Received: 16 December 2022 | Accepted: 27 August 2024

DOI: 10.1111/1752-1688.13230

AMERICAN WATER RESOURCES ASSOCIATION JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

RESEARCH ARTICLE

User needs for coastal inundation at climate time scales: A multi-sectoral case study in the coproduction of knowledge

Brenna M. Sweetman[1] | **Cayla Dean**[2] | **Lisa Auermuller**[3] | **Kathryn Noel Tremblay**[4] | **Christopher Katalinas**[5] | **Shannan Lewinski**[5] | **Lori Cary-Kothera**[1] | **Audra Luscher-Aissaoui**[2]

[1]NOAA Office for Coastal Management, Charleston, South Carolina, USA

[2]NOAA Center for Operational Oceanographic Products and Services, Silver Spring, Maryland, USA

[3]Rutgers Climate Institute, Rutgers University, New Brunswick, New Jersey, USA

[4]Ocean Associates, Inc., Arlington, Virginia, USA

[5]Lynker, Leesburg, Virginia, USA

Correspondence
Brenna M. Sweetman, NOAA Office for Coastal Management, Silver Spring, MD, USA.
Email: brenna.sweetman@noaa.gov

Abstract

Coastal regions are becoming increasingly vulnerable to flooding. Due to growing risk, there is a need for a variety of accessible flood inundation services and information to improve resilience and adaptation outcomes. To better understand these needs the National Oceanic and Atmospheric Administration's Office for Coastal Management and the Center for Operational Oceanographic Products and Services collaborated to host five virtual workshops during the COVID-19 pandemic to understand inundation needs and deficits of five professional sectors: coastal planning, transportation and navigation, realty and insurance, health and human services, and natural resource and floodplain managers. This paper outlines the information collected from these workshops, shares recommendations for future research to improve equitable coastal resilience and highlights the value of remote engagement for knowledge coproduction. From the project results, we share cross-cutting topics that emerged and propose a need for greater equity, inclusive engagement, interagency coordination and future research directions through scientist-stakeholder coproduction workshops for improved coastal resilience.

KEYWORDS
climate service, coastal flooding, coproduction, resilience, end user engagement, inundation

1 | INTRODUCTION

Coastal communities, ecosystems, and economies in the United States (U.S.) are becoming increasingly vulnerable to growing flood risks related to climate change (IPCC, 2022; Moftakhari et al., 2015; Sweet et al., 2022). However, there is often a gap between climate science and the science that is used by decision makers in local communities (Dilling & Lemos, 2011; Kirchhoff & Ramprasad, 2012). The complexities of adapting to climate change impacts and understanding flood-related vulnerabilities are guiding researchers toward more interdisciplinary

Paper No. JAWR-22-0165-P of the *Journal of the American Water Resources Association* (JAWR).

Discussions are open until six months from publication.

Research Impact Statement

Understanding stakeholder needs for coastal flood data, products, and services helps inform climate resilience science and reduce risk nationally.

approaches to provide tailored scientific information in coastal regions (Meadow et al., 2015; Pasquier et al., 2020; Tintoré et al., 2009). These participatory approaches to engagement, following coproduction models between scientific product developers and end users, are increasingly recognized as critical for the successful management of coastal resources and are proven to yield better long-term outcomes (Kasperson & Berberian, 2011; McKinley et al., 2021; Meadow et al., 2015; Thia-Eng, 1993).

As the relationship between science and policy shifts, participatory approaches to inform science and decision-making with increased coordination across agencies and institutions are gaining in popularity (Pasquier et al., 2020). The National Oceanic and Atmospheric Administration (NOAA), along with other coastal and marine scientific research entities, have developed numerous tools to help decision makers predict, mitigate, and adapt to coastal flood hazards. Such scientific developments include products that aid coastal communities to understand and address coastal hazards from storm surge, high tide flooding, sea level rise, among other flooding types as the climate continues to shift. Traditionally, many of these products have been focused on providing information on past, present, and near-term flood risk. However, there is a growing need to better understand coastal flood risk information at longer, climate time scales and as a result, updating the supporting data and information needs as well. For the purpose of this study, we defined "climate time scales" as temporal periods of "sub-seasonal, seasonal, annual, decadal, and beyond." In addition, the terms "flooding" and "inundation" are used interchangeably to cover all types of flood events where water covers normally dry land, and "stakeholder" is used in reference to end users of scientific data and products (NOAA, Water Initiative, 2020).

NOAA is striving to implement a more user-centric model of service development and delivery with the NOAA Service Delivery Framework (NOAA, Water Initiative, 2020). This framework, which is consistent with other models of scientist-stakeholder engagement for climate service coproduction (Collini et al., 2021; Fox et al., 2023; Molino et al., 2020; Pasquier et al., 2020), outlines an approach that embraces long-term, trusted relationships between federal scientists and stakeholders established in continuous and consistent two-way communication of data, information and research needs. Although stakeholder engagement activities and participatory processes by federal agencies are common, the information is rarely shared broadly in peer-reviewed literature or evaluated based on existing studies (Collini et al., 2021). Therefore, this study aims to fill a knowledge gap in research on this topic and support long-term adaptation outcomes of coastal communities. The objectives of this project were to (1) better understand what challenges future coastal flooding presents in distinct professional communities and to (2) understand what gaps exist in information and decision support tools needed to manage future flood risk and improve resilience during the era of COVID-19. The scientific results and conclusions, as well as any views or opinions expressed herein, are those of the author(s) and do not necessarily reflect the views of NOAA or the Department of Commerce.

