Climate Resilience and Water Resources

A report on a Convergence Accelerator workshop convened by Indiana University and the IU Environmental Resilience Institute for the National Science Foundation under agreement ITE-2231916

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Executive Summary

Water sits at the nexus of every human activity, yet water resources are complicated, and water quantity and quality are not consistently distributed around the planet, causing water inequities. Because water needs are ubiquitous and pervasive, there are no one-size-fits-all answers. We need a whole-of-society approach to addressing water resilience. We convened a Convergence Accelerator Workshop over four days in October 2022 to bring sharper focus to existing research gaps in water resources. Activities included focused brainstorming and sharpening of ideas, resulting in high priority recommendations for the NSF Convergence Accelerator program of topics that could be addressed in 2–3-year research programs. The workshop participants identified several overarching priorities, including focused stakeholder engagement and co-development; environmental and social justice requirements; cross-agency cooperation; evaluating water as a human right; improving water literacy and trust building; and prioritizing Diversity, Equity, Inclusion, and Justice (DEIJ). The participants also identified several specific recommendations that could be rolled out rapidly and would have translational opportunities: identify opportunities for fit-for-use water; use system-of-systems approaches to water resilience; reduce pollution sources; focus on antibiotic resistance genes (ARGs); and develop frameworks for nimble, scale-aware governance. Of key importance is setting up a process that continues to involve more stakeholders and participants from a variety of sectors so that individual and community priorities can be incorporated and so solutions can be co-developed.

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1. Introduction

Water sits at the nexus of every human activity. Agriculture, power generation, transportation, public health, and industrial processes depend on consistent availability and quality of water resources. When these conditions are not met, significant disease, famine, and conflict can ensue. But water resources are complicated, and water quantity and quality are not consistently distributed around the planet, causing water inequities. These disparities are only getting worse with ongoing climate change, and any disproportionately felt effects are likely to be amplified. If we are going to improve resilience to climate change, we need to improve water-resource access, management, and equity. Because water needs are ubiquitous and pervasive, there are no one-size-fits-all answers. We need a whole-of-society approach to addressing water resilience, and we don't really know what that is yet.

The nature of this problem makes it well suited for the National Science Foundation's (NSF) Convergence Accelerator Program. This program is designed to disrupt the present funding model at NSF by providing mechanisms for collaboration across and within numerous sectors, including academia, industry, government, and stakeholders. Two key aspects of the Convergence Accelerator Program are (1) rapid transfer of ideas into world-changing solutions, and (2) translational opportunities for research to be incorporated into the private sector, or other means of transition to practice.

We convened a Convergence Accelerator Workshop to bring sharper focus to existing research gaps in water resources. This workshop brought together experts from academia, industry, government, society, and numerous other stakeholder communities to identify critical research gaps that may have been missed by previous narrowly focused efforts and to highlight high priority areas to be addressed in a further, larger program. A particular focus of the workshop was connections between the research community and extensive efforts on the operational side for maximum societal impact. We built a network of partnerships among a wide variety of stakeholders, especially beyond academia. One of the main purposes of the workshop was to identify strategies and effectiveness of different approaches to climate resilience and water resources that will have societal impact in the next few years.

2. Workshop Activities

The workshop was convened virtually over four sessions in October 2022 (Appendix A). The first session on October 13 was a two-hour Microlab, in which participants met each other, and several provocateurs set the stage for brainstorming activities. Subsequent four-hour sessions on October 17, 19, and 21 involved synthesizing the numerous ideas and discussions amongst the workshop participants into priority research areas and specific recommendations for NSF. A total of 44 participants (Appendix B) registered for the workshop, and many were able to participate the entire time, which enabled a deepening of the discussions.

Workshop organization was contracted through KnowInnovation, Inc., which has substantial experience with the Convergence Accelerator workshops and program. In addition to facilitating the workshop, they provided access to KIStorm, a proprietary software platform that provides numerous opportunities for knowledge capture. By using KIStorm, we were able to ensure that information discussed during the workshop was retained and organized, providing a ready source of information that is summarized in this report.

The workshop collaboration website opened a week prior to the Microlab so participants could complete their biographies and engage with the pre-work (Appendix C). The pre-work included options for a variety of participants and learning styles, with the goal of engendering thoughts about what some of the major challenges are in water resources. Participants were encouraged to capture these thoughts on the Challenge Wall (Appendix D), which continues to be available to all registrants.

The Microlab focused on presentations by the Provocateurs, Cody Smith and Anna Gemolas. Cody Smith is a graduate student at Indiana University who discussed principles of water governance, focusing on lessons learned from his experiences working with governments in Brazil. Anna Gemolas is Global Leader of Communications and Strategic Partnerships at DuPont Water Solutions who talked about strategies and technologies to optimize the circular nature of water in a sustainable, equitable way. Upon completion of these presentations, participants were split into breakout groups that were roughly organized by sector (academia, government, industry, etc.) to discuss their impressions of the Provocateur presentations and to capture additional issues on the Challenge Wall. After a short break, there was an additional presentation by Steve Burian, Professor at the University of Alabama, who is leading a large NOAA-funded consortium to improve forecasting of water-resource availability; the goal was to identify additional challenges posed by his work as well as to identify synergies between NOAA and NSF. After these presentations, participants returned to breakout groups with the theme of "We are all experts," that is, anyone in attendance could have easily given a talk to kick off the workshop. The goal was to identify what the participants identify as important challenges in this

space, and to capture those on the Challenge Wall. The Microlab concluded with a plenary discussion on the points that had emerged thus far, especially identifying things that are missing from the Challenge Wall or discussions thus far.

With the stage set by the Microlab, ***Session 1*** began with an introduction from Linda Molnar, a Program Director at NSF in the Convergence Accelerator Program. The next activities aimed at further filling out the Challenge Wall, alternating between breakout groups and report-outs in plenary. The first prompt focused on Future Challenges: **what does the status quo look like in the next 25 years if we don't do anything?** The second activity narrowed this discussion: **building on the previous discussions, what are the most important issues on a 3-year timescale?** By this point, the Challenge Wall had approximately 145 items (Appendix D), with some duplication when multiple participants had similar ideas. For the next activity, participants were asked to vote on the contents of the Challenge Wall. Each participant was given ten votes and were asked to identify the most important challenges in water resources, with a focus on the priorities of the Convergence Accelerator program: multidisciplinarity of the challenge, society-changing outcomes, and solutions that require diverse partnerships. After reviewing the outcomes of the voting process, we asked participants to return to breakout groups, followed by a report-out in plenary, to identify common themes or categories of challenges that appear to be emerging; they were asked to identify themes on a separate page in KIStorm. This activity concluded Session 1.

After Session 1 concluded, the organizers reviewed the contents of the Challenge Wall and the participant-identified themes. We identified six themes on which the participants would focus for the remainder of the workshop: ***agriculture, governance structures, infrastructure, water quality, natural hazards,[1] and water valuation and pricing*** Many of the proposed themes focused on efforts in diversity, equity, inclusion, and justice (DEIJ). Instead of making this a separate theme, the organizers opted to include DEIJ as an important aspect of every theme.

Upon arrival for ***Session 2***, participants were presented with the six themes and were asked to sign up for breakout groups, each focusing on one of the themes. Participants were given a Google Doc template (Appendices F through K) with the following prompts:

- What is the Theme?
- Who's in this working group?
- What are the key / prioritized challenges that should be addressed within this theme?
- What are the research questions that would be appropriate for these challenges? How might you articulate the research questions?

[1] The group working on Natural Hazards requested that this topic be changed to Water-Related Hazards as the interaction between natural, built, and social forces are essential to hazards framing. We noted this comment too late to announce the reframing during the workshop, so we have left the original topic name for consistency. Nevertheless, the discussions and recommendations provided by that group reflect a broader interpretation of hazard than was originally provided to the workshop participants.

- If we could solve these challenges, what would be the positive societal outcomes? Amongst other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.
- If we could solve these challenges, what might be the anticipated transformative scientific/technical outcomes? THINK BIG. What will be disruptive?
    - Direct impacts over the next 3 years
    - Subsequent impacts over next 10 years
- How will this meet the NSF acceleration criteria (discuss speed and scale)?
- What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
  OR, What is stopping us from realizing the future you envision?
  OR, What is needed to get us started?
- What expertise is needed?
- Why/How do these challenges meet the NSF convergence research criteria? Include: multi-disciplinary research that is not specific to any current NSF program. Translational research that addresses a challenge of national interest.
- Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? (particular emphasis outside academia highly suggested)
- What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? (This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation, etc.)
- How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.

Groups were given approximately two hours (including a break) to engage with this task. Following the breakout group activities, each group was asked to present their discussions in plenary. During and after each presentation, participants were asked to provide Builds (how could the information presented be enhanced) and Concerns (what are some potential obstacles). Participants had access to all Google Docs for all groups, so they could follow along however worked best for them. After the share-out concluded, participants returned to their breakout groups to incorporate the Builds and Concerns feedback into the Google Docs. We then concluded Session 2.

Session 3 began with another brief presentation from NSF (Linda Molnar) to encourage participants to think big. Participants then individually familiarized themselves with the contents of all the Google Docs, followed by returning to breakout groups with the goal of writing a short funding call for each research question (see Appendix E for a more detailed prompt that was provided to the participants). More specifically, participants were asked to address the following

questions:

- What is the research question? Please flesh out the research question a bit more.
- We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
- What is the roadmap toward societal impact?
- Who needs to be involved in this process, who is not in the room, and how do we engage them?

Participants were given approximately two hours to address these questions in breakout groups of their choosing (Appendices F through K); many participants chose to remain in their Session 2 breakout groups, and some chose to contribute to multiple groups. Following the work in breakout groups, participants were asked to share-out in plenary, including an opportunity to provide Builds and Concerns. Upon conclusion of this activity, the workshop concluded.

Participants were asked how they preferred to keep in touch after the conclusion of the workshop. The unanimous preference was email; IU has created an email list to engender further discussions and collaborations.

3. Workshop Outcomes

In this section we present the outcomes of the breakout groups, including a detailed discussion of the high priority problems that were identified, as well as roadmaps to their solutions. An important caveat is that because it is impossible to convene a workshop with everyone interested in water resources, the prioritization and discussions were shaped by who was in each breakout session. While the problems presented here are indeed high priority research questions and actionable, they do not represent a comprehensive picture of water issues.

Participants were asked to formulate their breakout group documents in the form of short funding calls that could be used by NSF in a future Request for Information. Some groups had more experience with this than others, resulting in somewhat varied formats. For the ones that did produce funding calls, the information presented in this section is essentially repeated verbatim, with some light copy-editing. For groups that provided more brainstorming-type responses, editing by the workshop organizers was more substantial. The raw output from the breakout groups is provided in Appendices F–K.

3.1. Agriculture

Four key issues were identified in the second session on agricultural water issues: water quantity (usage), water quality (fit-for-use), siloed research support at programmatic agencies, and a need for integrative research and engineering solutions.

Agriculture is one of the largest consumers of water in the USA. This represents both a water quantity issue and a water quality issue. Water quantity issues have driven many large infrastructure, governmental, and legal initiatives. A common theme is the understanding that the linear take-use-waste model of the anthropogenic water cycle is no longer tenable and that a circular water economy is necessary. A resilient circular water economy must balance water rights with equitable distribution of the costs and benefits of water to all human and “natural” stakeholders.

Intrinsic to a circular water economy is the recognition that efficient and equitable use of water must include a fit-for-purpose framework. Requiring potable water treatment for non-potable uses is an inefficient use of energy with attendant potential impact on GHG emissions and the water cycle. A fundamental part of fit-for-use is understanding of water quality. While the US has a long-standing water quantity sensing network through USGS, USDA, the National Weather Service, and other agencies, a comparable water quality network is a long way off.

In addition, the recognition that diversity, equity, and inclusion (DEI) comprise major environmental and health equity components necessitates a more equitable distribution of water to disadvantaged communities. While such issues have gained recognition in urban communities, in many instances the most impacted are populations in rural areas that are not served by community water systems (CWSs) or subject to regulatory oversight.

