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Assessment of Coastal Flood Communication Mechanisms: A Case Study in Imperial Beach, California

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Master of Advanced Studies in Climate Science and Policy

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Caldwell, P. C., M. A. Merrifield, P. R. Thompson (2015), Sea level measured by tide gauges from global oceans — the Joint Archive for Sea Level holdings (NCEI Accession 0019568), Version 5.5, NOAA National Centers for Environmental Information, Dataset, doi:10.7289/V5V40S7W.

ABSTRACT:

As rising sea levels are anticipated to threaten coastal communities around the world within the next century, many low-lying coastlines are already experiencing threats of coastal flooding. The scientific research community is contributing to our understanding of these hazards by collecting data on historically significant flood events, developing short-term flood forecasting models, and projecting future coastal flood risks and vulnerabilities that combine with rising sea levels. For coastal leaders, hazard managers, planners, and residents, effective communication of this data is important to how well it is applied to local impacts, policies, and adaptive measures. A number of U.S. government agencies (e.g., NOAA, NASA) have developed educational guidelines and data mapping tools to enhance understanding of science and coastal flood risks. However, these resources often require a general understanding of flood science, coastal oceanography, or climatic influences. Accessible online communication tools can provide a public benefit by increasing community risk perception and engagement, but these resources should understand their specific audience needs to ensure that relevant language, data, and local priorities are incorporated. In Imperial Beach, California, the low-lying coastal city currently experiences occasional coastal flooding during periods of high tides concurrent with winter storms or large wave events. To better prepare and mitigate the impacts of these events, the City of Imperial Beach has become a longstanding collaborator with the Scripps Institution of Oceanography. This partnership has led to increased technical guidance and support, as well as an abundance of Imperial Beach coastal flood data. Utilizing the flood risk science available in Imperial Beach, this research project sought to work with city staff to identify opportunities and limitations of communicating flood risk in Imperial Beach. The research design included four components. First, a review of flood risk literature and three types of flood risk communication available for Imperial Beach: historical flooding, short-term flood forecasting, and projections of future flood frequency. An ArcGIS storymap was then developed compiling and demonstrating potential methods for communicating Imperial Beach flood risk data in a centralized and publicly accessible format. The storymap was used to facilitate an informal interview and survey with Imperial Beach staff to obtain input on the utility and effectiveness of flood risk communication formats. Finally, an analysis of limitations and opportunities was conducted based on climate risk communication literature and input received from Imperial Beach government staff. This assessment found that communicating historical flood data that could be validated using in-situ observations such as images, videos, or other media was effective for communicating past events. However, historical flood risk communication could be improved if it better described what the different coastal flood drivers were. The short-term flood forecasting system was found to be useful in increasing collaboration between researchers and city officials, as well as increasing hazard response capabilities. However, future workshops between specialists and the public could increase public understanding and engagement, while offering feedback and validation of forecasting models and warning systems. Future projections of sea level rise and coastal flooding communication often relies too much on projections of worst-case scenarios in

the long term (100+ years into the future). Additionally, flood frequency projection tools were useful for establishing a future timeline of increasing flood events, but inconsistent vocabulary defining flood days and events may complicate communication. Future coastal flood research projects could significantly benefit from increased stakeholder engagement, and relying on a bottom-up approach to communication and educational resource development.

INTRODUCTION:

When considering future risks of sea level rise (SLR) in the face of a changing climate, understanding how to best articulate and disseminate coastal flood science and impacts to those who most directly experience, respond to, and plan for these events is critical. Different stakeholders may include public safety and emergency management groups, city planning, leadership, or local residents who are most vulnerable to coastal flood risks. While researchers are continuing to advance data and models to better comprehend coastal flood drivers and impacts, the science is often technical and requires a relatively robust comprehension of global, regional, and local climatic and oceanic influences. Many U.S. federal agencies such as NOAA, NASA, and USGS have attempted to simplify the science of sea level rise and coastal flooding through educational resources and data visualization tools. However, the use of different methodologies and inconsistent vocabulary can often convolute public communication. Although these different methodologies are all valuable in the coastal flood communication toolkit, there is an urgent need to simplify coastal flood communication in a way that portrays risks as they are relevant to the public and those who respond to and plan for coastal flood hazards.

Southern California's coastal communities continue to face threats such as sea level rise, bluff and beach erosion, property and infrastructure damages, and increased flooding and inundation. As coastal planners begin to address these issues, it is vital that these communities understand the risks and potential action that may be necessary. In the low-lying community of Imperial Beach, California (Imperial Beach), roads, public transit, wastewater and stormwater infrastructure, homes, and schools are projected to be impacted by sporadic, few-hour, wave-driven coastal flooding events (Revell et al. 2016). Short-term solutions such as beach nourishments, groins, Tijuana River management, or other coastal armoring techniques have been implemented or proposed over the years (Revell et al. 2016). However, as sea level rise-induced high tide flooding is expected to impact California's coastal cities almost daily by 2100, communities must be able to better predict and understand these extreme water level events (Thompson et al. 2021).

METHODOLOGY:

The primary objectives of this capstone research were to determine how coastal flood risk data is being communicated to Imperial Beach; the effectiveness of these communication mechanisms for education, hazard preparedness, and planning purposes; and challenges and opportunities for improving the communication of flood risk data. A variety of methods were used to conduct this research. These included (1) a review of flood risk literature and flood risk tools available for Imperial Beach, (2) the development of an ArcGIS storymap compiling and demonstrating potential methods for communicating Imperial Beach flood risk data in a centralized and publicly accessible format, (3) an informal interview and survey with Imperial Beach staff to obtain input on the utility and effectiveness of flood risk communication formats; and (4) an analysis of limitation and opportunities based on climate risk communication literature and input received from Imperial Beach government staff (Figure 1).