2 | METHODS

The methods utilized in this study were adapted from in-person activities to online virtual engagement due to the impacts of COVID-19. These workshops were used as the primary research methodology, following a systematic process to gather information during five virtual events (McKinley et al., 2021; Ørngreen & Levinsen, 2017; Pasquier et al., 2020; Thoring et al., 2020). This approach allowed the opportunity to identify and explore relevant coastal information needs through semi-structured discussions. Research was conducted ethically with exception from Internal Review Boards and the Paperwork Reduction Act due to the information collection through a series of public webinars online (i.e. workshops). Participant information was protected by following the appropriate data management steps and NOAA's scientific integrity actions to ensure confidentiality and anonymity. Through the course of the workshops, a total of 209 participants from diverse sectors engaged and provided input on their coastal decision-making needs (Figure 1). These individuals represented a variety of affiliations from local, state, federal agencies, academia, non-profit organizations and the private sector. While each workshop shared the same goals and objectives, the process was tailored for each target audience based on each sector's application of flood information. During these workshops, a trained facilitator followed a semi-structured approach with a set of questions to select from and prioritized inquiries based on participant preexisting knowledge of coastal products and field of expertise (Harrell & Bradley, 2009). This flexible qualitative approach inspired new insights and allowed for focused discussions of participants' perceptions and experiences. The researchers were conscious of modifying the questions for each professional group given each sector had varying levels of technical expertise and familiarity with coastal flood science and terminology. The objectives of the workshops were:

AMERICAN WATER RESOURCES ASSOCIATION JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

FIGURE 1 Timeline, sectors, and total participants of workshops.

- Understand how participants use existing data, tools, and technical assistance resources in their decision-making processes;
- Understand how participants consider inundation risk on climate time scales during their planning processes;
- Identify knowledge gaps for decision-making based on inundation.

Workshop participants were recruited nationally across the U.S. states and territories through existing networks and professional organizations using a snowball sampling methodology (Naderifar et al., 2017). The sectors were selected based on those who currently use and need improved coastal flood information in their work and those who have been identified as groups that will need to apply this information in the future under changing climate conditions. Specifically, recent studies have shown an increased vulnerability of coastal transportation, real estate industries, and public health infrastructure to flood risk (Bradbury et al., 2015; NOAA, 2022). Participants were requested to share the types of decisions their work required and what resources they currently use to inform their decisions related to coastal flooding. The workshops were conducted virtually approximately every 3 months over the course of a year with varying degree of participation in each session (Figure 1).

Each virtual workshop ranged in duration from 1.5 to 2.5 h and included a NOAA subject matter expert(s) who provided an overview of coastal flood products, (Appendix A) and a skilled facilitator who guided the discussion using Adobe Connect, Google Meet or Padlet. The results of each workshop were archived and systematically reviewed in Microsoft Excel using a qualitative content analysis approach where common words and phrases were combined into themes based on emerging patterns revealed by the data (Elo & Kyngäs, 2008; Saldaña, 2021). The aim of this data analysis was to use an inductive "bottom up" approach based on methods from previous research given there was not substantial former knowledge to develop preexisting codes (Elo & Kyngäs, 2008). To prepare the data, needs identified by stakeholder groups were systematically coded to identify the emergence of core categories and subsequent related concepts by a single researcher to ensure a consistent data perspective. A manual open coding process was used to provide a descriptive, multidimensional understanding of the topic (Khandkar, 2009). Data were prepared, organized, and analyzed manually in a flexible framework using Microsoft Excel to make valid inferences. Multiple members of the research team reviewed the developed coded data until consensus was reached. Subsequently, the data were organized into cross-cutting themes based on smaller content categories. Codebooks were created for each individual workshop with a cross-analysis integration of all workshops to identify dominant and consistent themes.

3 | RESULTS

The following sections provide an overview of the key findings derived from each stakeholder workshop divided by sector. Individual workshop results are displayed below accompanied by a summary of what was expressed.

3.1 | Planning

Planning professionals were the first sector engaged in a virtual workshop conducted on November 8, 2021 using Adobe Connect and Padlet. Participant recruitment was completed through regional networks and professional connections including the American Planning Association, the National Estuarine Research Reserve System, and the National Sea Grant Extension network. Sixty-eight planning professionals consisting of local, state, and federal government; private industry; academia; and non-profit organizations from all coastal regions of the continental U.S. and territories attended the webinar. Key information heard from planners fell into two themes: needs that were technical and data-related in nature and those that were related to socioeconomic information. Technical needs included the observation that there are too many tools in existence; higher resolution and more local data are needed; greater ability to integrate products across federal agencies; stronger understanding of state versus national sea level rise projections; an understanding of combined riverine and coastal flooding impacts (compound flooding); and more Alaska-specific information as this is a region often lagging other areas in terms of flood-related data and products. Socioeconomic information needs shared included stronger collaboration across government on coastal flooding; greater understanding of social vulnerability and demographic information to work with underrepresented communities; guidance on interpreting new data and science; and assistance communicating changing science and terminology to the public. For example, several stakeholders noted a need to understand what other factors in people's lives contribute to their ability to respond to flooding such as not meeting other daily needs. Further, not just understanding where vulnerabilities are greatest but understanding the capacity of those people living and working in flood prone areas to proactively address and mitigate flooding concerns as also emphasized by multiple planners. When asked what was needed to know to make communities more resilient to coastal flooding, 12% shared if/when sea level rise scenarios; 12% the ability to interpret data easily; 4% shared high resolution compound flooding data (Table 1). Responses are outlined in Table 1.

3.2 | Transportation and navigation

The workshop with the transportation and navigation sector was held on January 25, 2022 using Google Meet. Thirty-four professionals from the U.S. Department of Transportation, Federal Emergency Management Agency (FEMA), U.S. Geological Survey, the Maritime Administration, NOAA Coast Survey, university representatives, private industry, state transportation professionals, and port managers joined. When asked about professional goals, a variety of topics related to transportation and navigation infrastructure challenges in coastal regions were raised, including concerns regarding understanding flood-related traffic disruptions (15%); raising roadway profiles without impacting nearby properties (12%); future wharf designs (9%); resilience of ferry terminals (9%); and mitigating current and future flooding for coastal airports (6%) (Table 2). In addition, multiple participants stated they were unfamiliar with coastal flood products and shared an interest in learning more. Participants expressed a need for more coordination and collaboration in product development activities, and like the planning sector, requested help in identifying the right tool—and how to apply information—to inform sound decision-making. Further, "mainstreaming" climate data into transportation service development was identified as key. See Table 2 for more information on the results gathered from participants.

