CLIMATE PROJECTIONS AND WATER RESOURCES: ADDRESSING BARRIERS & ADVANCING SOLUTIONS FOR EFFECTIVE DECISION-MAKING

EXECUTIVE REPORT

THE FLORIDA WATER AND CLIMATE ALLIANCE (FWCA)

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Climate Projections & Water Resources: Addressing Barriers & Advancing Solutions for Effective Decision-Making

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Acknowledgments

This includes individuals who have helped with the project but are not considered co-authors. This also includes the expert panel.

FWCA steering committee

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Executive Summary

This report provides insights into current challenges and solutions in incorporating high-resolution climate forecasts, including rainfall data, into water resource management decision-making. This study involved a listening session to include 7 panelists and about 150 participants representing scientists and practitioners in the climate and water resource management sectors. The session focused on informing the State of Florida's development of future rainfall projections for use in climate-related vulnerability assessments. Additionally, the discussion also touched on other relevant data, such as evapotranspiration and temperature, which are important factors in water resource management decision-making. By considering various climate variables, decision-makers can gain a comprehensive understanding of the potential impacts of climate change on water resources and develop effective strategies to address challenges and vulnerabilities in the region.

Using a moderated panel discussion combined with a virtual stakeholder participation activity, the goals of the session were to:

- Inform stakeholders of the State of Florida Flood Hub Statewide Rainfall Projections Working Group goals, process and timeline
- Understand how diverse stakeholders are currently using climate information in their planning and decision-making process
- Explore the types of future climate projections, e.g., spatial scale (regional extent, spatial resolution), temporal scale (seasonal climate, extreme events, planning timeframes) that would be useful to key stakeholders
- Brainstorm potential opportunities and barriers for the application of statewide regional climate projects for different stakeholders

Key findings showed that stakeholders appreciate and utilize a wide range of climate information/data from a multiplicity of sources with varying levels of integration into existing analytical tools and decision processes. However, certain barriers were identified to utilizing climate projections for decision-making. They ranged from the complexity and trustworthiness of the data; lack of standardized procedures; educational gaps among constituents to insufficient funding. Also, the panelists reported a noted mismatch between "data that is needed and what is available." Given the unique state topography, the need for varied levels of downscaling of gridded data is an ongoing issue. Since decision data come from multiple sources, there is an additional need for guidance on integrating these sources to understand a given local situation best. All this underscores a unique characteristic of the water resource field – the need for highly specialized and often location-specific data, further complicating the decision-making process.

Participants and panelists agreed on the importance of developing comprehensive regulatory standards, accessible tools, better education, and more secure funding to better incorporate climate projections in decision-making. This includes advocating for a holistic approach that combines data from various sources and fosters collaboration across different organizations.

Key findings include the risk-averse nature of water resource decision-making, the complexity of data used, and the necessity for a holistic approach. These findings reveal how difficult it may be for the water management sector to embrace new methods due to the potential consequences of inaccurate projections, i.e., risk aversion on the part of constituents and board members, the struggle to effectively employ extensive datasets, and the need for inter-organizational collaboration to overcome these difficulties.

The report concludes with recommendations for both academics and practitioners. These recommendations emphasize the need for a better understanding of the risk analysis calculations of water resource managers, a deeper exploration into how practitioners use, combine, and tailor data, and the establishment of partnerships between practitioners and scientists to foster greater collaboration. Implementing these recommendations will enhance decision-making processes and enable better adaptation and mitigation strategies in the face of climate change.

Background

This project was supported by the Florida Water and Climate Alliance (FloridaWCA), a collaboration between academic and practitioner scientists and stakeholders. The alliance is dedicated to developing climate science that is locally relevant and practical to aid decision-making in water resource management, planning, and supply operations in Florida.

Florida is a unique case in the United States due to its distinctive geographical characteristics. As a peninsula, three sides of the state are surrounded by the ocean, resulting in sea breeze and ocean currents influencing its weather systems. The entire state has low topographic relief and is underlain by shallow highly transmissive aquifers such as the Floridan, Biscayne, Sand and Gravel and Surficial aquifers. These geographic features make Florida particularly vulnerable to climate change, providing scientists and practitioners with an extreme example of how water resource management will be affected in the coming years.

As the effects of climate change become increasingly urgent, it is crucial to gain a deeper understanding of its impact on water resource management. Our resilience to flooding, access to safe drinking water (in terms of quantity and quality) and valuable environmental services face significant threats, such as rising sea levels, saltwater intrusion, and extreme storms, among others.

While additional data and more accurate projections are needed, scientists and practitioners currently employ multiple strategies to predict future weather and assess climate change’s implications. At present, scientists throughout the state are using advanced sea-level rise (SLR) projections primarily guided by the National Oceanic and Atmospheric Administration (NOAA) to develop vulnerability assessments. However, there are challenges in obtaining accurate rainfall projections, given changing weather patterns due to climate change. This leads to limited projections and considerable uncertainty in future rainfall forecasts. Nevertheless, recent efforts led by the South Florida Water Management District (SFWMD) in cooperation with the U.S. Geological Survey (UGSS) aim to address and reduce this gap.

In addition to SLR projections, statewide efforts led by the Resilient Florida Program and Florida Flood Hub for Applied Research and Innovation are working towards incorporating unified projections for both SLR and rainfall assessments in vulnerability evaluations. These endeavors seek to provide comprehensive and cohesive insights into the potential impacts of climate change on Florida’s water resources.

Furthermore, other statewide initiatives are examining how climate variables, in general, affect the assessment of future conditions and their implications for overall planning efforts. By understanding the complex interactions between climate factors, decision-makers can better prepare for the challenges of climate change and make informed water resource management decisions.

Methods

In April 2023, the FloridaWCA organized an online listening session with scientists and practitioners involved in water resource management. The key objective was to gain insights into their decision-making processes in the face of climate change. The session included two parts. In the first part, the panelists, consisting of seven individuals with diverse backgrounds, were asked a series of specific questions regarding their use of climate information in decision-making in the water management process. Descriptions of the panelists' professional backgrounds are as follows:

- **Panelist A** – Senior Manager for a large public water utility serving more than 2.5 million customers
- **Panelist B**– Chief Resilience Officer for a metropolitan area with more than 900,000 residents
- **Panelist C –** Executive Director of a drainage district that serves more than 800,000 residents
- **Panelist D**- Senior Principal at a consulting and engineering firm focusing on the environment, natural resources, and civil infrastructure
- **Panelist E**- VP of coastal resilience for a marine and coastal engineering firm
- **Panelist F** – Director of Water Resources at a global environmental nonprofit organization
- **Panelist G** – Professor at a large state university and executive director of a state organization focusing on flooding

In the second part of the listening session, the audience, comprised of about 150 individuals involved in water management, answered the same questions as the panelists using the Mentimeter software. This app provides real-time feedback to display group responses.

To analyze the session, three graduate-level students from the University of Florida's Department of Family, Youth, and Community Sciences, transcribed and coded the discussion under the supervision of their advisor. The researchers employed Glaser and Strauss' constant comparative technique (Glaser, 1965). This systematic and iterative process involves comparing and contrasting data to identify emerging themes rather than imposing preconceived notions onto the data.

The coding process began with open coding, where each researcher individually broke down the transcript into smaller codes or units of information. Next, the researchers met to compare their codes, identifying similarities and discussing differences until a consensus was reached for each code. This repeated process focused on broader trends and themes instead of specific codes. The researchers continued this iterative process until they reached the point of saturation or where further analysis no longer provided new insights.

The researchers achieved Inter-coder reliability by reaching a consensus on codes and themes, enhancing the data's validity and reliability and bolstering result dependability.

Upon completing the coding process, the researchers created visual aids such as word clouds, bar graphs, and diagrams whenever possible to enhance accessibility and comprehension of the information. The findings derived from the coding process served as the foundation for this report. The researchers divided the report into several sections: The first section exclusively examines questions answered solely by the panelists. The second section compares questions answered by panelists and the audience who participated through Mentimeter. Subsequently, the report explores overarching themes and trends identified during the listening session. Finally, the report proposes recommendations for academics and water resource practitioners. The report underwent thorough review, editing, and approval by all researchers and their supervisor to ensure its validity.

Results

Part One: Panelist Responses

Climate Projections Translated into Water-Related Risks

During the listening session, the panelists were asked, "How are climate projections translated into water-related risks by your organization?" Risk translation could take the form of models, decision trees, more qualitative methods, or others. Most respondents emphasized the importance of actionable information to attract investors, provide valuable insight, and promote transparency and confidence among their stakeholders.

Panelist A discussed the importance of using models to develop "what-if" climate scenarios, explicitly using the concept of residual risk management (FEMA, 2018). They acknowledged it's impossible to predict or build for all future extreme scenarios, such as drought or severe flooding, because it is too expensive for ratepayers. Instead, they put strategies and tools in place for these unpredictable situations. The panelist said, "I know that I cannot build for all extremes. If the extreme comes, I have some kind of tools to help me navigate some of those extremes. But if things start to come frequently, then that's not extreme anymore."

Panelist B, mentioned using a "structured decision-making methodology" for their city's resilience strategy. In structured decision-making, leaders gather input from a broad array of stakeholders and voices, analyze the pros and cons of each perspective, and develop priorities for actions and projects (Huang, Keisler, & Linkov, 2011). The goal of structured decision-making methodology is to ensure clarity in the logic behind decisions and establish confidence in the use of data. The structured decision-making process also helps strengthen the economic argument for investing in different resilience projects.

