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FLOOD RISK AND MANAGEMENT OF CALIFORNIA'S SACRAMENTO-SAN JOAQUIN DELTA LEVEE SYSTEM

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

ENVIRONMENTAL STUDIES

by

Pamela F. Rittelmeyer

September 2020

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Interim Vice Provost and Dean of Graduate Studies

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2020

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ABSTRACT

FLOOD RISK AND MANAGEMENT OF CALIFORNIA'S SACRAMENTO-SAN JOAQUIN DELTA LEVEE SYSTEM

Pamela Rittelmeyer

The Sacramento-San Joaquin Delta is a highly developed floodplain and the hub of the state's water supply system. It is an agricultural, recreational, historical, and cultural center where 1800km of levees protect the current land uses and prevent salinity intrusion into the freshwater supply. For decades the region has been ripe with political controversies stemming from conflicting interests over its natural resources. The threat of climate change has added a layer of urgency to understanding the mobilization of narratives at different scales. This dissertation is comprised of three distinct parts. I used the Q methodology to explore the discourses of the broad range of stakeholders about flood risk and flood management in the Delta. The results of the Q-study reveal five distinct views regarding the risk of submersion of one or more islands due to either overtopping during high waters or structural levee failures. Proximity, sense of vulnerability, values, trust, and views of climate change are the underlying factors in these perspectives. Then, using a collection of 345 newspaper articles from twelve different publications written between 1972 and 2017, I examined the trends and shifts in the narratives about floods in the Delta. Results show changes in framing over time and differences between local, regional, and national media. Lastly, I analyzed the characteristics of atmospheric rivers that have preceded floods in the Delta using MERRA-2 0.5 × 0.625 6-hourly global atmospheric river (AR) reanalysis V2.0 and details about 57 documented floods from 1980 to 2019. Results show that most of the ARs that have made landfall in the watersheds that feed the Delta are not severe. Most of the floods, however, have been preceded by strong ARs. The most recent years (1999 to 2019) have had a small number of floods, and even fewer levee failures. However, the most recent ARs that impacted the Delta made landfall in the San Joaquin watershed, not the Sacramento watershed, which was the predominant origin of the more destructive floods in the earlier decades of this study.

This dissertation is dedicated to my amazing husband and daughter, Nobuo and Naomi, for their love, patience, and never-ending encouragement.

ACKNOWLEDGEMENTS

This work was made possible by financial support from a Delta Science Fellowship awarded by Delta Stewardship Council Delta Science Program (R/SF-86 grant number 1167), California State University's Chancellor's Doctoral Incentive Program, CONCUR, Inc.'s Environmental Studies Scholarship, a Marilyn C. and Raymond E. Davis Memorial Scholarship, a University of California Regents Fellowship, and the Environmental Studies Department at the University of California, Santa Cruz. I am grateful for the guidance from my dissertation committee, Dr. Andrew Szasz, Dr. Michael Loik, and Dr. Ellen Hines, and also my qualifying committee members, Dr. Zdravka Tzankova and Dr. Gary Griggs. I received assistance from many people in the California Sacramento-San Joaquin Delta, including Dave Mraz, Gilbert Cosio, Emily Pappalardo, Dr. Jeffrey Mount, and too many others to list them all here! I thank Dr. Brent Haddad and Dr. Kai Zhu for their input and technical assistance. Last, but not least, I greatly appreciate the brainstorming and research that my intern Ash Nee-Amshoff contributed during the early phase of my research design for the Q-methodology and media analysis.

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INTRODUCTION

> In ’97 we passed the flood of record, which I believe was 93,000 cfs at Michigan Bar. Those flood flows were attenuated because of all those levee breaks high in the Consumes system – I believe there were 26 breaks – that allowed that water to spread out over the floodplain. We did not get the flood that DWR projected we would get. They said the water at Benson’s Ferry was going to get to 23’8”. I believed we [could] hold it to 22’. We had made levee improvements after the flood of ’86., and because of the breaks on the Consumes, the level only got to 21’8”. We did pass the flood, except for McCormack-Williamson, which is height limited, it's designed to flood, and Dead Horse, which is a 200-acre district that has little resources. With a 200-acre base, it's tough to raise enough money to maintain the levees. Our district is 8,500 acres and has 23 miles of levees. Dead Horse has two miles. It's tough for them.
>
> – Delta Resident (Interview #25)

The Sacramento-San Joaquin Delta, an area that you can easily drive past without even realizing that it is there as you drive along I-5 between San Francisco and Sacramento, is a special place. I was first drawn to it because the rural atmosphere served as a respite from my city life in the Bay Area, and it reminded me of the summers of my childhood on my family’s farm in Alabama. The small legacy towns, family-run restaurants, wineries, and bed and breakfast inns are welcoming to visitors, and there are roadside stands where you can buy freshly picked fruits and vegetables. Many families have lived there for generations, either farming the land or running businesses that support the agricultural industry. There are also numerous marinas for recreational boaters, fishers, and vacationers, and habitat conservation areas to support the migratory route of waterfowl on the Pacific Flyaway.

Choosing this location for my PhD research was an easy decision as I am drawn to complex cultural and physical environmental problems. The importance of the Delta for the state's freshwater supply and economy, coupled with the potential for flooding from levee failures were compelling to me. I immediately heard and saw many different sides to the story of resiliency in the Delta. As an outsider, I had read about the dangers lurking in the rivers that run through it from national papers and magazines. When I got up close, I heard another set of facts about resiliency from the people who live there. While earthen levees generally are very vulnerable, the ones in the Delta have been maintained by locals who have an understanding of the hydrological and technical details unlike anything that I would have expected. The quote at the beginning of this introduction is from one the interviews that I conducted early in my research. It is just one of many examples of the level of detail that Delta residents speak of when discussing flood risk to their levees. The controversies in the Delta over water export facilities and state financing of levee maintenance have pushed many of the locals to become experts in hydrology, engineering, and policy, too. Working through the differences was not a new idea – far from it – but even after decades of collaborative efforts involving locals, state, and federal agencies, it was clear that consensus had not been reached about the best solution to flood risk in the Delta.

I conducted my research in three stages. First, I used the Q methodology, a method developed in the 1930s by the psychologist William Stephenson to study subjective beliefs and values (Stephenson, 1953), to gain a better understanding of perceptions of risk. Then, I analyzed media narratives of floods in the Delta over a fifty-year period. Lastly, I used forty years of atmospheric river observations to better understand the characteristics of the winter storms that have coincided with many of the past floods. Each of the following chapters has its own detailed introduction, literature review, methods section, results, and conclusion. Finally, I reflect on my overall conclusions of this research in Chapter 5, "Conclusion."

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Socio-cultural perceptions of flood risk and management of a levee system: Applying the Q methodology in the California Delta☆

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A R T I C L E   I N F O

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Sense of place
Levee
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A B S T R A C T

The Sacramento-San Joaquin Delta is an agricultural, recreational, historical, and cultural center and the hub of the state's water supply system. For decades the region has been ripe with political controversies stemming from conflicting interests over its natural resources which all depend on the protection of approximately 1800 km of earthen levees that surround over 60 islands, some of which are below sea level and two-thirds of which are privately owned. This study uses the Q methodology to explore the discourses of the broad range of stakeholders, including farmers, land- and water-based recreation enthusiasts, water exporters, utilities, environmentalists, and government agencies, about flood risk and flood management in the Delta. The results of this study reveal five distinct views regarding the risk of submersion of one or more islands due to either overtopping during high waters or structural levee failures. The findings of this study also elucidate nuanced narratives on the viability of anticipatory climate change adaptation in the Delta. Proximity, sense of vulnerability, values, trust, and views of climate change are the underlying factors in these perspectives. The perspectives identified suggest that resolving decades of distrust among stakeholder groups will remain difficult; however, taking a cultural approach to understanding perspectives may provide an opportunity to open up the conversations to adaptation approaches, and thus fulfill the legal mandate to protect the Delta as an evolving place.

1. Introduction

Low-lying and coastal regions are increasingly at risk of flooding from sea level rise and storm surge (Hoegh-Guldberg et al., 2018; Sweet et al., 2017). While many individuals are aware of and experienced with responding to flood events, many do not associate floods with climate change (Grothmann and Patt, 2005; Ngo et al., 2019). Traditional risk assessments based on economics and rationality of knowledge fail to explain the diversity of responses to risk in historically flood-prone coastal areas; this failure complicates anticipatory climate change adaptation (Adger et al., 2016; Pidgeon and Butler, 2009; Quinn et al., 2018; Wachinger et al., 2013). As knowledge grows about the role of social processes that drive climate change, pathways to adaptation to hazards become more complex (Pidgeon and Fischhoff, 2011). Communicating the need to take action to adapt remains a challenge because the uncertainties lead many people to delay taking action while many others have become overwhelmed and hopeless (Moser, 2016). It is becoming apparent that even amongst the general public who are concerned about climate change, it is perceptions of risk that determine whether or not people are willing to take proactive adaptation measures.

Research on risk perceptions has long demonstrated that individuals tend to view risk irrationally (Kahneman and Tversky, 1979; Starr, 1969) and that there are long-standing disagreements about what is risky, what amount of risk is tolerable, and what can be done to reduce risk (Douglas and Wildavsky, 1982). Familiarity with a hazard and social affiliation influence risk perception (Kroll-Smith and Couch, 1990; Nigg and Mileti, 2002; Slovic, 1987), as do worldview and trust in authority (Douglas and Wildavsky, 1982). Framing a threat as uncontrollable and potentially catastrophic increases people's fear while those who benefit from a hazard or who feel they have control over it fear it less (Slovic et al., 1980). Risk perception research, which initially was the domain of psychological and economic studies, has become multidisciplinary in recent decades as anthropologists, sociologists, and geographers have contributed to the field's broad range of theories and methods. Placing the context of risk within social and cultural narratives is imperative for successful climate change discourse (Hulme, 2008). Bickerstaff (2004) elaborates that a "socio-cultural perspective" is one where "perceptions of and responses to risk and hazard are formed in the context of a range of social, cultural and political factors… grounded in the social and cultural experience of everyday life" (pp. 827–828). This paper examines the socio-cultural perspectives

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Table 1
Major federal, state, and regional agencies with Delta interests.

State agencies	Federal agencies	Regional
• Dept. of Fish and Wildlife • Dept. of Water Resources • Natural Resources Agency • State Water Resources Control Board • Central Valley Flood Protection Board • Caltrans • State Lands Commission	• National Marine Fisheries Agency • Army Corps of Engineers • Bureau of Reclamation • Environmental Protection Agency • Fish and Wildlife Service	• Delta Stewardship Council • Delta Protection Comm. • Delta Conservancy

among diverse stakeholders in an area where there have been long-held disagreements over flood management.

The remainder of this section describes the study region in detail. The sections that follow describe the Q method and my data and analysis. To conclude, I discuss how my findings may contribute to the understanding of perspectives in the Delta and the risk perception literature.

1.1. Sacramento-San Joaquin Delta

California's Sacramento-San Joaquin Delta (Delta) is a region of islands with land below sea level, similar to Holland. For decades planning efforts in the Delta have pitted water exporters, environmentalists, and agriculture interests against each other. Each group defines the Delta differently. For some, it is a critical pathway for much of their water supply. For others, it is a unique and fragile ecosystem. For others still, it is a community, a place to call home, and a livelihood. The Delta is a region where there is a need for a unified vision for flood management, yet there is a lack of agreement regarding the severity of flood risk and the best approach to manage the levee system for the future. A myriad of federal, state, and regional agencies have a role in the Delta (Table 1). The large number of government agencies tasked with different and often opposing issues illustrates the importance and inherent controversies of the region. It is unclear if and how all of the competing demands can be accommodated (Pitzer, 2010) and there is a need for a better understanding of the disparate values regarding the Delta's function as an export water supply and its agricultural, cultural, recreational, and natural resources (ISB, 2017; Kraus-Polk and Milligan, 2019).

Although California is known for its earthquakes and wildfires, floods are often the cause of natural disasters in the state. Each of the state's 58 counties has declared a flood emergency at least three times since 1950, hundreds of lives have been lost, and billions of state funds have been used for emergency response and recovery (DWR, 2013; Lauer, 2009). California's dams and reservoirs have reduced peak flows on many of the rivers, but the potential for flooding remains high. Recently, California state agencies have begun to favor restoration of floodplains and creating a "soft path" for flood management by using stream restorations, levee setbacks, and land use regulations (DWR, 2017).

The Delta is unique in that much of the land is near or below sea level making it technically difficult to apply the "soft-path" approaches being used in other areas, and two-thirds of the levees, which provide flood management in the Delta, are privately owned making it politically difficult for a state-mandated solution (DSC, 2018; Lauer, 2009). The Delta's islands were created when levees were built to reclaim over 2000 km^2 of overflow land for agriculture as allowed by the Swamp Land Act of 1850 (Kelley, 1989). Landowners progressively built them higher and wider to protect their farms from inundation, particularly as their land subsided over time (DWR, 2017; URS, 2007). Locally run reclamation districts maintain the levees with a cost-share program combining state funds with financing from land assessments on the islands (DWR, 1973). Historically a highly ecologically productive tidal marshland, the Delta has been converted to over 60[1] agricultural islands that are surrounded by about 1100 km of waterways and protected by 1800 km of earthen levees (DSC, 2013; Whipple et al., 2012). For many of the islands, the levees act more like dams, protecting the land from the force of daily tides, boat wakes, and wind (Figs. 1 and 2). Water exports from the Delta supply freshwater to approximately 25 million Californians, millions of acres of farms and ranches throughout the state, as well as much of the industry in Silicon Valley (Arcadis, 2017; Pitzer, 2010). The levees, which serve the dual purpose of providing flood protection and preventing salinity intrusion into the high quality export water, require constant maintenance and improvements. Projected sea level rise compounds the potential for flooding (Cayan et al., 2006, 2016; Griggs et al., 2017; Mount and Twiss, 2005; Pierce et al., 2018). Observed trends toward more extreme precipitation events, which could overwhelm upstream reservoirs, present additional challenges to levee management (Lamjiri et al., 2018; Musselman et al., 2018; Swain et al., 2018).

The Delta sits at the confluence of the Sacramento and San Joaquin rivers, inland of the San Francisco Bay and south of the state capital of Sacramento (Fig. 3). About 12,000 people live on the farms and in the small Delta communities, and over half a million people live in the urban areas on the fringes of the Delta (Arcadis, 2017; DSC, 2013). Roughly 50% of the state's average annual streamflow passes through the Delta. While most of the land is agricultural, there are also duck hunting clubs, habitat restoration areas, and wildlife-friendly farms that support North America's migratory waterfowl along the Pacific Flyway, and the waterways are popular with fishers, boaters, and windsurfers (DSC, 2013; URS, 2007). There are eleven "legacy towns"[2] that are

Fig. 1. Boating by a marina in the Delta. Credit: P. Rittelmeyer.

[1] Reports differ on the exact number of islands in the Delta. By many accounts there are over 100. There are about 60 named islands, most of which are used for farming, but many dozens more islands are not named and might not be counted. Others might not be counted because they are only separated from another "island'" by a canal, because they do not have a reclamation district, or because they are a small in-channel island that is difficult to locate on a mapping system (Mraz, 2016).

[2] The term "legacy" town is commonly used to refer to Delta communities that have not changed much in the past 100 years. The legacy towns are Bethel Island, Clarksburg, Courtland, Freeport, Hood, Isleton, Knightsen, Rio Vista, Ryde, Locke, and Walnut Grove (Delta Reform Act of 2009 SB X7 1).

Fig. 2. An agricultural island in the Delta. Credit: DWR.

vibrant centers for recreation and tourism. Major ground transportation routes traverse the Delta, including highways, rail lines, and deep-water shipping channels; there are hundreds of natural gas pipelines and five high-voltage power transmission lines that serve the broader region. The state's two largest surface water projects, the Central Valley Project and the State Water Project, have water export pumping facilities in the south Delta.

Under certain conditions, if the levees around a subsided island fail, salt water rushes (Lund et al., 2007). When a Delta levee failed in 1972, brackish water flowed into the export water conveyance channels and the space behind the levee, increasing salinity in the freshwater. Approximately 300,000 acre-feet of freshwater were released from three upstream reservoirs to remove the salinity from the export water supply (DWR, 1973; Foster-Morrison, 2016; Lauer, 2009). In response to this event, California legislators formed the Delta Levee Maintenance Subventions Program (Subventions) to supplement private funding for

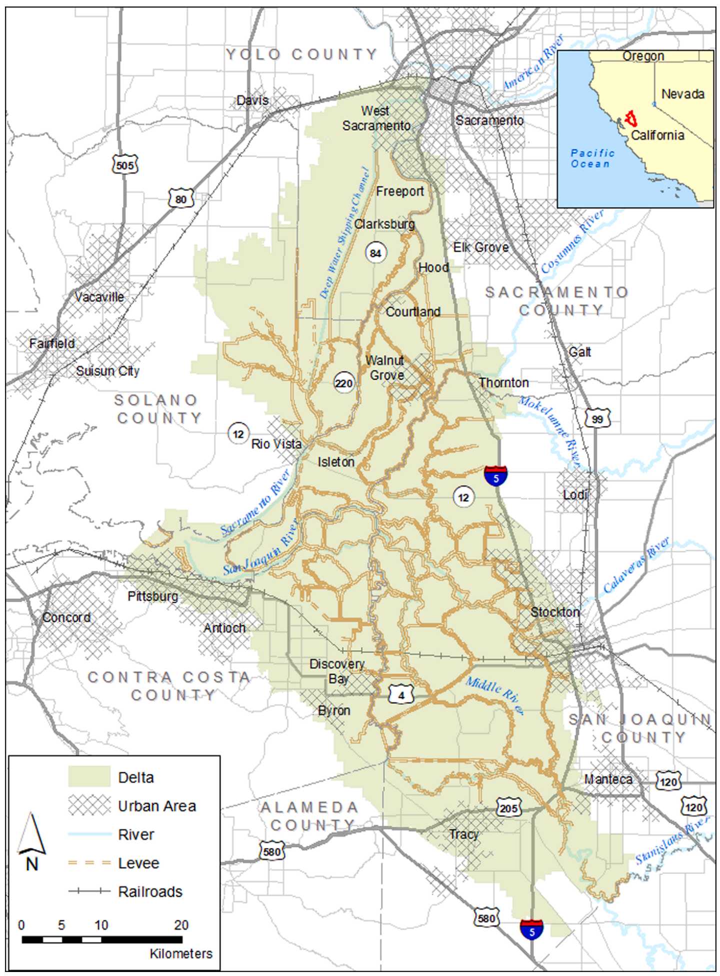

Fig. 3. Map of the study area. Sources: DWR, DSC, ESRI, US Census 2010.

levee maintenance through a cost-share agreement between more than 60 reclamation districts and the state (DWR, 2019a). However, maintenance and improvements did not happen quickly enough to protect the region from massive storms. In 2006, funding for Subventions increased, and the state began to make a stronger effort to improve the condition of the levees (DWR, 2019a; Lund et al., 2007). In 2007, the Delta Vision Blue Ribbon Task Force, which was created to carry on the work of CALFED[3], a decade long effort to achieve collaborative governance, issued a report that concluded that sustainable management of the Delta would require a healthy ecosystem and a reliable water supply – also known as the co-equal goals (BRTF, 2008).

Meanwhile, the California Department of Water Resources (DWR) convened a team of experts to assess risks to the levees. Their findings were published in the Delta Risk Management Strategy in which they concluded that there is a greater than sixty percent chance that an earthquake will cause multiple levee failures sometime in the next 50 years (DWR, 2009). However, the findings in the report were immediately criticized (Lauer, 2009), and even though the authors used methods that were state of the art at the time, years later it was stated that they overestimated the risk by two to four times (ISB, 2016).

In 2009, the Delta Reform Act became law, mandating that the state develop a comprehensive management plan (Delta Plan) to implement the co-equal goals of habitat protection and water supply reliability while also protecting and enhancing "the unique cultural, recreational, natural resource, and agricultural values of the Delta as an evolving place" (CA Water Code §85054). The Delta Plan called for the conveyance of export water in tunnels under the Delta. This approach to water conveyance was selected for several reasons, including the protection of endangered fish from entrainment at the existing export pumps (DSC, 2013). The authors of the plan reasoned that a system of underground tunnels through the Delta would also reduce risk to the water supply for exports from levee failures. The development of an isolated conveyance system has not yet occurred, and it remains a contentious issue that is the subject of much litigation.

As a result of hundreds of millions of dollars invested in flood control improvements, the levees have survived major storms in recent years, yet erosion, upstream dam failures[4], and unseen levee defects[5] remain constant threats (DWR, 2019a, 2019b). For years there has been a growing concern that the current management of the Delta is not sustainable, and the Delta is in crisis (DPC, 2012; Lund et al., 2007). To protect people, property, and the state's interest, there remains a critical need to reduce flood risk, particularly in the face of climate change (Dettinger et al., 2016; DSC, 2018; DWR, 2017).

1.2. The Need for New Ways to Understand Stakeholders' Perceptions

Uncertainties about climate change complicate taking action, even to those who are very worried about it (Leichenko and O'Brien, 2019; Norgaard, 2011, 2006). Local governments experienced in responding to extreme precipitation and floods are more likely to invest in flood protection than proactive climate change adaption measures (Amundsen et al., 2010). Likewise, individuals tend to believe in their capacity to respond to risks that they have experienced in the past, making adaptation to climate change less likely than taking action such as flood preparedness (Grothmann and Patt, 2005). Even when there is knowledge of global climate change, attention to culture and scale are critical for the implementation of local action (Adger et al., 2013; Hulme, 2008). Place attachment can be a motivator for adapting to changes (Amundsen, 2015; Devine-Wright, 2013); however, in a study of two historically flooded communities in France, Quinn et al. (2018) found that acceptability of risk (whether one is aligned with an approach of "living with floods" or "protection from floods") determines which adaptation pathway one is willing to take. Identifying perspectives held by different groups can help policymakers anticipate how their constituents will accept new environmental policy proposals (Barry and Proops, 1999). The competing demands on the natural resources of the Delta have historically impeded regional collaboration (Kallis et al., 2009; Lund et al., 2010, 2007). In a study of governance in the Delta, Norgaard et al. (2009) argue that a shared learning process is essential to improve management outcomes, given the region's dynamic nature. Policies to reduce flood risk are likely to be better received if they are developed with an understanding of how stakeholders perceive what is at risk, what causes the risk, who can reduce the risk, and what the solutions should include.

This study builds on extensive scholarship about the Delta's levees (Arcadis, 2017; Deverel et al., 2016; Hopf, 2011; Kelley, 1989; Ludy and Kondolf, 2012; Lund et al., 2010, 2007; Mount and Twiss, 2005; Pappalardo, 2014; Suddeth et al., 2010; Thompson, 2006; Thompson and Dutra, 1983). While these existing studies are useful for understanding the history and structural integrity of the levees and general flood awareness, the question remains of how various perceptions of flood risk align with acceptance of the suite of potential adaptation measures. Specifically, this paper investigates the social and cultural influences on risk perceptions of levee failures and visions for future flood management. Similar to this study, one other researcher used the Q method to "investigate the social perspectives held by the experts of the Delta levee system so that the critical differences and the areas of near agreement can be better understood" (Hopf, 2011, p.5). Hopf found four perspectives among his 22 participants, and he summarized the perspectives as Sustain the Delta, Abandon the Delta, Pragmatist, and Multi-purpose Advocate. One individual participated in both Hopf's research and this study. However, the present study included a broader group of stakeholders. Participants were chosen because of their familiarity with the Delta's flood risk instead of their levee expertise. The variety of participants allowed for the inclusion of Q statements focused on the social and cultural characteristics of risk perception. As a result, this study reveals nuances in the subjectivity of a wide range of stakeholders' perceptions of flood risk and flood management.

2. Methods

2.1. Q methodology

The Q method is a mixed-methods approach that is well established in the study of risk perceptions (Johnson and Chess, 2006; Niemeyer et al., 2005; Simmons and Walker, 1999; Tuler et al., 2005; Venables et al., 2009) and conservation and land use conflicts (Albizua and Zografos, 2014; Epstein et al., 2018; Farrell et al., 2017; Jenkins, 2017; Lévesque et al., 2019; Moros et al., 2019; Zabala et al., 2018). The method was developed in the 1930s to study people's beliefs and attitudes (Stephenson, 1953). It is a systematic process of assessing qualitative data to reveal subjectivity, and it can reveal otherwise overlooked perspectives about a complex topic. This method allows the

[3] A series of levee failures and overtopppings, the near extinction of several native fish species, and the defeat by the state's voters of a 1982 proposition to construct a peripheral canal for water exports led to the creation of the California Water Policy Council and Federal Ecosystem Directorate (CALFED) in 1994 to find a solution that would satisfy proponents of the disparate interests of fisheries, water exports, and agriculture. CALFED consisted of representatives of all stakeholders. In the ten years that followed, experts gained a better scientific understanding of the Delta through government-supported research. However, CALFED was not able to foster agreement between the different interests, so funding for it ceased (Kallis et al., 2009; Lund et al., 2007).

