A JUST AND EQUITABLE WATER FUTURE FOR ALL IN AN EVER-CHANGING ENVIRONMENT: AN URGENT CALL FOR ACCELERATED ACTIONS

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ABSTRACT

Access to clean and reliable water is critically important for health, well-being, and economic development. The natural, built, and social systems – which interact with each other and comprise the water system of systems – are threatened by intensifying hazards and stressors like crumbling infrastructure, floods, droughts, storms, wildfires, sea level rise, population growth, cyber threats, and pollution. Marginalized communities, including disadvantaged and rural communities and Tribal nations with insufficient access to clean water or regenerative sources of water, are often the most impacted. Responses to these issues are hampered by fragmented and uncoordinated governance and management.

A multi-stakeholder structured engagement process at the "One World, One Water" SWIM conference and workshop held in December 2023 identified the most critical current and future issues facing the water sector and what needs to change to find solutions. This paper synthesized these issues. Highlighted issues were the vulnerability and lack of resilience of water systems to hazards and stressors, inequities associated with water scarcity, and water quality problems – all affected by climate change, land-use change, and socio-economic changes. Finding solutions requires

- reducing fragmentation and lack of coordination in water management and governance.
- enhancing stakeholder collaboration and augmenting community understanding and support through opportunities for engagement, learning, and trust development.
- creating new flexible and adaptive water education processes and institutions to meet workforce recruitment and career development needs.
- increasing data-sharing and collective knowledge, and improving assessments and decision-making, through innovative technologies to advance smart and efficient water monitoring, modeling, and communication processes.

The Smart One Water (S1W) vision provided an important context for the SWIM 2023 conference. This paper expands the S1W vision with a synthesis of discussions at the conference about S1W-related fundamental concepts, practices, and implementation barriers. This extension of the S1W discussion also includes initial recommendations using a digital, stakeholder-driven approach that draws from the private sector, public sector, academia, government, and policymakers to help generate real-world adaptable ideas and solutions. Specifically, S1W envisions a future where water management and governance siloes are eliminated to provide the collaboration, community engagement, knowledge-sharing, and learning needed to enable efficient, resilient, affordable, and equitable water access capable of adapting to a changing environment. S1W envisions a future where communities govern collaboratively through integrated decision-making on policy, management, and funding of natural and engineered water systems at the river basin scale. Accelerated adoption and adaptation of innovative digital technologies, artificial intelligence and modeling tools, digital communication, and knowledge bases that connect people and organizations are gamechanging tools in addressing this societal grand challenge. The ideas and recommendations brought forth in this paper are the subject of a Blue Ridge PBS multimedia documentary that is being developed and is entitled "WATER: Empowering Our Future."

Keywords: Workforce, Sustainability, Resilience, Equity, Governance, Management, Water Infrastructure, Digital Twins, Digital Water, Knowledgebase, Database, Artificial Intelligence.

IMPACT STATEMENT

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The “One World, One Water” conference and workshop were organized with a focus on the critical importance of water for communities to function and thrive. Issues associated with water scarcity, flooding, and water quality, exacerbated by climate change, were highlighted. Powerful innovations and transformative approaches were presented, showcasing solutions to these challenges and how communities could prepare for a more resilient and equitable water future. Ultimately, the “One World, One Water” conference generated excitement and passion about water as an essential resource: educating, inspiring, showing all how to get involved, and resulting in this call-to-action paper. Much work remains to be done to determine specific solutions (including approaches, methods, and technologies) and pathways for implementation. Several initial recommendations were proposed for a Smart One Water (S1W) approach. The S1W approach suggested is based on an integrative, digital, framework and considers natural water sources, engineered water infrastructure, and social behaviors for comprehensive decision support toward sustainability and resilience goals.

INTRODUCTION AND BACKGROUND

Quality of life for all people and communities depends on the availability of clean, abundant water. The United Nations Sustainable Development Goal (SDG) target 6.1 is: “By 2030, achieve universal and equitable access to safe and affordable drinking water for all” (Mueller and Gasteyer 2021). Our natural and engineered water systems are threatened by crumbling infrastructure, and by the consequences of climate hazards (e.g., floods, droughts), land-use changes (e.g., urbanization), and chronic stresses (e.g., aging infrastructure) on water systems (e.g., rivers and built infrastructure systems) (WHO 2022; Mueller and Gasteyer 2021; UN n.d.; Brown et. al. 2019; ERVA 2022). Marginalized communities often experience the worst impacts (NSF 2020; UN n.d.). Over the past decades, our social, built and natural environments have suffered from accelerating impacts, heightening the need to overcome traditional water management siloes and to increase community resilience (Howe 2019; WRF 2017; USWA n.d.; USEPA n.d.). Societal responses to these crises have largely been reactive and continue to be hampered by fragmented and antiquated management practices. The water sector governance and management should consider a system-of-systems approach that considers the complex interactions and interdependencies in water infrastructure systems. This perspective is inspired by the SETS (Social-Ecological-Technical Systems) framework which highlights the importance of coordinating natural, built, and social systems for water management, and understanding their interactions and the factors that affect urban ecosystem services (Chester et. al., 2015; FAO and WWC, 2018; Pokhrel et. al., 2022; Hager et. al., 2021; Mukheibir et. al. 2014).

In the United States, there is no national program that integrates governance and management of natural systems with built and socio-economic water systems, and the existing legal and economic frameworks to support effective and intelligent water management decisions are insufficient. Digital technologies hold great promise for enhancing the mitigation and co-management of threats and challenges to water systems by fostering better connections and knowledge sharing among people and organizations while integrating processes and innovations across existing silos into proactive and adaptive plans and actions (NSF 2020). However, identifying a new way forward that fills knowledge and technology gaps as well as overcomes systemic hurdles in current frameworks and silos, requires that all stakeholders (e.g., researchers, practitioners, public, policymakers) be represented and included. The Smart One Water (S1W) vision presented in a previous publication of the authors provided an important context for the SWIM 2023 conference (Simha et. al., 2023). This paper summarizes

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findings from the effort that convened diverse water sector stakeholders and experts at a conference to co-identify specific issues, challenges, and opportunities. The findings can be used in the future to inform potential context-sensitive solutions (i.e., digital and/or social and/or physical solutions) and implementation plans for diverse communities.

THE ONE WATER PARADIGM

Drinking, waste, storm, industrial, agricultural, and environmental water, as well as water for energy, are typically managed independently, even though they all depend on the natural water cycle (WHO n.d.; USEPA n.d.; Brown et. al. 2019). Stakeholders of water in the natural, built, and social environments have called for more coordination and less siloed water management and governance across different natural environments, built facilities, and social organizations (UN n.d.). The shift advocated by many has been called One Water (USWA n.d.), or also Integrated Water (OWLA n.d.), Our Water (WRF 2017), or Total Water (WRF 2017). The concept of One Water is embedded in the concept of Integrated Water Resource Management (IWRM) that has been around since the first global water conference in Mar del Plata in 1977. The widely accepted definition of IWRM provided by Global Water Partnership (UN n.d.) describes it as “a process which promotes the coordinated development and management of water, land, and related resources, to maximize the resultant economic and social welfare in a just manner without compromising the sustainability of vital ecosystems.” The application of IWRM has, however, been mostly focused on the natural water resources (the ‘natural water system’) and has been limited in its capacity to integrate built water infrastructure systems – especially, drinking water, wastewater, and stormwater infrastructure. One Water, while focused on integrated water management in urban environments in the United States, expands on the IWRM initiative by connecting the engineered water infrastructure, or what we term the ‘built water system’, to water resources. The social and behavioral factors and value prioritizations affecting water management and governance, or what we call the ‘social water system’ are also considered in One Water approaches, and especially in the Smart One Water (S1W) approach which is discussed next. A more complete definition of the natural, built and social water systems is presented in the Figure 1.

The shift to One Water and similar initiatives is driven by the public water sector’s need to improve water management, reduce vulnerabilities, enhance resilience, and improve the understanding of water system interdependencies. Essentially, this approach will seek governance and management that integrates complex interdependent water management problems across the natural, built, and social environments of water, enabling policymakers and communities to have a clearer accounting of their water supplies, demands, accessibility, and use. Adopting and implementing One Water management at a river-basin scale offers the potential to help communities tackle major challenges and create sustainable and resilient water systems. A conceptual framework is shown in Figure 2.

THE SMART ONE WATER (S1W) APPROACH

One Water is a data-driven and community-centered approach for solving water issues that need to be coordinated across many current silos and governing agencies. It needs to be operationalized – into Smart One Water (S1W) – by leveraging digital technologies (hardware and software) to support the use of multi-sectoral data, analysis tools, and AI-powered infrastructure for decision-making. Decisions enabled by the S1W approach would span from real-time control decisions for municipalities to rules and strategies for basin-wide water management to guidelines for improved state and national laws and policies.

To realize the S1W vision for governance and management of water systems, we must design, assess, and improve water systems that consider all elements of the water cycle in the built and

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natural water environments, up to the watershed, river-basin, or regional scales – as appropriate (NSF n.d.; NSF n.d.; NSF 2022; NSF 2020; NSF 2020; NSF 2020; NSF 2020; NSF 2020). S1W seeks to integrate data on water systems with a wide range of models and tools into a cyberinfrastructure platform enabling stakeholder-centered, regional to national scale water accounting, information sharing, and decision support, as shown in Figure 2. Advances in the Internet of Things, AI, sensor networks, communication systems, data analytics, automation, high-performance computing, and human-computer interfaces ought to be leveraged to develop a digital, AI-enabled cyberinfrastructure platform with appropriate safeguards and constraints. This Digital Research and Operational Platform (DROP) would exploit advances in data analytics, artificial intelligence, and decision support systems as delineated in the Digital-Water ecosystem (Figure 3). The availability of a large amount of water data and computational resources, together with the development of advanced AI-enabled techniques tailored to specific applications, would foster the development of more robust, trustworthy models and algorithms to process and analyze water systems.

THE ONE WORLD, ONE WATER CONFERENCE AND WORKSHOP The S1W approach recognizes that water management and governance requires the integration of knowledge from multiple disciplines, involves cross-scale consideration of spatial and temporal scales in natural and built environments, and is driven by a diversity of societal factors -- that include distinct and/or conflicting policies, market forces, culture, politics, economics, and administrative systems. The Sustainable Water Infrastructure Management (SWIM) (NSF n.d.) Conference and workshop entitled “One World, One Water” was held in Arlington, Virginia, USA, December 12-14, 2023. Its aim was to address water issues by providing innovative S1W ideas and solutions (NSF n.d.). Figures 4 and 5 show the structured process used to organize the event and obtain the desired knowledge synthesis respectively.

Key themes of the Conference and Workshop

The ultimate goal of the 2023 ‘One World, One Water’ conference and workshop was to develop a “unified vision” for collaborative water sector management and governance to ensure a secure, just, and affordable water future for all. The conference and workshop topics, themes, and processes were discussed with SWIM board members, moderators, and annotators. A wide diversity of water professionals were involved in the conference and workshop process and in the analysis and synthesis that followed with the following distribution of representation: 31% from private (technology and service providers), 25% from water utilities, 10% from US Federal Government, 12% from Academia, 9% from Non-Governmental Organizations, 11% from Regional / Compact / State / Local government agencies, and 2% from media. Conference and workshop participants were provided with review materials to allow them to prepare, come up with ideas for discussion, and ask probing questions. The entire event was organized according to six foundations and their associated panels. These panels were used to identify needs and develop guidelines for creating and implementing our envisioned ‘just and equitable water future for all in an everchanging environment’ (cf. Figure 6).

The conference and workshop brought forward the critical importance of water for our communities to function and thrive. It highlighted issues associated with water scarcity, flooding, and water quality exacerbated by climate change and presented powerful innovations and transformative approaches to solving these challenges to prepare for a more resilient and equitable water future. ‘One World, One Water’ generated excitement and passion about water as an essential resource, and it educated and inspired all and showed how to get involved to make a difference. One of the first deliverables for this event was the development of a

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whitepaper entitled 'Just and equitable water futures for all: principles, recommendations, and possible pathways in an ever-changing environment.' An overview of the conference and workshop findings and recommendations is provided below. The results for each of the six foundations and panels are presented first, followed next by a consensus, overarching, set of recommended actions and principles.

PANEL -1: COMPETING WATER INTERESTS

Panel Overview: This panel focused on understanding competing water interests (CWI), their influences on water management and governance, and improving the trade-off decisions that are invariably made by society. S1W goals provided the context within a watershed-scale Systems of Systems approach. Both built and natural water were considered along with different water sources, uses, and distribution and processing mechanisms. Participants were reminded of the S1W vision which seeks 'integrated, collaborative, smart water management and governance to ensure clean, just, and affordable water'. The panel and its discussions provided a broad framing for many diverse issues, challenges, and tradeoffs; several of which were further explored during the rest of the conference and workshop.
Panel Summary: The competing water interests panel discussed various issues, challenges, and opportunities for the water sector. Figure 7 provides a synopsis of the topics discussed.
Overarching Questions: An overarching question was posed to the CWI panel: how can the existing siloed and fragmented culture transition to a governance and management structure that (1) engages communities, (2) couples and shares data on natural, built and social systems, and (3) allows holistic decision support at watershed scale (and possibly at regional to national scales)? Through its answers, the panel examined CWI as might arise from: (1) different uses of water or needs; (2) different perspectives relating to water management and governance (incl. balancing of water availability and quality, 3-waters management, reuse); (3) immediate and local needs vs. long-term or regional/national scale needs); and (4) water management and governance in relation to other societal interests. Three questions were posed to the panelists and audience. Figures 8-10 illustrate the questions and the abstracted responses obtained during the conference and panel discussion. Figure 11 provides a summary of the primary concerns and suggestions later elaborated during the SWIM workshop.
Workshop Summary: The workshop participants discussed the overall panel topics from the conference and summarized the key action items as shown in Figure 11.
Overall Outcomes: The overall outcomes synthesized from the competing water interests conference and workshop discussions are presented in the form of a "Temple Diagram" (Figure 12). The seven pillars (numbered left to right) are the recommended objectives. The 'Architrave' above of the pillars is the recommended strategic goal, and the "Tympanum" provides an overarching goal of 'a just and equitable water future for all in an ever-changing environment'.

Architrave: We must adopt a Smart One Water approach for governance and management at watershed and/or river basin scales that enables implementation of the strategic goals and actions presented in each of seven pillars.
Pillar -1: We need to develop a trustworthy water accounting and allocation mechanism across all sectors for effective water governance and management.
Pillar -2: The System of Systems (SoS) approach can help decision support for multi-sector water users and stakeholders. Also, the approach needs to be implemented at river-basin scale.
Pillar -3: Additional research is needed to establish acceptable accounting metrics for natural water resources. Valuing water means recognizing and considering all the diverse benefits and risks provided by water, and encompassing its economic, social, and ecological dimensions as well as its diverse cultural and religious meanings.
Pillar -4: We have to explore new ways of financing water services, including by making users pay their fair share. Full cost pricing of water needs to be implemented.

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Pillar -5: Physically and digitally secure systems are critical to water system resilience and sustainable practice. Cross-sector collaboration is required for integrated planning to ensure sustainable, secured, and resilient water infrastructure systems.
Pillar -6: Determine new, even unconventional, strategies and tactics to encourage community engagement. Above all do not repeat previous failed efforts!
Pillar -7: Expand data sharing and knowledge dissemination. Make them easily accessible.

PANEL -2: COMMUNITY, STAKEHOLDERS, AND WORKFORCE

Panel Overview: The panel sought to understand the tools for successful community engagement, the value of stakeholder diversity and input, and solutions for addressing workforce gaps.
Panel Summary: The panel discussed various issues, challenges, and opportunities for the water sector. The overall topics discussed are presented in Figure 13.
Overarching Questions:
Three questions were posed to the panelists and audience. Figures 14-16 illustrate the questions and the abstracted responses obtained during the conference and panel discussion. Figure 17 provides a summary of the primary concerns and suggestions later elaborated during the SWIM workshop.
What tools can we use to make it easier for community members to participate? Through the discussion, the panel examined: (1) positive media exposure; (2) traditional versus digital communication tools; (3) communication through schools and community-based organizations; and (4) regular interactions with staff. Highly abstracted responses are presented in Figure 14.
What stakeholder groups should be engaged to provide a more balanced and diverse engagement? Through the discussion, the panel examined: (1) reaching all impacted community members; (2) incorporating disadvantaged community needs and benefits; (3) using community-based organizations to help drive participation (4) including local schools, churches, and business groups to provide balance. Highly abstracted responses are presented in Fig. 15.
What cohorts should we focus on to have the greatest impact on our future workforce? Through the discussion, the panel examined: (1) identifying diverse candidates; (2) attracting younger people; (3) the aging workforce (4) thinking outside the box. Highly abstracted responses are presented in Figure 16.
Workshop Summary: The workshop participants discussed the overall panel topics from the conference and summarized key action items as shown in Figure 17.
Overall Outcomes: The overall outcomes from the 'One World, One Water' conference and workshop discussion are presented in the 'Temple Diagram' as shown in Figure 18. The seven pillars (numbered left to right) are the recommended strategic objectives and above of the pillars "Architrave" is the recommended strategic goal, and in the "Tympanum" is the overarching goal to meet just and equitable water future for all in a changing environment.

Architrave: We must promote stakeholder diversity and encourage community participation and engagement. We must engage community-based organizations and consider non-traditional workforce development strategies.
Pillar -1: We need to promote water sector stakeholder diversity to provide more balance and collaboration.
Pillar -2: We need to engage Community Based Organizations trusted by the community and eager to get involved.
Pillar -3: We need to incorporate predictive models to identify workforce gaps and develop recruitment plans.
Pillar -4: We need to promote continuous communication with the public so that we are engaging them on an ongoing basis and emphasizing the value of water.

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Pillar -5: We need to be developing partnerships with high schools, community colleges, and universities and engage them as stakeholders and to identify potential candidates to fill workforce needs.
Pillar -6: We need to use traditional face to face as well as digital tools and platform to engage stakeholders and provide access to collaboration.
Pillar -7: We need to consider non-traditional candidates to fill workforce gaps including resources from disadvantaged communities, high school students, non-technical individuals, and previously incarcerated individuals.

PANEL -3: GOVERNANCE AND MANAGEMENT

Panel Overview: Smart One Water approach necessitates multi-agency and non-governmental stakeholder integration opportunities to manage water in a more efficient, cost-effective, and sustainable manner. The water resource governance and management plan (the Plan hereafter) should represent a continued and improved commitment to proactively manage all its water resources and implement innovative solutions driven by societal needs and the United Nations Sustainable Goals for resilience, sustainability, equity, and social and environmental justice.
Panel Summary: The panel discussed various issues, challenges, and opportunities for the water sector. The overall topics discussed are presented in Figure 19.
Overarching Questions: What are some examples where water management has been well integrated across governance scales and organizational units? How was multi-stakeholder and cross-domain trust established? and How can a Smart One Water approach facilitate trade-off evaluations, coordination, and governance of environmental, energy, food, and other issues related to water provision and needs, including ecological needs? Three questions were posed to the panelists and audience. Figures 20-22 illustrate the questions and the abstracted responses obtained during the conference and panel discussion. Figure 23 provides a summary of the primary concerns and suggestions later elaborated during the SWIM workshop.
Workshop Summary: The workshop participants discussed the overall panel topics from the conference and summarized key action items as shown in Figure 23.
Overall Outcomes: The overall outcomes from the 'One World, One Water' conference and workshop discussion are presented in the "Temple Diagram" as shown in Figure 24. The seven pillars (numbered left to right) are the recommended strategic objectives and above of the pillars "Architrave" is the recommended strategic goal, and in the "Tympanum" is the overarching goal to meet just and equitable water future for all in a changing environment.

