. https://cimss.ssec.wisc.edu/.

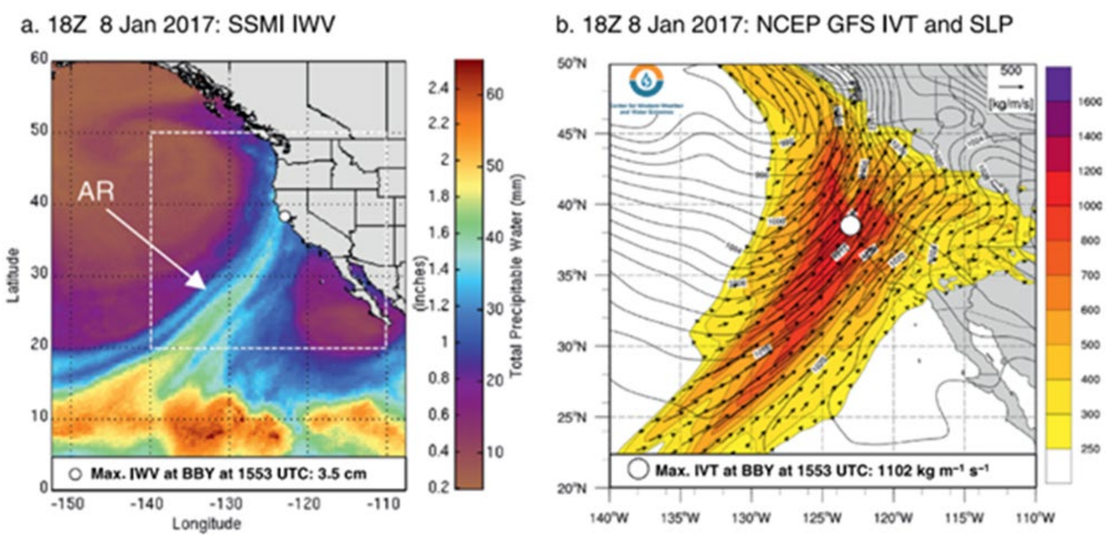


Figure 3. Satellite observations of IWV and the analyzed IVT of an analogous AR event that transpired over the northeastern Pacific Ocean and the western United States in 2017 lasted over 36 hours. Source: Figure 2. A, and B. Ralph 2019.

3. AR Scale

To gain insight into the nature of ARs and their defining characteristics, it is helpful to conceptualize an AR as an "object" existing within a specific space and time within the lower troposphere (Ralph 2018). The AR scale describes the time AR conditions occur at a specific location. The potential impact of ARs in California can be classified as either beneficial or harmful, depending on the duration and intensity of the event during landfall. To categorize each AR landfall, Ralph, (2018) and a team of hydrometeorological scientists created a scaling system to categorize ARs and their intensities, common among ARs in the western U.S (Table 1).

The objective of the scale is to assist meteorologists and environmental managers in the western United States by characterizing the attributes of ARs. Similarly, hurricane scales are employed to describe the characteristics of these meteorological phenomena (Ralph, 2018). The characteristics of an atmospheric river (AR) that serve as the basis for the scale can be identified by measuring thermodynamic variables, such as wind speeds associated with cold low-level jets (LLJs), and water vapor content. The spatial extent and intensity of ARs are described using IWV and IVT. However, IVT is a more accurate measure of intensity than IWV because it incorporates wind speed, which is an important characteristic of AR formation (Ralph 2018). Therefore, IVT is used to quantify AR intensity. Ralph (2018) evaluated the intensities of January 2017 data collected by a radiosonde-derived IWV and IVT magnitudes of 3.5 cm and 1,102 kg m–1 s–1, at Bodega Bay (BBY), California (Figure). It is important to note that the application of Ralph's (2018) AR scale can facilitate the categorization of historical ARs when there is available IWV, IVT, and wind speed data. The AR scale can assist researchers in associating previous heavy precipitation events with ARs and potentially linking the causation of flood events to ARs.

A category scale using the intensity values was simplified to AR CAT 1-5, with AR CAT 1 primarily beneficial and AR CAT 5 primarily hazardous (Ralph 2018). The duration of AR conditions and intensity (IVT) are the variables for creating the AR category scale (Table 1). The maximum intensity of IVT can measure hourly rain rates when the landfalling of an AR occurs, and then the storm-total precipitation (runoff) is closely related to the storm-total water vapor transport (Ralph, 2018). The ARs with a greater duration (greater than 24 hours) are associated with greater impacts. There are two exceptions to the categorization of an AR: the maximum category on the scale is AR CAT 5, even if the duration is longer than 48 hours, and weak ARs that are between 250 and 500 kg m-1s-1 with a duration less than 24 hours do not get a categorical ranking. The categories of AR intensities are ranked from "not an AR" to "exceptional" (Figure 4).

3.1. Frequency

ARs are distributed throughout the West Coast, with the majority of AR Cat 5 and Cat 4 events occurring north of Point Conception along the coastal regions (Ralph 2018). Weak ARs (those without a category ranking) occur with some frequency in all locations across the western United States (Ralph 2018). Rutz (2014) identified a pattern of greater intensity AR events occurring exclusively in the troposphere in northern coastal regions of California.

AR season near Bodega Bay through October and March (peaking in December) (Ralph 2018). The return periods of the most intense ARs (750-1,250 kg $m^{-1}s^{-1}$) in various locations on the west coast range from one to 20 years. San Francisco, for instance, experiences a strong AR once every three years (Ralph 2018).

Table 1. The AR scale categorizes AR events based on their conditions and the duration of the event at a given point. Source. Table 2. Ralph, 2018.

Max IVT ($kg\ m^{-1}\ s^{-1}$)	Duration of AR conditions (h)		
	≤24	≥24–48	≥48
≤250	Not an AR	Not an AR	Not an AR
≥250–500	Weak AR	AR Cat 1	AR Cat 2
≥500–750	AR Cat 1	AR Cat 2	AR Cat 3
≥750–1,000	AR Cat 2	AR Cat 3	AR Cat 4
≥1,000–1,250	AR Cat 3	AR Cat 4	AR Cat 5
≥1,250	AR Cat 4	AR Cat 5	AR Cat 5

AR category scale	Assessment of beneficial vs hazardous impacts
AR Cat 1	Primarily beneficial
AR Cat 2	Mostly beneficial, but also hazardous
AR Cat 3	Balance of beneficial and hazardous
AR Cat 4	Mostly hazardous, but also beneficial
AR Cat 5	Primarily hazardous

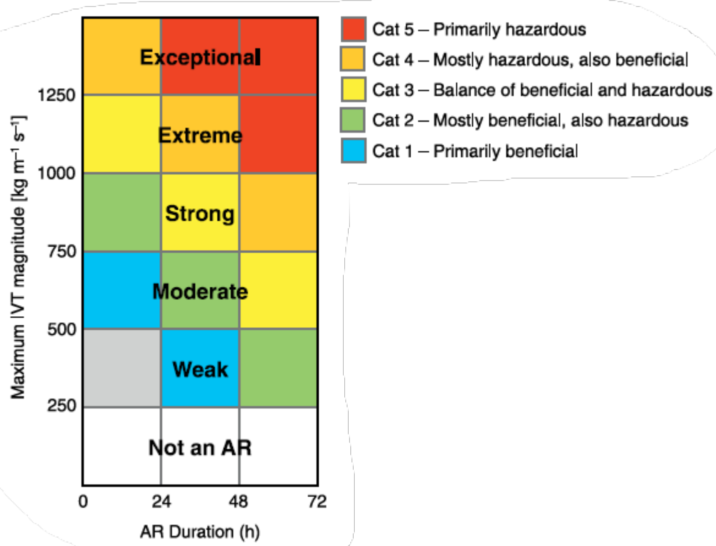


Figure 4. The categorization of an AR event at a given location involves the localization of the associated row, which represents the maximum IVT value, in conjunction with the associated column, which denotes the duration of the event. For example, a maximum IVT ≥500 and <750 kg m^{-1} s^{-1} would be classified as being of "moderate" intensity, and a duration ≥24 and <48 h would rank this as an AR category CAT 2 event. Source: Figure 4. Ralph, 2019.

4. Orographic Forcing

Exchanges in warm and cold fronts cause an increase in localized precipitation rates along coastal terrain. The "forcing" is caused by moist, statically neutral airflow encountering steep slopes, and the air ascents cool, and then condensates (Valenzuela, 2017). An AR can hold its water vapor volume until an interaction with the mixture of air forces orographic precipitation (Payne, 2020), and the heaviest flood events occur when forced orographic precipitation occurs (Ralph, 2006). Coastal terrain along the west coast is subject to extratropical cyclones that are coupled with ARs landfall most commonly during winter seasons (Valenzuela, 2017).

Heavy precipitation events from ARs occur unexpectedly when an unstable warm front is associated with a pre-frontal cold front that causes water vapor to condense at the peak of a mountain (Ralph, 2005). ARs are paired with LLJs and travel longitudinally across the Pacific Ocean, growing in volume with water vapor until interacting with mountain barriers on the west coast and causing forced orographic precipitation (Ralph, 2005). There is a positive correlation between upslope flow and orographic rainfall in the coastal mountains because LLJs are observed by coastal profilers (Neiman, 2002). The advection from a warm front windward of a mountain increases wind speeds at the same time the cold front from the LLJ interacts with the warm air in the troposphere. The combination of warm air and cool dry air rapidly ascending a mountainside quickly condenses and induces forced heavy precipitation (Payne, 2020; Ralph, 2005, 2006). The warm air forces the water vapor to travel upwards.

A study by Ralph (2006), was able to identify an AR-correlated flood event because of the concurrent increase in IWV vertical height and wind speed with a flood stage increase in the Russin River (Figure 5). The change in wind speed was caused by a warm front along local Guerneville Mountain and forced the AR to precipitate. The Ralph 2006 study used Russian River discharge data collected by a USGS river gauge from February 16- 22, 2004. From the 2004 AR series, Guerneville received 10.7 inches of rain that caused flooding (Ralph 2006). The Russian River watershed receives 60%–70% of its total annual precipitation from ARs (Fish 2019).

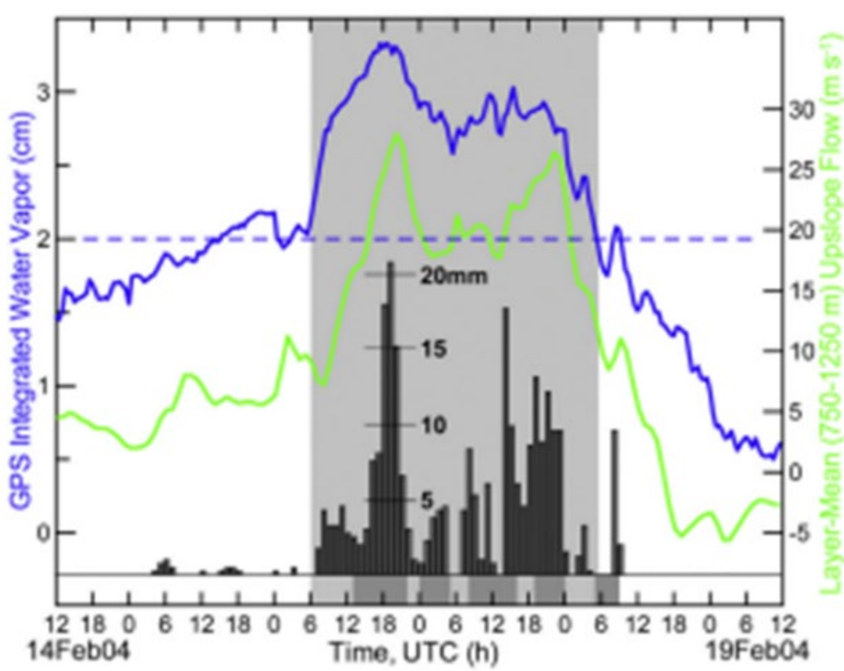


Figure 5. Correlation between wind speed (green line) and IWV (blue line) ascending coastal mountains. Forced orographic precipitation (bar graph) occurs at the peaks at the same time as hourly rainfall peaks. Source: Figure 3. Ralph (2006).

5. Climate Change

Climate change poses an imminent and intensifying threat to the environment, public health, and economic vitality of California (Sonoma County Multijurisdictional HMP Update 2021). According to the Sonoma County Multijurisdictional HMP Update 2021, mitigation in climate change discussions is defined as a human intervention to reduce the impact of human activities on the climate system. Sonoma County's HMP encompasses strategies for reducing the sources of greenhouse gases and emissions, as well as enhancing the sinks for these gases. As a result of climate change, there is a projected increase in the amount of precipitation falling during the heaviest precipitation events, with a range of 3 to 10 percent. This increase in precipitation could potentially lead to an increase in the risk of flooding (National Research Council, 2011).