Furthermore, the panelist explained that this form of decision-making has the added benefit of gaining buy-in and trust from community members. Specifically, the panelist said, "This structured decision-making methodology will allow us to have a lot of transparency in how decisions are made and how priorities are set…I think that you can have the best data in the world, but if people don't have a lot of confidence in how it's being used…it doesn't really help you…And so again, not just having the data [but] connecting it to action, and then having a lot of transparency around decisions."

In summation, these water management experts use a range of climate projections and decision-making tools to translate water-related risks in their organizations. It is clear there is no "perfect decision" in water resource management, but by using available data and seeking consensus, experts can prioritize actions and prepare for unexpected events.

Communicating Results, Risks, Uncertainties, and Assumptions to the Public and Policymakers

Another question posed to the panelists was, "How are you communicating results, processes, risks, uncertainties, and assumptions to the public and policymakers?"

Panelist E explained their collaboration with a Water Management District and their use of the Deltares Dyanmic Adaptvie Policy Pathways approach (DAPP). This model considers various weather events, such as sea level rise and rainfall patterns, and visually presents the projected changes in water resources over the next 10, 5, or 20 years based on different decision-making scenarios. For instance, it helps determine the impact of flood mitigation measures like raising sea walls. These visuals resemble a colorful transit map, where each decision is represented by a different color, outlining the various pathways and their associated impacts.

The panelist found the DAAP model an effective communication tool, stating, “Having this kind of colored map of ‘here’s a different strategy, here’s the different timelines. We don’t have to do them all today.’ You know. And how do these [strategies] compare with doing nothing? I think that’s a really good way to communicate it to the public.”

Another strategy used by multiple panelists involved communicating risks in terms of financial implications. Panelist B, emphasized the need for scientists to build compelling cases for resilience planning using language that policymakers can easily understand, specifically in terms of costs. The panelist stressed the importance of communicating questions such as, “What are the costs? How many lives are at stake? What are the costs if we do nothing? What are the avoided costs if we take action?” Furthermore, the panelist suggested converting raw climate and hydrologic data into monetary figures to motivate decision-makers to take action. This approach, focusing on the financial narrative of climate change, has proven effective in engaging policymakers.

Similarly, Panelist A highlighted stakeholders’ concerns about the financial implications of decisions. While technical scientists within the utility focused on the impact of climate data on water supply and quality, decision-makers and stakeholders, including the board of directors and executives, were primarily interested in the investment required for climate adaptive resilience efforts. Moreover, external stakeholders include consumers who are also concerned with utility costs. The panelist explained, “So at the end of the day, what our board, executives and others would like to see is, if this [climate change] is a situation, what is the corresponding investment? So that kind of linking the risk and level of service from [a] water supply perspective as well as financial implication[s].” Some of these financial uncertainties mentioned included how to secure investment funding for projects and determining what projects should be the highest priority and scheduled first.

In addition to financial considerations, another strategy discussed involved framing climate change risks regarding their impact on people’s daily lives and the broader implications for the entire state. In this view, it is essential to recognize that climate change affects not only those living in coastal areas, who are more vulnerable to sea level rise and hurricanes but also people across the state. Panelist B illustrated this point by saying, “You know you don’t need to have a major named Hurricane to have impacts if…the road you take to drive your kids to school is inundated from rainfall on a monthly or bi-monthly basis. That’s enough to really have you question where you’re living, and why you’re living there, and to cause a lot of public backlash.” By simplifying the explanation of how climate change will negatively impact a considerable number of individuals, decision-makers can grasp the larger implications, such as the potential flux of “climate refugees” seeking to escape the adverse effects and its impact on the state’s economy.

Lastly, Panelist B emphasized the importance of effectively communicating ongoing activities, decision-making processes, and the rationale behind infrastructure development to constituents, the public, and municipal officers. Clear and accessible communication of complex water management concepts is crucial for garnering support for various projects, building trust with stakeholders, and engaging and informing the public.

Navigating and Incorporating Future Climate Uncertainties into Resilience Planning

During the panel discussion, the moderator raised a crucial question regarding how organizations handle uncertainties when forecasting future climate conditions, particularly concerning rainfall.

Panelist E once again highlighted the effectiveness of the Dynamic Adaptive Policy Pathways approach (DAPP). The core objective of this approach is to address the evolving nature of climate change by gradually implementing adaptive strategies rather than attempting to enforce all solutions immediately. The panelist stressed that DAPP is a valuable tool for breaking down and prioritizing actions. Presenting engineers with multiple timelines for different scenarios enables them to identify the most urgent issues and projects. Moreover, showing various strategies and timelines helps the public understand that they do not need to take all actions simultaneously. Furthermore, effectively conveying the urgency and significance of adaptation, we compare these strategies with the consequences of inaction.

Drawing attention to the similarity of this method, the moderator mentioned Ripple Effect Mapping, a participatory approach that involves various stakeholders. This technique captures the intended and unintended consequences of any initiative over time. For instance, if a community decides to construct a bridge, the ripple effect map encompasses all aspects of the bridge, including its long-term impacts. The information gathered through this process helps determine the best approach to implementing the project while considering its future consequences.

Panelist A explained their organization has been using Tsuyoshi Hashimoto's method of assessing the reliability, resilience, and vulnerability of their water resource system performance for nearly a decade (Hashimoto, Stedinger, & Loucks, 1982). In this method, reliability refers to the system's ability to consistently meet water supply demands without interruptions. Resilience refers to how quickly the system can recover from disruptions. At the same time, vulnerability focuses on the severity of consequences on the water supply, ecosystem, and human populations, if the system fails.

Scientists use this reliability, resilience, and vulnerability evaluation with the previously discussed residual risk management approach. Residual risk management acknowledges that it is impossible to eliminate all water-related risks that but argues that we can mitigate risk by developing strategies and tools for unexpected events. Examples include contingency planning that outlines necessary actions in different scenarios, implementing backup systems in case primary systems fail, and land and watershed management to sustain water sources. This method helps organizations become more flexible and adaptable when unexpected challenges arise. However, it is essential to consistently revisit these scenarios since climate change is causing extreme events to occur more frequently.

In conclusion, the panelists acknowledged the inherent challenges of incorporating uncertainties into water-resource decision-making due to the dynamic nature of climate change. Predicting future weather events and effectively planning for water resource management becomes difficult, with rainfall projections being particularly challenging. Climate change alters the likelihood of rainfall occurrences, making it hard to plan accurately for water storage, as extreme rainfall, whether caused by tropical storms and hurricanes or drought, directly impacts water supply levels. Furthermore, rainfall patterns are influenced by seasonality, temperature, and atmospheric pressures, adding complexity to the task. Despite these complexities, scientists and practitioners must work with uncertainty while developing estimates of rainfall, depth, duration, and frequency for the entire state. In light of this, the panelists stressed the importance of resilience planning, highlighting that organizations can devise specific strategies and tactics to prepare for extreme weather events.

Accounting for Future Rainfall Projections in Resilience Planning and Decision-Making

During the discussion, experts highlighted the importance of accounting for future rainfall and climate projections when making decisions and plans for water management in the face of climate change.

Panelist C shared that their organization relies on rainfall estimates provided by the water management district based on 50 years' worth of historical rainfall data. However, they acknowledged that this approach might become less effective in the coming years due to climate change-induced extreme weather events that deviate from historical rainfall patterns. The panelist said, "We don't know how climate is going to adjust that of those probabilities of rainfall occurrences, and so [we need] some way to understand that change as we look forward, and more importantly, how it's going to reflect in the hydrology of water management [and] water resource systems in South Florida I think is really critical."

Panelist B emphasized their organization's comprehensive and holistic approach. To determine future land uses, they incorporate future rainfall into their comprehensive planning, sea level rise projections, and compound flooding. They said, "I can't just look at sea level rise. I can't just look at riverine or stormwater runoff. It really has to be one holistic view, and I think everybody here would probably echo that." Like Panelist C, this expert stressed the importance of accurate projections in decision-making. The expert explained that inaccurate predictions could lead to significant costs associated with infrastructure planning and adaptation efforts, not to mention water quality and quantity that do not meet consumer demand.

To "get it right" when making these decisions, scientists and engineers must provide decision-makers with the best available data and associated uncertainties, along with recommendations on how to best interpret these uncertainties. Achieving this requires collaboration and cooperation among various entities, such as municipalities, counties, utilities, and water management districts. By involving stakeholders and integrating adaptation strategies into models that simulate future rainfall scenarios, decision-makers can assess the financial benefits and effectiveness of different approaches.

However, merely sharing data among stakeholders is not sufficient. Scientists must communicate the data so that each stakeholder can understand and find it useful for their projects. Panelist B explained, "[We need a] conduit between [decision-makers], the engineers, scientists, consultants, universities, and the elected officials, and the county staff that are doing this; I think to me that's the number one thing…." This collaboration and information exchange were deemed essential for successful decision-making.

In conclusion, the experts stressed the need to consider a wide range of future scenarios rather than trying to predict a specific outcome, especially when dealing with high levels of uncertainty still associated with rainfall projections in Flrida. They advocated for robust decision-making, which involves considering various possible futures when making investments and decisions. Ultimately, the participants agreed that building bridges between scientists, practitioners, and policymakers is crucial for accurate future projections. Integrating climate projections, including future rainfall, into water management strategies significantly benefits all stakeholders.