With this background, a convergent research initiative that crosses scientific, engineering, social/behavioral/economic science, and policy boundaries is necessary to address the major gaps in our ability to produce and manage fit-for-purpose resources in a circular agricultural water economy. It is recognized that such efforts will necessarily cross programmatic and science-driven agency boundaries. For that reason, our recommendation is that such a convergent Federal initiative be supported by multiple agencies in collaboration. We have identified the following research goals for such an initiative:

Contamination Prevention:

The best way to address water quality issues is to not allow water to be degraded in the first place. For that reason, we identify the following research foci in contamination prevention:

- ***Green chemistry for agriculture*** (not just consumer products and industry)
- Circular economies through ***waste valorization*** (energy recovery and feed stocks) with a strong focus on recovery of high-value nutrients (i.e., nitrogen, phosphorus)
- Identifying **environmental justice communities** in terms of water quality and reducing pathogen exposure in these communities
- Institutional controls incorporating ***data-driven decision science*** to better inform the public and other stakeholders
- ***Distributed source identification*** methods

Mitigation:

While prevention is preferred, improved infrastructure-integrated technologies and approaches for mitigating the risk to human and ecological health are needed, including understanding the interplay between air/water exchange. These include (but are not limited to) the following:

- Reactive/smart ***passive treatment infrastructure***
- ***Sensor networks*** integrated with water quantity assessment networks
- Big data processing of ***health effect endpoints***
- Better understanding of the ***impacts of agricultural contaminant mixtures*** on human and ecological health

Cross-cutting Research to Enable Implementation:

Research is needed to develop integrated approaches and technologies to identify, match, and align resources to achieve equitable distribution of fit-for-use water in a circular economy. Specific research foci include (but are not limited to) the following:

- Utilizing artificial intelligence (AI), machine learning (ML) modeling for ***data-driven decision making*** based on upstream information and risk
- Development of a ***national sensor-based monitoring network*** that can achieve specific chemical or health-based assays at low cost
- Incorporation of a ***Systems of Systems (SoS) approach***:
    - Recognize ***impacts on dependent systems*** of actions taken to ***identify unintended consequences***
    - Understanding how the complexity of ***agrochemical mixtures and interactions in both water and air impact human and ecological health***
    - Recognizing that a circular water economy has no "downstream", and that ***equitable distribution of the true life cycle costs*** must be maintained

3.2. Governance Structures

The working group on Governance Structures identified four high priority research questions, each addressing different aspects of governance:

- What are the water supply/quality implications of a transition to a carbon free future across all sectors (food, buildings, energy, transportation, materials)?
- Where do different degrees of community participation versus technocratic decisions make sense in water governance?
- At what scale should we govern? Do we centralize or decentralize? Does this vary geographically by water domain/region?
- How do we reevaluate Western water law philosophy and better incorporate alternative (indigenous frameworks, personhood status of rivers, decommodify water, etc.) approaches to how we value/view/relate to water?

The group posed three additional questions that they were not able to answer in the time allotted by the workshop:

- How do we incentivize coordination between institutions as they address water management?
- How do we encourage innovative solutions that accelerate political and institutional shifts regarding water management in a quickly changing climate?

- How do we determine data of authority to drive policy changes and consider how climate change has altered the representativeness of existing datasets?

What are the water supply/quality implications of a transition to a carbon free future across all sectors (food, buildings, energy, transportation, materials)?

As consensus builds towards the need for a global shift to carbon neutrality, various sectors are/will be evaluating how to accomplish this shift within their own operations. While carbon neutrality is a critical goal, these shifts may have considerable down and upstream impacts on water supply and quality, for instance the production and end-of-life management of EV batteries, compostable or reusable packaging materials, and energy production. Considering each specific sector, what are the most carbon intensive elements of that sector that are currently or in the future likely to be targeted for major shifts? Looking at those shifts, what new materials or processes may be involved, and where will they be concentrated spatially? What are the impacts on water quality and water supply of those new materials or processes: is it likely that the new processes/materials will result in more/less/different emissions? What are the water supply and quality oversights to regulate the new processes/materials? Are there geographic constraints to the new materials/processes, and if so, what are the key areas of concern regarding water management in those areas? How do these overall water quality/supply impacts compare to the status quo? How do we develop interventions that center environmental justice in the conversation about water quality and quantity? Are there alternative materials/processes that could be used that have less water supply/quality impacts? What tools can be developed to facilitate analysis of these water supply/quality impacts so that new processes/materials/technologies can be quickly and consistently assessed to guide policymaking, problem-solving, and investments? What tools can be developed to assess the carbon footprint of these water supply/quality impacts so that this may be a consideration in technology shifts and policymaking? Who is likely to benefit, industry-wise and community-wise from these transitions' impact on water supply and quality?

Many of the questions listed above highlight the gaps in knowledge to answer these questions. Partnerships are needed across sectors (food, energy, materials) to understand in depth the state of the industry and future direction, as well as the processes/technologies/materials themselves. New cross-cutting regulatory systems and their representatives will need to be present. Depending on the geographic specificity of potential new processes/materials, expertise may be needed on the local level to understand specific water-management challenges and concerns. Expertise is needed to build user-friendly analytical tools that can be used to communicate issues to policy makers, as well as across disciplines and areas of expertise. Tools and results that are user-friendly and also clear enough to be understood across various sectors/disciplines have a higher likelihood of adoption by practitioners as well as policymakers and can shift ongoing conversations about what processes/materials/technologies should be invested in broadly.

Building more permanent bridges and connections between these sectors (water, energy, food, etc.) can lead to better communication and collaboration.

This topic will need to involve experts in these other sectors, for instance academics, as well as industry and policy-makers who understand energy/food/materials systems at all levels: from those who deeply understand the processes and technologies and can identify water impacts across all stages of the life-cycle, to those who understand where investments are being made and why, to those who understand the direction that policy is going within those sectors.

Where do different degrees of community participation versus technocratic decision make sense in water governance?

Governance has traditionally been viewed as a top-down process by government "decision-makers" for communities. It has been more recently recognized that communities both have a right, from a procedural justice perspective, and have unique technical insights based on lived experience to inform how (water) systems should be governed most efficiently and from a distributional equity perspective.

Broadly, the shift to centering local needs and preferences in project planning ensures that later results of projects, such as multi-benefit outcomes, are most sought by community members who experience the landscape daily and intimately. Moreover, engaging communities in disadvantaged areas necessitates an understanding of the additional time required to engage individuals beyond a traditional infrastructure project cycle, from stages including but not limited to soliciting open-ended input, building rapport, maintaining relationships, sharing outcomes transparently, and including compensation for local consultations.

- How does the continuum from weak "consultation" to co-design of policies, programs and plans map onto water-governance domains?
- Where is community voice less and more essential in water-governance contexts? Where should we not place undue pressure on communities to contribute their time and knowledge (where compensation is not feasible)?
- Where is it more and less feasible and what are the barriers to inclusion?
- What are grounded examples of real success, nominal inclusion, and complete roadblocks?
- What tools and data could be created to facilitate community participation on an equal footing to water practitioners and in what steps of decision making should these be applied?

We will likely need to draw on just emerged coalitions focused on environmental justice procedures (the Justice40 Initiative;

https://www.whitehouse.gov/environmentaljustice/justice40/) and water equity nationally, as well as existing international networks of Community Based Organizers (CBOs) focused on sub-domains of water equity, as well as more broadly on "greening" (traditional environmental justice concerns) and new coalitions focused on climate. We need these groups to come together with major agencies that govern water domains in a new, transparent, and enduring way to see the most success.

There are several key components of a roadmap toward societal impact. First, there is need for an analysis of implementable inclusion pathways of community voice in different domains of water governance which ranges across the typology in the engagement literature from weak "consultation" to co-design of policies, programs, and plans. This should include case studies with operational details and demonstrated outcomes. Moreover, a realistic assessment of where the tradeoffs in efficacy and practical realities of including community voice depend on the scale, technical nature, and timing of decision-making, i.e., where is community voice less and more essential in water-governance contexts? Where is it more and less feasible and what are the barriers to inclusion? This research agenda then needs to be implemented with numerous parties on a 5–10-year time frame with meaningful baseline commitments by agencies regarding metrics, and then 5 year or so iterative evaluations on progress.

In this case, we first need to involve a range of community types, from highly privileged to highly-disadvantaged (with an emphasis on the latter) community members and representative CBOs, including from different political contexts. We need to compensate these individuals and groups for their time and ensure them upfront that this research process is not simply about consultation. We also need to have representatives from public agencies, both high-level "decision-makers" as well as staff-level individuals who set and mediate how public engagement rules are implemented. These folks need to be willing to talk about ways of doing and be open to instituting new formal rules that facilitate more robust community voice and informal norms. Finally, we need community engagement scholars and institutional governance (probably legal) scholars present in this conversation, to both help mediate it, as well as to help design and evaluate new inclusionary governance forms going forward.

At what scale should we govern? Do we centralize or decentralize? Does this vary geographically by water domain/region?

Water is a flow entity which in many ways does not respect jurisdictional (socio-political) boundaries and needs to be managed at different scales and across those boundaries. Yet the literature on over-fragmentation and proliferation of governance structures, and the channelization of water for human purposes well documents how management has led to adverse environmental, economic and equity purposes.

The broadest question is how do we toggle between "One Water" approaches and the existing fragmented paradigms? Sub-questions start with:

- How are the traditional domains of water governance (drinking, waste, storm; ground versus surface, point source/stock versus flow; utility versus agriculture, etc) and at what scale are they implemented most rigorously? How well do they comparatively work?
- How does geography and broader political-economic regimes of governance affect the structure of water governance more specifically?
- What does the reality of "One Water" apart from settler-colonial ways of managing it suggest as low-hanging fruit for returning water governance to more respectful and sustainable forms? How does new technology fit into to support One Water (water recycling, better understanding via remote sensing of sub-surface flows)?
- Where does "One Water" fall short recognizing the constraints and path dependence of existing water-governance structures? (i.e., what should not try to unify?)
- How can we get beyond endless "centralize versus decentralize" debates in sub-domains of water governance, or should we just ignore them?

This topic needs truly interdisciplinary scholars who will think and act across boundaries constructively. Siloed scholars are likely to obstruct progress. It also needs to involve politicians who can create wholly new agencies, ways of governing, or inter-agency coordination. Non-profits and Foundations will be critical partners, in that they can invest meaningful resources in governance proposals that can work their way into the political process (see Sustainable Groundwater Management Act in California). And finally, Indigenous communities have not been in the room to have space to present their methods and understandings, rather than reacting to others in a room.

This idea could also benefit from evaluating the applicability of other governance models, such as adaptive governance and polycentric governance. Moreover, some settings may be more suitable for different models; as an example, private well owners may not want oversight.

How do we reevaluate Western water law philosophy and better incorporate alternative (indigenous frameworks, personhood status of rivers, decommodify water, etc.) approaches to how we value/view/relate to water?

Many of the past and ongoing issues with water management are at least partially due to the way in which water is viewed as a commodity, something to be controlled purely for human use in the short term, and managed/priced according to rules of supply and demand similarly to other resources, as well as relying on individual decision-making and fragmented governance rather than a more holistic view of the myriad ways in which water touches society. We are growing toward a better, albeit incomplete understanding of alternative ways to view and relate to water, for instance Indigenous perspectives, in which water is viewed more holistically, in some

perspectives as an entity possessing its own rights, rather than as a "resource." Rethinking our relationship to water and how we view it may spark more creative and innovative approaches to how we manage water systems and ensure adequate, clean, accessible, and affordable water for both the needs of people and nature.

Embedded in this topic are sub-questions:

- What are the underlying assumptions, values, legal principles that drive our current approach to water management?
- How do these differ from assumptions, values, and principles in other cultures, especially those indigenous to the geography being studied?
- If we adopted these differing approaches/perspectives, how might they impact current water systems and approaches to management,and equity and ecosystem health?
- What can we incorporate into our management practices, and what would be an equitable way of evaluating these questions and incorporating knowledge?
- How do we ensure that Native knowledge and expertise is valued and incorporated into processes as well as end outcomes?

This research could lead to better outcomes in terms of long-term sustainability of our water, more thoughtful approaches that avoid problems and impacts proactively rather than waiting to fix them after they've happened, and potentially (if done correctly and in an inclusive and respectful manner) address long-standing equity issues as well as past harms done to Native/Indigenous communities through historic mistreatment as well as ongoing erasure/lack of visibility of their culture. Addressing this topic will necessarily require involvement of Native/Indigenous experts, as well as social scientists with expertise on how water is viewed/managed in other countries/cultures. With Native/Indigenous experts in particular, we need to build in fair compensation, pathways to at least some degree of "water back," as well as ensuring that interactions are carried out in a culturally competent way that recognizes historical relationships and harms and avoids processes that feel extractive and one-sided.

3.3. Infrastructure

The Infrastructure working group focused their efforts on two categories of research questions dealing with smart systems/data and prioritizing investments.

Smart systems/data

How can the adoption of smart systems modernize and optimize our national water infrastructure to increase capacity, decrease cost, and increase sustainability? How can data models be used in

water management and which technologies best enable this data-driven water infrastructure, integrating the human response (smart systems include monitoring, networks, sensors, AI, automation, real-time data-based decision making)?

Innovation in this space is rapidly moving and is mature enough to now benefit our water infrastructure with less risk than early adopters. Gains can be quickly realized by focusing on this area. Nevertheless, there is much disparate work going on in this space, but no one group is connecting all of the projects. We need to connect the dots and tie the pieces together as a "system" that can be replicated and scaled, affordably. There is also a big gap in environmental justice, and there is an opportunity to optimize for all communities, not just infrastructure that is dependent upon the ability to invest. Addressing this will also require a discussion of system affordability and diversity of business models, as well as community engagement.

Success in this area will have enormous societal impact, including increases in water quality and quantity, equitable access to water, reduced cost, increased communication about water-related issues, and transparency with consumers. To achieve success, we will need to involve numerous partners, all of whom are working on water but not as coordinated as is needed. This includes the Tech Community (Amazon Web Services, Google, Microsoft), NGOs (Water.org, Charity: Water), Government Agencies (e.g., EPA, NASA, NOAA, USGS, USDA), and the Water Resilience Coalition (industrial partners).