Architrave: We must manage water governance and management at watershed and/or river basin scales for implementation of the 7 strategic pillars goals.
Pillar -1: We need to create a centralized governance and management structure that provides a voice for all watershed stakeholders in decision-making.
Pillar -2: The watershed organization should consider aligning to and/or adopting Regional and National solutions. Establishing the basis for a consistent approach to Watershed Governance and Management nationally promotes data and knowledge-sharing successes and failures.
Pillar -3: Governance and Management must focus on three legs of the organization, People, Policy, and Processes, to create a long-term sustainable solution. Ignoring any of these three legs of the organization will lead to failure.
Pillar -4: The United Nations Sustainable Development Goals that pertain to water and the environment should be considered when developing short- and long-term solutions.
Pillar -5: The Governance and Management approach should foster cross-sector collaboration between local stakeholders, regional organizations, and federal governmental organizations.
Pillar -6: The watershed stakeholders must collaborate to identify disparate benefits and develop a balanced approach to creating a sustainable solution. This will require a mindful give-

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and-take between all stakeholders and suitable ecosystems that encourage proactive cost-benefit exchanges.
Pillar -7: Stakeholder collaboration and cooperation are essential for successful Governance and Management. Frequent communications and meaningful group discussions need to include all parties.

PANEL -4: WATER ACCESS AND AFFORDABILITY

Panel Overview: Universal access to reliable, safe, affordable, water service is essential to maintaining public health, economic prosperity, and wellbeing. It is in our collective national interest that everyone has sustained access to clean water and sanitation. Yet, the reality is that maintaining and operating water systems is extremely costly. The time is right to re-envision how we price and distribute the costs of water in a way that reflects its value as a public good. Effective tools are emerging to help utilities achieve financial stability and provide more compassionate policies and practices to ensure no residents go without water and sanitation.

Panel Summary: The water access and affordability panel discussed various challenges and opportunities for the water sector. The overall topics discussed are presented in Figure 25.
Overarching Questions: Three questions were posed to the panelists and audience. Figures 26-28 illustrate the questions and the abstracted responses obtained during the conference and panel discussion. Figure 29 provides a summary of the primary concerns and suggestions later elaborated during the SWIM workshop.
Workshop Summary: The workshop participants discussed the overall panel topics from the conference and summarized the key action items as shown in Figure 29.
Overall Outcomes: The overall outcomes from the 'One World, One Water' conference and workshop discussion are presented in the "Temple Diagram" as shown in Figure 30. The seven pillars (numbered left to right) are the recommended strategic objectives and above of the pillars "Architrave" is the recommended strategic goal, and in the "Tympanum" is the overarching goal to meet just and equitable water future for all in a changing environment.

Architrave: Water is a basic human right and ensuring that right is provided to each community requires the implementation of the 7 strategic pillar goals.
Pillar -1: Enhancement in funding for the water sector is a dire need. However, enhancement in the resources and training on accessing available funds is a bigger need with limited resources.
Pillar -2: Industry protocols would add great value for resource limited agencies and provide industry consistency to build trust with the communities served.
Pillar -3: The siloed nature of water agencies is a hindrance for solving challenges and identifying opportunities. Robust collaboration and coordination between agencies would help each agency learn from others on the most efficient way to address a specific challenge.
Pillar -4: Regionalization should be evaluated for each community. Economies of scale, standardization, and effective resources could be realized if implemented. Political and other factors may be in the way so community should be evaluated to identify the best approach.
Pillar -5: Water sector data is limited and not standardized. Improving data collection, analysis, and dissemination protocols would provide great efficiencies and benchmarking capabilities.
Pillar -6: A special attention to disadvantaged communities is needed. Funding, training, resource augmentation, and other approaches are needed to lift these communities to solve current water access and affordability challenges and prevent future ones.
Pillar -7: Water agencies should be innovative in their approach to addressing their challenges. Future challenges cannot be solved with historical solutions. An equity lens is needed to improve community prosperity for community and water is at the center of enabling prosperity.

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PANEL -5: ADAPTATION, SUSTAINABILITY, AND RESILIENCE

Panel Overview: The panel sought to understand adaptation, sustainability, and resilience at different water stakeholder levels. It reviewed the challenges and opportunities in this arena associated with defining and understanding resilience, sustainability and adaptation at different scales, investigated decision making approaches, and discussed opportunities for improvement in decision-making, data, information, tools, and inter agency collaboration.

Panel Summary: The panel discussed issues, challenges, and opportunities for the water sector. The overall topics discussed are presented in Figure 31.
Overarching Questions: Three questions were posed to the panelists and audience. Figures 32-34 illustrate the questions and the abstracted responses obtained during the conference and panel discussion. Figure 35 provides a summary of the primary concerns and suggestions later elaborated during the SWIM workshop.
Workshop Summary: The workshop participants discussed the overall panel topics from the conference and summarized key action items as shown in Figure 35.

Overall Outcomes: The overall outcomes from the 'One World, One Water' conference and workshop discussion are presented in the "Temple Diagram" as shown in Figure 36. The seven pillars (numbered left to right) are the recommended strategic objectives and above of the pillars "Architrave" is the recommended strategic goal, and in the "Tympanum" is the overarching goal to meet just and equitable water future for all in a changing environment.

Architrave: We must develop a sustainable and resilient water infrastructure systems for implementation of the 7 strategic pillars goals.
Pillar -1: We need to establish a mechanism and approach to cross-sector, regional-scale collaboration for definition and adaptation of good practice in this arena.
Pillar -2: Develop and empower transformative leaders to 'ACT' (adapt, create, and transform) in championing adaptation, sustainability and resilience and ensure they become mainstream elements of effective utility management practice.
Pillar -3: Improve data and processes/procedures to evaluate system vulnerability and undertake risk assessment for both chronic and acute risks. Identify, how, when, and why to measure key indicators and cross or inter-system performance criteria.
Pillar -4: Develop advanced data analytic tools for proactive decision making. Specifically, the decision support tools for long term management and the necessary data standards to support these models and tools.
Pillar -5: Develop standards, best practices, and share lessons learned. Advancing the state of the art in assessment, strategy and action plan development ranging in scope from application of technical approaches and tools through to proactive stakeholder engagement.
Pillar -6: Improve cost/benefit analysis for investment. Focusing on the quantitative and quantitative benefits across system components. Ensure adaptation, sustainability and resilience related investments are included in capital improvement programs.
Pillar -7: Create education and identify/sponsor/fund research for sustainability and resilience. Focus on collaborative means to improve practice and eliminate road blocks/gaps.

PANEL -6: TECHNOLOGY & DIGITAL TRANSFORMATION

Panel Overview: The objective of this panel and workshop that followed is to facilitate diverse perspectives on continued adaptation of technology and digital transformation in operationalizing S1W initiatives. Discussed experiences around intelligent water systems that are technological, and socially enabled through integration of information from cyber-space,

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physical-space and social-space. Perspectives were collected on realizing smart water operations that are affordable, dependable, sustainable, resilient, and efficient.
Panel Summary: The panel discussed various challenges, opportunities, and call to action for the water sector. The overall topics discussed are presented in Figure 37.
Overarching Questions: The panel and a follow-up workshop explored the following overarching questions/topics in relation to the themes: (1) current state of panelist's organization in advancing digital adoption and adaptation and their aspirations of next 3- 5 years; (2) what are solutions for typical barriers experienced by water agencies in realizing coherent/sustainable digital transformation?; (3) what are best strategies for addressing a range of cybersecurity concerns?; (4) what is a recommended road map for an effective/sustainable digital transformation?; (5) what are top three trending technical innovations impacting how we address water industry challenges?; and (6) what are you envisioning for digital one water transformation over next decade? Three questions were posed to the panelists and audience. Figures 38-40 illustrate the questions and abstracted responses obtained during the conference and panel discussion. Figure 41 provides a summary of the primary concerns and suggestions later elaborated during the SWIM workshop.

Workshop Summary: The workshop participants discussed the overall panel topics from the conference and summarized key action items as shown in Figure 41.
Overall Outcomes: The overall outcomes from the 'One World, One Water' conference and workshop discussion are presented in the "Temple Diagram" shown in Figure 42. The seven pillars (numbered left to right) are the recommended strategic objectives and above of the pillars "Architrave" is the recommended strategic goal, and in the "Tympanum" is the overarching goal to meet just and equitable water future for all in a changing environment.

Architrave: We must build a national-scale digital innovation ecosystem for the implementation of the 7 strategic pillars goals.
Pillar -1: We need to develop a new digital business plan and adaptive transformation road map by water utilities for sustained transformation.
Pillar -2: The water industry needs standards for digital resilience and interoperability which is a critical success factor.
Pillar -3: Water utilities need to continue the evolution of stakeholders driven and collaborative intelligent water planforms to maximize the technology used to deliver affordable public service.
Pillar -4: It is critical to develop guidelines for water utility level cyber-data security protections assuring safe operations, public safety and health.
Pillar -5: Water utilities needs to be intentional in developing a next-generation digital water workforce and practice effective stakeholder change management.
Pillar -6: We need to develop guidelines for governance transformation to operationalize smart one water initiatives leveraging connected digital solutions.
Pillar -7: Water utilities need guidelines for practical adoption of augmented and artificial intelligence incrementally with demonstrable proven benefits to sustain digital transformation.

KEY TAKEAWAYS FROM THE SWIM CONFERENCE AND WORKSHOP

The '**One World, One Water**' SWIM 2023 conference and workshop confirmed that there is an urgent need for a new water sector governance and management model. The authors believe that a participatory and collaborative approach to co-producing and implementing Smart One Water (S1W), an approach built on a culture of inclusion diversity, and community engagement, is the only way to create an innovation ecosystem that is able to deal with the complex set of contemporary and future water sector management and governance challenges across the country and the world. Motivational and keynote speakers provided high-level ideas and overarching topics to consider for water sector governance and management. Six panel

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sessions were followed by a workshop that all served to identify critical challenges, research needs, and issues while aiming for just and equitable water systems for all. The insights gained were used to generate a "**Temple Diagram**" based on seven foundational pillars and an overarching goal. Recommendations spanned a range from broad principles and missions to be adopted by various participating programs and their initiatives on actions for communities and their water management and governance activities across the country and around the globe.
Overall Outcomes: The outcomes are presented in a final "Temple Diagram" shown in Figure 43. The seven pillars (numbered left to right) are the recommended strategic objectives. The "'Architrave"' above of the pillars is the recommended strategic goal. The "Tympanum" provides the overarching of *'a just and equitable water future for all in an ever-changing environment*'.

Architrave: Create a Collaborative Organization for Water Governance and Management
In the United States, there are 7,450 stormwater systems, more than 16,000 publicly owned wastewater treatment systems, and more than 50,300 community water systems (PBS 2009). Water systems are managed and governed differently, serve different populations and social and economic needs, and have a wide diversity of water quality and water supply challenges (Hall et. al. 2019). Thus, achieving widespread adoption of any single innovation in the water sector is not only a monumental task but an impossible one. All innovations must be tailored for each water utility. Moreover, smaller systems often struggle to meet their existing obligations and do not have the staff, resources, or expertise to pursue funding opportunities to adopt technological improvements. There are around 22 federal agencies in the US that are managing water related activities and each one has their own mission and vision for water (GAO n.d.). This differs from the management and governance used for many other resources and societal functions. For example, the U.S. transportation system is governed by federal and state departments. In contrast, the governance and management of water systems occurs almost exclusively at the local level through water utilities and agencies. These organizations typically operate as standalone entities with limited interactions with one another or with other stakeholders (e.g., industry, agriculture, energy). With minimal communication and collaboration, even among neighboring areas, this fractured system has little ability to predict the impact of decisions and implement broad changes. New technologies, processes, and other innovations commonly lead to greater efficiencies and higher productivity. Through years of underinvestment, deferred maintenance, and frequent mismanagement, the water sector has struggled to maintain the status quo, let alone innovate (SWIM 2022 conference). *There is need to create a collaborative body to facilitate and coordinate water governance and management in the United States. Research is required to find the appropriate models and principles to build on in creating such an organization.*

Pillar -1: Build a Culture of Trust and Empower Communities of Practice
The use and stewardship of natural and built water systems at the river basin scale involves building trust with many individual and institutional actors, making decisions about water. These decisions are driven by a wide range of factors including health, cost, economic development, laws and regulations, recreational activities, cultural norms, and aesthetics. This decentralized, multi-level, and dynamic milieu comprises the context of S1W governance and management. The effectiveness of a national-scale digital platform for facilitating communication and collaboration will depend on its acceptance and effectiveness in engaging and connecting water users and other stakeholders. For the collaborative platform to facilitate and improve efficient, effective, cross-sectoral and multi-stakeholder governance, the activities, values, decisions, and actions of the human actors involved need to be better understood. A focus on Diversity, Equity, and Inclusion (DEI) is critical to cultivate buy-in from a broad range of stakeholders and to build community trust (Piemonti et. al. 2021). Deepening collaboration between the industry, and

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communities can foster acceptance of the S1W paradigm. In turn, this will alleviate diversity, affordability, and equity issues by expanding access, creating wealth, realizing the power of community, and of proactive management and governance. This requires a comprehensive understanding of water usage, socio-economic forces, and water sector needs. *There is a need to develop interdisciplinary research activities that leverage partnerships and investigate: (1) the values, perspectives, constraints, goals, and future visions of the different types of stakeholders that affect social water accounts, (2) social-digital interactions of water users and other stakeholders, and how these interactions affect their decisions, (3) quantitative management models employed by stakeholders, and how these models affect their decisions, (4) the genuine opportunities that individual stakeholders have for water management, through improved understanding of physical and social water accounts, and (5) the economy-wide costs and benefits of digital platform, under different scenarios of implementation in basins.*

Pillar -2: Implement a Smart One Water Approach at the River-Basin Scale

The S1W vision calls for a paradigm shift in how data and knowledge are shared and used by different decision-makers in a river basin for more reliable and integrative monitoring, analyses, modeling, forecasting, and decision-making. The One Water approach recognizes that water management problems often require the integration of knowledge from multiple disciplines, involve cross-scale consideration of spatial and temporal scales in natural and built environments, and are driven by a diversity of societal factors -- that include distinct and/or conflicting policies, market forces, culture, politics, economics, and administrative systems. These challenges, along with droughts, flooding, fires, and sea level rise, are exacerbated by climate change; addressing them will require new approaches and tools. With significant and sustained investment, these tools can transform the way society confronts looming threats to water systems (Brown et. al. 2019). Numerous organizations have recommended a shift towards One Water, an approach that recognizes interconnectedness in the water cycle and involves collaborative governance and management of natural and engineered water systems at watershed or river-basin scale (Healy et. al. 2007). The S1W vision supports transformative changes towards a One Water approach at the river basin scale through development of an artificial intelligence-enabled cyberinfrastructure that will dramatically enhance collaboration, information sharing, predictive modeling, and decision support. This approach can shift the paradigm of water management towards one that can meet societal needs for resilience, sustainability, and social and environmental justice. *A national effort is required to build and transition scalable decision-support systems that (i) harness big data and digital technologies to link interdependent natural, built, and socio-economic water systems, and (ii) empower small and large communities to balance competing demands for water resources, infrastructure, and services in a sustainable and resilient manner. This crucial, unprecedented research and development effort will provide coupled cyber- and socio-technical tools to support collaborative S1W management and governance for healthy and thriving communities.*

Pillar -3: Operationalize Water Sector Sustainability and Resilience

Resilience and sustainability are two separate terms and concepts that are often used interchangeably, sometimes without fully understanding what they mean. To reap the full benefit of combining resilience thinking with sustainable development, the nexus between the two concepts needs to be both understood and appreciated. Sustainability ensures that current and future generations are not compromised with respect to the environment, the economy, the society or human health. Resilience refers to the ability to withstand and recover quickly from disruptions or shocks such as natural and/or manmade hazards and/or cyber-attacks (Blagojević et. al. 2022). The socio-ecological definition is “the capacity of linked social-ecological systems to absorb recurrent disturbances such as hurricanes or floods so as to retain essential structures, processes, and feedbacks.” (Sinha et. al. 2023). The sustainability and resilience of the water sector are of utmost importance to modern societies that are highly dependent on continued access to water sector services. It is critical for society to transform siloed water

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governance and management systems into smart, connected, sustainable, and resilient systems (Sinha et. al. 2023). This transformation will allow us to address the effects of increasingly extreme climate events, ecosystem demands, urbanization, and infrastructure deterioration. Over the past decades, accelerated impacts of climate change on social, built, and natural environments have heightened the need to overcome traditional water management siloes and to increase community resilience in the face of the consequences of climate hazards, land-use changes, and chronic stresses. Resilience planning needs to become a mainstream part of water management and governance, with investment in resilience related improvements being considered as an integral part of capital investment planning (Alanis and Sinha 2013). *A new framework for water sector sustainability and resilience is required that embraces a social-ecological-technical system-of-systems approach and a whole-life approach to allow communities to better understand and operationalize short-term to long-term resilience in their water systems. The framework should also endorse the integration of the goals of sustainability and resilience for overcoming global water challenges, and provide insights on how communities could identify technologies and policies that promote both goals in the near term and in the far future. Finally, a case should be made for using technologies and artificial intelligence to operationalize sustainability and resilience in communities.*

Pillar -4: Create an Innovation Ecosystem for Water Sector Technology

Achieving the S1W vision requires strengthening the innovation ecosystem in the water sector (Sinha et. al. 2022). We must establish an innovation and collaboration support center to accelerate innovation, development, outreach, and adoption of S1W solutions across scales. Innovation efforts should be driven by understanding that the customers and stakeholders, their pain points, and their individual goals are critical to long-term success. It is important to conduct research in especially promising technology areas in collaboration with water providers and other members of the innovation ecosystem network (planners, designers, builders, operators, suppliers, managers, and users). The development of a technology and a digital platform, with capabilities for aggregating and sharing data, generating predictive analytics, and facilitating communication, provides an organizing framework. Our envisioned innovation ecosystem will positively impact water sector culture by (1) fostering an inclusive culture for knowledge sharing, (2) embracing new kinds of partnerships, (3) encouraging risk-taking and allowance for failure, (4) enabling simultaneous technology development, evaluation, and transfer, and (5) setting bold goals focused on long-term community benefits for diverse stakeholders. The innovation ecosystem may include six core program areas: River-basin Innovation Testbeds (RITs); Entrepreneurs-in-Residence (EiR); Technology Entrepreneurship Challenge (TEC); Research and Entrepreneurship Experience for Undergraduates (REEU); Academy of Innovators (AoI); and Industry Seminar Series (ISS). The programs will leverage the unique infrastructure, expertise, and resources located within water utilities and in regional watersheds. Through collaborations, the aim will be to model new kinds of sustainable, effective working relationships among the diverse groups involved. The innovation ecosystem network will be leveraged to move the water sector culture to embrace new kinds of partnerships, risk-taking, allowance for failure, and the setting of bold goals for long-term community benefits. *There is a need to establish a national "Innovation Ecosystem Hub" that will transfer knowledge and technology and develop a diverse and educated workforce via a series of activities that integrate industrial partners, from small start-ups to large corporations, that span powerhouse water companies to information technology companies, and innovation partners.*