The influence of climate change is predicted to cause more extreme weather patterns and unpredictability globally. Changes in global precipitation patterns occur because of the slow-down circulation of warm and cold jet streams from declining sea ice in the polar regions (Payne, 2020). Cheung (2023) found extratropical cyclones formed in the tropics have higher destructiveness (indicated by integrated kinetic energy) and became more frequent in response to greenhouse warming, although the number of events did not change significantly. Similarly, climate change is also associated with influencing the west coast of North America's hydroclimate by increasing the frequency and intensity of atmospheric river events (Gershunov, 2017; Wuebbles, 2017). Climate change is also causing unpredictability, as average precipitation could increase by 35 percent or decrease by 21 percent and would impact California's water budget (California Landscape Conservation Partnership. 2021).

One potential consequence of global warming is that warmer air may increase atmospheric moisture, which could result in an increase in IVT in midlatitudes (Gershunov 2017, Payne 2020). ARs are sensitive to temperature changes, and it has been known that the Pacific Ocean's sea surface temperatures (SST) influence the seasonal predictability of heavy precipitation (Gershunov 2017). ARs and El Ninos events have a positive correlation because IVT increases under El Nino conditions (Khouaki 2016). ARs are detrimental when they are in a series or combined with another high-intensity variable like El Nino conditions, defined as temporal compounding. Temporal compounding is defined as the phenomenon whereby a series of ARs impact the same area rapidly before there can be any environmental recovery (Bowers 2024). Temporal compounding is most frequent during California's wet winters because of the state's Mediterranean climate (Bowers, 2024). The combined effects of ARs and El Niño have destroyed infrastructure along the California coast (Khouaki, 2016).

ARs and extratropical cyclones (EC) share similar characteristics, therefore an AR is likely to develop when there is an extratropical cyclone (EC) occurs in the east Pacific (Ralph, 2005). ARs are associated with extratropical cyclones (ECs) because they form under the same temporal and spatial conditions in tropical areas longitudinally around the world (Zhang, 2018). Eighty-two percent of atmospheric rivers are associated with an extratropical cyclone, while 45% of extratropical cyclones have an atmospheric river (Zhang, 2018). The aftermath of an extratropical cyclone on the weather patterns of mid-latitudes can result in the formation of a weakened cyclone moving into a region and bringing strong winds and heavy precipitation associated with rainfall rates >100 mm/day on the west coast of the U.S. (Cheung, 2023., Corderia, 2023).

ARs and ECs enhance each other's characteristics when they occur simultaneously, or an AR can be found inside an EC (Ralph, 2005). New studies revealed that if a low-level jet (LLJ) is present or a tropical storm, ARs can intensify the precipitation reaction and increase runoff (Rutz, 2013). Low-level jets are bands of wind that travel horizontally in the troposphere and usually hold larger volumes of water vapor (Ralph, 2005). ARs are associated with extratropical cyclones (ECs) because they form under the same temporal and spatial conditions in tropical areas longitudinally around the world (Zhang, 2018).

A case study (Zhang, 2018) analyzed the relationship between ARs intensity and ECs strengths by comparing the characteristics of ECs paired with ARs and ECs without an AR. ECs associated with ARs can intensify ARs by increasing wind speed, and AR enhances ECs by providing more water vapor for greater precipitation events (Zhang, 2018). In 2010, Corderia (2013) documented the evolution of two atmospheric rivers forming during two simultaneous ECs in the east Pacific and converging into one long atmospheric river across the Pacific headed towards the west coast along the North Pacific Jet (NPJ). The impact from the merged AR landfall produced heavy precipitation across Northern California, Oregon, and Washington.

It is becoming increasingly accepted that extreme precipitation from ARs can cause flooding. Approximately 87% of floods the lower Russian River region has experienced are caused by ARs (Sweetwater Springs Water District HMP 2021). The impacts from ARs range because of multiple factors like AR orientation when landing, duration, intensity of moisture transport, antecedent soil, and existing flood control infrastructure (Bowers, 2024; Payne, 2020). The standard for designing and operating water supply protection projects has been based on historical hydrologic data with the assumption climate patterns will be consistent and similar to previous records. Precipitation and runoff patterns are changing and increasing for water supply and flood management (Payne, 2020; Ralph, 2019).

The unincorporated cities in Sonoma County have recognized the necessity to adapt to changes in extreme weather patterns and to implement updated flood mitigation plans in anticipation of the potential for climate change to result in more intense and frequent AR events (Sweetwater Springs Water District HMP 2021). The City of Guerneville predicts the average annual precipitation will increase by 2100 because climate change causes more variable rain patterns (Sweetwater Springs Water District HMP 2021). The 0.2 percent annual chance floodplain inundation area may become a higher probability risk, thus increasing flood vulnerability (Sonoma County Multijurisdictional HMP 2021). Sonoma County's Climate Change Action Resolution Plan has a goal to reduce greenhouse gas emissions to 40 % below 1990 levels by 2030 (Sonoma County Multijurisdictional HMP 2021). Local actions include climate change mitigation actions in Table 2. that the County is pursuing.

Table 2. Sonoma County Multijurisdictional HMP 2021 is pursuing the listed climate change mitigation actions to protect their residents from the consequences and increased risk of hazards. Goals. Multijurisdictional Hazard Plan 2021

Goals	
Increase building energy efficiency	Reduce idling
Increase renewable energy use	Increase solid waste diversion
Switch equipment from fossil fuel to electricity	Increase capture and use of methane from landfills
Reduce travel demand through focused growth	Reduce water consumption
Encourage a shift toward low-carbon transportation options	Increase recycled water and graywater use
Increase vehicle and equipment fuel efficiency	Increase water and waste-water infrastructure efficiency
Encourage a shift toward low-carbon fuels in vehicles and equipment	Increase use of renewable energy in water and wastewater systems
Reduce emissions from livestock operations	Reduce emissions from fertilizer use
Protect and enhance the value of open and working lands	Promote sustainable agriculture
Increase carbon sequestration	Reduce emissions from the consumption of goods and services

6. Impacts

Floods are the most frequent natural hazard to impact Sonoma County, cause the greatest property loss, and the highest number of presidential disasters (Sonoma County Water LHMP Draft 2021). Two types of floods impact Sonoma County: slow-rise or flash flooding (Sweetwater Springs HMP, 2021). Slow-rise flows occur over hours or days, allowing sufficient time for evacuation or sandbagging if necessary. Flash floods occur without warning and can be caused by one or more of the following factors: extreme precipitation, saturated soil, and recently burned areas from wildfires.

Urban flooding occurs in dense urbanized areas with impermeable surfaces that can either collect water or direct the flow of water into unnatural channels (Sweetwater Springs HMP, 2021). In contrast, riverine flooding represents a natural process whereby runoff is absorbed or collectively drained into a single river channel during periods of heavy precipitation. A floodway and a flood fringe collectively comprise a floodplain. A flood pain is an area along a river that becomes inundated during a flood event and acts as natural flood and erosion control (Multijurisdictional, 2021). A floodway, defined by the Federal Emergency Management Agency (FEMA), is a channel of a river and not a physical geologic feature for National Flood Insurance Policy (NFIP) purposes. NFIP is a federal government initiative that provides financial assistance during natural disasters. Created by Congress in 1968, the NFIP makes flood insurance available in communities that enact minimum floodplain management rules consistent with the Code of Federal Regulations §60.3 9 (Sweetwater Springs Water District HMP, 2021). Any development in a floodway is subject to severe damage and high risks for occupants and emergency responders (Figure 6.). FEMA determines where the special hazard flood risk zones are depending on the elevation a 100-year flood can occur. A 100-year flood is the 1% chance of a worst-case scenario flood to occur once any given year (Sweetwater Springs Water District HMP, 2021). FEMA provides a public source for flood hazard information where an individual can find a flood map for an address or longitude/attitude coordinates in the United States.

A flood initial study (FIS) is conducted by FEMA for counties that participate in the NFIP. FIS is used to identify and map the flood hazard areas in Sonoma County and the last FIS was updated in October 2017 (Sonoma County Water Agency HMP Draft 2023). Corresponding water-surface elevations describe the elevation of water that will result from a given discharge level, which is one of the most important factors used in estimating flood damage (Multijurisdictional, 2021). Land covered by floodwaters of the base flood is the special flood hazard area (SFHA) on a FIS map, an area where NFIP floodplain management regulations must be enforced, and where the mandatory purchase of flood insurance applies (Figure 6) (Multijurisdictional HMP, 2021). A structure within a 1-percent-annual-chance floodplain has a 26-percent chance of undergoing flood damage during the term of a 30-year mortgage. FEMA typically does not designate SFHAs for areas subject to flooding from local drainage problems, particularly in urban areas; drainage basins of less than 1 square mile in area; or hillside areas subject to runoff, erosion, and mudflow. FIS has found many Sonoma County properties are outside any mapped 1 percent annual chance (100-year) floodplain (Figure 6).

Repetitive loss properties are defined by FEMA as insured properties that have experienced four or more paid losses of more than $1,000 in 10 years (Anderson, 2008). FEMA-sponsored programs, such as the Community Rating System (CRS), identify repetitive loss areas (Sonoma

County Multijurisdictional HMP 2021). FISs have found that many properties that experience repetitive flooding are outside any mapped 1 percent annual chance (100-year) floodplain, indicating that data from flood risk maps are outdated (Anderson, 2008). From 1978 to 2021, FEMA has identified 969 properties which equates to a total payment of $90,925,808.27 (Sonoma County Multijurisdictional HMP 2021).

Through Sonoma County's Community Development Commission Affordable Housing, there is funding for homes to be elevated through. To date, the CDC has elevated over two hundred residential structures, more than any other jurisdiction in the Western United States (Flood Elevation Mitigation Program, 2024). The average cost in 2024 to elevate a home is $28,000 (Forbes, 2024). The Flood Elevation Program will cover 75% of the cost of raising a home in a flood risk zone and will raise it above the 100-year flood level (Flood Elevation Mitigation Program, 2024). The property owner must cover the remaining 25 % of the cost at the start of the construction. In an interview with a Guerneville resident and the local librarian, Mell McCallen stated that private flood insurance will not insure her property in Guernewood Park, which is in a special hazard flood risk zone, because it is too high of a risk. Mel depends on the NFIP to file claims on her property after flood damage. The unincorporated areas of the County within the Sweetwater Springs Water District participate in the NFIP through Sonoma County enrollment in NFIP (Sweetwater Springs Water District HMP, 2021). The most recent flood, New Year's Eve 2022-2023, was the first flood of her property, and she had to remove everything. She continues to explain how the first floor of her property is not usable and her family only resides on the second floor.

There is a growing awareness connecting ARs to being the primary source of major flood events in Northern California (Corringham, 2019). ARs have caused almost all of the floods in the Russian River watershed over the last 65 years (Sonoma County Water LMHP Draft, 2023). From 1978 to 2017, the total cost of damage caused by ARs in Sonoma County was 5.2 billion dollars (Corringham, 2019). A study by Raph, (2019) was able to categorize the intensity of ARs and the flood associated with the time the AR occurred (Table 3). Seven floods that occurred in the Russian River watershed between 1997-2006 were caused by ARs (Ralph, 2006).

One example of an AR causing a significant flood event in Northern California is the 1995 incident on January 4th. The AR traveled from Hawaii and made landfall in Sonoma County with

IVT greater than 712 kg m^{-1} s^{-1} and continued to grow to 966 kg m^{-1} s^{-1}. The AR was classified as category five on the intensity scale (Table 3). The extreme rainfall caused the Russian River to peak 48 feet above gauge height at Guerneville (Sonoma County Water LMHP Draft, 2023). The flood was severe enough for a presidential disaster declaration (Multijurisdictional HMP, 2021). After being flooded over three days, insured losses in Sonoma County totaled over $50 million (Corringham, 2019). The Sweet Water Local Hazard Mitigation Plan 2021 collected data from USGS to find the peak flow of the Russian River exceeded its flood stage 34 of 59 years between 1960-2019.

The town of Guerneville, in conjunction with the surrounding unincorporated communities in the lower Russian River region, experiences flooding at a rate exceeding that of the rest of Sonoma County due to its location within the Russian River floodplain. The Guerneville gauge monitors peak discharge 4.3 miles upstream from the Guerneville Bridge and 20.8 miles upstream from the mouth of the Russian River reaching a gauge height of less than 34 feet at the Guerneville Bridge is common during a typical winter but does not usually present significant problems for the community (Multijurisdictional HMP, 2021) (Table 4). For County emergency response purposes, a staff gauge on the Guerneville Bridge is used to monitor flood elevation levels and risk to the community of Guerneville. Emergency flood responses are triggered by flood gauge height. At the Guerneville Bridge, the Russian River is considered to be at flood stage when it reaches a height of 32.0 feet (River Flood Plan 2023. Major flooding events occur at a level 40.0 and greater and flooding of roadways becomes an issue. Sonoma County flood plans ensure that there is enough time (>48) before a flood occurs so that the emergency operations response teams can respond adequately and evacuate people if necessary. The challenge is the lack of emergency resources, and some areas flood faster than others, isolating residential areas with large populations.