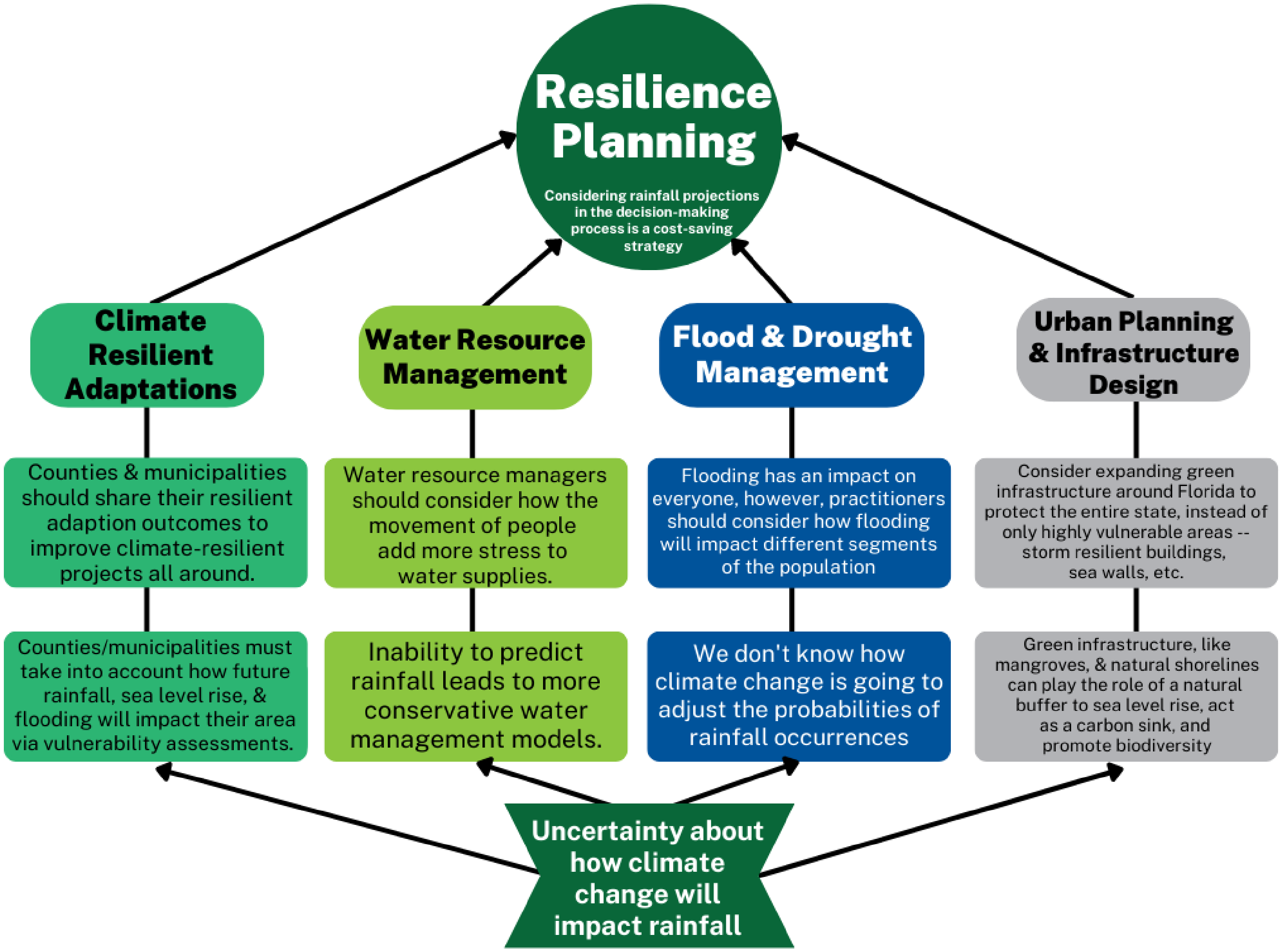

Figure 1 Uncertainty and resilience planning

After carefully analyzing and synthesizing the insights provided by experts, the researchers have developed a comprehensive conceptual model that visually represents the impact of changing rainfall patterns on resilience planning across various sectors. Figure 1 above displays this conceptual model. The first level of cells beneath the "Resilience Planning" circle in the figure represents the sectors of climate resilient adaptations, water resource management, flood & drought management, as well as urban planning & infrastructure design, encompassed by the model.

Moreover, this model illustrates the intricate relationships and interdependencies between sectors. It is based on a thorough analysis of the data provided by the experts, ensuring that it accurately captures the observed connections. These valuable insights shed light on decision-making processes concerning resilience planning in the face of climate change.

With the alternation of historical rainfall patterns due to climate change, scientists are grappling with uncertainties regarding potential outcomes such as rainfall inundation, severe droughts, or other unprecedented weather events. A cell labeled “uncertainty about how climate change will impact rainfall” is included at the bottom of the diagram to capture this uncertainty.

Recognizing the wide-ranging impact of this uncertainty on decision-making, the model depicts how it influences multiple sectors. The cell indicating uncertainty about rainfall patterns connects to the next level of cells, each representing a specific sector: climate resilient adaptations (dark green), water resource management (lime green), flood and drought management (blue), and urban planning and infrastructure design (gray).

The changing rainfall patterns prompt adjustments within each sector of applied environmental science. These middle-level cells represent the adjustments. By visually connecting the uncertainty cell with these sector-specific cells, the diagram highlights the direct influence of uncertainty on decision-making across various domains. According to the experts, counties and municipalities must assess how changing rainfall patterns, along with SLR, will impact flooding to implement effective climate-resilient adaptations. Vulnerability assessments conducted for their specific area can analyze these changes. The US Department of Agriculture explains that vulnerability assessments “determine the degree to which specific resources, ecosystems, or other features of interest are susceptible to the effects of climate change” (Joyce & Janowiak, 2011). As the climate changes, specific areas within a region may become more vulnerable to damage from extreme weather events.

Furthermore, the panelists emphasized the importance of sharing methodologies and findings with other organizations during these assessments. Collaborative efforts and knowledge sharing can significantly enhance the process of climate-resilient adaptations. By working together and exchanging information, stakeholders can improve their understanding of vulnerabilities, identify effective strategies, and ultimately strengthen the resilience of their communities.

Moving on to water resource management, the panelists highlighted a crucial challenge decision-makers face in predicting future rainfall. Traditionally, they have relied on analyzing historical rainfall patterns as a primary source of information. However, due to the extreme effects of climate change, these past trends can no longer provide accurate predictions for future rainfall. Changing weather patterns present a significant obstacle for water resource managers, who must determine the appropriate water supply for their customers. Consequently, public water utilities are adopting more conservative water management models to mitigate the risk of water shortages. This adaptive approach helps address the uncertainties associated with changing rainfall patterns and ensures communities a more sustainable water supply.

In addition to climate change, the experts highlighted the significance of considering the impact of human migration on water supplies in water resource management. The movement of people, whether through emigration or immigration, places additional stress on these resources. This consideration becomes particularly crucial in Florida, a migration hotspot. According to the US Census Bureau, Florida ranks first in total net and domestic migration and second in international migration. In 2020 alone, approximately 1,218 people relocated to the state daily, making it the primary destination for migrants across the United States (Tampa Bay Economic Development Council, 2023). Given these trends, effective management of water supplies becomes paramount in Florida to meet the growing demands.

Now, shifting our focus to flood and drought management, the uncertainties surrounding the impact of climate change on rainfall patterns pose challenges in forecasting both floods and droughts. While the consequences of flooding affect all segments of society, practitioners must recognize its disproportionate impact on specific populations, such as low-income individuals and people of color (Walker & Burningham, 2011). Furthermore, climate change is driving up the cost of flood insurance, exacerbating the vulnerability of these marginalized groups (Palmer, 2022). Addressing these disparities and ensuring equitable management strategies are essential components of effective flood and drought management in the face of changing rainfall patterns.

Now let’s delve into the crucial aspects of urban planning and infrastructure design. With the intensification of storms caused by climate change, it is imperative to strengthen our infrastructure to withstand stronger wind gusts, reduce vulnerability to power outages, and effectively manage heavy rainfall. A striking example of the urgency for such upgrades is the record-breaking flooding in South Florida in April 2023. During this event, rainfall reached staggering levels, with 3-6 inches per hour and 12-hour amounts exceeding 20 inches (National Weather Service Miami, 2023). The sheer volume of rainfall overwhelmed the urban areas, leaving little room for proper drainage and resulting in stranded individuals and prolonged power outages.

To address these challenges effectively, experts strongly recommended implementing strategic green infrastructure solutions. Incorporating environmental features such as mangroves and natural shorelines can serve as organic buffers against rising sea levels. Moreover, with the likelihood of increased stormwater volumes due to more extreme rainfall events, green infrastructure can also alleviate rainfall-driven flooding while preparing for potential sea-level rise. This approach enhances the sustainability of our stormwater infrastructure. Beyond their protective benefits, these nature-based strategies act as carbon sinks, capturing harmful greenhouse gases and promoting biodiversity. By integrating these natural elements into urban planning and infrastructure design, we can bolster our resilience to climate change impacts and create more sustainable and livable environments.

Recognizing the numerous benefits of green infrastructure, designers, city planners, and practitioners must consider expanding its implementation across Florida. Rather than focusing solely on vulnerable coastal areas and implementing sea walls, a comprehensive approach should be adopted to safeguard the entire state. Such an approach would entail constructing storm-resilient buildings and incorporating green infrastructure measures.