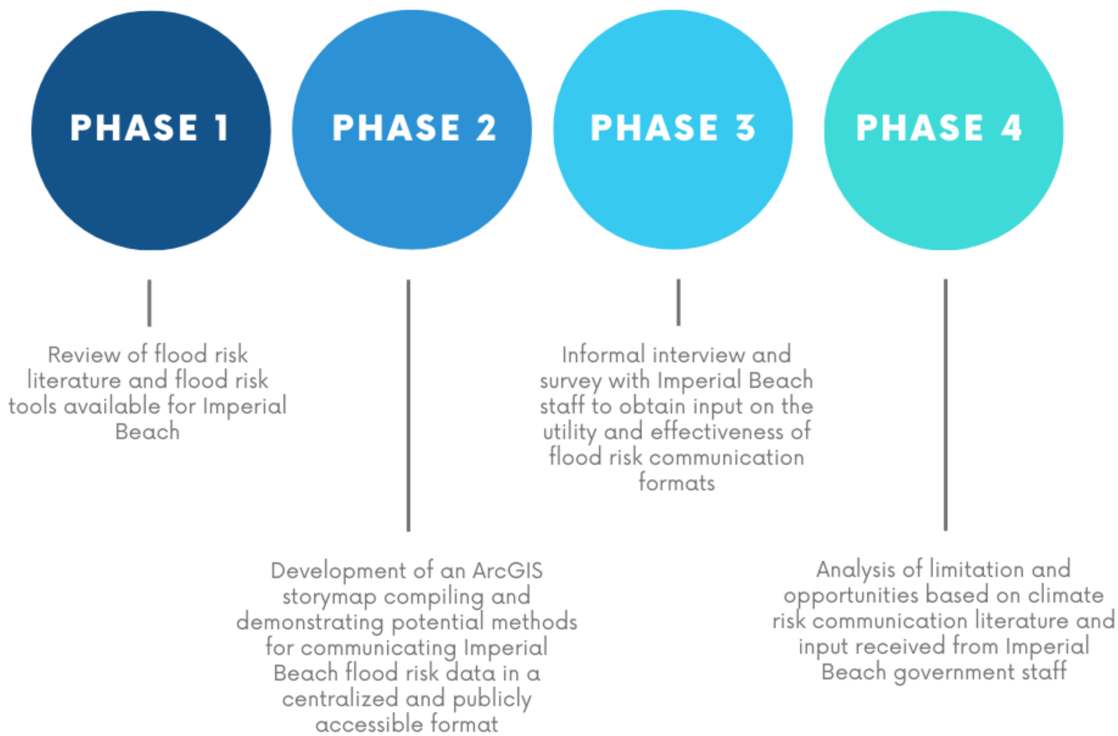


Figure 1: Assessment phases - (1) a review of flood risk literature and flood risk tools available for Imperial Beach, (2) the development of an ArcGIS storymap compiling and demonstrating potential methods for communicating Imperial Beach flood risk data in a centralized and publicly accessible format, (3) an informal interview and survey with Imperial Beach staff to

obtain input on the utility and effectiveness of flood risk communication formats; and (4) an analysis of limitation and opportunities based on climate risk communication literature and input received from Imperial Beach government staff.

Scripps Institution of Oceanography (SIO) has developed a long-lasting partnership with the City of Imperial Beach (Imperial Beach). This relationship utilizes the vast resources and research capabilities of SIO to provide technical assistance to Imperial Beach in better preparing and mitigating coastal flood impacts on their community. To assess communication of past, present, and future threats of coastal flooding, this project divides communication into three major components: historical flooding, short-term flood forecasting, and projections of future flood frequency. Access to historical and short-term forecast data paired with San Diego sea level rise projections makes Imperial Beach a unique case study in how these three components of coastal flooding are communicated to the public. Using Imperial Beach as a case study for assessing coastal flood communication mechanisms allows us to gather information on effective risk communication and perception, data synthesis and delivery, and community engagement and action. To understand the communication of extreme water level events to the Imperial Beach community, this project seeks to work in collaboration with the local stakeholders of Imperial Beach to identify where ingenuity gaps exist, how data dissemination and early flood warning systems can be improved, and how past and present flood data can be used as references for future projections of sea level rise and flood frequency.

(1) Review of flood risk literature and flood risk tools available for Imperial Beach:

The first phase of the project was a review of available literature and online coastal flood data visualization tools that were currently available in Imperial Beach. To assess communication of past, present, and future threats of coastal flooding, this project differentiated communication into three major types: historical flooding trends, short-term flood forecasting, and projections of future flood risks (frequency, water levels, and flood extent).

Information on historical flooding was compiled by SIO Coastal Processes Group researchers and consisted of simulations of historical total water levels (TWL) at four Imperial Beach sites at the End of Seacoast Drive, Encanto Avenue, Descanso Avenue, and Cortez Avenue (Figure 2). The historical data was compiled by SIO based on historical data on wave height and wave period collected since 2000. This wave data is paired with a static beach slope to simulate the historic hourly wave runup. The communication of this historical flood data was provided through the Imperial Beach Resilient Futures online tool. This tool allows users to navigate through past events to observe photos and videos of significant flooding events while viewing the total shoreline water level (TWL) model of that event (Figure 3). TWL is a metric that describes the combination of SLR, climatic and seasonal cycles, oceanic eddies, storm surge, and local waves. In California, the total water level is primarily defined by local wave effects (Serafin et. al 2017). Thus, TWL used in the Imperial Beach Resilient Futures tool was calculated by adding hourly tides and wave runups from 2010 through 2019. Events that could be validated by photos or videos were then highlighted.

MOP Transect	Location	Mild Threshold	Moderate Threshold
D0038	End of Seacoast Drive	3.1 meters	4.6 meters
D0041	Encanto Ave	3.2 meters	4.7 meters
D0043	Descanso Ave	3.0 meters	4.5 meters
D0045	Cortez Ave	2.7 meters	4.2 meters

Figure 2: Imperial Beach Study Site Locations - These sites have been identified as areas particularly vulnerable to coastal flooding and contain both mild and moderate thresholds. These thresholds are based on the maximum sea level at the shoreline.