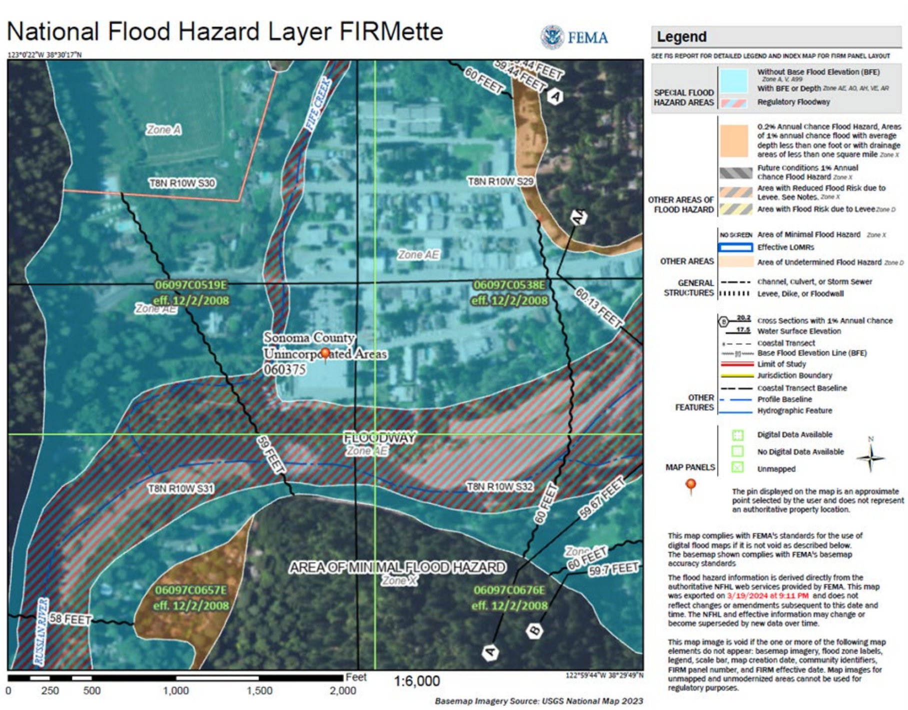


Figure 6. A flood map for Guerneville, California shows the demarcation of a floodway (red stripes) and the special flood hazard zones (blue) created by FEMA. The data in this map was last updated in 2008. The location of where the red pin is located is a local grocery store. Source: FEMA Flood Map Service Center. 2024. https://msc.fema.gov/portal/home

Table 3. There have been ten different AR Cat 5 events that occurred near Bodega Bay between January 1980 and April 2017. Source: Table 5. Ralph, 2019.

AR Cat 5 event No.	Water year	Year	Start time/date	End time/date	Duration (h)	Flood stage (32 ft) at Guerneville?
1	1980	1980	0600 UTC 11 Jan	1200 UTC 14 Jan	78	Yes (37 ft)
2	1984	1983	0600 UTC 9 Nov	0600 UTC 11 Nov	48	—
3	1986	1986	0000 UTC 14 Feb	0000 UTC 20 Feb	144	Yes (49 ft)
4	1991	1991	1200 UTC 2 Mar	0000 UTC 5 Mar	60	Yes (33 ft)
5	1996	1995	1500 UTC 10 Dec	0000 UTC 13 Dec	57	Yes (32 ft)
6	1997	1996	1800 UTC 16 Nov	0000 UTC 20 Nov	78	No
7	1997	1996/97	1800 UTC 28 Dec	0600 UTC 3 Jan	132	Yes (45 ft)
8	2011	2010	0900 UTC 23 Oct	1200 UTC 25 Oct	51	No
9	2015	2015	0900 UTC 5 Feb	1200 UTC 7 Feb	51	No
10	2017	2017	0600 UTC 7 Jan	0600 UTC 9 Jan	48	Yes (40 ft)
Frequency		1 event per 3.8 yr	Oct (1), Nov (2), Dec (2), Jan (2), Feb (2), Mar (1)		Average: 75 h	

Table 4. The Sonoma County Operational Area Emergency Operations Plan Annex was created by the Sonoma County Department of Emergency Management which used USGS data to create a table with peak gage height (level) and the type of event (major). The table also includes dates

when a major flood reached a certain level (orange). Source: Sonoma County Department of Emergency Management. 2023. Sonoma County Operational Area Emergency Operations Plan Annex. Russian River Plan.

Time:	Level:	Event:
	40.0	*Major Flooding*
	40.0	**Guerneville:** Travel on River Road is becoming a problem; River Road at Korbel **Monte Rio:** Upper Redwood Dr. in Northwood. **Cazadero:** Austin Creek Road closes. Crest on 3/10/95
	40.5	**Guerneville:** River Road between Rio Nido & Guerneville closes; Redwood Chapel on Mill St.; Buck's Restaurant. **Monte Rio:** Main St. begins to inundate. **Forestville:** River Road at Martinelli.
	41.5	**Guerneville:** Mill Street at 4th closed; businesses on high side of River Road start going under; Old River Road on Guerneville end closed. **Monte Rio:** Main St. intersection impassable. Elementary school begins to flood. **Forestville:** River Road at Mirabel closed. Crest on 1/3/06
	42.0	**Guerneville/Rio Nido:** DuBrava starts flooding; Neeley Road across from DuBrava closed; Rio Nido post Office; Burdon's Restaurant on River Road; Hwy 116 at Gabe's Rock Road getting wet; Sweetwater Springs Water District office. **Monte Rio:** Bohemian Hwy in town.
	43.0	**Guerneville:** Safeway parking lot; Main St.; Guerneville school old buildings.
	44.0	**Guerneville:** Guerneville now isolated: Hwy 116 closed at Drums by Fife Creek.
	44.5	**Guerneville:** Old Noonan's property at 4th and Church under; River Lane in Vacation Beach.
	45.0	**Guerneville:** DuBrava under; most of Fife's under; Hwy 116 west of Safeway to Old Cazadero Road under. **Monte Rio:** Bartlett's store and surrounding area.
	45.3	Crest on 2/27/19
	46.0	*Disastrous Flooding* **Guerneville:** River Road at Rio Nido, the River Club, River Theater, River Inn and Chevron service station going under. Crest on 1/10/95
	47.0	**Guerneville:** Businesses on North side of Main Street: King's, Pat's, Rainbow Cattle Co., Bakery, etc. Crest on 2/28/40
	47.4	Crest on 12/23/64
	47.6	Crest on 12/13/55
	48.5	**Guerneville:** Veteran's Building begins to flood.
	48.9	Crest on 2/18/86
	49.0	**Guerneville:** 4 feet of water in parking lot; boat needed to travel down Main St.
	50.0	**Guerneville:** Water enters door of Sheriff's Substation.

7. Regulatory Framework

7.1. Hazard Mitigation Plans

The three HMPs concur that natural hazards have a profound impact on communities, resulting in loss of life, disruption of daily activities, property damage, and economic loss (Sonoma County Water HMP Draft 2023). A lack of preparedness for natural hazards can have long-term consequences for the recovery and rebuilding of a city. The objective of HMPs is to reduce the risk posed by hazards by identifying resources, information, and strategies for risk reduction through mitigation actions. The responsible party will uphold the obligation to protect a county, local government, special district, or tribal group. Hazard mitigation plans are a requirement through the federal Disaster Mitigation Act (DMA) 2000 (Public Law 106-390), Title 44 Code of Federal Regulations (CFR) Part 201, for any state and local governments to receive federal disaster grant assistance (Multijurisdictional HMP 2021; Sonoma County Water HMP Draft 2023). The objective of the DMA is to motivate state and local governments to develop hazard mitigation plans to minimize community vulnerability and economic loss from natural hazards like major flood events. A FEMA-approved HMP is a prerequisite for receiving grants under FEMA's hazard mitigation assistance programs, and other federal assistance during declared emergencies. FEMA requires a review and update of the local government's HMP at least every five years to maintain in status (Sonoma County Water HMP Draft 2023).

7.2. Sonoma County Multijurisdictional Hazard Mitigation Plan Update 2021

The Sonoma County Multijurisdictional HMP is a collaboration between Sonoma County, four out of nine Sonoma County incorporated municipalities, and nine Sonoma County special districts. The collaborating jurisdictions involved in the creation of the Sonoma County Multijurisdictional Hazard Mitigation Plan 2021 are the County of Sonoma, the City of Cotati, Santa Rosa, Sonoma, the Town of Windsor, and nine special districts which include; Cloverdale Fire Protection District, North Sonoma Coast Fire Protection District, Northern Sonoma County Fire, Rancho Adobe Fire, Sonoma Valley Fire, Timber Cover Fire, Gold Ridge Resource Conservation District, Sonoma Resource Conservation District, and Sonoma County Agricultural & Open Space District. Each representative from each local government and local business owners were a part of the Steering Committee (planning team) and reviewed measured risks from natural hazards to protect all residents in Sonoma County to create mitigation actions and rank them by priority. Historically, the Sonoma County Hazard Mitigation Plan did not involve the feedback and efforts of incorporated cities and special districts up until 2021, the newest update. The Sonoma County Multijurisdictional HMP planning committee conducted a review of the previous goals and objectives from their 2010 Hazard Mitigation Plan and determined that the aforementioned goals and objectives continue to reflect the community's priorities and the results of the risk assessment. The objective of involving local governments is the establishment of a unified HMP with flood mitigation actions. These would protect those participating, while simultaneously summarizing the goals each collaborating jurisdictional area hopes to reduce vulnerability from natural hazards across Sonoma County.

All citizens and businesses of Sonoma County are the ultimate beneficiaries of this hazard mitigation plan. Public involvement and participation provided the Steering Committee with data about what areas are the most vulnerable to distinct types of natural disasters and comments on what Sonoma County could improve on to reduce the risk of injury or property damage in the future. Public comments were available for two weeks, June 14 – 28, 2021 and 691 surveys were complete.

There has been an overall decline in population in Sonoma County since the 1960s. There are an estimated 494,336 residents who live in Sonoma County as of 2019 according to the U.S Census Bureau. There has also been a decrease in residents who live in unincorporated communities, but a slight population increase of 4% in incorporated communities (Sonoma County Multijurisdictional Hazard Mitigation Plan 2021). The Multijurisdictional Hazard Mitigation Plan Update 2021 assumes because of the population increase in incorporated communities, there is a new development in unidentified flood hazard areas.

This plan does include benefits and risk hazard information for unincorporated communities, but no unincorporated communities were involved in the creation of this plan. Before Sonoma County approved the Hazard Mitigation Update October 2021- Volume 1. Area-Wide Elements, Volume 2 of the Hazard Mitigation Plan Update July 2021 is a public review draft that includes steps for Sonoma County local governments that did not participate in the 2021 planning process to determine eligibility and "link" themselves to the 2021 Hazard Plan and receive eligibility for programs under the federal Disaster Mitigation Act (DMA). California Office of Emergency Services and FEMA pre-approve a hazard mitigation plan and then each planning partner can individually adopt the updated plan (Sonoma County Multijurisdictional Hazard Mitigation Plan 2021).

Risk

The Hazard Mitigation Plan identifies hazards as dam failure, drought, earthquake, flooding, landslide/mass movement, sea level rise, severe weather, tsunami, and wildfire. The Steering Committee identified risks associated with each hazard of concern with the following information: a summary of past events, geographic locations most impacted by hazards, frequency, and severity of hazards. Exposure to each hazard was found by analyzing hazard maps with identified structures, facilities, and systems and determining which one of those would be most at risk by each hazard. Vulnerability of exposed facilities was found through GIS countywide and individual incorporated areas.

One of the flood mitigation objectives of the Multijurisdictional Plan is to minimize adverse impacts of flood risk on vulnerable communities. The probability of natural disasters was rated by planning partners with high—hazard events that are likely to occur within 25 years (Probability Factor = 3). Flooding and severe weather were both identified as a probability factor of 3. Planning partners were directed to identify mitigation actions, at a minimum, to address each hazard with a "high" or "medium" risk rating.

The County of Sonoma established a Department of Emergency Management to create and update flood emergency plans for natural disasters. The Sonoma County Operational Area Emergency Operations Plan Annex: Russian River Flood Plan (EOP) 2023 describes a system for flood response teams during a major flood event along the Russian River. The purpose of this plan is to establish an order of response for cities in Sonoma County because there is not just one public safety organization for the entire flood region. The response effort is broken up into two regions because the hydrology and geography differ in the Middle Russian River and the Lower Russian River.