TABLE 1 Summarized results from the planning participants ($N = 68$).

	Number of participants	Percent of total
What are your greatest concerns related to flood risk?		
Loss of property	12	18
Loss of life	7	10
Loss of ecosystems	5	7
How will you make your community more resilient to flooding?		
Relocate homes inland	15	22
Buyout and preserve open space	12	18
Increase funding for coastal resilience	5	7
Receive bipartisan political support	5	7
Prohibit future development	3	4
What do you need to know to make your community more resilient to coastal flooding?		
If/when sea level rise scenarios	8	12
The ability to interpret data easily	8	12
High resolution data on compound flooding (coastal and riverine)	3	4

AMERICAN WATER RESOURCES ASSOCIATION JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

TABLE 2 Summarized results from the transportation and navigation participants ($N = 34$).

	Number of participants	Percent of total
What are your goals and/or needs for transportation projects as they relate to future flooding?		
Understanding flood-related traffic disruptions	5	15
Future wharf designs	3	9
Resilience of ferry terminals	3	9
Water level information and assistance on raising roadway profiles without impacting nearby properties	4	12
Mitigating current and future flooding for coastal airports	2	6
What are the key gaps you see in these National Oceanic and Atmospheric Administration (NOAA) products that would help you make more informed decisions regarding coastal flood risk?		
Sea level rise projections	6	18
Precipitation and compound flooding information	4	12
Ability to incorporate high tide information into Integration with Department of Transportation tools	2	6
Baseline infrastructure data	2	6

TABLE 3 Summarized results from the realty and insurance participants ($N = 19$).

	Number of participants	Percent of total
What key information and/or tools would help you better understand and communicate with your clients about flood risk?		
Simplified messaging on coastal flood risk with multiple learning options (mobile app, video, pictures, online tool)	7	37
Better understand and address equity challenges of property owners	5	26
Ability of NOAA tools to apply to local, underserved populations	3	16

3.3 | Realty and insurance

The third workshop with realtors and insurance professionals was held on March 22, 2022, with 19 attendees using Google Meet and Padlet. Of those who participated, affiliations included FEMA, the insurance sector, the realty sector, state government, and academic institutions. During the session, several attendees expressed strong interest in this topic and a desire to educate themselves and colleagues by gaining a better understanding of flood risk decision support tools. However, many participants were silent or shared they had no prior knowledge of NOAA products. The overarching themes from this session included a need for simplified information with multiple learning options; a desire to understand and address equity challenges; and the limited ability of NOAA tools to apply to local populations. Of interest, several stakeholders noted some of the flood risk challenges in their profession include the ethics of nondisclosure of information on historic property flooding, intentional neglect and of not informing themselves on flooding due to a lack of understanding of the scientific technical content. Others recognized the value of scientific flood tools as a reliable means to stay informed on data versus anecdotal evidence or previous property owners' perspectives. Thirty-seven percent shared a need for simplified messaging on coastal flood risk with multiple learning options (mobile app, video, pictures, online tool), 26% shared a need to better understand and address equity challenges of property owners, and 16% shared a need for the ability of NOAA tools to apply to local, underserved populations. The discussion points and the responses from this group are summarized in Table 3.

3.4 | Health and human services

The fourth workshop for health and human services professionals was held on May 22, 2022 using Google Meet. Recruiting participants for this session was challenging despite casting a large net given the non-traditional nature of NOAA's interaction with this group. Eleven participants joined, including individuals from Sea Grant, academia, U.S. Geological Survey, EPA, and local health specialists. The small size of this group allowed for a rich and focused discussion. The participants shared challenges related to public health and future coastal flooding including barriers for low-income communities to receive pre- and post-flooding event information, impacts on public transportation, churches, and houses experiencing mold growth post-flooding, drinking water contamination by flood waters, and education disruptions from school closures. The discussion also explored inequities of marginalized communities pre- and post-flooding and a lack of information on what to do when people are unable to leave flood-impacted areas,

TABLE 4 Summarized results from the health and human services participants ($N = 11$).

	Number of participants	Percent of total
What challenges does future flooding present as it relates to public health in your community?		
Barriers for low-income communities to receive pre- and post-flood information	3	27
Churches and houses experiencing mold post-flood	3	27
Impacts on public transportation	2	18
Drinking water impacts from flood waters and toxic water releases	2	18
Education disruptions from school closures	1	9

highlighting inequities of flood risk management. When asked about challenges presented to public health, 27% of participants discussed barriers for low-income communities to receive pre- and post-flood information; 27% recognized health impacts from churches and houses experiencing mold as a result of flooding; 18% identified impacts on public transportation; 18% identified drinking water impacts from flood waters and toxic water releases and 9% recognized education disruptions from flood-related school closure. Attendees commented that their experiences show that the general public does not engage well with technical, data- or map-based products, and suggested alternative communication approaches, such as virtual reality or disseminating information through public libraries. Additional discussion centered on performing social science-based research to identify the needs of diverse and underserved community populations. See Table 4 for summarized results from this workshop.

3.5 | Natural resource and floodplain management

The fifth workshop was held on June 27, 2022 engaging those who work in natural resource and floodplain management sectors using Google Meet. Participants were recruited through NOAA networks, Digital Coast partners, and at the Association of State Floodplain Managers' annual conference. Seventy-seven participants joined this session including individuals from Sea Grant, academia, the U.S. Geological Survey, coastal zone management programs, county planners, local floodplain managers, private industry, and state government. The participants shared challenges related to future coastal flooding in their regions including a lack of detailed information on sea level rise projections (23%); greater collaboration across various scales of government (13%); a need for information from compound flooding and multiple flooding sources (10%); expanded precipitation frequency estimates of Atlas-14 (9%); information on impacts of flooding on septic systems (9%); tools for municipal governments (9%); understanding flood impacts on septic systems (5%); assistance balancing competing economic development interests (4%); information to understand the complexity of Great Lakes water levels (4%); and accessible, mobile-friendly geospatial products (4%). Other important elements of the discussion included recognition of the frequent pressure to put profit and development over adequate floodplain management. Further, and similar to other sectors, the need to have comprehensive collaboration between agencies working on sea level rise projections and mapping products is critical. In addition, participants shared a variety of tools and resources they use to inform coastal flood decisions (Appendix B). Summarized responses from this group are provided in Table 5.