Pillar -5: Build a National Digital Platform for Decision-Support System

The use of big data and cyber-enabled technologies underpins the S1W vision to connect people, the internet-of-things, and processes through a common platform designed to integrate stakeholders, knowledge, and system processes, across scales. There are three concepts fundamental to S1W. First, all water – surface or groundwater, drinking water, wastewater, stormwater, recycled water, etc. – is part of a single water cycle. Second, water management

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and cycling occur through the collective decisions of many different stakeholders in a basin. Third, water accounting serves as a foundation for effective data-driven auditing of all the stocks and flows of water in a basin and for bringing together stakeholders to communicate and develop a shared awareness of their holistic water systems for governance and management at the basin scale. To realize the vision of the S1W approach to governance and management of water systems, we must design, assess and improve water systems and consider all elements of water cycling in the built and natural water environments, up to the watershed, river-basin, or regional scales – as appropriate. The availability of a large amount of integrated water data and computational resources, together with the development of advanced AI-enabled techniques tailored to specific applications can foster more robust, trustworthy models and algorithms to process and analyze One Water systems at the river-basin scale. At a granular level, machine learning algorithms will be used to reconstruct missing data and/or identify and fill data quality gaps (Jain et. al. 2021). At a higher level, data-driven surrogate modeling can create end-to-end digital twins. *There is an urgent need to create a digital platform that will integrate data on water systems with a wide range of models and tools into a cyberinfrastructure for stakeholder-centered, river-basin scale, One Water accounting, information sharing, and decision support. This digital platform will connect fundamental knowledge with new digital tools to facilitate information sharing and provide an intelligent decision support system. This comprehensive AI-enabled cyberinfrastructure platform will support evidence-based policies, regulations, planning, and investments at the river basin scale, improving equitable community awareness, preparedness, and proactive responses to evolving pressures and stresses.*

Pillar -6: Ensure Water Accessibility and Affordability for All Communities

Water, an essential resource to all communities, is in danger globally and in many regions of the U.S. The World Health Organization estimates that 2 billion people have inadequate drinking water supplies (Nika et. al. 2020). In the U.S., one study concluded that there are 1,165 community water systems in serious violation of the Safe Drinking Water Act and 21,035 Clean Water Act permittees in significant noncompliance (Patterson et. al. 2017); another study predicts that 92 of the 204 freshwater basins in the U.S. will annually experience shortages by the year 2070 (Vermeulen et. al. 2019). Access to clean and reliable water is critically important for health, well-being, and economic development. Despite this, many communities of color, rural residents, and Tribal nations do not have reliable access to clean water, to regenerative sources of water, or to the water needed to bring hope and improve their future. In the U.S., over 480,000 households lack proper plumbing facilities, 1,165 community systems violate the Safe Drinking Water Act, and more than 9,400 Clean Water Act permit holders fail to meet compliance standards (UN 2012; Adedeji 2022; ASCE 2021). These failures particularly affect marginalized populations, individuals with lower education and income levels, older adults, and Tribal nations. Equity refers to fairness in the treatment of individuals as well as groups of people who have been systematically disadvantaged. Fair treatment does not always mean identical treatment; equity requires attention to the different needs and situations of communities. In the context of water, marginalized communities are currently unable to meet their water needs due to barriers to access and insufficient recognition and protection or their rights across natural, built, and social water systems (Howe 2019; WRF 2017). Achieving equity requires removing key barriers arising from historical and current biases and from the structure of institutions that advantage some and disadvantage others. Equity matters – whether it is to meet demands for justice (intrinsic reasons); or to minimize detrimental consequences in communities that don't have suitable access to water (instrumental reasons). Suitable water access means not only meeting immediate basic needs - but also enabling improvements in community social and environmental situations. Meeting the needs of the most marginalized, underserved, and vulnerable communities will allow us to meet the needs of all. *An urgent need exists for a comprehensive nationwide effort incorporating the natural, built, and socio-economic*

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factors at the watershed scale to assess equity in access to clean, safe, reliable and affordable water.

Pillar -7: Develop and Sustain Innovative Water Sector Workforce of the Future

The paradigm shift to S1W will require new, convergent teamwork; workforce development to cultivate and attract new employees with enhanced skill sets; and the design of novel solutions for engaging these individuals and providing ongoing training. In recent years, several leading organizations, including the Brookings Institution (Kane and Tomer 2018) and the U.S. Environmental Protection Agency (USEPA n.d.), have significantly elevated the importance of workforce development. In a white paper on Workforce Skills of the Future, the Water Research Foundation and Water Services Association of Australia identified a series of key enablers for success based on the predicted state of the water sector in 10 to 20 years (WRF and WSA 2018). The water utility of the future is envisioned as a digital utility managed by a diverse workforce. Developing this workforce will require an intentional and holistic focus on the workforce development pipeline to grow talent and provide new skills to the existing workforce. To address these critical workforce needs, we need to establish an educational organization, which we refer to as the Water Academy. The Academy will be the primary entry point for experts to provide digital access to information and learning experiences to people interested in the water sector. The objective is to produce a talented water workforce by improving the development pipeline from "K to Gray". *There is a need to establish a national level Water Academy. This umbrella organization will comprise universities, water-associated industries, federal, state, and local water agencies, and non-profit organizations. The Academy will provide a compelling platform to inspire and educate K-12, undergraduate and graduate students, and water professionals by connecting this societal grand challenge to scientific discovery and innovation. The Academy's convergent educational plan will prepare students to tackle the inherently interdisciplinary challenge of water equity, affordability, security, sustainability, resilience, and social and environmental justice.*

CONCLUSIONS AND FUTURE DIRECTIONS

The critical water issues and challenges brought forward in the '**One World, One Water**' 2023 SWIM conference and workshop reflect worldwide concerns relating to governance, management, and just access to safe drinking water. A World Health Organization report (WHO, 2021) estimated that, in 2020, 2 billion people (about 1 in 4 people) around the world lacked access to safely managed drinking water services. More recent modeling (Greenwood et al., 2024) using a combination of on-the-ground household survey data for low to middle income countries and earth observations geospatial data finds that an estimated 4.4 billion people lack safely managed drinking water services. Nonetheless, as mentioned by Hope (2024) in his perspective summary of Greenwood et al. (2024), progress has been made, in some countries, in the provision of safe water. Government investments in India, for example, have resulted in a major increase in household water taps from 16% in 2019 to 77% in 2023. Improved water system monitoring and assessments of water delivery services support the attention and investments of water policymakers and funding entities: data, and attention to data, are key.

The 'One World, One Water' SWIM 2023 conference and workshop findings and recommendations, focusing largely on water systems in the United States, support the importance of access to quality water data – but go beyond that by considering the need to bring together, integrate, communicate, share, and enable the use of available water system-of-systems (SOS) data and knowledge, now and into the future, in a just and equitable way. It was determined that digital technologies and AI tools are essential to this effort, and so are governance, policymaking, and business models that control water provision services.

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Water data and knowledge need to be integrated from 'source to tap'; and decision-making and investments need to consider not only the immediate needs of communities, but also their longer term needs, as well as the resilience of the water SOS (incl. natural, built, and social water systems) in the face of dynamically evolving stressors (incl. climate change, land-use change, socioeconomic change). What does this mean in practice? It means that even in higher income countries like the United States, fragmentation of water knowledge, water operations, and water investments is a major, largely unaddressed, problem. Adherence to past legacies and institutionalized practices, largely stove piped into three separate systems of interest (natural water provision, built water treatment and delivery, socioeconomic water uses), are for the most part designed to face the water problems of the past, rather than the water problems of the present and of the future. Water SOS failures (e.g. Flint, MI; Jackson, MI; Colorado River basin over-allocation) keep occurring, at a systems level. Responses are largely reactive and parsed out (when even feasible) to meet the immediate crisis. Anticipatory planning, and adaptive management and governance are lacking. There is a paucity of creative, integrative, yet practical, thinking and decision-making needed to address present water and future challenges.

So, did the 'One World One Water' conference and workshop – with its focus on 'a just and equitable water future for all in an ever-changing environment' – change this state of affairs? No, a much larger and longer effort is needed. Nonetheless, we (the authors and participants) believe that it identified critical challenges and suggested important recommendations to improve the governance and management of water in the United States. The S1W vision provided an important framework and integrative conceptualization that goes well beyond previous efforts (such as IWRM). S1W also leverages new technologies and modeling to improve data and knowledge integration, and identification of gaps and quality issues. The seven major recommendations of the conference (detailed in the previous section) are part of a larger effort by the SWIM community of practice to create a roadmap for further progress, not only for the United States but also for other countries.

The next two SWIM conferences have been designed to (1) elicit and detail further recommendations, solutions, guidelines, standards and (2) suggest possible pathways for implementation. On a national level, the SWIM community of practice – collaborating with water utilities and with the US Geological Survey and other partners in academia, the private sector, and government agencies at the national, state and local levels – has started a major project that seeks to improve efficiency and resilience of drinking water provision, delivery, and use (across the natural, built, and social water systems). The project started in Georgia where it has had a major State-wide impact and attracted national attention (AP May 2024 article link). Other States are now actively participating (e.g. Alaska, California, Georgia, Florida, and Texas) or have expressed interest (e.g. Virginia, Pennsylvania, New York). Momentum is building, nationally and internationally, towards the establishment of a widely accessible digital water platform offering access to data, modern technologies and tools (including AI and Digital Twin modeling), guidelines and standards for assessments, and a knowledgebase for enabling comparisons of situational contexts and for advancing development of best practices and innovation. At the international level, the S1W vision and approach and the SWIM community of practice are also working on a project to improve the resilience of water systems management, operations, planning and community and stakeholder engagement in India with the help of a USAID-funded project.

Lastly, a Blue Ridge PBS multimedia documentary entitled "WATER: Empowering Our Future" is in development and expected for release in two years (NSF 2020). Filming and interviews

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with water professionals and decision-makers started at the 2023 'One World, One Water' conference and workshop and is expanding internationally with the projects just mentioned. The S1W vision; equitable, affordable, resilient, access to water; digital tools and modern technologies; planning and investing for the future while maintaining (or putting in place) efficient present-day operations – are all foci for this PBS multimedia documentary and its set of educational modules targeted to a diversity of audiences. Big challenges solicit big aspirations and require multiple experiences and creative perspectives. Ultimately, this is what drives the budding efforts of the SWIM community of practice, and in a larger context, the creation of an innovative roadmap for implementation of the Smart One Water vision.

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Author Contribution Statement

All authors contributed to the research conception, literature review, practice review, and development of this manuscript. All authors reviewed and commented on prior manuscript versions. All authors read and approved the final manuscript.

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REFERENCES

1. Adedeji, K.B.; Ponnle, A.A.; Abu-Mahfouz, A.M.; Kurien, A.M. (2022). Towards Digitalization of Water Supply Systems for Sustainable Smart City Development—Water 4.0. Appl. Sci. 2022, 12, 9174. https://doi.org/10.3390/app12189174.
2. Alanis L.F.G. and Sinha, S.K., (2013) "Resilience of Civil Infrastructure Systems: Literature Review for Improved Asset Management," International Journal of Critical Infrastructures, InderScience Publication, vol. 9, no. 4, pp. 330-350.
3. American Society of Civil Engineers. The American Infrastructure Report Card: Drinking Water Infrastructure https://www.infrastructurereportcard.org/cat-item/drinking_water/ (2021). Accessed 19 September 2022.
4. Blagojević, N., Didier, M., Stojadinović, B., (2022). 'Quantifying component importance for disaster resilience of communities with interdependent civil infrastructure systems.' *Reliability Engineering & System Safety*, 228, 108747, https://doi.org/10.1016/j.ress.2022.108747.
5. Brown, T. C., Mahat, V., & Ramirez, J. A. (2019). 'Adaptation to future water shortages in the United States caused by population growth and climate change'. *Earth's Future*, 7, 219–234. https://doi.org/10.1029/2018EF001091
6. Brown, T. C., Mahat, V., & Ramirez, J. A. (2019). Adaptation to future water shortages in the United States caused by population growth and climate change. *Earth's Future*, 7, 219–234. https://doi.org/10.1029/2018EF001091. https://agupubs.onlinelibrary.wiley.com/doi/10.1029/2018EF001091
7. Engineering Research Visioning Alliance. (2022). 'The Role of Engineering to Address Climate Change: A Visioning Report.' Columbia, SC: SSRN. http://dx.doi.org/10.2139/ssrn.4173381.
8. GAO, Water Quality and Protection, https://www.gao.gov/water-quality-and-protection
9. Healy, R.W., Winter, T.C., LaBaugh, J.W., and Franke, O.L., (2007). *Water budgets: Foundations for effective water-resources and environmental management* (Vol. 1308, p. 90). Reston, Virginia: US Geological Survey.
10. Howe, C., (2019). 'Pathways to One Water: A Guide for Institutional Innovation.' *Water Research Foundation, Denver, CO*. https://www.waterrf.org/research/projects/pathways-one-water-guide-institutional-innovation
11. https://www.who.int/news-room/fact-sheets/detail/drinking-water
12. Jain, H., Buch, M., Babu, P. (2021). 'Water Management System Using Machine Learning.' In: *Bhateja, V., Satapathy, S.C., Travieso-González, C.M., Aradhya, V.N.M. (eds) Data Engineering and Intelligent Computing. Advances in Intelligent Systems and Computing*, vol 1407. Springer, Singapore. https://doi.org/10.1007/978-981-16-0171-2_45.
13. John A. Hall, Christopher P. Weaver, Jayantha Obeysekera, Mark Crowell, Radley M. Horton, Robert E. Kopp, John Marburger, Douglas C. Marcy, Adam Parris, William V. Sweet, William C. Veatch & Kathleen D. White. (2019). Rising Sea Levels: Helping Decision-Makers Confront the Inevitable, Coastal Management, https://doi.org/10.1080/08920753.2019.1551012
14. Joseph Kane & Adie Tomer (2018). Renewing the Water Workforce: Improving water infrastructure and creating a pipeline to opportunity, page 15. Retrieved from: https://www.brookings.edu/research/water-workforce/
15. Meran, G., Siehlow, M., von Hirschhausen, C. (2021). Integrated Water Resource Management: Principles and Applications. In: The Economics of Water. Springer Water. Springer, Cham. https://doi.org/10.1007/978-3-030-48485-9_3
16. Mueller, J.T., Gasteyer, S. 'The widespread and unjust drinking water and clean water crisis in the United States.' *Nat Commun* 12, 3544 (2021). https://doi.org/10.1038/s41467-021-23898-z

https://doi.org/10.1017/wat.2025.1 Published online by Cambridge University Press

17. Nika, C.E., Vasilaki, V., Exposito, A., and Katsou E. (2020). Water Cycle and Circular Economy: Developing a Circularity Assessment Framework for Complex Water Systems
18. NSF-ERC Planning Grant - Diversity, Equity, and Culture of Inclusion Workshop (2020); https://www.smartonewater.org/sow-projects/workshops/diversity-inclusion
19. NSF-ERC Planning Grant - Innovation Ecosystem Workshop (2020); https://www.smartonewater.org/sow-projects/workshops/innovation-ecosystem
20. NSF-ERC Planning Grant - Policy and Governance Workshop (2020); https://www.smartonewater.org/sow-projects/workshops/policy-governance
21. NSF-ERC Planning Grant - Policy and Governance Workshop (2020); https://www.smartonewater.org/sow-projects/workshops/policy-governance
22. NSF-ERC Planning Grant - Smart One Water Whitepaper (2020) Available at. https://www.smartonewater.org/ (Accessed 15 August 2023).
23. NSF-ERC Planning Grant - Smart One Water; https://www.smartonewater.org/
24. NSF-ERC Planning Grant - Stakeholder Engagement Workshop (2020); https://www.smartonewater.org/sow-projects/workshops/stakeholder-engagement
25. NSF-ERC Planning Grant – The Future of Water Summit (2022); https://www.smartonewater.org/future-of-water-summit/summit-2022
26. NSF-ERC Planning Grant - Workforce Development Workshop (2020); https://www.smartonewater.org/sow-projects/workshops/stakeholder-engagement
27. NSF-ERC Planning Grant– for Smart One Water. Grant# 1936893. https://www.nsf.gov/awardsearch/showAward?AWD_ID=1936893&HistoricalAwards=false
28. One Water LA: A Guide Towards Sustainable and Integrated Water Management; https://www.cwea.org/news/one-water-la-a-guide-towards-sustainable-integrated-water-management/
29. Patterson, L., Doyle, M., King K., and Monsma, D. (2017). Internet of Water: Sharing and Integrating Water Data for Sustainability. A Report from the Aspen Institute Dialogue Series on Water Data. Obtained from https://www.aspeninstitute.org/wp-content/uploads/2017/05/Internet-of-Water-Report-May-2017.pdf.
30. PBS Documentary, Liquid Assets: The Story of our Water Infrastructure (2009); https://www.smartonewater.org/sow-projects/documentaries/liquid-assets
31. Piemonti, A.D., Guizani, M., Babbar-Sebens, M., Zhang, E., and Mukhopadhyay, S. (2021) "Exploration and Visualization of Patterns underlying multi-Stakeholder Preferences in Watershed Conservation Decisions Generated by an Interactive Genetic Algorithm." Water Resources Research, 57(5), DOI:10.1029/2020WR028013.
32. Sinha, S., Babbar-Sebens, M., Dzombak, D., Gardoni, P., Watford, B., Scales, G., Grigg, N., Westerhof, E., Thompson, K., & Meeker, M. (2023, October 18). "Smart One Water: An Integrated Approach for the Next Generation of Sustainable and Resilient Water Systems," Oxford Research Encyclopedia of Environmental Science. https://oxfordre.com/environmentalscience/view/10.1093/acrefore/9780199389414.001.0001/acrefore-9780199389414-e-835.
33. Sinha, S.K., Davis, C., Gardoni, P., Babbar-Sebens, M., Stuhr, M., Huston, D., Cauffman, S., Williams, W.D., Alanis, L.G., Anand, H. and Vishwakarma, A., 2023. 'Water sector infrastructure systems resilience: A social–ecological–technical system-of-systems and whole-life approach.' Cambridge Prisms: Water, 1, p.e4. doi:10.1017/wat.2023.3
34. Smart One Water, https://www.smartonewater.org/
35. SWIM Center, https://www.swim.cee.vt.edu/

https://doi.org/10.1017/wat.2025.1 Published online by Cambridge University Press