The catalogs provide a baseline of mitigation alternatives that are backed by a planning process, are consistent with the established goals and objectives, and are generally within the capabilities of the planning partners to implement. Alternatives consider manipulating and reducing exposure and vulnerability methods for hazards. For all categories, clear storm drains and culverts are the first alternative. Adaptive capacity is the ability of organizations to change their goals according to potential damage, opportunities, and response to consequences.

7.3. Sonoma County Water Agency Local Hazard Mitigation Plan Draft 2023

Sonoma Water, formerly known as the Sonoma County Water Agency, plays an essential role in the Sonoma County region through water supply services. Their activities include water services, operating wastewater treatment facilities, investment in new AR detecting technology, and maintaining flood protection infrastructure for incorporated communities (Sonoma County Water LHMP Draft 2023). Sonoma County Water continues to expand its water service area in Sonoma County and also provides water services in Marin County. The primary water supply customers of Sonoma Water include municipalities such as the City of Santa Rosa, Marin Municipal Water District, North Marin Water District, City of Petaluma, City of Rohnert Park, Valley of the Moon Water District, City of Sonoma, City of Cotati, and Town of Windsor.

Approximately 2% of their water supply is provided to customers in unincorporated communities such as California-American Water Company (Larkfield District), Penngrove Water Company, Lawndale Mutual Water Company, Kenwood Village Water Company, and Forestville Water District.

The total population served by Sonoma Water exceeds 630,000 people in Sonoma and Marin counties, and the population is projected to increase to more than 770,000 by 2045 (Sonoma County Water LHMP Draft 2023). Sonoma Water is a special district within Sonoma County that acts as its local government. Sonoma County gives Sonoma Water the authority to levy property taxes separately from the County, collect benefit assessments for flood control purposes, charge for sanitation services, and charge for water delivered from the transmission system (Sonoma Water LHMP Draft 2023). Sonoma Water has eight departments with over 260 professionals to cover various operations including water supply, flood protection, and sanitation. The planning process for the LHMP was broken up into teams and had a Core Planning Team with engineers and technical writers.

The purpose of Sonoma Water's LHMP Draft 2023 was to update previously established goals, objectives, and mitigation actions, and conduct a comprehensive assessment of the risks and vulnerabilities facing Sonoma Water's infrastructure from natural hazards. Sonoma Water plays a pivotal role in flood mitigation, investing in infrastructure and various projects designed to address flood issues. Sonoma Water is responsible for the maintenance of more than 75 miles of engineered flood control channels and approximately 100 miles of modified or natural channels (Figure 7.) (Sonoma County Water LHMP Draft 2023). All properties owned by Sonoma Water are insured under the County of Sonoma Self-Insured Property Insurance Program (Sonoma County Water LHMP Draft 2023). In addition, the agency is responsible for the maintenance of levees, fish ladders, and embankment protection on the Russian River.

Sonoma Water is the local sponsor for the two federal water supply and flood control reservoirs in the Russian River watershed: Coyote Valley Dam at Lake Mendocino and Warm Springs Dam at Lake Sonoma. Sonoma Water collaborates with the United States Army Corps of Engineers (USACE) and the Natural Resources Conservation Service (NRCS) to oversee the management of water supply storage within Lakes Mendocino and Sonoma. This involves regulating the release of water from the water supply pools in order to maintain the annual minimum stream flows in the Russian River and Dry Creek. For flood control purposes, Sonoma Water has helped build and manage Spring Lake Reservoir, Matanzas Creek Reservoir, Piner Creek Reservoir, and Brush Creek Reservoir (Sonoma County Water LHMP Draft 2023).

External funding sources provide Sonoma Water with grants from a multitude of stakeholders, including many state agencies in California. These include the California Department of Water Resources (DWR), the California Natural Resources Agency, the California Department of Fish and Wildlife, and the California State Water Resources Control Board. One of the grant programs that Sonoma Water participates in that gives public agencies the primary responsibility to handle flood emergency responses is the Statewide Flood Emergency Response Projects (FERP) through CA DWR (Sonoma County Water LHMP Draft 2023). CA DWR and Sonoma Water also provide financial support for the Integrated Regional Water Management (IRWM) program, which facilitates the implementation of the Advanced Quantitative Precipitation Information System (AQPI). The AQPI System uses observational technology to improve accuracy in predicting precipitation and hydrological events like ARs. The objective of AQPI is to accurately provide information to environmental managers in Northern California, with the intention of assisting Sonoma County in improving flood mitigation and maximizing water supply.

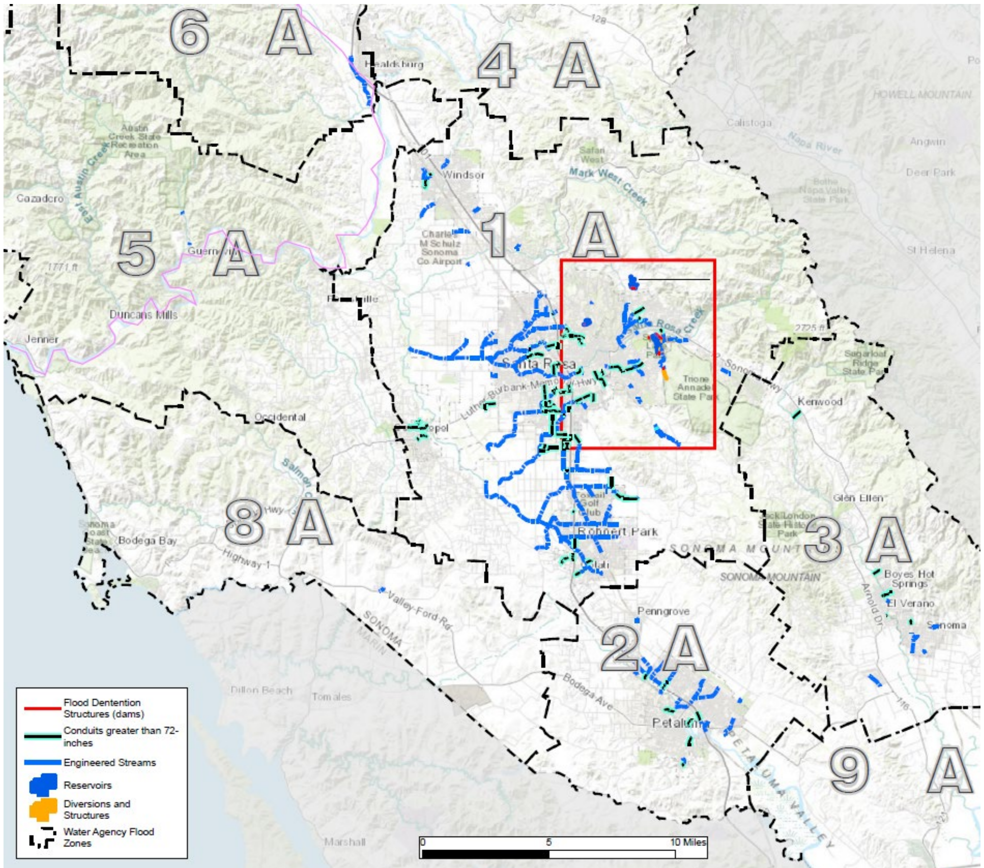


Figure 7. Sonoma Water divided Sonoma County into nine flood control zones, which include, 1A Laguna-Mark West Watershed, 2A Petaluma Creek Watershed, 3A Valley of the Moon Watershed, 4A Upper Russian River Watershed, 5A Lower Russian, River Watershed, 6A Dry Creek Watershed, 7A North Coastal Watershed (not shown), 8A South Coastal Watershed, and 9A Bay Watershed. The pink line is the location of the Russian River. Source: Sonoma County Water LHMP Draft 2023. The blue dotted lines are the locations of engineered streams.

7.4. Sweetwater Springs Water District Hazard Mitigation Plan 2021

Sweetwater Springs Water District provides water service to approximately 8,000 individuals (Sweetwater Springs Water District HMP 2021). Unincorporated communities in District 5 like Guerneville, Rio Nido, Guernewood Park, Villa Grande, Monte Rio, and Vacation Beach, receive potable water from Sweetwater Springs Water District (SSWD). The SSWD facility and treatment plant is located in Guerneville, California, and is run by 11 people. There are miles of pipeline for maintenance along with five wells and 17 pump stations (Sweetwater Springs HMP 2021). The system serves approximately 8,000 individuals, with approximately

3,600 accounts. Of these customers, approximately 95% are residential (SSWD HMP 2021). The California Department of Water Resources has developed a mapping tool that has enabled SWWD to identify its service community and to identify itself as a Disadvantaged Community and a Severely Disadvantaged Community. Disadvantaged Communities are areas with an annual median household income that is less than 80% of the statewide annual median household income. Severely Disadvantaged Communities are Census geographies having less than 60% of the statewide annual median household income.

This HMP is the first for the SWWD and was created with data from SWWD 2015 Urban Water Management Plan, Sonoma County's LHMP 2017, California's State Hazard Mitigation Plan 2023, and NFIP with various other government sources. The Planning Committee members were three managers from SSWD and had no other stakeholders. The SWWD works independently from Sonoma County because they are a special district. As a special district, SWWD is permitted by its bylaws to levy flat rates for water usage rather than directly taxing users (SSWD HMP 2021).

The purpose of SSWD's hazard mitigation plan is to establish goals, and mitigation initiatives that will minimize loss of their property from natural disasters and provide continuous services to residents. The acceptance of the SWWD HMP by FEMA allows the facility to receive federal and state grants to support their mitigation efforts, which are designed to protect the facility. The mitigation strategies were developed based on a risk assessment to determine the vulnerability of the facility, treatment plant, storage tanks, wells, and pipelines to natural disasters at various intensities.

8. Methods

A comparative analysis was conducted between the most recent hazard mitigation plans (HMPs) from Sonoma County which, includes the Sonoma County Multijurisdictional Hazard Mitigation Plan Update 2021 Volume one, and two water service special district's HMPs from Sonoma County Water Agency Draft 2023, and Sweetwater Springs Water District 2021. The Sonoma County Multijurisdictional and Sweetwater Springs Water District 2021 hazard mitigation plans are the most updated approved plans from 2021 and the Sonoma County Water Agency local hazard mitigation plan is in the process of being approved by FEMA.

To address the effectiveness of HMPs in protecting Sonoma County residents from flood events, the following criteria of each mitigation action in relation to flood hazards were evaluated:

benefits based on risk reduction, cost, and expected implementation timeline (Table 5). The data to support the criteria was provided in the document by each HMP's mitigation benefit/cost review section. The definitions for the criterion from each HMP varied but all HMPs used a qualitative benefit-cost review method required by FEMA.

To standardize the cost and time criterion for this analysis, the cost was classified as low, medium, or high and the implementation timeline was classified as ongoing (currently being funded or in process), short-term (0-5 years), or long-term (>5 years) (Sonoma County Multijurisdictional HMP 2021). The standards for the cost were determined if the mitigation action would be funded under an existing budget or if more funding would be required. The cost was measured as "high" if the mitigation action was over the existing budget and required additional funds. The cost was considered "medium" if the action could fit under the current budget but other actions receiving money from the budget would have to be reconsidered. If the cost was measured as "low" then the mitigation action can be covered by the budget.

The criteria to define categories of "benefit" was standardized by low, medium, and high with respect to a mitigation action decreasing life and property vulnerabilities exposed to floods. The benefit was considered "high" if the mitigation action immediately reduced the risk to life and property. An action with a "medium" status could either provide an immediate reduction in risk exposure or provide long-term reduction of risk. An action with a "low" benefit status may provide long-term benefits but more information is needed to determine if short-term benefits are achievable.

Individual mitigation actions were determined effective if the action met the following criteria: ongoing and medium or high benefits. Cost was a deciding factor in the effectiveness of a mitigation action if the benefit was unmeasurable. For Sweetwater Springs mitigation actions were considered effective if the action met the following criteria: ongoing and low or medium costs. Also, the mitigation action goals were analyzed for strengths and weaknesses, similarities, and differences. The comparison analysis between the HMP jurisdictional areas was evaluated to determine what community group in Sonoma County benefits from each plan (incorporated, unincorporated, or both). The key stakeholders that funded these plans were also identified to determine which of these three plans has more funding and influence on flood mitigation and flood protection in Sonoma County.

Table 5. This study used the table's criteria to identify mitigation actions among HMPs that were effective. The criteria use benefit, cost, and implementation timeline standards from Sonoma County Multijurisdictional HMP 2021.