In summary, this diagram elucidates the impact of changing rainfall patterns on decision-making regarding resilience planning across multiple sectors and the interconnectedness of these changes. Furthermore, the model proposes suggestions for enhancing the decision-making process through collaboration and innovative considerations. The key takeaway from this model is that incorporating rainfall projections into resilience planning is vital for practitioners and a cost-saving strategy in the face of uncertain future climate.

Part Two: Panelist and Participant Responses

In the second part of the listening session, the audience, comprising of more than 100 individuals from various backgrounds in water management, including practitioners, scientists, and stakeholders, answered the same questions as the panelists using the Mentimeter software. This app provides real-time feedback to display group responses. The rest of the results section will compare and contrast the panelists’ answers to that of the audience members. The graphs show the results of the Mentimeter responses.

Characterizing Vulnerabilities

When asked, “How do you use current and future climate data, especially rainfall, to characterize vulnerabilities? The panelists and audience members discussed two broad categories of vulnerabilities – infrastructure/land vulnerabilities and hydrologic/hydraulic vulnerabilities.

Infrastructure & Land Vulnerabilities

Panelist E highlighted their organization's reliance on rainfall data to develop models and analyze flooding scenarios. These models consider various factors, including timing, to identify risks associated with compound flooding events. Additionally, the panelist emphasized the significance of evaluating vulnerabilities related to infrastructure and service levels integrating water vulnerability considerations into an engineering framework.

This panelist's response echoed the sentiments of some audience members who emphasized the importance of conducting risk analysis for project areas. Mentimeter responses included utilizing sea-level-rise (SLR) curves, inundation overlays with geographic information systems (GIS), depth damage flooding assessments, and real-time flooding forecasting to assess flooding risks and determine appropriate levels of flood protection.

Panelist B discussed their city's data-driven approach to making informed decisions. For instance, they mentioned constructing taller bulkheads and incorporating adaptive management principles into infrastructure design. They recognized that different types of flooding necessitated other solutions and stressed the need for public engagement to enhance understanding of the complex dynamics and systems involved.

Similarly, audience members shared their practices of utilizing climate data and over-exposure databases to assess the impact of rainfall on critical facilities and assets, such as properties and roads. Others mentioned leveraging climate data to inform future land-use policies through strategic infrastructure planning and design. Furthermore, one audience member highlighted using data to identify vulnerable habitats and habitat migration corridors, aiding in determining habitat protection or restoration projects.

Hydrologic & Hydraulic Vulnerabilities:

The panelists and participants also addressed hydrologic and hydraulic vulnerabilities, which impact water supply quality and quantity. Panelist A explained how their organization evaluates various scenarios of future climate projections, localizes them to their specific area, and analyzes their implications for crucial water sources. The panelist also considers factors such as daily flow, groundwater withdrawal, and wetland protection regulations. Climate projections are incorporated into hydrologic and systems models to assess future flows, operations, and potential risks.

The response from the panelist closely aligned with the Mentimeter responses, where organizations utilize hydrologic and hydraulic (H&H) modeling, incorporating current and future rainfall data, to drive hydrologic models which predict inundation. Some respondents elaborated further, the Mentimeter responses mentioning using rainfall data to determine storage adequacy in basins and to understand potential vulnerabilities posed by saltwater intrusion and minimum flow level (MFL) projections on water supplies. Another respondent mentioned leveraging climate data to identify suitable locations for hydrologic restoration projects.

In conclusion, the discussion on characterizing vulnerabilities in water-resource decision-making highlighted the significance of integrating current and future climate data, particularly rainfall data, into the assessment process. Participants and panelists recognized infrastructure/land and hydrologic vulnerabilities as crucial factors. These insights and approaches provide valuable tools for experts in this field to navigate the complex challenges climate change poses in water-resource decision-making.

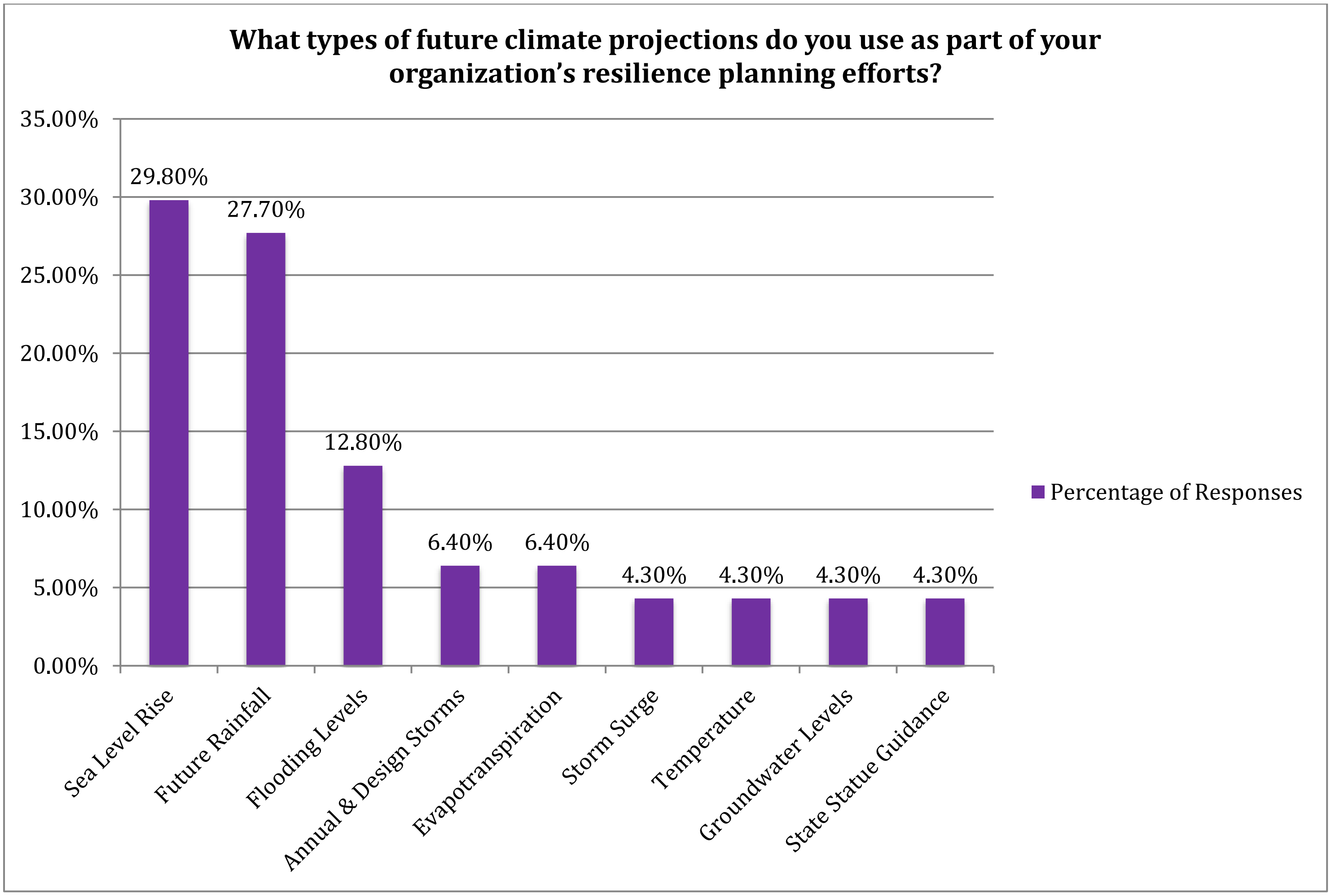

Figure 2 Future climate projections and resilience planning

We asked the participants about the types of future climate projections utilized for their organization's resilience planning. Sea-level rise emerged as the most common response, with 29.8% of the participants highlighting this climate projection. Following closely behind was future rainfall, cited by 27.7% of participants, while flooding levels garnered 12.8% of the responses.

Other factors taken into account for planning included annual & design storms, as well as evapotranspiration, both receiving 6.4% of the responses. Storm surge, temperature, groundwater levels, and state statute guidance were each mentioned by 4.3% of respondents. It's essential to note that some individual participants provided additional answers beyond those displayed on the graph. These responses encompassed freeze events, NOAA, USACE, Resilient Florida, habitat evolution models, MIKESHE Mike 11, river modeling, drought projections, and red tide monitoring. On a contrasting note, one participant mentioned their organization does not currently employ any future climate projections for resilience planning efforts.

Although the panelists and audience had similar answers, there were some variations. The panelists primarily focused on future rainfall and flooding, while the audience mentioned nine primary climate projections. Panelist A emphasized the significance of rainfall projections for their organization's decision-making process. They considered seasonal shifts, temperature changes, and tropical storms to predict the impact on water sources. Two other panelists also highlighted the influence of rainfall on water supplies.

Panelist E explained how their organization collaborates with the US Geological Survey and the local water management district to understand the interaction between rainfall, compound flooding, and the state's groundwater. Similarly, Panelist C mentioned their reliance on the local water management district for future rainfall projections and other climate indices, enabling them to balance flood protection and water supply.

Flooding was another important topic of discussion. Panelist D stated that their organization considers the impacts of sea-level rise and future rainfall projections on coastal and rainfall-induced flooding. Panelist B echoed this sentiment, emphasizing the use of data from the Army Corps, FEMA, and internal comprehensive flooding datasets. They analyze factors such as tributaries, storm surges, and sunny day flooding to understand the complexity of flooding hazards.