36. The Future of Water Summit. (2022). https://www.smartonewater.org/sow-projects/future-of-water-summit. (Accessed 15 August 2023).
37. The SWIM Conference (December, 2023), Arlington, Virginia. https://www.smartonewater.org/swim-conference/2023
38. United Nations (2012) System of Environmental-Economic Accounting for Water, Department of Economic and Social Affairs, New York, ISBN: 978-92-1-161554-8.
39. United Nations (n.d.). 'Integrated Water Resources Management (IWRM) | International Decade for Action "Water for Life" 2005-2015. (n.d.).' https://www.un.org/waterforlifedecade/iwrm.shtml
40. United Nations, Integrated Water Resources Management (IWRM); https://www.un.org/waterforlifedecade/iwrm.shtml
41. United Nations, Sustainable Development Goal 6: Ensure access to water and sanitation for all https://www.un.org/sustainabledevelopment/water-and-sanitation/
42. US EPA (n.d.) 'EJScreen: Environmental Justice Screening and Mapping
43. US EPA (n.d.). 'How's my waterway.' https://www.epa.gov/waterdata/hows-my-waterway. (Accessed 15 August 2023).
44. US EPA, https://www.epa.gov/water-innovation-tech/economic-impact-water-technology-innovation-clusters
45. US Water Alliance (n.d.). 'One Water Roadmap: The Sustainable Management of Life's Most Essential Resource.' http://uswateralliance.org/one-water. (Accessed 15 August 2023).
46. US Water Alliance; One Water Roadmap: The Sustainable Management of Life's Most Essential Resource; http://uswateralliance.org/one-water
47. Vermeulen, J., Whiteoak, K., Nicholls, G., Gerber, F., McAndrew, K., Cherrier, V., Cunningham, E., Kirhensteine, I., Wolters, H., Verweij, W., and Schipper, P. (2019). Fitness Check Evaluation of the Water Framework Directive and the Floods Directive. https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/1155-Fitness-Check-of-the-Water-Framework-Directive-and-the-Floods-Directive_en
48. Water Research Foundation (WRF). (2017). 'Blueprint for One Water.' *Water Research Foundation Project #4660*. https://www.waterrf.org/research/projects/blueprint-one-water
49. Water Research Foundation and Water Services Association of Australia (2018). Workforce Skills of the Future; https://www.wsaa.asn.au/sites/default/files/publication/download/WSAA%20Workforce%20Skills%20of%20the%20Future_0.pdf
50. Water Research Foundation, Blueprint for One Water (2017); https://www.waterrf.org/research/projects/blueprint-one-water
51. Water Research Foundation, One Water Implementation: A Path to Reliability and Resiliency for Water Utilities (2017); https://www.waterrf.org/resource/one-water-implementation-path-reliability-and-resiliency-water-utilities
52. World Health Organization. (2022). "Drinking-water." https://www.who.int/news-room/fact-sheets/detail/drinking-water. (Accessed August 15, 2023)

https://doi.org/10.1017/wat.2025.1 Published online by Cambridge University Press

Graphical Abstract

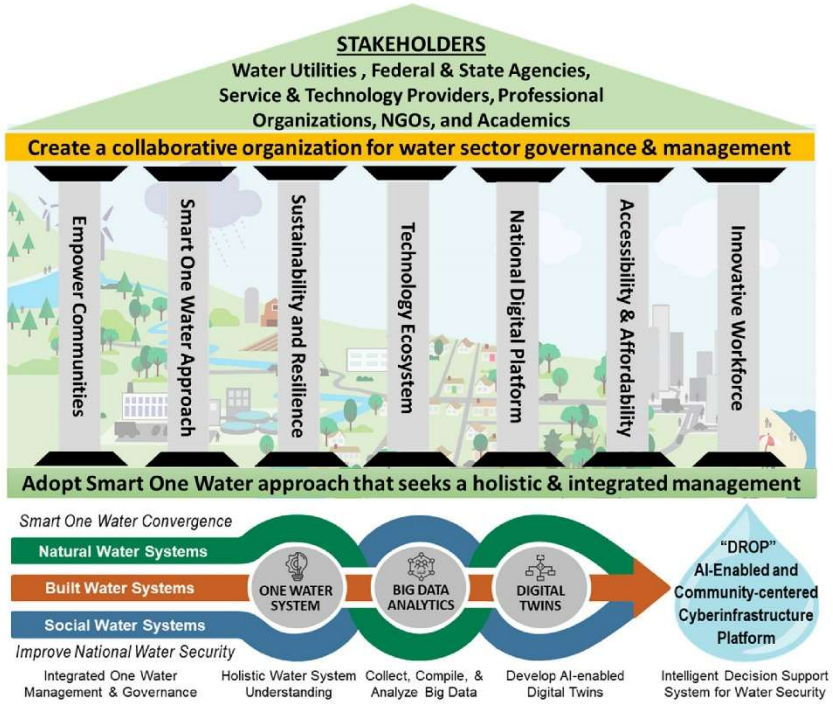

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Figure 1. Natural, Built, and Social Water Systems Definition

Natural water system definition: The natural water system relates to the provision of water from ground, surface, ocean, and atmospheric water sources, and changes in those provisions as may be affected by human and environmental factors. The S1W approach includes consideration of water from different sources, their quality or condition, as well as the fluxes (e.g. withdrawals) and environmental changes (e.g. climate change) that impact those sources. Characterization of the natural water system is a first step in assessing the availability and suitability of water for given societal purposes.

Built water system definition: The built water system in the S1W approach considers the engineered water systems – and the management and governance of built infrastructure – used to capture, transfer, treat, store, and deliver water (in any form or condition) for societal uses. Characterization of the built water system includes not only description and tracking of its state, but also assessments of its resilience and sustainability of its functions in the face of changing environmental and societal conditions and stressors.

Social water system definition: The social water system in the S1W approach relates to the understanding (and potential improvement) of human behaviors and tradeoff decisions (conscious or unconscious) affecting: (1) water supplies (quantity as well as quality and condition); (2) water distribution and accessibility; (3) individual and societal water demands; (4) water pricing, markets, financing; and water uses. Assessments of water equity, affordability, social and environmental justice and other questions of value and societal prioritizations are critical in characterizing the needs of the social water system in the S1W approach.

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Figure 2. Integration of Siloed Management of Water Systems and Services in the One Water

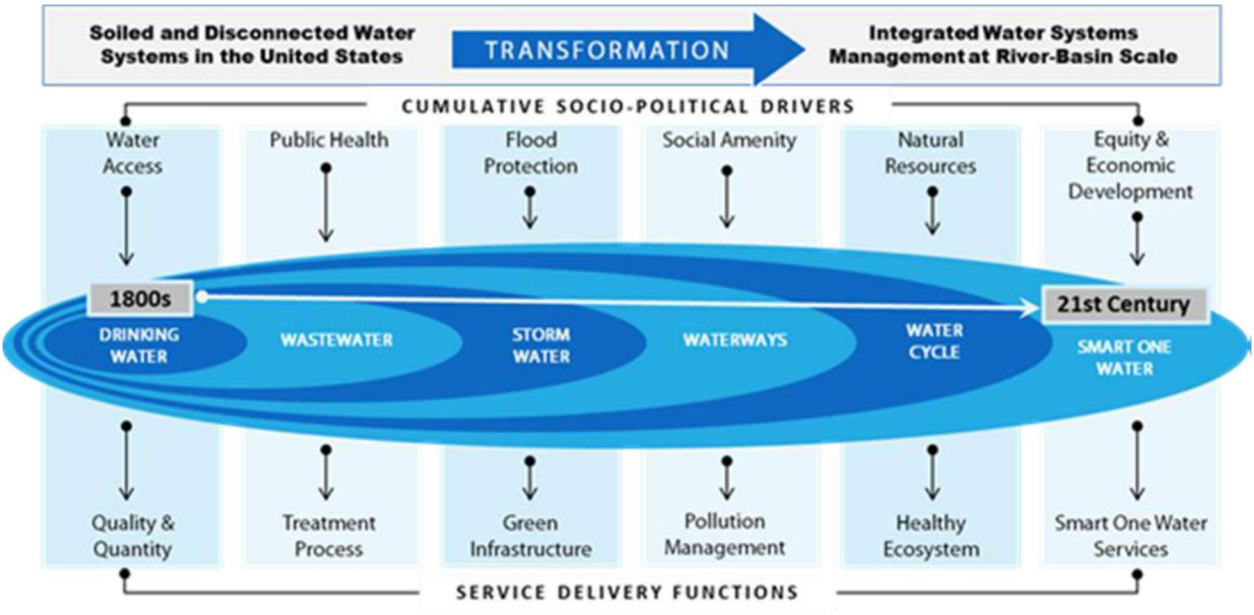

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Figure 3. Smart One Water Implementation for Societal Impacts

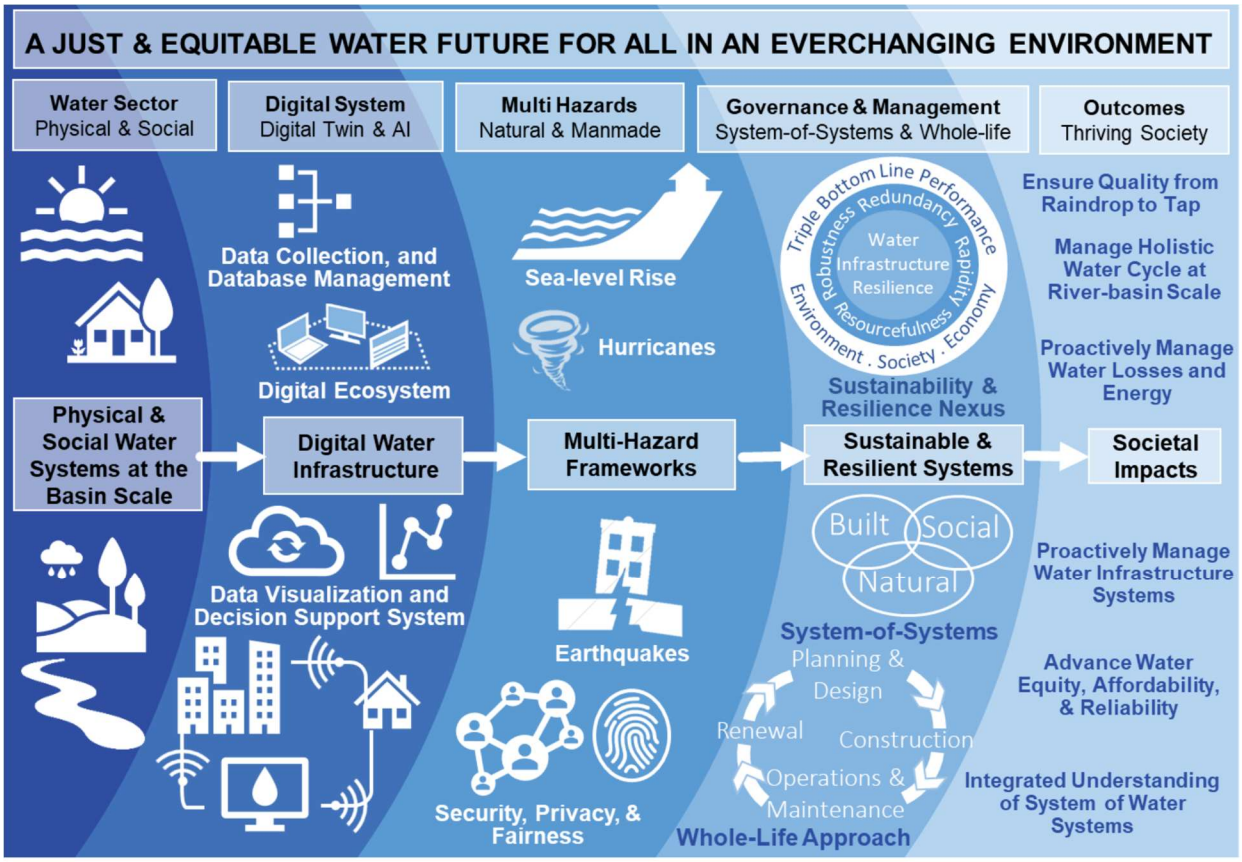

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Figure 4. The SWIM Conference and Workshop Development Process

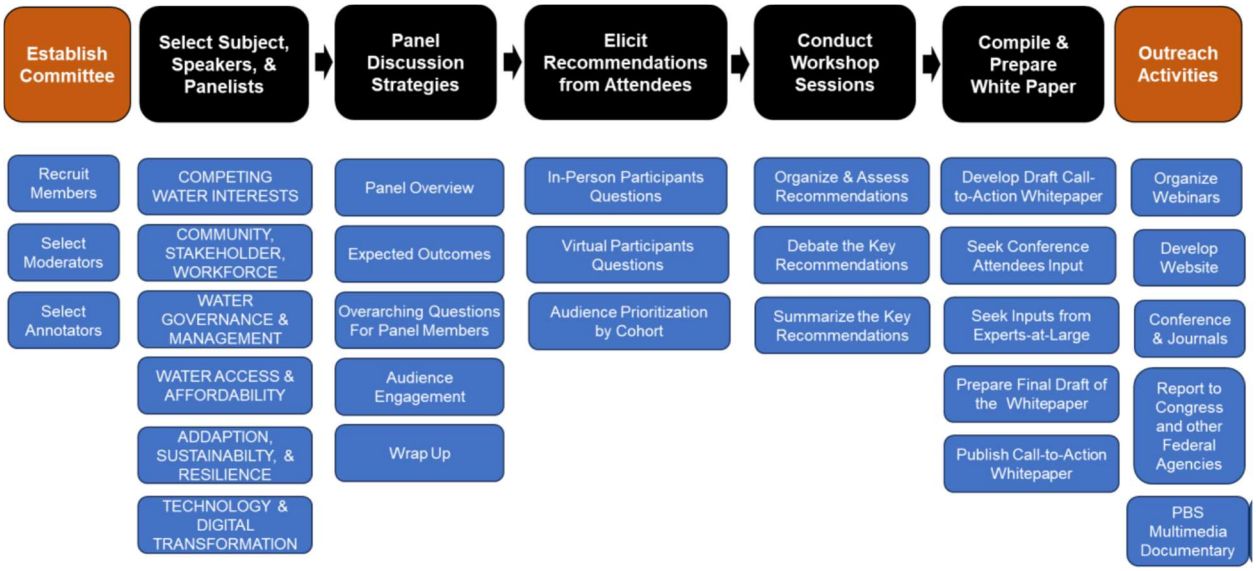

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Figure 5. The SWIM Conference and Workshop Information and Knowledge Synthesis

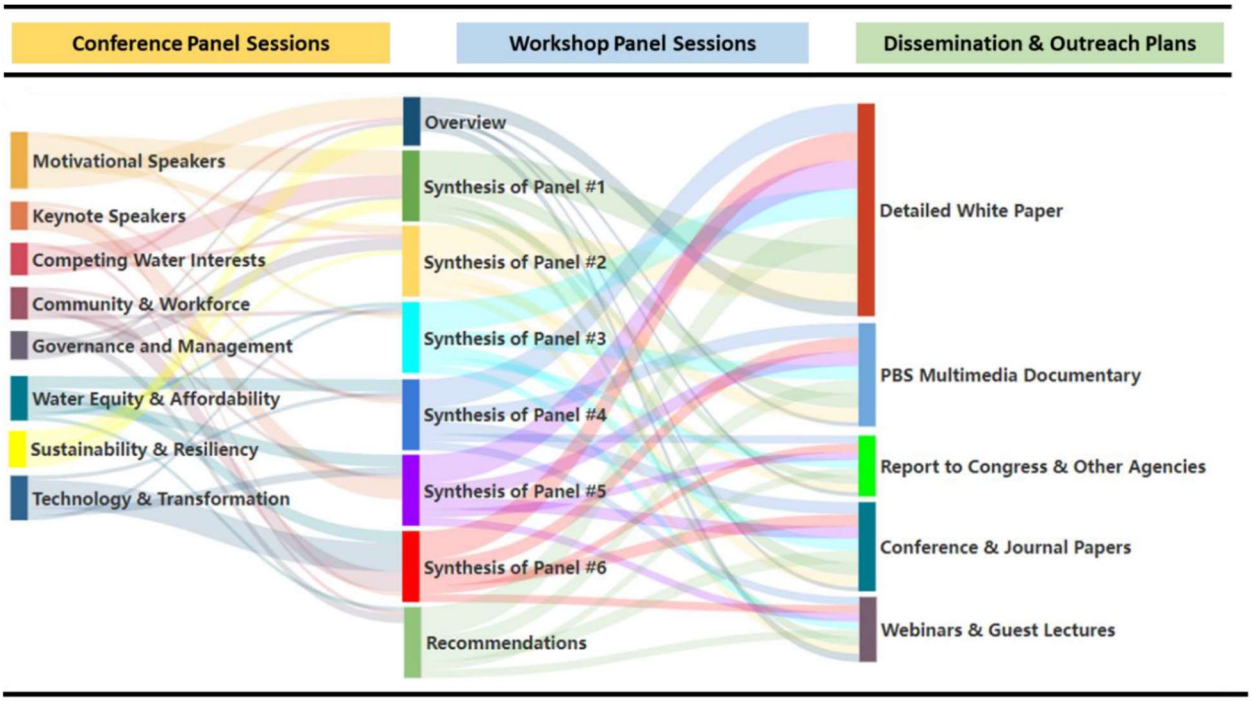

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Figure 6. The Six Foundational Pillars and Panels of the SWIM 2023 'One World, One Water' Conference and Workshop

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Figure 7: Conference Panel Session Overall Summary

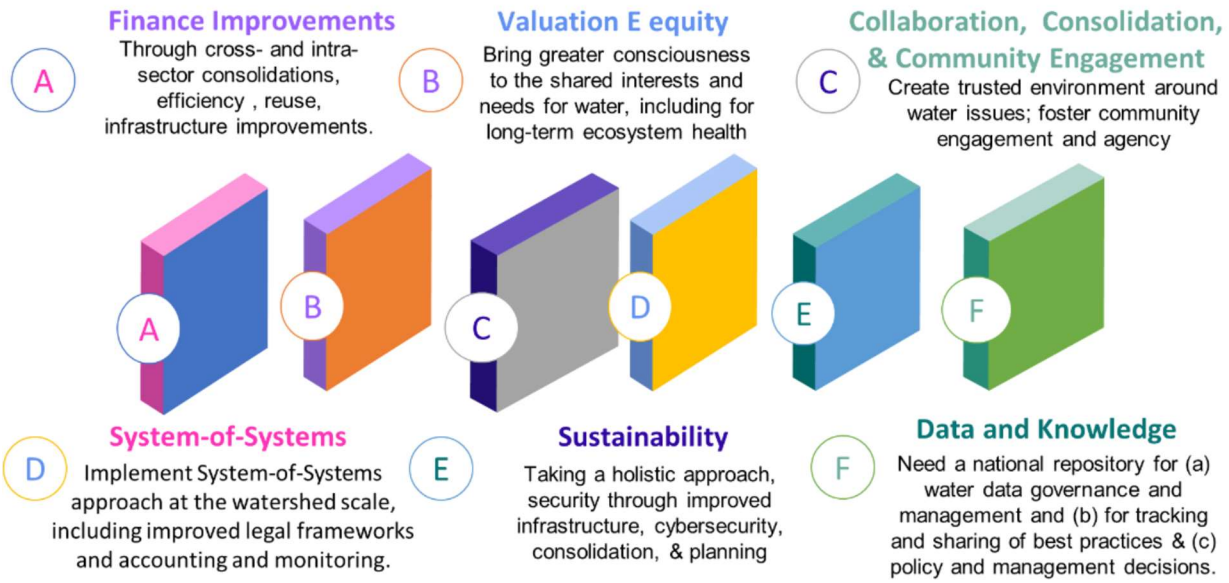

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Figure 8: Conference Panel Session Question-1 Response