Prioritizing investments

How do we better prioritize investments in our water infrastructure for modernization, capacity expansion, and climate resilience (in the face of uncertainty to the future)? How do we do it in a way that is equitable, engages the community, and enables fit-for-purpose water?

This question is very timely. There is an influx of infrastructure funding across the United States, and we need to ensure that funding is used appropriately, with a lens to the future, and properly accounting for areas of uncertainty. There is currently no vision or model of modern water infrastructure that takes a holistic view of all of the stakeholders who influence the water infrastructure. We are struggling to bring the right groups together at diverse scales and across diverse sectors. This topic is very aligned to work on governance of water. Through the right investments in the modernization of our water infrastructure, there is a path toward optimizing our water so that all people have daily, equitable access to safe and affordable water and all industries have enough water to produce the products, services and food on which society relies. This will involve maximizing our investment, from taxes to water consumers, in the best areas to make the system more resilient and sustainable (and figuring out what it means to maximize our investment in the best areas). This will require various partners across a variety of sectors, including water utilities, water investors, water innovators, NGOs, large industrial water users,

and experts studying optimization (e.g., the Economist Water Optimization Index or a global water expert panel) There also needs to be attention to existing governance structures and economic/political structures. For example, there are approximately 40 million private well users in the United States, and that infrastructure is privately held, so it may not make sense to have centralized piped water supply in low population areas; such topics need to be evaluated, and as a prerequisite, we need to have the right people involved in discussions who can bring up issues like this.

3.4. Water Quality

The water quality working group focused on contaminants: How do we prevent them from getting into the water supply, and once they are in the water supply, how do we deal with them? An important aspect of the discussions throughout this topic (and others) is fit-for-use water: some contaminants may be problematic in some water streams and not in others.

Some of these contaminants include microbial pathogens, geogenic sources in groundwater (like arsenic or uranium), sources from water supply infrastructure (e.g., lead), emerging contaminants (PFAS, pharmaceuticals, microplastics), nutrients from agricultural runoff, and algal toxins. There was a specific callout to include genetic elements, such as antibiotic resistance genes (ARGs), as water contaminants; this is a vastly understudied area and touches on the critical societal need of effective antibiotic development and maintenance.

First, how could surface and groundwater pollution be reduced? Barriers to this topic include a variety of factors, such as precedent (some pollutants or pollution levels are historically allowed), insufficient regulations, and a lack of data. Regarding the data aspect, measurements are spatially heterogeneous, and even in areas that are measured, there has often been a focus on key nutrients or select chemicals rather than a more holistic approach that would focus on the end users. To address this problem, there needs to be a pervasive network of water quality sensors and data dissemination/analysis for decision making. This will require a wide variety of partners, including academic, industry, technology, and end users. Accomplishing this will improve transparency and information dissemination. Also, preventing pollution in the first place will require engagement with farmers, cooperative extensions, and other sources to incorporate land management practices and, if necessary, enforcement.[2] This network of participants will be necessary in selecting sites for water quality monitoring, as it will be impossible to instrument the entire water network.

[2] Farmers generally do not want to be sources of pollution. To a large degree, nutrient pollution in agricultural runoff is because there is a lack of precision agriculture determining the nutrient needs of crops, so farmers often over-fertilize, which is essentially wasted money (they do not want to pay for fertilizer that just ends up in the waterways).

The next topic focused on drinking water, which has some of the highest quality requirements. More specifically, the group asked, what are the barriers to access to high quality drinking water for all? The answers to this question are numerous: aging infrastructure or, in some cases, lack of infrastructure; lack of testing to understand whether drinking water is meeting quality standards, affordability of infrastructure (piping, treatment), appropriately set standards (or other examples of plans and policies that are not informed by data), data siloing and accessibility/transparency (including the data used in making pricing decisions), inequity in resource distribution, risk perception, a slow/inflexible regulatory process or a lack of regulatory levers in general (e.g., issues that originate from on-premise plumbing where property owners may not have incentives to test/address the problem), the transient nature of acute contamination events (especially if there are gaps in monitoring), and large point sources (e.g., agriculture or industrial discharge). Addressing these numerous issues will require partnerships between consumers (especially communities that are marginalized), government at all levels, industry (both from a pollution source standpoint and from a monitoring/treatment technology development standpoint), and water utilities (especially regarding data availability and transparency). Additionally, involving schools and science museums in understanding water quality issues will make a better-informed consumer base that can be aware of issues in drinking water and, possibly, help address those issues. This latter point will also address issues of trust (both rational and misguided) that are not covered by a conception that is limited to information deficit.

3.5. Natural Hazards

Question 1: How can complex systems-based approaches address multi-faceted, compound, and cascading water-related hazards/disasters?

The very essence of complex hazards are their multifaceted interactions and potential cascading impacts that can trigger additional hazards and their consequences. Given the ubiquity of water and how essential it is, there are few sectors or social entities unaffected in a place experiencing a water-related hazard event. For example, climate change may bring extreme precipitation events causing flooding in headwaters. These waters may overwhelm aging dam infrastructure posing risk of dam failure (and downstream dam failure) and leading to intense downstream vulnerability to critical infrastructure, ecosystems, and populations. Additionally, there may be impacts felt far beyond inundation zones along networks related to water use, supply changes, power grids, etc.

This research question on complex, compound water-related hazards calls for research that

bridges disciplines related to water-related hazards using systems approaches to better understand the linkages across sub-systems and new innovative approaches to manage this complexity and move from states of vulnerability to greater resilience. Beyond scientific domains, it is essential to engage beyond science to professional and local entities and expertise to inform collaborative problem identification, integrated and co-designed and co-implemented research to address compound hazards most directly. Moving beyond theoretical approaches to place-based and real-world hazard contexts is essential for convergent research. By conceptualizing hazards through to the consequence of an event for vulnerable infrastructure, ecosystems, and populations, a diverse array of research stakeholders can be identified along with clearly identifying key societal outcomes. A nexus of scientific (earth science, hydrology, engineering, social, etc.), professional (i.e., emergency/hazard managers, critical infrastructure managers), and representatives of vulnerable ecosystems and populations related to compound, nested, or cascading hazards is needed. The difficult part is to avoid an unwieldy number of participants. Addressing barriers to participation such as jargon, timing, resources, etc. are key to attracting key individuals and entities into the research space. Innovative approaches such as citizen science, stakeholder assessments and analysis, and community-based research can help to bring in diverse perspectives along the research timeline. It is key to bring the diverse array of research specialists together early in the process to help form a cohesive articulation of research goals and problem framing. Advanced geospatial techniques will be crucial for capturing complex linkages and integrating data. By involving diverse and place-based stakeholders involved in hazard mitigation and event response and recovery, this research can provide critical information and roadmaps for reducing social, ecosystem, and infrastructural vulnerabilities.

Question 2: What innovative strategies are useful for addressing post-disaster societal well-being, livelihoods, and water management?

Post-disaster management is a key process, which requires innovative measures in the way hazard-induced damages to human and natural systems are addressed. It is, therefore, important to identify or develop innovative tools that could be used to better assist in the way peoples, their livelihood and wellbeing, water resources, and other natural systems are managed especially in the aftermath of a weather or climate hazard, which often could have significant impacts on both human and natural system across the globe. Anthropogenic greenhouse gas emissions continue to rise, which is likely to increase the risk of severe weather and climate hazards across the world. It is, therefore, imperative to better our understanding of how this risk will manifest and impact human and natural systems in most parts of the world, especially in regions - mostly in the developing world - that are the most vulnerable to the impacts of climate change with less adaptive resources. Understanding how this risk is changing and will continue to change in the future is important in inducing preparedness and designing innovative adaptation strategies, which could assist in alleviating post-disaster management.

The focus here is to assess how the risk of water-related weather and climate extremes under anthropogenic forcings has changed and will continue to change in the future. Also it is important to address some of the critical knowledge gaps related to post-disaster management, water resource management through the evaluation and testing of existing post-disaster management tools/strategies in the context of climate change - testing their limits under anthropogenic influences in the present and future climate conditions. It is important to improve these tools/strategies when possible and suggest and test new ones.

Being able to clearly articulate the following is crucial:

1. Who are the end users (beneficiaries)?
2. Where is the most need of such tools (Developing world and/or marginalized regions across the developed world)?
3. Why is such action required?

It is crucial to adopt an interdisciplinary and/or transdisciplinary approach here by assessing climate change risks from the perspective of both those working in the risk-management sector, early warning systems, other related sectors by developing collaborative research with those in practice (e.g., insurance sector, post-disaster management organizations, etc.). Establishing advisory boards and research partners in these sectors early and often in the research process is key to engagement and meaningful collaboration.

Question 3: How can the lack of local observational data be accounted for when examining local and/or high-resolution detail on the relationships between natural hazards, water resources, and their impacts?

While there are vast data sources related to water resources as well as characterizations of ecosystems and populations at risk to water-related hazards, these datasets are often plagued by problems related to scale, data resolution, units of analysis, and vague or conflicting data goals and purposes.

There is a need to expand integrated data management, analysis, and visualization related to water resources and connections across hazards, sectors, and vulnerabilities, particularly at local scales. This effort will require relationships and partnerships with locally focused entities who produce and maintain high-resolution data relevant to water resources and local-to-regional contexts. Often, local governmental and non-governmental entities have place-based data collections that are not connected with large spatial or temporal data systems. Combining interdisciplinary teams of water scientists with place-based experts with local to regional professional knowledge, new platforms can be created to integrate multi-scale data and to identify critical gaps needed to advance time-sensitive research and to protect vulnerable communities and locations. Attention to high-resolution and place-based data can help to

ground-truth macro-level data and evaluate the accuracy of predictions based on lower-resolution data.

Information/data management experts and those with cyberinfrastructure expertise are essential to this endeavor, as are those with technical communication skills to ensure that platforms and data sources are accessible and usable to those who need them most for hazard mitigation, preparedness, and event response and recovery. Co-produced research on the integration of local and high-resolution data related to water resources and their broader contexts is essential and is predicated on the early and consistent interactions among all key entities. These pathways ensure multifaceted and targeted flows toward societal benefits, vulnerability reduction and enhanced resilience.

3.6. Water Valuation and Pricing

Topic 1: Develop a new valuation methodology for water

Determine whether a water-credit scheme like carbon can lead to the ability to trade within a water market yielding investment dollars for water projects. Any carbon valuation might include contemporaneously a water valuation, costs and savings on a fully-loaded basis. Water valuation should consider long-term costs (e.g., water degradation, future infrastructure) and long-term benefits (e.g., quality enhancement) should be taken into consideration by rate-setters. If you can quantify savings, you can incentivize others (e.g., foundations) to pay for outcomes based on those savings. Water utility personnel, politicians, and regulators are missing a full toolbox in valuing water. Local water valuation does not currently include the full lifespan of the utility or the consequences of degradation of quality or depletion of supply (i.e., good water is worth more than bad water; avoiding water degradation and averting associated future infrastructure is more valuable than not anticipating the degradation).

Once water can be fully valued, there is an opportunity for financial innovators to create tradable securities or derivatives based on specified outcomes. These may initially be supported with soft money, non-financial return seeking funds, from foundations that seek societal improvement over financial return. Utilities and others who have water can more properly value good potable water at a higher value if it lacks contaminants and potentially borrow against an enhanced value of assets. Accounting downgrades for less valuable water would encourage spending to bring the asset values up.

A research call should require proposers to outline how they would scale local water valuation up to a global water market. In addition, how they would attempt to replicate a carbon-market approach to water based on quantity and quality. Such a market would include exploration of

financing for projects that can integrate water credits into the transaction structure. A time-scaling approach, in addition to magnitude-scaling, would be needed as project companies and investors would get more comfortable valuing cash flow from water credits as the market for water credits matures. The proposal should include an exploration of how technical assistance grants can enhance the water sustainability and impact of financed transactions looking strategically, not just at one-off transactions. Knowledge gaps in this sector are among and between local water utilities and their stewardship of regional water supplies, as well as the connection of local water management to national and international sectors that intersect with water. A funding call would require an inquiry into the various ways in which water usage, stewardship and protection (against contamination) is embedded in the direct and indirect value chain of a project.

Positive societal impact follows from the research team identifying the connections between sectors and builds a road map to scale and aggregate solutions by creating toolboxes/dashboards for multiple variables to be assessed by stakeholders (utilities, investors), resulting in the ability to value water and establish tiered pricing systems designed with equity and water as a human right in mind. A proposal team would ideally include local utilities (or regulators familiar with setting water pricing rates using existing considerations), water scientists, environmental regulators, financiers, actuaries, infrastructure experts or engineers, economists, and other communities that can contribute to all facets of water valuation (e.g., indigenous communities). An important part of the proposal review would be an assessment of the constitution of the research team and the way and timing that the team would integrate stakeholders and the level of collaboration proposed with those stakeholders and practitioners.

Topic 2: Development of tools for promotion of water literacy

This would be akin to financial or ecological literacy. Water literacy is needed at different scales and is directly related to stewardship and valuation. The premise is that only with water literacy as a condition could water markets be equitable - otherwise it would be yet another imposed and opaque system where public engagement would be very limited. How can we help governments provide carrots to states, businesses and individuals to value husbandry of water? Tax systems, performance payments, staggered pricing for excessive users, weighted financial benefits for water users to use less quantity -speaks to adoption of water saving locally.