[4] In 2017, the largest dam in the US, the Oroville Dam, experienced the collapse of its emergency spillway and barely averted a major failure. This event highlighted the region's vulnerability from upstream management (Swain et al., 2018).

[5] In 2004, unseen defects, possibly burrowing rodents, caused a levee failure on Jones Tract. It cost an estimated $90 million to pump water off the island, repair the levee, replace infrastructure, and recover from crop loss (Pitzer, 2010).

researcher to find patterns (or factors) shared by individuals. Conducting a Q study involves several steps: developing the "Q concourse," or range of thoughts, about a single topic by conducting interviews or reviewing existing documents; selecting statements of opinions about the topic from the concourse; choosing participants for the "Q sort"; having participants sort the selected statements on a scale from most agree to most disagree (usually this is done by printing the statements onto cards and having participants place them onto a grid of a quasi-normal distribution (Danielson et al., 2012; Eden et al., 2005; Watts and Stenner, 2005)), and conducting factor analysis of the sorts. The factor analysis determines which Q sorts are most highly correlated, and it derives the number of possible factors by grouping those Q sorts that resemble each other[6]. The final step is the interpretation of the perspectives that are revealed through statistical analysis. Several papers and books provide guidance for conducting a Q study (Barry and Proops, 1999; Brown, 1993, 1980; Dryzek and Berejikian, 1993; Stephenson, 1953; Watts and Stenner, 2012, 2005; Webler et al., 2009; Zabala et al., 2018). Also, the Q Methodology Network listserve (Q-METHOD@LISTSERV.KENT.EDU) is a useful resource for Q method researchers.

A participant's responses are regarded in the context of the entire set of statements in the Q sort. The factor analysis generates idealized sorting patterns by weighting the average of the Q sorts that were sorted by participants in a similar pattern, and, along with analysis of post-sort comments, these idealized patterns allow the researcher to find narratives of different perspectives within the context of the discourse (Barry and Proops, 1999; Benitez-Capistros et al., 2016; Danielson, 2009; Webler et al., 2009). Unlike other survey methods, generalizations are not made based on statistical information from a large, random sample. Q method only requires a small group of purposefully chosen participants because "there are a limited number of ordered patternings within a particular discourse domain" (Barry and Proops, 1999, p. 339). The intention of the Q method is to identify distinct views, not to describe the viewpoint of a particular population (Brown, 1980; Dryzek and Berejikian, 1993; Ramlo, 2018; Watts and Stenner, 2012; Woolley et al., 2000). The method works best with participants who are knowledgeable about the topic. While the researcher strives to include participants who represent the full range of perspectives, there might be some perspectives that are missed.

2.2. The Q Concourse and Q Set

The perspectives, ideas, and thoughts about a topic are referred to as the Q concourse (Brown, 1993). The most common way to develop a Q concourse is to pull quotes from interviews. Statements or quotes from news articles, opinion pieces, and other documents can be used as well. I collected data to form the Q concourse for this study from 25 semi-structured interviews with experts on Delta flood management between March 2016 and December 2017. Interviews were recorded and transcribed verbatim. Interview questions centered around how the Delta got to be the way it is, why past attempts at a unified solution have not worked, what are the threats today, who stands in the way of taking corrective action, and what should be done to manage future flood risk. Flood management in the Delta has been a contentious issue for many decades, often dividing stakeholders into proponents of either maintaining the levee system to protect the current uses of the Delta or re-routing the export water to reduce dependence on the levees. At the time of this study, there was a considerable amount of public debate because of advances in permitting for construction of two 12 m high, 56 km long underground water export tunnels running from north of the Delta to the existing water export facilities in the south. For this reason, data gathering for the concourse also included participant observation of over twenty public meetings and workshops where flood management was on the agenda, and analysis of hundreds of public comments, newspaper articles, op-eds, and blogs that mentioned the levees and flood risk. The meeting notes and archival documents were used to ensure that all perspectives were included. Several recurring themes emerged from the data: the cause of floods, Delta history, vision for the future, consensus and cooperation, trust in government and decision-making, and resiliency. From this classification scheme, I selected over 500 quotes. It is typical for a Q concourse to contain hundreds of statements and then be narrowed down for the Q set (Eden et al., 2005; Gram-Hanssen, 2019; Hooker-Clarke, 2002).

The Q set should include around 30 or 40 statements to make the Q sort manageable for the study's participants to perform in about 60 min (Webler et al., 2009). There are a number of methods that researchers use to select the statements for the Q set (Eden et al., 2005). One approach to narrow the concourse is to place them into subtopics using a theoretical framework and then choose a balanced number of each (Barry and Proops, 1999; Jacobsen and Linnell, 2016; Webler et al., 2009; Zabala et al., 2018). I grouped the statements into the socio-cultural risk perception framework suggested in Bickerstaff (2004) of place, trust, and agency or power (more specifically resilience and adaptive capacity), aiming for about ten statements in each category.

Statements that were unclear, repetitive, or did not fit clearly into any of the three broad themes were discarded. The intent was to maintain the original voice, but minor edits were made for brevity. Once the number of statements was narrowed to 60, I test ran the selection with three academic colleagues and two stakeholders for completeness and consistency. It is common to pilot test Q sorts to ensure that the statements are clear to participants (Watts and Stenner, 2005; Zabala et al., 2018). Statements found to be confusing, redundant, or irrelevant by the test participants were discarded until the number in the set was narrowed to 45 statements. I test ran the set with two more stakeholders and one academic colleague. More redundancies were eliminated, resulting in a final set of 35 statements with roughly equal numbers of statements falling into each of the three themes. Twenty-eight of the statements in the final Q set came from interviews; seven statements were from public meetings and archival documents.

A limitation of this study should be acknowledged. The Q set included some statements that have more than one message (e.g., S1, S9, S10, S16). In a Q study, each statement should ask about only one item at a time and should be explicitly clear (Webler et al., 2009). Clarification on the intention of those statements was given to participants during the Q sorts to reduce ambiguity.

2.3. Q sorters

The 33 participants for the Q sorts were chosen because they have spoken in public, served on a committee, or are a decision-maker for an organization on the issue of Delta flood management. A larger sample size is not necessary for the Q method. In a study of 52 studies, Zabala et al. (2018) found that most of them used between 26 and 46 participants. The Q method is useful to reveal the breadth of opinions on a topic; therefore, it is common for participants to be chosen purposively to include people from a variety of stakeholder groups (Webler et al., 2009). I intentionally picked participants from the following groups: farmers, land- and water-based recreation enthusiasts, water exporters, utilities, environmentalists, and government agencies, as well as people from the different geographic regions of the Delta. A number of the people in the various interest groups do not live in the Delta. Some work in the Delta daily, while others only travel there occasionally for work or recreation. As suggested by Webler et al. (2009), in order to have a robust study, participants were chosen because they were known to have well-informed and different opinions. It should be acknowledged that using a small number of participants is a limitation of Q

[6] The Q method statistically finds the correlations between sorts and generates factors according to the correlations. The correlations themselves serve as the "raw material" with which further analysis is conducted (Brown, 1993, p. 112).

studies from concluding that individual traits are necessarily representative of the general population.

2.4. Q sorting procedure

The Q sorts were conducted in people's offices, homes, or a place convenient to them. Interviews were recorded on a handheld device and conducted with IRB approval. Participants signed consent forms and were informed that no personal identifying information would be included in the results. They were instructed to read through all the statements which were printed onto index cards, make three piles, and place them onto a poster board with a nine column grid according to their level of agreement or disagreement, ranging from most strongly disagree (−4) to most strongly agree (+4).

2.5. Analysis

Principal Component Analysis and Varimax rotation of the Q sorts was conducted for 33 sorts using PQMethod 2.35 software (Schmolck, 2014). The Q factor analysis "correlates people's Q sorts across the sample of Q statements" (Danielson et al., 2010, p. 10). The first step of analysis is to extract a small number of factors that are representative of most of the responses obtained through the Q sorts (Zabala et al., 2018). There are several ways for a researcher to decide how many factors to extract, and most Q studies use two or more criteria. For this study, I first looked at the eigenvalues of the correlations between sorts (Watts and Stenner, 2012). Eigenvalues demonstrate the contribution of a factor to explain the variance more than a single sort would (Donner, 2001). Eight factors had eigenvalues greater than one. An eigenvalue of greater than one generally signifies that a factor could explain variance in the study (Barry and Proops, 1999; Watts and Stenner, 2005). An additional criterion was used, whereby only factors with two or more significant loaders were chosen (Watts and Stenner, 2005). Significant loadings indicate a strong relationship between a respondent and a factor and are flagged by the PQ Method software (Zabala et al., 2018). Seven factors had two or more significant loaders. A smaller set of factors may more clearly describe the variation in the perspectives, so a Cattell's scree test was employed to further narrow down the number of factors (Appendix A). A change in slope on the scree plot can be used as an indication of the number of factors to extract (Watts and Stenner, 2012). According to the scree plot, either three or four factors could be extracted. A preliminary interpretation of the factors was conducted to ensure that the number chosen explained the most variance without oversimplifying the discourses (Zabala et al., 2018). Ultimately, four factors were extracted, explaining 59% of the variance in the study, which is within the range of other Q studies (Albizua and Zografos, 2014; Benitez-Capistros et al., 2016; Watts and Stenner, 2012; Zabala et al., 2018). Twenty-seven of the Q sorts loaded significantly onto one of the four factors. Factor loadings of ± 0.44 were significant at $p < 0.01$.[7] Of the four factors, one factor included two sorts with significant negative loadings. This factor was copied, inverted, and then analyzed as a fifth factor (Brown, 1993, 1980).

The next step of analysis is rotating the factors "to obtain a clearer and more interpretable structure of the results" (Zabala et al., 2018, p. 1189). The key results of the rotation are the factor loadings and the z scores. The factor loading indicates the correlation between a participant and a factor (Brown, 1993; Zabala et al., 2018). Z scores are the weighted average of the scores given to a statement by participants who responded similarly, and they indicate the relationship between each statement and a factor (Zabala et al., 2018). These scores are used to create a hypothetical array of the groups of similar individual responses to the statements (Brown, 1993; Dryzek and Berejikian, 1993; Eden et al., 2005; Zabala et al., 2018). The Q statements and idealized arrays for the factors analyzed in this study are shown in Table 2. The following section is a description of each of the factors based on quantitative analysis of the factors and qualitative analysis of interviews during the Q sorts.

3. Findings

Five factors were interpreted for this study primarily using their factor scores. None of the factors are highly positively correlated, and two, F1a and F1b, are strongly negatively correlated (Table 3). Comments made by the participants during the sorting process were used to clarify the narrative. Each of the factors provides a unique view of flood risk from levee failure in the Delta.

As is common practice with the Q method, each narrative is written as if from the perspective of someone who typifies that factor. The narratives are subjective and are not necessarily statements of fact. Each factor's distinguishing statements, i.e., the statements whose values were statistically significant for one factor compared to the other factors, served as the basis for the interpretation of each narrative (Webler et al., 2009; Zabala et al., 2018). The brackets in the following section contain the corresponding statement number. An asterisk indicates a distinguishing statement for that factor. Quotations are included from the post-Q sort interviews to retain the voice of the participants. Table 4 illustrates the factor statistics and participants' affiliations.

3.1. Factor 1a: Crisis is certain

The "crisis is certain" view refers to the Delta as an "altered landscape" with "low economic productivity"(S26*). This view, which was loaded onto by mostly by non-residents, many of whom do not frequently work in or visit the Delta, places much of the blame on the Delta residents. This perspective believes that residents prevent proactive decision-making from being accomplished because of their desire to keep the Delta in their "snapshot of time," and it is their fault that they have chosen to live in a flood zone (S1*, S15*, S25*). F1a believes that scientists are more knowledgeable about the seismic risk and some of the other threats than the people who are working directly on the levees every day. One participant aligning with this view asserted that using "first-hand observations leads to a sense that tends to make people feel more confident than they necessarily should" (S17*).

This view proclaims that flood risk is growing because climate change is making extreme storms more likely, and the levees are not engineered to hold back high water (S28*, S29*). Participants explained that the status quo in the Delta is not sustainable because subsidence is making farming unviable (S13*). Also, this view strongly believes that there is a high likelihood of a strong earthquake that will cause many simultaneous levee failures (S7*). Because of these threats, this view believes that the state has needed to protect the islands to protect the water quality, but protecting every single levee to maintain the water quality throughout the Delta "really ties your hands" (S3, S15*, S18, S25*). Hardening levees is not the solution to flood management because it displaces the flood risk and creates more stress on the system. One F1a participant said, "I think that if you isolate the conveyance in some way or another, it opens up flexibility in a lot of other areas for a lot of different methods" (S22*). This perspective strongly supports the idea that an isolated conveyance system would reduce the need to maintain all of the levees (S24*). According to F1a, reducing the amount of levees would be good because the levees and the maintenance of them are "doing a lot of damage" (S2*, S26*). The F1a perspective is that it would be best if the state could pay off the landowners so that the levees could be decommissioned (S2*). One respondent explained that preserving the Delta as place, which is required by the Delta Reform Act, means ensuring that there are some recreational opportunities, protection of the legacy towns, and

[7] Significance at $p < 0.01$ can be defined as $x = 2.58\left(\frac{1}{\sqrt{n}}\right)$, where n equals the number of items in the Q set (Brown, 1980; Watts and Stenner, 2005).

Table 2
Statements and grid positions of idealized factor arrays.

#	Statement	Z-score (a) and Q-sort rank (b)									
		F1a		F1b		F2		F3		F4	
		a	b	a	b	a	b	a	b	a	b
1	The rivers are much shallower now than before. There is a flood risk because they aren't dredged anymore.	**−1.76**	**−4***	0.97	+2	−0.38	−1	−0.17	0	0.58	+1
2	If the state doesn't need to maintain the levees anymore for water conveyance, they will just walk away.	**−0.48**	**−1***	1.23	+3	0.88	+2	0.92	+2	0.57	+1
3	Environmental regulations are big obstacles for levee maintenance and improvements.	0.06	0	**2.33**	**+4***	0.32	+1	−0.09	0	**−0.71**	**−2**$^{+}$
4	Creating habitat on a widened levee benefits the public.	0.52	+1	−1.03	−2	−0.36	0	**1.20**	**+3**$^{+}$	0.39	0
5	Adaptive management for ecosystem enhancement is necessary because you can't really tell what's going to happen until you go out there and do it.	**1.28**	**+3**$^{+}$	−1.36	−4	**0.11**	**0**$^{+}$	−0.74	−1	**0.74**	**+2**$^{+}$
6	The risk of Delta residents being caught by surprise by a levee failure is very low because the local farmers and the flood districts keep a good watch on the condition of the levees.	−1.38	−3	1.29	+3	−0.49	−1	−1.04	−2	0.84	+3
7	The Delta is "locked and loaded" for a major earthquake and the shaking will inevitably cause the levees to fail en masse.	**0.62**	**+2***	−1.23	−3	−1.68	−4	−0.99	−2	**−2.58**	**−4***
8	I think the state will always step in and help the Delta after a disaster.	−0.64	−2	−0.64	−1	**−1.66**	**−3***	−0.44	0	−0.45	−1
9	The state is responsible for levee maintenance because public use of the channels for recreational boating and their use for water conveyance are what damage the levees.	−1.51	−3	0.58	+1	−1.21	−3	0.19	0	0.04	0
10	*Delta communities need to think about how they can have continued growth as conditions in the Delta change. The communities have adapted in the past and they must do it in the future.*	*0.75*	*+2*	*0.46*	*+1*	*0.75*	*+2*	*1.16*	*+3*	*0.52*	*+1*
11	Flooded Delta islands are not necessarily a bad thing. A flooded island could create good fish habitat for recreational fishing.	0.47	+1	−0.97	−2	−0.50	−1	0.95	+2	−1.20	−3
12	When state funds are invested in a levee project, they should include enhancing habitat on the levees to increase natural habitat.	0.62	+2	0.52	+1	−0.19	0	1.15	+3	−0.10	−1
13	Subsidence causes farming in the Delta to be less viable over time.	**1.78**	**+4***	**−1.10**	**−3***	0.18	0	0.71	+1	0.53	+1
14	Turning the Delta into a big recreation area would have catastrophic local economic and social impacts.	−0.59	−1	0.00	0	−0.44	−1	−1.07	−2	0.23	0
15	The Delta flood districts can keep up with sea level rise as far as the levees are concerned because it happens slowly. They can do a little bit of work every year and keep up with it.	**−1.71**	**−3***	1.10	+2	**−0.29**	**0***	0.71	+2	1.37	+4
16	Science in the Delta is jaded because it's narrowly focused on finding a predetermined answer. It is driven by the grant process and is therefore not independent of the political process.	−0.87	−2	0.06	0	0.26	0	−0.86	−1	0.00	−1
17	The first-hand observations and knowledge of people working directly with the levees on a daily basis is more valuable to preserving the levee system than the science used by state agencies.	**−0.68**	**−2***	2.01	+4	1.30	+3	0.48	0	0.75	+2
18	The state needs to acknowledge that it's important to protect and maintain productivity on the fertile agricultural land in the Delta.	−0.45	−1	−0.26	0	**2.18**	**+4***	−0.51	−1	**0.83**	**+2***
19	We don't know really what's going to happen as a result of sea level rise, climatic warming or earthquakes, so we have got to do the best we can knowing that we will have to change our actions if and when disasters happen.	−0.08	0	−0.14	0	1.12	+3	0.20	0	0.62	+1
20	There's a lot of valuable infrastructure that crosses through the Delta that the state should protect.	0.53	+1	0.06	0	0.69	+1	0.49	+1	**2.17**	**+4***
21	Everything that is done in the Delta is all about liability. It's not about solving real world problems.	−0.42	0	−0.52	−1	**0.35**	**1**$^{+}$	−0.47	−1	−1.27	−3
22	The best solution to the risk of levee failure is to protect the water supply through engineering - either by hardened levees or in an isolated conveyance system.	**0.62**	**1**$^{+}$	−0.72	−1	−0.87	−2	**−1.67**	**−4**$^{+}$	**0.05**	**0**$^{+}$
23	If a levee is covered in vegetation, then you can't see it. As long as you have access to the top and both sides, the levee can mostly be controlled and managed.	−0.60	−1	0.52	1	−0.37	−1	0.17	0	0.13	0
24	You don't have to protect all of the Delta levees to continue to transport water through the Delta.	**1.48**	**+3***	−0.97	−2	−0.04	0	−0.94	−2	−0.16	−1
25	Any ecosystem restoration planning needs to ensure the economic vitality of the Delta.	**−0.12**	**0**$^{+}$	0.90	+2	1.63	+4	0.50	+1	1.27	+3
26	I genuinely question whether spending money to improve all of the levees is in the taxpayers' interest because of the low economic productivity on these islands.	**0.45**	**0***	−0.64	−1	−1.96	−4	−0.65	−1	−1.81	−4
27	Federal agencies should be involved in the flood management of the Delta.	0.56	+1	0.20	+1	0.91	+2	0.65	+1	0.16	0
28	Because of all the work that has been done to improve the Delta levees over the last 30 years, the levees can survive flood events like never before. Any problems now are nominal.	**−1.77**	**−4**$^{+}$	1.17	+3	−0.62	−2	−1.10	−3	0.64	+2
29	Flood risk is growing because climate change is making extreme events more likely.	**2.03**	**+4***	−0.78	−2	0.91	+2	0.66	+1	−1.16	−2
30	Farmers should move towards growing crops that are more suitable to seasonally flooded lands along the rivers.	0.27	0	0.14	0	−0.97	−2	0.77	+2	−0.78	−2
31	A key to flood management in the Delta is building more reservoirs.	−0.74	−2	0.90	+2	0.63	+1	−1.50	−3	−1.04	−2
32	There are opportunities on the subsided islands for reversing subsidence and sequestering carbon which are really exciting to me.	1.02	+2	−1.81	−4	−0.91	−2	−1.35	−3	1.01	+3
33	I worry about whether or not we are going to be able to restore ecosystem function in the Delta fast enough to keep species from going extinct.	**1.22**	**+3**$^{+}$	−1.17	−3	**0.69**	**+1**$^{+}$	**2.51**	**+4***	−0.52	−1
34	I think that landowners are not willing to include environmental enhancements into their levee maintenance because they don't know how to do it.	−0.63	−1	−0.58	−1	−1.39	−3	−1.56	−4	−1.72	−3
35	The state and NGOs should do community outreach up front so that planning is locally initiated and developed.	0.12	0	−0.52	−1	1.41	+3	1.33	+4	0.04	0

Bold type indicates grid placement that is statistically significant for a factor score.
Italics indicate a consensus statement between all the factors. Non-Significance is indicated at $P < 0.01$.
* Indicates Significance at $P < 0.01$; $^{+}$ Indicates Significance at $P < 0.05$.

Table 3
Correlations between factor scores.

Factor Array	F1a	F1b	F2	F3	F4
Crisis is certain	**1.0000**	−0.6420	0.1270	0.2593	−0.1860
There is no crisis		**1.0000**	0.2568	0.0559	0.2910
Locals are resilient			**1.0000**	0.3915	0.4491
Nature is resilient				**1.0000**	0.1722
Human ingenuity will prevail					**1.0000**

Table 4
Factor statistics and participants' affiliations.

	F1		F2	F3	F4
Eigenvalue	**8.36**		**6.60**	**2.40**	**2.15**
Explained variance	**22**		**13**	**10**	**14**
	F1a	**F1b**	**F2**	**F3**	**F4**
# of significant sorts	9	2	6	4	6
Resident/Non-resident:					
Rural Resident		1	4		1
Urban Resident	1		1	2	
Frequent Visitor	4			2	5
Infrequent Visitor	4	1	1		
Regions represented[a]	N,NW,C	N,NW,C	N,NW,C,W	W,S,E	C,W
Affiliation[b]**:**					
Agriculture			3		1
Water-based recreation			1		1
Other Local Business		1			
Engineer	5	1			3
Conservation	2		1	2	1
Local Advocacy		1	2	2	1
Environmental Justice				1	
County Government			1		1
Land-based recreation	1			1	
Natural resource management	2				
Fish/wildlife management				1	
Transportation		1			
Water exports	2				
Utilities	1				
Federal Government	1				
Academia	2				

[a] Geographic delineations are based on Sacramento-San Joaquin Delta Boating Needs Assessment 2000–2020 map (https://dbw.parks.ca.gov/?page_id = 29440): N = north, NW = northwest, C = central, W = west, S = south, E = east.
[b] Some participants had multiple affiliations and were placed in more than one category.

maintenance of transportation routes through the Delta. This perspective does not think that the state's role is to protect the local agricultural economy (S25*).

F1a believes that we have changed the ecosystem so much that some native species are not going to survive, especially with warmer waters from climate change (S33*). Catastrophic levee failure will undoubtedly occur, according to this perspective. It might be from climate change, an earthquake, or threats that "are beneath the surface and you can't really see them well unless you do geotechnical analyses which I don't think these local farmers do" (S6). This view asserts, "Unfortunately, we cannot just let nature run its course" (S5*) To restore the estuarine-like flow of water and function as it was before the levees were constructed, this perspective believes that we have to use adaptive management (S1*, S5*).

3.2. Factor 1b: There is no crisis

The factor that is most in opposition to F1a is F1b, the "there is no crisis" view. F1b does not think that the risk is insurmountable; however, this view emphasizes that environmental regulations are " a huge obstacle" to efficient flood management (S3*, S13*). F1b places blame on the water exporters for influencing politicians for their self-interests. One respondent said, "It's all about votes… They've got 25 million-plus additional votes on the other side down there" (S18). This view emphasizes that subsidence does not increase flood risk in the northern part of the Delta, and the state ignores this local variability in its decision-making. Besides, F1b asserts, "As long as there is peat there, [even if there is some subsidence], it's still a good growing medium" and "farmers make their decisions based on the marketplace and what they can make to survive while they are paying money to keep the levees up" (S13*). The flood risk is "nominal now" because the levees are stronger than they used to be, the locals patrol them regularly, and when necessary, they "band together" and flood fight[8]" (S6, S28).

Environmental regulations are "roadblocks" to hardening the levees, which would make them even stronger (S22). The regulators, especially the federal agencies, "won't even talk to you. They will basically say, 'No, you can't do it.' That's what it is. It's not helpful" (S3*). According to F1b, federal and state agencies are already abandoning the Delta. They will not continue to step in to help if there are levee failures in the future (S8).

Regarding changes to flood risk from climate change, one respondent said, it "could dry us up or could flood us. Who knows which way it's going to go?"(S29). This perspective believes that the potential extinction of endangered species in the Delta is not something that we can plan for because "for human beings to somehow think that we are going to keep what is evolving from happening, I think is ludicrous" (S33).

3.3. Factor 2: Locals are resilient

F2, the "locals are resilient" view, believes that the potential for devastating floods exists, but they do not impact the entire Delta at the same time, so individuals can help each other cope when hazards strike. Participants who loaded onto this factor are rural residents from the north, northwest, west, and central Delta. They pointed out that floods can be devastating to an individual farm, but the impacts are temporary and are not widely felt, and farmers are adept at making adjustments to survive (S28). This view strongly emphasizes that the Delta has "the richest agricultural soil in the world" (S18*, S26). Living with the flood risk is worth it as long as there is profit to be made, but, as one participant explained, "there is always that unknown factor where a levee could just suddenly go. It has happened in the past, so we do not want to be too smug about it" (S6). However, farming is a business. One respondent explained, "We are driven by profit, and frequently we do not make a profit, but profit is what keeps our operation sustainable and resilient over time" (S30).