4 | DISCUSSION

Despite a variety of viewpoints expressed, there were multiple cross-cutting themes that were derived from across all of the sectors. While there were many challenges distinct to specific sectors (e.g., flood-related impacts on transportation systems), there was consensus and widespread recognition that coastal flooding is increasing and will continue to have significant impacts on vulnerable infrastructure and economic activities across all engaged. Based on the information gathered from the workshops, a range of participant information and tool needs were documented with results revealing consistency with similar studies on this topic such as participant benefiting from various learning opportunities, engagement with boundary spanning organizations and greater technical assistance (Elko et al., 2022; Molino et al., 2020; Slinger et al., 2023; Tribbia & Moser, 2008). Additional specific themes identified are outlined below.

4.1 | Increased coordination and collaboration

Many government science entities across local, regional and national levels have similar scopes of work but do not always effectively communicate, coordinate and collaborate on existing flood information and services. However, recent research demonstrates enhanced coordination

AMERICAN WATER RESOURCES ASSOCIATION JAWRA JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION

TABLE 5 Summarized results from the natural resources and floodplain management participants ($N = 77$).

	Number of participants	Percent of total
What key information and/or tools would help you better understand and communicate with your clients about flood risk?		
Greater detailed information on sea level rise projections	18	23
Further collaboration across various scales of government	10	13
Compound flood hazard information to understand impacts from multiple sources	8	10
Updated NOAA Atlas-14 data	7	9
Tools designed specifically for municipal governments	7	9
Understanding flood impacts on septic systems	4	5
Assistance balancing competing economic development interests	3	4
Information to understand the complexity of Great Lakes water levels	3	4
Accessible, mobile-friendly Geographic Information System products and services	3	4

often results in greater equity outcomes (Fox et al., 2023). For example, a lack of clarity on the distinctions of flood mapping across NOAA, FEMA, and the U.S. Geological Survey was raised across the workshops for planners, transportation and navigation professionals, and natural resources managers. A number of U.S. government agencies and private entities have developed flood mapping tools for coastal flood risk; however, future workshops would benefit from increasing engagement across agencies and with the public to reduce confusion on the multiple information sources as proposed by (Djenontin & Meadow, 2018; Vollstedt et al., 2021). This study's findings suggest there is a clear need for assistance in keeping track of the myriad of entities, projects, and resources useful for addressing coastal flooding consistent with similar studies (Collini et al., 2021; Elko et al., 2022; Molino et al., 2020; Raub & Cotti-Rausch, 2019). The continued appearance of this demonstrates a need to find strategies to better address and implement these into action.

4.2 | Fewer tools

Moreover, multiple sectors expressed there are too many tools, a concept that is resolved when duplicate tools and information are removed through greater organizational coordination. Additionally, many participants voiced there are too many decision support tools with varying levels of complexity, intended audience, and purpose. The result is decision support tool fatigue, where the sheer volume of tools is challenging. The comment was made several times regarding a lack of understanding between state-specific and national-level sea level rise tools, which leads to confusion and inaction. High touch technical assistance, where individuals are guided on navigating the decision support tool space with "climate translators" and understanding specific tool strengths and limitations was recognized as an effective approach to address this as also demonstrated by Le Cozannet et al. (2017).

4.3 | Equitable engagement approaches

In addition to greater coordination of scientific entities, another example of cross-sectoral overlap was discussion around information and resources to understand and engage underrepresented groups to support equitable adaptation. Planners; health and human services professionals; and natural resource and floodplain managers expressed needs for demographic information to increase understanding of vulnerable populations at risk of coastal flooding and those who could be better engaged. Equity and justice concepts to address uneven impacts of hazards is increasing as suggested by similar studies (Fox et al., 2023; Herb & Auermuller, 2020); however, these results demonstrate further research on the topic is needed to identify finer resolution information. While notable advances have emerged among federal agencies, organizations and institutions working on equitable flood risk (Fox et al., 2023), the focus should continue to strive in this direction. Increasing stakeholder workshops with an equity lens, such as the work of Herb and Auermuller (2020), convey the importance of community engagement with socially vulnerable populations to integrate needs and challenges appropriately in coastal hazards planning. Similarly, equity-centered topics raised in the workshops heard in other literature ranged from inequitable financial support for adaptation work, barriers to community engagement and funding based on income, post-disaster event inequality, and tribal areas not incorporated appropriately in federal maps (Fox et al., 2023; Herb & Auermuller, 2020). These results support the importance and growing demand of incorporating principles of equity and

justice in coastal community resilience planning. Findings related to equity challenges demonstrate a need for further social science research to better identify place-based population risks and local impacts as well as a need to fill equity gaps in underserved regions noted as lacking important flood-related data (i.e., Alaska and the Great Lakes region).

4.4 | Updated data with climate shifts

Multiple sectors also expressed that due to the dynamic nature of coasts, data must continually be updated to stay current. High resolution, local data and the incorporation of compound flooding information were needs expressed across sectors. Other studies have demonstrated the need for localized risk assessments on infrastructure to support adaptive planning (Valente & Veloso-Gomes, 2020). Additionally, needs related to social, behavioral, economic, and cultural considerations and data were expressed across sectors. These needs included social vulnerability metrics; infrastructure vulnerability; and additional research focused on better understanding public values and behaviors.