Benefit	Cost	Implementation Timeline	Effective
Low, Medium, High	Any	Ongoing (currently funded or in process)	Yes
Low	Low or Medium	Short-term (0-5 years)	Yes
Low	High	Short-term (0-5 years)	No
Medium	Any	Short-term (0-5 years)	Yes
High	Any	Short-term (0-5 years)	Yes
Low, Medium, High	Any	Long-term (>5 years)	No

Sonoma County Multijurisdictional HMP 2021 conducted a risk assessment that measured the vulnerability of Sonoma County residents to flood events in each Sonoma County Supervisorial District. FEMA developed a multi-hazard methodology called Hazus, a geographic information system (GIS) based software program that is used to support risk assessments, mitigation planning, and emergency planning and response (Sonoma County Multijurisdictional HMP 2021). This methodology is utilized to identify areas with varying risks and estimate losses caused by earthquakes, hurricanes, floods, and tsunamis. FEMA requires HMPs to follow a risk rate protocol to find the probability of an impact (natural hazard) occurring on people, property, and the economy for each natural hazard.

To find the risk of each natural hazard, the probability of occurrence of a natural hazard was assigned a probability factor (Table 6). To find impacts, people (total population exposed), property (total property value exposed), and economy (total property value vulnerable) were assigned a weighted factor to reflect the significance of the impact. The impact on people was under the assumption that all people exposed to a hazard who live in an identified hazard zone (flood hazard area) will be equally impacted when a hazard occurs (flood). To find the risk rating (total probability x impact), the probability factor and the sum of the weighted impact factors from each category (people, property, economy) were multiplied together (Table 7). Risk rating data was extracted from the Sonoma County Multijurisdictional HMP's risk assessment section and categorized into Sonoma County's five Supervisorial Districts. It may be noted that some results were adjusted based on local knowledge and information that did not make it into the quantitative assessment.

Table 6. Each natural hazard was assigned a "probability factor" with the hazard that matched the description. If a hazard were likely to occur within 25 years, it would be assigned a probability factor of three which means it has a high probability of occurring. Source: Multijurisdictional Hazard Mitigation Plan 2021 Volume 1.

Category	Description	Probability Factor
High	A hazard event is likely to occur within 25 years.	3
Medium	A hazard event is likely to occur within 100 years.	2
Low	A hazard event is not likely to occur within 100 years.	1
No exposure	There is no probability of occurrence.	0

Table 7. The risk rate for each natural hazard was calculated by multiplying the probability factor by the sum of the weighted impact factors to find a total (probability x impact). Source: Table 18.3. Risk rating/ Sonoma County Multijurisdictional HMP 2021.

Hazard Event	Probability Factor	Sum of Weighted Impact Factors	Total (Probability x Impact)
Dam Failure	2	6 + 4 + 2 = 12	24
Drought	3	0 + 2 + 2 = 4	12
Earthquake (Hayward Scenario)	2	9 + 6 + 3 = 18	36
Flooding (1% annual chance)	3	3 + 2 + 1 = 6	18
Landslide/Mass Movement (very high/high risk areas)	3	6 + 6 + 2 = 14	42
Sea Level Rise (200-cm + 100-yr)	3	3 + 2 + 1 = 6	18
Severe Weather	3	6 + 2 + 1 = 9	18
Tsunami	1	3 + 2 + 0 = 5	5
Wildfire (very high/high risk areas)	3	3 + 4 + 2 = 9	27/36[a]

a. The quantitative score for wildfire (27) was adjusted base on the judgment of County staff to a score equivalent to earthquake.

To understand inequalities among unincorporated communities and procedural justice issues for the environmental justice component of this study, I traveled to Guerneville to interview locals on how flood events have personally impacted them and their communities. The questions were the following:

1. How long have you lived in Guerneville?

2. Have you experienced major flood events while living in Guerneville and if so, what was it like?
3. Do you feel like Sonoma County cares about the residents of Guerneville?
4. Do you want the city of Guerneville to be incorporated and why?

I was in Guerneville for an afternoon and used the library as my first resource. The sample size of people was three and I cataloged their information. The anecdotes from the three individuals supported the information I learned from the HMPs, and I utilized one of the respondents' answers in this study.

Geographic Information System (GIS) is a key tool to spatially identify the flood risk zones in Sonoma County and along the Russian River and create flood risk maps for development and insurance purposes. The data available through Sonoma County's Permit Sonoma GIS portals encompasses a range of social, economic, and hazard information that directly affects both incorporated and unincorporated areas within Sonoma County. Special hazard flood zone data is available through the Federal Emergency Management Agency's (FEMA) website and made an available link on Sonoma County's website sources page. The FEMA Map Service Center was used to identify flood risk zones along the borders of incorporated and unincorporated areas in Sonoma County. The map products created through the FEMA Flood Map Service Center were used to calculate the percent of urban land cover in 1 % annual chance flood hazard zones in a study area of Guerneville.

9. Results

9.1. Sonoma County Multijurisdictional Mitigation Actions

The Sonoma County Multijurisdictional HMP included eight countywide (CW) mitigation actions related to the HMP's CW goals and objectives. This study analyzed four of the eight identified CW flood mitigation actions because they were designed to mitigate flood impacts. Each mitigation action serves to minimize the severity of impacts from natural hazards, such as floods, in Sonoma County. All eight mitigation actions were categorized as having a medium benefit and high priority because each goal met a grant eligibility requirement and provided an immediate or long-term reduction of flood risk toward life and property. This study identified four of the four CW mitigation actions as effective in mitigating flood risks in Sonoma County (Table 8).

CW-1 was the mitigation action for the establishment of an "Information Sharing Access Agreement" with FEMA. The description in the HMP highlights the significance of having readily accessible data from FEMA on repetitive flood loss properties across the entire county and utilized to identify and address any issues that may arise. Available through Permit Sonoma, a map showing locations of repetitive flood loss properties in the lower Russian River map with data from 2015 was available (Permit Sonoma, 2024). Further information about updated maps or any context about repetitive flood loss properties in Sonoma County was unavailable. CW-1 action was categorized as having a medium benefit, high priority, low cost, and coverage by the County General Fund. Based on the criteria, CW-1 was effective by having a short-term implementation timeline, a medium benefit, and a low cost (Table 8). In accordance with the parameters established by this study, it is currently hypothesized that the CW-1 action may be potentially effective, although this will be confirmed in the next HMP update.

CW-2 and CW-6 are both effective because the actions both fall under the criteria of having an ongoing status and a medium benefit for flood mitigation (Table 8). Action CW-2 is effective and ongoing because the Story Map hazard tool is available on Permit Sonoma's website and GIS layers with information on various natural hazards are available. The county-wide hazard mitigation website's Story Map serves as a repository for the most recent Sonoma County Multijurisdictional HMP 2021, providing the public with the opportunity to monitor the progress of every HMP implementation step and to submit public comments. The data available on the website indicates that the countywide FEMA flood data for areas with a 1% annual probability of flooding reflect data from 2017. The website states that the active Story Map and the other natural hazard maps use data from the Multijurisdictional HMP 2021 (Sonoma County Permit Sonoma, 2024).

CW-4 was the only mitigation action with a medium cost relative to the other goals, which had a low cost (Table 8). The analysis determined that CW-4 was effective because the County participates in FEMA's Risk Mapping, Assessment and Planning (Risk MAP), to receive Flood Insurance Rate (FIR) Maps. FIR Maps function as a dataset for Sonoma County to use for hazard mitigation assessments (FEMA Risk MAP, 2023). Updated HMPs from Sonoma County ensure they are continuously enrolled in FEMA's programs and services like Risk MAP service.

The efficacy of the mitigation action, CW-6, can be identified by its medium benefit criterion, low cost, and current funding status. Sonoma County used FEMA Public Assistance funds that provide grants for cleanup, debris removal, emergency protective measures, and rebuilding public infrastructure (Assistance for Governments and Private Non-Profits After a Disaster, 2024). And after a declared flood disaster. CW-6 mitigation action is to collect live hazard data such as high-water marks (during a flood event), extent and location of hazard, and loss information for updates to the risk assessment.

9.2. Sonoma County Water Agency Mitigation Actions

Sonoma County Water LHMP Draft 2023 has three goals unchanged from their 2018 LMHP. The following goals and objectives, accompanied by mitigation actions, are designed to reduce the risk of loss of life, property, and environmental values while pursuing economic recovery from natural hazards. The third goal of the LHMP Draft 2023 is to mitigate the impact of floods on Sonoma Water infrastructure and to enhance the resilience of Sonoma County residents against flooding (Sonoma Water LHMP Draft 2023). The Sonoma County Water LHMP Draft 2023 included a total of twenty-five flood protection infrastructure mitigation actions across three objectives listed as 3.1, 3.2, and 3.3 (Table 9).

This study analyzed seven of the twenty-five flood mitigation actions identified in the literature because the seven mitigation actions had a commonality of criteria that was a high priority and served to minimize the severity of the impacts of only floods instead of other natural hazards. Sonoma County Water mitigation actions were also categorized into three distinct types of flood protection infrastructure (all infrastructure, channels, conduits, and reservoirs). The reasoning behind the categorization is that the actions pertain to flood infrastructure maintenance, as Sonoma County Water is authorized to cooperate with the USACE and NRCS to maintain flood protection projects. Action 3.3.3 was an exception because it represented the only instance of a flood mitigation goal being considered of low priority, despite offering a high benefit to the city of Santa Rosa. This study determined six out of seven mitigation actions were effective in mitigating flood impacts with Sonoma Water infrastructure (Table 10).

Seven mitigation actions were effective because they are ongoing and have high benefits, despite the costs. The maintenance cost is low for mitigation actions that require access because Sonoma Water owns and controls its network of sewage and water pipelines; actions 3.1.2, 3.1.3., 3.1.4. Sonoma Water controls flood detention reservoirs in Sonoma County and action 3.1.3 and 3.1.4 determines whether sediment removal is needed to maintain flood protection capacity.

Mitigation action 3.1.5 is effective and continues to offer benefits to all of Sonoma County and Northern California. As a stakeholder in the Advanced Quantitative Precipitation Initiative (AQPI), Sonoma Water is utilizing new technology to facilitate the identification of ARs and their intensity, thereby preparing for necessary actions such as dam releases and minimizing potential flood risks.

The Stream Maintenance Program (SMP), action 3.3.1 provides Sonoma County with the authority to maintain its constructed flood protection channels through the issuance of a programmatic permit, thereby ensuring that the construction will not result in a "taking" of endangered salmonids (Sonoma County Water LHMP Draft 2023). The effective action plan is to remove accumulated sediment and overgrown vegetation to maintain the SMP channels.

Action 3.3.2 is effective because it has high benefits and an ongoing collaboration with other jurisdictional agencies and stakeholders to maintain the flooding impacts from the Petaluma River. The Petaluma Creek Watershed is located in Flood Zone 2A (Figure 1.) and experiences frequent major flooding events expanding over the areas from Penngrove to Petaluma (Sonoma County Water LHMP Draft 2023).

Mitigation Action 3.3.3 represents a long-term plan that has been in progress since 2018 and is ineffective. The proposed mitigation is ineffective because it will not be implemented for at least ten years from 2023. The mitigation action is to increase the transportation capacity of Santa Rosa Creek to regulate water flows during 100-year floods. While this solution would appear to offer a number of advantages, in practice the benefits are relatively limited due to the costs and effort involved, which is why it has a medium benefit.

9.3. Sweetwater Springs Water District Mitigation Actions

Sweetwater Springs HMP's mitigation actions supported their goal two which aims to identify cost-effective actions that minimize potential damage and reduce economic losses associated with natural hazards (Sweetwater Springs Water District HMP 2021). Goal two had twelve mitigation actions of which four of the twelve actions were target mitigation for flood events (Table 11). Goals one, three, and four had mitigation actions that applied to all hazards, earthquakes, or wildfires and did not include flood mitigation actions. There were no objectives associated with the goals or mitigation actions.

From the analysis, there were three out of four actions that were effective and had a high priority in reducing flood risk for the unincorporated communities in Sweetwater Springs' jurisdictional area. Sweetwater Spring's HMP did not have an established metric for their identified benefits, unlike the two contrasting HMPs. The benefit criteria used to determine efficacy were not utilized; instead, the focus was on the criteria for costs, priority, and implementation time, which were analyzed and used to identify the efficacy of each mitigation action.

Mitigation action 2.4 has been ongoing and has high costs, but it is effective because of FEMA's hazard mitigation grant, and FEMA's Building Resilient Infrastructure and Communities Program (BRIC) has been able to support the ongoing infrastructure maintenance. The funding available for Sweetwater Springs to invest in its infrastructure is restricted to funding solely from FEMA and customer fees.

Mitigation action 2.5 is effective because it has a medium cost and the district has been implementing effective flood protection measures, hence their approved and updated HMPs. The costs are not high because investigating the district's infrastructure because they are in charge of their network of water pipelines and sewage lines.