As for climate change, an F2 respondent said, "Of course we don't know exactly what's going to happen, but we can plan and predict a little bit and do what's prudent and intelligent, reasonable now" (S19). This perspective believes that not all the levees need to be strengthened to the 500-year flood event, but historically most of the floods that have happened have been from failures of the weakest levees, so it makes sense to improve all of them (S19). For now, risk can be managed effectively through emergency response, inspections, maintenance, and improvements. Sea level rise could become a problem, but "it is hard to know exactly how rapidly this will happen" (S19). One participant said, "We will need some brilliant minds to work on this over the next 50 years or so" (S15*).

For F2, the state's goal should be the protection of people and

[8] When flood conditions exist, actions can be taken pre-breach including patrolling to identify problems early and preventing erosion by using plastic sheeting and sandbags, or an active flood fight might take place after a breach happens involving organized placement of sandbags and rocks to reduce overtopping, divert water from structures, and control boils (Burnett, 2014; Pappalardo, 2014).

property from flooding, but many of the state's decisions are putting that second to the interests of the water exporters (S21*). Even more strongly than F1b, the participants in F2 "feel like the state is looking for a reason to eliminate the Delta and just let it go back to a huge marshland so they can take all the water south" (S8*). The F2 view is that the amount of water is variable from year to year, so to "try to use it as a reliable water supply [when it is] nothing more than an intermittent water supply is unreasonable" (S22). This perspective believes that the state will not always help after a disaster unless there is a state interest like water supply or roads at stake, which is what happened in 2004 when Jones Tract flooded. One participant explained, "the initial response from [Governor] Schwarzenegger was 'let it flood.' Then, as it started approaching Highway 4, and other things that were more important to the state, they said, 'Oh, we've got to take care of this,' so they jumped right in there and took care of it," but we cannot rely on the state to help if something like that happens again (S8). F2 advocates for looking at the watershed as a whole. One participant said that you have to look at "the entire system with the bypasses, the entire thing. You can't look at it like sections." Management of reservoirs and development upstream of the Delta "is every bit as important as what happens here with the levees," but "you see this effort to hold more water and provide less flood control capacity, and I think we are losing some of the flood control management that we've had from these reservoirs" (S31).

Ecosystem restoration is needed, but landowners should be assured that there will not be impacts to their land and water by restoration projects (S5*). One respondent said, "It is not in the agricultural interest for endangered species to be in a death spiral because it means that regulations will get that much more stringent… If we do not move fast enough, things are going to get worse for the fish" (S33*). Another F2 participant stressed, "I think we are running out of time and these last ten years of arguing… is not doing any of us, any of the species, any good" (S33*).

3.4. Factor 3: Nature is resilient

The "nature is resilient" view emphasizes that "we've created this new system and there's no going back" (S33*). Participants who loaded onto F3 are mostly urban Delta residents or frequently work in the Delta, primarily on the southern, eastern, and western islands. This view believes that agriculture is becoming more difficult in the Delta because of the loss of peat soil over the decades, so there needs to be a transition to increase recreational opportunities and public access (S14). The perspective of F3 is that we should not be overly concerned about a crisis from any natural hazard. One respondent said, "To manage a resource with doom and gloom waiting for a catastrophe that may or may not ever happen is uncertain, so I don't know that that's viable" (S7). This view blames much of the need for flood control on the urban development on the Delta's edges and also the farmers who "put in vineyards, nut trees and [other high investment permanant crops] in flood risk areas that are likely to be impacted" (S21, S30).

F3 declares that the risk of flooding will be very high if the state does not continue to contribute funds because the locals "always say that they need help from the state and the federal agencies" (S28). Setback levees are the preferred approach for levee improvements for F3. They provide flood protection while also benefiting the public by improving biodiversity and aesthetics. As one participant said, "Creating more habitat creates more living space for animals, and I think that's a key thing for protecting these species for future generations" (S4*). This view insists that we should not rely on engineering – neither hardened levees nor isolated conveyance – to protect water quality or reduce the flood risk because engineered solutions could cause other problems to the Delta's existing ecosystems. One participant said, "It's turning into pipes versus plants" (S22*). F3 advocates against adaptive management reasoning that "we spend too much time trying to develop an adaptive management plan rather than building things and then taking the time, once it's been built, to go back and adjust the pegs" (S5). This perspective is a proponent for the inclusion of "first-hand knowledge and observations…, [because] state agencies and science don't always support organic, cost-effective solutions" (S17). Like F2, this perspective believes that "the levees are connected. They're all one piece" (S26). Another participant said, "It should be a shared financial responsibility" to protect the islands from permanent flooding because there are people who live there, recreate there, and there is potential for riparian habitat restoration (S26).

3.5. Factor 4: Human ingenuity will prevail

Of all the perspectives, the "human ingenuity will prevail" view most strongly believes that the concern about earthquakes is overblown. Like F1a, most of the participants who loaded onto this factor are non-residents, and several are engineers. This perspective holds that if a major earthquake happens, "the whole Bay Area will go and be destroyed, and so the Delta will be irrelevant frankly" (S7*). However, unlike F1a, F4 believes that levee failures should be of little concern, given the improvements that have been made in recent years. Furthermore, this view rationalizes that the potential for crisis is low if levee failures happen because the most deeply subsided islands have "restaurants and a handful of marinas, but… they are no longer intensely farmed (S14).

F4 strongly emphasizes the importance of the Delta for multiple sectors and the need for and the possibility of multi-stakeholder collaboration to maintain the Delta for the long-term. This view stresses that the infrastructure (roads, highways, railways, shipping channels, and gas and power lines) serves not just Delta residents, but all of California; therefore, levee maintenance and improvements should not be the sole responsibility of any particular entity. One respondent said, "We should cobble together the resources and do it in a way that hopefully has sustainability because this region is very important. All of us should make the investment to maintain and protect it" (S20*). This view stresses that the rest of the state should better recognize the Delta for its contributions to the state's economic prosperity. It provides "a couple of billion dollars of value-added as relates to agriculture, recreation, and all the affiliated industries" (S9). One F4 sorter noted, "People come here from all over the world for recreation" (S25). Similar to F3, this view asserts that locals should transition away from agriculture and more towards recreation and tourism; however, maintaining the legacy towns and cultural heritage is critical as well for F4 (S18*). Like F1b, F4 believes that the root of the problems in the Delta is the weather variability (S29). However, there is little flood risk, according to this perspective, because of maintenance and emergency preparation (S28). One participant mentioned, "We got through one of the worst winters last year with lots of flood fights but no significant losses" (S21).

For F4, the ecosystem is complicated, and interactions are uncertain in the environment. This perspective supports adaptive management. One respondent said, "The key is you gotta make some decisions to move forward… You have to make some decisions, and then, you know, steer the ship (S5*). In addition to adaptive management, environmental regulations are necessary. They are not significant obstacles for levee maintenance because "work is still getting done" (S3*).

F4 values local knowledge of the levees, emergency response preparation, and hardened levees. One participant pointed out that the flood risk has been reduced because the engineers now use advanced technology that allows them to "see" what is happening underneath the levees (S6, S21, S23). The best, most reliable solution is hardening and widening the levees. One respondent said, "If you make [the system] further robust for 500- or 1000-year floods instead of just struggling to maintain a 100-year level of flood protection, you can do multiple things all at one time. You can help restore the ecosystem and revitalize the Delta as a place without necessarily destroying its historical value" (S22*). F4 is optimistic that future floods can be overcome if there is collaboration between the state and locals on a long-term regional vision.

3.6. Consensus statement

Consensus statements in the Q method are statements that are ranked similarly by all factors, i.e., did not distinguish between any pair of factors, $p < 0.01$. Given the long history of a lack of success in multi-stakeholder, multi-agency attempts for consensus in the Delta, it was not surprising that this study did not find consensus in many statements. Nonetheless, there was agreement that Delta communities will need to adapt to future conditions (S10). However, there were different explanations behind each perspective's agreement with this statement. Each perspective defined "adaptation" differently. F1a defines adaptation as people changing livelihoods as conditions change. Accordingly, this factor believes that landowners should adjust to a livelihood that does not rely on farming in the Delta. F1b defines adaptation as starting new types of businesses or elevating and fortifying houses. For F2, adaptation means learning to live with less, focusing on "viability and resilience," traits that are "natural to farmers." F3 believes that incremental adaptation should continue along the path that they are already on, including promoting the Delta as a place for recreation and tourism. F4 reflects on adaption more globally, explaining that "a capitalist economy is an economy that is always in change," "the only constant is change," and "most people are a little bit resistant to change, but the kind of changes that have occurred in the past, like mechanization of agriculture, have pretty much run their course, so I don't think this is a really big issue."

4. Discussion

This study used the Q method to discover nuances within the discourse about the current and future flood risk in the Delta. Given that the region has been steeped in disagreements for many years, placing environmentalists against farmers and residents against water exporters, polarized views were expected. I anticipated that the study would find one view that there is a strong potential for catastrophic levee failure, and one view that the potential for catastrophic failure has been exaggerated. However, I believed that there were tacit explanations for people's views that could be better understood by looking at the cultural and social influences of their risk perceptions. What this study found were five distinct perspectives. Distinguishing statements for each factor (shown in parentheses) were used to create a label for each. "Crisis is certain" (F1a) perceives that the levees will inevitably fail in the coming decades, and farming is not sustainable in the Delta (S7 + 2*, S13 + 4*, S15 − 3*). "There is no crisis" (F1b) has faith that the status quo can be sustained through levee maintenance and gradual improvements (S3 + 4*, S13 − 3*). "Locals are resilient" (F2) believes that locals can continue to help each other, stresses that past floods have not been Delta-wide, and living with the historic, yet unpredictable, threat is a trade-off that farmers make because "every storm is different, every flood is different" (S8 − 3*, S18 + 4*). The "nature is resilient" (F3) view favors setback levees to allow for natural flood protection, and advocates for incrementally transitioning towards more recreation and eco-tourism (S4 + 3^+, S22 − 4^+, S33 + 4*). Finally, "human ingenuity will prevail" (F4) believes that engineering can reduce flood risk, and it is possible to have regional collaboration to widen the levees for long-term flood management if decision-makers would realize how vital the Delta is to the state's economy (S7 − 4*, S20 + 4*). Table 5 provides a summary of the characteristics of each factor based on the interviews with respondents as they conducted the Q sort. The following is a discussion of how the findings of this study relate to risk perception.

4.1. Uncertainty of scale

It has long been understood from research concerning technological risk that voluntariness, benefit, familiarity, control, level of knowledge, and catastrophic potential influence perceptions (Slovic, 1987; Starr, 1969). The perception of the scale of a disaster can range from manageable local emergencies to devastating regional catastrophes (Fischer, 1998). The uncertainties of climate change impacts increase the complexity of understanding risk perceptions from natural disasters. Understanding perceptions is essential because they determine the adaptation approaches that people are willing to take (Albizua and Zografos, 2014; Grothmann and Patt, 2005; Quinn et al., 2018). In the present study, all participants believed that there is a substantial flood risk. The perceptions of potential impacts range from catastrophic and uncontrollable statewide economic disruption to controllable local emergencies, and each perception leads to different visions of what future flood management should entail.

4.2. Place and proximity

There is a growing body of literature on sense of place. Quinn et al. (2018) explain, "Attachments are about strength of feeling for a place, and meanings reflect the symbolic significance of a place to a person… Increasingly a mixed methods approach combining meanings and attachments are mobilized to examine sense of place" (p. 2). In a study in Spain's Ebro Delta, Albizua and Zografos (2014) show that proximity and an individual's value for a natural resource are telling of one's sense of place. In the present study, F1a, which is primarily an outsider's view, values the water resources for exports more than the agricultural, cultural, and recreation resources. Similar to F1a, F4, which is also dominated by non-residents, values the resources that can benefit the state, but for this perspective, it is the in-Delta activities and utilities (boating, fishing, transportation routes, and electrical power generation) that are most important. On the other hand, the rural view, F2, values the Delta's soil and access to water for irrigation most highly. However, one rural resident loaded onto F1b (which values community cohesion most strongly) and one onto F4, showing that rural identity is not the only determining factor for the prioritization of values. F3, the view that values the Delta the most for its natural, park-like environment, was the perspective loaded onto by inhabitants from the urban fringe of the south Delta. These results illustrate that proximity does influence a person's sense of place, but we cannot predict a person's perspective by proximity alone. According to this study, as with Albizua and Zografos (2014), the combination of proximity and natural resource values indicate a preference for a particular view of a place.

4.3. Trust

It has long been acknowledged that trust in government to fulfill its responsibilities influences risk perceptions (Freudenburg, 1993). This study found five distinct views of the state's responsibility in flood management ranging from responsibility to taxpayers to weigh the costs and benefits of protecting the islands (F1a), to protecting property rights (F1b), agriculture (F2), ecosystem values (F3), and revenue generated from agriculture, recreation, energy, and transportation (F4). While none of the perspectives believe strongly that the state will help the Delta recover if a major catastrophe happens, there are differences between the views about whether or not it is even within the state's realm of responsibility to assist. Wachinger et al. (2013) found that confidence in protective measures is one of the most important factors of risk perceptions of natural disasters. Many studies have found that residents who live behind engineered flood protection have perceptions of low risk (Ludy and Kondolf, 2012; Wachinger et al., 2013). In the Delta, however, levees are mostly earthen, a number of islands are subsided, and there is a keen awareness of past levee failures. Many of the residents have an active role in levee maintenance through their participation in their community's reclamation board, so rather than being complacent about levee integrity, they advocate for continual maintenance and improvements.

Table 5
Risk perception characteristics of the five perspectives.

F1a: Crisis is certain	F1b: There is no crisis	F2: Locals are resilient	F3: Nature is resilient	F4: Human ingenuity will prevail
What is the scale of the risk?				
State's economy from damage to water supply	Local communities (if levees are not maintained)	Local economy; Endangered species	Public safety; Ecosystem services; High value crops	State's economy from damage to infrastructure; Endangered species
Who/what is to blame for the risk?				
Reclamation of marshland; Subsidence; Earthquakes; Climate change; Sea level rise; Residents' political power	Water exports; Environmental regulations; Water exporters' political power	Poor upstream management; Neglected levee maintenance by absentee landowners	Development in flood zones; Permanent crops; Burrowing rodents	Naturally variable climate; Poorly designed water conveyance system; Lack of transparency in decision-making
Who has agency/capability to reduce the risk?				
Some species cannot be saved; Locals cannot save themselves; State can raise or relocate infrastructure; Adaptive management is needed	Humankind cannot control the climate or extinctions; Routine maintenance and improvements wil work	Local communities can band together and use collective knowledge	Regional coalitions could work; Local knowledge is important; Locals are dependent on the state for funds; Some species cannot be saved	Local cohesion and knowledge combined with engineering and regional and state partnerships can work; Adaptive management is needed
Solutions/Vision for the future				
Nature will take over; Isolated conveyance is needed for water exports	Hardened levees are needed	Wait and see; Fish friendly habitat on levees <u>only if</u> public access is prohibited	Gradual transition away from agriculture towards more recreation; Setback levees	Wider, hardened levees with vegetation, where possible

4.4. Agency, vulnerability, and adaptive capacity

People who feel less control over a hazard tend to perceive a risk to be higher than those who think that they have control over it (Slovic, 1987; Watts and Stenner, 2005). In this study, those who believe that the residents have little control over the risk have the highest risk perceptions (F1a). Alternatively, studies have found that people who have experience with floods are more likely to believe that they have can adequately prepare for future floods (Adger et al., 2016; Wachinger et al., 2013). In the rural Delta, community ties are strong from multiple generations of land ownership. When a levee breaches, the community gathers together to provide the resources and skills needed to minimize the damage. This act of flood-fighting together provides a strong sense of capacity among the community, as seen in F1b and F2.

Perceptions of one's vulnerability are associated with willingness to make anticipatory adaptation decisions (Adger et al., 2016, 2013; Grothmann and Patt, 2005; Jooste et al., 2018). The perspective that believes the least in local adaptive capacity (F1a) is the one that is most willing to take a drastic approach to adaptation. The perspective that is the least willing to accept substantial steps towards adaptation is the view that believes that climate change is not certain, and locals are capable of adapting to any changes that happen (F1b). Belief in the strength of the communities to help each other and a connection to an agricultural livelihood contribute to F2′s view that adaptation means learning to live with less. F3 strongly feels that locals lack the funding that they need to maintain the levees, so the better option is to use nature for flood protection by creating setback levees. Skepticism that any future changes will be much more extreme than the climatic swings the region has historically endured leads F4 to believe that the best solution is investing in higher and wider levees. All of the participants with engineering degrees loaded onto F1a, F1b, or F4. Each of these factors believe that the solution to flood management should be engineered; however, the additional qualities of place, trust, and agency contributed to differences in the engineered pathway discussed by each of these factors: isolated conveyance for water supply (F1a), maintenance of the existing levees (F1b), and more strongly engineered levees (F4).

5. Conclusion

This study posits that we must look beyond polarized views to gain trust and advance productive decision-making. Using the Q method illuminates nuances in the values and beliefs that underlie stakeholders' perspectives. This approach illustrates that a cultural approach to risk perception is needed to bridge knowledge and uncertainty and to understand the acceptability of risk. Controversial decision-making often rallies opposing sides against each other. Particularly as we face unprecedented challenges from climate change, decision-makers need to move beyond issues of blame, responsibility, and uncertainties when developing climate adaptation programs. Understanding the social and cultural characteristics of individuals can explain what influences their risk perceptions (Bickerstaff, 2004; Bickerstaff and Walker, 2002). This study found that the combination of trust, what a person values most about a place, and their perceptions of the scale of risk and adaptive capacity is a strong determinant of their tolerance for risk. Illuminating such subtle areas of disagreement and agreement may provide a path towards more equitable and efficient decision-making.

One of the strengths of the Q method is the ability to find consensus among different perspectives about a complex topic that might otherwise go unnoticed. As Danielson et al. (2010) wrote, "It can be useful in contexts where conflict is high and focus groups run the risk of degenerating into shouting matches" (p. 95). Despite decades of conversations between stakeholders, there is much animosity in the Delta. Climate change adaptation is a conversation that has been less explored. This study found general agreement that residents will have to adapt to changes in the future. However, each of the factors provided alternative scales of adaptation, presenting a new understanding of the disagreements between perspectives. The findings of this study elucidate the meanings behind perspectives, and this can lead to more inclusive and productive collaborative decision-making efforts for the future of flood management in the Delta.

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Appendix A. Supplementary material

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CHAPTER THREE: MEDIA COVERAGE OF FLOOD EVENTS IN THE SACRAMENTO-SAN JOAQUIN DELTA, 1972-2019

1. Introduction

Floods pose a serious risk to life and property. The number of lives lost and financial losses from natural disasters have steadily escalated in the United States since 1980 (NOAA National Centers for Environmental Information (NCEI), 2020). While experts traditionally have relied on quantitative risk assessments using probability and estimation of loss, risk perception is largely subjective, and people often over- or underestimate risk (Kasperson and Kasperson, 1996; Slovic, 2000). Awareness of the potential for floods can increase risk perception. It can also lead to an increase in preparation, which can result in a sense of control, leading to a decrease in flood-risk perception (Raaijmakers et al., 2008).

News media influences perception (Doulton and Brown, 2009). The framing of a problem and the presentation of evidence can direct policy decisions and public acceptance of policy (Crow and Lawlor, 2016; Doulton and Brown, 2009; Robinson, 2001). The amount of media coverage and the framing of an issue influence how people respond to risk and perceive responsibility for risk management (Escobar and Demeritt, 2014; Kasperson et al., 1988). In the past, media coverage defined events for the public and limited public discourse (Holliman, 2004). It has long been understood that people react differently depending on whether an issue is framed with certainty or uncertainty, and if it is presented as a loss or a gain (Kahneman and Tversky, 1979). Framing conveys what the communicator believes is important. The inclusion or absence of particular words expresses a specific viewpoint (Entman, 1993).

News articles are interpretations by the journalist even when they appear to be fact-based narratives (Cotter, 2015). For example, the journalist constructs a story by embedding quotes from an interviewee with information about the event. When done seamlessly, this becomes a coherent story to the reader. Risk communication theory posits that the media can amplify or attenuate risk perceptions (Kasperson, Roger E. and Kasperson, 1996; Yang et al., 2018). This paper applies a framework of risk communication set forth by Kasperson et al. (1988), which includes analyzing textual content by information and source, the conclusions drawn, and value implications to a longitudinal study of the dissemination of information about flooding through the media in California's Sacramento-San Joaquin Delta (Delta). This study addresses the following questions:

(1) Who has a voice in the media?

(2) How is the issue of flooding framed by different actors?

(3) Are there differences in the framing in papers from different regions?

(4) Are there potential implications for policy from the various framings?

1.1. Issue framing of floods and climate change in the media

News coverage of flood events has been the subject of many studies. Reporting about flood events often takes on a human-interest angle by including interviews with victims and dramatizing through headlines and language. However, much reporting about distinct flood events is purely descriptive and bipartisan (Escobar and Demeritt, 2014). Escobar and Demerrit (2014) found a shift in reporting of floods in Britain over the past 25 years from descriptive articles that framed the event as an uncontrollable act of God to frame it as a foreseeable risk managed through preventative measures. Consequently, they found that blame, particularly for land use policies encouraging development, has increased. Bohensky and Leicht (2014) examined the media's framing of floods in Australia. They found that framing the event as the result of policy-making and climate change leads to the community absolving themselves from responsibility.

When people do not directly experience a phenomenon, they learn about it from other people and the media. Perception of risk is influenced by the potential harm to people, nature, and social structures. It can be amplified or attenuated depending on the media's coverage, including "volume, the degree to which information is disputed, the extent of dramatization, and the symbolic connotations of the information" (Kasperson et al., 1988, p. 184). For most people, their perception of an event is shaped by how the media has characterized it. Kasperson and Kasperson (1996) use the term "social station" to describe the media's role. When risk becomes a contentious part of a political campaign, it gets more attention and involves more value-laden interpretation and polarization of rhetoric follows. When debate is intense, non-direct impacts come to light, including distrust of others, mental images, economic losses, and anti-technology views. Interpretations of risk by the media become anchors for subsequent events and remain steadfast even in the face of conflicting information (Kasperson & Kasperson, 1996).

Amplification of risk in the media increases the public's perception of the need for response and protection, while attenuation of risk impedes taking protective action (Kasperson et al. 1988). Amplifying risks beyond those who are directly physically affected by emphasizing broader economic and social impacts. Attenuation can occur when the consequences are deemed as acceptable, or when the affected people are marginalized. Understanding framing and narrative explains the motivation for advocating a particular strategy for mobilization. Those on the winning side of policy and those with less proximity to the event tend to blame the victim (Crow and Lawlor, 2016). Non-proximate outlets typically frame a broad societal context while proximate ones frame the event as episodic and emphasize the local impacts (Wirz et al., 2018).

1.2 Study Area

The Delta sits at the confluence of the Sacramento and San Joaquin rivers, inland of the San Francisco Bay and south of the state capital of Sacramento.

Beginning in the 19th century, the marshland in the Delta was converted to over 60 agricultural islands that are surrounded by about 1100 km of waterways and protected by 1800 km of earthen levees (DSC, 2013; Whipple et al., 2012a). About 12,000 people live on the farms and in the small Delta communities, and over half a million people live in urban areas on the fringes of the Delta (Arcadis, 2017; DSC, 2013). Two-thirds of the levees are on private property, and landowners on each island control the reclamation districts that maintain the levees (Arcadis, 2017). Roughly 50% of the state's average annual streamflow passes through the Delta on its way to the state's two largest water export projects, the Central Valley Project and the State Water Project.

The Delta's levees are subject to twice-daily tides and constantly hold water back, like dikes built to prevent ocean water (Deverel et al., 2016). The Delta is about 2800 km^2, making it almost as large as the state of Rhode Island. The islands in the Delta are not homogenous, and there are differences in the topography, land elevation, and soil structure according to where the islands sit in the Delta. For instance, in the western Delta, islands are well below sea level, and if a levee fails, saltwater will rush in. It is often said that the Delta's levees work as a system, such that if one levee fails and the island is completely flooded, adjacent islands at are higher risk of levee failure from waves. However, the risk might not be as high if the neighboring island is already far away. The levees and the pressures that are placed on them are unlike any others in the world. Many outside experts and government reports stress that the levees are fragile and are doomed to catastrophic failure in the future. Local experts believe that the data and models that have been used to determine levee stability have been inappropriate for use in the Delta and have led to poor decisions. Despite numerous attempts for multi-stakeholder collaboration, animosity grew between locals and the state in the early 2000s (Kallis et al., 2009). In retrospect, local experts say that their input no longer played a role in the state's decisions regarding the long-term management of the levees during this period.