Other related research highlights activities to improve the science consistent with those heard in these workshops including: enhanced climate projections, dynamic projections of sea level rise; and more impact assessments at the local scale with high resolution data (Toimil et al., 2020; Vollstedt et al., 2021). Besides Landeg's recent study (Landeg et al., 2019), there is a very limited body of literature on coastal flood impacts on health care services. From the results of this study, those consistent with these findings include a need to determine local vulnerability of highly at-risk populations and health care infrastructure disruptions caused by flooding (Landeg et al., 2019). Given unique coastal flood needs are not well-documented in the literature for public health impacts and real estate flood-related challenges points to a growing need for further cross-cutting, integrated research for effective coastal management (Tintoré et al., 2009; Tribbia & Moser, 2008). Emerging health issues include flood-related indoor mold and septic impacts on drinking water. Participants shared that NOAA data are valuable for certain national and regional applications, but many locally relevant products developed outside NOAA provide greater value. While some geographic regions are data rich, others are lacking.

4.5 | Continuous assessment and engagement on emerging coastal hazards

Another emerging area, for the transportation and navigation workshop, when follow-up questions were asked about what information was needed to address these challenges, many participants did not respond or were unsure. This lack of response demonstrates a clear complexity and uncertainty with regard to this issue and is consistent with a study by Morris (2020) emphasizing greater stakeholder collaboration as a pathway to climate adaptation at coastal ports. The results of the dialogue illuminate the need for future discussion on this topic—with the transportation and navigation sector and with other government agencies including the Department of Transportation that work closely on flooding impacts and transportation challenges. Additionally, the realty and insurance sector workshop also highlighted limited understanding of coastal flood science and reveals an opportunity for future intentional relationship-building and research with this sector to build greater resilience in the context of coastal land and property management. As climate challenges are inextricably intertwined with social and equity issues, the need for greater interdisciplinary assessments with new sectors can improve understanding of human-environmental interactions and work toward equitable resilience outcomes.

Other research suggests that co-production methods are beneficial for understanding and learning about intricacies at local scales allowing for greater nuance of local challenges (Slinger et al., 2023). Community participation results in greater understanding of coastal hazards approaches and leads to more equitable adaptation and decision-making processes (Fox et al., 2023). However, a major challenge of coproduction for coastal and climate science is the significant requirement of time and energy to engage those intended to use the information (Beier et al., 2017; Djenontin & Meadow, 2018). We argue they are necessary for successful coastal and flood risk management. Research entities striving to advance equity work and serve those facing historical barriers must aim for greater engagement of those who work closely with underserved populations and have existing relationships underway. Similar to existing studies, working with NGOs, academia, and other professional organizations to help translate scientific information and creatively communicate with diverse and underserved audiences would greatly advance this field of work and improve equitable outcomes (Fox et al., 2023; Herb & Auermuller, 2020).

4.6 | Virtual engagement efficacy

An alternative important perspective of this study is it occurred in the broader global temporal context of COVID-19. The global impact from COVID-19 posed an unexpected and unprecedented shift on community engagement approaches worldwide from in person to virtual gatherings. Although it is not a "catch all" solution, "going digital" has been demonstrated to offer a range of benefits to effective coastal community

engagement (McKinley et al., 2021) and this study affirms this is a valid methodological approach. In addition, this study reveals important lessons consistent with other research revealing success for future climate change adaptation research and effective engagement to broaden participation, support multi-way knowledge exchange, promote social learning, reduce carbon footprints, and build community capacity through online workshops (Beier et al., 2017; McKinley et al., 2021).

4.7 | Limitations and future research

These findings represent an initial baseline understanding of coastal decision makers coastal flood-related challenges and information needs from five professional sectors. While there is no "one size fits all" to coastal resilience and future flood planning, striving for coproduction through user engagement is key. This study indicated that future exploration with sectors that federal government has not traditionally worked with is warranted. Key limitations of the present study are it captured the needs and perspectives of a particular representative subset of professionals at a set moment in time. Additional project constraints include a small, uneven sample size from varied geography due to method limitations from COVID-19. Future research would benefit from working to engage with larger audiences and evaluating flood risk focused on specific geographies. In particular, expanding on engagement with the health and human services sector would be beneficial to establish understanding of flood risk impacts on public health and building communication pathways to scientific entities developing new information and services. Additionally, further research should be conducted to assess information demands among different stakeholder categories.

5 | CONCLUSION

An important starting place for coastal adaptation and resilience is understanding climate challenges and the subsequent information needs of professionals and practitioners to address them (Saleem Khan et al., 2020). Decision support tools designed through direct stakeholder input and interaction (i.e. co-production models) such as the virtual workshops held with this study are proven to result in more usable and understandable information (Dilling & Lemos, 2011; Lathrop et al., 2014). The purpose of this project was to (1) better understand what challenges future coastal flooding presents in distinct professional communities and to (2) understand what gaps exist in information and decision support tools needed to manage future flood risk and improve resilience during the era of COVID-19. Coastal decision makers' information needs to address and adapt to flood-related climate impacts are complex and variable. This study contributed to the broader body of knowledge around understanding coastal flood information needs in a rapidly changing world. Additionally, this study highlights the need for integrated, adaptive planning approaches for dealing with changing risks over climate time scales in dynamic coastal environments. For this project, participants' specific information needs varied across professional groups; however, consistent themes emerged across multiple sectors included needs for increased coordination and collaboration; fewer tools; equitable engagement approaches; continually updated data; and assessment and engagement on emerging coastal hazards. As a result, this study suggests there may be benefits in encouraging dialogue across multiple sectors who share overlapping concerns for future research. The findings from this project point to the importance of intentional planning for stakeholder engagement processes with underserved and historically marginalized prior to product development. Related, this study provides an example of how virtual workshops in the setting of COVID-19 were an effective methodology to engage and conduct qualitative analyses. While moving to virtual platforms was perceived to pose challenges to community engagement, the results of this project show evidence that delivering events online can provide effective participation approaches, even broadening accessibility for more inclusive engagement and equitable outcomes. Löschner et al. argues that scientist-stakeholder workshops on flood risk are unlikely to become a common practice (Löschner et al., 2016), however, looking ahead we argue that continued end user engagement is essential for coproduction of knowledge. In the future, we recommend drawing on these methods of online engagement as an approach to holding scientist-stakeholder workshops to integrate and advance science for coastal decision-making.