Lastly, Panelist F explained how their organization utilizes rainfall data and various sources of climate information to assess the effects of climate change on biodiversity and human resilience. In summary, the panelists and audience members rely on similar future climate projections for resilience planning. However, the audience places greater emphasis on sea-level rise projections, while the panelists prioritize rainfall and flood projections.

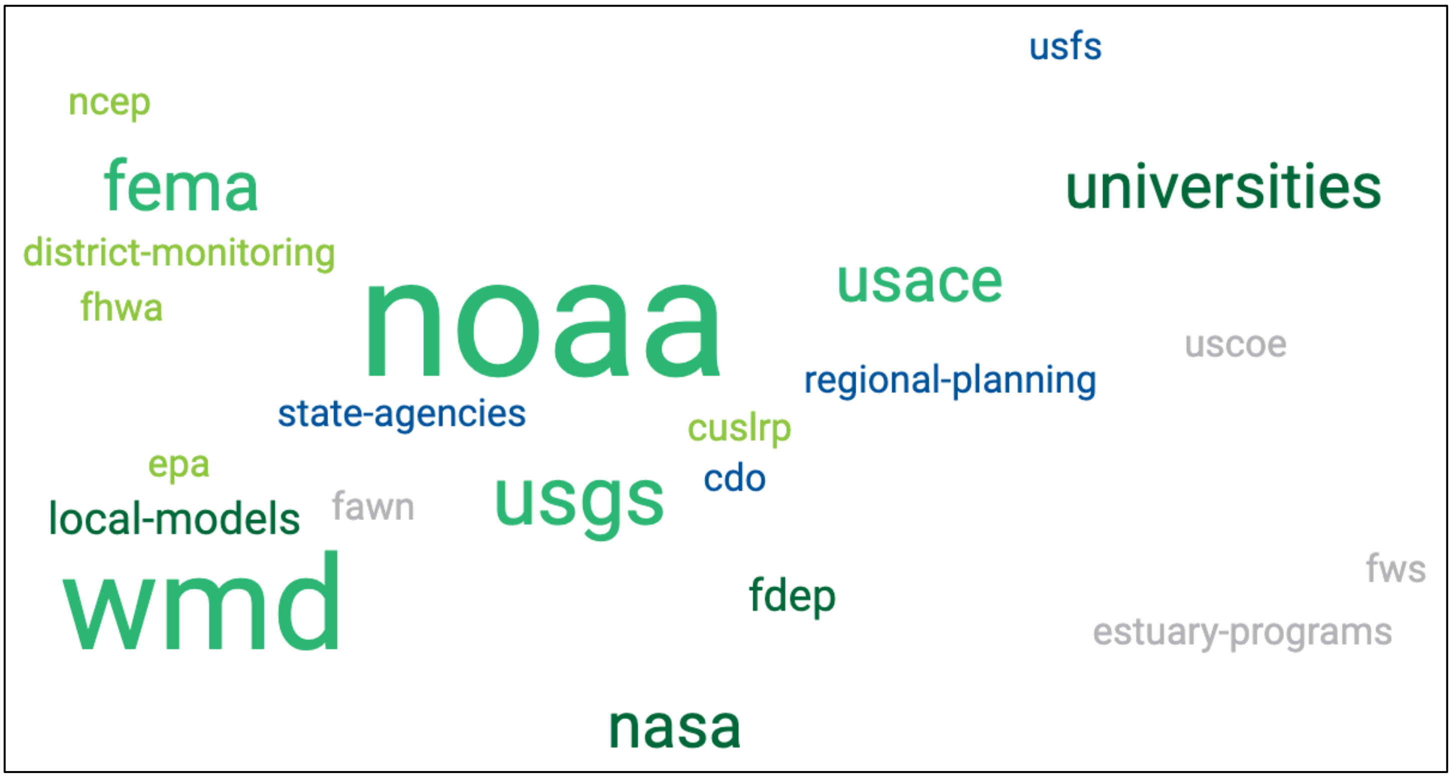

Figure 3 Sources of data

Another question posed to both the panelists, and participants was what kinds of sources and organizations they rely on for up-to-date and well-documented climate data in the context of water resource management amid climate change. To visually represent their responses, Figure 3, displays a word cloud, where the size of each word corresponds to its frequency of mention, with larger words indicating more frequent responses.

"NOAA" (National Oceanic and Atmospheric Administration) was mentioned by 26.19% of the participants making it the most frequently cited source. "Water management districts (WMDs)" followed closely, with 19.05% of participants mentioning it. "USGS" (United States Geological Survey) was mentioned by 9.52% of respondents, while "FEMA" (Federal Emergency Management Agency) was mentioned by 7.14%.

Interestingly, 5.92% of respondents mentioned three sources in unison: “USACE,” (United States Army Corps of Engineering) “NASA,” and “universities.” Additionally, “FDEP” (Florida Department of Environmental Protection) and “local models” were each mentioned by 2.38% of participants). All other responses accounted for 1.19% each or 15.47% of the total responses.

The panelist responses are very similar to participant responses, mentioning various sources, including FEMA, Water Management Districts (WMD), NOAA, USGS, state agencies, universities (UF, FAU, USF), Regional Planning Councils, Local/County sources, and the US EPA; however, the panelists went into more detail.

In addition to federal and state agencies, the Panelist B highlighted collaboration with outside consultants such as the Water Institute, an applied research nonprofit based in Louisiana, and Fern Leaf, a climate resilient planning firm in North Carolina, which help transform raw data into usable forms for planning efforts and risk visualization. They explained the consultants incorporate social data from the census bureau to provide a holistic picture of vulnerability in different parts of the city.

Panelist A explained their organization has its group dedicated to climate data and utilizes sources such as the management district, NOAA, and national authorities. They explained that the utilities had implemented an API procedure to download and incorporate data into their database seamlessly. In addition, the organization also collaborates with the University of Florida and other universities to translate data into locally actionable information.

Panelist E emphasized the importance of considering the specific stress or threat when selecting appropriate data sources. They mentioned FEMA studies for baseline data on storm surge areas, the UF-IFAS FAWN system for rainfall data, NASA as a source, and local government modeling for aspects like rain-induced flooding.

The participants and panelists rely on multiple sources at different levels, including federal, state, local, and private sector organizations, to gather a comprehensive range of climate data for water resource management decisions. NOAA is the most used source.

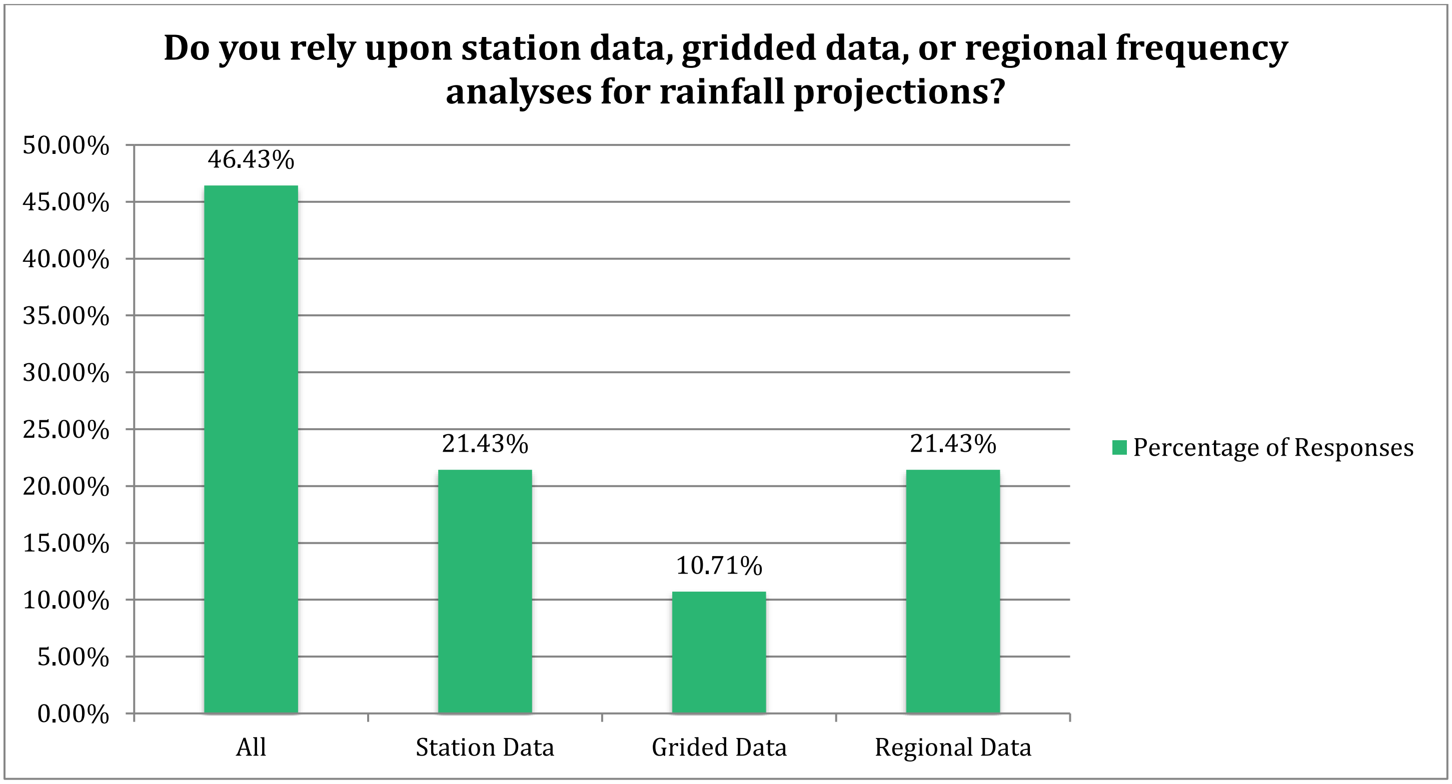

Figure 4 Rainfall projections data

During the discussion, we asked participants and panelists about their reliance on different data types for rainfall projections, specifically station, gridded, and regional data. Station data is taken from a specific weather station and includes climate information such as temperature, relative humidity, pressure, precipitation, and wind speed and direction. Gridded data includes area averages of daily maximum, minimum, and average temperature and precipitation. Regional data includes the averages of climate information from specific regions, such as the Midwest, Southeast, or smaller areas, such as a city or neighborhood. Regional data can be tailored to project needs. Most participants (46.43%) expressed utilizing a combination of station data, regional data, and gridded data to determine rainfall projections. Among the three data types, “station data” and “regional data” received equal support, with 21.43% of responses each, while “gridded data” was mentioned less frequently, with only 10.71% of responses. Other less frequently cited answers provided by the participants but not displayed on the graph included change factors, NOAA Atlas 14, and rain gauge corrected NEXRAD.