2. Data and Methods

2.1 Data Collection

The data set for this study consists of coverage of major levee failure events in twelve daily newspapers from 1972-2017. Initially, I searched for news articles using LexisNexus (Nexis Uni) using the search terms: Flood! AND levee! AND delta AND (Sacramento OR California OR San Joaquin). Many papers have not been digitized pre-2000, so I searched microfilm by dates of known flood events and the weeks after the floods in 1972, 1980, 1982, 1983, 1986, and 1997. In order to be included for analysis, the article needed to be written directly in response to a flood event in the Delta and contain at least one direct quote or paraphrase from an individual. Opinion pieces and editorials were excluded. The intent was to pick articles suitable for analysis of framing and narratives being told through the media. A final set of three hundred and forty-five articles from twelve different newspapers was included for analysis.

Fourteen flood events are included in this study. While these are not the only incidences of flooding in the Delta during this period, these events were chosen because they had the most amount of coverage by a large variety of newspapers. However, some of the publications included did not cover all of the floods. This study commences with a levee failure in 1972 because the resulting flood led to the creation of the California Department of Water Resources' (DWR's) Delta Levees Maintenance Subventions Program, a cost-share program between the state and local reclamation districts in the Delta for the purpose of levee maintenance and repairs. To date, the state has invested over $200 million to the program (DWR, 2020). Most floods occurred during winter storms. Several extreme storms impacted the Delta and the broader region in the early 1980s, 1986, 1997, 2006, and 2017[1].

The newspapers included in this study were chosen because they contained at least one article from almost every year in the study. While none of the papers are published within the Delta, several are from surrounding areas, while others are from other parts of the state with an interest in the Delta (Fig. 1). The *Sacramento Bee* is based in the state's capital, which borders the north Delta. The

[1] California experienced drought periods in 1975-77, 1986-1992, 2000-2002, 2006-2009, and 2011-2016.https://ca.water.usgs.gov/california-drought/california-drought-comparisons.html. 2017 was an extremely wet year and a reprieve from the record-setting five-year-long drought (Swain et al., 2018); however, some areas of the state still were in a drought as of 2020, according to the US Drought Monitor.

Stockton Record is published just outside of the eastern Delta. The *Oakland Tribune*/*East Bay Times*[2], *San Francisco Chronicle*, and *Santa Rosa Press Democrat* are based further outside of the Delta to the south and west. The *Modesto Bee* and *Merced Sun-Star* serve agricultural areas in the San Joaquin Valley upstream from the Delta. The *San Jose Mercury News*, *Fresno Bee,* and *Los Angeles Times* are all located in areas that receive some of their water supply from the Delta. The *New York Times*, *Los Angeles Times*, and *Washington Post* are among the top ten most widely circulated newspapers in the U.S.[3]

Hundreds of additional articles written about floods or levee failure risk in the Delta were not included because they were written in response to flood events elsewhere, such as coastal Louisiana, the Mississippi River, and northeastern Japan. Those articles that only briefly mentioned the Delta or were not written about a particular flood in the Delta were excluded. Additionally, a few levee failures and floods in the Delta during this period are not included in this study because they did not receive ample coverage.

[2] The *Oakland Tribune* merged with *the East Bay Times* in 2016.

[3] https://web.archive.org/web/20190722203322/https://www.cision.com/us/2019/01/top-ten-us-daily-newspapers/

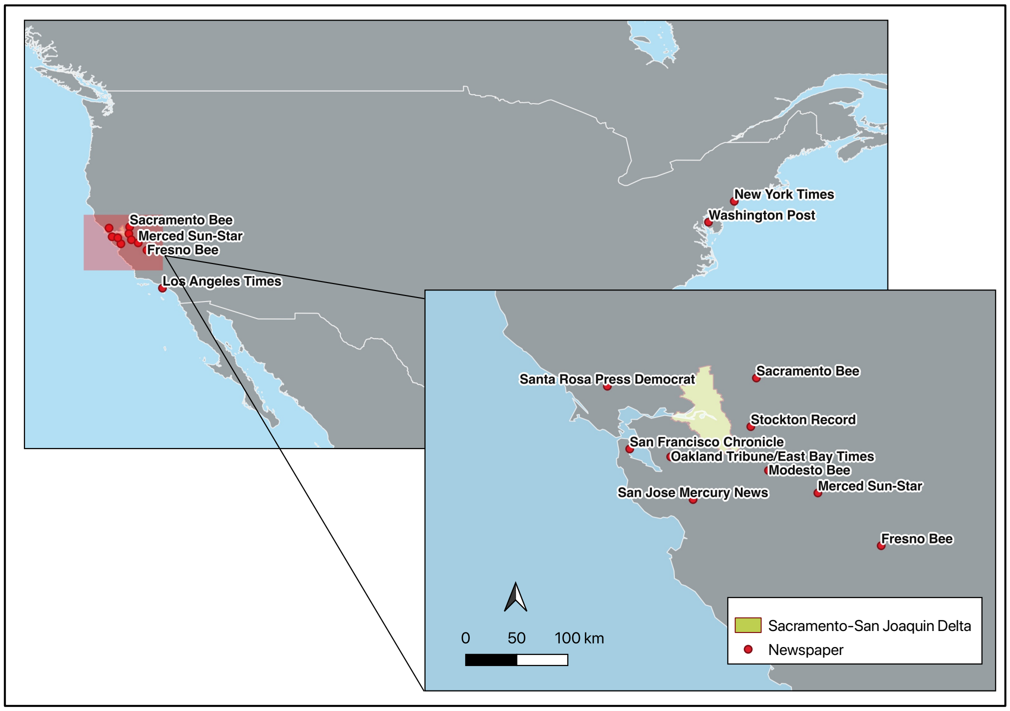


Figure 1. The locations of the 12 newspapers in this study. Inset map shows the nine newspapers in close proximity to the Delta. Source: DWR. Credit: P. Rittelmeyer.

2.2 Data Analysis

In a first step, I coded each article by the newspaper, date, people interviewed, description of the flood event, cause of the flood, place description, what is at risk, and response to the flood. Then, I analyzed the data according to the following criteria: the article's purpose, the characterization of the risk, and inferences from the article. I determined the purpose of the article by whether it was written to predict flooding or in response to a flood event. Characterization of the risk comes from the metaphors of symbols used in the article's text, and the type of impact discussed. Lastly, I analyzed the narratives according to their conclusions, such as what should be done and by whom.

3. Findings

Three hundred and forty-five newspaper articles from twelve newspapers written in direct response to a flood in the Delta between 1972 and 2017 were analyzed (Table 1). The years with the most coverage were 1980, 1986, and 1997. The *Sacramento Bee* had the most articles, followed by the *San Francisco Chronicle*, *Stockton Record*, and *Los Angeles Times*. The *Merced Sun-Star*, *New York Times*, and *Washington Post* each had the fewest articles.

Table 1. Distribution of articles by year and newspaper

Newspaper	1972	1980	1982	1983	1986	1997	2004	2006	2017	Ttl.
Sacramento Bee	6	4	4	5	11	15	10	2	9	**66**
Stockton Record	3	14	5	7	4	0	0	6	1	**40**
Santa Rosa Press Democrat	4	1	2	0	2	0	0	5	0	**14**
San Jose Mercury News	3	3	0	0	9	9	5	3	0	**32**
San Francisco Chronicle	5	10	3	4	6	8	7	3	0	**46**
Oakland Tribune	3	4	3	2	2	3	3	8	2	**30**
Modesto Bee	4	4	3	3	3	8	7	1	0	**33**
Merced Sun-Star	3	2	1	1	1	0	1	0	0	**9**
Fresno Bee	4	5	1	2	2	4	1	0	0	**19**
Los Angeles Times	7	8	1	0	5	4	5	3	4	**37**
New York Times	1	1	1	0	1	2	0	2	1	**9**
Washington Post	1	2	1	0	2	1	0	2	1	**10**
Total by year	*44*	*58*	*25*	*24*	*48*	*54*	*39*	*35*	*18*	***345***

The characteristics of each flood event included in this study are shown in Table 2. A few years had multiple flood events, and some flood events involved several levee breaches within a few days of each other. Of all of the floods in this study, the 1972 event directly impacted the largest number of households. Most of the other floods occurred in predominantly agricultural or sparsely populated areas. A few flood events led to the evacuation of urban communities that border the Delta. Large regional storms led to the floods in 1980, 1986, and 1997, and 2006 most damage occurred upstream of the Delta, so many of the articles only included a small mention of the Delta. From 2011 through 2016, the state was in a record, five-year-long drought. The drought paused in 2017, and there were several intense storms throughout the region putting all of the agricultural levees in the Central Valley at risk of flooding from high river flows. Media outlets based in the San Joaquin Valley focused much of their writing on the smaller agricultural levees upstream of the Delta. Likewise, Bay Area media focused on local flooding more than flooding in the Delta. While most of the floods were storm-related, a few of the flood events were unique to the Delta. These levee failures occurred in the absence of inclement weather and could be attributed to rodent burrows, accidents, or structural weaknesses.

Table 2. Characteristics of flood events in this study

June 21, 1972	Not weather-related. Small town flooded, 1,500 people evacuated, including residents and vacationers.
January 18, 1980	Intense winter storms. Levees collapsed on a couple of islands; tens of thousands of acres of farmland flooded; 20-25 residences, hundreds of farm workers, and dozens of duck hunters evacuated. One duck hunter drowned; thousands of cattle died.
September 26, 1980	Not weather-related. Lower Jones Tract flooded when 300 feet of levee gave way near a railroad embankment. Crop losses. 200 residents and farm workers evacuated.
August 23, 1982	Not weather-related. 100 farm workers and several natural gas facility workers evacuated, crop damage, small amount of damage at an underground natural gas storage facility.
November 30, 1982	Record high tide and winds. 3,000-acre island flooded; 11 people died from very high winds in other parts of the state
January 27, 1983	Intense winter storms and record high tides. Mostly uninhabited farmland flooded on six or more Delta islands over the course of several days putting over 4,000 acres underwater; more damage in urban areas outside of the Delta; fringe urban Delta threatened but not flooded.
December 3, 1983	High tide and strong winds. 2,000-acre rural island and small 50-person community flooded; 1,000 cattle and sheep evacuated; storm damage including deaths also occurred elsewhere in Northern California
February 19-20, 1986	Intense winter storm. Much storm damage north of the Delta where a levee broke along the Yuba River; several islands flooded, 9,300 acres total with a few dozen homes; small town of about 1000 people evacuated (tens of thousands evacuated outside of the Delta)
January 1997	Intense winter storms. Eleven islands flooded, but most damage outside of Delta
June 3, 2004	Not weather-related. Railroad track and highway threatened.
January 2006	Strong storms throughout the region. Levees damaged; 100 people evacuated.
April 2006	Strong storms. Most damage outside of Delta; boats prohibited due to wakes.
January 2017	Strong winter storm after 6 years of drought. Most damage to levees in Suisan Marsh adjacent to the Delta.
February 2017	Strong winter storms and failure of spillway at upstream dam; highest river flow since 1997. Many levees failed upstream. In Delta: sparsely populated islands flooded.

Some other events triggered media coverage of flood risk during this period. Levee failures devastated New Orleans during Hurricane Katrina in December of 2005. In the following months, there were numerous articles in newspapers and magazines predicting that a similarly catastrophic event will likely happen in the California Delta. In 2006, there was a marked increase in awareness of global warming. There was new research on the vulnerability of levees to sea level rise and seismic activity in 2009. Several government reports employed these new findings and models to examine flood risk in the Delta (*Delta Risk Management Strategy*; *Bay-Delta Conservation Plan*; *Delta Vision Task Force* report). Also, in 2009, several newspapers reported about a group of levee experts from the Netherlands who toured the Delta to explore common challenges and exchange knowledge. A Dutch visitor concluded, "This complex situation of conflicting interests, that's something that really needs to be tackled. In the Netherlands, we are used to doing things together. If we don't do it together, we drown together. So that's simple" (*Sacramento Bee* July 1, 2009). A cargo ship breached a levee in 2009; however, the event was not widely reported.

By 2011, there was a growing body of research on the benefits of wetland restoration on carbon sequestration, atmospheric rivers, and experimental simulations of seismic shaking on levees. Also, the Great Sendai earthquake caused devasting flooding in Japan and floods devasted areas along the Mississippi River in the Midwestern U.S. The possibility of Fukushima- or

Katrina-level of flooding in the Delta was a focus of numerous news articles. The *New York Times* wrote, "Scientists consider Sacramento -- which sits at the confluence of the Sacramento and American Rivers and near the delta -- the most flood-prone city in the nation" (July 3, 2011). Mostly, these articles were not written in response to a flood event in the Delta; therefore, they are not included for analysis in this study. Nonetheless, some of these events appear in the narratives in 2017.

3.1 The voices

Most of the articles in this study include state agency representatives, particularly from the flood division of the Water Resources Agency, residents, and state or county emergency operations staff. Other types of people interviewed in many of the articles include elected politicians (county supervisors, state legislators, U.S. representatives, and the state's governor), sheriffs, local farm owners and workers, and local non-agricultural business owners or workers (e.g., marina, restaurant, duck club). Additional voices vary over the years (see Appendix B). Figure 2 shows the different types of people (local, county, state, federal, other) interviewed by all papers each year. Many of the choices of interviewees align with the location, timing, and impact of the flood. For example, the floods in 1986, 1997, and 2006 mostly impacted areas outside of the Delta; therefore, it is not surprising that fewer Delta locals were interviewed during those years. The number of outside sources equaled those with state officials and surpassed those with locals and county officials in 2017.

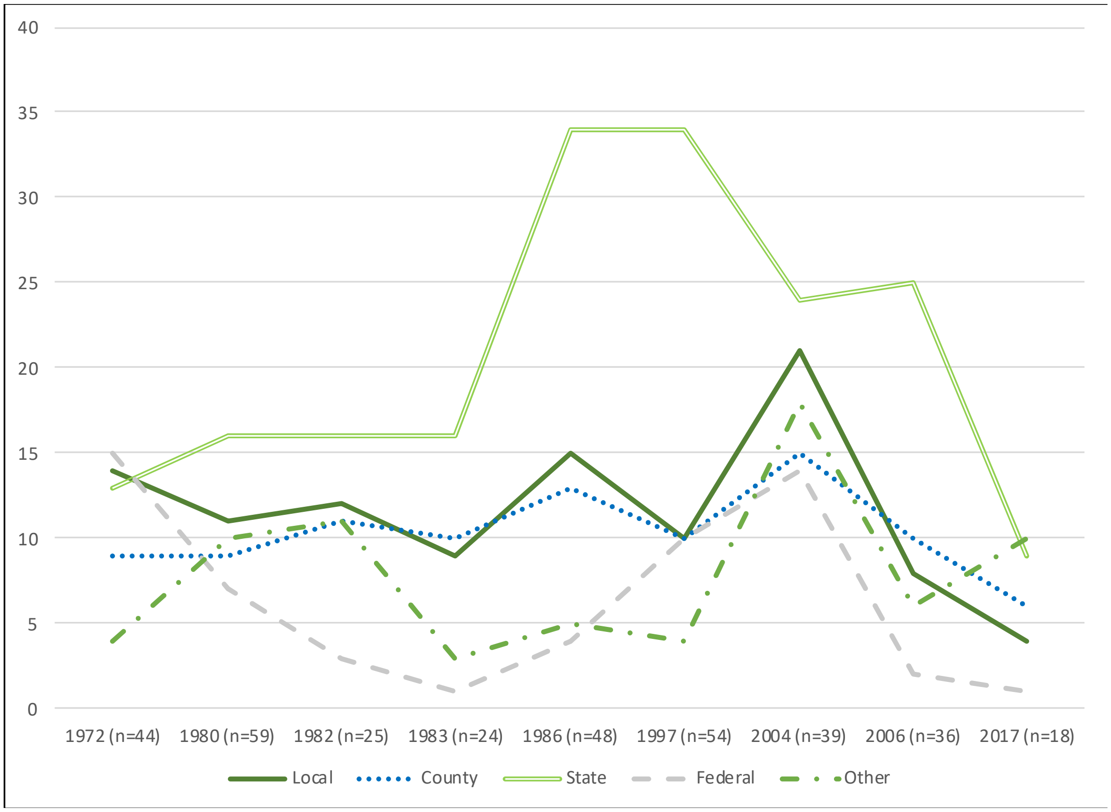


Figure 2. Number of types of interviewees quoted each year

All except two newspaper interviewed a higher percentage of state officials than any other category (Fig. 3). The *Modesto Bee* included an equal number of interviews with state and county officials. The *Merced Sun-Star* interviewed more county officials. The *Stockton Record* had the most balanced inclusion of state, county, and local sources. The *Fresno Bee* included the highest percentage of federal sources, almost equal to their state sources, and in contrast to the *Stockton Bee*, which included very few federal agency interviewees. The

New York Times did not include any county representatives, and the *Washington Post* did not interview any local voices.

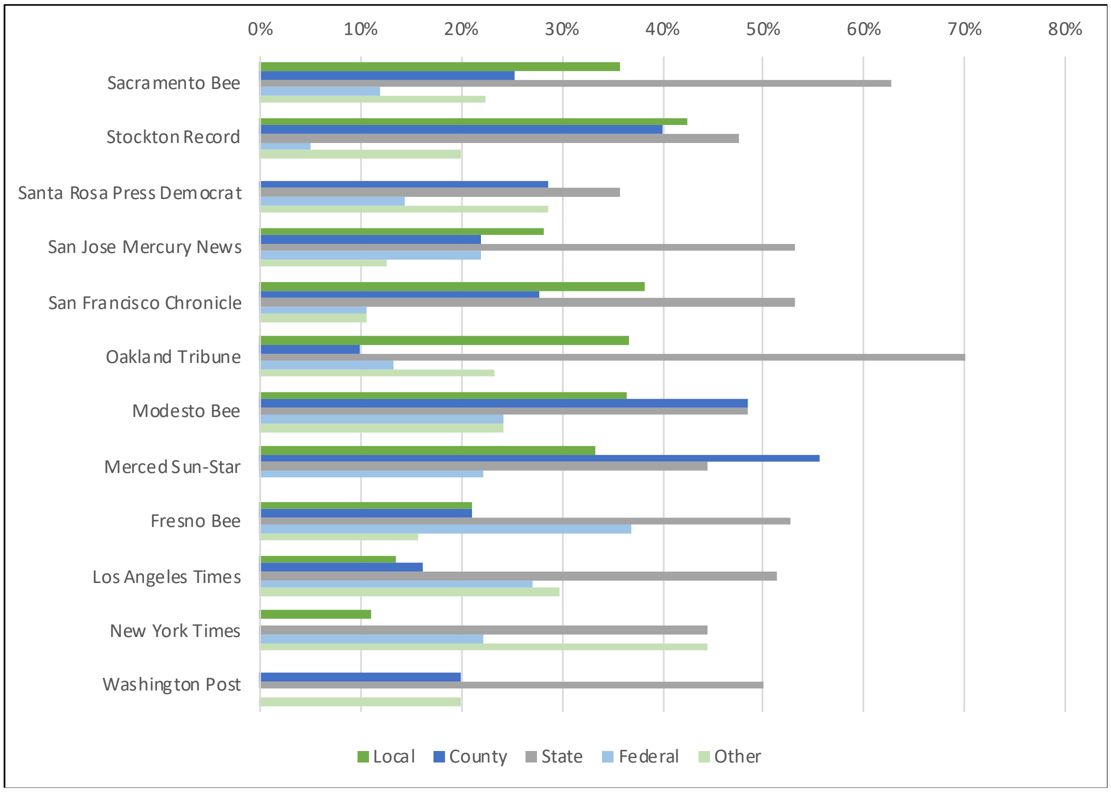


Figure 3. Total percent of interviewee type in each newspaper

3.2 The narratives

I used the framing in each of the articles to decipher the author's narrative about the flood event. To frame an event "is to select some aspects of a perceived reality … make them more salient in a communicating text … to promote a particular problem definition, causal interpretation, moral evaluation, and/or treatment recommendation for the item described" (Entman, 1993: 52). Framing for this study is based on the objects of concern as expressed by the impacts of the flood (the damages), where blame is placed (the cause), and the conclusions (short- or long-term solutions).

3.2.1 Concern

Longitudinal analysis

Concern for life and personal property was most prevalent in articles from 1972, 1980, and 1986 (Fig. 4). The 1972 event directly impacted about 1,500 residents in the small town of Isleton. The two flood events in 1980 led to the evacuation of over 100 people and thousands of livestock and game birds. The 1986 floods led to the evacuation of about 300 people in the Delta town of Walnut Grove and 1,300 people in the city of Thornton, which borders the Delta. The other floods primarily occurred on sparsely populated agricultural land, leading to less concern about lives and residences, although crop loss was a major concern. A few floods also directly impacted highways, railroads, and gas storage areas, which explains the emphasis of some of the articles on utilities and transportation. While no lives were lost in 2004, several papers expressed concern about the fate of 500 migrant farm workers who lost their homes and jobs. Concern for export water quality was the object of most concern in 2004, although some papers wrote about it in other years. The lack of discussion of damages in articles in 2006 and 2017 reflects the small amount of actual impacts in the Delta from those storms.

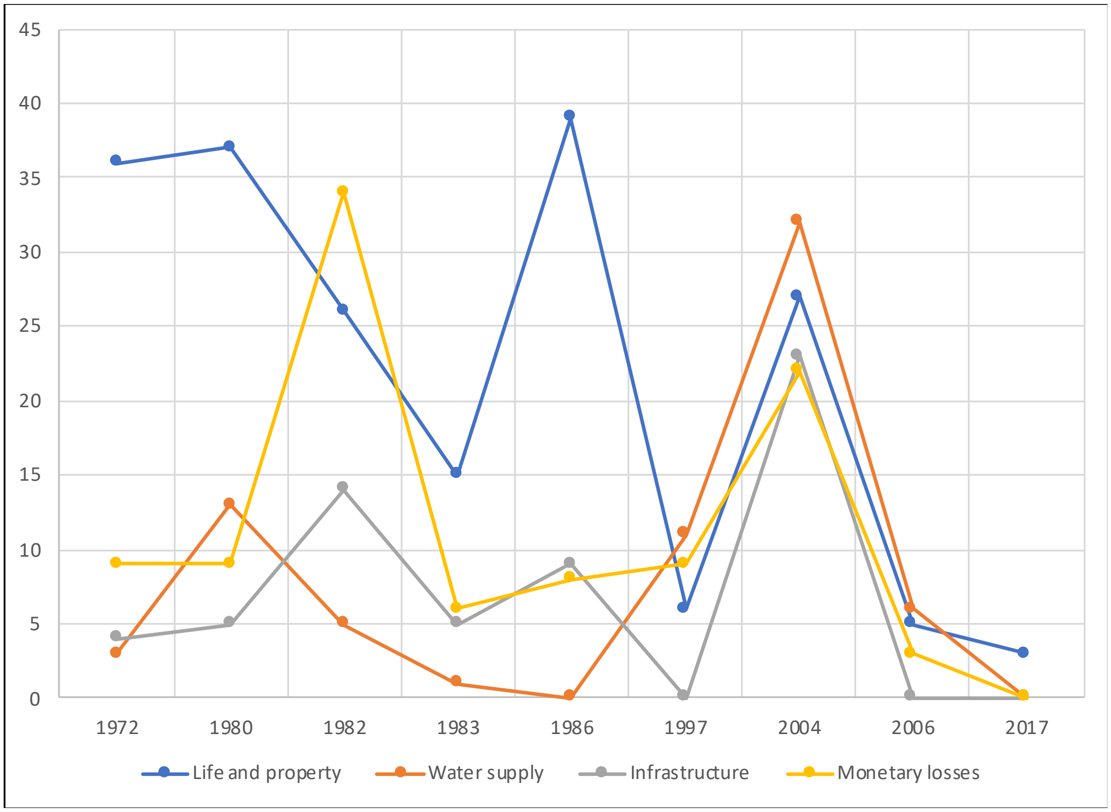


Figure 4. Number of articles reporting of damages by year

Differences between publications

Concern for life and property occurred as a topic of interest the most in all papers in this study except for the *Washington Post*, which was generally most concerned about water exports (Fig. 5). Water quality was also of particular concern in the *Los Angeles Times* and *San Jose Mercury*, two places that depend on water exports from the Delta. The *San Francisco Chronicle* reported the most of all the papers about monetary losses. Monetary losses ranged from crop loss and building damages to levee repair costs. Repair costs were a significant concern for the *Sacramento Bee*. Crop loss was an important concern for two papers based in the Central Valley agricultural areas of Fresno and Modesto. The cost of dewatering flooded islands was a notable concern for the more local *Stockton Record*.