This project describes and reports on the process and results of scientist-stakeholder workshops for improving coastal flood decision support information. As those working on climate resilience move into the next era of climate science, there is a critical need to understand gaps and find ways to provide services that reach stakeholders at greater spatial and temporal scales. Listening to stakeholders' specific needs is critical for the efficacy and usability of coastal and climate research in government agencies and beyond. Faced with continuously evolving data and information, the comments from this study suggest that stakeholders' perspectives are of interest to researchers and policymakers in improving coastal flood risk management and communication practices.

AUTHOR CONTRIBUTIONS

Brenna M. Sweetman: Conceptualization; data curation; formal analysis; methodology; project administration; writing – original draft; writing – review and editing. **Cayla Dean:** Conceptualization; methodology; project administration; visualization; writing – original draft; writing – review and editing. **Lisa Auermuller:** Methodology; project administration; writing – review and editing. **Kathryn Noel Tremblay:**

Data curation; methodology; project administration; writing – review and editing. **Christopher Katalinas:** Methodology; project administration; writing – review and editing. **Shannan Lewinski:** Methodology; project administration; writing – review and editing. **Lori Cary-Kothera:** Conceptualization; project administration. **Audra Luscher-Aissaoui:** Conceptualization.

ACKNOWLEDGMENTS

In memory of Dr. Cayla Dean, NOAA Outreach Specialist and Coastal Scientist, who led boundary spanning efforts for our nation's coasts through this project and the Coastal Coupling Community of Practice. Her dedication to science and people continues to inspire us. Current employment of co-author Kathryn Tremblay is Peraton Inc. The authors thank Laura Rear-McLaughlin, Patrick Burke, Nicholas Schmidt, Ellen Mecray, Ginger Hinchcliff, Heidi Stiller, Doug Marcy, Billy Brooks, and Mary Culver from NOAA for their help and support of this work.

CONFLICT OF INTEREST STATEMENT

The authors declare no competing interests.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author (BMS).

REFERENCES

Beier, P., L.J. Hansen, L. Helbrecht, and D. Behar. 2017. "A How-to Guide for Coproduction of Actionable Science." *Conservation Letters* 10(3): 288–96. https://doi.org/10.1111/conl.12300.

Bradbury, J., M. Allen, and R. Dell. 2015. *Climate Change and Energy Infrastructure Exposure to Storm Surge and Sea-Level Rise*. Oak Ridge, TN: Office of Energy Policy and Systems Analysis and Oak Ridge National Laboratory. https://www.energy.gov/policy/articles/climate-change-and-energy-infrastructure-exposure-storm-surge-and-sea-level-rise.

Collini, R.C., M.C. Heming, C.F. Mohrman, M.T. Daigle, C.A. Fulford, C.L.G. Lowry, M.D. Hanisko, et al. 2021. "Understanding End-User Adoption of an Online Climate Resilience Tool." *Environmental Science & Policy* 124: 247–53. https://doi.org/10.1016/j.envsci.2021.06.022.

Dilling, L., and M.C. Lemos. 2011. "Creating Usable Science: Opportunities and Constraints for Climate Knowledge Use and their Implications for Science Policy." *Global Environmental Change* 21(2): 680–89. https://doi.org/10.1016/j.gloenvcha.2010.11.006.

Djenontin, I.N.S., and A.M. Meadow. 2018. "The Art of Co-Production of Knowledge in Environmental Sciences and Management: Lessons from International Practice." *Environmental Management* 61(6): 885–903. https://doi.org/10.1007/s00267-018-1028-3.

Elko, N., T.R. Briggs, R. Marsooli, P. Barrineau, C. Hapke, K. McKenna, J. Simm, M. Beyeler, M. Smith, and Troy 10, C. 2022. "US Community Perspectives on Coastal Flooding." *Shore & Beach* 90(3): 17.

Elo, S., and H. Kyngäs. 2008. "The Qualitative Content Analysis Process." *Journal of Advanced Nursing* 62(1): 107–15.

Fox, N., J.H. Tilt, P. Ruggiero, K. Stanton, and J. Bolte. 2023. "Toward Equitable Coastal Community Resilience: Incorporating Principles of Equity and Justice in Coastal Hazard Adaptation." *Cambridge Prisms: Coastal Futures* 1: e36.

Harrell, M.C., and M.A. Bradley. 2009. "Data Collection Methods." In *Semi-Structured Interviews and Focus Groups*, 31–49. Santa Monica, CA: RAND National Defense Research Institute. https://www.rand.org/pubs/technical_reports/TR718.html.

Herb, J., and L. Auermuller. 2020. *Final Project Report: A Seat at the Table: Integrating the Needs and Challenges of Underrepresented and Socially Vulnerable Populations into Coastal Hazards Planning in New Jersey*. New Brunswick, NJ: Prepared for the New Jersey Department of Environmental Protection. https://njclimateresourcecenter.rutgers.edu/wp-content/uploads/2020/06/A-Seat-at-the-Table-Final-Report-5-31-20.pdf.

IPCC. 2022. "Climate Change 2022: Impacts, Adaptation, and Vulnerability." In *Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, and K. Mintenbeck, 100–200. Cambridge, UK and New York, NY: Cambridge University Press. https://doi.org/10.1017/9781009325844.

Kasperson, R.E., and M. Berberian, eds. 2011. *Integrating Science and Policy: Vulnerability and Resilience in Global Environmental Change*. New York, NY: Routledge.

Khandkar, S.H. 2009. *Open Coding*, Vol 23. Calgary, Canada: University of Calgary.