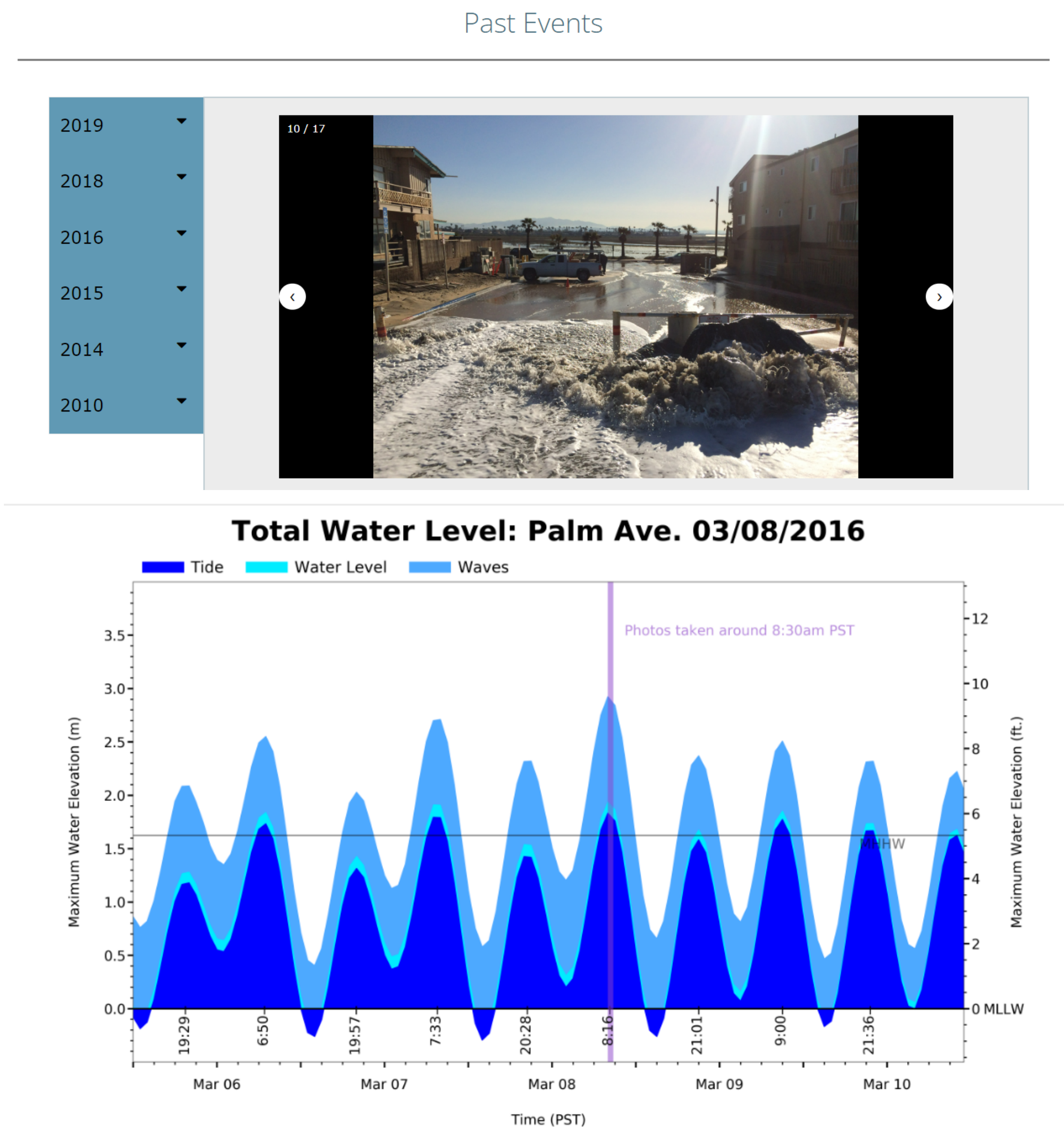


Figure 3: Imperial Beach Resilient Futures Tool - This tool allows users to view past coastal flood events in Imperial Beach through images, videos, and water level records. Shown above is a flood event documented on March 8, 2016.

In collaboration with Imperial Beach, SIO's Coastal Processes Group has created an early warning system for coastal flooding that allows for better understanding and notification of flood forecasting. [This short-term forecast system]() is used to help Imperial Beach better plan for present or short-term risks of coastal flood hazards. This prediction model also utilizes measurements of TWL outlined above. Using wave forecast data in combination with in-situ observations can help validate these predictions and thresholds (Merrifield et al. 2021).

For future flood risks, several resources exist. In 2016, Imperial Beach released the Imperial Beach SLR Vulnerability Assessment (Revell et al. 2016). This report represents an assessment of flooding risks based on sea-level rise projections and coastal storms. It includes maps of potential inundation and estimates of roads, infrastructure, and community assets. Through the development of Imperial Beach's SLR Vulnerability assessment, coastal flood risks were also communicated through a series of educational public workshops.

In addition to resources available to Imperial Beach, many publicly-available coastal flood projection tools communicate future coastal flood risks. These tools primarily utilize SLR projections to showcase flood extent, frequency, and water level changes. More comprehensive tools also focus on education to the general public or emphasize the socioeconomic impacts of different flood risk scenarios. This study primarily assessed the following online flood risk communication tools: (1) Surging Seas: Risk Finder; (2) NASA: Interagency Sea Level Scenario Tool; (3) NASA: Flooding Days Projection Tool; (4) NOAA: Sea Level Rise Viewer; (5) U.S. High Tide Flooding Probability Scenarios Through 2100; and (6) United States Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS): Our Coast Our Future. These tools allow end-users to explore a variety of information relevant to future SLR projections at different locations. This study explored the limitations and opportunities of using these tools to explore and communicate flood risks in Imperial Beach.

1. *Surging Seas: Risk Finder: This tool focuses on mapping the extent of future flooding or inundation in various sea-level scenarios, and highlights potential socioeconomic vulnerabilities. This resource is catered to a wider audience and offers resources for public education and addresses real-world applications to flood risks.*

2. *NASA: Interagency Sea Level Rise Viewer: This tool showcases the change in sea level in feet under different emission scenarios.*

3. *NASA: Flooding Days Projection Tool: This tool allows-end users to assess future flood risk in terms of flood frequency. The Flooding Days Projection Tool defines 'flood days', 'flood thresholds', and 'tipping points' of different SLR scenarios to assist coastal planners understand timelines of increased flood frequency, and better plan accordingly.*

4. *NOAA: Sea Level Rise Viewer: NOAA's SLR Viewer allows users to explore the mapped extent of sea level rise, high tide flooding, marsh migration, and vulnerable populations.*

5. *U.S. High Tide Flooding Probability Scenarios Through 2100: This tool utilizes XY point data at different locations to synthesize projections of high tide flood frequency projections in terms of 'flood day' counts.*

6. *USGS CoSMoS: Our Coast Our Future: This tool utilizes a comprehensive simulation framework to showcase flooding, coastal erosion, and rising groundwater risks of various sea level scenarios. This tool also allows users to explore relevant sea level rise and flood risk science resources.*

While some tools offered an introduction and general education about coastal floods, others delivered a more technical approach for specialists interested in assessing flood risks. Although different resources can be useful to different audiences, few tools consolidate key components of historic flood events, short-term forecasts, and future flood risks in a way that is accessible to a wider audience. A review of these communication resources identified some best practices and limitations of communicating coastal flooding based on the subjects of risk perception and communications, effective data synthesis and delivery, and community engagement and action. Based on these findings, this project developed a demo tool that could consolidate and synthesize Imperial Beach flood risk science for the public.

(2) Development of an ArcGIS storymap compiling and demonstrating potential methods for communicating Imperial Beach flood risk data in a centralized and publicly accessible format:

An online ArcGIS StoryMap and interactive web tool called 'Flood-Ready IB' was constructed containing sections for general education and introduction of coastal flooding in Imperial Beach, historical flooding, short-term flood forecasts, and future flood frequency.