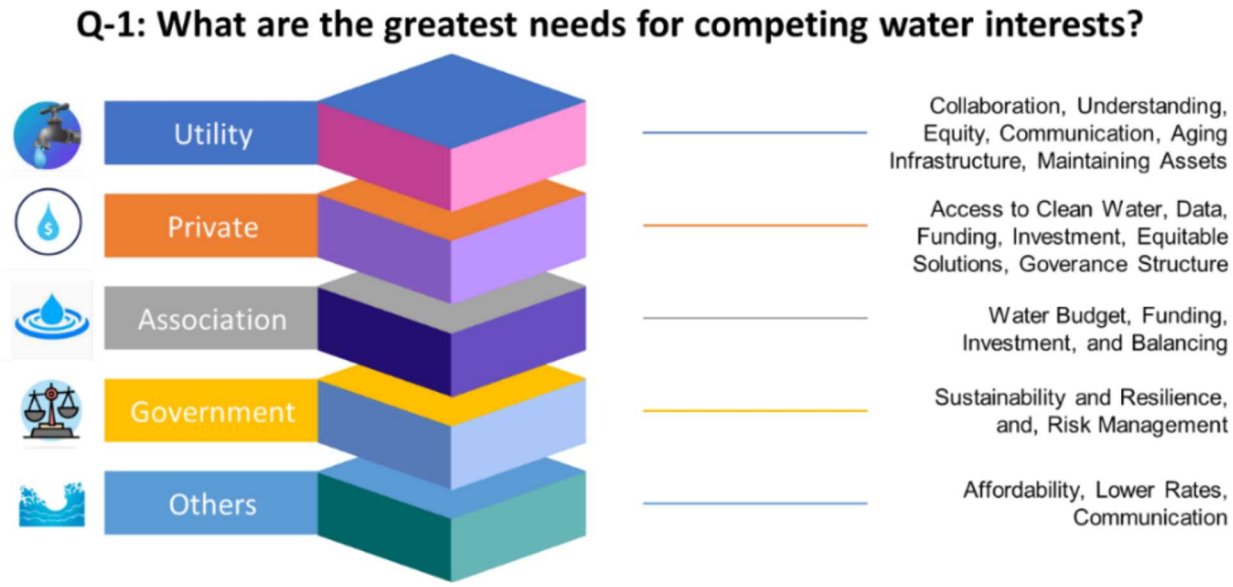

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Figure 9: Conference Panel Session Question-2 Response

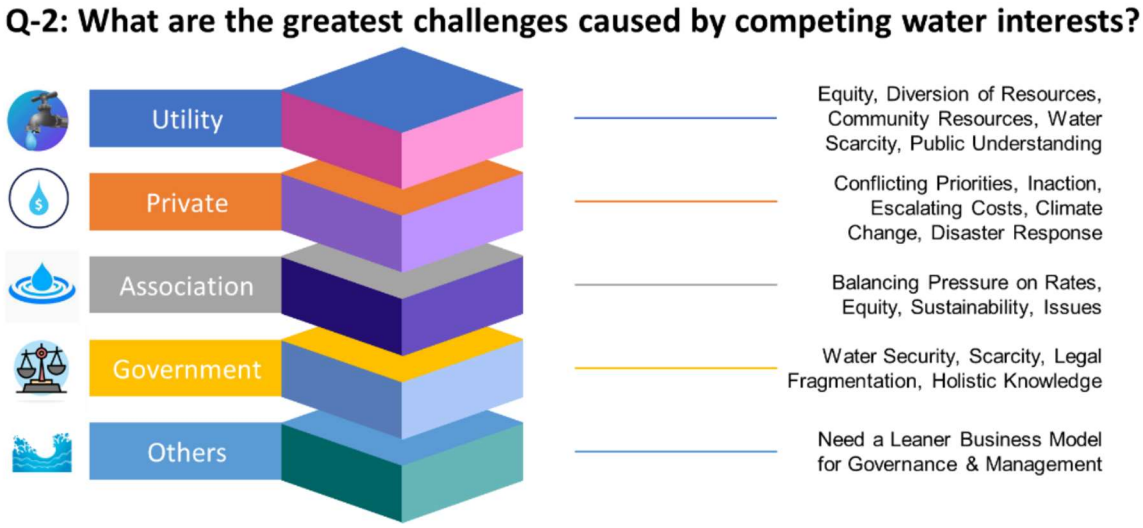

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Figure 10: Conference Panel Session Question-3 Response

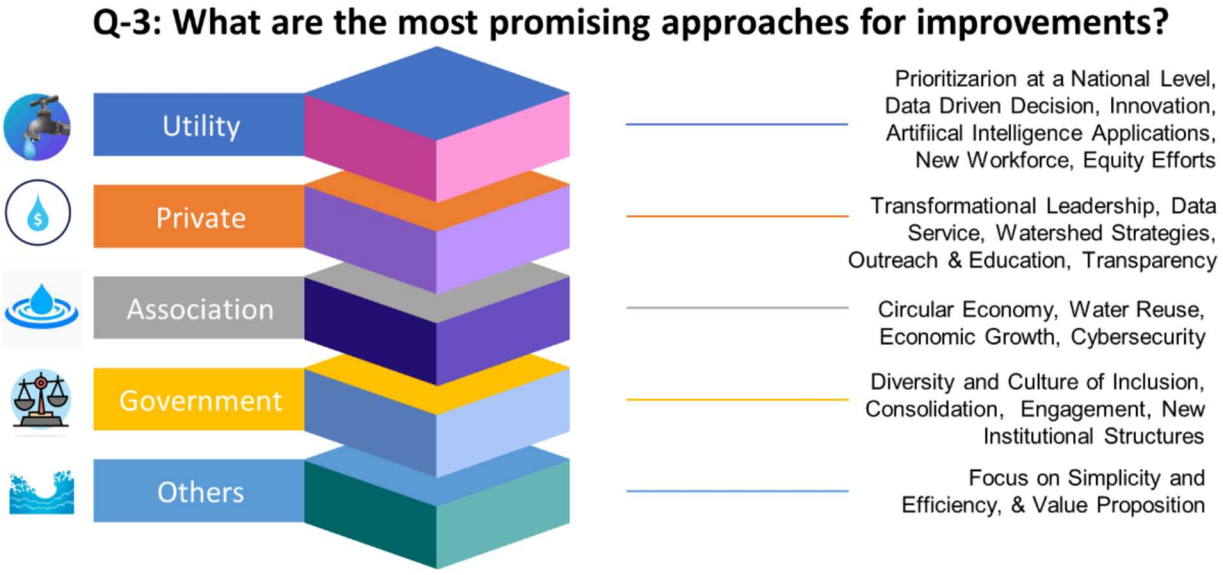

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Figure 11: Workshop Panel Session Overall Summary

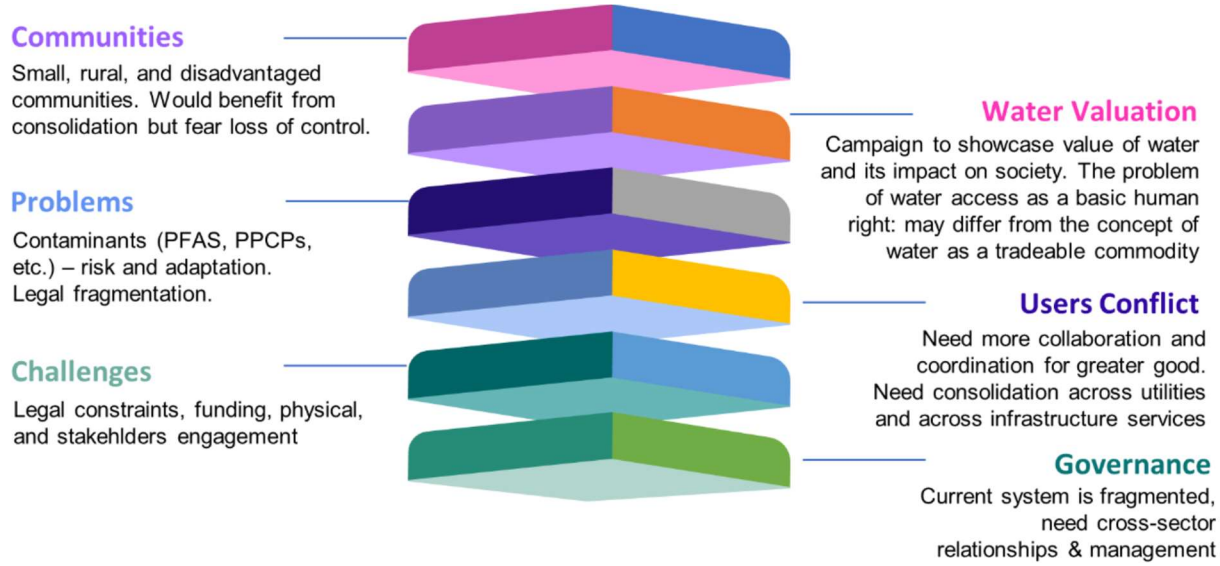

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Figure 12: Overall Outcomes from Conference and Workshop Panel-1 Session

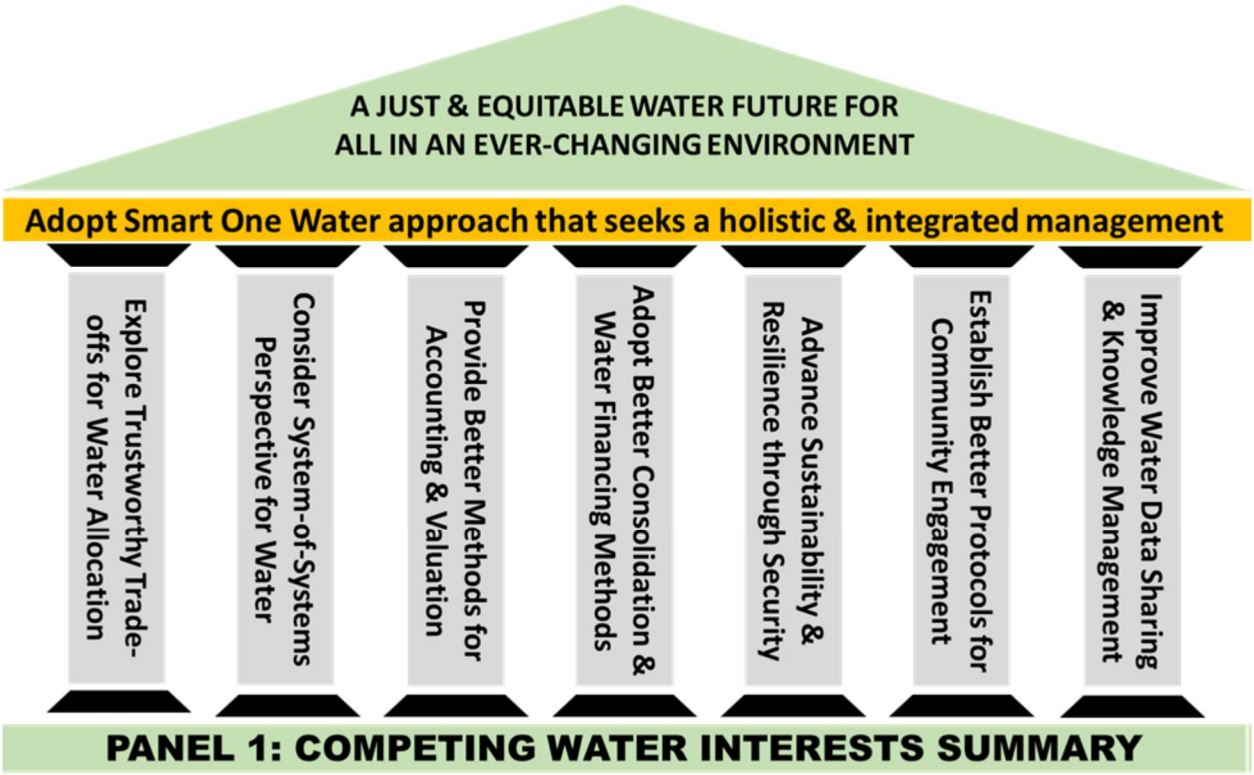

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Figure 13: Conference Panel Session Overall Summary

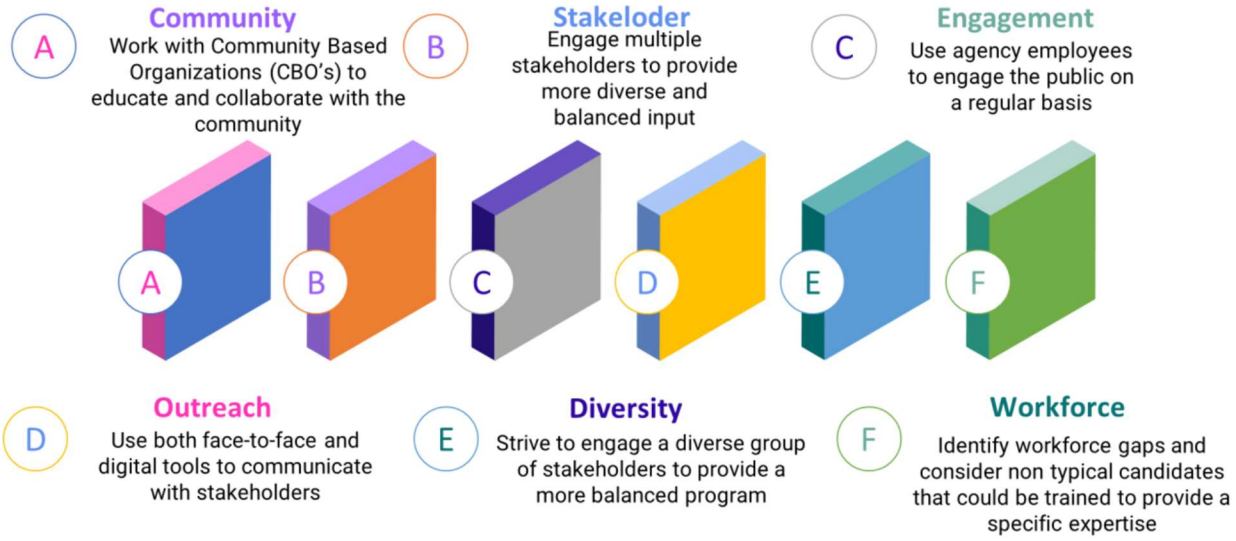

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Figure 14: Conference Panel Session Question-1 Responses

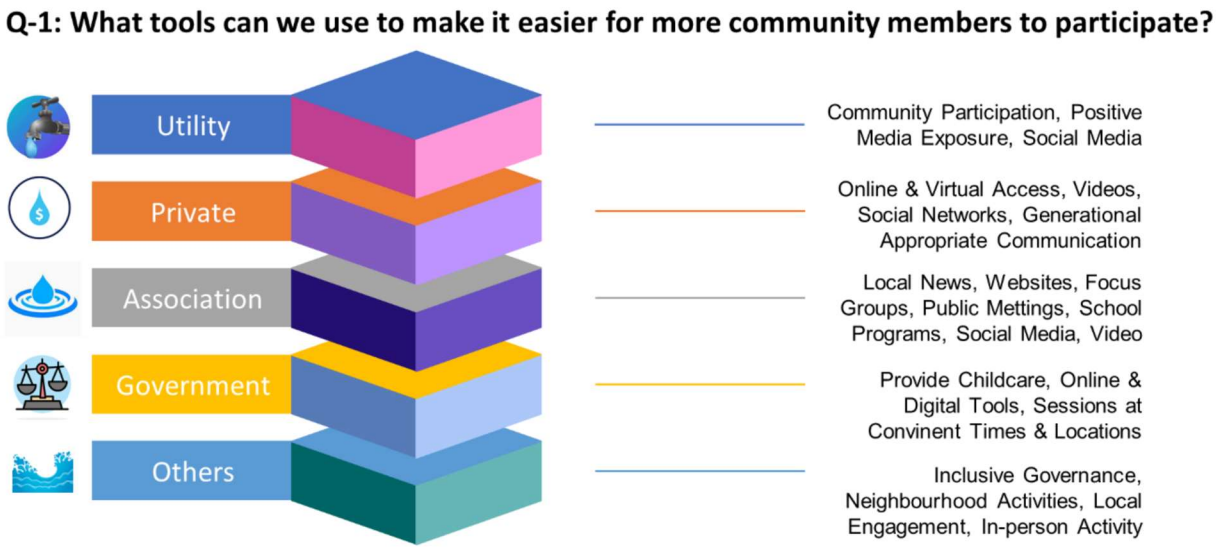

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Figure 15: Conference Panel Session Question-2 Responses

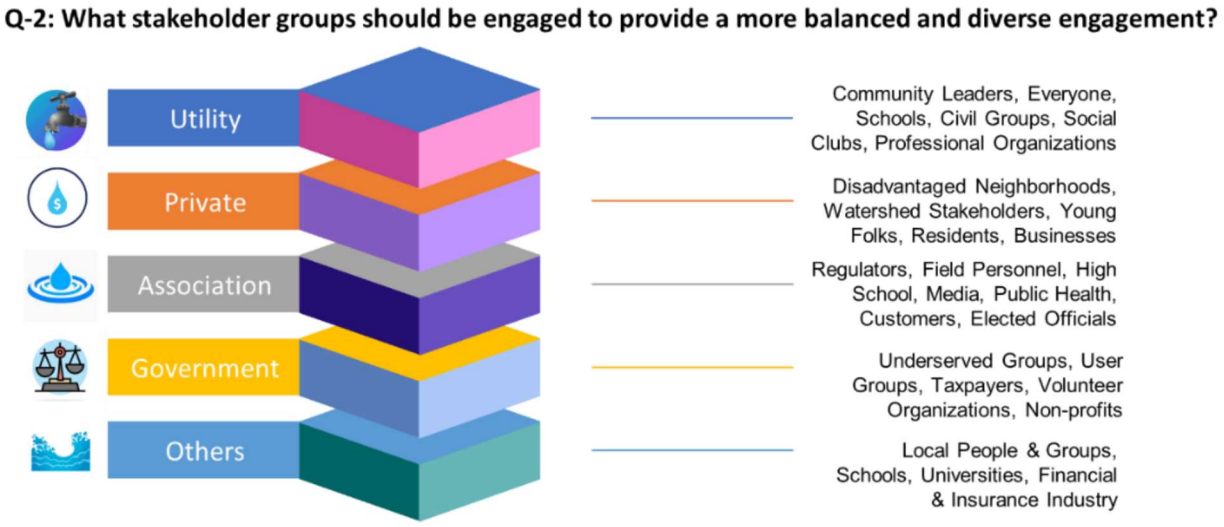

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Figure 16: Conference Panel Session Question-3 Responses

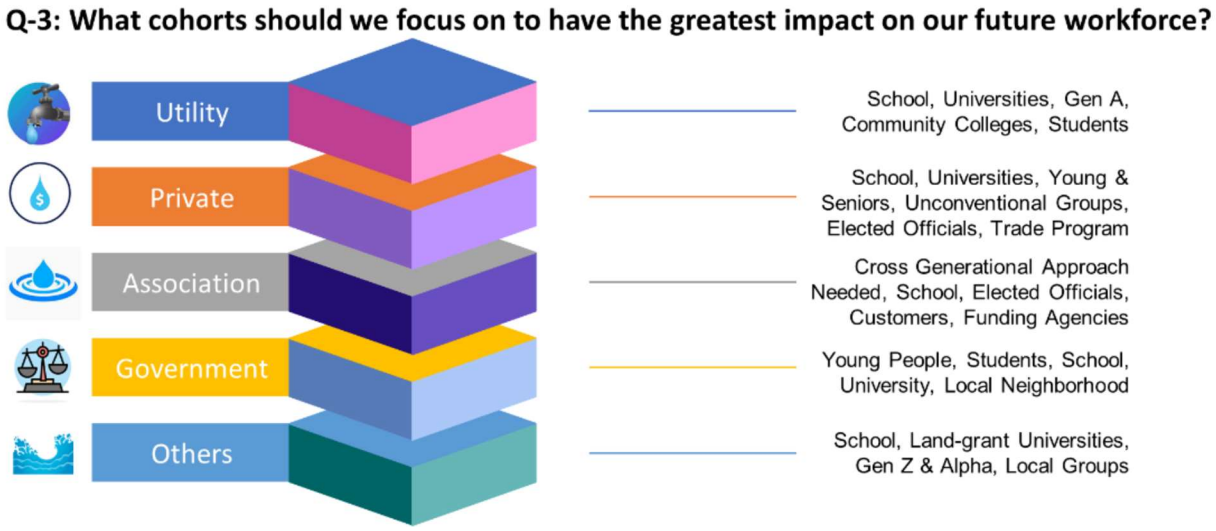

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Figure 17: Workshop Panel Session Overall Summary