Kirchhoff, C.J., and V. Ramprasad. 2012. "Narrowing the Climate Information Usability Gap." *Nature Climate Change* 2: 789–94. https://doi.org/10.1038/nclimate1614.

Landeg, O., G. Whitman, K. Walker-Springett, C. Butler, A. Bone, and S. Kovats 2019. "Coastal flooding and frontline health care services: challenges for flood risk resilience in the English health care system." *Journal of health services research & policy* 24(4): 219–28.

Lathrop, R., L. Auermuller, J. Trimble, and J. Bognar. 2014. "The Application of WebGIS Tools for Visualizing Coastal Flooding Vulnerability and Planning for Resiliency: The New Jersey Experience." *ISPRS International Journal of Geo-Information* 3(2): 408–29.

Le Cozannet, G., R.J. Nicholls, J. Hinkel, W.V. Sweet, K.L. McInnes, R.S. Van de Wal, et al. 2017. "Sea Level Change and Coastal Climate Services: The Way Forward." *Journal of Marine Science and Engineering* 5(4): 49.

Löschner, L., R. Nordbeck, P. Scherhaufer, and W. Seher. 2016. "Scientist–Stakeholder Workshops: A Collaborative Approach for Integrating Science and Decision-Making in Austrian Flood-Prone Municipalities." *Environmental Science & Policy* 55: 345–52.

McKinley, E., P.R. Crowe, F. Stori, R. Ballinger, T.C. Brew, L. Blacklaw-Jones, et al. 2021. "'Going Digital'-Lessons for Future Coastal Community Engagement and Climate Change Adaptation." *Ocean and Coastal Management* 208: 105629.

Meadow, A.M., D.B. Ferguson, Z. Guido, A. Horangic, G. Owen, and T. Wall. 2015. "Moving toward the Deliberate Coproduction of Climate Science Knowledge." *Weather, Climate, and Society* 7(2): 179–91. http://www.jstor.org/stable/24907440.

Moftakhari, H.R., A. AghaKouchak, B.F. Sanders, D.L. Feldman, W. Sweet, R.A. Matthew, and A. Luke. 2015. "Increased Nuisance Flooding along the Coasts of the United States Due to Sea Level Rise: Past and Future." *Geophysical Research Letters* 42(22): 9846–52. https://doi.org/10.1002/2015GL066072.

Molino, G.D., M.A. Kenney, and A.E. Sutton-Grier. 2020. "Stakeholder-Defined Scientific Needs for Coastal Resilience Decisions in the Northeast US." *Marine Policy* 118: 103987. https://doi.org/10.1016/j.marpol.2020.103987.

Morris, L.L. 2020. "Stakeholder Collaboration as a Pathway to Climate Adaptation at Coastal Ports." *Maritime Policy & Management* 47(7): 953–67.

Naderifar, M., H. Goli, and F. Ghaljaie. 2017. "Snowball Sampling: A Purposeful Method of Sampling in Qualitative Research." *Strides in Development of Medical Education* 14(3): 20–24. https://doi.org/10.5812/sdme.67670.

National Oceanic and Atmospheric Administration (NOAA). 2022. "A NOAA Capability for Coastal Flooding and Inundation Information and Services at Climate Timescales to Reduce Risk and Improve Resilience." NOAA. https://cpo.noaa.gov/Portals/0/Docs/Risk-Teams/NOAA-Coastal-Inundation-at-Climate-Timescales-Whitepaper.pdf?ver=2022-09-20-155133-450.

National Oceanic and Atmospheric Administration (NOAA), Water Initiative. 2020. "A Model of Service Delivery for the NOAA Water Initiative: A Proven Method for Integrating Decision Support and Service Delivery." NOAA Water Team. https://www.noaa.gov/sites/default/files/2022-02/A-Model-of-Service-Delivery-for-the-NOAA-Water-Initiative_FINAL.pdf.

Ørngreen, R., and K. Levinsen. 2017. "Workshops as a Research Methodology." *Electronic Journal of E-learning* 15(1): 70–81.

Pasquier, U., R. Few, M.C. Goulden, S. Hooton, Y. He, and K.M. Hiscock. 2020. ""We Can't Do It on Our Own!"—Integrating Stakeholder and Scientific Knowledge of Future Flood Risk to Inform Climate Change Adaptation Planning in a Coastal Region." *Environmental Science & Policy* 103: 50–57.

Raub, K.B., and B.E. Cotti-Rausch. 2019. "Helping Communities Adapt and Plan for Coastal Hazards: Coastal Zone Management Program Recommendations for National Tool Developers." *Coastal Management* 47(3): 253–68.

Saldaña, J. 2021. *The Coding Manual for Qualitative Researchers*. Thousands Oak, CA: Sage Publishing.

Saleem Khan, A., M. Sabuj Kumar, R. Sudhir Chella, and B. Devdyuti. 2020. "BASIEC: A Coastal Climate Service Framework for Community-Based Adaptation to Rising Sea-Levels." In *Handbook of Climate Services*, 11–31. Hamburg, Germany: Springer.

Slinger, J.H., S.C. Cunningham, and B.L. Kothuis. 2023. "A Co-Design Method for Including Stakeholder Perspectives in Nature-Based Flood Risk Management." *Natural Hazards* 119(3): 1171–91.

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, et al. 2022. "2022 Sea Level Rise Technical Reports." https://oceanservice.noaa.gov/hazards/sealevelrise/sealevelrise-tech-report-sections.html.

Thia-Eng, C. 1993. "Essential Elements of Integrated Coastal Zone Management." *Ocean and Coastal Management* 21(1–3): 81–108.

Thoring, K., R. Mueller, and P. Badke-Schaub. 2020. *Workshops as a Research Method: Guidelines for Designing and Evaluating Artifacts through Workshops*. Manoa, Hawaii: Hawaii International Conference on System Sciences.