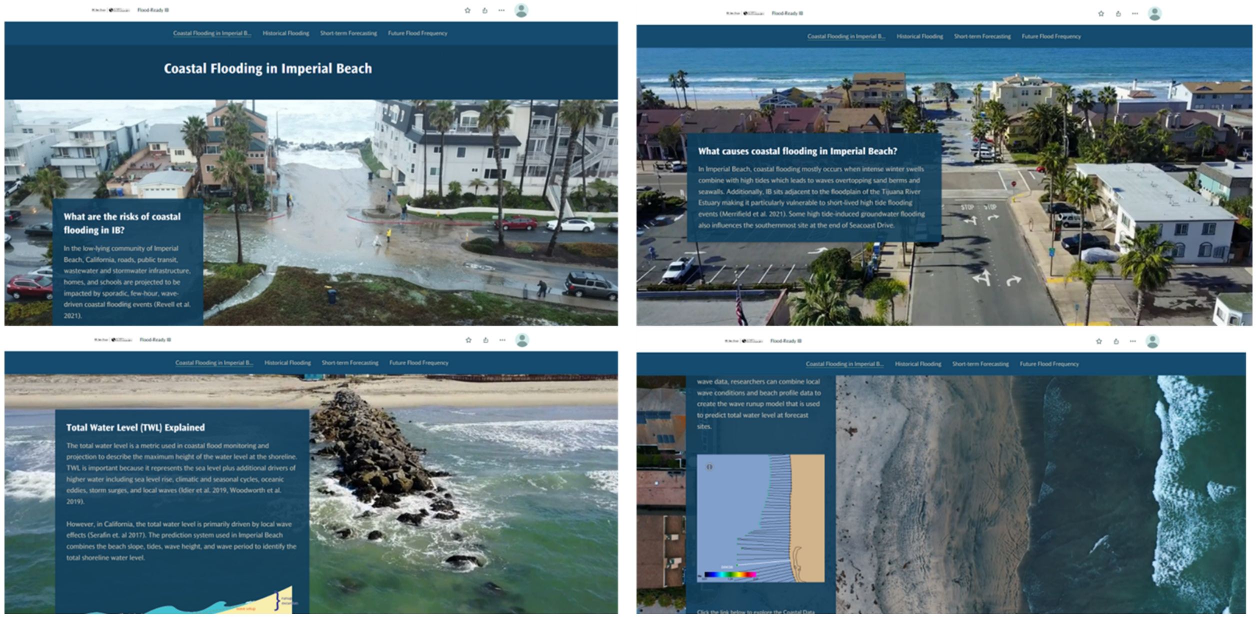


Figure 4: The introduction section explained the risks of coastal flooding as they pertained to Imperial Beach, offered educational information regarding coastal flood measurements like TWL, and highlighted SIO's Imperial Beach research and methodologies.

Figure 5: The historical component of this online tool utilized TWL data from the 22-year period of 2000 through 2022. This data was collected through the Coastal Data Information Program (CDIP) MOPS (O'Reilly 2016) network at the four sites outlined above (Figure 2), and tide data collected at the La Jolla Tide Gauge. Hours that exceeded minor or moderate thresholds were added to an interactive historical timeline data tool which allowed users to navigate periods of coastal flooding.

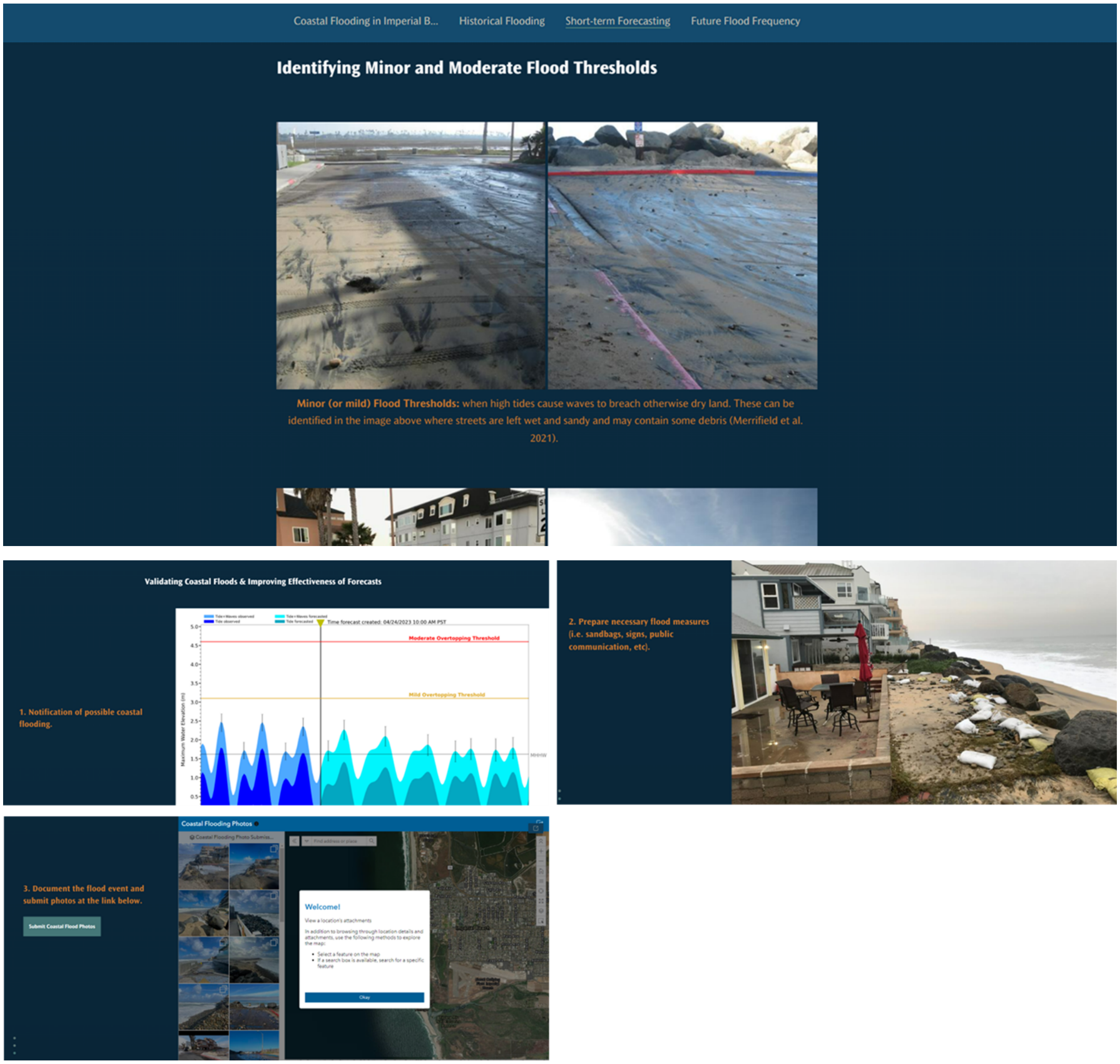


Figure 6: The short-term flood forecast section served as an interactive guide for coastal managers and planners and explained how the flood forecast system works, the physical characteristics that describe mild or moderate flooding, and how the system can be improved through flood validation and feedback.