The panelists largely agreed with the participants, emphasizing the preference for multiple data sources when constructing models. They stressed there is no universal approach and that the data selection depends on the scale of the problem at hand.

Panelist E highlighted a shift in incorporating climate change into rainfall projections. In the past, there was either no consideration of rainfall projections or historical rainfall data were increased by a relatively consistent figure each year and would prove fairly accurate to actual weather events. However, due to climate change, rainfall patterns are changing dramatically and there is now a focus on using global climate models and downscaling them to the regional level. The panelist stressed the importance of studying compound flooding, which occurs when rainfall coincides with storm surge events.

Similarly, Panelist D mentioned that their organization typically relies on gridded data, particularly for localized flooding work. They also examine return event-based scenarios, such as the 10-year and 25-year events. However, they cautioned against solely focusing on individual event-based scenarios as it may overlook important factors, such as changes in storage and antecedent conditions. They emphasize the need to consider real cases and address all relevant aspects.

Panelist C further expanded on this point, suggesting that organizations should consider the impact of a sequence of smaller rain events, in addition to major ones, when evaluating flood projections. They emphasized the importance of factoring in the probability of these smaller events and their cumulative effect.

Furthermore, Panelist B pointed out that flood risk extends to a larger population affected by rainfall inundation. When considering flood risk, it is crucial to recognize its impact on a broader scale.

Overall, both the panelists and participants stressed the necessity of adopting a comprehensive approach and utilizing different data sets to gain a complete understanding of flood risk. They acknowledged the requirement for more sophisticated and comprehensive data to make informed decisions about water resource management and the advancements in modeling and understanding compound flooding.

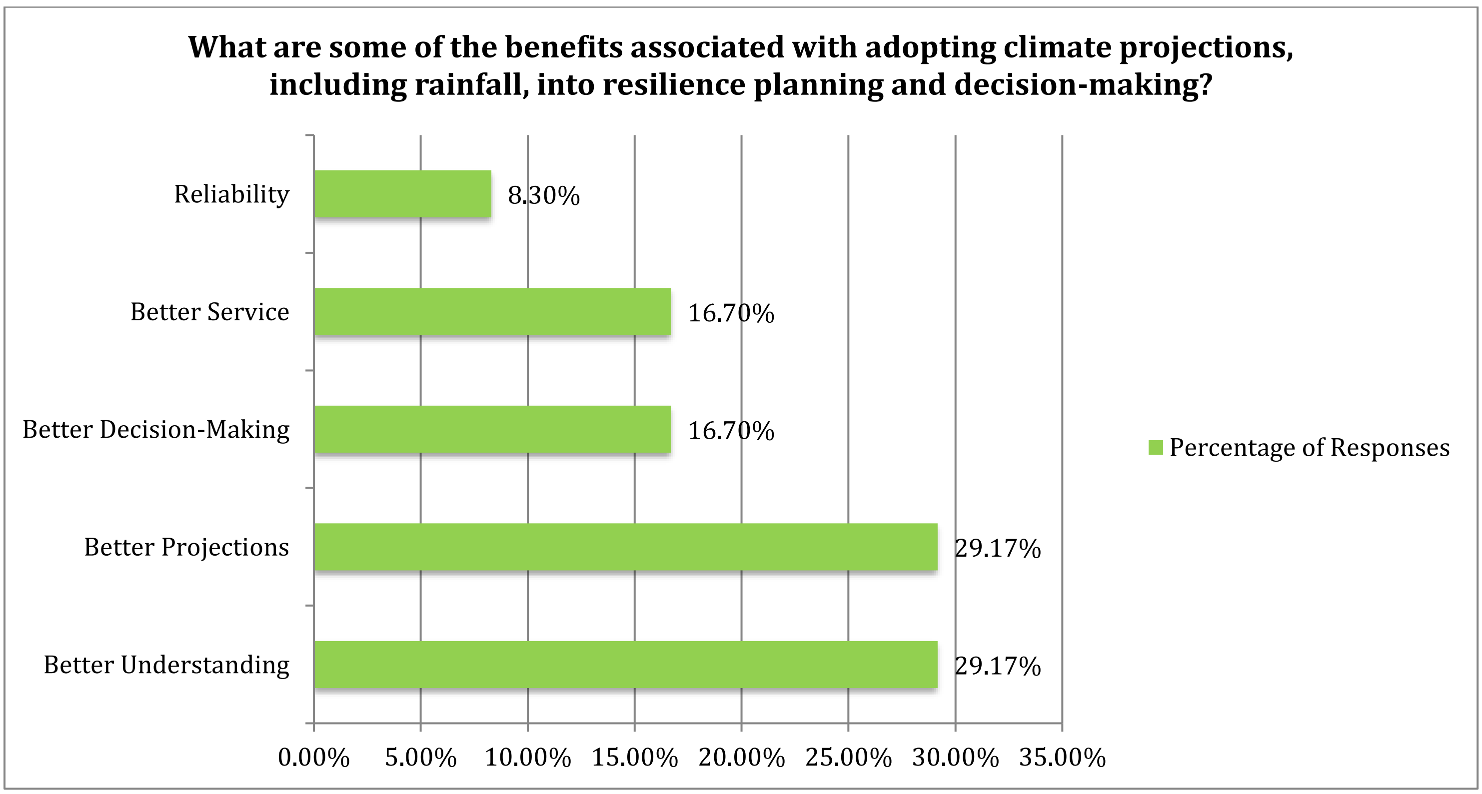

Figure 5 Benefits of climate projections

During the discussion, an important question was raised to both the panelists and the audience: "What are the benefits of integrating climate projections, including rainfall, into resilience planning and decision-making?" The responses from the audience mainly centered on two main points, with 29.17% of individuals emphasizing the significance of "better projections" and an equal number highlighting the importance of"better understanding." "Better projections refers to the ability to predict future climate and weather events more accurately, while “better understanding” entails a more comprehensive grasp of the factors influencing climate predictions.

These audience responses aligned with the perspective shared by Panelist F. This panelist emphasized the resilience of nature in the face of climate change and stressed the significance of comprehending how natural systems would respond to increased rainfall, impacting water storage in areas such as the Everglades and other natural systems.

Coming in as the next significant factors, “better decision-making” and “better service,” were identified by 16.7% of respondents each. It’s worth noting that improved decision-making in water management directly correlates with enhanced customer service, as these aspects are interlinked.

Panelist E underscored the importance of incorporating future climate projections into comprehensive planning and future land use decisions. By developing policies that consider compound flooding, climate factors, and the implementation of natural defenses and green infrastructure, we can ensure resilience and mitigate the impacts of rainfall inundation. Panelist A discussed their organization’s focus on robust decision-making and investment strategies adaptable to different scenarios.

8.3% of the audience members further stressed that integrating climate projections into resilience planning would enhance reliability, a sentiment shared by the panelists. In support of this point, Panelist D highlighted the significant cost implications of inaccurate projections and emphasized the importance of making informed decisions based on reliable data. Similarly, Panelist E explained their utilization of models to evaluate the pros and cons of various resilient adaptations, such as injection wells, green spaces, pumps, and stormwater conveyances. Incorporating future rainfall scenarios enables them to assess different adaptation strategies' effectiveness and financial benefits.

In conclusion, the discussion highlighted the critical role of integrating climate projections, including rainfall, into water-resource decision-making and resilience planning. The benefits of this integration encompassed improved forecasts of a better understanding of climate dynamics. Overall, the consensus among the panelists and the audience emphasized the significance of reliable data, effective decision-making, and the pursuit of adaptive measures to address the impacts of climate change on water resources.