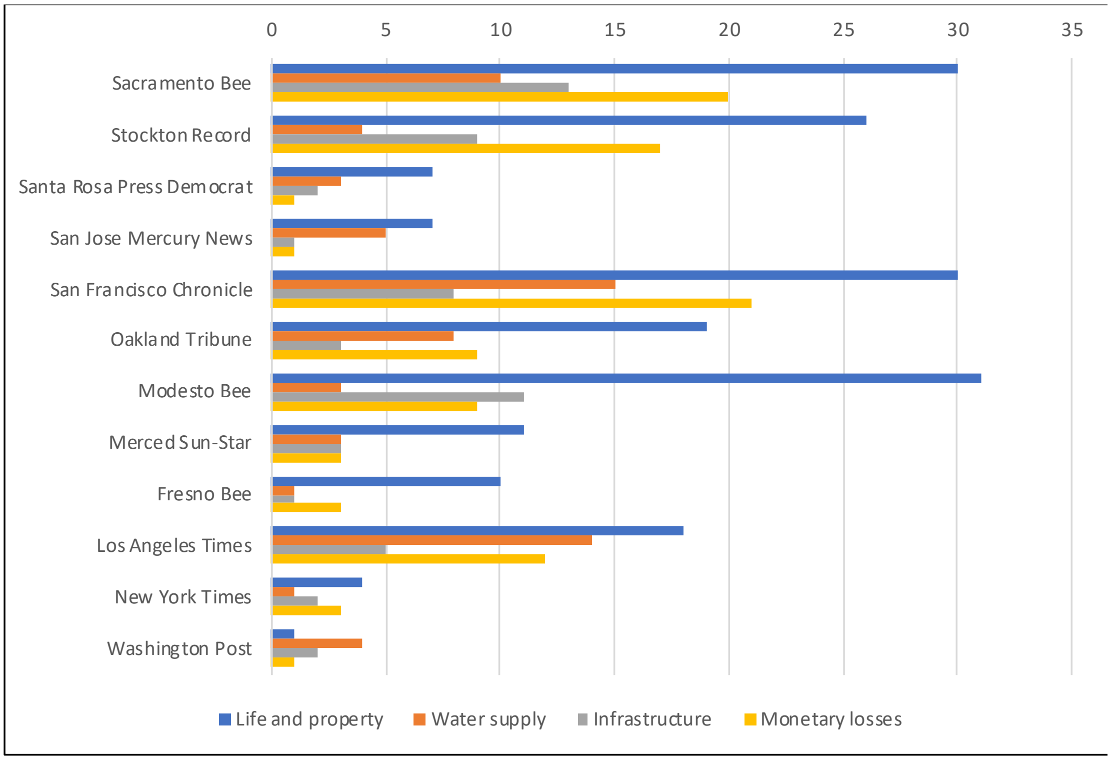


Figure 5. Number of articles in each newspaper reporting on damages from floods

3.2.2. Blame

Longitudinal analysis

The causes of levee failures in these news articles included storm-induced high river flows and waves, rodent burrows, levee maintenance equipment mishaps, inadequate upstream dams and reservoirs, and structurally weak levees (Fig. 6). The cause of levee failure was not determined in some cases, although it was often assumed. For instance, a rodent burrow, which several articles explained as the cause of the 1972 flood, is not likely to be seen, and once the levee collapses, all evidence of the burrow might wash away. Other possible causes of the 1972 levee collapse were structurally poor levee or strong winds. The January 1980 floods were mostly blamed on the levees being too small to handle the storms, while the September flood was primarily explained to have had an undetermined cause. A weak levee was the most commonly mentioned cause of the August 1982 flood. Strong storms were mostly to blame for the November 1982 flood and both of the floods in 1983. 1986 saw the beginning of the blame being shifted to inadequate water storage in the upstream reservoirs during winter storms. Upstream flood mismanagement as also blamed for the floods in 1997 and 2017. The 2004 and 2006 floods were blamed mostly on weak levees.

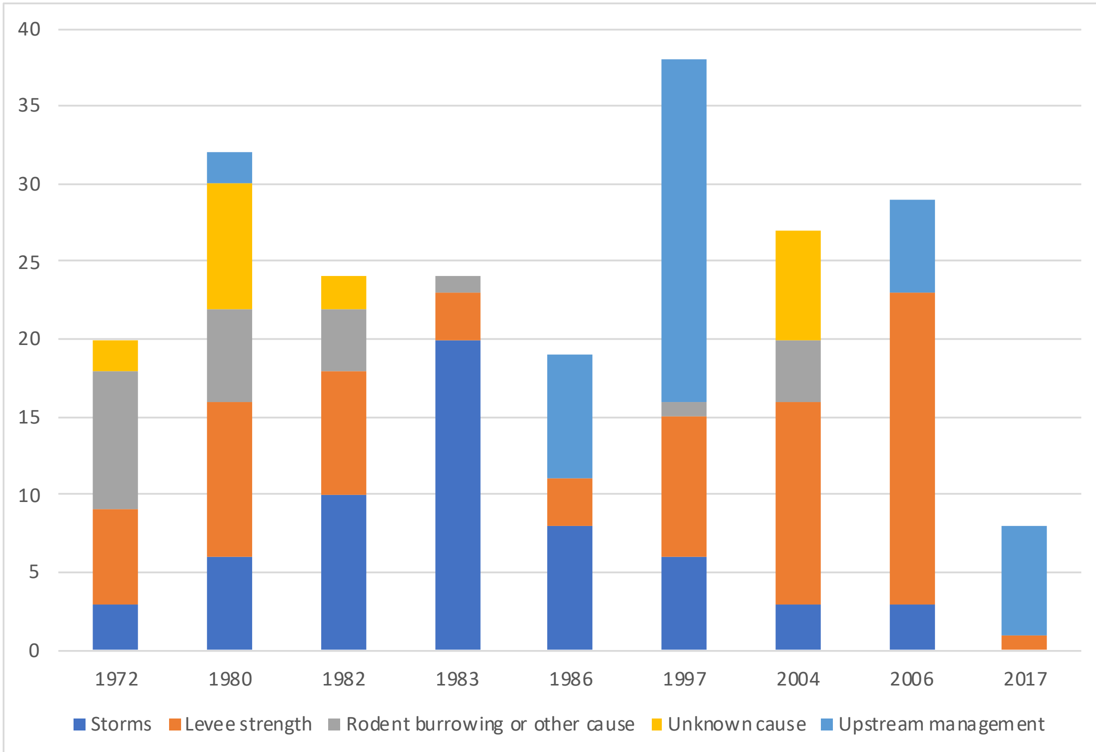


Figure 6. Number of times possible cause of flood mentioned in articles by year

Differences between publications

Most California publications blamed the 1972 levee failure on either a rodent burrow or an overturned maintenance vehicle. Many papers cited both causes as a possibility. It is important to note that all of the mentions of a rodent burrow were quoting one individual from the U.S. Army Corps of Engineers. In contrast, most of the remarks of recent construction as the cause quoted a local engineer. The national papers did not comment on why the flood happened.

The majority of the blame for the floods in January 1980 were the levees themselves. The *San Francisco Chronicle* (January 22, 1980) stated, "The trouble in the delta goes back to the turn of the century when the marshland between the Sacramento and San Joaquin Rivers was diked off and reclaimed for farms." On the other hand, the *Stockton Record* (January 20, 1980) quoted a local engineer who said, "The levee broke in a spot that had been considered strong… One of the real contributing factors was that everything was wet and the water level was high for a very long time." The same *Stockton Record* article interviewed another local who stated that "reports have been received that during the drought, someone, possibly from a state or federal agency, dumped 11 bargeloads of rock into the Sacramento River to force water to flow into Georgina Slough." For both of the floods in 1980, each of the California papers included a variety of possible causes, whereas the national newspapers only placed blame on the levees.

There were two flood events in 1982. The cause of the August flood was most commonly attributed to a weak levee. Several articles also mentioned that the flood might have happened because of a beaver burrow or recent levee maintenance. The *Fresno Bee* and *Modesto Bee* placed all of the blame on the latter and did not discuss levee weakness. A series of floods occurred from the end of November through early December. All of the California papers that reported on these floods spoke of the record-tying high tides and winds as the reason the levees failed. Throughout both 1982 events, the *New York Times* and *Washington Post* alluded only to the levee fragility.

Severe winter storms struck the region in 1983, 1986, and 1997. In 1986, many articles pointed to the upstream reservoirs being at or beyond capacity and inadequate to manage the large volume of water safely. One piece in the *Stockton Record* (February 20, 1986) remarked that the weather was different from in the past. This article noted that the high flows were caused by warm winter rains, which historically would be snow at this time of the year and would have been slowly released into the river throughout the spring and summer. In 1997, there were many more discussions about the inadequacy of the flood management system, from the upstream dams and reservoirs to the levees themselves. The *Modesto Bee* (January 8, 1997) explained that "a combination of high tides in the Sacramento-San Joaquin Delta and more mountain runoff coming into the Delta from dam releases could be too much of a strain for the levee." The *Oakland Tribune* (January 8, 1997) wrote, "California's elaborate system of reservoirs, levees and channels is not enough to help perpetuate this artificial environment."

The 2004 flood was an unexpected sunny day flood. Many blamed it on a rodent burrow or said that the cause was unknown, but even more than that, many articles blamed poor maintenance or poor materials in the levee. Lack of adequate maintenance was again a topic discussed during the storms of 2006 although there was little actual damage in the Delta. Articles during these floods addressed the need to improve the levees as well as upstream flood management. After a narrowly avoided catastrophe of the Oroville Dam spillway collapse, the 2017 floods were blamed on the combination of upstream management and the levee system. The *East Bay Times* (January 12, 2017) wrote, “the influx of water flowing down from Sacramento, with the rare opening of the Sacramento weir, combined with king tides has put pressure on the levees, causing many to rupture or have water pour over the top.”

Some papers included multiple reasons for a flood within the same article. Fig. 7 shows the percentages of coverage of the various causes of floods as reported in the articles in this study. The *Stockton Record*, *San Francisco Chronicle, Modesto Bee, Merced Sun-Star, and Fresno Bee* all placed the most blame on weather. The levees and upstream flood management were blamed the most in the *Sacramento Bee*. The *Los Angeles Times* and *New York Times* overwhelmingly blamed levee fragility. The *Oakland Tribune* attributed the floods to flood management, and *San Jose Mercury* blamed upstream management and weak levees equally, while seldom mentioning weather or any other cause.

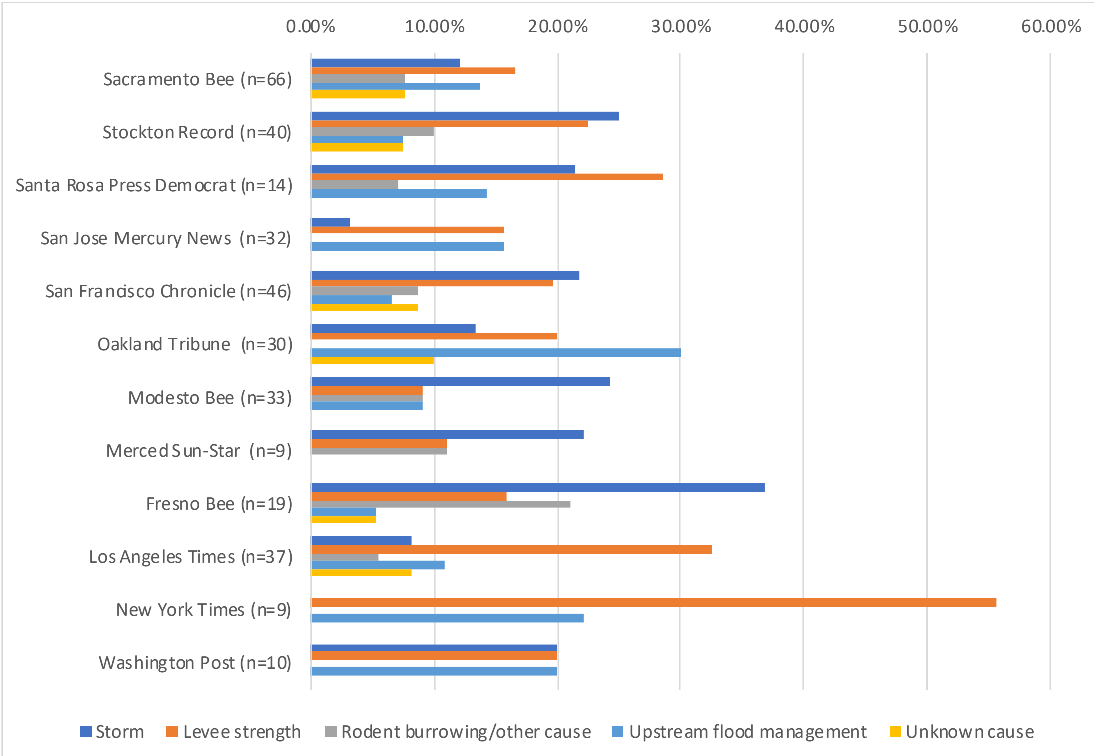


Figure 7. Percentage of causes of flood in each newspaper

3.2.3 Solutions in the narratives

This section looks at the conclusions either made directly or inferred in the articles. Some articles emphasized managing and recovering from the flood. In contrast, others focused on long-term solutions such as building more flood capacity in reservoirs, setback levees, increasing federal funding, insurance, and letting the island remain flooded.

<u>Recovery and resiliency</u>

Many articles focused on managing the risk and recovering from damages caused by the flood. Most of the articles written in 1972 remarked that it would take many months, if not a year, to recover, but there was no question that there would be a return to normal (*Los Angeles Times; Modesto Bee; Stockton Record; Sacramento Bee; San Jose Mercury News; San Francisco Chronicle*). Most articles reporting about the October 1980 floods discussed successful floodfighting (*Los Angeles Times; Stockton Record; Washington Post; Modesto Bee; Sacramento Bee; Fresno Bee*). The majority of articles written about the floods in 1982 and 1983 had a positive tone of recovering from the levee failures. There were a few exceptions during these early years. In 1972, a few days into the recovery effort, the *Fresno Bee* noted that floodfighters had decided to "abandon to the fate of the tides" when they noticed some new weak spots on the levee (*Fresno Bee* June 23, 1972). In 1980, the *New York Times* focused on the fragility of the levees and the potential for widespread levee failures and flooding (October 4, 1980) without mentioned the floodfighting efforts. In 1982, one article reported "uncertainty over the future" of one particular island (*Stockton Record* December 2, 1982). However, there was still a positive tone of "hoping to prevent more flooding of the low-lying, below sea level farm tracts" (*San Francisco Chronicle* December 3, 1982).

There were only a few mentions of a need to improve the levees for the long-term during these early years. The potential for long-term improvements to strengthen the levees was mentioned several times in *Sacramento Bee* (August 25, 1982) and *Stockton Record* (February 19, 1986). The *Stockton Record* (February 20, 1986) indicated that it would take "several hundred million dollars" to "completely bolster Delta islands," at a time when state funding for levee repairs has become a political bargaining chip.

For the most part, by 1986, the discourses centered on the idea that flooding was not as devastating as it had been in the past, particularly in the more local media. The *Sacramento Bee* reported, "The levee system can withstand more than they thought it could" (February 23, 1986). There were different explanations for the region's flood resilience. The *Stockton Record* reasoned, "The state has provided $1.8 million a year in recent years to match money spent by reclamation districts for levee rehabilitation" (February 20, 1986). In contrast, the *San Francisco Chronicle* stated that the complex network of engineered upstream reservoirs and a flood bypass system prevented a catastrophe (February 19, 1986). A few days later, however, the *San Francisco Chronicle* had a less optimistic tone: "The levee survived the flood and a high tide of more than 12 feet yesterday, but another big tide is due today. There is concern that if the levee breaks the water will roll over the island and crack the next levees, like a row of falling dominos" (February 22, 1986). Here the levees are framed as weak despite the increase in state funding.

Most coverage of the 1997 floods emphasized the benefits of emergency planning and stronger levees. Residents had become more prepared from experiencing floods in the past. Even though two small agricultural islands were flooded, there was a tone of resilience. The *San Jose Mercury* remarked, "Normally it takes a few hours for things to get worse, from the time a levee problem is spotted until the collapse occurs," and floodfighters were standing by to get to work (January 4, 1997). The *Sacramento Bee* reported, "Sometimes a levee break can provide a little bit of relief" (January 6, 1997). The *Modesto Bee* was "hopeful" that damage would be minimal to homes in the Delta (January 13, 1997). The *San Francisco Chronicle* expressed, "The potential for danger on the delta does not dampen the ardor for… island residents, who see beauty in the expanse of patchwork farmlands embraced by peaceful sloughs" (January 6, 1997). It was noted that "the levees have performed very well [because of] recent improvement projects, including $60 million in strengthening after the 1986 floods" (*San Francisco Chronicle* January 8, 1997). On the other hand, the *New York Times* warned, "The threat to levees on the delta and the Central Valley rivers will remain critical for several more days as the swell of water pouring from the Sierra pushes downstream" (January 7, 1997), and the *Washington Post* talked of the "worrisome" conditions (January 6, 1997). However, the national papers did not distinguish between the Delta levees and the smaller, less well-funded agricultural levees upstream.

<u>Abandoning flooded islands</u>

Discourse about letting an island remain flooded appeared in articles after a few specific floods. In response to the floods in January 1980, many newspapers stated that the cost of pumping the water out of the island would be prohibitive and the two flooded islands, Holland and Webb, would likely be abandoned (*Merced Sun-Star*; *Modesto Bee*; *Oakland Tribune*; *Santa Rosa Press*

Democrat; *Fresno Bee*). However, the *Sacramento Bee* pointed out that "not reclaiming the land also may have serious consequences [because] the increased water surface allows winds to be stronger" (January 19, 1980). The *San Francisco Chronicle* reported, "The effort might take months, but the tract could be pumped out" (January 20, 1980). The *Stockton Record* (January 20, 1980) stated that the islands could be reclaimed only if there is state or federal assistance. The islands were ultimately reclaimed after a cost-benefit analysis showed that the islands' benefit to agriculture and water quality in the southern Delta outweighed the cost of pumping water out (McCullough, 1982).

The winter floods in 1983 flooded several islands near those that were flooded in January 1980. Several articles drew attention to the likelihood that a cost-benefit analysis would not weigh in favor of reclaiming some of the islands this time (*Stockton Record* January 28, 1983; *San Francisco Chronicle* January 29, 1983). Mildred Island was indeed left flooded and became a popular anchoring spot for recreational boaters. The *Los Angeles Times* (June 19, 2004) stated, "the state Department of Water Resources has floated another possible solution, less popular among farmers: returning the delta to marshland where only bushes and grass grow. Converting the delta, however, would make the land worthless for farmers. The state would have to buy the property, then pay to convert the land." The idea of eliminating the current land uses in the Delta, and therefore the need for the levees, was beginning to be discussed in several venues (see

Lund et al., 2007). However, it rarely was called for in response to a flood event in a newspaper article in the first three decades of this study.

After the 1997 floods, there were several mentions of the need to redesign the levee system. A proposal for long-term solutions, including setback levees to widen channels, surfaced in the *Modesto Bee* (January 16, 1997). The following month, the state government called for a study of the feasibility of flood bypass systems and levee setbacks (*Fresno Bee, Los Angeles Times, San Francisco Chronicle*). However, by May 1997, the idea seemed to be losing favor: "``In the beginning, there was grand excitement. Then political reality set in" (*San Francisco Chronicle* June 1997). The benefits of increasing bypass systems resurfaced in 2017 with a growing understanding of the heavy precipitation generated by atmospheric rivers in California (*Los Angeles Times* January 27, 2017). However, very few other media outlets wrote about it. The *Sacramento Bee* (February 22, 2017) briefly mentioned, "Even commitment to restoring the state's existing flood protections – a vast network of dams, weirs, bypasses, pumping plants, channels and levees jointly managed by the federal government, California and local districts – may wither when the bill comes due."

On the other hand, the *New York Times* wrote extensively on the topic of widened channels in several articles. The *New York Times* (February 4, 1997) wrote, "There is a wide consensus that rivers need more room 'to do their own thing.'" After more flooding a few weeks later, the *New York Times* (February 28, 1997) reported, "Scientists and environmental groups say deliberately creating similar areas — floodplains to allow the state's rivers to overflow more naturally and benignly — is a way to help ease the strain on this water infrastructure, especially as climate change poses new challenges." However, the *New York Times* article did not distinguish between the Delta's levees and the rest of "the state's 13,000 miles of levees".

Growing concern about economic viability

In 2004, the need for federal funding to assist with levee repairs and upgrades became a focal point in many of the articles. The projected cost of $90 million to recover from a levee failure that protects California Highway 4, a major route through the Delta, and a railroad led to questions about the economic viability of the status quo. Several articles emphasized that if there is not federal assistance, the burden will be felt by the entire state. The Sacramento Bee (July 1, 2004) wrote, "If the White House declines a request for disaster relief, state taxpayers may ultimately pay the cost for repairs and damages," which contradicted their earlier article (June 9, 2004) stating that "the state will seek "a reasonable sharing of costs from all beneficiaries" of the state response, including railroads and utilities that have infrastructure on the flooded island west of Stockton." Federal funding was the focus of several *Sacramento Bee* articles, including one from June 5, 2004 stating that the federal government was assisting only because a "key piece of infrastructure [was] being threatened." Both the *Sacramento Bee* and *Los Angeles Times* reported on July 2, 2004 that President Bush made a federal declaration of a state of emergency, which would make the county eligible to apply for federal funds for recovery and improvements. The *Modesto Bee*, on the other hand, argued, “The cost of maintaining levees is getting prohibitive [for the private landowners]” (June 11, 2004), and “legislators are skeptical of paying more because the 85-year-old levee is privately owned and maintained. Fifteen people own the 6,000 acres that form the Upper Jones Tract” (July 1, 2004). The public cost of levee repairs on private land became a growing concern.

Flood insurance was increasingly mentioned. After the 1997 floods, the *San Francisco Chronicle* and the *San Jose Mercury* noted that very few homeowners and businesses who lost everything from the flood had insurance. After the flood in 2004, three papers discussed crop insurance, but each had a different conclusion. The *Sacramento Bee* (June 12, 2004) mentioned, “The water submerged about 15 farm operations - many without crop insurance.” The Modesto Bee (June 4, 2004) said, “The farm was too close to the river to qualify for flood insurance.” The *Los Angeles Times* (July 2, 2004) noted, “Farmers have also had trouble collecting from their catastrophic-insurance policies with the U.S. Department of Agriculture. Their claims will not qualify if the department rules that the flood is not a "natural" disaster.”

<u>Uncontrollable catastrophic risk</u>

The “sunny day” levee failure in 2004 was a stark contrast to the storm-induced events in the preceding two decades. The *Modesto Bee* (June 4, 2004) described the “whitewater rapids” created by the small break and the “commotion” caused by the rapid flooding and wrote extensively about the dozens of farmers who lost everything (June 4, 2004; June 11, 2004). Similarly, the *Sacramento Bee* wrote about the unexpected failure and loss of crops (June 4, 2004; June 5, 2004). The *Sacramento Bee*, *Modesto Bee*, *Oakland Tribune*, and *San Francisco Chronicle* described that residents and state officials were surprised by the levee failure. The *Oakland Tribune* (June 4, 2004; June 5, 2005) and *San Francisco Chronicle* (June 5, 2004) mentioned that the levee had been well-maintained and was not a known weak spot. In contrast, the *Los Angeles Times* (July 2, 2004) stated, “Early reports also mentioned poor maintenance and engineering,” while the *Sacramento Bee* (June 4, 2004) included quotes from both sides of the story. The *Los Angeles Times* (June 19, 2004) described that letting the islands flood and return to “a more stable system of wetlands that would protect the drinking-water source,” and emphasized that all of the levees on private land are not regulated by the state; therefore, they concluded, “other levee in the area could also be on the verge of collapse.”

Hurricane Katrina devastated New Orleans in August 2005. In the following months, it was concluded that the cause of the flooding was from not just the storm itself, but rather from levee failures. After storms in January and April 2006 that led to hundreds of evacuations but very little actual damage in the Delta, numerous articles predicted that a catastrophic event like Hurricane Katrina would happen in California. The Sacramento Bee (April 23, 2006) stated, "Sacramento, a low-lying community bounded by two major rivers, is considered one of the nation's most vulnerable major cities for a New Orleans-style disaster if its levees fail." The *Santa Rosa Press Democrat* (January 5, 2006) expressed, “For years, engineers have been pleading with state officials to focus attention -- and money -- on improving the physical, political and financial conditions of the state's levees. It took the flooding in New Orleans and the partial failure of five levees in the New Year's storm in Northern California for people to start listening.” While the greatest fear was the threat of levee failures in the metropolitan Sacramento area, the concern extended to the Delta's levees. The *Stockton Record* (January 11, 2006) said, “Supervisor Victor Mow said the vulnerability of the century-old earthen walls was made top priority in the wake of recent disasters such as Hurricane Katrina in New Orleans and the 2004 Jones Tract flood." The topic gained national attention. The *Washington Post* (February 19, 2006) said, “U.S. officials have not absorbed the lessons of Hurricane Katrina, in which floodwaters breached levees and inundated most of New Orleans, relying on outdated models to forecast risks to low-lying areas and allowing development in places that have been under 10 feet of water as recently as 1993, the experts said… But perhaps a worse flood risk exists in California's Sacramento-San Joaquin Delta.”