Figure 7: Finally, the future flood frequency section used the historical data as a baseline for what to expect with an added projection of SLR. This section used the 22-year period to show past flood frequency compared to flood frequency with 1 meter of projected sea level rise.

While this data tool was meant to serve as an educational resource for the public and Imperial Beach staff, this phase was also intended to serve as a starting point for understanding educational gaps, identifying what the City of Imperial Beach felt was valuable or useful data, and how elements of coastal flooding could be better communicated. Following the stakeholder engagement phase of the project, feedback from city officials was meant to restructure the direction and use of Flood-Ready IB.

(3) Informal interview and survey with Imperial Beach staff to obtain input on the utility and effectiveness of flood risk communication formats:

Once initial prototypes of the geospatial tools were complete, they were presented to various staff in Imperial Beach to identify where improvements in accessibility can be made. Additionally, this meeting allowed a collaborative dialogue to identify where science communication, data dissemination, and public education can be improved within the community of Imperial Beach. The feedback session consisted of both Chris Helmer, Director of Environment & Natural Resources (ENR), and Meaghan Openshaw, Director of Community Development (CD). The meeting began by focusing on the currently available online data tools, the current Imperial Beach coastal flood forecast, and the beta stage of Flood-Ready IB. After the data tool feedback session, the following questions helped guide an informal discussion of Imperial Beach flood communication:

1. ***What is your role in assisting with coastal flood events?***
    a. ***How does this typically impact your day-to-day schedule?***
    b. ***What is your main priority when it comes to responding to flood risks? (i.e. businesses, residential, infrastructure, municipal, etc.)***

2. ***Are we seeing more days/hours of flooding? Is flooding occurring in more areas of the city?***
    a. ***If yes, then where? What gives you the impression that this is happening?***

3. ***How are you currently using the Imperial Beach flood forecasting system?***
    a. ***How is this tool helpful to you in your position?***
    b. ***What would you like to see improved?***
    c. ***Are you looking at it 3-5 days in advance to help prepare?***
    d. ***Do you rely on email alerts or the website? Is it easy to navigate?***

4. ***How would you describe mild flooding? Moderate flooding? (i.e. is there pooling on Seacoast?, Cobbles, and debris in the road?; Are there public safety concerns?)***
    a. ***Are there considerations related to how many areas flood or the depth of the flood?***
    b. ***How does the duration of flooding impact your work? (i.e. is flooding more than 1 hour in a single day more significant than shorter floods multiple days in a row?)***
    c. ***Do you have a sense of when flood levels require heavier equipment, and more staff to clean up? What are the conditions that require more work?***

5. ***Which of the following is the most valuable and relevant information to share in your job/position (Multiple Choice)?***
    a. ***Early warning systems.***
    b. ***Historical flood events (i.e. most extreme water levels, flood days or hours).***
    c. ***Where locations are most vulnerable to flood drivers like waves, tides, or groundwater.***
    d. ***Future projections for how flood frequency is likely to increase with SLR.***

6. ***What do you feel are the most effective methods for communicating flood risks and notifications (i.e. face-to-face, email, TV, Phone/SMS, Social Media, or Web sites and applications)?***
    a. ***Are notifications best communicated using written warnings, infographics, photos and videos, data, or flood maps?***

7. ***How do you feel research can be better communicated to those of you responding to or planning for coastal floods?***
    a. ***Are there ways to increase the ongoing dialogue between stakeholders and scientists?***

(4) Analysis of limitations and opportunities based on climate risk communication literature and input received from Imperial Beach government staff:

In addition to the feedback gathered in our discussions with Imperial Beach staff, this project evaluated broader literature on climate risk communication. Through a literature review and collaboration with ENR and CD departments, this project was able to identify several recurring themes around coastal flood risk communication practices and opportunities for improvement.

Three prevalent themes are described in the findings below for historical, current, and long-term flood communication tools.

RESEARCH FINDINGS:

Historical Flooding Trends:

Historical flood data can provide real-world examples of specific flood risks that can be tied to individual or community lifestyles and livelihoods (Agyeman et al., 2007). Understanding the consequences of the past is an effective way for communicators to understand what the community values most, how prepared they are to respond to flood events, and how willing they are to implement adaptive solutions. Risk perception is often stronger when communities have experienced floods in the past, and individuals who are particularly vulnerable are more likely to consider threats of a potential flood hazard (Kuller et al. 2021). Historical data can also serve as a valuable baseline for planning for future flooding. Presenting flood data of the past can help shift the perception that coastal floods and climate change are distant phenomena, which can increase community member participation (Akerlof et al. 2017). Communicators and leaders should understand the different types of biases, perceptions, common language, and audiences of a community when communicating risks (NOAA, n.d., 2023).

This project analyzed both the content available on the Imperial Beach Resilient Futures tool as well as a compiled 22-year dataset of TWL (2000 - 2022) at the four study site locations. TWL data from both the online tool and the 22-year dataset were calculated with the same hourly tide and wave runup models. The historical dataset was filtered based on site-specific minor and moderate flood thresholds to identify hours where flood thresholds were exceeded. Through this analysis, flood thresholds were found to be frequently exceeded, overestimating observed flood records.

The historical data utilized in this study were intended to be used as a reference to past floods that have occurred in recent decades. SIO's model for wave runup used a static (unchanging) beach slope which led to an overestimate of flood frequency during the 22-year period (Figure 8). Additionally, SIO's historical dataset focused on flood impacts from wave and tide-driven flooding, and Imperial Beach is also subject to other flood drivers such as groundwater flooding and potential storm surge. Therefore, coastal flood simulations may also have the potential to underestimate these floods if multiple drivers coincide with one another. One of the major challenges associated with communicating coastal floods in Imperial Beach is the ability to communicate these different types of flood drivers. In Imperial Beach, many residents have experienced some form of coastal flooding. Most of that flooding is minor, but occasionally El Niños, high tides, winter swells, or other storms combine to bring large high-energy wave impacts to the coastline resulting in more moderate to severe flooding (Merrifield et al. 2021). ENR Director, Chris Helmer, emphasized that most severe flooding occurs when high tides overlap with El Niños, winter storms, or extreme wave events, and that specifying flood driver variability or which severe floods are due to these compound events often makes it complicated to communicate risks. This tendency to look to past experiences may result in different interpretations of flood events and risks, so understanding these varying perspectives is an important step in communicating coastal flood risks.