A proposal should include an initiative to develop a living case study for business schools and universities. Topics to work through would be how to avert likely corruption that could be a key challenge in the sort of market where this approach would be likely to be trialed. Any proposal needs to consider governance mechanisms including recommendations on how engagement of entities that currently verify (and certify) carbon, auditing firms and accounting standards boards and organizations might assist in oversight. These entities might assist to create a braking

mechanism (possibly through the verification process) for when and where the reviews showed pinch points or abuses. The proposal should address the optimal methodology for disseminating the learning/lessons and address how ideas might be spread between similar initiatives. The proposal should also address the deliverables and the timing of dissemination of the knowledge to the public. As an example, the proposal should address the timing of the development of the priority water valuation tools with a sense of the urgency of the work so that the results may be shared publicly as soon as practicable to encourage building on the knowledge with a broader range of input.

4. Recommendations for the Convergence Accelerator Program

Based on the discussions at the workshop, we have identified several recommendations for the Convergence Accelerator Program related to convergence research on water resources.

Guiding principles

The following points are guiding principles for Convergence Accelerator funded projects that focus on water resources. NSF has long encouraged many of these points, but the workshop participants specifically wanted them to be pointed out. **Programs focusing on water resources will not be effective if these are omitted.** In some cases, despite substantial NSF work on the points below, participants still believed that more work was needed, perhaps representing a fundamental disconnect that will require specific attention.

1. ***Enable stakeholder engagement and co-development at all stages of the Convergence Accelerator process.*** Many participants noted that relevant stakeholders did not participate in the workshop. As a ready example, agriculture was identified as "the elephant in the room" and is responsible for (on average) 70% of water usage worldwide, but there were no farmers at the workshop, largely because farmers are busy harvesting in October (when the Convergence Accelerator workshops were taking place) and cannot take a week off. Similarly, many potential participants working in Indigenous programs were unable to participate in the workshop because they are already stretched too thin. Indeed, very few non-academic participants have the available time to devote to a workshop, let alone a 3-year research project.

2. ***Reinforce environmental and social justice practices.*** Throughout the workshop, recurring environmental and social justice themes kept emerging across all the topical themes and involving many the workshop participants. These discussions were in-depth explorations of equity that concluded that targeted research should be within or applied to geographies that would benefit from interdisciplinary problem solving. Key to these ideas was the necessity of co-production, which is a core tenet of the CA program: stakeholder involvement throughout the entire lifespan of a project, including planning, methods, and implementation.

   A key feature of co-production is that subcontracts or community collaborations be compensatory, i.e., not expecting community engagement to be voluntary or used as an in-kind contribution. In the spirit of a growing literature on decolonizing research

methods, researchers no longer find it acceptable to identify local partners or stakeholders after funding has been awarded or to consume resources from local project participants, including their time. Nevertheless, budgetary restrictions and standard ways of doing business often cause roadblocks to progress in this area. Suggestions from workshop participants included modifying some of the "business as usual" indirect-cost recovery (ICR) models embedded in federal and university grant agreements by negotiating lower rates for educational institutions and using those offsets to compensate local stakeholders or collaborators. Additional ideas included packaging research results for transparency, benefit, and (for example) ongoing use of the subject community using dashboards or interactive maps.

3. ***Incorporate cross-agency opportunities.*** When identifying initial concerns across all themes, workshop participants identified cross-agency cooperation as an aspirational goal that is currently obstructed by siloed organizational structures, particularly at the state and federal levels. There were more examples of inaction or harm that had been encountered by the lack of collaboration, data access, and database schema crosswalks than there were proposals for solutions. Of the six main water-resiliency themes identified by the group, topics involving agriculture garnered the most votes in an initial ranking exercise. When breakout groups were self-selected by the group, there were initially no participants that volunteered to work on the agriculture issues. When the organizers inquired, the participants stated that agriculture is a USDA issue and NSF would never fund research on those topics. Yet the Convergence Accelerator program has specific tracks for interagency (Track G) and international (Track I) collaboration. The number of examples provided and the perceived intractability of the problem suggests a fundamental disconnect between the existing program structure and potential investigators.

4. ***Water as a human right.*** Another cross-theme topic that emerged throughout the workshop was the concept, or tenet, of the Human Right to Water and Sanitation (U.N. General Assembly Resolution 64/292, 2010). This tenet served as a catalyzing objective at the far end of discussions of technologies or debates about structures and systems, a goal that unified the participants. For example, access to water for individuals in small communities (i.e., rural, Indigenous, off-grid) was recognized as dominantly self-supplied (“distributional inequities”) and likely exposed to sustainability and resiliency concerns in the face of climate change. Solutions modeled on off-grid utility models for water supply or implementing other decentralized solutions such as community septic systems were discussed. Transparency concerning water quality via publicly accessible dashboards was proposed as a mechanism to fulfill a right-to-know ethos for all human water consumers.

Equity issues in all themes were articulated through a refinement of the tenet: (Clean) Water as a human right, *regardless of ability to pay*. Numerous discussions were peppered throughout the workshop with existing templates such as the Philadelphia, PA Tiered Assistance Program (TAP) for water utility customers; brainstorming on how to fund "pay what you can" water-pricing structures; noting the inequities that result from dysfunctional governmental agency silos; and appropriate pricing with many examples of what the participants considered too-cheap pricing (especially for large water users) to provide sustainable clean water into the future.

While this topic may be outside of the remit for NSF, we provide it as a guiding principle. Projects that do not fundamentally value water as a human right are not conducting effective research to solve water resource problems.

5. ***Data management to support improved water literacy and to build trust.*** Despite water being essential for all of humanity in a variety of ways, decisions about water are often opaque and are not necessarily data driven. Data can be sparse, especially in areas where it is needed; for example, not all species relevant for human health are measured, and not all areas (especially regions with marginalized communities) are monitored carefully, which can make decisions seem arbitrary. Data that are collected are not always accessible by all the relevant stakeholders, which concentrates decision-making power inequitably, eroding trust. A national sensor-based monitoring network, augmented by smart systems/artificial intelligence to make sense of the complexity of the system's behavior, with automatic dissemination of data, would enable a water-literate populace, and hence decision making can become more transparent and more equitable. Because everyone has a right to sufficient quantity and quality of water, governance of water needs to prioritize equitable decision making, and transparency is a tenet of good governance. If everyone has access to the same data, it's much easier to see how people are using that information to make decisions. We argue that Data Management plans included in CA proposals should go beyond storage and usability for the lifetime of the project and beyond. Instead, the plans should discuss how the data generated by the project fits into a national data network with the overall goal of an informed public and decision support.

6. ***Specify the role of Diversity, Equity, Inclusion, and Justice (DEIJ).*** DEIJ is increasingly a focus across all research endeavors, especially in the US federal landscape. Not only does DEIJ focus on rectifying marginalization, but it is also a way of doing better research. There are numerous examples in a wide variety of fields that demonstrate inclusion can lead to new insights and help avoid erroneous lines of inquiry or erroneous conclusions. Water is a prime example of both advantages, given its ubiquitous need. While federal funding has a DEIJ requirement, we argue that the CA

program must maintain its greater emphasis on DEIJ due to the cross-cutting, inclusive nature of the research.

Topical high-priority research recommendations

The following points are high-priority water resource research recommendations that stemmed from the workshop discussions. These were identified by the participants as research directions that could be accomplished in a three-year Convergence Accelerator funded program. Details are provided in Appendices E–K, specifically the Session 3 activities.

1. ***Identify opportunities for fit-for-use water.*** There is a massive amount of waste in the current water economy. In the US, much of the water that is used is treated to drinking water quality standards, which requires large infrastructure (exacerbating inequality because only communities that can afford the infrastructure will have it) and contributes to environmental pollution (including climate change, as water treatment requires power, much of which is fossil fuel-based). If water is ultimately going to be incorporated into a circular economy (as is called for in many conservation efforts), there will no longer be a "downstream" or transferred costs (e.g., emitting pollutants into the environment because it is expensive to capture them). The true life cycle costs of water must be properly assessed and distributed equitably across the economy.

2. ***System-of-systems approaches.*** Effects can cascade across time, scales, and sectors. Investments today will face risks posed by climate change, so water infrastructure needs to be updated in a climate-resilient way. The Gulf of Mexico anoxic zone is caused by agricultural runoff across the Midwest. Water use by power plants affects drinking water supply. There are numerous other examples of this interconnectedness of the water landscape. Complex systems approaches to studying this problem are necessary to capture emergent behaviors and feedbacks between sectors, as well as to predict the potential for cascading failures. This is especially true for a system that is changing as rapidly as the water sector is, both in terms of human development and environmental changes.

3. ***Reducing pollution sources.*** Environmental pollution is, in many cases, easier to prevent than to clean up after the fact. This topic also ties in with the idea of a circular economy to reduce waste: if byproducts of industrial processes or high-value nutrients from agricultural runoff can instead be recycled or repurposed, preventing pollution can result in economic gains. Moreover, technology development for more environmentally friendly solutions (e.g., green chemistry for agriculture) can reduce environmental pollution, at least make it less toxic, and potentially be merged into a capture and re-use technology. This latter is best illustrated by the case of excess phosphorus in the waste stream, where it is a pollutant and contaminates waterways whereas it is a critical limited

nutrient for biological productions and should be preserved at all costs. Paralleling some of the other recommendations, this approach will require data-driven decision science to better inform decision makers, the public, and various other stakeholders. It also requires distributed source identification methods, as not all important pollution sources are large.

4. ***Antibiotic resistance genes (ARGs).*** While a seemingly narrow topic, this resonated strongly with the workshop participants and is indicative of a broader issue. Antibiotics, hormones, and other byproducts of medical treatments end up in the water supply. These are largely untreated yet have important health impacts. Antibiotics in the water supply are contributing to ARGs and are accelerating the obsolescence of numerous classes of antibiotics, which is a high priority issue for health organizations across the world. Hormones in water supplies disrupt endocrine systems of humans and animals; not only are the effects largely unknown, but the overall level of contamination and how widespread it is are also unknown. This topic needs urgent attention, likely in coordination with other federal agencies (like the National Institutes of Health).

5. ***Nimble, scale-aware governance.*** Because water can be viewed as a basic human right, a commodity, and a byproduct (in the case of polluted water), its governance is complicated. Many of the governance systems that apply to one of these aspects do not apply to others; for example, water rights in the Western United States conflict with how major population centers have developed. There needs to be a thorough study of governance mechanisms of water, identifying the scale of effective governance, as well as who governs (community-based approaches versus more technocratic approaches). Included in this recommendation is identifying opportunities for governance to become nimbler, especially in the face of rapid changes posed by climate change.

5. Conclusions

Problems in water resources span temporal and spatial scales, as well as numerous sectors. Problems can cascade across all those scales, leading to emergent behaviors and unforeseen consequences. In this report we have identified some key problems that could be rapidly addressed with coordination across numerous partners. With hard work and sufficient investment, we can get ahead of these problems before their effects become more widespread.

It is important to remember that while the priorities and recommendations outlined in this report are certainly important and are backed by numerous community representatives, because we cannot involve everyone in the workshop, there are likely others involved in water resources who would identify different priorities. We not only need to figure out how to identify these potential participants and their priorities, but also set up a process whereby that input can be regularly incorporated into co-developed solutions. Water is critical to life and society, and we need to make sure that we are not missing anything.