Fears of an event like Hurricane Katrina amplified the call for federal funding. The *Los Angeles Times* (April 21, 2006) stated, “Schwarzenegger has been saying for months that without federal aid to repair the levees, California could face a Hurricane Katrina-like flooding disaster that could cost the government a lot more than what it would need to make the fixes now." The *New York Times* (April 22, 2006) reported, "Mr. Bush brought a gift for Mr. Schwarzenegger: a directive to the Army Corps of Engineers that lets it accept $23 million from the state to repair 29 weak levees to prevent flooding in the Sacramento-San Joaquin River delta. Mr. Bush did not issue a federal disaster declaration, as Mr. Schwarzenegger had wanted, but the governor said the directive showed that the federal government was beginning to pay attention." However, the national paper labeled all of the levees in the Central Valley as Delta levees. In contrast, the more local *Stockton Record* (April 21, 2006) made the distinction between the levees in the Delta and the others. It stated, "Gov. Arnold Schwarzenegger is hoping a personal meeting with President Bush today will help win federal approval to quickly repair 29 critical erosion sites on the Central Valley's levees… Three of the newly identified sites are in the Delta between Walnut Grove and Isleton, bringing the total number of critical erosion sites in the Delta region to eight" (Stockton Record April 21, 2006). Recognizing the recent improvements to the Delta levees, the *San Jose Mercury* (January 4, 2006) noted that "the flood control performed well overall."

In 2017, uncontrollable circumstances became the focal point of media narratives. Many articles mentioned predictions of atmospheric rivers. The *Stockton Record* (January 12, 2017) stated, "Even though the mood seemed to be one of optimism that the levees would hold, … forecasters now expect another atmospheric river to take aim at California around the middle of next week".

However, there was not as much damage as expected. After another winter storm, the *Sacramento Bee* (February 14, 2017) commented that the levees further upstream on the San Joaquin river were more worrisome. Meanwhile, the *Los Angeles Times* (February 16, 2017) reported more generally, "Perceived as failsafes, levees were meant to reduce the frequency of floods, not stop them altogether, experts say" and warned that the failure of an emergency spillway at the Oroville Dam upstream of the Delta caused a "catastrophic torrent that… could have rushed more than 100 miles down the Feather and Sacramento rivers, breaching levees all the wat to the Sacramento-San Joaquin River Delta" (February 19, 2017). The Oroville Dam incident raised awareness about the risks posed by flood management systems, including the upstream dams and reservoirs. The *Sacramento Bee* (February 22, 2017) concluded, "Broader solutions for California's aging flood-control facilities will likely not emerge for months, until at least the current emergency passes. But long-standing disagreements over how best to resolve the compounding water problems facing the state are already resurfacing, pointing to the challenges ahead for a deal when tax revenue is tight and budget commitments vast."

4. Discussion and Conclusion

This media analysis shows the changes in framing of floods in the Delta over time and differences in publications. The narratives shift over time from management and recovery to system change. Specifically, this study shows a shift in framing the floods as a problem for agricultural to a flood management system problem, and from an issue that is manageable to one that is unmanageable. There is a progressive increase in the portrayal of the amount of time and money needed for recovery. Consequently, there is a progression of concluding that the best solution is to move away from reliance on the levees for flood control. The framing became increasingly politicized and divisive over time. Also, the threat of climate change added a layer of urgency to the narratives.

Framing of the ability of the community to recover (or not) by the media can be used as a measure of resilience in the discourse. Articles in the early years of this study often described the recovery efforts. There was widespread agreement that many of the levees were inadequately maintained. Once the Subventions Program increased funding for repairs and maintenance and locals became adept at preparation and floodfighting, the local attitude, as seen through interviews in the articles, became one of resilience, along with continued calls for funding and support.

Other media analysis studies have found that reporting of climate change first appeared as early as the 18th century, began to increase in 1988, and rose sharply in the early 2000s (Boykoff and Rajan, 2007). In this study, changes in weather patterns were discussed in some articles as early as 1986 and 1997. However, very few pieces in this study mention climate change. Escobar and Demeritt (2014) found that media coverage of climate change is markedly different from that of floods. Compared to flood events, climate science is probabilistic and requires a technical understanding of science. Instead of framing floods as climate change issues, many articles emphasized the inadequacy of the engineered flood management system to handle the large volume of water that accompanies the winter storms that occur in this region of California.

Publications in this study that are the least proximate covered the floods in a markedly different manner than the more proximate newspapers. The lack of including local and county-level sources led to telling a story that did not differentiate between the Delta's unique levees and those in other areas of the state. Furthermore, newspapers that are published in areas with a strong interest in water exports from the Delta told a slightly different narrative than other papers. Likewise, papers centered in the San Joaquin Valley framed the flood events through an agricultural lens. This is of interest because if the media's portrayal does not capture the nuances in the conversations, it might seem to be favoring one side over all others, which can increase animosity and distrust.

CHAPTER FOUR: TIMING OF ATMOSPHERIC RIVERS AND FLOODING IN THE SACRAMENTO-SAN JOAQUIN DELTA FROM 1980-2019

Abstract

The Sacramento-San Joaquin Delta sits at the confluence of the Sacramento and San Joaquin rivers. Over 60 mostly agricultural islands are protected by levees that are maintained by local landowners. The region has experienced hundreds of floods since the levees were first built in the mid-1800s; however, levee failures have become less frequent in recent decades. The state of California has been contributing millions of dollars to levee maintenance and improvements since the 1970s. The use of public funds has been justified because of the importance of the Delta to the state's freshwater supply. Given the cost of levee maintenance and predictions of more frequent and intense flood events throughout the region, this study looks at the characteristics of atmospheric rivers that have preceded floods in the Delta using MERRA-2 0.5 × 0.625 6-hourly global atmospheric river (AR) reanalysis V2.0 and details about 57 documented floods from 1980 to 2019. Floods analyzed in this study included levee breaches, levee overtoppings, and seepage events. Results show that most of the ARs that have made landfall in the watersheds that feed the Delta are not severe. Most of the floods, however, have been preceded by strong ARs. Although

roughly an equal number of ARs occurred in each of the watersheds, the majority of floods occurred after ARs that landed in the Sacramento watershed. Although floods occurred following "beneficial ARs", fewer of these floods involved levee failures. The most recent years (1998 to 2019) have had a small number of floods, and very few levee failures. However, the most recent ARs that impacted the Delta made landfall in the San Joaquin watershed, not the Sacramento watershed, which was the predominant origin of the more destructive floods in past decades.

1. Introduction

California's Delta (Delta) sits at the confluence of the Sacramento and San Joaquin Rivers, south of Sacramento and east of San Francisco. There are over 60 low-lying islands in the Delta, downstream of the Sierra Nevada, where much of the state's annual precipitation falls. The islands, which are mostly agricultural, are on reclaimed land in a historic floodplain. After a major levee failure in 1972 and a series of devastating storms in the early 1980s, many of the levees that protect the islands were improved. Levee maintenance and improvements are managed by local landowners and funded through a cost-share program with the state of California. Between 1973 and 2019, California has invested over $700 million in the levees. There are estimates that it will cost a further $1-$3 billion to sufficiently improve all of the levees to US Army Corps of Engineers (USACE) Federal Public Law 84-99 (PL 84-99) standards (DSC, 2015).

Short, intense storms, referred to as atmospheric rivers (ARs), deliver most of the precipitation to California (Guan, Molotch, Waliser, Fetzer, & Neiman, 2010). These narrow, elongated "rivers" of water vapor in the sky cover about 10% of the earth's midlatitude regions and account for roughly 90% of the poleward water transport (Zhu & Newell, 1998). ARs are critical to hydrologic cycles and are drivers of the geomorphic changes in rivers. They are often also associated with floods. A better understanding of local characteristics of ARs can help to predict potential flood events (Ralph et al., 2006). Much of the winter precipitation at high latitudes in northern California comes in the form of snow, which melts slowly over the spring and summer months and provides a sizable amount of the state's annual water budget. Some studies have shown that as the atmosphere warms, the impacts of atmospheric rivers will cause more flood events (Neiman, Ralph, Wick, Lundquist, & Dettinger, 2008; Rutz, James Steenburgh, & Martin Ralph, 2014).

This paper examines ARs alongside documented floods in the Sacramento-San Joaquin Delta from 1980-2019. Improving knowledge about integrated vapor transport (IVT) and the timing of ARs can be valuable for flood management. This paper addresses the following questions:

1. Do ARs always precede floods in the Delta? If not, what percent are "coupled"? And, what were the characteristics of the ARs that led to floods between 1980 and 2019?

2. What are the temporal characteristics of coupled ARs and floods? Are there changes in these patterns over time?

1.1 Study Area

1.1.1 Levee development

Before Euro-American settlement began in the Delta, the area was home to thousands of indigenous peoples who lived, hunted, fished, and harvested in the marshlands (Whipple, Grossinger, Rankin, Stanford, & Askevold, 2012). Indigenous villages occupied the higher ground, protected by natural and artificially constructed levees and sand mounds. For thousands of years, it appears that groups of people moved around seasonally for harvesting and in response to floods (Whipple et al., 2012). European contact began in the late 1700s, and hunting, ranching, and agriculture began in earnest in the early 1800s. After the California Gold Rush, conversion of the Delta's marshland to farmland began. In 1861, the California Board of Swamp Land Commission was created by the state to encourage the reclamation of marshland for agriculture.

The Great Flood of 1861-62 was the first major flood to affect the newly claimed land, destroying crops and livestock and resulting in numerous other forms of damage in the Delta (Hanson & Corporation, 2009; Kelley, 1989). The debris from upstream increased the sediment in the Sacramento River and raised the river beds (USACE, 2002; Whipple et al., 2012). A series of floods throughout the late 1800s led to farmers building higher and wider levees;

nonetheless, many islands were devastated by floods for the decades to come, well into the 20th century. For the first one hundred years of farming in the Delta, flood losses were the burden of the farmers and residents (Thompson, 2006). Later, the Delta became central for the state's water supply, and highways, railways, natural gas pipelines, and power transmission lines were built across the Delta to service the urban areas outside. As a result, the state's economic interests are at stake when a flood occurs.

About 1800 km of levees, two-thirds of which are on private land, protect the islands in the Delta. Reports differ on the exact number of islands. There are between 60 and over 100 islands or tracts, depending on how one counts an "island." Over 60 of the islands are named. Some accounts might not count dozens of others because they are only separated from another island by a canal, because they do not have a reclamation district, or because they are a small in-channel island that is difficult to locate on a mapping system (Mraz, 2016). The primary use of the Delta's islands is agriculture. Some of the islands are home to duck hunting clubs, and others are owned by state or non-governmental organizations for conservation purposes. There are eleven small towns within the Delta, and several urban centers just outside its border.

The Suisun Marsh, a brackish wetland area, is adjacent to the western edge of the Delta. Together with the Suisun Marsh, the Delta makes up the largest estuary on the West Coast of North America, covering over 3400 sq. km (URS, 2007). The Suisun Marsh is primarily tidal marsh, managed wetlands, grasslands, and waterways. Most of the levees in Suisun Marsh are smaller and less protective than those in the Delta. Only about 30 out of 300 km of levees in Suisun Marsh are eligible for public funds, making maintenance and improvements to the levees in Suisun Marsh much less feasible than those in the Delta. Most Delta-Suisun islands have flooded at least once, and there have been over 100 floods since 1900. Multiple floods have occurred during some years during winter storms. Nineteen islands flooded in 1907 and eleven in 1997.

The extensive system of levees is part of a complex flood management system. The majority of the land is used for agriculture; however, some areas are set aside for flood bypass, conservation, recreation, urban, or other uses. Most of the Delta's levees are designated as "non-project" levees to distinguish them from the federal flood control "project" levees (DSC, 2015; DWR, 1995) (Fig. 1). The non-project levees are maintained by private landowners or local reclamation districts and funded by property assessments on the individual islands. The landowners of an island control its reclamation district. Islands vary in size, and some contain only one or a few landowners; therefore, capacity for levee maintenance is highly heterogeneous. Project levees are designated by law (CWC §9110(e)) as levees for which the state has given assurances to the federal government that they will be prioritized for maintenance to meet federal 100-year flood standards.

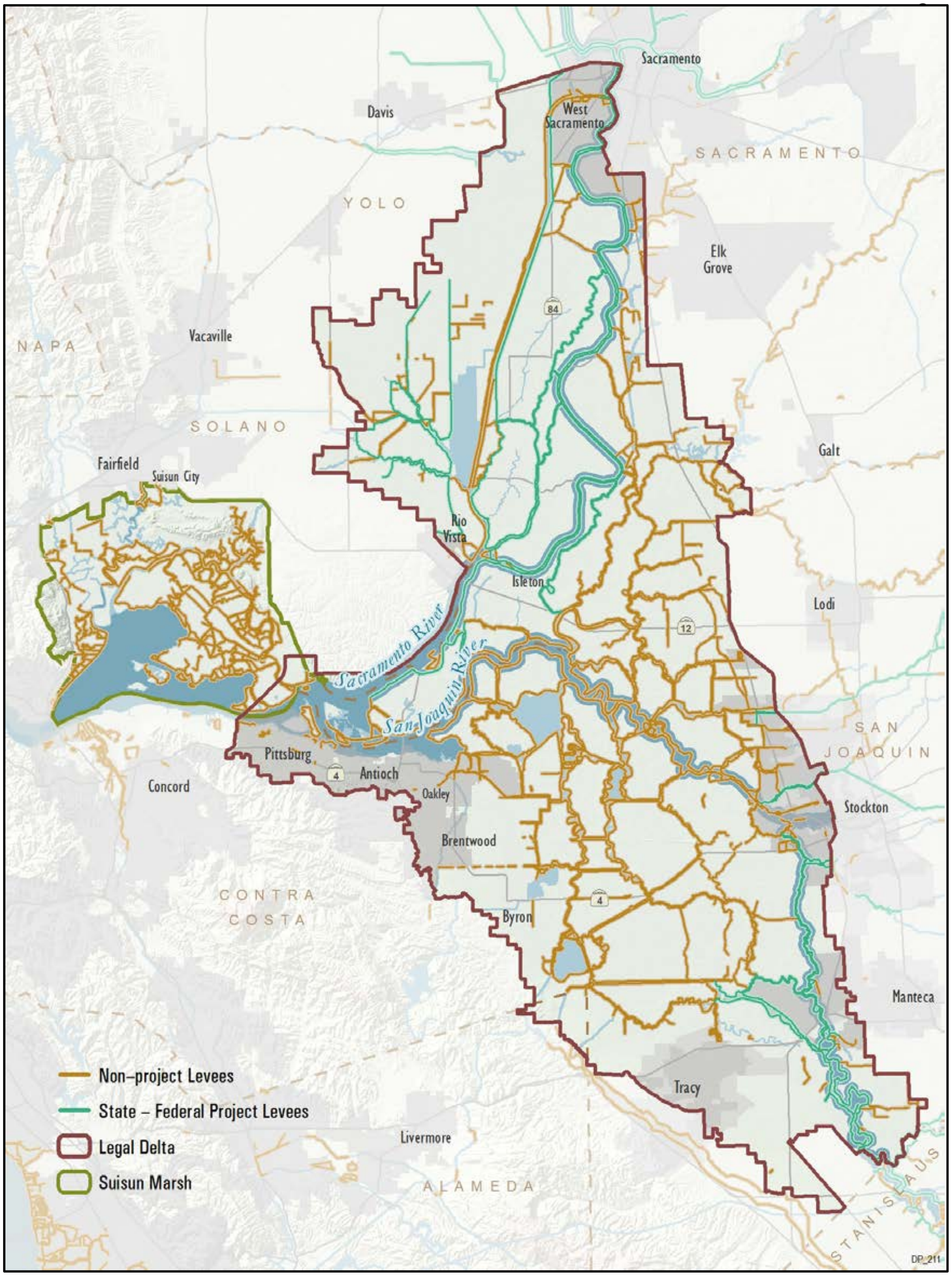


Figure 1. Map of project and non-project levees within the Delta. Map credit: Delta Stewardship Council, Chapter 7 in the Delta Plan, 2013.

1.1.2 Levee improvements

Many of the islands are below sea level. When a levee fails, the island floods like a bowl. This flooding can place pressure on the inside of the levee, leading to more seepage or breaching. Some islands have been flooded intentionally for flood control or habitat restoration, such as Prospect and Liberty islands in the Yolo Bypass (Hopf, 2011). Similarly, the levees at McCormack-Williamson Tract are intended to relieve flood pressure from the city of Thornton, which is on the border of the Delta. Some other levees are limited in height for different reasons. Fay Island, Rhode Island, Little Mandeville Island, and Little Franks Tract are small, less than 140-hectare point bars with minimal land fit for agriculture, and, therefore, few financial resources for levee investments.

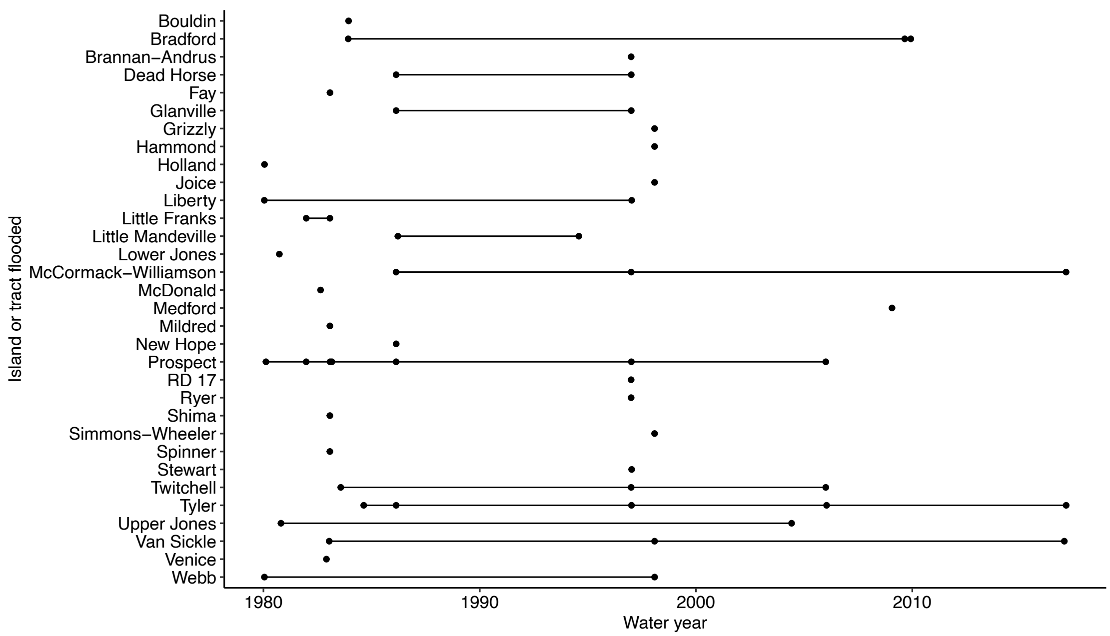
Floods occur when a levee breaches, is overtopped, or seeps, which most often occurs during times of inclement weather due to high river flow or wind-driven waves. On occasion, floods have occurred on "sunny days" for non-weather-related reasons, including burrowing rodents, erosion, or penetration by pipes or other equipment (DSC, 2013).

The Delta Levee Maintenance Subventions (Subventions) Program began in 1973 as a cost-share agreement between the state and local reclamation districts on most of the Delta's agricultural islands to fund levee maintenance. After the floods of 1986, the goal of the program was to increase the height of levees to one foot about the 100-year flood stage (URS, 2011). Subsequently, most of the levees were upgraded to meet the state Hazard Mitigation Plan (HMP) standards. A little over a decade later, PL 84-99 became the new goal for improving the Delta's levees to six inches over the basic HMP; however, the estimated $1.4 billion were not immediately available to upgrade all of the levees (Lund, Hanak, Fleenor, Bennett, & Howitt, 2010). To date, the Subventions Program has invested over $200 million of state dollars to eligible Delta levee and habitat repairs and maintenance (DWR, 2020). The California Department of Water Resources (DWR) also operates the Special Projects Program for levee improvements, which has invested over $300 million since its inception in 1988 (DWR, 2019).

Several reports have documented levee failures in the Delta (Table 1). DWR's 2009 Delta Risk Management Study (DRMS) compiled a list of levee failures in the Delta-Suisun region, collectively, to determine the sustainability of the levees for the next 100 years (URS, 2009). According to DRMS, between 1900 and 2009, there were 158 floods caused by levee failures. The report stressed, "considering the probability of all high water-related levee failures under current conditions and existing levee maintenance programs, about 140 levee failures are expected to occur in the Delta over the next 100 years" (URS, 2009, p. ES-16). However, there are inconsistencies in the documentation of floods in the Delta. In a dissertation, Hopf (2011) found that DRMS overestimated the number of levee failures by including Suisun Marsh, islands that are intended to flood (Prospect Island in Yolo Bypass), have restricted height (McCormick-

Williams Tract), or are small (Fay, Rhode Island, Little Mandeville, Little Frank's Tract are all < 140 hectares). Hopf concluded that levees that are eligible for and receive funding through the Subventions Program have experienced far fewer failures than perceived by state reports. Likewise, a Delta landowner has compiled an extensive list of documented flood reports, and debates the numbers in the DRMS report, concluding that there were at most thirty-three floods between 1967 and 2011 (Suard, 2011).

Table 1. Floods in the Delta by island or tract between 1980 and 2019 (WY[1]). Connector line shows multiple floods on an individual island. Data are from Hopf (2011) and DWR (2009).



[1] WY, or water wear, describes the annual precipitation cycle. As defined by the United States Geological Survey, a water year begins on 1 October of the previous calendar year and ends on 30 September of the next year, and it is designated by the calendar year in which it ends. Therefore, WY 1980 begins 1 October 1979 and ends 30 September 1980.

1.2 Atmospheric Rivers

ARs are responsible for 25-50% of the annual precipitation on the West Coast of the US (Ralph & Dettinger, 2012). Although not all ARs cause floods, 85% of floods on the U.S. Pacific Coast, including California, Oregon, and Washington from 1949 to 2015 resulted from AR storms (Konrad & Dettinger, 2017). The definition of an AR is "a long, narrow and transient corridor of strong horizontal water vapor transport that is typically associated with a low-level jet stream ahead of the cold front of an extratropical cyclone" (Ralph et al., 2006; Ralph, Rutz, et al., 2019; Zhu & Newell, 1998). Most of the precipitation brought by ARs is beneficial. The storms replenish reservoirs and nourish wetland habitat (Florsheim & Dettinger, 2015; Guan et al., 2010; Ralph, Rutz, et al., 2019). Zhu and Newell (1998) were the first to highlight ARs and introduce the concept of their zonal scale, which is the ratio of the zonal extent of all rivers to the total longitudinal length along a latitude. According to their calculations, 10% of an AR carries the moisture. However, moisture fluxes do not always indicate that an AR is present. ARs occur when air is dense and stable (Ralph, Neiman, & Rotunno, 2005). These storms range from short events of less than 24 hours to storms that last more than 72 hours. The longer an AR, the more distance it travels, and the stronger it becomes (Zhou, Kim, and Guan 2018).

There are several methods to detect, quantify and model ARs (Ralph, Wilson, et al., 2019; Zhou, Kim, & Guan, 2018). The central component of an AR is integrated water vapor transport (IVT). Other elements include wind, direction, shape, length, width, and trajectory. As our understanding of ARs has grown, scientists have recently begun to categorize them by intensity (Zhou et al., 2018) and their strength and impacts (Ralph, Rutz, et al., 2019). Duration of IVT magnitude is also important to consider when assessing the scale of impacts (Ralph, Rutz, et al., 2019).

The efficacy of AR detection tools has only recently begun to be evaluated (Ralph, Wilson, et al., 2019). In a study comparing AR detection tools, Ralph, Wilson, et al. (2019) found that the use of different variables, requirements, and thresholds leads to differences in sensitivity. The authors noted that some methods for AR detection employ constant IVT thresholds, while others use percentile-based thresholds. Geometric requirements, i.e., length, width, shape, and orientation, vary. These differences in methodology impact the number of ARs detected. Agreement between the methods increases when detecting stronger and longer ARs (Ralph, Wilson, et al., 2019).

Several studies have looked at the relationship between ARs and floods in California. Ralph et al. (2006) found that the Russian River in northern California only floods during AR events. Similarly, Neiman et al. (2008) found that winter conditions make ARs stronger, and there is double the amount of precipitation during winter. In an analysis of annual peak daily flow from four stream gauges, Neiman et al. (2011) show that peak snowmelt is at higher elevation on the day of the flood event than the day before a flood. The authors found that out of 48 flood events, all except two fit into their definition of an AR. Although flooding is most commonly associated with strong ARs, flooding can occur even with ARs of low intensity when they last for several consecutive days and when soil moisture is already high (Konrad & Dettinger, 2017; Ralph, Coleman, Neiman, Zamora, & Dettinger, 2013). AR conditions vary geospatially within California. For instance, AR-related rainfall events in northern California tend to last longer and deliver more precipitation than those in southern California (Maryam A Lamjiri, Dettinger, Ralph, Oakley, & Rutz, 2018).