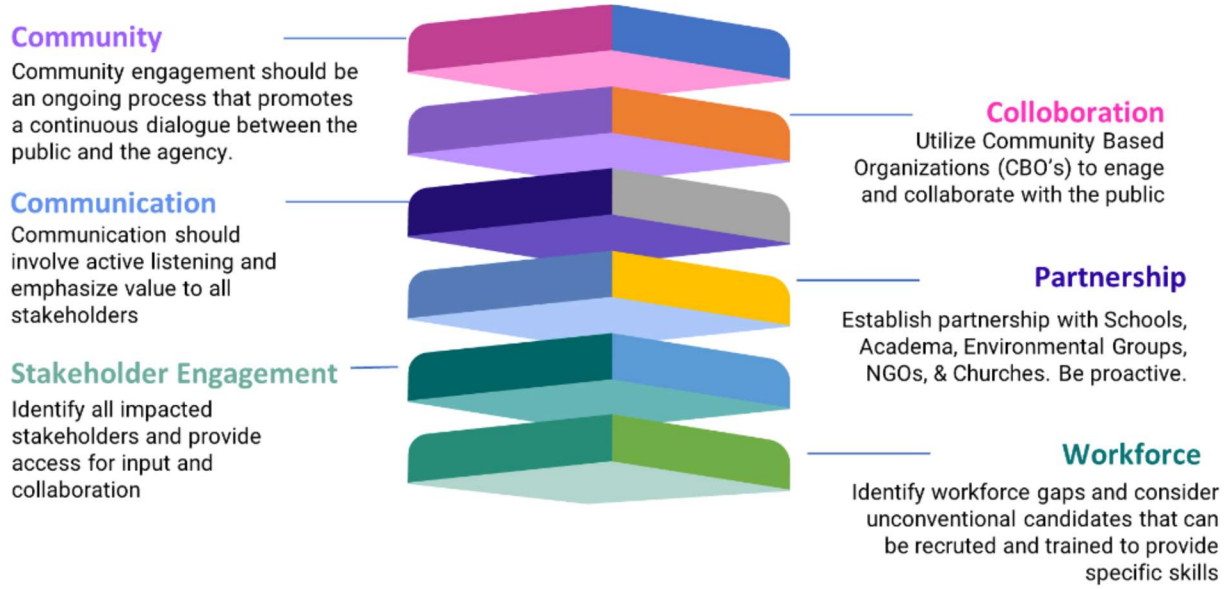

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Figure 18: Overall Outcomes from Conference and Workshop Panel-2 Session

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Figure 19: Conference Panel Session Overall Summary

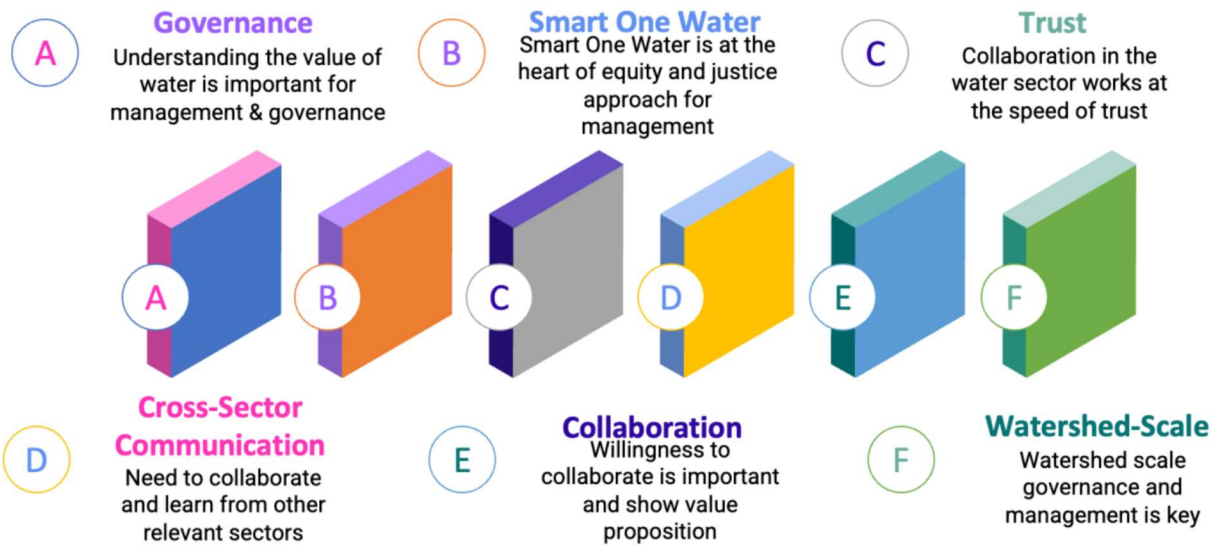

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Figure 20: Conference Panel Session Question-1 Responses

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Figure21: Conference Panel Session Question-2 Responses

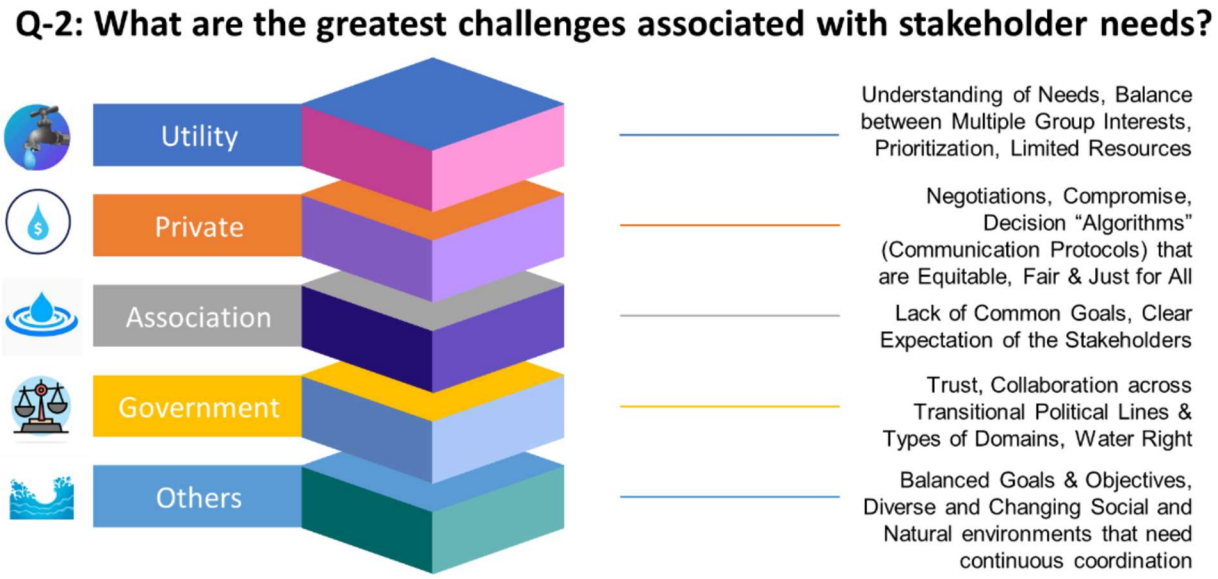

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Figure 22: Conference Panel Session Question-3 Responses

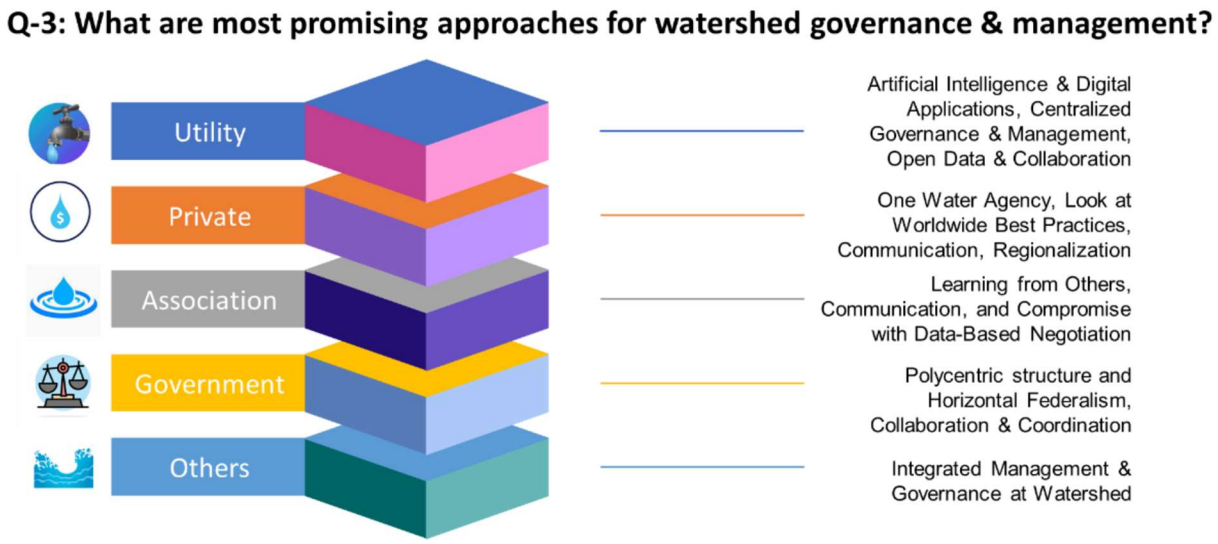

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Figure 23: Workshop Panel Session Overall Summary

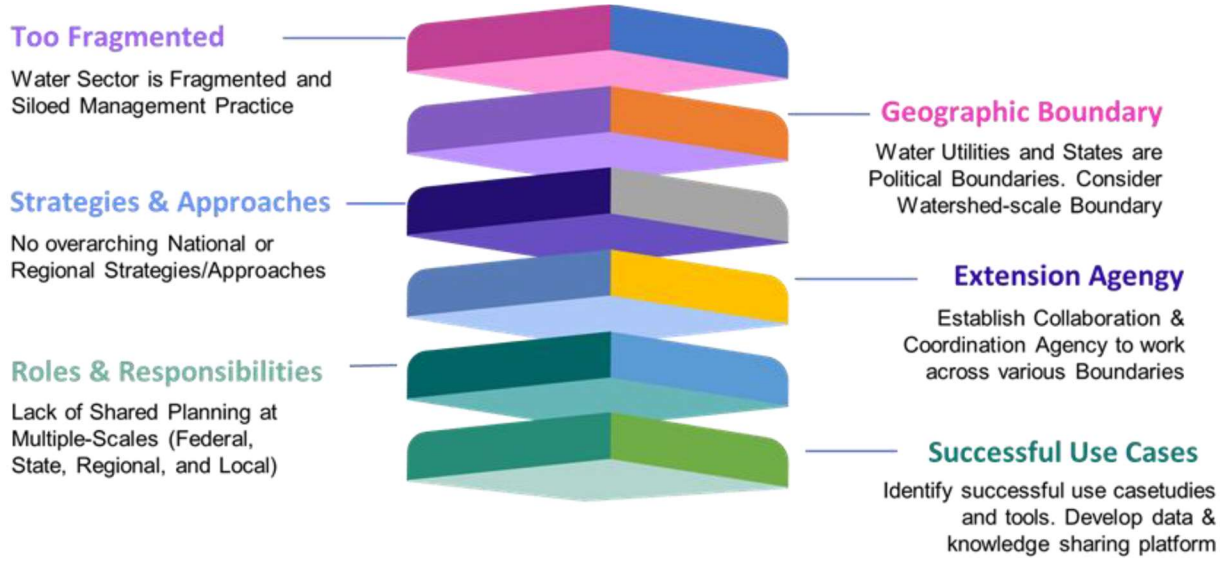

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Figure 24: Overall Outcomes from Conference and Workshop Panel-3 Session

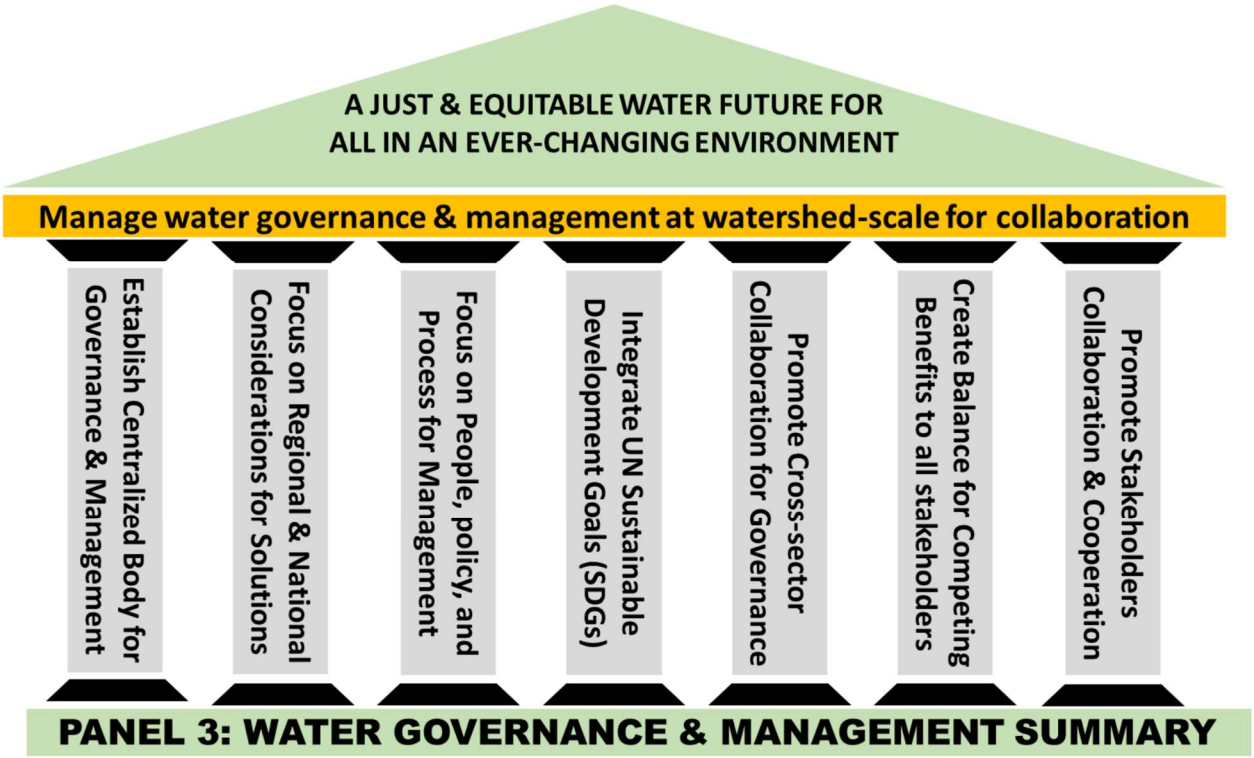

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Figure 25: Conference Panel Session Overall Summary

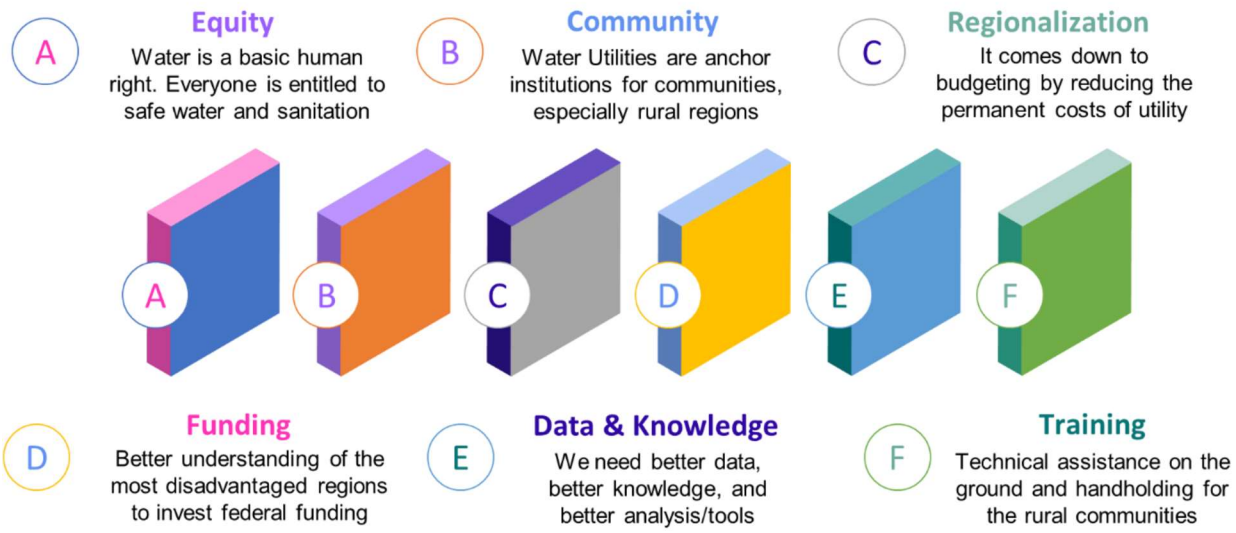

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Figure 26: Conference Panel Session Question-1 Response

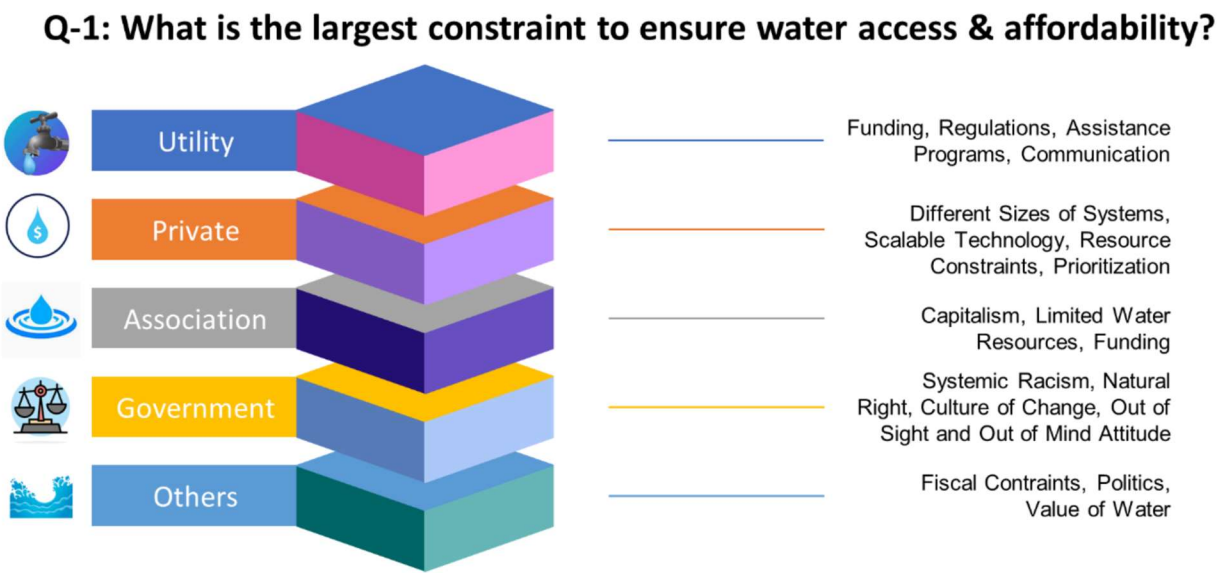

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Figure 27: Conference Panel Session Question-2 Response