Appendix A. Workshop Agenda

Thursday, October 13: Microlab	
1:00 PM	ARRIVAL
1:05 PM	Welcome, Workshop Objectives
1:10 PM	Demonstration of KIStorm
1:15 PM	Provocateur presentations: Cody Smith (IU) and Anna Gemolas (DuPont)
1:50 PM	Breakout discussions: discuss thoughts on previous presentations, identify challenges to put on the Challenge Wall
2:05 PM	BREAK
2:15 PM	Presentation by Steve Burian (U. Alabama)
2:30 PM	We are all experts: If any one of us were presenting on the challenges facing water, what would we be pointing out as important challenges? (Capture challenges on the Challenge Wall)
2:50 PM	Plenary discussion: A reflection on the points that have come out of discussions so far. What are we seeing / feeling? What's missing? What haven't we talked about yet?
2:55 PM	Reminders/preparation for the forthcoming workshop
3:00 PM	END

Monday, October 17: Session 1	
1:00 PM	Welcome back, reminder of overall objectives, introduction from NSF
1:15 PM	Facilitator welcome, reminder of how to use KIStorm, set up for next activity
1:25 PM	Set up Future Challenges activity: Reflecting on current capabilities and the gaps we need to close to get to where we want to be. What does the status quo look like in the next 25 years if we don't do anything? What new challenges does that present?
1:35 PM	Breakout discussions (Capture discussions in KIStorm)
2:05 PM	Share-out from groups to highlight points of interest or contention
2:20 PM	BREAK
2:35 PM	Set up Real world Issues activity: Building on the previous discussions, what are the most important issues on a 3-year timescale?
2:40 PM	Breakout discussions (Capture discussions in KIStorm)
3:20 PM	Share-out from groups

3:35 PM	Set up for next activity: Voting (10 dots per person)
3:40 PM	Voting and break
4:10 PM	Review of voting outcomes
4:20 PM	Breakout Groups: Are there any themes or categories of challenges emerging?
4:40 PM	Plenary discussion: What's missing?
4:55 PM	Preparing for our next session
5:00 PM	END

Wednesday, October 19: Session 2	
1:00 PM	Welcome back, plan for the day
1:10 PM	Reviewing the themes (individually), sign up for breakout groups
1:25 PM	Explanation of process, introduce working documents (Appendix B) and task
1:35 PM	Work in breakout groups + break
3:30 PM	Report back from working groups, constructive feedback
4:15 PM	BREAK
4:25 PM	Breakout groups: Incorporating feedback
4:35 PM	Preparing for our next session
4:40 PM	END

Friday, October 21: Session 3	
1:00 PM	Welcome back, brief presentation from NSF, discussion of the day's activities
1:10 PM	Participants individually re-familiarize themselves with all google docs
1:20 PM	Breakout groups working on Session 3 prompts
2:25 PM	Break and opportunity to switch documents / groups
2:40 PM	Back into breakout groups to work on Session 3 prompts
3:30 PM	Report back from working groups, constructive feedback
4:15 PM	Workshop close-out

Appendix B. Registered attendees

Name	**Affiliation**
Newsha Ajami	Lawrence Berkeley National Lab
Eva Allen	Indiana University
Sankar Arumugam	North Carolina State University at Raleigh
Jerad Bales	CUAHSI
Steve Burian	University of Alabama
Scott Coffin	California State Water Resources Control Board
Katie Dagon	NCAR
Aaron Deslatte	Indiana University Bloomington
Gabriel Filippelli	Indiana University - Purdue University Indianapolis
Courtney Flint	Utah State University
Christian Freitag	Conservation Law Center at Indiana University Maurer School of Law
Anna Gemolas	DuPont Water Solutions
Ellen Gilinsky	Ellen Gilinsky LLC
Beth Hall	Purdue University / MRCC / IN State Climate Office
Bruce Hamilton	NSF
Meredith Holgerson	Cornell University
Joseph Hoover	University of Arizona
George Hornberger	Vanderbilt University
Steve Jons	Dupont
Rita Kampalath	Los Angeles County
Ben Kravitz	Indiana University
Eve Labalme	Economist Impact
Justin Lawrence	NSF
Kelsey Leonard	University of Waterloo
Sally Letsinger	Indiana University
Alex Mayer	University of Texas at El Paso
Linda Molnar	NSF

Jennifer Murphy	US Geological Survey (USGS)
Romaric Odoulami	University of Cape Town
Chelsea Peters	Roanoke College
Gregory Pierce	UCLA
Erik Porse	Sacramento State | UCLA
Renata Rimsaite	University of Nebraska
Karl Rockne	University of Illinois Chicago
Dipesh Roy	University of North Bengal
Kelsey Semrod	The Meridian Group - Assistant Secretary of the Navy for Energy, Installations, and Environment
Cody Smith	Indiana University
Mark Stone	University of New Mexico
Mitchell Strauss	United States International Development Finance Corp
Larry Susskind	Massachusetts Institute of Technology
Vincent Tidwell	Pacific Northwest National Laboratory
Alexander van Geen	Lamont-Doherty Earth Observatory of Columbia University
Philippe Vidon	Desert Research Institute
Lilit Yeghiazarian	University of Cincinnati

Appendix C. Pre-work

Watch: Brave Blue World, a powerful documentary on Netflix, explores how new technologies and ground-breaking innovations can create a sustainable water future for the entire planet. The documentary paints an optimistic picture of how humanity is adopting new technologies and innovations to re-think how water is managed. (If you don't have access to Netflix, skip this pre-read.)

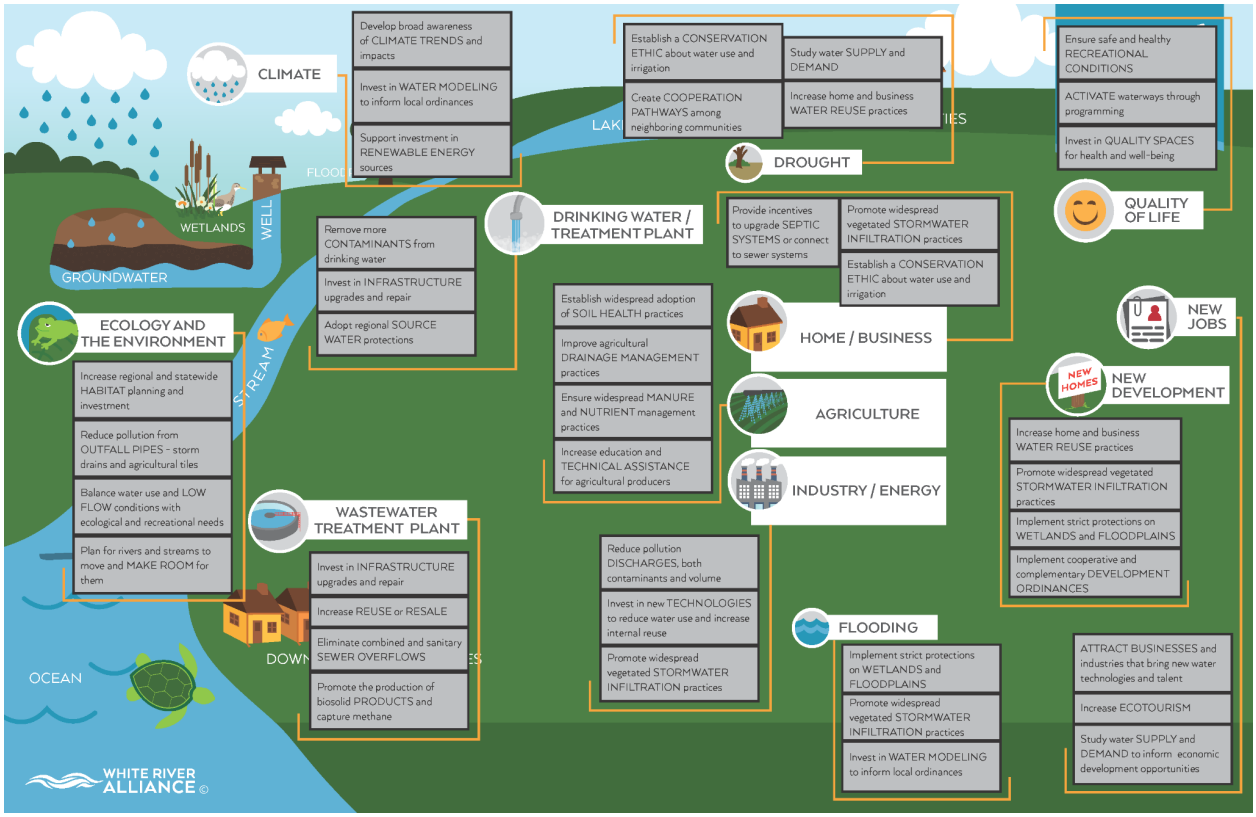
Read: A critical first step in any effort to optimize water resources is robust infrastructure planning. In 2021, Economist Impact created the inaugural City Water Optimization Index, a tool that creates a common framework for benchmarking factors that contribute to developing and maintaining an optimized, ample water supply. Its findings incorporate 47 quantitative and qualitative indicators that assess how well each city's policies and infrastructure are safeguarding its water supply, treatment, and distribution networks. With climate change increasingly challenging our water supplies and projected urban population growth, this Index offers a powerful tool for decision makers around the world to measure how prepared their cities are to deliver safe, reliable, and sustainable access to water.

- For the findings after the first 50 cities were analyzed: EconomistImpact-CityWaterOptimisationIndex-Nov-2021.pdf
- For an overview of the index: Reimagining urban water systems (economist.com)

Play: Water Optimization Calculator - Reimagining urban water systems (economist.com). The Water Optimization Index ranks cities on how they manage their water systems to achieve reliability, accessibility and sustainability. Enter the tool to adjust one of 50 cities' policies, resources and developments to unlock the full potential of the water system and plan your next step towards an accessible, reliable and sustainable urban water system. (Here's a hint: most cities have the most opportunity in the Sustainability category.)

Listen: SDG6 SDG6 – Clean Water & Sanitation – how innovation can lift us out of water poverty . One of the fundamental challenges we face is that the UN's sustainable development goals use outdated assumptions of water availability: water scarcity is not adequately taken into account and if we were to roll out the established Victorian system of piped water to every home to an extra 2 billion people, we would almost certainly end up replicating all of its current problems. A paradigm shift is needed which focuses on innovations in technology, but also within business models: how can we realize the market opportunity of meeting SDG6? Paul O'Callaghan, CEO, BlueTech Research, recently conducted a thought leadership interview with David Lloyd Owen, author of 'Global Water Funding: Innovation and Efficiency as Enablers for Safe, Secure and Affordable Supplies' (Palgrave Macmillan, 2020).

Map: Below is a graphic of Indiana's water roadmap. Consider: is it possible to build a similar map for a nation or the world?



(https://thewhiteriveralliance.org/wp-content/uploads/2019/08/Sustainable-Water-Future-Roadmap-Graphic.png)

Appendix D. Challenge Wall

This section provides the Challenge Wall prompt and all of the content provided by the participants on the Challenge Wall. Posts to the Challenge Wall are anonymous, and many resulted from group discussions. While the Challenge Wall was not organized, we have performed a post hoc organization into the six identified themes.

Please share your thoughts about the challenges that keep you up at night when thinking about water usage and management. Be Specific and please capture as questions and not statements. Use one post-it per question. Write as many questions as you'd like.
We find it useful to start questions with what we call statement starters.

- "How might we...?" (HMW)....
- "How to...?" (H2).....
- "What might be all the ways...?" (WMBAT)....

Theme: Agriculture

- Agriculture is the "gorilla in the room" for making significant progress on water quality and water quality challenges. There is a lack of political will to overcome many of the structural challenges to making progress in this area. For example, billions have been spent on reducing phosphorus loads in the midwest but there has been little or no impact on harmful algal blooms.
- How do we plan for the future without understanding the complex downstream (pun intended) impacts of policy changes? A ready example is corn subsidies.
- How might we use artificial intelligence to improve water usage and management?
- Water-food nexus: the water footprint of food waste and Ag supply chain
- Agriculture is the largest consumer of water in the US. Western water is largely managed according to a water rights paradigm that distributes water in times of drought. The challenge is understanding how intensifying drought by climate change will begin to force farmers out in the West. Similarly, irrigation will be increasingly needed in the East to cover changing patterns of rainfall and drought. Where is the appropriate management structure in the East?
- Can there be more cross--agency collaboration (i.e., between NSF and USDA given the high water use for agriculture) in terms of research and cooperative work?
- How might we provide for the water needs of aquatic biota (e.g. fish and invertebrates), while also meeting the needs of people?

Theme: Governance structures

- How to engage stakeholder communities that have not been engaged in the past?

- How do we ensure that water management impacts are considered within other sectors/industries, especially as we push for transitions to more sustainable approaches - thinking about hydrogen production, land use management, plastics alternatives, EV batteries, etc.
- This workshop is supposed to be multi-sector and multi-disciplinary. Seems like we don't have all the stakeholders at the table. Where are the social scientists?
- How might we leverage citizen science programs to improve water usage and management?
- How do we move forward effectively and equitably in terms of managing water when water rights regimes are based on outdated assumptions and principles?
- A critical barrier that prevents many solutions is siloed data. We are very good at getting data, but not so much at curating and storing (which would require millions of $$s). How might we address this barrier across multiple organizations, projects, disciplines?
- How can we establish a funding mechanism that supports multidisciplinary research (physical science, social science & stakeholder) to address climate change and water resource challenges holistically?
- Most important challenges: Individual actions have very little impact on water in other communities, other states, other nations--there is no national or international grid for water, no "water market" like for carbon. Can there be a "water market"?
- Spatial analysis (mapping) of equity issues should be used, and those tools should be sharpened and developed. The distribution of fair and equitable resources should be transparent, and these tools can facilitate that. Funding is needed on the back-end research to develop dashboards that would be open access and provide transparency.
- Community engagement is a powerful tool for advancing solutions that reduce the equity gap but there are major challenges to develop trusting relationships within the timelines of federal/academic projects. The communities that would benefit the most are often the ones with the least capacity to engage.
- How might we support institutional changes in water management agencies towards adopting social and technical innovations?
- How do we convince leaders and resource sponsors that funding water resilience upgrades, innovation, and projects needs to be a priority?
- How will we adapt our systems of government and management to reflect the new climate reality?
- How can we further incorporate diverse experiences into the design and assessment of water security and insecurity metrics for multiple end users?
- What processes can we institute to facilitate dialogue among partners with different backgrounds, cultural values, and languages?
- Environmental tradeoffs associated with water management decisions need to be accepted when developing policy. Further, we need to be aware of people's worldviews (e.g. regarding climate change) when developing policies. Sometimes no amount of data will suffice.
- Prove through quantitative models the savings that can accrue to nations, states, corporations and individuals of taking existing known steps to preserve potable water.
- Considerations for water management over the next 25 years: 2. Climate migration and water resources