One previous study has looked at ARs and levee failures in California. Florsheim and Dettinger (2015) found that since 1951 over 80% of 128 levee breaks in California's Central Valley occurred during AR storms and concluded that “despite construction of levees and other flood-control structures, climate and floods continue to cause unintentional levee breaks” (p. 138). The Central Valley is a 153,000 km^2 watershed of which much of the land is lowland floodplain. The Delta is a 2,800 km^2 downstream area on the western edge of the Central Valley. This present study looks at floods only within the Delta boundary, where there has been a substantial investment in levee maintenance and improvements under DWR's Subventions Program. However, the Delta receives water from a large region; therefore, this study looks at the ARs that have made landfall in both the Sacramento and San Joaquin river watersheds, from Mount Shasta to Fresno (DSC, 2013; URS, 2007) (Fig. 2).

Figure 2. Map of the Delta (red outline in the center), the watersheds that feed into the Delta (green), and the areas that use Delta water (light orange). Map credit: Agriculture and Natural Resources, University of California, modified from the Delta Stewardship Council's Delta Plan[2].

2. Methods and Data

2.1 Flood data

There are differences in records of levee failures and floods in the Delta. For this study, I compared documentation of floods in a DWR report (URS, 2009), a dissertation by Frank Hopf (Hopf, 2011), a data compilation by a Delta

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[2] Map from the Delta Plan (Figure ES-1) (DSC, 2013)modified by UC ANR with watershed names. http://ucanr.edu/blogs/UCDWeedScience//blogfiles/41417_original.jpg.

landowner (Suard, 2011), and media analysis study of newspaper articles about flooding in the Delta (Chapter 2 of this dissertation). By compiling these various data sources, I have categorized floods by levee type and level of failure. For levee type, following the example from Hopf (2011), I applied categories of levees based on the land uses that they protect: agriculture, wetlands, Suisun Marsh-specific wetlands, and urban communities. "Limited height" levees are ones that are designed to fail at lower water levels in order to provide flood relief for the rest of the Delta. To describe the type of flood, I categorized floods as a permanent levee failure, temporary failure, or a non-failure. Floods can result when a levee is breached, which I categorized as a failure, or when the water overtops or seeps through the levee, which I call a non-failure. The latter type of flood often triggered an emergency response, and levee failure was averted. In a few cases, the island was not reclaimed after the flood, resulting in the permanent failure of the levee.

2.2 Atmospheric river data

In this study, I used IVT to categorize the ARs that made landfall in the Delta between 1980 and 2019 using MERRA-2 0.5 × 0.625 6-hourly global AR reanalysis V2.0 (Guan & Waliser, 2015; Guan, Waliser, & Ralph, 2018)[3]. Guan and Waliser apply a percentile-based IVT threshold, which accounts for more

[3] The AR data were provided by Bin Guan via https://ucla.box.com/ARcatalog. Development of the AR detection algorithm and databases was supported by NASA.

ARs than other detection methods (Ralph, Wilson, et al., 2019). Several scholars have used global AR data to study flooding at the regional scale (Eiras-Barca, Lorenzo, Taboada, Robles, & Miguez-Macho, 2018; Huning, Guan, Waliser, & Lettenmaier, 2019; Ralph, Wilson, et al., 2019). I aggregated to daily resolution by using maximal daily values of the variables by grid cell. This allowed for direct comparison with flood dates. I further narrowed the global AR data set by choosing only the incidences where AR landfall was on the western coast of North America between 36.5-41.5 degrees N, which encompasses the Sacramento and San Joaquin watersheds that feed into the Delta. A scale based on maximum IVT at a given location can be used to signify the magnitude of AR strength (Ralph, Rutz, et al., 2019) (Table 2). Incidences with IVT less than 250 kg/m per second were removed from the dataset in accordance with the definition of an AR (Ralph, Rutz, et al., 2019).

Table 2. Scales of AR intensity and thresholds of risk based on analyses of ARs that have made landfall on the US West Coast (Ralph, Rutz, et al., 2019)[4].

Beneficial	Weak: IVT ≥ 250–500 kg m^{-1} s^{-1}
	Moderate: IVT ≥ 500–750 kg m^{-1} s^{-1}
Hazardous	Strong: IVT ≥ 750–1,000 kg m^{-1} s^{-1}
	Extreme: IVT ≥ 1,000–1,250 kg m^{-1} s^{-1}
	Exceptional: IVT ≥ 1,250 kg m^{-1} s^{-1}

[4] Ralph, Rutz, et al. (2019) further developed a categorical system (AR Cat 1- AR Cat 5) to facilitate in communicating AR forecasts using both maximum IVT and duration (< 24 hrs, > 24-48 hrs, > 48 hrs).

3. Results

3.1 Floods and levee failures

Fifty-seven floods were included in this study. Almost 70% of the floods involved a levee failure, either temporary or permanent (Fig. 3). The remaining floods, roughly 30%, occurred when a levee was overtopped or had seepage, but the levee was not breached, designated in this paper as "No failure." The majority of floods occurred where the levees were non-project agricultural or limited height. Almost an equal number of agricultural levees were saved through flood fighting and emergency management as those that were breached during this time period. None of the limited height levees were saved through emergency management, although most of them were rebuilt.

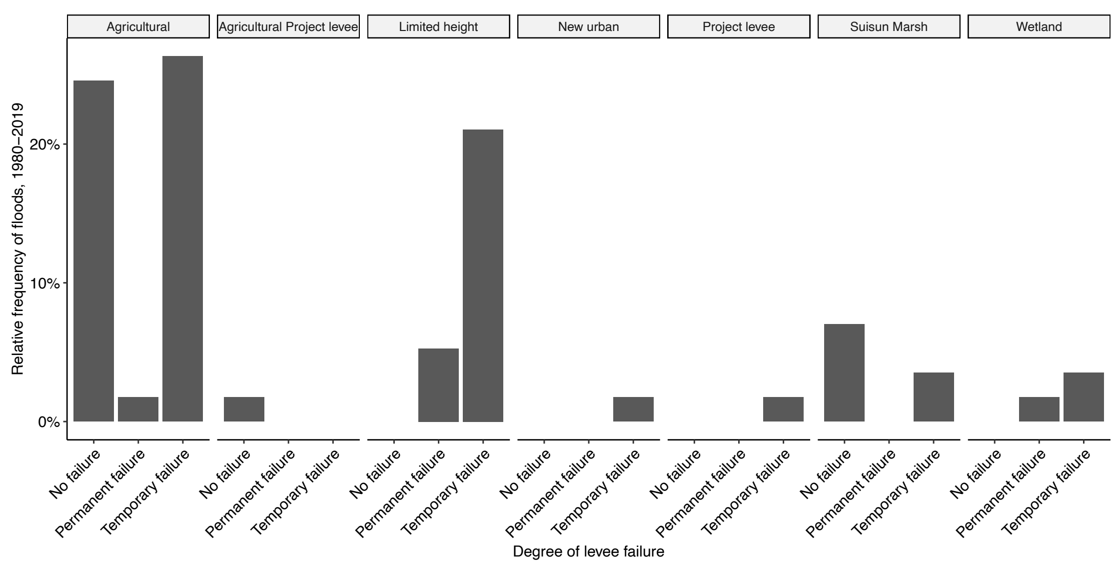


Figure 3. Frequency of floods based on type of levee (i.e., standards to which it is maintained based on land uses that it protects) and the degree of the failure (i.e., the outcome of the flood). Some floods were averted through emergency management and flood fighting, resulting in "no failure." Some levees were not

rebuilt, leading to a "permanent failure." Levees that were repaired are categorized in this study as "temporary failures."

About 80% of the floods from 1980 to 2019 occurred during the winter months of December, January, and February (Fig. 4a). The early 1980s had the greatest number of floods, and there were also many floods in the mid- to late-90s. Far fewer floods have occurred between 1999 and 2019 (Fig. 4b).

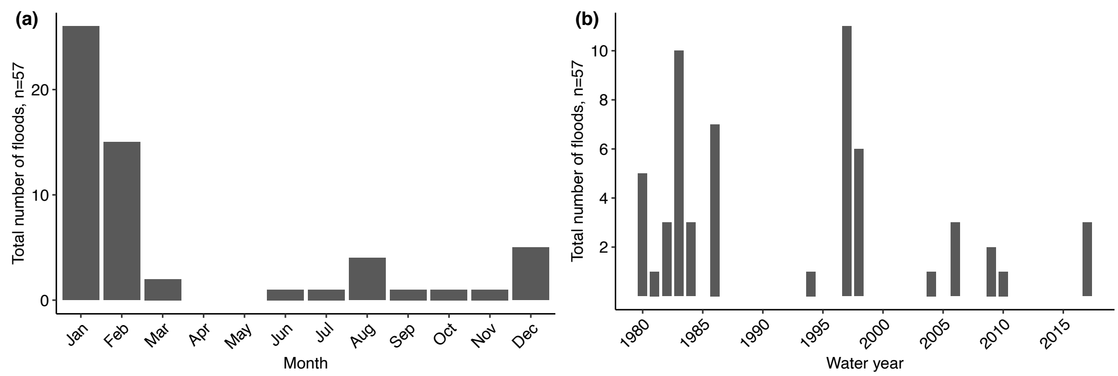


Figure 4. Total number of floods by month (**a**) and year (**b**) from 1980-2019. Total flood numbers include floods that involved a levee breach, overtopping, or seepage.

3.2 Atmospheric river frequency and intensity

Analysis of the AR reanalysis dataset shows that ARs fluctuate on the US West Coast in a cyclical pattern, with extremes similar to those found in El Niño-Southern Oscillation (ENSO) events (Wang et al., 2019). The greatest number (≥ 30) of annual ARs, based on daily maximum total IVT, occurred in WYs 1981-1984, 1986, 1993, 1997, and 2017 (Fig. 5a). The strongest ARs (IVT ≥ 1,000 kg/m per second) occurred in 1982, 1993, 1997, 2003, 2006, and 2019 (Fig. 5a and 5c). WY 2017 had the greatest number of ARs; however, all of its ARs had an IVT value less than 1,000 kg/m per second.

Over the 40 years analyzed in this study, most of the AR storms are categorized either as “weak” (IVT ≥ 250–500 kg/m per second) or “moderate” IVT ≥ 500–750 kg/m per second), with the mean slightly higher than 500 kg/m per second (Fig. 5b). These lower IVT values correspond to what can be considered beneficial precipitation (Ralph, Rutz, et al., 2019). ARs with an IVT value greater 750 kg/m per second are considered hazardous. Most of the hazardous ARs in this study are in the “strong” category (IVT ≥ 750–1,000 kg/m per second), rather than “extreme” or “exceptional” (IVT ≥ 1,000-1,250 kg/m per second, IVT ≥ 1,250 kg/m per second, respectively). Trendlines show that the intensity of ARs is relatively stable over time in the study area, except for the strongest, yet infrequent, storms (Fig. 5c and Table 3).

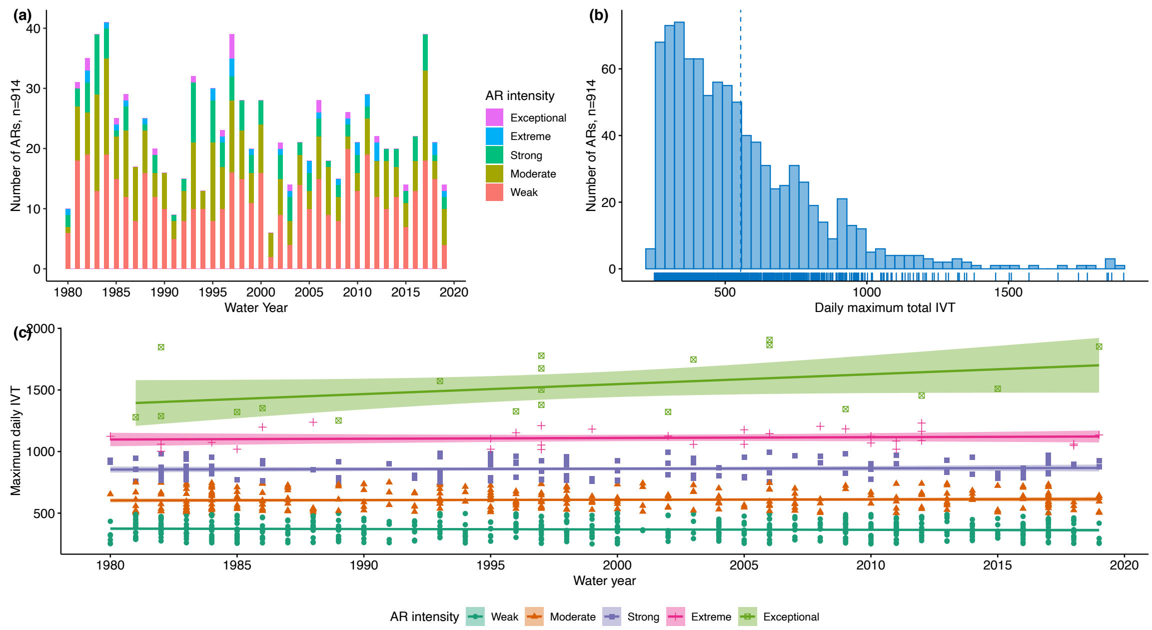


Figure 5. Frequency of all ARs in the study region from WY 1980-2019, and their corresponding category of intensity (**a**). Strength is based on daily maximum of IVT kg/m per second. The AR intensity scale is (daily total IVT kg m^{-1} s^{-1}): Weak (IVT ≥ 250–500), Moderate (IVT ≥ 500–750), Strong (IVT ≥ 750–1,000), Extreme (IVT ≥ 1,000–1,250), Exceptional(IVT ≥ 1,250) (Ralph, Rutz, et al., 2019). Total daily maximum IVT mean during the entire study period is around 555 kg m^{-1} s^{-1} (**b**). The AR dataset begins in January 1980 and ends in May 2019, resulting in partial water years for those years. (**c**) Regression lines of IVT intensity over time by scale of maximum daily IVT (1980-2019 WYs). Colors and shapes signify the category of AR intensity. While the strengths of ARs mostly remained stable, the strongest of the ARs ("Exceptional") became stronger in the spatial domain and time period in this study.

Table 3. Regression coefficients and number of observations of each of the five scales of AR strength visualized in Fig. 5c.

IVT (kg m^{-1} s^{-1})	**Slope**	***N***	***R2***	***p* value**
≥250-500	-0.00089	471	0.003	0.23
≥500-750	+0.00071	272	0.0017	0.5
≥750-1000	+0.00085	120	0.0024	0.6
≥1000-1250	+0.0017	31	0.01	0.59
≥1250	+0.022	20	0.15	0.089

3.3 Timing of atmospheric rivers and floods

The Delta is impacted by water flowing downstream from both the north and the south. Therefore, in order to better understand AR characteristics during past flood events, I look at the watersheds where the ARs made landfall by dividing the data into the Sacramento and San Joaquin watersheds at 38.5 degrees N. In this section the intensity of ARs is grouped into beneficial (IVT < 750 kg/m per second), hazardous IVT > 750 kg/m per second), and NA, the latter signifying that a flood occurred in the absence of any significant precipitation.

Most of the ARs (80%) from 1980-2019 were beneficial. Roughly half of the ARs came from each of the two watersheds, and this proportionality carried over to the two categories of AR risk (beneficial and hazardous) (Fig. 6a). Of the 57 floods in this study, more occurred within 14 days of a hazardous AR (n=35) than floods that happened after a beneficial AR (n=13). More floods happened after an AR landed in the Sacramento watershed (36) than in the San Joaquin watershed (12). Nine floods occurred without the presence of an AR.

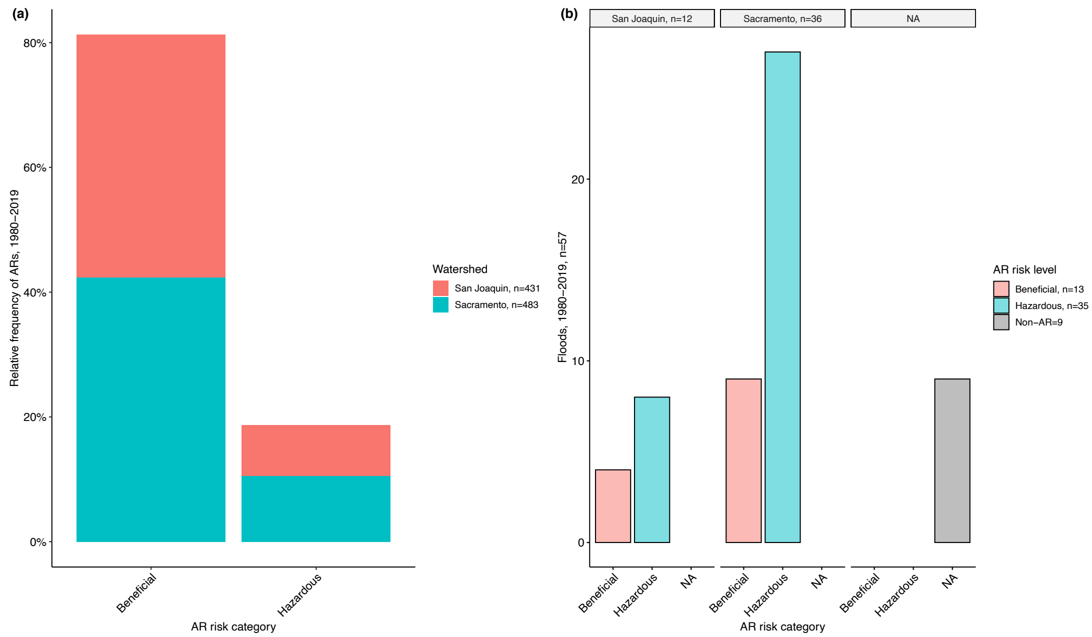


Figure 6. Level of risk (based on maximum daily IVT) of all ARs (n=914) in the Delta, and the proportion coming from each of the watersheds **(a).** About 80% of all of the ARs during the time period were beneficial. Slightly more ARs made landfall in the Sacramento Watershed (n=483) compared to the San Joaquin Watershed (n=431). Of the ARs that occurred fourteen days or less before a flood in the Delta, most ARs were ranked as hazardous (n=35, coupling with 61% of all floods), and most (77%) of the floods following a hazardous AR came from the Sacramento watershed **(b).** Thirteen of the ARs (23% of total) that preceded floods were weak or moderate ("beneficial"), and nine floods (16% of all floods) were not preceded by an AR.

As described in detail above in Section 3.1, most of the floods in the Delta occurred in the early 1980s and 1997. A smaller number of floods have occurred since 2000, and the differences in the outcomes of the floods have been previously documented (Hopf, 2011). Figure 7 shows when floods occurred, the relative AR strength (risk level), location of the AR's landfall, and the outcome of the flood. Most of the floods that followed ARs from the Sacramento watershed occurred in the 1980s-90s. The more recent floods came from ARs in the San

Joaquin watershed. Since 1997, the floods have seldom resulted in a levee failure. Floods that occurred from a non-AR event have mostly been non-failures as well.

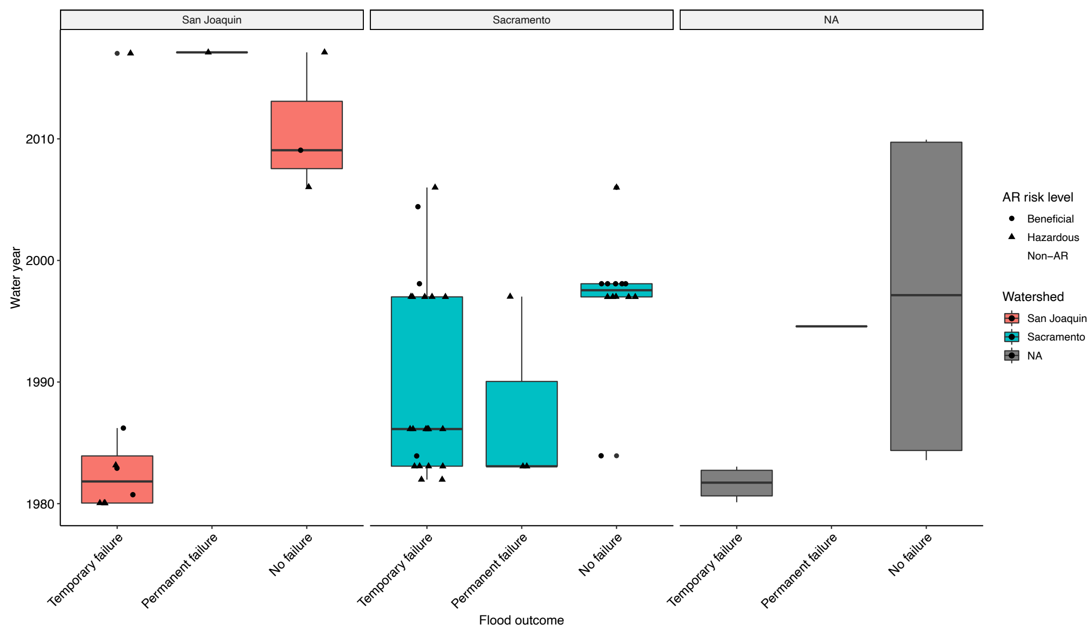


Figure 7. Timing of floods, the relative AR strength (risk level), location of the AR's landfall, and the outcome of the flood. Numerous hazardous ARs occurred in the early 1980s, along with many levee failures, both temporary and permanent, from ARs that made landfall in both the Sacramento and San Joaquin watersheds. The late 1990s saw a number of floods from overtoppings, but not as many levee failures, and all of these happened after ARs in the Sacramento watershed. More recent floods, but no levee failures, occurred after ARs landed in the San Joaquin watershed. Floods from non-AR events occurred throughout the study period but have not resulted in levee failures in recent years.

4. Discussion

Global reanalysis AR data were used for this study to address questions about the characteristics of ARs preceding floods on the Delta's leveed islands. The ARs were classified by strength according to a scale developed by Ralph, Rutz, et al. (2019) as part of an AR classification system in order to better communicate past events and forecasts. This scale was recently used by Huang, Swain, and Hall (2020). This paper adds an empirical example of the efficacy of the categories at the local scale.

IVT values greater than 1,000 kg/m per second, values associated with the most severe storms, are rare. And yet, the strongest category of ARs ("Exceptional", Fig. 5c) are getting stronger (2.2% kg m^{-1} s^{-1} $year^{1}$, $r^2 = 0.15$, P = 0.089) over the 40-year study period. The rest of the ARs in this study (80%) were found to have a value less than 750 kg/m per second IVT, which is congruent with Ralph et al. (2019), who found that most of the precipitation in northern California comes during ARs, and much of this precipitation is beneficial. For this study, to align better with known flood dates, IVT was aggregated to daily maximum IVT. This methodology might have resulted in a higher count of ARs than some other studies that aggregate storms that meet the definition of an AR over consecutive hours. Some AR storms last for two or more days. Also, as mentioned above in the Methods section, the high sensitivity and percentile-based IVT threshold of the Guan and Waliser reanalysis data set used for this study has been found to detect more weak ARs than other AR detection tools; however, there is consistency in detection of the number of strong ARs between all of the existing AR detection methods (Ralph, Wilson, et al., 2019). Therefore, this study shows a large number of ARs (n=914, average 23/year) over the forty-year period. Ralph, Wilson, et al. (2019) found an average of 18

ARs per year from 2005-2015 that made landfall at Bodega Bay, California, a similar, but more limited area than used in this study. Their study took an average all six diverse AR detection methods, of which one was the Guan and Waliser reanalysis used in this study. The Guan and Waliser method counts more weak storms as ARs than some of the other methods; therefore, the high number of ARs in this study is congruent with Ralph, Wilson, et al. (2019).

The results from this study show that not all hazardous ARs cause floods, but most floods follow ARs. AR strength increases the likelihood of a flood; however, even less intense ARs can be followed by floods. The latter case is more likely to happen during a very wet year when soil has likely become saturated from a series of rainstorms, which is supported by findings by Konrad and Dettingger (2017) and Lamjiri, Dettinger, Ralph, and Guan (2017).

The ARs in 1997 had slightly higher IVT than those in 1996. There were several floods during the winter storms of ’97, yet there were few levee failures. Levee improvements after the '86 floods and better preparation for flood fighting could have contributed to the lower number of failures. The levees performed well during the 2017 storms as well; however, although numerous the ARs were not as strong (IVT < 1000 kg/m per second) in 2017 as they were in 1986 and 1997 (IVT ≥ 1200 kg/m per second).

A better understanding of the ARs that are potentially hazardous specifically in the Delta can help locals and the state better prepare for floods, such as re-enforcing the levees with rocks, or having a barge with rocks on stand-by during ARs. Distinguishing floods by levee type and the location of AR landfall shows trends that would be missed if analysis was at a broader scale.

Changes in runoff in the Sacramento and San Joaquin rivers could be a challenge to the current flood protection system (Water Education Foundation, 2009). The potential for more frequent and intense ARs will increase as the climate warms (Wuebbles et al., 2017), and there could be a higher volume of water on the hourly scale (Huang et al., 2020). A warmer climate where there is less snow and more rain will increase winter river flow. In addition to heavy rains, ARs bring strong winds when they make landfall on the west coast of North America, and these conditions will likely intensify with climate change (Huang et al., 2020). It would be beneficial for a future study to look at the wind speeds during ARs because the levees are vulnerable to increased erosion from wind and waves.