The efficacy of Mitigation Action 2.6 can be identified in the context of Sweetwater Springs's current relocation efforts to protect their property. The main facility is in the process of being relocated to a higher elevation area, away from its current location along the Russian River in the 1% flood risk zone. As of 2024, the facility is still in the same location in Guerneville. The mitigation action 2.6 is not limited to relocation of vulnerable pump stations, wells, and the wastewater treatment facility. The financial expense of relocation is high, and the priority is low. Additionally, there is a lack of a comprehensive plan describing the relocation process.

Mitigation action 2.7 to remove impermeable surfaces surrounding the Sweetwater Springs' main facility is ineffective because it will not be implemented in five years and has a high cost. Considering the previous mitigation action 2.6 to relocate the entire facility, the district cannot implement this action until the relocation is finalized or abandoned. Removing impermeable surfaces would allow runoff to absorb into the ground instead of the Russian River or storm drains, therefore reducing flood risk. The examples of permeable hardscape replacements that were presented in the HMP included permeable pavement, green infrastructure, and any low-impact design that would allow and improve runoff infiltration (Sweetwater Springs Water District HMP 2021).

Table 8. Source: Three out of the four mitigation actions analyzed were effective. All four mitigation actions have a medium benefit to mitigate floods in Sonoma County. Source: Sonoma County Multijurisdictional HMP 2021.

Mitigation Actions	Benefit	Cost	Timeline	Priority	Funding (Grants)	Effective
CW-1—Pursue an "Information Sharing Access Agreement" with FEMA	Medium	Low	Short-term	High	County General Fund	Yes
CW-2- Continuous provide updated data to the Sonoma County Hazard Story Map.	Medium	Low	Ongoing	High	County General Fund	Yes
CW-4—Continue to update hazard mapping with the best available data and support FEMA's RiskMAP initiative.	Medium	Medium	Ongoing	High	-FEMA mitigation grant funding -FEMA's Cooperating Technical Partners program -County capital improvement program funding	Yes
CW-6—Improve obtaining capture of time-sensitive, perishable data.	Medium	Low	Ongoing	High	-County General Fund -FEMA Public Assistance following declared disaster events	Yes

Table 9. The objectives supporting goal three are to increase the reliability of flood protection infrastructure to reduce the vulnerability of people and property to flooding hazards. Source: Sonoma Water LHMP Draft 2023

Objectives	Description
3.1	Improve the understanding of the vulnerability of Sonoma Water's flood protection infrastructure
3.2	Implement reliability measures for reservoir facilities to maintain flood protection capabilities
3.3	Implement reliability measures to maintain the flood protection capability of engineered channels and conduits

Table 10. The mitigation actions support the objectives from Table 9. Of the four selected mitigation actions, two were found to be effective, while the remaining two were determined to be ineffective. Source: Sonoma County Water LHMP Draft 2023

Mitigation Actions	Benefits	Cost	Timeline	Priority	Funding (Stakeholders)	Effectiveness
3.1.2- Assess concrete structures deteriorating from the erosive effects of floods.	High	Low	Ongoing	High	FEMA, Sonoma Water, SWRCB, CA DWR	Yes
3.1.3- Assess conditions at flood detention reservoirs	High	Low	Short-term	High	Sonoma Water, CDFW	Yes
3.1.4- Assess design strategy options for addressing capacity deficiencies of the primary spillway at the Matanzas Dam	High	Low	Short-term	High	NRCS, FEMA, Sonoma Water, SWRCB, CA DWR	Yes
3.1.5- Continue to support Advanced Quantitative Precipitation Initiative (AQPI)	High	High	Ongoing	High	CA DWR IRWM, FEMA, Sonoma Water	Yes
3.3.1- Restore flood protection capacity of Stream Maintenance Program (SMP)	High	Low	Ongoing	High	Sonoma Water, WCM, CSCC, CDFW	Yes
3.3.2- Develop operational or design strategies to mitigate the effects of flooding within the Petaluma River	High	Low	Ongoing	High	FEMA, Sonoma Water, SWRCB, CA DWR, WCB, CSCC	Yes
3.3.3- Increase the designed flow conveyance capacity for portions of Santa Rosa Creek flood control channel to convey the 100-year flood event without overtopping.	Medium	High	Long-term (10+ years)	Low	FEMA, Sonoma Water, SWRCB, CA DWR FERP, WCB, CSCC	No

Table 11. Out of the four mitigation actions analyzed, there were three deemed effective. Source: Sweetwater Springs Water District HMP 2021.

Mitigation Actions	Benefits	Cost* cons	Timeline (years)	Priority	Funding (Grants)	Effective
2.4- Property protection (elevate, armor, or relocate) of critical infrastructure, facilities, and systems from flooding, including but not limited to pump stations, wells, and the wastewater treatment facility.	Reduce flood risk	High	Ongoing	High	Hazard Mitigation Grant; BRIC	Yes
2.5- Identify and implement effective flood protection measures around water supply facilities and pumping stations, prioritizing facilities located within the 100-yr floodplain.	Reduce flood risk	Medium	Ongoing	High	Hazard Mitigation Grant; Building Resilient Infrastructure and Communities Program (BRIC)	Yes
2.6- Relocate facilities currently in the floodplain to higher ground	Reduce flood risk	High	Ongoing	High	Hazard Mitigation Grant	Yes
2.7- Retrofit hardscaped areas on District property (i.e. parking lots) to use permeable pavement, green infrastructure, or other low-impact development design features to allow for improved infiltration	Reduce flood risk	High	5	Low	Hazard Mitigation Grant	No

9.4. Comparison Analysis

The three (Sonoma County Multijurisdictional 2021, Sonoma County Water Agency Draft 2023, and Sweetwater Springs Water District 2021) HMPs had contrasting mitigation actions because they each served different purposes, jurisdictional areas, and funding sources. The results indicated that the Sonoma County Multijurisdictional 2021 plan had four effective mitigation actions out of the four that were evaluated (Table 12). The Sonoma County Water Agency had six out of seven effective mitigation actions, while the Sweetwater Springs Water District had three out of four effective mitigation actions (Table 12). When comparing funding, FEMA provided the most financial support for each HMP as hypothesized because FEMA requires and approves HMPs from each local government before issuing funding. Sonoma Water received the most funds out of the three HMPs because they have partnerships with California state agencies like the Natural Resources Conservation Service (NRCS), State Water Resource Control Board (SWRCB), The Water Control Board (WCB), the California Department of Water Resources (CDWR), and the California State Coastal Commission (CSCC).

Table 12. A table summary of effective flood-related mitigation actions evaluated from each HMP. Sonoma County and Sonoma Water's mitigation actions were evaluated based on benefits, cost, and implementation timeline. The efficacy of Sweetwater Springs's mitigation actions was based on cost, implementation, and priority.

HMP	Flood Related Mitigation Actions Evaluated	Effective
Sonoma County Multijurisdictional 2021 Volume 1	4	4/4
Sonoma County Water Agency Draft 2023	7	6/7
Sweetwater Springs Water District 2021	4	3/4

The Multijurisdictional HMP for Sonoma County was unlike the other two HMPs, Sonoma County is not a water utility special district and is therefore responsible for all the risks from natural hazards for all Sonoma County residents. Sonoma County's HMP applies to all residents (unincorporated or incorporated, and special districts). The proposed mitigation actions in Sonoma County are countywide in scope, unlike the opposing HMPs who serve their specific jurisdictional areas. The objective is to gain more information from FEMA and to provide residents with continuous hazard risk information during hazard events. This will be achieved through the County's funding. Sonoma County also collaborated with other Sonoma County local governments that were a part of the planning team to create Sonoma County Multijurisdictional HMP 2021 Volume 1 and 2, unlike the other two special districts that used their district's planning team.

The Sonoma County Water Agency and the Sweetwater Springs Water District adopted similar mitigation strategies because they are both special districts responsible for providing water to their service members and owning infrastructure (water pipelines, wells, sewage lines, etc.) vulnerable to natural hazards, specifically flooding. Sonoma Water has control over channels, reservoirs, and two dams (Coyote Valley Dam at Lake Mendocino and Warm Springs Dam) that need to be continuously monitored and maintained to ensure water will not build up into the floodplain or reservoir spillover during a heavy precipitation event. The service area of Sonoma County Water encompasses both incorporated and unincorporated areas within Sonoma County, with its services extending into Marin County. The only unincorporated area Sonoma Water services are California-American Water Company (Larkfield District), Penngrove Water

Company, Lawndale Mutual Water Company, Kenwood Village Water Company, Forestville Water District and Sweetwater Springs's customers are only in the unincorporated area of the Lower Russian River (Figure 8). The Agency also participates in programs like the AQPI and SMP which are both effective mitigation actions with high benefits towards flood prevention and mitigation. The Sweetwater Springs Water District does not participate in any external programs or has established any internal programs about water supply or flood protection issues.

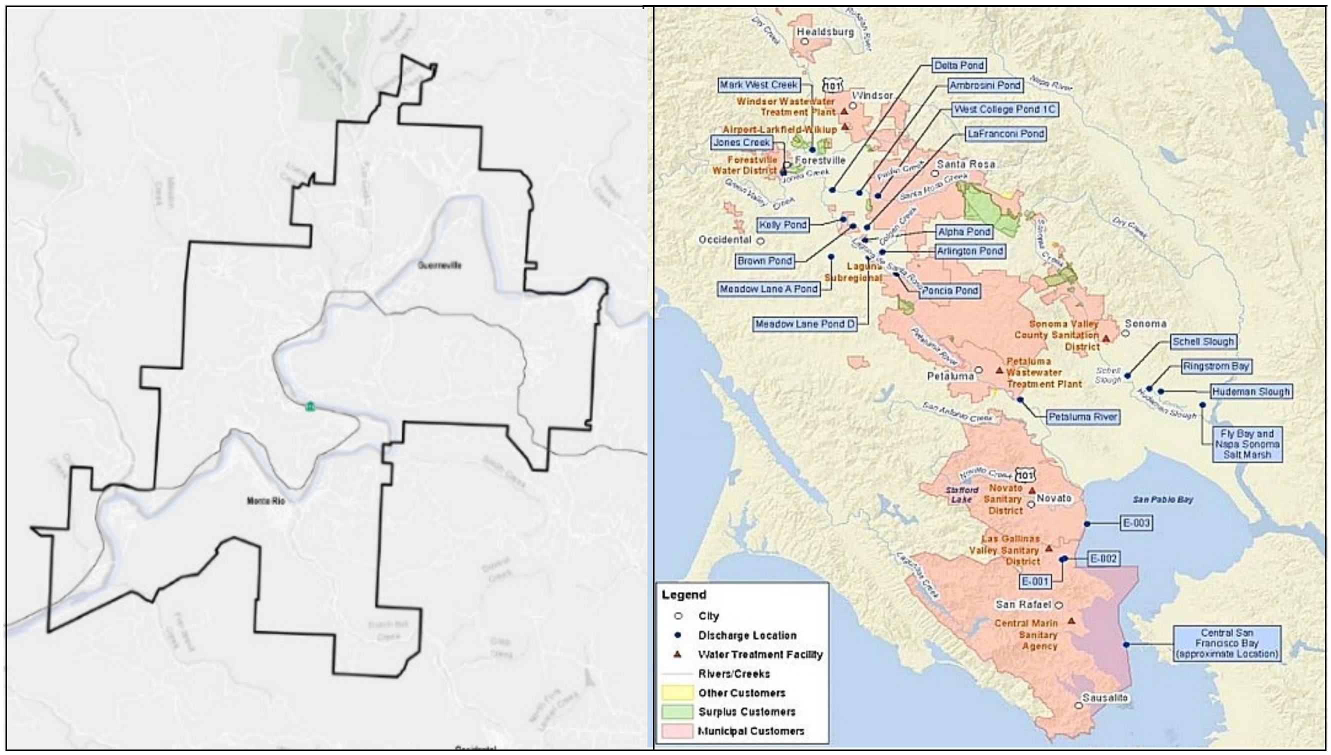
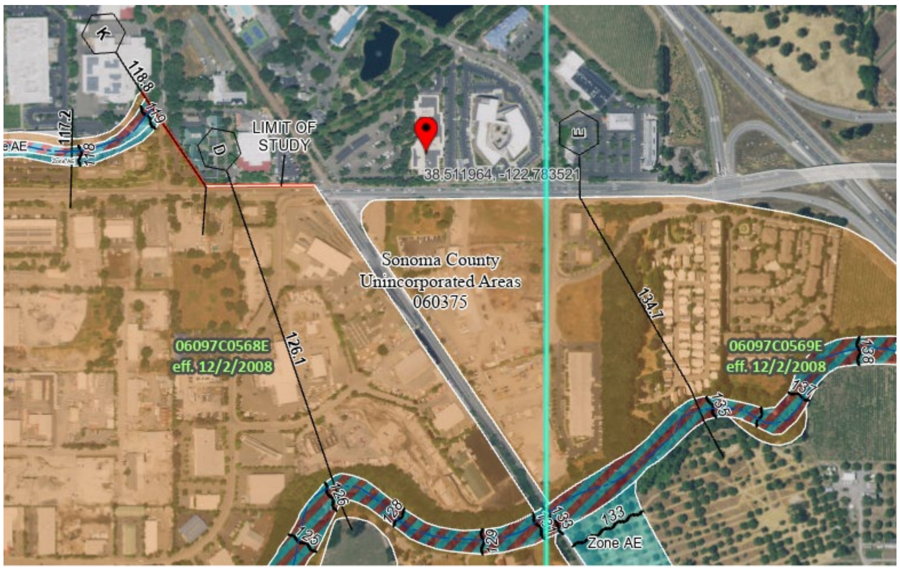


Figure 8. Sweetwater's service area is limited to the Lower Russian River (left map) and Sonoma Water's service area encompasses large areas of Sonoma County and expands into Marin County (pink-shaded areas, right map). The area Sweetwater Springs is responsible for is unincorporated and Sonoma Water is responsible for unincorporated and incorporated areas. Source: Sweetwater Springs Water District Hazard Mitigation Plan 2021; Sonoma County Water Agency Local Hazard Mitigation Plan 2023 Draft.