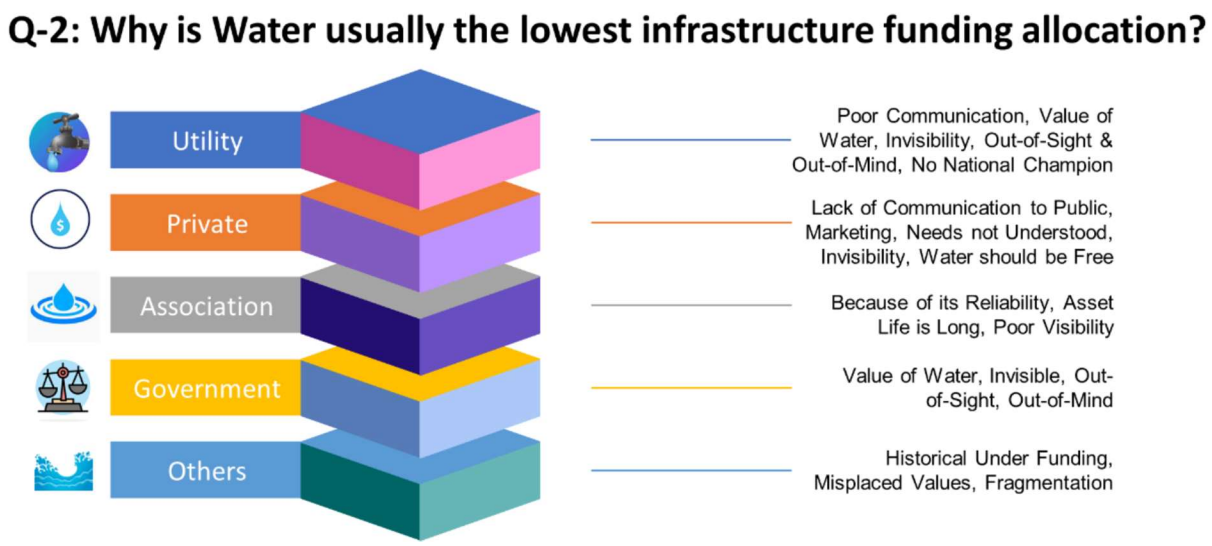

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Figure 28: Conference Panel Session Question-3 Response

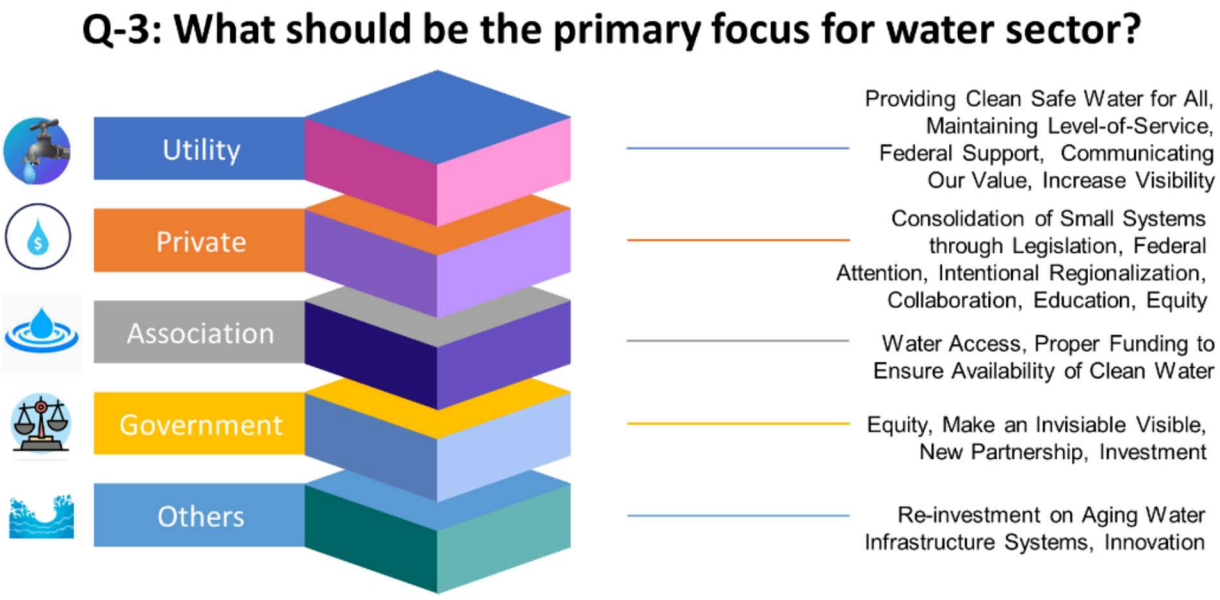

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Figure 29: Workshop Panel Session Overall Summary

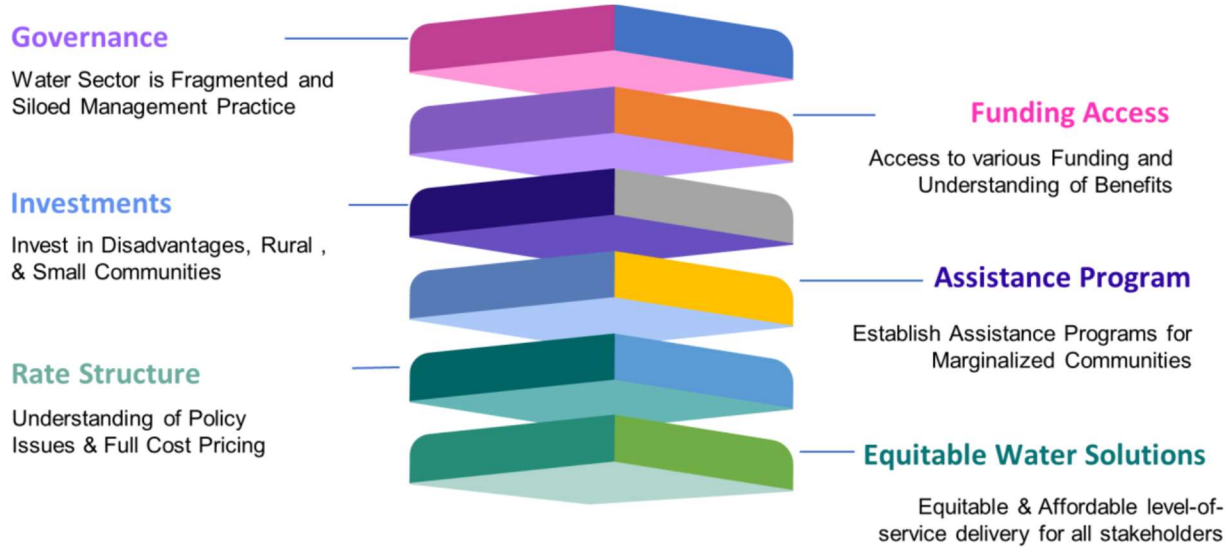

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Figure 30: Overall Outcomes from Conference and Workshop Panel-4 Session

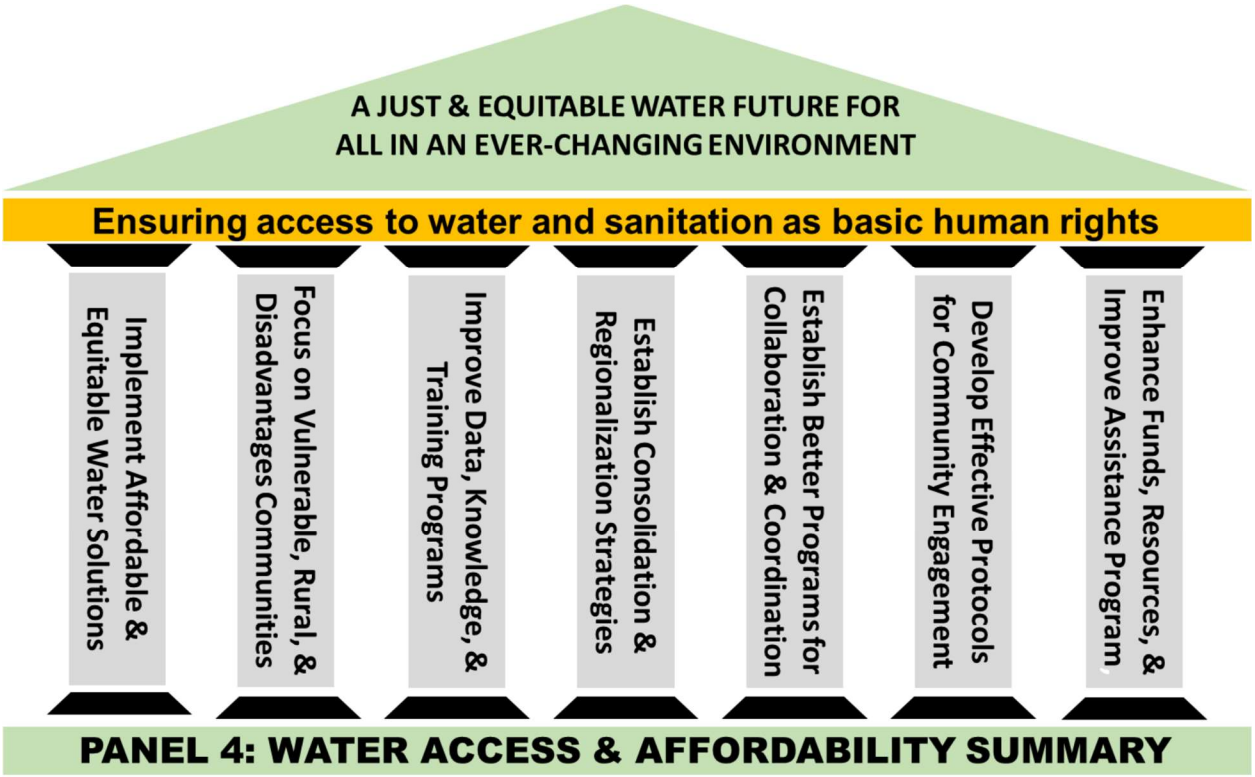

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Figure 31: Conference Panel Session Overall Summary

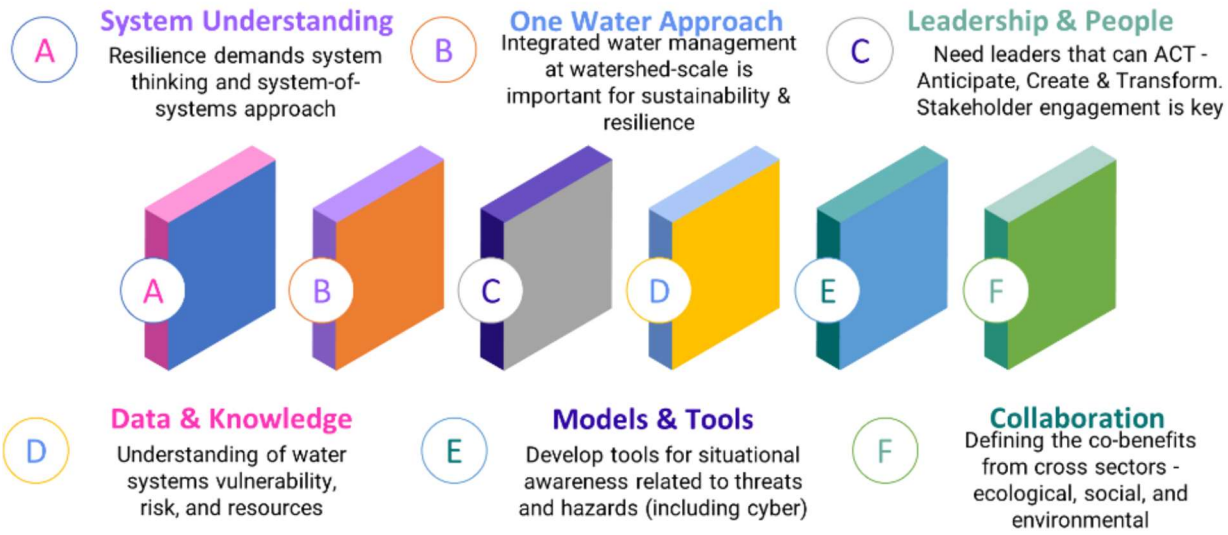

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Figure 32: Conference Panel Session Question-1 Responses

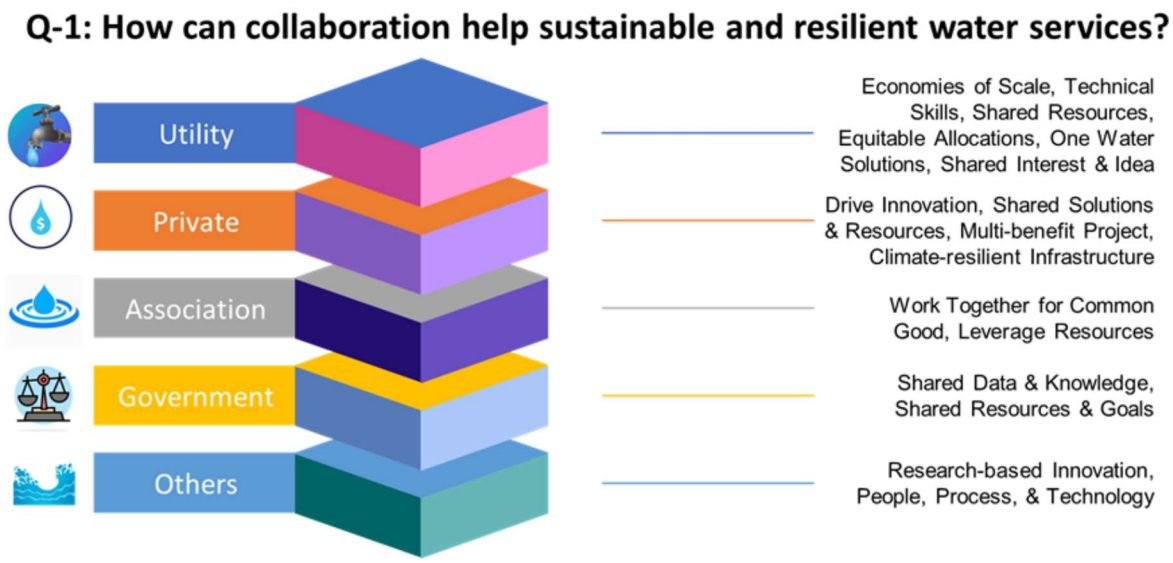

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Figure 33: Conference Panel Session Question-2 Responses

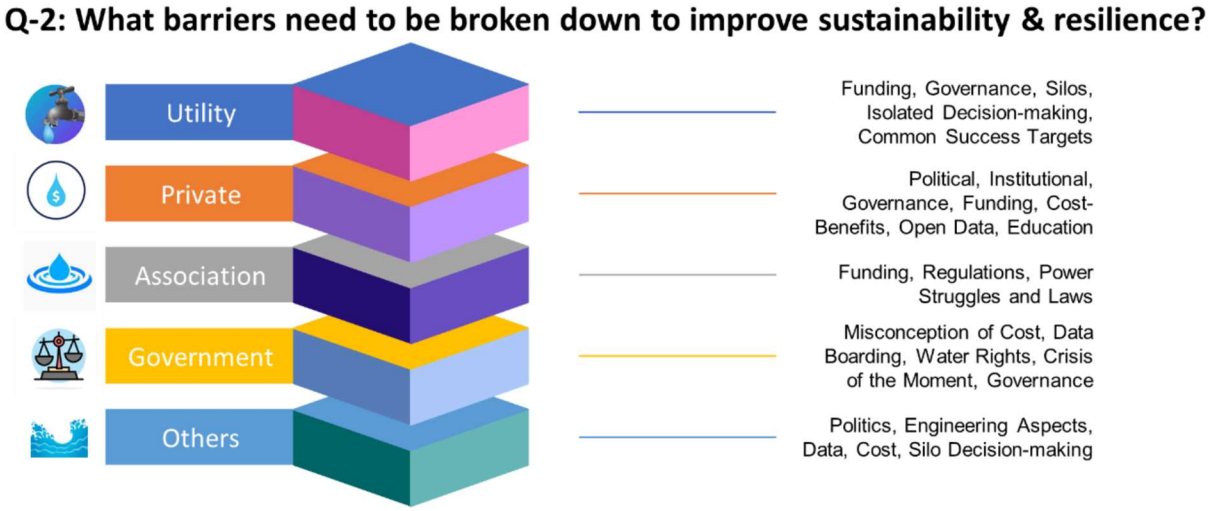

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Figure 34: Conference Panel Session Question-3 Responses

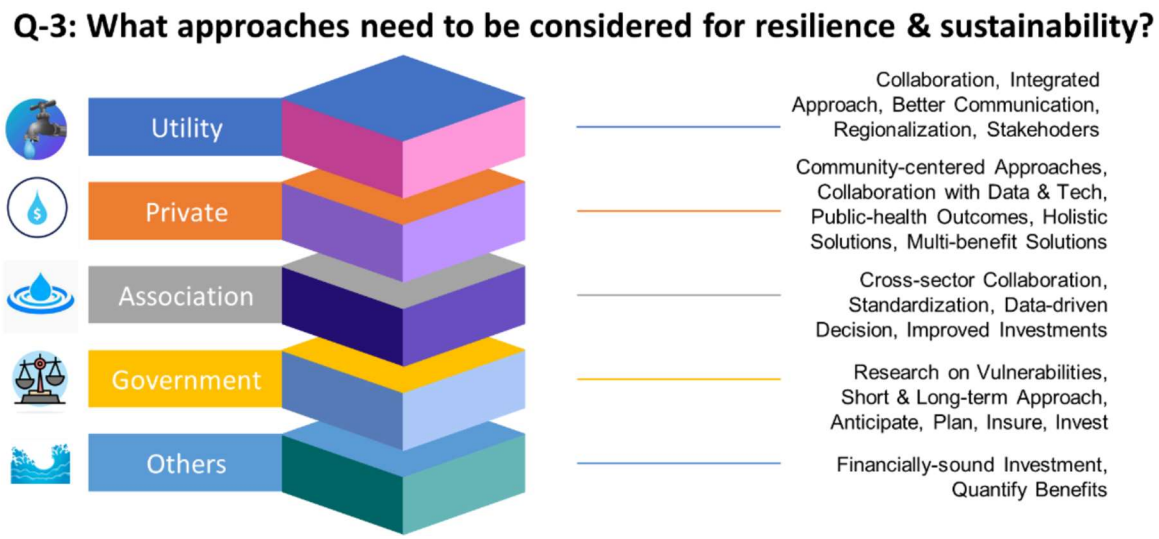

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Figure 35: Workshop Panel Session Overall Summary