- Considerations for water management over the next 25 years: 6. Coordination across institutions and scale to address local water management.
- The "who" is just as important as the "what" of research.
- Focus on policy-relevant research.
- How can we diagnose the institutional arrangements of coupled human-physical infrastructure systems for water management and predict when they are more or less likely to be (mal)adaptive?
- How to actually scale water back to indigenous communities
- Integrated water resource management in the developing world in the context of climate change. How to better manage the existing resources?
- The convergence accelerator is a US based effort. The presentations were on global issues. How might we learn from efforts across the globe and leverage this knowledge within the US?
- Incorporate the rapidly changing landscape of water use in the energy sector into water resources planning.
- Need to integrate perceptual and experiential data in with hydrologic (etc.) data to understand the full social-ecological-technological challenges and opportunities. e.g. perceptions of climate change can influence directions of policies and actions (or can inhibit). https://climatecommunication.yale.edu/visualizations-data/ycom-us/
- Considerations for water management over the next 25 years: 3. Increases challenges to governance (e.g. undermining of democratic institutions and large-scale consolidation) that may make it challenging to manage water locally.
- We need a very explicit statement (US) from Washington on how local decisions and conflicts should be resolved (equitably). How to resolve conflicts of interest. Ensure Indigenous knowledge is used.
- The notion of participatory action research starts with the groups participating in the analysis are part of structuring the analysis - and are not just on the receiving end of academic research. We need to talk about collaboration, not just "partnerships." Partnerships should not be developed after funding is received.
- Where is the line between regulation and personal choice?
- Business Roundtable in 2019 made a huge change to the definition of the value created by a corporation--away from gaining profits for shareholders who then invest on their own (Milton Friedman model) to being responsible for a more holistic view of business as part of society with responsibilities to ensure sustainable societies
- Different tribes (indigenous communities) have different issues in their own communities, but share some issues (e.g., tribal sovereignty). Suggestion that NSF allocate funds directly to indigenous communities - not just in name only, but in collaboration with the tribes. Some obstacles to receiving benefits of research advances in water resources include basic infrastructure limitations that likely first need to be met/resolved. Linked to this issue are water rights, tribal rights, constitutional rights of water and green resources. Inclusion of constitutional law experts is recommended.
- Climate change impacts are very regional and that imprints on water resources issues: e.g. western vs. eastern US impacts, soil quality, groundwater resources, land cover transitions, fires.
- Distinguishing what we can manage with what we can't. Relates to climate change as a stressor but not necessarily the only driver of these impacts. How important is it to

distinguish between drivers vs. focus on solutions?
- How do we proactively deal with water rights so that they don't conflict with equitable water distribution and use?
- Populations drive water use. How do we predict migration, especially climate migration?
- How does (spatial and temporal) scale impact water management and governance?
- How to decentralize water governance where we need to, and decentralize in other spaces?
- How do we ensure a just transition toward (local) water?
- How to achieve "One Water", or should we try?
- How to enable the public to consider science around risks, especially for news-worthy concerns?
- How might we encourage more people to be water entrepreneurs who start businesses?What might be the ways to better integrate local and professional knowledge into assessments of water risk and resilience?
- How to learn from water usage and management mistakes?
- How might we better address transboundary water issues (e.g. US-Canada, US-Mexico)?
- How might we encourage innovative solutions that change the status quo?
- It is so necessary to have critical 2-way conversations with stakeholders before the outcome is pre-disposed
- how might we fully consider the impacts of available water technology in terms of the feasibility of various technologies on economics, society and values, and the environment rather than trying to engineer our way out of water scarcity
- Need for educating future scientists to work on this problem
- Considerations for water management over the next 25 years: 4. Transferability of scientific advancements to community adaptation & governance change
- What the world will look like in 25 years: Hope in 25 years to have grappled with community engagement and equity
- What the world will look like in 25 years: Water inequity will increase, not just between nations but within nations
- What the world will look like in 25 years: We do think that the issues are solvable, integrating finance, engineering, technologies, science, communities, etc.
- Most important challenges: Need solutions across the spectrum of small to large scales
- Most important challenges: Solving with, and not solving for communities. Considering the continuum of age in families and exploring connecting with the passions of younger generations
- Public perception, industrial priorities, and policy do not always intersect--i.e., public more amenable to drinking reclaimed water, and industry more interested in engaging with this.
- Cyber security is a critical (current) priority.
- One example of the mis-match between policies and innovation: The city of Indianapolis is almost finished with a $1.2B stormwater infrastructure upgrade, using a deep tunnel system to stabilize wastewater cleanup and divert CSO outfalls. The city and the water company both wanted to experiment with unique re-use of finished water for sustaining and improving urban water systems upstream Plan failed for lack of $$$

and concerns about public perception
- Important to grow the water-educated community within government staffers, whether at federal or state levels

Theme: Infrastructure

- Investments in infrastructure (especially from the two big congressional bills) present an opportunity to address pressing challenges. However, there appears to be minimal stipulations for ensuring investments are climate resilient and that innovations can be incorporated to build back better.
- How do we deal with decentralized water distribution? (treatment, wastewater, proliferation of utilities, etc.)
- How do we build capacity in rural areas to manage water systems? Especially, in a nation where many of our systems are small and rural.
- How might we encourage valorization of water, treating the water but also recovering components within for reuse. One issue is selective separations. Another factor is reducing energy for these processes.
- Considerations for water management over the next 25 years: 5. Making megacities sustainable
- How to change our response to capturing, storing, and distributing water, as climate change impacts the timing, incidence, and frequency of extreme precipitation and drought events?
- How might we revolutionize rural drinking water delivery, such as areas with low population density, low socioeconomic status?
- What might be a more holistic way of evaluating and measuring drinking water accessibility that takes into account culturally informed water experiences?
- Considerations for water management over the next 25 years: 1. Improvements in desalinization and other water treatments
- Implementation of everything that has been passed down to local governments through recent (US) legislation is top priority.
- How might our approaches to long-distance electricity transmission and micro-grids inform how we think about water management?
- What happens when snow-fed watersheds run dry (or drier than they are now)?
- How do we systematically approach water utility infrastructure upgrades for our failing systems and make it a priority? How do we decide where the biggest "bang for the buck" is for replacement when there is a lack of metering to even determine where there may be leaks, major users, or failing pipe?
- How might we protect groundwater quality in rural areas with aging or failing septic pipes?
- How might we desalinate water in an economical way?
- What might be all the ways to transport water from where it is abundant to where it is scarce?
- Help the developing world avoid expanding their energy infrastructure along carbon intensive pathways.
- Considerations for water management over the next 25 years: 7. The feat of

infrastructure investments needed to get us through the next phase of utility shifts (e.g. renewable energy, aging water infrastructure)
- Water.org is now focusing heavily on carbon emissions, climate impacts, and sustainability of the technologies that are being developed and implemented--should be an approach over the next three years across many sectors
- New desalination technologies are coming online - major shifts in technologies - can be applied to oceans, and deep waters, and can be supported with renewable energy.
- Water quality and quantity and the intersection with infrastructure. Taking the infrastructure for granted, surprised when it impacts water quality/quantity.
- How do we forecast the life spans of confined aquifer systems? Especially in areas with incomplete inventories (like the glaciated Midwest US, among others).
- How might we conceptualize and measure equitable and robust drinking water delivery at multiple scales (i.e, household, community, etc...)?
- How might we better design the aesthetics of water features to enhance public perception?
- reservoir management
- salt water intrusion into aquifers
- failing water supply infrastructure
- combined sanitary and stormwater sewers
- low-cost desalination
- dam problems
- water-energy nexus issues

Theme: Natural disasters

- Recent disasters (hurricanes, wildfires, floods, etc.) provide a window of opportunity while public perception is heightened. We need to consider the impacts of cascading disasters and the resilience of our systems to absorb and recover from disasters.
- How might we manage the compound hazards associated with water (e.g. landslides and debris flows)?
- Management of existing water resources should be top of mind when developing policies and management plans (recall heat waves in Europe this summer when rivers were drying up - commitment to solve problems often dissipates when the current emergency subsides).
- How might we stop chemical contamination of water from fires at the wildland urban interface?
- How might we support communities to be more climate resilient as water abundance changes (e.g., more flooding, more droughts)? How do we do so in a way that is also carbon friendly? For example, some states subsidize farm pond creation for climate resiliency, but we know these ponds can have water quality issues and release CH4.
- aquifer depletion
- US drought challenges/US flood challenges
- How might we turn periods of extreme precipitation into an opportunity?
- Improved CONUS-scale Streamflow Forecasts for Gauged & Ungauged Basins using a Spatio-temporal Hierarchical Model

- Providing index-based insurance for drought relief, particularly in sub-Saharan Africa

Theme: Water quality

- Challenge: Lack of political will to address the problems that we already know about, and the lack of public trust in public water supplies
- Challenge: communicating risk - e.g. desire for safe/unsafe binary categorization, but health thresholds are somewhat arbitrary. Also - how do you compare different contaminants and make informed choices?
- How to increase water trust when the biggest obstacles are past experience and government record?
- water quality at the faucet
- Challenge: Increase access to free water testing (microbial, arsenic, lead) and help households address the implications (possibly in part with their own resources)
- How do we approach monitoring/modeling of urban stream systems to assess water quality and inform decisions on proximal and upstream land use?
- How can we build trust in our water quality? There are lots of aspects to this: dynamic water treatment (algae blooms in hot summers), persistent inequities (Flint, Michigan comes to mind), PFAS or Arsenic, inconsistent compliance, etc.
- How do we address emerging contaminants such as personal care products, pathogens, PFAS, in surface waters?
- From our breakout session: to what extent is it productive to couple climate change and access to enough and/or safe water under the same heading?
- How do we create affordable water of acceptable quality for economically challenged areas.
- What the world will look like in 25 years: Huge uptick in frequency and severity of coastal impact, fires, and other issues that impact water quality and communities
- How do we implement solutions to water quality solutions in regions that could not afford this. This applies in the US (e.g. infrastructure) as well as globally.
- Challenge: How do you not only communicate risk, but also come to a shared understanding of acceptable levels of risk that can be used to inform policy decisions?
- Can we communicate comparative risk assessments for various water quality issues, and do this in a way that information is generally understood and accepted.
- Priorities from a water-program administrator who cannot attend the forum (summary: find cost-effective solutions): - All things lead – water and dust and soil and infrastructure: cheaper ways to find and remove - PFAS and microplastics: cheaper ways to remove - Sediment and nutrients in supply water that causes treatment costs to be high: cheaper ways to remove - Stormwater and flooding: cheaper ways to manage both
- How can we assure the safety of the various sources of water reuse when we don't know enough about health and environmental effects of the known (and unknown) contaminants in the source water (esp true of industrial sources)
- What the world will look like in 25 years: While the world will have the same amount of water, it will be of the wrong quality and in the wrong places

Theme: Water valuation and pricing

- How do governments provide carrots to states, businesses and individuals to value husbandry of water? Tax systems, performance payments, staggered pricing for excessive users, weighted financial benefits for water users to use less quantity -speaks to adoption of water saving locally.
- How might new or redirected tax revenues (say, for the US) be used to fund needed water-infrastructure (including quality, quantity) investments?
- How do we rethink how to finance/support water systems in a way that both incentivizes efficiency, but also builds in equity considerations to ensure affordability and access?
- Many technologies, including recycling, circular economy, full life cycle analysis, are often impeded by policies from federal to state levels
- How do we balance the increasingly fraught drinking water quality and affordability tradeoff?
    - 1) How to create more affordable water of sufficient quality for areas without resources?
    - 2) How to change how we pay for water infrastructure?
    - 3) Commodified water can yield more efficiency, but how can we ensure it is equitably distributed, with minimum amounts of free water for households in a scalable manner?
- How do we encourage tax incentives for rain scapes and rain barrel collection?
- How to motivate more willingness to pay by those who can in achieving the Human Right to Water
- Should we pursue the utility model for really small off the grid communities?
- How to link water usage and management to the bioeconomy?
- What might be all the ways to finance water projects?
- How do we rethink how to finance water service so that water conservation isn't at odds with the "business" of providing water?
- Factors driving water use and understanding how water use has decoupled from population and economic growth in the US over the past four decades.
- Implementation of Philadelphia-like water pricing, based on ability to pay. Fastest way to move towards equity in water in urban areas.

Appendix E. Session 2 and 3 Activities

Session 2 was the first opportunity for the workshop participants to refine challenges and needs within the set of themes that emerged from the Challenge Wall contributions. For each theme, a set of questions guided the discussions, intended to draw out articulation of specific scientific/technical and societal objectives. The process of identifying needed expertise, stakeholders, potential obstacles, and timelines was started in this session.

The Session 2 questions included:

- What is the Theme?
- What are the key / prioritized challenges that should be addressed within this theme?
- What are the research questions that would be appropriate for these challenges? How might you articulate the research questions?
- If we could solve these challenges, what would be the positive societal outcomes?
- If we could solve these challenges, what might be the anticipated transformative scientific/technical outcomes? THINK BIG. What will be disruptive?
    - Direct impacts over the next 3 years
    - Subsequent impacts over next 10 years
- How will this meet the NSF *acceleration* criteria (discuss speed and scale)?
- What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
    - OR, What is stopping us from realizing the future you envision?
    - OR, What is needed to get us started?
- What expertise is needed?
- Why/How do these challenges meet the NSF *convergence* research criteria?
- Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why?
- How would this team's work connect to or leverage other initiatives or programs?