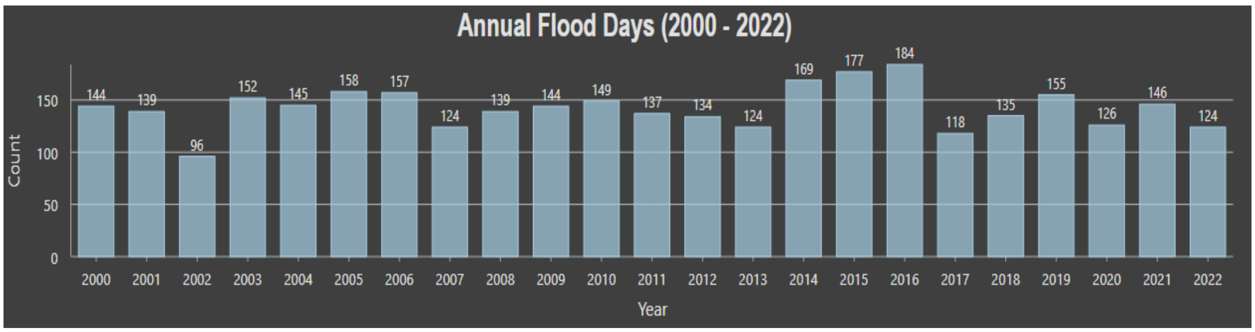


Figure 8: Historical Flood Days (2000 - 2022) - Flood days were established as sea level events exceeding minor or moderate thresholds at one or more sites for more than one hour.

Through observing an overestimated flood frequency in our 22-year period, we were able to acknowledge another unique communication challenge. When using historical data to simulate coastal flood events of the past, it is vital to validate these events based on in-situ observations. The Imperial Beach Resilient Futures tool avoided such estimations by focusing on flood events that could be validated by photos, videos, or other observation records. Thus, the online tool was able to showcase a historical record of flooding while understanding the limitations of static simulation variables. Additionally, when presenting flood data to Imperial Beach staff, the teams suggested that photos and videos of past flood events along with simplified infographics better served their purpose of communicating complex concepts and past coastal flood events, and Imperial Beach Resilient Futures was also successful in synthesizing data of past events. Ultimately, maps and graphs tend to be less intuitive and impactful than photographs, videos, or illustrations (Campbell et al. 2020), so using more visual rather than quantitative methodologies may better communicate the historical flood events to a wider audience. Historical storytelling that utilizes real-life observations such as photos, videos, or other in-situ observations is also able to present the whole sequence of events rather than maps or models which often do not accurately represent the event's duration or magnitude (de Bruijn et al. 2016).

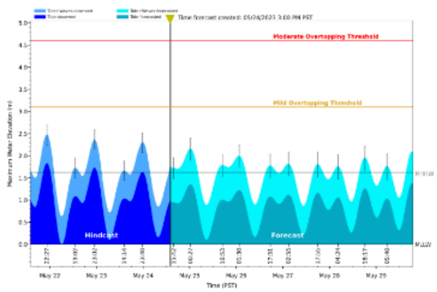
Short-Term Forecasts:

Imperial Beach

Click plots to view larger in browser (see all IB flood forecasts online **here**)

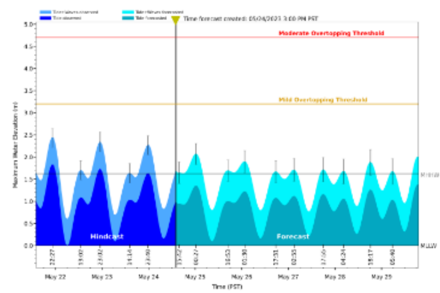
End of Seacoast Drive:

4/3/2023 21:03 PST: *possible mild flooding*



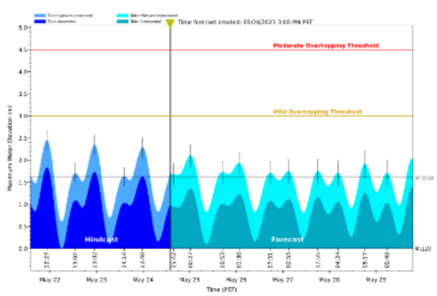
Encanto Avenue:

4/3/2023 21:03 PST: *possible mild flooding*
4/4/2023 8:54 PST: *possible mild flooding*



Descanso Avenue:

4/3/2023 21:03 PST: *possible mild flooding*
4/4/2023 8:54 PST: *possible mild flooding*



Cortez Avenue:

4/3/2023 21:03 PST: *possible mild flooding*
4/4/2023 8:54 PST: *possible mild flooding*
4/4/2023 21:21 PST: *possible mild flooding*

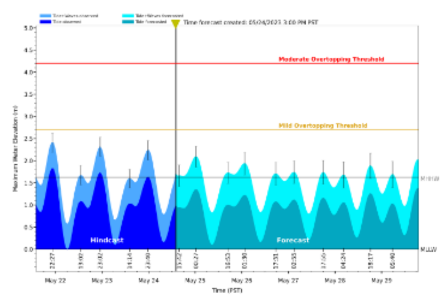


Figure 9: Imperial Beach Early Flood Warning System - End-users receive email notification with the subject of "Possible Coastal Flooding: Imperial Beach". Site-specific models showcase events where the total shoreline water level exceeds mild or moderate thresholds.

The early warning system in Imperial Beach has offered a new opportunity for coastal stakeholders to identify coastal flood risks and how to respond accordingly. This system combines and analyzes global, regional, and local wave and tide conditions to better understand potential coastal impacts at the Imperial Beach forecast sites. Pairing global and regional observations helps identify possible swell events that may reach the area, and modeling local waves can provide general information on wave conditions. By collecting both offshore and nearshore wave data, researchers can combine local wave conditions and beach profile data to create the wave runup model that is used to predict total water level at forecast sites. When the total water level exceeds mild or moderate thresholds, coastal researchers and Imperial Beach city officials are notified five days ahead of time (Merrifield et al. 2021).