Sweetwater Springs Water District's HMP was the only document to have a mitigation action about the relocation of their facilities because they are in the floodplain of the Russian River while Sonoma Water's main facility is in Santa Rosa in a non-flood risk zone (Figure 9). Sweetwater Spring's facility is located along the Russian River in FEMA regulatory floodway and sections of their property are in 1% and 0.2% annual chance of flood hazard areas. Areas with a 0.2% probability of flooding are characterized by low drainage areas, which aligns with Sweetwater's mitigation action 2.7, which is to replace their hardscaped areas on district property with more permanent materials. Relocation of their facility would avoid major flood impacts and minimize damage to infrastructure.



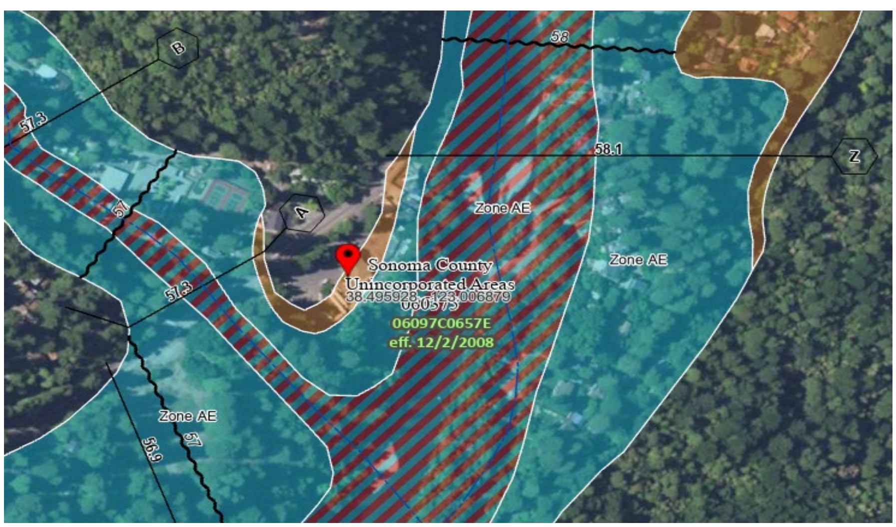


Figure 9. Sonoma Water is located within an area that is not at risk of flooding in Santa Rosa (the top red location pin). Sweetwater Springs sits within the 1% and 0.2% annual flood hazard zones area of Guerneville, California (bottom red location pin). Source: FEMA Flood Map Service Center. 2024. https://msc.fema.gov/portal/home.

Vulnerability

Hazard risk ranking data of unincorporated and incorporated communities in each Sonoma County Supervisorial District Sonoma County from Multijurisdictional Hazard Mitigation Plan Update 2021; Volume 2, Planning Partner Annexes was categorized by natural hazards. Sonoma County Districts Four and Five have the highest flood hazard risk rating score (Figure 10). These districts make up the largest area of unincorporated communities and has high urbanization along the Russian River floodplains. The overall risk rating of all unincorporated areas in Sonoma County was determined to be 21, indicating a medium risk of flooding.

Build exposure data of unincorporated and incorporated communities in each Sonoma County Supervisorial District Sonoma County from Multijurisdictional Hazard Mitigation Plan Update 2021; Volume 1 was categorized by the dollar value of the building structure and contents inside the structure (Figure 11). District five has the highest value reaching over two billion dollars in building structure and content value exposed to a potential 100-year flood. The total estimated value of the building structures and contents exposed to a potential 100-year flood across Sonoma County is approximately twelve billion dollars.

Before Sonoma County's HMP was finalized, surveys were available online for Sonoma County residents to be involved in the HMP. The Steering Committee developed 42 survey questions that guided them in selecting goals, objectives, and mitigation strategies. The survey was made available online through the hazard mitigation plan website in 2020. A total of 691 completed surveys were submitted. One of the questions (Q11) asked the respondents if their property or rental is located in or near a designated floodplain. A total of 627 survey responses were received (64 survey responses skipped the question). Of these, 472 (75%) stated their property was not in or near a floodplain (Figure 12). The following question 12 asked respondents if they had flood insurance. A total of 634 survey responses were received (57 survey responses did not answer the question). Of these, 517 (82%) stated they did not have flood insurance (Figure 13).

From the interviews conducted, a librarian lost the ability to use the first floor of her house because of a major flood. She depended on grants from FEMA because private flood insurance will not insure her due to her property being in a 1% flood risk zone in Guerneville. She also mentioned how culverts near her house are overgrown and not maintained. The Flood Elevation program can cover up to 75% of the cost to residents who live in flood-prone areas like Mel, as long as they can cover the remaining 25% (Flood Elevation Mitigation Program, 2024). In a scenario where the cost is $28,000 to lift a home, the Flood Elevation program will cover up to $21,000 of the project cost and the homeowner must pay the remaining $7,000 (Crail, 2024).

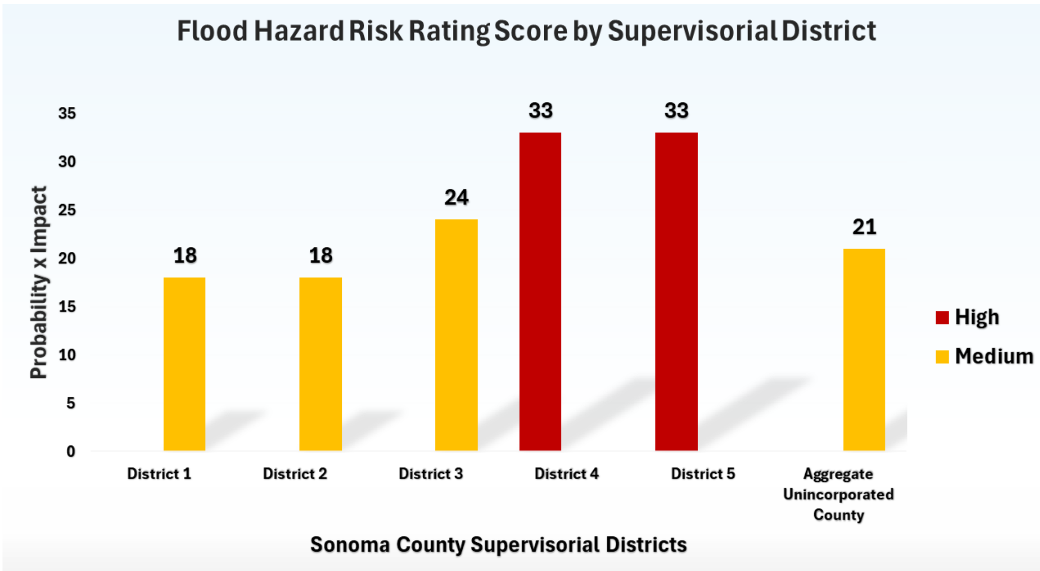


Figure 10. Source: Sonoma County Supervisorial District Sonoma County from Multijurisdictional Hazard Mitigation Plan Update 2021; Volume 2, Planning Partner Annexes.

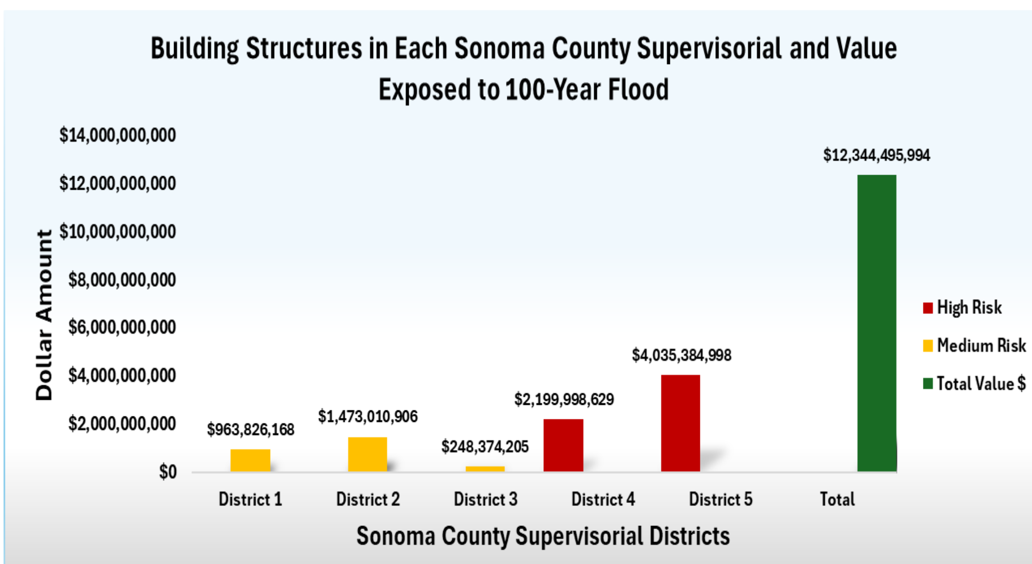


Figure 11. Sonoma County obtained values based on 2020 tax assessor data provided by Sonoma County. Source: Sonoma County Supervisorial District Sonoma County from Multijurisdictional Hazard Mitigation Plan Update 2021; Volume 1.

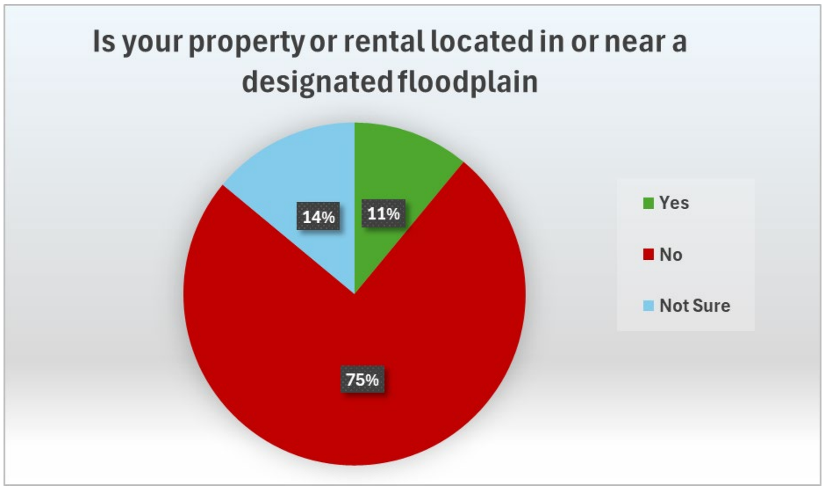


Figure 12. Source: Sonoma County Supervisorial District Sonoma County from Multijurisdictional Hazard Mitigation Plan Update 2021; Volume 1.

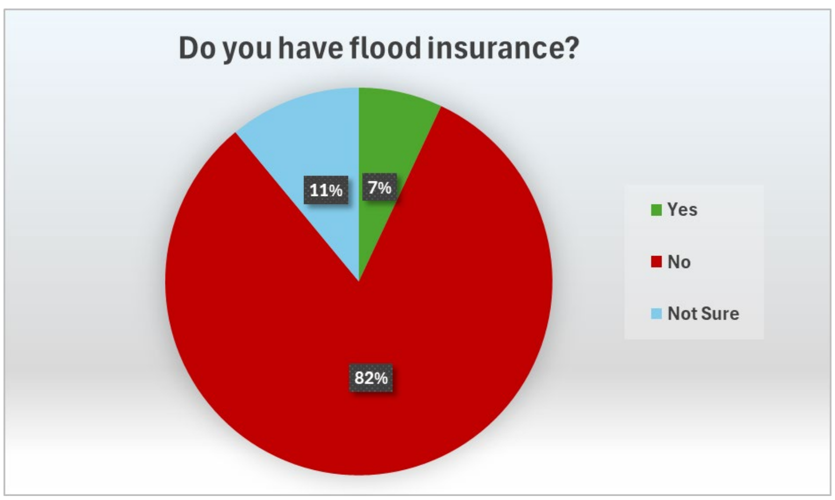


Figure 13. Source: Sonoma County Supervisorial District Sonoma County from Multijurisdictional Hazard Mitigation Plan Update 2021; Volume 1.