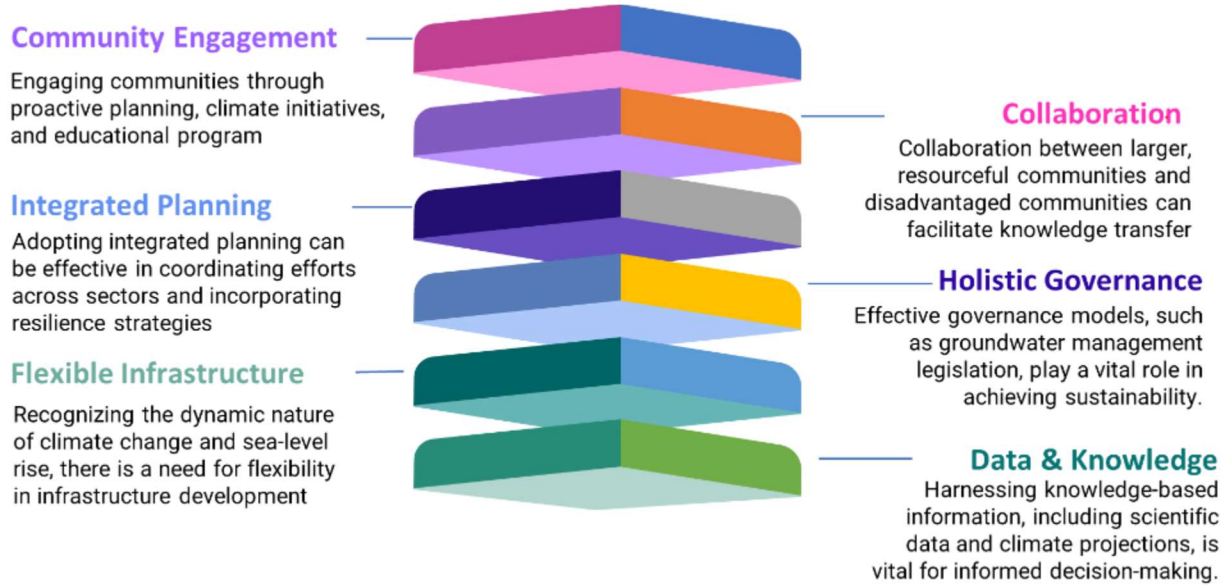

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Figure 36: Overall Outcomes from Conference and Workshop Panel-5 Session

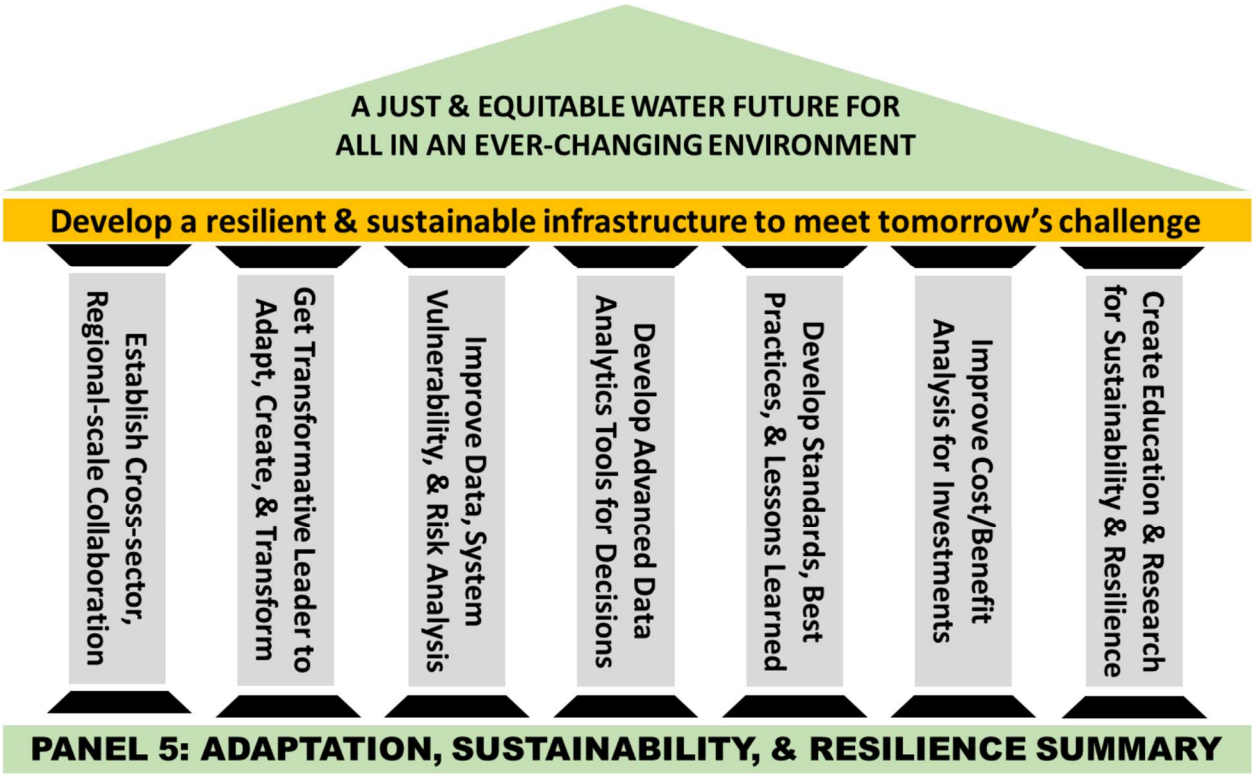

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Figure 37: Conference Panel Session Overall Summary

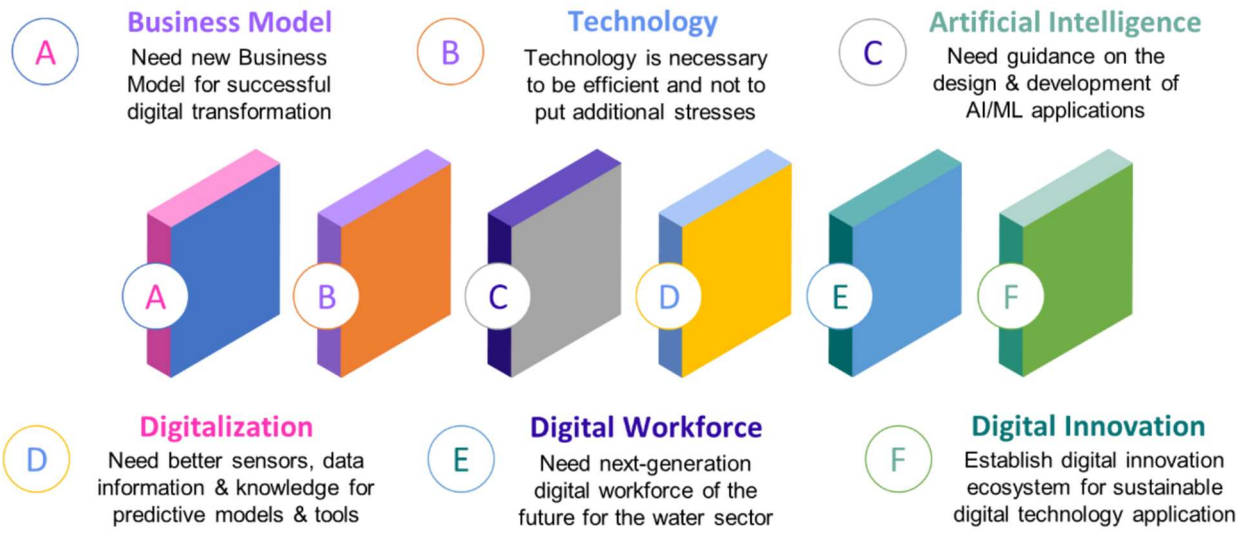

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Figure 38: Panel Session Question-1 Responses

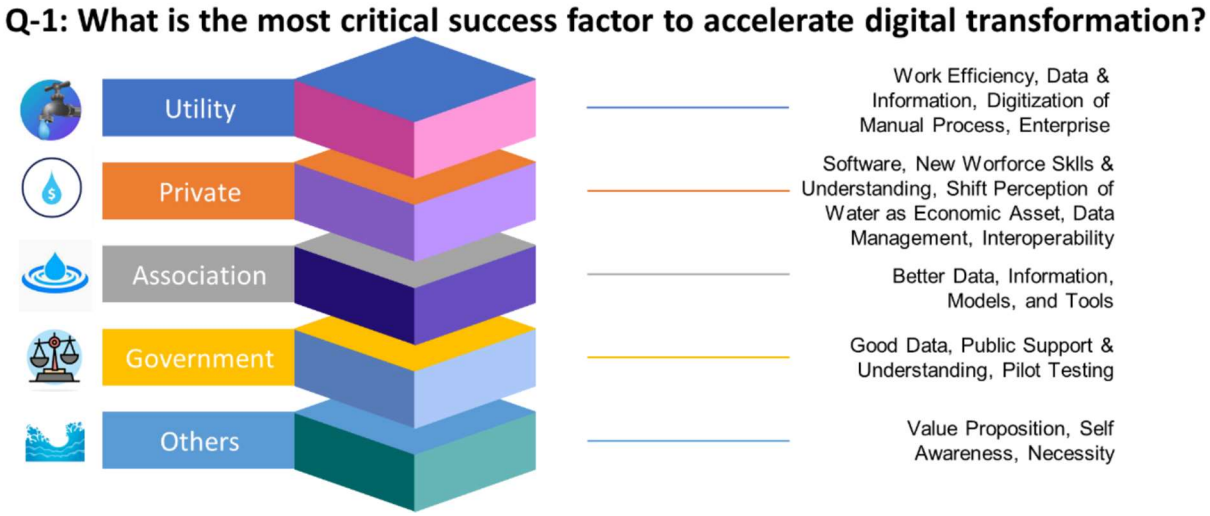

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Figure 39: Panel Session Question-2 Responses

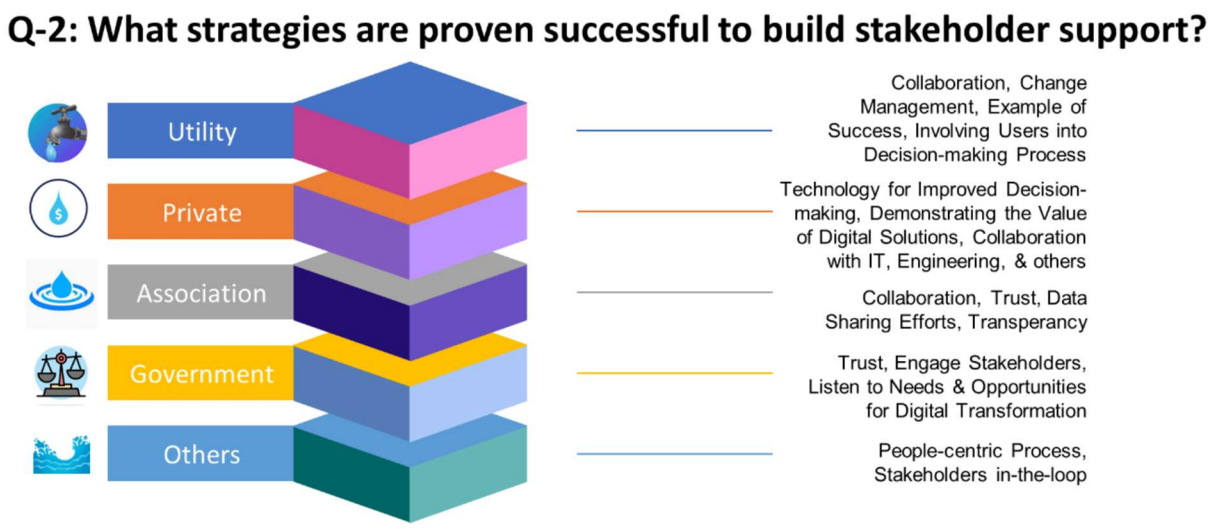

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Figure 40: Conference Panel Session Question-3 Responses

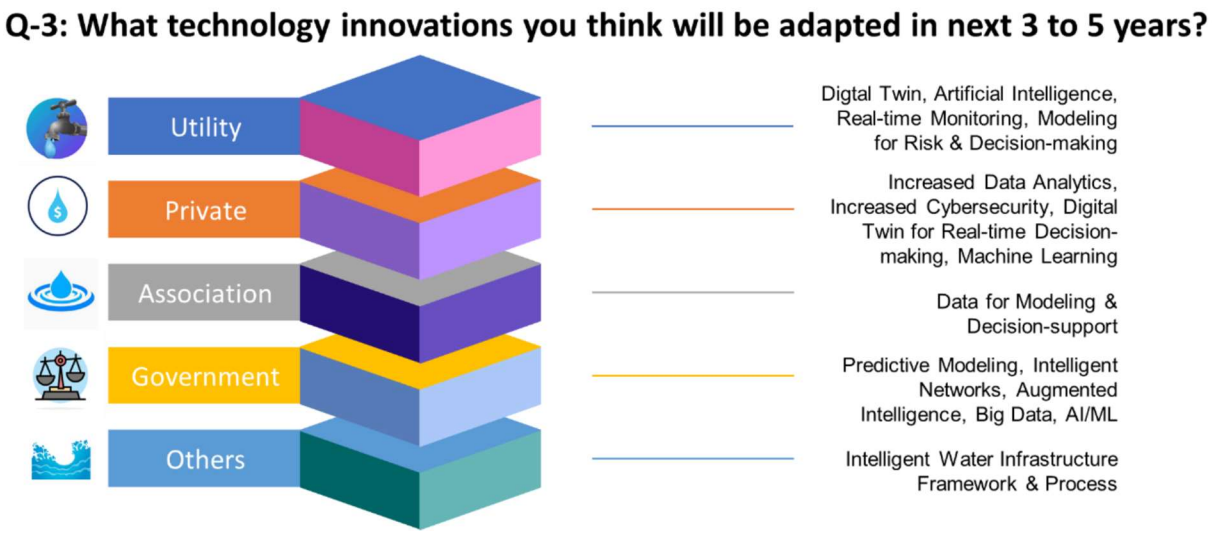

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Figure 41: Workshop Panel Session Overall Summary

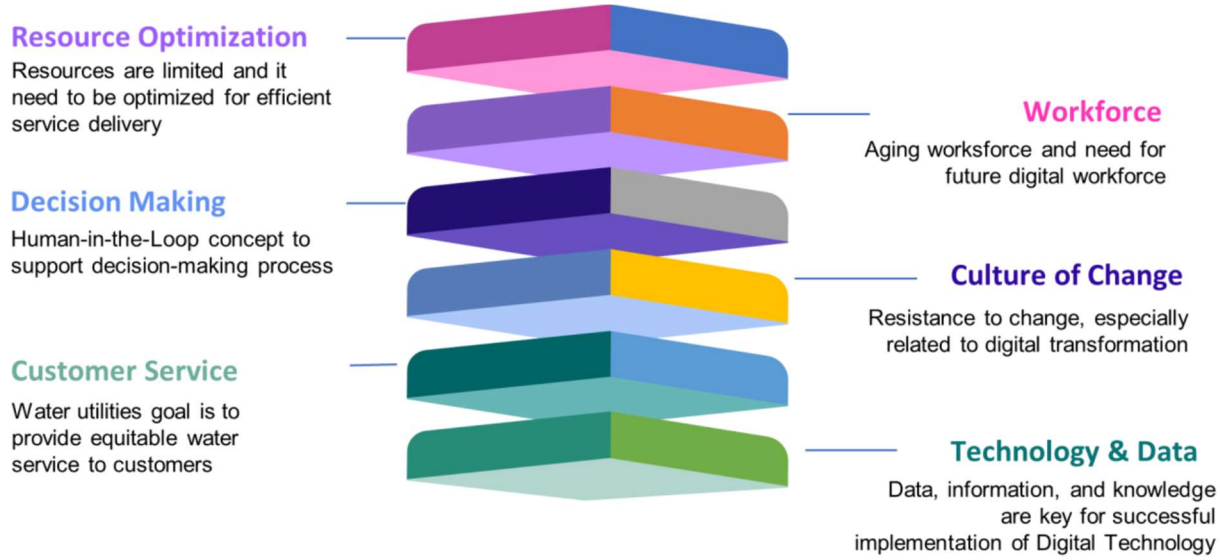

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Figure 42: Overall Outcomes from Conference and Workshop Panel-6 Session

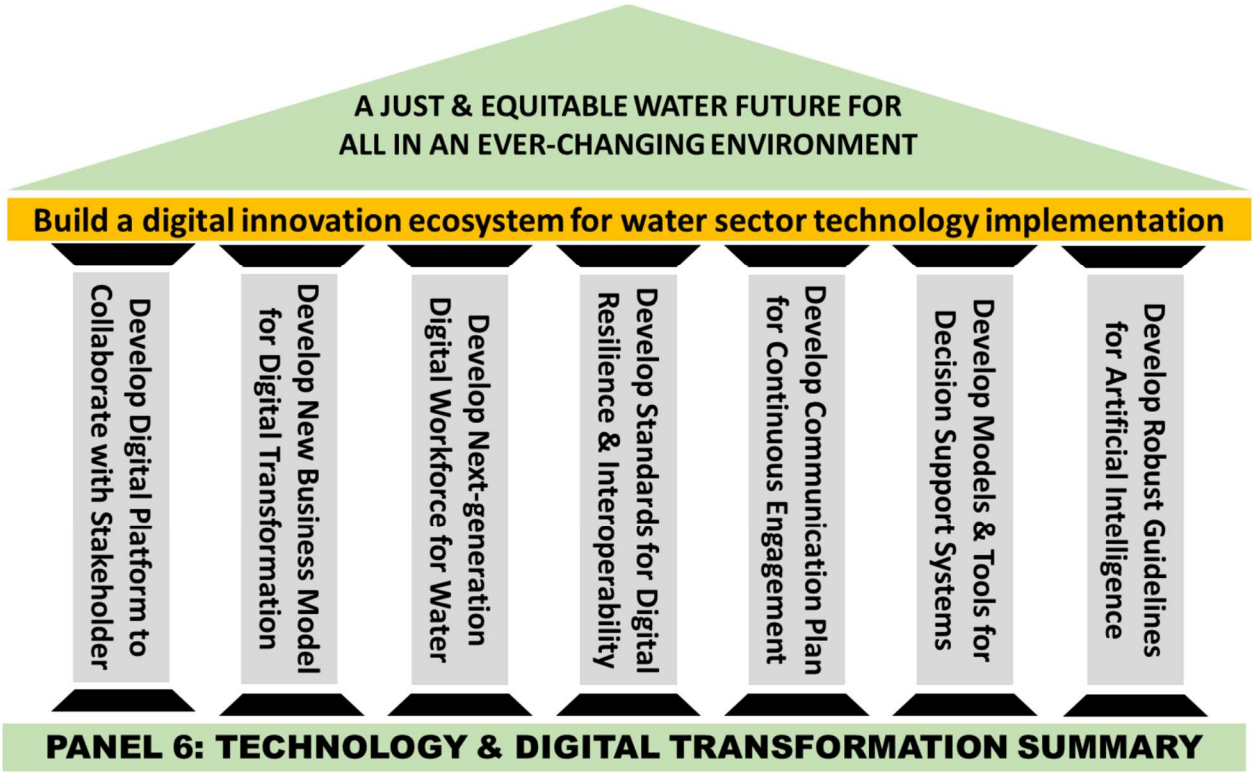

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Figure 43: Overall Outcomes from Conference and Workshop Sessions

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