Summary of findings

<u>Do ARs always precede floods in the Delta? If not, what percent are "coupled"? And, what were the characteristics of the ARs that led to floods between 1980 and 2019?</u> This study found that 48 flood events (84% of total floods) in the Delta were preceded by at least one AR within the 14 days prior to the flood. The ARs made landfall on the US West Coast between 36.5 and 41 degrees North. Most ARs that preceded floods were ranked as hazardous (n=35, 61% of all ARs that coupled with floods), and most (77%) of the floods following a hazardous AR came from the Sacramento watershed.
<u>What are the temporal characteristics of coupled ARs and floods? Are there changes in these patterns over time?</u> The ARs showed a cyclical pattern over the forty years of this study with the most activity during the years 1981-1986, 1997-98, and 2017. Although about half of the ARs made landfall in each of the two watershed in this study, the majority (n=27, 77%) of the stronger ("hazardous") ARs landed in the Sacramento watershed. However, no ARs from the Sacramento watershed have preceded floods in the Delta since 2006. The most recent couplings of ARs and floods have been from ARs from the San Joaquin watershed. During this time period in this spatial domain, AR strength has remained constant, except the strongest category of ARs has increased in strength by 2.2%.

CONCLUSION

This dissertation research was conducted in three distinct parts. Each of the previous chapters includes its own detailed conclusion. In this section I will briefly summarize each chapter, and I discuss my overall concluding thoughts.

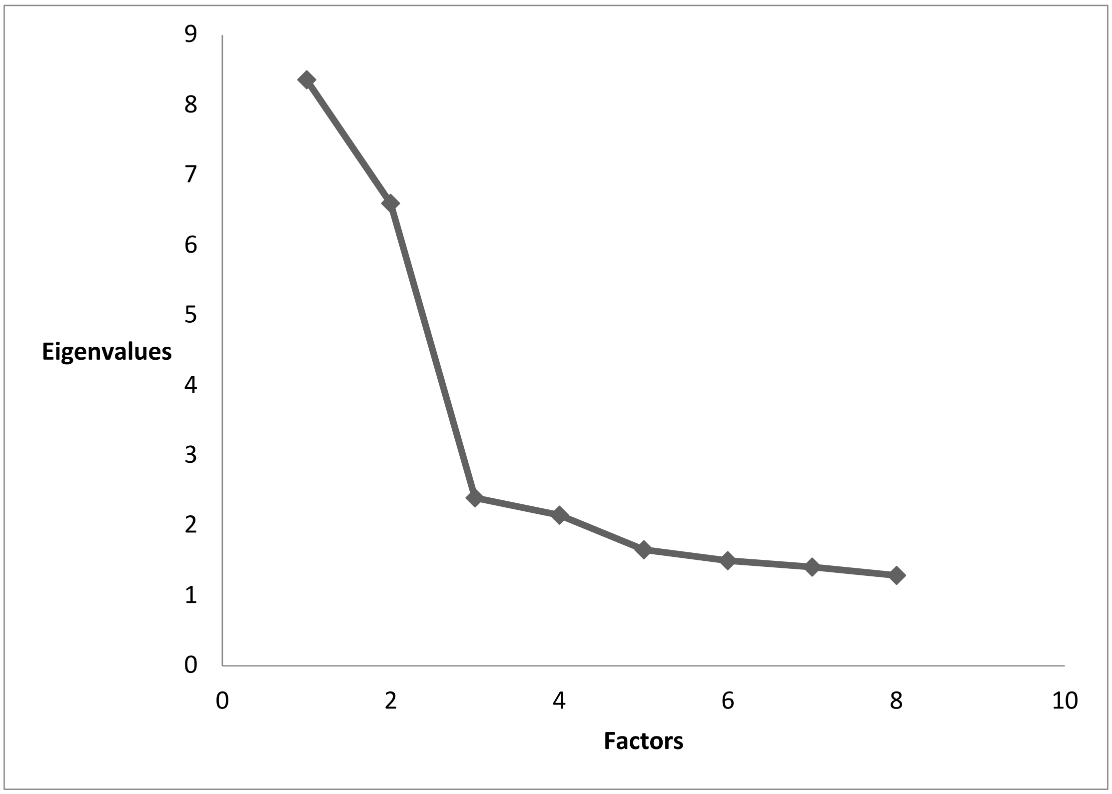
The Q methodology study found five perspectives of flood risk in the Delta. I had expected to find two polar opposite perspectives: crisis is certain and there is not a crisis, and I had previously understood that there is a lack of trust between the Delta stakeholders and conflicting values for the natural resources of the Delta because local, state, and federal agencies have worked for several decades without finding a consensual solution. However, this study found subtle differences among the other perspectives. Looking at the scale of what a person thinks is at risk, who they blame for the risk, who they think can implement a viable solution, and what they ultimately envision for the Delta led to more nuanced, unexpected narratives largely based on a person's sense of the Delta as place and their own vulnerabilities. Their views of the urgency of climate change also played a role.

The media analysis of newspaper articles about floods between 1972 and 2019 showed that many articles from national and southern California newspapers did not include local knowledge of flood events to the same extent as the local papers. This lack of inclusion could exacerbate local distrust of reporting by those media outlets, and it gives a partial picture of the risk potential to the newspapers' readers. Reporting about increasingly costly levee repairs and catastrophic floods caused by levee failures in other parts of the world began to dominate non-local news articles during times when few floods happened in the Delta.

This study found that the majority of ARs are beneficial and have not been followed by flood events, which is congruent with existing research. However, ARs are commonly mentioned in weather forecasts during the winter rainy season. This distinction is important because there could be improvements in the communication about the benefits and hazards from the various scales of ARs. I used the IVT scale developed by Ralph, Rutz, et al. (2019) to describe the strength of the storms and the risk that strength of storm poses. Most significantly, this study found that the strongest of the ARs have been increasing in strength. While this finding is based on a small number (n=20) of storms and the p value (p=0.89) is more than the normally accepted 0.05, the findings are compelling enough to warrant further study of longer-term oscillation of the ARs in the Sacramento and San Joaquin watersheds.

APPENDICES

Appendix A.



Scree plot of Eigenvalues for 8 factors with an Eigenvalue greater > 1

Appendix B. Interviewees types by year

Interviewee	1972 (n=44)	1980 (n=58)	1982 (n=25)	1983 (n=24)	1986 (n=48)	1997 (n=54)	2004 (n=39)	2006 (n=35)	2017 (n=18)	Total n=345
Local	**19**	**24**	**13**	**9**	**15**	**10**	**21**	**8**	**4**	**123**
City or town mayor	6	0	0	1	0	1	0	1	0	9
Doctor	1	0	0	0	0	0	0	0	0	1
Farm worker	0	2	2	1	1	0	2	0	0	8
Farmer	0	9	2	1	0	0	4	0	0	16
Fire chief	1	2	0	0	3	1	0	1	0	8
Engineer	4	8	3	3	1	0	1	1	1	22
Reclamation district	1	4	9	1	0	1	11	1	0	28
Non-farm business owner or worker	6	8	3	4	2	2	4	1	2	32
Police	7	0	0	0	0	2	0	0	0	9
Resident	12	9	4	1	12	7	11	5	3	64
County	**12**	**18**	**11**	**10**	**13**	**10**	**15**	**9**	**6**	**104**
County Ag Comm.	2	0	3	0	0	1	0	0	0	6
County Emergency	1	11	5	5	8	3	9	4	2	48
County Supervisor	1	4	3	0	6	3	1	2	4	24
Sheriff	10	5	4	6	5	3	6	3	0	42
State	**16**	**27**	**17**	**16**	**34**	**34**	**24**	**25**	**9**	**202**
Boating-Waterways	0	0	0	0	0	0	0	3	0	3
Conservation Corps	2	1	0	3	0	0	1	0	1	8
Dept. Food & Ag.	0	0	0	0	0	2	0	0	0	2
Fish & Wildlife	0	0	0	0	0	0	2	0	0	2
Governor	0	1	0	0	3	0	2	8	0	14

Senator-Congressperson-Legislator	3	2	1	2	5	4	6	4	2	29
Special District	0	0	0	0	0	0	0	1	1	2
State Emergency	8	5	3	5	1	7	0	1	0	30
Reclamation board	0	0	0	0	0	1	0	0	0	1
Toxic Substances	0	0	0	0	0	1	0	0	0	1
Water Resources	5	21	15	10	29	27	19	14	6	146
Federal	**20**	**11**	**3**	**1**	**4**	**10**	**14**	**2**	**1**	**66**
Federal CEQ	0	0	0	0	0	0	0	1	0	1
Federal Emergency Management	2	1	0	0	0	3	0	0	0	6
Army Corps	19	2	1	1	1	8	12	0	0	44
Coast Guard	2	7	2	0	3	1	0	0	0	15
Dept of Ag	0	0	0	0	0	0	1	0	0	1
Dept of Energy	0	0	0	0	0	0	0	0	1	1
Dept of Interior	1	1	0	0	1	1	5	1	0	10
Other	**5**	**16**	**11**	**3**	**5**	**4**	**18**	**6**	**10**	**78**
Environ. group	0	0	0	0	0	1	4	0	4	9
Levee repair worker	1	5	1	0	0	1	1	0	0	9
Meteorologist	0	3	4	3	2	0	0	2	1	15
Flood Control	0	0	0	0	0	0	2	0	0	2
Outside expert	0	0	0	1	0	3	2	4	7	17
Utilities	0	4	6	0	0	0	4	0	0	14
Recreational visitor	3	2	0	0	0	0	0	0	0	5
Emer. volunteer	1	1	0	0	2	0	4	0	0	8
Water exporter	0	4	1	0	1	1	6	1	0	14
Total (Unique)	**34**	**51**	**23**	**22**	**46**	**50**	**37**	**35**	**17**	**315**

Appendix C. R code for atmospheric river activity in the Sacramento and San Joaquin watersheds coupled with floods from 1980-2019

```
library(tidyverse)
library(ggplot2)
library(readr)
library(lubridate)
library(dplyr)
library(sf)
library(maps)
library(scales)
library(ggpubr) #for better looking plots
theme_set(theme_pubr())
#show Delta shapefile
delta_boundary <- st_read("Data/Legal_Delta_Boundary.shp")
ggplot(delta_boundary) +
  geom_sf() +
  coord_sf() +
  theme_pubr()
#Flood event data and plots
floods <- read.csv('Data/flood_sheet2.csv', header=TRUE) #read data of known floods
floods$Date <- with(floods, ymd(sprintf('%04d%02d%02d', Year, Month, Day))) #add
variable Date
floods$nFlood_date <- with(floods, ymd(sprintf('%04d%02d%02d', Year, Month, Day)))
#correct format for flood only dates
df2 <- floods %>%  #add w_year to df
  mutate(wy = ifelse(month(Date) %in% c(10:12), year(Date) + 1, year(Date))) #add
column with water year
colnames(df2)
myvars <- c("Date", "Year", "Month", "Day", "Island", "condition",  "type",
"nFlood_date", "wy") #pick variables that we need
df2 <- df2[myvars] # edited flood data
colnames(df2)
#TABLE 1 - Floods by island
ggplot(df2, aes(nFlood_date, Island)) +
  geom_point() + #plot points
  theme(axis.text = element_text(size = 10)) +
  geom_line() +
  scale_y_discrete(limits = rev(levels(as.factor(df2$Island)))) +
```

```
  theme_pubr() +
  labs(x = "Water year", y = "Island or tract flooded")
#Part 1: Floods
# FIGURE 3 - Frequency of different levee failure outcomes
ggplot(df2, aes(x= condition)) +  #percentage plot - use this one
  geom_bar(aes(y = (..count..)/sum(..count..))) +
  scale_y_continuous(labels=scales::percent) +
  facet_grid(~type) +
  theme_pubr() +
  theme(axis.text = element_text(size = 12)) +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  theme(legend.position="right") +
  labs(x= "Degree of levee failure", y = "Relative frequency of floods, 1980-2019",
fill = "Levee type")
#Figure 4a - Flood counts by month
mth <- ggplot(df2, aes(x= Month)) +
  geom_bar(aes(y = ..count..), stat="count") +
  labs(y = "Total number of floods, n=57") +
  scale_x_discrete(limits = month.abb) +
  theme_pubr() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
#FIGURE 4b - Flood counts by year (levee type not included)
yr <- ggplot(df2, aes(x = wy)) +
  geom_bar(width = 0.75) +
  scale_y_continuous(breaks = c(2,4,6,8,10)) +
  scale_x_continuous(breaks = c(1980,1985,1990,1995,2000,2005,2010,2015,2020)) +
  theme(axis.text = element_text(size = 12)) +
  theme_pubr() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  theme(legend.position="right") +
  labs(x = "Water year", y = "Total number of floods, n=57")
fig4 <- ggarrange(mth, yr,
                    labels = c("(a)", "(b)"),
                    ncol = 2, nrow = 1)
fig4
#Atmo River data
global <- read.csv('Data/globalAR_1980-2019.csv', header=TRUE) #read AR global data
(csv file from Bin Guan's txt file)
colnames(global) #get column names
```

```
colnames(global)[19] = "lfloc_lon" #change name of Landfall_lon
colnames(global)[20] = "lfloc_lat" #change name of Landfall_lat
nlfloc_lon <- ifelse(global$lfloc_lon > 180, -360 + global$lfloc_lon,
global$lfloc_lon) #convert coordinates from 0-360 to -180 to 180
global$nlfloc_lon <- with(global, nlfloc_lon) #add nlfloc_lon to global_ar
global$Date <- with(global, ymd(sprintf('%04d%02d%02d', Year, Month, Day)))  ##make
new variable "Date" combining year, month, day
west <- global %>% # Mount Shasta (41.41, 122.2) to Fresno (36.75, 119.77). 37.5-41
for Northern Sierra Nevada- see Kim et al 2013.
  filter(lfloc_lat > 36 & lfloc_lat < 41.5, lfloc_lon > 230 & lfloc_lon < 240) #ARs
that landed in Sac and SJ watersheds
#(see EPA:
#https://www.epa.gov/sfbay-delta/about-
watershed#:~:text=The%20Sacramento%20River%20Watershed%20is,%2C%20Cascade%2C%20and%20
Coast%20Ranges.)
colnames(west)
# Plot AR points on CA map
library(mapdata)
states <- map_data("state")
cal <- subset(states, region %in% c("california"))
#Map of AR points here
library(ggmap)
library(mapdata)
library(rgdal)
library(ggsn)
library(maptools)
shp <- readOGR("Data/Legal_Delta_Boundary.shp")
ggplot() + #study points mapped
  geom_point(data = west, mapping = aes(x = nlfloc_lon, y = lfloc_lat),
             colour = "blue", shape=22, fill="blue", size = 3,
             show.legend = FALSE) +
  geom_polygon(data = shp, aes(long, lat, group = group), colour = alpha("darkred"),
size = 1,
               fill = "lightgreen", alpha = .5) +
  geom_polygon(data = shed_shp, aes(x = long, y = lat, group = group), fill = "gray",
color = "black", alpha = .5) +
  geom_polygon(data = cal, aes(x = long, y = lat, group = group), fill = "gray",
color = "black", alpha = .5) +
  coord_fixed(xlim = c(-125, -118),  ylim = c(36, 42), ratio = 1.3) +
```

```
  labs(x="Longitude", y="Latitude")
test <- global %>%
  filter(lfloc_lat > 36 & lfloc_lat < 40, nlfloc_lon > -130 & nlfloc_lon < -110)
ggplot() +
  geom_point(data = test, mapping = aes(x = nlfloc_lon, y = lfloc_lat), colour =
"red", size = 2, show.legend = FALSE) +
  geom_polygon(data = cal, aes(x = long, y = lat, group = group), fill = "gray",
color = "black", alpha = .5) +
  coord_fixed(xlim = c(-125, -121.0),  ylim = c(36, 40), ratio = 1.3)
#yes, same results
write.csv(west, "Data/arswestcoastAR.csv", row.names=FALSE) #create smaller file to
work with
df <- read.csv('Data/arswestcoastAR.csv', header=TRUE) #smaller file than global
#transform AR dataframe
df1 <- df %>%  #subset of west coast ARs by daily max IVT
  mutate(Date = as.Date(Date)) %>%
  group_by(Date) %>%
  filter(Total_IVT == max(Total_IVT)) %>%
  filter(Total_IVT >= 250) %>% #remove IVT values less than AR definition
  mutate(wy = ifelse(month(Date) %in% c(10:12), year(Date) + 1, year(Date))) #add
column with water year
df1$basin  <- cut(df1$lfloc_lat, breaks = c(36,38.5,41),  #categorize by watershed
and add column
              labels = c("San Joaquin", "Sacramento"))
myvars <- c("Year", "Month","Day","Hour","Total_IVT", "lfloc_lat",
"nlfloc_lon","Date", "wy", "basin")
df1 <- df1[myvars]
ggplot(df1) + #quick scatterplot of IVT by water year
  geom_point(aes(wy, Total_IVT))
#set AR strength categories from Ralph et al 2019
catIVT <- cut(df1$Total_IVT, breaks=c(250,500,750,1000,1250,2000),
              labels=c("Weak", "Moderate","Strong", "Extreme", "Exceptional"),
              right=FALSE)
df1$Total_IVT[1:10]
catIVT[1:10]
Strength <- cut(df1$Total_IVT, breaks=c(250,500,750,1000,1250,2000),
                labels=c("Weak", "Moderate","Strong", "Extreme", "Exceptional"),
                right=FALSE)
df1$Total_IVT[1:10]
```

```
Strength[1:10]
df1$intensity <- with(df1, Strength) #add "intensity" column to df
#****Part 2: ARs
#1st AR figure:Shows proportion of strength of ARs by WY
summary(df1) #summary of df - means of each variable
library(pastecs)
stat.desc(df1) #to find # nbr.val, nbr.null, nbr.na, min max, range, sum,
# median, mean, SE.mean, CI.mean, var, std.dev, coef.var
library(psych)
describe(df1)
ARYrly <- ggplot(df1) +
  geom_histogram(aes(x = wy, fill = intensity), binwidth = 0.5, position =
position_stack(reverse = TRUE)) + #count of #of ARs by year
  labs(x = "Water Year", y = "Number of ARs, n=914", fill = "AR intensity") +
  theme(axis.text = element_text(size = 12)) +
  theme_pubr() +
  theme(legend.position="right") +
  #facet_grid(~ basin) +
  guides(fill = guide_legend(reverse=TRUE)) +
  scale_x_continuous(breaks = c(1980,1985,1990,1995,2000,2005,2010, 2015, 2020),
                     labels = c("1980", "1985", "1990", "1995", "2000", "2005",
                                "2010", "2015", "2020"))
ARYrly
ARYrlyv2 <- ggplot(df1) +
  geom_histogram(aes(x = wy), binwidth = 0.5) + #count of #of ARs by year'
  #geom_density(aes(y=..count../10)) +
  labs(x = "Water Year", y = "Number of ARs, n=913") +
  theme(axis.text = element_text(size = 12)) +
  theme_pubr() +
  scale_x_continuous(breaks = c(1980,1985,1990,1995,2000,2005,2010, 2015, 2020),
                     labels = c("1980", "1985", "1990", "1995", "2000", "2005",
                                "2010", "2015", "2020"))
#2nd AR figure: IVT and Mean of total ARS  - dashed blue line is mean
IVTmn <- gghistogram(df1, x = "Total_IVT", bins = 50,
            fill = "#0073C2FF", color = "#0073C2FF",
            add = "mean", rug = TRUE) + #shows mean IVT value
  #facet_grid(~ basin) +
  labs(x = "Daily maximum total IVT", y = "Number of ARs, n=914")
IVTmn
```

```
#****3rd AR figure: scatter plot of all ARs over time with regression line for each
category
arScat <- ggscatter(df1, x = "wy", y = "Total_IVT", color = "intensity",
          palette = "Dark2",
          shape = "intensity", legend = "bottom",
          legend.title = "AR intensity",add = "reg.line", conf.int=TRUE) +
    #facet_grid(~ basin) +
    scale_x_continuous(breaks = c(1980,1985,1990,1995,2000,2005,2010,2015,2020)) +
    scale_y_continuous(breaks = c(500,1000,1500, 2000)) +
    labs(x = "Water year", y = "Maximum daily IVT")
arScat
df1$Total_IVT <- round(df1$Total_IVT, digits=0)
df1
scatEq <- ggscatter(df1, x = "Date", y = "Total_IVT",  #to find slope, r2, and p
values of each scale
                    palette = "jco",
                    add = "reg.line") +
  stat_cor(aes(label.y = 1500,
               label = paste(..rr.label.., ..p.label.., sep = "~`,`~")),
           label.x = 500
  ) +
  stat_regline_equation(label.y = 1500, label.x = 500) +
  facet_wrap(~intensity)
scatEq
fig5 <- ggarrange(ggarrange(ARYrly, IVTmn,  ncol = 2, labels = c("(a)", "(b)")),
arScat,
                  labels = c("","(c)"), nrow = 2)
fig5
###Part3: Timing of ARs and floods
catRisk <- cut(df1$Total_IVT, breaks=c(250,750,2000),
              labels=c("Beneficial", "Hazardous"),
              right=FALSE)
df1$Total_IVT[1:10]
catRisk[1:10]
Risk <- cut(df1$Total_IVT, breaks=c(250,750,2000),
                labels=c("Beneficial", "Hazardous"),
                right=FALSE)
df1$Total_IVT[1:10]
Risk[1:10]
```

```
df1$risk <- with(df1, Risk) #add "risk" column to df
colnames(df1)
#****1st figure for part 3: # of ARs in each risk level
gghistogram(df1, x="risk", stat="count", binwidth = 0.5, fill="risk",
                      xlab="AR risk category",
            ylab = "ARs, 1980-2019, n=913", legend="right", legend.title="Risk",
            palette = "jco")
arRisk <- ggplot(df1, aes(x= risk, fill=basin)) +  #percentage plot showing Basins
  geom_bar(aes(y = (..count..)/sum(..count..))) +
  scale_y_continuous(labels=scales::percent) +
  scale_fill_discrete(name = "Watershed", labels = c("San Joaquin, n=431",
"Sacramento, n=483")) +
  theme_pubr() +
  theme(legend.position="right") +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  labs(x= "AR risk category", y = "Relative frequency of ARs, 1980-2019")
arRisk
#Create interval period for flood dates to include previous 14 days
combinations <- expand.grid(df1$Date, df2$nFlood_date)
matches <- combinations[combinations[,2] >= combinations[,1] & combinations[,2] -
combinations[,1] <= 14,]
colnames(matches)[1] <- "Date" #rename column
colnames(matches)[2] <- "nFlood_datev2"
#join df1 and matches to add AR details to interval period dates
df_jn <- full_join(df1, matches, by = "Date", copy = TRUE)
myvars2 <- c("nFlood_datev2", "risk", "Total_IVT", "wy", "lfloc_lat",
             "nlfloc_lon", "basin")
df3 <- df_jn[myvars2] # new df
df3 <- df3 %>%  #subset daily max IVT
  mutate(Date = as.Date(nFlood_datev2)) %>%
  group_by(Date) %>%
  filter(Total_IVT == max(Total_IVT))
distinct_df3 <- dplyr::distinct(df3) #remove duplicate rows to show single flood date
distinct_df3 <- distinct_df3 %>%
  drop_na()
fld_jn <- full_join(df2, distinct_df3, by = "Date", copy = TRUE)  #join floods that
occurred in hazardous period with total floods
#****2nd figure for part3: Number of floods within 2 weeks of ARs showing risk level
of the AR
```

```
fldRisk <- gghistogram(fld_jn, x="risk", stat="count", binwidth = 0.5, fill="risk",
xlab="AR risk category",
                        ylab = "Floods, 1980-2019, n=57", legend="right",
legend.title="Risk",
                        palette = "jco") +
  scale_fill_discrete(name = "AR risk level", labels = c("Beneficial, n=13",
"Hazardous, n=35", "Non-AR=9")) +
  theme(axis.text.x = element_text(angle = 45, hjust = 1))
fac_names <- c("San Joaquin" = "San Joaquin, n=12",
               "Sacramento" = "Sacramento, n=36",
               "na" = "Non-AR, n=9"
               )  #add text to facet
fldRisk2 <- fldRisk +
  facet_grid(~basin, labeller = as_labeller(fac_names))
#remove NA from risk cat. These are floods that happened w/o an AR. Label NA in facet
grid as such.
fig6 <- ggarrange(arRisk, fldRisk2,  ncol = 2, labels = c("(a)", "(b)"))
fig6
fig7 <- ggplot(fld_jn, aes(x=condition, y=nFlood_date, fill=basin)) +
  geom_boxplot() +
  geom_jitter(aes(color=risk, shape = risk),width = 0.2, size =2) +
  scale_fill_discrete(name="Watershed") +
  scale_shape_discrete(name="AR risk level", labels=c("Beneficial", "Hazardous",
"Non-AR")) +
  scale_color_manual(values = c("#000000", "#000000"), guide=FALSE) +
  labs(x="Flood outcome", y="Water year") +
  facet_wrap(~basin) +
  theme(axis.text.x = element_text(angle = 45, hjust = 1)) +
  scale_x_discrete(limits=c("Temporary failure", "Permanent failure", "No failure"))
+
  theme(legend.position="right")
fig7
```

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