For Session 3, the participants selected research objectives from the Session 2 exercise and conducted a "deeper dive" into research ideas. The introduction to the exercise in Session 3 directed the participants to sketch out a funding call for selected ideas within their theme, followed by detailed instructions on factors to consider in their work.

Session 3 instructions:
The Google Docs have a lot of ideas, and now we need to make them more concrete. Everyone has identified some research questions and what issues come up when discussing those questions. So if the participants were to write a short funding call for each of those questions, what would it look like? Some key things to pay attention to:

- **Flesh out the research questions a bit more.** What sorts of work might need to be done? As an example, if your question is "What is the fate, transport, and health impacts of emerging contaminants?" then what does the work look like? Would you need more monitoring (and if so, where), pulling together existing data sources (which ones? what do they measure?), or modeling activities? You don't need to be overly specific, but it would help if NSF knows some details about where the key gaps are. And if the answer is "This topic needs a lot of attention, but we don't even know the basic research questions" that's okay too!

- **Flesh out arguments that these are critical gaps that can only be addressed through diverse partnerships.** What are the limitations of the way we currently do things (including some examples of things we are currently doing), and why couldn't this research question just fit into something that already exists? What sort of work do you need from academics, government, industry, stakeholders, etc.? And can you demonstrate that the work actually needs partnerships between those sectors, not just individual people doing separate things?

- **What is the roadmap toward societal impact?** NSF is keen on use-inspired research (we don't just want research for research's sake) and translational opportunities (research that can be rolled out into startups or industry). And keep in mind that convergence accelerators are meant to be fast - these roadmaps should have about a 3 year timescale.

- **Who needs to be involved in this process who is not in the room, and how do we engage them?** Examples: farmers are harvesting right now, and many tribal organizations are overburdened and under-resourced - these two groups can't take a week off to come to a workshop. How do we solve this problem? What sorts of things does NSF need to fund, and what does that look like? [Note: It's easy to talk about "stakeholder engagement" and leave the details to others, but that's not what I want here. If you think stakeholder engagement is important for your research question, please give details!] And at what stage would you want to engage these groups? By not having them here, are we missing out on some critical data sources or prioritization? Or do we not even know the research questions without engaging with them? The goal is to provide some context for our recommendations - essentially how confident we are that the research questions we've identified are the right ones.

Maybe not every idea on these Docs will work for the Convergence Accelerator. That's okay and please don't throw them out – modify them so that they will work or save them for another funding call! Maybe you only have time to work on one of them, or maybe you get through all of them. But having that sort of detail will make NSF's job a lot easier.

Also, please don't worry about turf or mission at this stage. (A great example I've heard is that we shouldn't be looking at agriculture because that's USDA's domain.) A good research question is a good research question, and there's always a way to figure out NSF's role in a partnership with other agencies.

Appendix F. Working Document for ***Agriculture*** Theme

The content provided here is a direct copy of the working document with which the participants engaged. The workshop organizers did not modify any content; we did lightly edit the formatting. Participants did not necessarily answer all questions, and any blanks were left by the participants. The brainstorming in Session 2 was used as motivation for the activities in Session 3. For the Session 3 prompts, participants were provided with the content in Appendix E, but that content was not reproduced verbatim in the working documents.

Working Document: Session 2
Agriculture

Instructions:

- *Please have your camera on and quickly introduce yourself (name, expertise, experience, commitment, passion?) (5-10 minutes).*
- *You will have a total of 60 minutes in this breakout session.*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the end of the alphabet?)*

What is the Theme: Agriculture
Who's in this working group? ● Beth Hall - Purdue U., Indiana State Climatologist ● Karl Rockne - University of Illinois Chicago Associate Dean for Research and Professor of Environmental Engineering
What are the key / prioritized challenges that should be addressed within this theme? ● Ag is largest consumer of water. With major drought issues in the agricultural western US, where water rights are heavily governed, how will water resources impact the future of western ag production? ● Irrigation is increasing in usage in historically rain-fed regions of US to respond to periodic intense drought. How will this cooperate with other demands for water from municipal, private, and transportation sectors? ● USDA research priorities tend to be siloed from other research disciplines. How can cross-disciplinary research be encouraged that includes non-ag science that would benefit ag production and resiliency? ● Timing of agricultural chemical applications with precipitation events have caused water contamination of loss of field nutrients. (added challenge)
What are the research questions that would be appropriate for these challenges? How

might you articulate the research questions?

- What are some political strategies that would incentivise agricultural production in water-vulnerable areas that go beyond insurance protection?
- How can non-agricultural infrastructure be innovatively applied to agricultural production in moderate- and high-risk locations?
- What observational data in other sectors (e.g., atmospheric science, economics, transportation of goods, health, education) would provide more resiliency and preparedness to vulnerable agricultural communities and production?
- How can poorly-timed chemical runoff be eliminated?

If we could solve these challenges, what would be the positive <u>societal</u> outcomes? *Amongst other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.*

- Reduction of food scarcity for vulnerable, at-risk populations
- Increased awareness, education, and self-sustainment of food production at individual levels in urban environments
- Reduction of water scarcity and quality risks for populations, communities in traditionally arid climates

If we could solve these challenges, what might be the anticipated transformative <u>scientific/technical</u> outcomes? THINK BIG. What will be disruptive?

Direct impacts over the next 3 years:

- Alternative crop considerations during periods of drought or excess flooding
- Improved water quality and quantity for underserved and drought-vulnerable communities
- Improved downstream water health and ecosystems

Subsequent impacts over next 10 years:

- Increased collaboration between agriculture, commerce, health, and local/state policymakers and researchers
- Increased usage of nature-based solutions within urban environments that are often characterized as “food deserts” due to their lack of diverse, healthy food options
- Improved access to clean water among vulnerable communities often dependent upon well water (e.g., rural, tribal, low-income)

How will this meet the NSF *<u>acceleration</u>*** criteria (discuss speed and scale)?**

What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
OR, What is stopping us from realizing the future you envision?
OR, What is needed to get us started?

- The communities most at risk of poor water quality and access tend to have small representation from voting, financial, etc., means. Therefore, what is the political and economic incentive to focus on these "smaller" populations most at risk?
- Research areas/disciplines needing to be at the table with this agricultural/water resources theme tend to be drawn toward high-impact (i.e., broader impact) funding opportunities, not realizing that the agriculture/water resources theme goes beyond just food security and under-served populations

What expertise is needed?

- Infrastructure, engineering designers
- Supply chain, goods delivery, economics
- High spatial, temporal resolution atmospheric/hydrological modelers

Why/How do these challenges meet the NSF *convergence* research criteria?
NSF Convergence Accelerator website

- *Multi-disciplinary research that is not specific to any current NSF program.*
- *Translational research that addresses a challenge of national interest.*

Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? *(particular emphasis outside academia highly suggested)*

- Policymakers and legal sector to better deliberate and communicate water rights, impacts, and incentive in the area of agricultural production with municipal/individual water needs
- Social scientists and NGOs who can collect and communicate the water resources needs and risks with vulnerable populations within the framework of food scarcity and clean water access
- Climate scientists, weather forecasters, and media who can communicate and educate the risks and potential solutions to the general audience

What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? *(This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation ,etc.)*

- The populations most at risk of food scarcity and access to clean water tend to be under-reprepresented minorities who lack a 'voice in numbers', the financial means to access adequate health care, and the educational opportunities to develop strong self sustainability practices.
- Climate refugees within the U.S. may become more prevalent if extreme climate and variability creates lack of adequate food and water. Where will they go and are the destinations ready for them?

How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.

Please be prepared to give a 3-minute summary in plenary. We will hear summaries from each

group when we reconvene. *(we will screen share your document and give you an indication of 30 seconds and out of time remaining)*

Working Document: Session 3
Agriculture

Instructions:

- *If you have new members in your group, please quickly introduce yourselves (name, expertise, experience ??)*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the beginning of the alphabet?)*

Goal: please write a short funding call for each of the research questions (from the session 2 document below). Please address the questions in the blue boxes below - one research question per box, feel free to add as many boxes as needed *(you can refer to the KIStorm page "Session 3 Goals" for more details).*

Note: If you find out that a research question won't end up working for the convergence accelerator, that's okay – you can modify it so that it will work, or you can move on to the next research question.

Four key issues were identified in the second session on agricultural water issues: Water quantity (usage), water quality (fit for use), siloed research support at programmatic agencies, and a need for integrative research and engineering solutions.

Agriculture is the largest consumer of water in the USA. This represents both a water quantity issue and a water quality issue. Water quantity issues have driven many large infrastructure, governmental, and legal initiatives. A common theme is the understanding that the linear take-use-waste model of the anthropogenic water cycle is no longer tenable and that a circular water economy is necessary. A resilient circular water economy must balance water rights with equitable distribution of the costs and benefits of water to all human and "natural" stakeholders.

Intrinsic to a circular water economy is the recognition that efficient and equitable use of water must include a fit-for-purpose framework. Requiring potable water treatment for non-potable uses is an inefficient use of energy with attendant potential impact on GHG emissions and the water cycle. A fundamental part of fit for use is understanding the quality of the water. While the USA has a long-standing water quantity sensing network through USGS, USDA, the National Weather Service, and other agencies, a comparable water quality network is a long way off.

In addition, the recognition that diversity, equity, and inclusion (DEI) comprise major environmental and health equity components necessitates a more equitable distribution of

water to disadvantaged communities. While such issues have gained recognition in urban communities, in many instances the most impacted are populations in rural areas that are not served by community water systems (CWSs) that are often exempt from regulation.

With this background, a convergent research initiative that crosses scientific, engineering, social/behavioral/economic science, and policy boundaries is necessary to address the major gaps in our ability to produce and manage fit for purpose resources in a circular agricultural water economy. It is recognized that such efforts will necessarily cross programmatic and science driven agency boundaries. For that reason, our recommendation is that such a convergent Federal initiative be supported by multiple agencies in collaboration. We have identified the following research goals for such an initiative:

Contamination Prevention:

The best way to address water quality issues is to not allow water to be degraded in the first place. For that reason, we identify the following research foci in contamination prevention:

- **Green chemistry for agriculture** (not just consumer products and industry)
- Circular economies through **waste valorization** (energy recovery and feed stocks) with a strong focus on recovery of high-value nutrients (i.e., nitrogen, phosphorus)
- Institutional controls incorporating **data-driven decision science** to better inform the public and other stakeholders
- **Distributed source identification** methods

Mitigation:

While prevention is preferred, improved infrastructure-integrated technologies and approaches for mitigating the risk to human and ecological health are needed; including understanding the interplay between air/water exchange. These include (but are not limited to) the following:

- Reactive/smart **passive treatment infrastructure**
- **Sensor networks** integrated with water quantity assessment networks
- Big data processing of **health effect endpoints**
- Better understanding of the **impacts of agricultural contaminant mixtures** on human and ecological health

Cross-cutting Research to Enable Implementation:

Research is needed to develop integrated approaches and technologies to identify, match, and align resources to achieve equitable distribution of fit for use water in a circular economy. Specific research foci include (but are not limited to) the following:

- Utilizing artificial intelligence (AI), machine learning (ML) modeling for **data-driven decision making** based on upstream information and risk
- Development of a **national sensor-based monitoring network** that can achieve specific chemical or health-based assays at low cost

- Incorporation of a **Systems of Systems (SoS) approach**:
    - Recognize **impacts on dependent systems** of actions taken to **identify unintended consequences**
    - Understanding how the complexity of **agrochemical mixtures and interactions in both water and air impact human and ecological health**
    - Recognizing that a circular water economy has no “downstream”, and that **equitable distribution of the true life cycle costs** must be maintained

Appendix G. Working Document for ***Governance Structures*** Theme

The content provided here is a direct copy of the working document with which the participants engaged. The workshop organizers did not modify any content; we did lightly edit the formatting. Participants did not necessarily answer all questions, and any blanks were left by the participants. The brainstorming in Session 2 was used as motivation for the activities in Session 3. For the Session 3 prompts, participants were provided with the content in Appendix E, but that content was not reproduced verbatim in the working documents.

Working Document: Session 2
Governance Structures

Instructions:

- *Please have your camera on and quickly introduce yourself (name, expertise, experience, commitment, passion?) (5-10 minutes).*
- *You will have a total of 60 minutes in this breakout session.*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the end of the alphabet?)*

What is the Theme: Governance Structures
Who's in this working group? ● Chelsea Peters, Assistant Professor Roanoke College, Hydrologist ● Rita Kampalath, Acting Chief Sustainability Office, County of LA ● Gregory Pierce, Co-Director & Faculty, UCLA School of Public Affairs ● Kelsey Semrod, Water Resilience Program Manager, Dept. of Navy
What are the key / prioritized challenges that should be addressed within this theme? ● Transboundary and transectoral governance (shift in climates will alter water availability and may induce climate migration; transitions in other policy domains sectors will require changes in water management) ● Legal water rights (current rights don't reflect equitable use for current and future governance scenarios) ● Completely overhauling governance systems and funding streams with participation of multiple stakeholders (indigenous communities, transdisciplinary projects) ● Spatial and temporal scale
What are the research questions that would be appropriate for these challenges? How

might you articulate the research questions?