Ultimately, the warning system was found effective in planning for potential flood hazards in Imperial Beach as the departments suggested that this data allowed sufficient time for planning and response. Imperial Beach staff described that these regular automated emails served as a useful tool for early notification which could be forwarded to their public safety team. For mild events, Imperial Beach city staff would put out signage to notify residents of road closures or potential hazards. When more severe events were forecasted, public safety teams were notified and engaged in an emergency preparedness plan, and occasionally several departments became involved. This allowed them to establish a potential plan and discuss internally as the event approached whether or not the on-the-ground conditions warranted more significant measures. While the tool was useful for enhanced planning and response, two key opportunities for improvement were identified by Imperial Beach staff. Specifically, they hoped to better articulate flood threshold definitions and expand public awareness of forecasting capabilities and present-day flood risks. The Imperial Beach staff further suggested that enhanced collaboration or regular workshops between researchers, city responders, and the public could help with these improvements.

While early flood warning systems offer language and insight into a flood risk, confusion about what defines a mild or moderate flood can further complicate the perception and response to different flood magnitudes. For Imperial Beach, Merrifield et al. defined mild or minor floods as an event where high tides cause waves to breach otherwise dry land leaving streets wet, sandy, or with some debris. Moderate to severe flooding were characterized by significant sand, debris, and traffic disruptions on Seacoast Drive that may require bulldozers for clean-up (Merrifield et al. 2021). These definitions are a useful first step for communicating the physical conditions of coastal flooding, but Imperial Beach staff highlighted concerns that changing offshore and nearshore topography might alter the future impacts of different flood magnitudes. Helmer specified that flood events have already transitioned from a maintenance nuisance to a public hazard as more frequent cobble-exposed beaches present the added threat of waves causing aerial cobbles. Currently, when thresholds are exceeded, SIO researchers or Imperial Beach staff will document anticipated events to observe if thresholds were exceeded and the subsequent conditions of a flood event. Collaboratively discussing these observations post-flood events can serve as a way to improve and evolve threshold models and heights, including adapting minor and moderate flood definitions.

Currently, the Imperial Beach flood warning system is sent to researchers and city coastal specialists. Should this information be made more widely accessible to the public, more clear and simplified communication methods may be required. Kuller et al. emphasize that effective flood warning systems should provide concise and easily accessible data that is paired with written warnings, graphics, maps, or other visuals (Kuller et al. 2021). Based on these recommendations, the current short-term forecast approach of simplified written warnings paired with easily comprehensible TWL data diagrams (Figure 9) effectively communicated forecasted flood warnings. However, flood warnings can often fail in their ability to be received, comprehended, or trigger actions. Imperial Beach staff emphasized that wider communication of flood risks could be enhanced through more frequent workshops and town halls led by SIO experts. They described that opportunities for public education and risk communication were better communicated through experts than through Imperial Beach leadership and government staff. Kuller et al. found that flood warnings and risk communication from a trusted expert strengthened hazard response, while occasional lack of trust from local government authorities can lead to a weak interpretation of warnings (Kuller et al., 2021). For more wide communications to the public, educational workshops with multiple stakeholders can help describe the science of forecast models, the benefits of their use, and their potential limitations. Additionally, these feedback sessions or collaborative community meetings can also offer insight into thresholds through community science participation. Researchers suggest that citizen science projects have the potential to increase flood risk awareness and motivate participation in data collection (Cheung & Feldman, 2019). Since the established Imperial Beach flood thresholds are constantly evolving, they rely on in-situ observations and validation from those experiencing flood events. By explaining the forecast system in workshops, researchers can utilize observations to better understand definitions of different magnitudes of flooding and improve their early detection. Cheung and Feldman further explain that collaboration with residents and relevant stakeholders helps create a two-way dialogue that can help understand specific concerns about flood hazards, and their involvement in the data collection allows ongoing monitoring of current risks and perceptions of current solutions (Cheung & Feldman, 2019). These feedback and collaboration sessions may also offer insight into what different tools, data, and resources researchers and experts can provide departments such as emergency managers, first responders, local officials, and citizen activists (Fuchs, 2012).

Projections of Future Flood Frequency:

Improving communication of past and present risks provides a guideline for describing increased flood risks with future rising sea levels. While coastal flood events are not uncommon in the low-lying city of Imperial Beach, increased sea levels will result in an increased frequency of flood events as high tides, waves, and storm events are more likely to combine and breach existing flood thresholds (Merrifield et al. 2021). As these coastal flood events become more frequent, infrastructure can become overwhelmed, making it much harder to provide solutions. For example, while more minor flood events currently require some additional labor and cleanup, more chronic flooding events can also introduce bacterial contamination and toxic waste (Roesler, 2021). This risk is particularly relevant to Imperial Beach, as the region already experiences pollution from the Tijuana River. Public understanding of how these more minor events limit a community's ability to rebound from increased frequency of flooding can help assist in making projected climate change issues feel more present. In addition, communicating these events as currently manageable can help communities perceive present solutions as tangible and trigger actions. However, communicating climate change-related hazards such as sea level rise often comes with complications, as many perceive these threats as distant in the future, hard to comprehend, uncertain, or intangible. Much like communicating active or historical coastal flooding, communicators should first understand the mental models and knowledge gaps that exist between stakeholders and experts (Covi and Kain, 2015). Finding ways to make these future risks of increased flood frequency relevant to a community's existing perceptions, concerns, and understandings can assist in describing risks as more imminent.

Data modeling and projection tools are a useful way to help end-users identify future flood risks and explore what these vulnerabilities look like under different coastal conditions. For exploring potential flood vulnerability, many tools are available to identify flood extent under varying SLR scenarios. By modeling future flood extent, planners can identify areas that are likely to experience increased hazards and develop adaptive plans accordingly. In recent years, researchers have begun to approach future flood risk in terms of the future frequency of floods. Future projections of flood frequency allow end-users to establish a timeline of when these flood hazards will become more frequent, and explore the local, real-world socioeconomic impacts. By pairing future flood projection tools that are able to both identify potential vulnerabilities in current property and infrastructure, as well as a timeline of when these events become more common, planners have a valuable toolkit for predicting future coastal flooding. Common tools that have mapping capabilities under various SLR scenarios include the Surging Seas: Risk Finder, NOAA SLR Viewer, and USGS CoSMoS: Our Coast Our Future. For assessments of future frequency projections, this assessment focused mostly on the NASA Flooding Days Projection Tool and U.S. High Tide Flooding Probability Scenarios Through 2100.

For this research effort, several tools were reviewed that mapped future flood extent and those that modeled the frequency of flooding days, and were evaluated for how this information was then used or communicated in Imperial Beach. While these mechanisms help further our understanding of how future flooding may impact Imperial Beach, collaboration with Imperial Beach staff identified some limitations in how their teams are able to communicate future risks of coastal flooding. Imperial Beach staff described that these tools often showcase worst-case scenarios for 2100 which can result in feelings of apathy or helplessness. Additionally, while flood frequency data was increasingly valuable from a planning perspective, inconsistent vocabulary between modelers, city staff, and researchers complicates how these metrics were communicated.