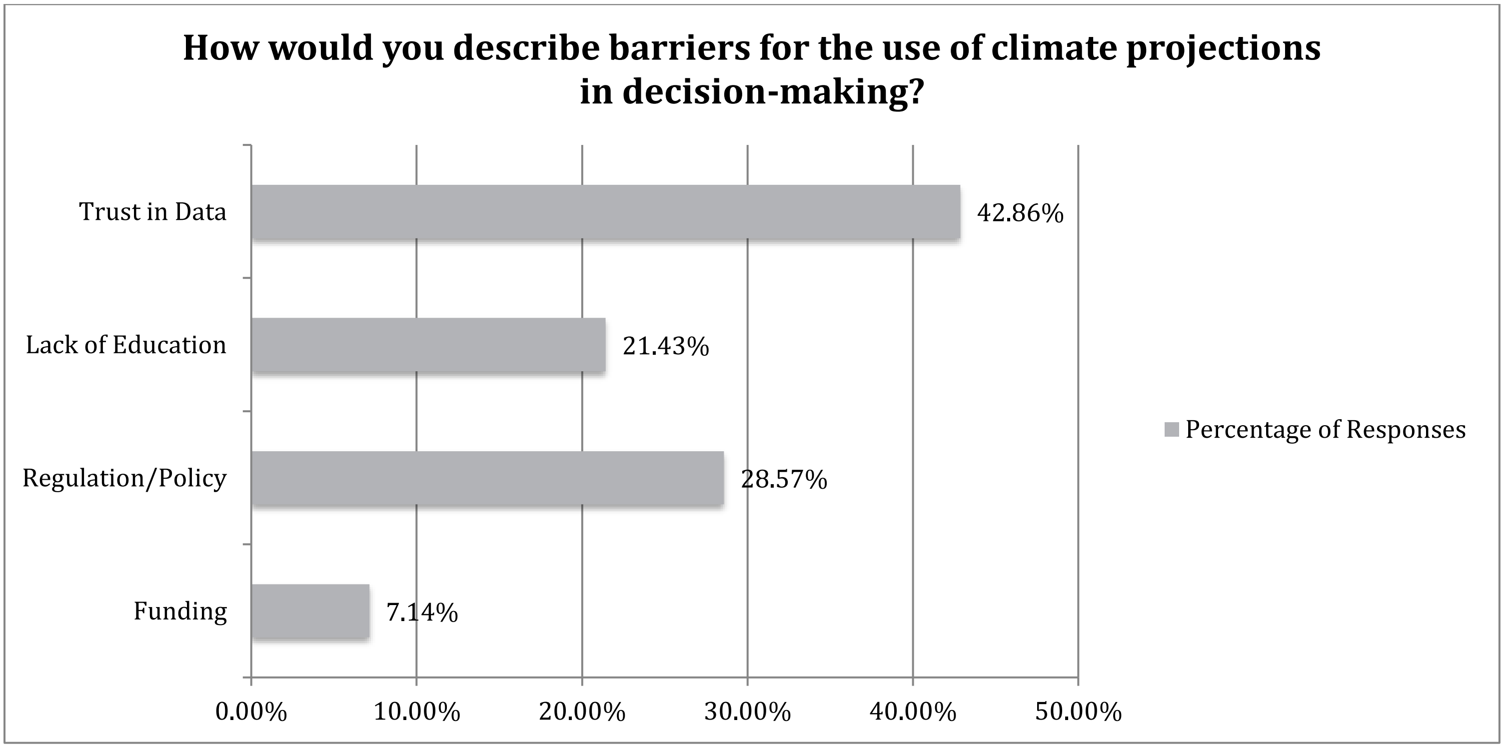

Figure 6 Barriers to utilizing climate projections

We asked the participants and panelists about the barriers to utilizing climate projections in decision-making. The majority of the audience, 42.86%, emphasized the issue of trust in the data provided.

Given that many of these individuals are practitioners in water resource management, it is understandable that unreliable data would significantly impact the accuracy of their work. Another notable obstacle that emerged was the absence of standardized regulation and policy concerning the application of climate projections, as indicated by 28.57% of the responses. Numerous participants expressed frustration with this absence, as it creates significant disparities in understanding future water quality and quantity, hampering consensus among scientists.

Similarly, 21.43% of participants mentioned a lack of education on applying these climate projections and determining which data types are appropriate for their creation. Insufficient knowledge regarding implementing high-resolution climate forecasts can result in incorrect usage or even complete avoidance of these valuable tools. This issue relates to the lack of standardized guidance and regulations on implementing these tools.

Furthermore, 7.14% of respondents identified a lack of funding as a hindrance to incorporating climate projections in their decision-making process. Insufficient financial support restricts their ability to utilize these projections effectively. The panelists echoed the sentiment expressed by the participants, with their discussion primarily revolving around the usability and trustworthiness of the data in climate projections. Panelist B said, "One of the drawbacks, one of the barriers, one of the things that makes this challenging, is that this data is very complicated." Other panelists, particularly Panelists A and C, shared their challenges in downscaling large datasets and tailoring them to their geographic areas and specific project requirements. Moreover, inconsistencies arise when organizations employ different methods and approaches to disaggregate data and have diverse objectives, further exacerbating the lack of consistency mentioned in the participant responses.

The panelists also emphasized the difficulty in effectively communicating complex data and related systems and dynamics to the public. Panelist B explained that engaging in knowledge-translation conversations with the public adds an extra layer of complexity to an already demanding process. Nonetheless, the absence of public support for projections severely hampers the decision-making process.

In summary, both participants and panelists concur that the actual data, encompassing reliability or complexity, represents a significant barrier to using climate projections in decision-making. Additionally, they unanimously recognized that the lack of standardized policies, regulations, and education poses a challenge when applying climate projections. While more participants than panelists identified funding as a problem, it remains a shared concern among both groups.

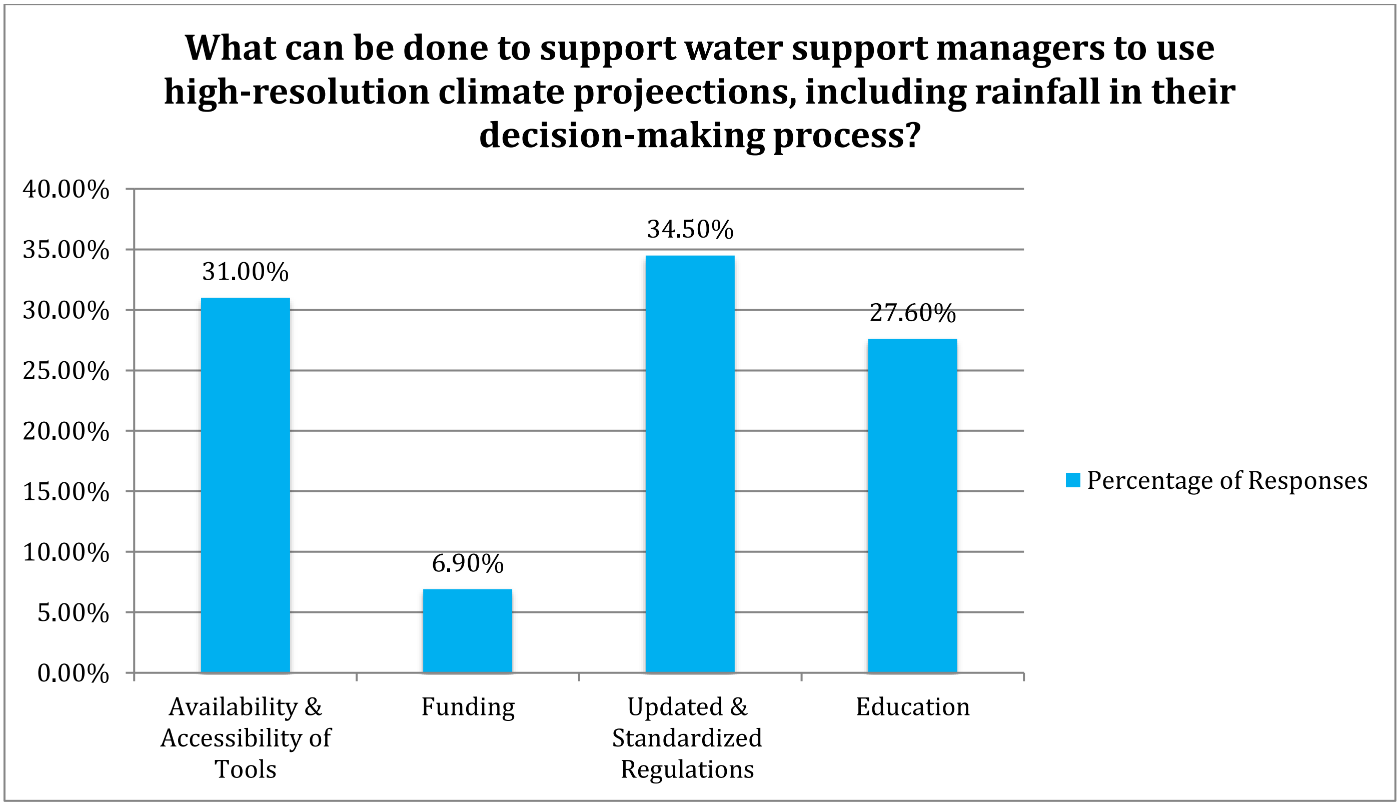

Figure 7 Support for adopting high-resolution climate projections

On the other hand, we asked both panelists and participants about measures that could aid water managers in incorporating high-resolution climate forecasts in their decision-making processes. The responses revealed several key areas of focus. Notably, 34.5% of participants stressed the importance of having up-to-date and standardized regulations about climate data. Additionally, 31% of respondents emphasized the need for accessible tools to integrate this data into the decision-making process. Another crucial aspect, as mentioned by 27.6% of participants, was education. They stressed the importance of comprehensive training and information to empower practitioners in understanding and effectively utilizing climate forecasts. Lastly, a smaller fraction of respondents, comprising only 6.9%, highlighted the importance of funding, underscoring the value of financial resources in implementing, comprehending, and developing high-resolution climate forecasts for decision-making purposes.