10. Discussion

The updates to the HMPs and collaborations with stakeholders have enhanced efforts to mitigate flood risks and protect Sonoma County residents. These initiatives have ultimately led to the establishment of Sonoma County's first multijurisdictional HMP. By joining with other local governments, and municipalities included in Sonoma County Multijurisdictional HMP, Sonoma County was able to maintain its NFIP status and have good standing in FEMA’s programs such as CRS (Sonoma County Multijurisdictional HMP, 2021). However, the Multijurisdictional HMP planning committee for Sonoma County did not include representatives from unincorporated communities. Consequently, the committee did not receive input from these communities causing social equities. There is a perception that these efforts are not being applied uniformly, potentially due to the lack of involvement of unincorporated communities in the HMP process, which has implications for the efficacy of flood management in Sonoma County

Special districts are not allowed to individually participate in the NFIP; however, Sonoma Water and Sweetwater Springs District are permitted to participate in the NFIP through Sonoma County if it creates its own LHMP and if Sonoma County complies with the floodplain management requirements of the NFIP. Sonoma Water is not as reliant on the NFIP as Sweetwater Springs Water District, as it is self-insured through the County of Sonoma’s Property Insurance Program. Sonoma County's eligibility is contingent on its periodic updates to its HMP, which effectively enforces enrollment in the NFIP for all residents in the county. Hazard mitigation plans must be updated every five years to continue to qualify for benefits from grants from FEMA (Sonoma Water LHMP Draft 2023).

The goals of all three HMPs aim to reduce the vulnerability of people and property exposed to the relevant natural hazards in Sonoma County. Since Sonoma Water and Sweetwater Springs Districts are water service special districts, they conducted cost/benefit analyses on their existing infrastructure. They used cost/benefit analyses to establish mitigation actions to reduce flood risk with the use of their infrastructure. The objectives of Sonoma Water have remained consistent since 2018, with recent updates aligned with the Sonoma County Multijurisdictional Hazard Mitigation Plan 2021. This is even though Sonoma Water is not a partner in Sonoma County’s HMP 2021 update, Sonoma Water uses Sonoma County’s HMP as a guideline.

It is evident that unincorporated communities depend on the services provided by Sonoma County and Sonoma County's other special districts, such as the Sweetwater Springs Water District, for flood protection. Flooding frequently occurs in lower the Russian River region, especially in the residential and commercial districts of Mirabel Park, Duncans Mills, Monte Rio,

Rio Nido, and Guerneville (Sonoma County Water LMHP Draft, 2023). The Sweetwater Springs Water District's main facility is along the Russian River in its floodplain, which makes it extremely vulnerable to major flood events like the more recent 2019 flood. Sweetwater's HMP lacked the most detail and information about its mitigation action's benefits and costs compared to the other two HMPs, which made it difficult to analyze efficacy. This study suggests the three HMPs in the comparative analysis have effective flood mitigation actions but still need more research to find the total efficacy.

A considerable proportion of the population resides in unincorporated areas due to the relative affordability of such locations compared to those in the surrounding incorporated areas. This is why the residents with the highest vulnerability to floods live in unincorporated areas (Districts Four and Five). Since residents who live in unincorporated communities cannot purchase private insurance due to their location within designated flood risk zones, consequently, they rely on Sonoma County to maintain their enrollment in the NFIP. Only after the declaration of a federal or state emergency, can uninsured residents receive grants from FEMA through Sonoma County (Sonoma Water LHMP Draft 2023). Qualifying property owners may be eligible for the Flood Elevation Mitigation Program to protect their houses from flood damage. Some residents may be unable to pay the remaining 25% of the cost of renovating and lifting their houses. It is also important to consider the possibility of unforeseen circumstances during construction, which may result in increased costs for homeowners. Sonoma County has the highest number of repetitive loss properties in California. Repetitive losses in Sonoma County occur for a combination of reasons like more frequent major floods, lack of funding for infrastructure maintenance, and not enough residential and commercial buildings elevated above the recommended base height.

Four of the four CW mitigation actions to mitigate floods were found to be effective in the Sonoma County Multijurisdictional HMP Update 2021. This indicates that Sonoma County is actively engaged inside FEMA's network trying to obtain critical information about natural hazards, specifically repetitive loss data. When provided, the data is updated on Sonoma County's hazard mitigation website with information on natural hazard risks and FEMA's repetitive loss data. FEMA's repetitive loss data is important to improve flood mitigation actions and provide benefits to property owners that have these properties. FEMA data would enable Sonoma County and other local districts with repetitive loss issues to create or invest in mitigation strategies or flood protection for property owners. Since Sweetwater Springs and Sonoma Water do not directly participate in the NFIP, they are not allowed to have repetitive loss of property data.

The most effective mitigation actions are those that invest in the maintenance of infrastructure throughout Sonoma County. Such actions can help to prevent the accumulation of sediment and the obstruction of culverts, which can contribute to urban flooding during heavy precipitation. Another key mitigation strategy is the continuous investment and utilization of AQPI. The APQI is a tool that can be used to calculate the duration and water vapor volume of an AR approaching the California coastline. This information is vital for environmental managers and community leaders to prepare for the possibility of flood events. It can be argued that Sonoma Water may be more influential than Sonoma County in flood mitigation and protection for Sonoma County residents. This is because Sonoma Water has the authority to initiate dam releases, maintain infrastructure when necessary, and fund the AQPI programs. Sonoma Water is responsible for the maintenance of more than 150 miles of engineered and natural creek channels throughout Sonoma County. In contrast, Sweetwater Springs is responsible for the maintenance of 66 miles of water pipelines and no creeks.

For future studies to gain a more comprehensive understanding of the efficacy of the Sonoma County Multijurisdictional HMP 2021 Volume 1 in protecting Sonoma County residents from flood events, it would be essential to analyze the effectiveness of the mitigation actions defined by each stakeholder and listed in Sonoma County Multijurisdictional HMP 2021 Volume 2. To have a better grasp on the efficacy of Sonoma Water's HMP, all listed mitigation actions should be evaluated. Sweetwater Springs HMP lacked information, therefore understanding how effective each goal was would be a new method of evaluating efficacy.

11. Recommendations

It is time for unincorporated communities to consider the advantages of incorporation. The incorporation process would necessitate the formation of an unofficial city council by members of the community, the collection of funds, and the submission of an incorporation request to the County of Sonoma. As a special district, Sweetwater Springs is not allowed to enroll in NFIP directly and must depend on Sonoma County to allocate FEMA grants to them. Should Guerneville attain municipal status, it would be in a position to establish a city council, form a planning committee to create an HMP and enroll in NFIP directly. Enrollment in NFIP provides them access to data on repetitive flood losses, which is utilized to identify the properties that are flooded with the most regularity. Repetitive loss of data can influence the creation of flood mitigation actions with high benefits. Upon incorporation, a city gains the authority to regulate land use and enact land ordinances.

Guerneville, being the largest town of the surrounding unincorporated communities, could become a city and form its own multijurisdictional HMP with the other lower Russian River communities or join other local government's HMPs. The number of necessary steps as outlined in Sonoma County's Multijurisdictional HMP, involved makes this an arduous process. In order to enhance inclusivity within Sonoma County and Sonoma Water's HMPs, it would be recommended that a representative from the lower Russian River region or a resident who resides in unincorporated areas of Districts 4 and 5 be included. Planning members from both HMPs collaborate and rank risks that apply to all Sonoma County communities, but there is a lack of input from unincorporated communities about the specific hazards and risks they are directly impacted by. It is possible for unincorporated communities to join HMPs, although this requires a considerable degree of effort, structure, and funding.

FEMA should give Sonoma County repetitive loss data and allow special districts to participate in their NFIP program. There is a gap in the available data regarding the identification of repetitive loss properties that are controlled by special districts. This is because special districts are not permitted to enroll in the NFIP, which precludes them from making insurance claims. Insurance claims serve as a means of quantifying the damages incurred by cities, counties, and FEMA in the event of natural disasters such as major floods. The next Sonoma County Multijurisdictional updated HMPs must focus on providing funds or flood insurance policies to high flood-risk residents who cannot be covered by private insurance instead of relying on NFIP. Many residents in Guerneville and other unincorporated communities do not have flood insurance, therefore it should be a priority for Sonoma County to provide more funds or create an insurance policy for disadvantaged communities. Private insurance companies do want to insure residents in high flood-risk zones because they will not make a profit, therefore many residents must rely on FEMA.

The HMP survey from the Sonoma County Multijurisdictional HMP had less than 700 respondents out of the 494,336 residents that live in Sonoma County. The survey was accessible via the online survey platform, but to increase the number of respondents, it may be recommended that a physical in-person survey be conducted in the community. Sonoma County volunteers or county employees may proactively conduct door-to-door surveys in residential neighborhoods to get more responses. The questions can be electronically answered through a smart tablet and sent to a database to be analyzed for the next HMP update. Questions could include a selected list of mitigation actions residents would like to see Sonoma County fund and incorporate in their hazard mitigation plans. This is also an opportunity for the County to be involved in the community and share information about the importance of an HMP.

12. Conclusion

Unincorporated cities in Northern California face a disadvantage compared to incorporated communities due to a lack of repetitive loss information and funding to maintain their infrastructure, which is continuously impacted by major floods. The indirect effects of climate change will continue to degrade existing infrastructure, thereby increasing the vulnerability of unincorporated communities in Sonoma County. There is a notable distinction between the advantages that incorporated communities receive compared to unincorporated communities. Incorporated cities can allocate their taxes to local flood mitigation funds, enforce flood management policies, organize hazard mitigation ordinances, and have the benefit of Sonoma County Water Agency investing their money into flood protection infrastructure. Unincorporated cities in the lower Russian River such as Guerneville rely solely on the County of Sonoma for federal assistance through FEMA and county emergency assistance. The comparison analysis revealed that the current infrastructure in the unincorporated areas Sweetwater Springs Water District manages requires more substantial investment in maintenance and, therefore would be incapable of adequately managing a series of intense precipitation events. The impacts from intense ARs have caused major flooding and huge economic losses for Sonoma County.

A warming climate will continuously increase moisture in the atmosphere and cause ideal conditions for more frequent extreme weather such as ARs to form. The challenges presented by ARs are that their frequency and intensity are difficult to anticipate. However, ongoing funded projects by Sonoma Water, such as AQPI, make precipitation rates easier to predict for environmental managers and meteorologists. Precipitation data collected from AQPI can better inform communities about local flood risks, water management, and the possibility of flood evacuations during heavy precipitation events. Understanding and preparing for varying categories of atmospheric rivers advises Sonoma Water with decisions that will minimize impacts from anticipated runoff like releasing dam water or signaling to a community to evacuate.

Vulnerability to floods differs across Sonoma County. Districts 4 and 5 are the most vulnerable to floods in Sonoma County and climate change will continue to put them at a greater risk of floods. Climate change will continue to intensify ARs and there is the possibility of an AR category 5 to landfall in Sonoma County like one did in 1995 that cause more than $50 million in damages (Corringham, 2019). Many homeowners in Sonoma County do not have flood insurance, which will become a problem when floods occur more frequently than Sonoma County residents are accustomed to. If the frequency of major flood events increases, and the impacts occur in larger areas than anticipated, local and county emergency response teams will be unable to cope with the situation and will be left exhausted. The absence of preparedness increases the probability of loss of life and property in all areas of flood risk zones in Northern California.

Overall, all three HMPs have effective mitigation actions toward reducing flood risks for Sonoma County residents. The findings revealed the differentiation between the jurisdictions and stakeholders of each HMP. Notably, unincorporated communities were the most significantly impacted by this differentiation because of the lack of funding and enrollment in beneficial programs through FEMA. Sonoma County Multijurisdictional HMP was created with the intention of protecting all residents of Sonoma County, but representatives from unincorporated communities were not involved in the collaboration. In addition to the suggestion that unincorporated resident members participate in the next Sonoma County update, it is recommended that unincorporated communities like Guerneville form a coalition and propose to Sonoma County that they be incorporated and included in the next HMP to receive more funding and aid from Sonoma County. Funds from FEMA will continue if HMPs are updated every five years and aid local governments. Appropriate updates to HMP’s flood mitigation actions may be able to prepare Sonoma County for worse-case flood scenarios.

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