Tintoré, J., R. Medina, L. Gómez-Pujol, A. Orfila, and G. Vizoso. 2009. "Integrated and Interdisciplinary Scientific Approach to Coastal Management." *Ocean and Coastal Management* 52(10): 493–505.

Toimil, A., I.J. Losada, R.J. Nicholls, R.A. Dalrymple, and M.J. Stive. 2020. "Addressing the Challenges of Climate Change Risks and Adaptation in Coastal Areas: A Review." *Coastal Engineering* 156: 103611.

Tribbia, J., and S.C. Moser. 2008. "More than Information: What Coastal Managers Need to Plan for Climate Change." *Environmental Science & Policy* 11(4): 315–28.

Valente, S., and F. Veloso-Gomes. 2020. "Coastal Climate Adaptation in Port-Cities: Adaptation Deficits, Barriers, and Challenges Ahead." *Journal of Environmental Planning and Management* 63(3): 389–414.

Vollstedt, B., J. Koerth, M. Tsakiris, N. Nieskens, and A.T. Vafeidis. 2021. "Co-Production of Climate Services: A Story Map for Future Coastal Flooding for the City of Flensburg." *Climate Services* 22: 100225.

How to cite this article: Sweetman, Brenna M., Cayla Dean, Lisa Auermuller, Kathryn Noel Tremblay, Christopher Katalinas, Shannan Lewinski, Lori Cary-Kothera and Audra Luscher-Aissaoui. 2024. "User Needs For Coastal Inundation at Climate Time Scales: A Multi-sectoral Case Study in the Coproduction of Knowledge." *JAWRA Journal of the American Water Resources Association* 00(0): 1–13. https://doi.org/10.1111/1752-1688.13230.

APPENDIX A

The general process agenda is documented below. There were some minor changes between workshops in order to work with the specific audience in attendance.

Expected Outcomes:

- NOAA understands information needs for coastal inundation decision making on climate time scales.
- NOAA understands the data and tool gaps that would allow target audiences to make more informed decisions based on inundation risk on climate time scales.

Objectives:

- Participants share how they use existing resources, including data, tools, or technical assistance, in their decision-making processes.
- Participants increase their awareness of NOAA/NOS, OCM, and CO-OPS coastal inundation tools and resources.
- Participants describe how they consider inundation risk on climate time scales during their planning processes.
- Participants identify knowledge gaps for making decisions based on inundation risk over climate time scales.

All of the meetings started with setting the stage of the background of the project and then continued to conduct a CO-OPS and OCM product overview (this was done at the end for the last session). There was then a facilitated discussion with the participants including some of the following questions.

- What are your greatest concerns related to flood risk?
- How will you make your community more resilient to flooding?
- What do you need to know to make your community more resilient to coastal flooding?
- What are your goals for transportation projects as they relate to future flooding?
- What are the key gaps you see in these NOAA products that would help you make more informed decisions regarding coastal flood risk?
- What key information and/or tools would help you better understand and communicate with your clients about flood risk?
- What key information and/or tools would help you better understand and communicate with your clients about flood risk?

APPENDIX B

There were several tools shared with the workshop attendees and some shared back to the project team from participants throughout the course of these workshops. See below for a list of those resources.

- The Digital Coast. A NOAA-sponsored website focused on coastal communities. The site provides data, tools, and training. The focus: making communities more resilient.
- NOAA Sea Level Rise Viewer and the NOAA Lake Level Viewer. Used to view sea level rise and potential coastal flooding impact areas.
- Inundation Analysis Tool. Documents the frequency and duration of high water levels.
- Adapting Stormwater Management to Coastal Floods. Used to address current and future impacts on stormwater management.
- Coastal County Snapshots. County-level data combined and provided via easy-to-understand charts and graphics. Used to create printable handouts that help articulate a community resilience message.
- Map of NOS coastal stations. Used to view local tides and currents.
- Physical Oceanographic Real-Time System (PORTS®). Collects and disseminates observations (water levels, currents, salinity, bridge air gap, meteorological parameters, etc.) mariners need to navigate safely.
- Coastal Inundation Dashboard. Provides real-time and historical coastal flood information at select locations.
- Trends. Uses tide gauge measurements to document local relative sea level trends.
- Extreme Water Levels. Use of tide gauges to measure storm tides, which are a combination of the astronomical tide, the storm surge, and limited wave setup caused by breaking waves.
- 2022 Sea Level Rise Technical Report. Most up-to-date sea level rise projections available for all U.S. states and territories.
- State of High Tide Flooding and Annual Outlook. Visualization tool and report that displays information on increasingly common high-tide flooding, often referred to as “king tides,” “nuisance,” or “sunny day” flooding.
- Application Guide. A companion to the 2022 Sea Level Rise Technical Report. Developed to help people use the data in the technical report to make their communities more resilient. will help coastal communities plan for significant sea level rise.
- High Tide Bulletin. Shows when regions around the nation may experience higher than normal high tides. Bulletins are updated quarterly.

Resources Shared by Workshop Participants

No specific tools are being endorsed by the authors. These are items that were provided by workshop participants as tools that they use to help in their decision making process.

- Peer-to-Peer Case Study—Flood awareness for Realtors
- ASFPM Flood Notebook
- Virginia the Commonwealth Center for Recurrent Flooding (CCRFR) GIS-based community mapping tool to log flood issues and community assets
- Virginia Beach Sea Level Wise StoryMap
- Queen Anne's County Maryland Sea Level Rise and Vulnerability Assessment
- University of Washington's Climate Impacts Group
- NC Flood Risk Map Viewer/NC One Map
- First Street Foundation's Risk Factor tool
- New York City Flood Hazard Mapper
- Delaware flood planning tool
- Indiana DNR Floodplain Portal

- Coastal New York Floodplain mapper:
- Mycoast.org
- NC Institute for Climate Studies
- Interagency Sea Level Rise Scenario tool
- Climate Central Global Sea Levels
- Reducefloodrisk.org
- Floodsmart.gov
- Inspect2protect.org

Pinellas County's Floodplain Maps