The panelists offered slightly different perspectives than the participants, focusing more on external support for water managers. Panelist D proposed developing a risk framework encompassing various aspects of water management, including groundwater, rainfall changes, and compound flooding. This approach emphasizes the necessity of collective risk management. Panelist C shared a similar viewpoint, stressing the importance of effective collaboration among different agencies and districts involved in water management. The sentiment was also echoed by Panelist E, who emphasized the need for collaboration and exerting pressure at the federal level to secure support and funding for climate projections, aligning with the participants' call for increased funding. The panelist further emphasized the need to engage the public and effectively communicate the significance of complex climate projections.

Moreover, Panelist F reiterated the importance of translating research findings into meaningful information for the public and bridging the communication gap. Panelist B highlighted scientists' role in translating scientific data into politically and financially relevant figures to drive decision-making and underscore the financial risks and benefits associated with taking action.

In summary, both participants and panelists agree that we can provide substantial support to water managers in incorporating high-resolution climate forecasts into their decision-making process. While participants emphasized the need for internalized support, such as updated regulations and improved accessibility of tools, panelists advocated for external assistance, including cross-sector collaboration and accessible translation or knowledge tools to garner public support.

Findings

We can distill many significant findings from the analysis of this listening session. Here we focus on three main findings – the risk-averse nature of water resource decision-making, the complexity of the data used in decision-making, and the need for a holistic approach in this process.

Risk-Averse Field

Firstly, it is evident that practitioners in the water resource management field exhibit a high level of risk aversion and a conservative approach to decision-making. This inclination is justified, considering the potential consequences of inaccurate projections, which could impact the quality and quantity of water and overall water management decisions, thereby impacting millions of lives. Moreover, the changing weather patterns brought about by climate change have compelled water resource managers to rely on less reliable data when making decisions. In an environment characterized by risk-averse individuals and imperfect information, accepting new methods becomes challenging, as substantial uncertainties often lead to a lack of action. Consequently, professionals in this field tend to opt for familiar and established approaches, assuming that incorporating anything new would introduce unnecessary risks. Instead, they often resort to "satisficing," or deeming their current methods satisfactory and refraining from embracing additional risk.

Complexity of Data and Decision-Making

Another key finding highlights the intricate nature of the data used by water resource managers and practitioners in their decision-making processes. The research has revealed that professionals in this field often work with extensive datasets, which they must disassemble and adjust to suit their specific project objectives and geographic area. This data modification requires considerable cognitive effort and time since tailored data that meets organizational needs is not readily available due to its complexity and cost. Adding to the complexity is Florida's unique geographical features, such as its peninsular form, low topographic relief and high water tables, and the influence of sea breezes and ocean currents on climate. Due to these distinctive features, scientists and practitioners cannot rely on data from other parts of the US, further emphasizing the need for geographically specific, and locally relevant climate data.

Insights also shed light on the heavy reliance of water resource management professionals on their network of colleagues and organizations. However, each entity utilizes diverse datasets and tailors them in their own ways, complicating decision-making as different data sources and assumptions yield varying projections. This contextual aspect of data in the water resource field is unique. While the focus is on gathering data, organizations struggle to understand how to employ it effectively. It is not a lack of data but rather the absence of a standardized approach to combining and customizing the data according to each organization's requirements and locally relevant interpretations.

Like all scientists, those in this field aspire to make "evidence-based" decisions. Yet, the dynamic nature of climate change and the traditional reliance on historical climate data undermine establishing a stable evidence base. This mismatch presents a unique challenge for decision-makers in this domain.

Holistic Approach

The final key finding for this listening session underscores the increasing demand for a holistic approach in the decision-making process of water management. This approach encompasses multiple layers, including the data utilized and the involvement of individuals and organizations, along with the ability to incorporate uncertainty and advance dynamically adaptive strategies to address evolving conditions

Data

Both participants and panelists unanimously agreed that a comprehensive approach combining various data types should form the basis of climate projections to obtain a more complete understanding of potential climate scenarios. As one panelist emphasized, a singular focus on sea-level rise, riverine or stormwater runoff is insufficient. Instead, a holistic view is essential. Moreover, it is not just the diversity of data types that matters; the data sources must also vary. Incorporating data from different organizations, such as FEMA and NASA, becomes crucial to account for variations in methodologies and analyses. This approach highlights the significance of comprehensive planning and the emerging framework of understanding "One Water," which is a holistic approach to water management with the objective to optimize each drop within the overall water system (NYC Environmental Protection, n.d.).The concept also explores the interdependence of resilience planning and decision making across all water resources including stormwater, drinking water, wastewater, and natural hydrologic systems.

Enhancing our understanding and generating more accurate predictions of future climate conditions requires the vital step of combining diverse data sources. However, achieving this task is easier said than done. The panelists acknowledged the importance of this holistic approach and its inherent challenges. Accessing data from multiple organizations and Effectively aligning them with their organization's objectives and projects poses significant difficulties. This challenge is further compounded by the need to work with ranges of data estimates instead of relying on a point or number for the future. Given the uncertainty of future weather events, evaluating multiple forecast scenarios from different models becomes essential. Observing low, high, and median projections is critical in looking holistically at future evolving conditions. A comprehensive assessment of future evolving conditions necessitates observing low, high, and median projections.

These intricacies in data usage underscore the complexity of decision-making, as discussed earlier in this report. A concerted effort to address these challenges and integrate diverse data sources will be critical in shaping robust water-resource management strategies in the face of climate change.

People and Organizations

Another vital aspect of the holistic approach involves fostering collaboration among diverse individuals and organizations to consider all perspectives. Working closely with federal and state agencies, universities, as well as public, private, and nonprofit partnerships is crucial. This collaborative effort harnesses a wide range of expertise to address the potential impacts of climate change and identify vulnerabilities. Moreover, such collaboration serves as a safeguard against groupthink and encourages the development of creative solutions to complex problems. By embracing collaboration, we increase our chances of finding effective solutions for climate change.

Furthermore, collaboration and cooperation are essential to prevent service duplication, unnecessary expenditure of time and resources, and reinventing the wheel. One panelist highlighted that many organizations, including municipalities and private corporations, often work in isolation without engaging in meaningful dialogue with others who might be working on similar projections. The panelist commended the Florida Water and Climate Alliance for its collaborative nature and urged the establishment of more events to bring together stakeholders from the water resource management field. This gathering would facilitate discussions on collaborative approaches to strengthen the sector.

However, as with previous challenges, implementing effective collaboration is easier said than done. Reaching consensus on the specific climate models or projections to use becomes challenging due to variations in population vulnerabilities and the specific objectives and interests of organizations or projects. Achieving consensus in this regard requires careful consideration and negotiation among stakeholders.

In conclusion, these findings shed light on the risk-averse nature of water resource decision-making, the complexity of data used, and the necessity for a holistic approach. Understanding these aspects is crucial in navigating the challenges of climate change and ensuring effective water resource management. By embracing new methods, leveraging comprehensive data, and fostering collaboration, decision-makers can enhance their ability to tackle the complex issues arising from climate change and make informed decisions to safeguard water resources for future generations.

Recommendations for Academics and Practitioners

The insights gathered from this listening session enable us to make valuable recommendations to academics and practitioners involved in understanding and addressing the challenges of water resource decision-making.

Future research must assess water resource managers' knowledge level and awareness. The existing literature lacks a comprehensive understanding of the data and support tools managers perceive to be available for making climate projections. Identifying these gaps in access will help determine how to effectively disseminate data and tools that managers are unaware of. Despite its highly risk-averse nature, the literature has not adequately explored risk aversion in water resource management. Conducting further research to examine different types of risks and how managers calculate risk costs when making decisions is essential.

To further enhance water-resource decision-making, it is crucial to gain a deeper understanding of how practitioners and scientists currently utilize, combine, and tailor the available data. This examination will offer valuable insights into presenting data in a manner most useful to practitioners and identifying decision-support tools that would enhance the integration of high-resolution climate forecasts within their organizations.

Additionally, further research should aim to understand how to advance effective decision-making under uncertainty. Navigating ranges of projections that incorporate uncertainty and account for future evolving conditions is vital in considering multiple scenarios. Even sensitive analysis of possible futures can lead to better decision-making compared to not adopting any projections at all. Therefore, it is essential for academics to understand and promote these complex decision-making skills.

Moreover, academics should delve into knowledge management and knowledge translation within this field. While the necessary knowledge and data exist, the challenge lies in effectively integrating and utilizing them. Exploring the most effective ways to share and co-produce knowledge in this sector will be instrumental in bridging this gap and fostering better-informed water-resource decisions in the face of climate change.

Finally, stakeholders in the water-resource sector should strongly consider establishing partnerships between practitioners and scientists. Such collaborations would foster greater collaboration and enhance the overall field. By breaking down knowledge silos and addressing the issue of service replication, these partnerships would lead to more efficient and effective decision-making processes.

Overall, implementing these recommendations will contribute to advancing our understanding of water-resource decision-making and enable better adaptation and mitigation strategies in the face of climate change.

List of Acronyms

CDO	
CUSLRP	Compact Unified Sea Level Rise Projection
EPA	Environmental Protection Agency
FAWN	Florida Automated Weather Network
FDEP	Florida Department of Environmental Protection
FEMA	Federal Emergency Management Agency
FHWA	Federal Highway Administration
FWS	Fish and Wildlife Service
NASA	National Aeronautics and Space Administration
NECP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
SLR	Sea-level rise
USCOE	United States Corps of Engineers
USGS	United State Geological Survey
USFS	United States Forest Service
WMDs	Water Management Districts

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