As established in the sections above, data delivery and communication are audience-dependent, and many of these tools focus on the potential, but uncertain, worst-case scenarios of sea level rise in 2100 which can make flooding outreach and education less credible. Imperial Beach offices of CP and ENR explained that they were less likely to plan adaptive measures based on more uncertain and extreme scenarios, and instead would prefer to prioritize more regular and realistic impacts that were likely to be seen in the near-term (30 years). In Imperial Beach's stakeholder workshops and subsequent SLR Vulnerability Assessment, projections highlighted extreme scenarios of 2 meters of SLR by 2100. Even future projections highlighted in the Flood-Ready IB tool, using a less extreme scenario of 1 meter of SLR by 2100, were seen as ineffective for communicating future risks by Imperial Beach staff. Additionally, the maps showcased in these communication outlets used the CoSMoS projection tool, which does not account for adaptive measures in the various modeled scenarios. In our stakeholder focus group, Helmer emphasized that not taking into account these measures leads them to be somewhat stuck in time if the static beach or land conditions are not updated. Gallien et al. describe this flood mapping methodology as an 'all-or-nothing' approach where any total water level that exceeds the flood threshold is anticipated to be flooded while areas below the threshold are dry (Gallien et al., 2014). This static approach has the potential to lead to extreme overestimations or underestimations, as realistic circumstances will have much more variation in flood influences.

Many researchers and communicators have attempted to provide frequency metrics or vocabulary that can be used by coastal planners to better identify flood projections. For example, Thompson et al. have tried to bridge these communication gaps by providing a definition of what is considered a 'flood day'. Using this metric, planners can better understand what constitutes a flood day and how that factors into projection timelines. They define a flood day as at least one hour where an hourly sea level event exceeds a relevant flood threshold (Thompson et al., 2021). These projections suggest that flooding will occur almost daily in California by 2100 and will experience a rapid increase in frequency in the coming decades. Communicating when to expect this inflection is valuable for public communication of SLR-induced flooding.

City officials in Imperial Beach highlighted a lack of their ability to communicate when we might expect to see tipping points of increased flooding due to SLR. Understanding definitions of flood days and SLR acceleration "tipping points" have the potential to provide a timeline for coastal flood planning (Sweet & Park, 2014). While Imperial Beach constructs its coastal resiliency plan, transitions from a more gradual to a rapid increase in flood frequency are essential. Thompson et al. projections suggest that while moderate flooding thresholds may occur only about once a year between 2023 through 2033, the following decade is anticipated to increase rapidly to approximately 49 days per year (Thompson et al., 2021). This information is particularly useful from a planning perspective allowing a guideline of when adaptive measures need to be taken. However, since flood days describe any event that exceeds one hour above flood thresholds, this definition may be misleading to coastal planners since one flood day can mean multiple consecutive hours of flooding at several sites or a single hour at a single site. Establishing a common terminology to describe flood frequency is valuable for wider understanding and communication. Otherwise, if the same, or similar, terms are used, this can further confuse messaging when applied to differing methodologies and local values or understanding (NOAA, n.d., 2023). Overall, these tools were found to be an important step toward understanding real-world coastal flood decision-making timelines, but communicators should focus on continually evolving definitions of flood days, and what they mean for future frequency tipping points.

DISCUSSION:

Considering the time and scope of this research, this project is limited in its ability to properly assess all areas of communication of coastal flooding in Imperial Beach. As this study mostly relied on feedback from the Offices of CP and ENR, gathering a more comprehensive stakeholder audience can better assess the communication needs of the wider Imperial Beach community. Nonetheless, this project was able to identify key limitations and opportunities of coastal flood communication through a review of available literature and data visualization tools. A future study could focus on gathering further information on local Imperial Beach public perceptions of coastal floods and available resources.

CONCLUSION:

As researchers seek to communicate coastal flood risks to end-users like coastal planners, hazard managers, leaders, or residents, ensuring that messaging is clear and accessible is crucial. While there is a vast network of educational resources that attempt to synthesize data and make it readily available, many of these tools risk further complicating the science of coastal flooding as they introduce additional language, methodology, or standards of measurement. When communicating to diverse audiences, it is vital that communicators avoid a "one-size-fits-all" approach and instead focus on local risk perceptions. Identifying how a coastal community understands coastal flood impacts on their way of life can serve as the foundation for developing communication strategies and increasing community engagement. Across all three components of historical flooding, short-term flood forecasting, and projections of future flood frequency, applying real-world socioeconomic impacts was a limiting factor in communicating coastal flood risk. Available communication tools currently do not sufficiently translate the available coastal flood science into decision-making relevant to a community's physical and socio-economic risks (NOAA, n.d., 2023). Utilizing historical coastal flood events can be useful in creating a connection and emotional tie between coastal flood risk and real-life experiences (Agyeman et al. 2007; Kuller et al. 2021; NOAA, n.d., 2023; Mazzoglio et al. 2021; Akerlof et al. 2017; de Bruijn et al. 2016). However, in Imperial Beach, historical flood data was unable to provide additional context of what the flood drivers were. In order to combat this, focusing on historical photos, videos, or other storytelling methodologies can both validate these modeled water level events and trigger memories of more significant events to effectively initiate a response. Evaluating the communication used in the short-term forecast system showed that the tool was ultimately useful for fostering collaboration between the researchers and stakeholders, as well as enhancing flood hazard response times. However, communication of short-term forecasts and early flood warning systems could utilize feedback sessions and workshops in the future to better communicate science and improve flood threshold validation. Finally, communicating future projections of flood frequency and sea level rise risks highlighted the largest challenges associated with describing distant climate-related events. Through assessment of resources available in Imperial Beach, flood frequency projections were especially useful for planning, and understanding tipping points of increased flooding was effective for allowing communication of more near-term and comprehensible risks to the public. However, limitations of inconsistent vocabulary surrounding what constitutes a flood day had the potential to convolute flood risk communications between stakeholders. Additionally, Imperial Beach's history of communication of future flood risks and many available projection models had a tendency to highlight worst-case SLR scenarios, where more intermediate or likely scenarios were more effective for public communication of risks. Effective data synthesis should be audience-dependent and consider specific local needs and perspectives. Through assessment of coastal flood communication in Imperial Beach, this research found that a bottom-up approach to risk communication and data synthesis is valuable in identifying how to best communicate coastal flood hazards. As SIO continues to develop its relationship and collaboration with the Imperial Beach, best practices of communication are key to facilitating climate action and coastal flood adaptation and mitigation policy measures.

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