- What are creative ways to tackle reallocation/overallocation of water rights, directly and indirectly?
- What are the water supply/quality implications of a transition to a carbon free future across all sectors (food, buildings, energy, transportation, materials)?
- Where do different degrees of community participation v. technocratic decision making make sense in water governance?
- At what scale should we govern? Do we centralize or decentralize? Does this vary geographically by water domain/region?
- How do we incentivize coordination between institutions as they address water management?
- How do we encourage innovative solutions that accelerate political and institutional shifts regarding water management in a quickly changing climate?
- How do we determine data of authority to drive policy changes & consider how climate change has altered existing datasets?
- How do we reevaluate Western water law philosophy and better incorporate alternative (indigenous frameworks, personhood status of rivers, decommodify water, etc.) approaches to water value?

If we could solve these challenges, what would be the positive societal outcomes? *Amongs other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.*

- All of the above would lead to equity enhancements
- Some of the above (on governance, shifts from Western philosophy, institutional coordination) would lead to greater inclusion and diversity
- Some of the above (data of authority, accelerating shifts) would lead to greater education and capacity training
- Flexibility to adapt to future challenges
- Closer to "One Water", breaking down inefficient siloes

If we could solve these challenges, what might be the anticipated transformative <u>scientific/technical</u> outcomes? THINK BIG. What will be disruptive?

Direct impacts over the next 3 years:

- Projections that accurately portray localized water resources trends to better plan for future needs in a changing climate
- User-friendly data tools to inform new governance possibilities
- Changing rules/norms so indigenous voices have more say in as many traditional water domains as possible
- Institutional roadmap for the below on long-term management structures

Subsequent impacts over next 10 years:

- Balancing the scale (supply > demand)?
- Redesign/shifting/creation/elimination of water management structures
- New major funding streams/revenue reorganizations to make participation possible
- Shifts in public evaluation of water

- New innovations in materials/energy production/etc.

How will this meet the NSF *acceleration* criteria (discuss speed and scale)?

- Convergence research approach
- Strong, multi-organization partnerships involving researchers, users, and other stakeholders

What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
OR, What is stopping us from realizing the future you envision?
OR, What is needed to get us started?

- Political willpower/ power status quo
- Lack of constructive vision around actionable alternative futures
- Collaboration among institutions and communities to establish a collective goal.
- Funding prioritization
- Complete and shared understanding/agreement on how climate change will impact water systems
- Limited stakeholders with decision making power

What expertise is needed?

- Innovators and entrepreneurs
- Policy makers
- Law experts
- Community-based organizations
- Engineers
- Tribal/indigenous culture/knowledge

Why/How do these challenges meet the NSF *convergence* research criteria?
NSF Convergence Accelerator website

- *Multi-disciplinary research that is not specific to any current NSF program.*
- *Translational research that addresses a challenge of national interest.*

- Works across geographic scales
- Works across water sub-domains and water-other sector domains
- Bridges environmental science -society-public administration siloes

Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? *(particular emphasis outside academia highly suggested)*

- Have to include governments as they "govern" most domains of water
- Have to include publics as the reforms we are discussing above necessitate greater public involvement, if not co-design
- Institutional, legal and water science scholars are essential to this
- Tribal/indigenous water experts

What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? *(This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation ,etc.)*

- Representation of indigenous communities
- Rural and urban approaches must evaluated independently
- How governance disarray leads to distributional inequities in Human Right to Water Outcomes
- How governance exclusion/reification leads to restorative justice inequities

How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.

- Too much to say here…

Please be prepared to give a 3-minute summary in plenary. We will hear summaries from each group when we reconvene. *(we will screen share your document and give you an indication of 30 seconds and out of time remaining)*

Working Document: Session 3
Governance Structures

Instructions:

- *If you have new members in your group, please quickly introduce yourselves (name, expertise, experience ??)*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the beginning of the alphabet?)*

Goal: please write a short funding call for each of the research questions (from the session 2 document below). Please address the questions in the blue boxes below - one research question per box, feel free to add as many boxes as needed *(you can refer to the KIStorm page "Session 3 Goals" for more details).*

Note: If you find out that a research question won't end up working for the convergence accelerator, that's okay – you can modify it so that it will work, or you can move on to the next research question.

What is the research question?
What are creative ways to tackle reallocation/overallocation of water rights, directly and indirectly?

What is the research question?
What are the water supply/quality implications of a transition to a carbon free future across all sectors (food, buildings, energy, transportation, materials)?

Please flesh out the research question a bit more.
As consensus builds towards the need for a global shift to carbon neutrality, various sectors are/will be evaluating how to accomplish this shift within their own operations. While carbon neutrality is a critical goal, these shifts may have considerable down and upstream impacts on water supply and quality, for instance the production and end-of-life management of EV batteries, compostable or reusable packaging materials, and energy production. Considering each specific sector, what are the most carbon intensive elements of that sector that are currently or in the future likely to be targeted for major shifts? Looking at those shifts, what new materials or processes may be involved, and where will they be concentrated spatially? What are the impacts on water quality and water supply of those new materials or processes: is it likely that the new processes/materials will result in more/less/different emissions? What are the water supply and quality oversights to regulate the new processes/materials? Are there geographic constraints to the new materials/processes, and if so, what are the key areas of concern regarding water management in those areas? How do these overall water quality/supply impacts compare to the status quo? Are there alternative materials/processes that could be used that have less water supply/quality impacts? What tools can be developed to facilitate analysis of these water supply/quality impacts so that new processes/materials/technologies can be quickly and consistently assessed in order to guide policy-making, problem-solving, and investments? What tools can be developed to assess the carbon footprint of these water supply/quality impacts so that this may be a consideration in technology shifts and policy-making? Who is likely to benefit, industry-wise and community-

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
Many of the questions listed above highlight the gaps in knowledge to answer these questions. Partnerships are needed across sectors (food, energy, materials) to understand in depth the state of the industry and future direction, as well as the processes/technologies/materials themselves. New cross-cutting regulatory systems and their representatives will need to be present. Depending on the geographic specificity of potential new processes/materials, expertise may be needed on the local level to understand specific water management challenges and concerns. Expertise is needed to build user friendly analytical tools that can be used to communicate issues to policy makers, as well as across disciplines and areas of expertise.

What is the roadmap toward societal impact?
Tools and results that are user friendly and also clear enough to be understood across various sectors/disciplines have a higher likelihood of uptake by practitioners as well as policy-makers, and can shift ongoing conversations about what processes/materials/technologies should be invested in broadly. Building more permanent bridges and connections between these sectors (water, energy, food, etc.) can lead to better communication and collaboration.

Who needs to be involved in this process, who is not in the room, and how do we engage them?

Experts in these other sectors, for instance academics, as well as industry and policy-makers who understand energy/food/materials systems at all levels: from those who deeply understand the processes and technologies and can identify water impacts across all stages of the life-cycle, to those who understand where investments are being made and why, to those who understand the direction that policy is going within those sectors.

What is the research question?
Where do different degrees of community participation v. technocratic decision make sense in water governance?

Please flesh out the research question a bit more.
Governance has traditionally been viewed as a top-down process by government "decision-makers" for communities. It has been more recently recognized that communities both have a right, from a procedural justice perspective, and have unique technical insights based on lived experience to inform how (water) systems should be governed most efficiently and from a distributional equity perspective.

Broadly, the shift to centering local needs and preferences in project planning ensures that later results of projects, such as multibenefit outcomes, are most sought by community members who experience the landscape daily and intimately. Moreover, engaging communities in disadvantaged areas necessitates an understanding of the additional time required to engage individuals beyond a traditional infrastructure project cycle, from stages including but not limited to soliciting open-ended input, building rapport, maintaining relationships, sharing outcomes transparently, and including compensation for local consultations.

- How does the continuum from weak "consultation" to co-design of policies, programs and plans map onto water governance domains?
- Where is community voice less and more essential in water governance contexts? Where should we not place undue pressure on communities to contribute their time and knowledge (where compensation is not feasible)?
- Where is it more and less feasible and what are the barriers to inclusion?
- What are grounded examples of real success, nominal inclusion and complete roadblocks?
- What tools and data could be created to facilitate community participation on an equal footing to water practitioners and in what steps of decision making should these be applied?

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
See answer to the final question below. Otherwise, we likely need to draw on just emerged coalitions focused on environmental justice procedures (J40) and water equity nationally, as well as existing international networks of CBOs focused on sub-domains of water equity, as well as more broadly on "greening" (traditional environmental justice concerns) and new

coalitions focused on climate. We need these groups to come together with major agencies which govern water domains in a new, transparent and enduring way to see the most success.

What is the roadmap toward societal impact?
There are at least 2 key components:

An analysis of implementable inclusion pathways of community voice in different domains of water governance which ranges across the typology in the engagement literature from weak "consultation" to co-design of policies, programs and plans. This should include case studies with operational details and demonstrated outcomes.

Moreover, a realistic assessment of where the tradeoffs in efficacy and practical realities of including community voice depend on the scale, technical nature and timing of decision-making. Ie, where is community voice less and more essential in water governance contexts? Where is it more and less feasible and what are the barriers to inclusion?

This research agenda then needs to be implemented with the below parties on a 5-10 year time frame with meaningful baseline commitments by agencies regarding metrics, and then 5 year or so iterative evaluations on progress.

Who needs to be involved in this process, who is not in the room, and how do we engage them?
In this case, we first need to involve a range of community types, from highly-privileged to highly-disadvantaged (with an emphasis on the latter) community members and representative CBOs, including from different political contexts. We need to compensate these individuals and groups for their time, and ensure them upfront that this research process is not simply about consultation.

We also need to have representatives from public agencies, both high level "decision-makers" as well as staff level individuals who actually set and mediate how public engagement rules are implemented present. These folks need to be willing to talk about ways of doing and be open to instituting new formal rules that facilitate more robust community voice and informal norms.

Finally, we need community engagement scholars and institutional governance (probably legal) scholars present in this conversation, to both help mediate it, as well as to help design and evaluate new inclusionary governance forms going forward.

At what scale should we govern? Do we centralize or decentralize? Does this vary geographically by water domain/region?
Please flesh out the research question a bit more.
Water is a flow entity which in many ways does not respect and needs to be managed at different scales and across jurisdictional (socio-political) boundaries. Yet the literature on over-fragmentation and proliferation of governance structures, and the channelization of water for human purposes well documents how management has led to adverse environmental, economic and equity purposes.

The broadest question is how do we toggle between "One Water" approaches and the existing fragmented paradigms?

Sub questions start with:

How are the traditional domains of water governance (drinking, waste, storm; ground v surface, point source/stock v flow; utility v agriculture, etc) and at what scale are they implemented most rigorously? How well do they comparatively work?

How does geography and broader political-economic regimes of governance affect the structure of water governance more specifically?

What does the reality of "One Water" apart from settler-colonial ways of managing it suggest as low-hanging fruit for returning water governance to more respectful and sustainable forms? How does new technology fit into to support one water (water recycling, better understanding via remote sensing of sub-surface flows)?

Where does "One Water" fall short recognizing the constraints and path dependence of existing water governance structures? (Ie, what should not try to unify?)

How can we get beyond endless "centralize v. decentralize" debates in sub-domains of water governance, or should we just ignore them?

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
What is the roadmap toward societal impact?
Who needs to be involved in this process, who is not in the room, and how do we engage them?

Truly interdisciplinary scholars who will think and act across boundaries constructively. Siloed scholars are likely to obstruct progress.

Politicians who can create wholly new agencies, ways of governing, or inter-agency coordination.

Non-profits and Foundations that will invest meaningful resources in governance proposals that can work their way into the political process (see Sustainable Groundwater Management Act in California)

Indigenous communities have not been in the room to have space to present their methods and understandings, rather than reacting to others in a room.

How do we incentivize coordination between institutions as they address water management?

How do we encourage innovative solutions that accelerate political and institutional shifts regarding water management in a quickly changing climate?

How do we determine data of authority to drive policy changes & consider how climate change has altered existing datasets?

How do we reevaluate Western water law philosophy and better incorporate alternative (indigenous frameworks, personhood status of rivers, decommodify water, etc.) approaches to how we value/view/relate to water?

Please flesh out the research question a bit more.
Many of the past and ongoing issues with water management are at least partially due to the way in which water is viewed as a commodity, something to be controlled purely for human use in the short term, and managed/priced according to rules of supply and demand similarly to other resources, as well as relying on individual decision-making and fragmented governance rather than a more holistic view of the myriad ways in which water touches society.

We are growing toward a better, albeit incomplete understanding of alternative ways to view and relate to water, for instance Native perspectives, in which water is viewed more holistically, in some perspectives as an entity possessing its own rights, rather than as a "resource." Rethinking our relationship to water and how we view it may spark more creative and innovative approaches to how we manage water systems and ensure adequate, clean, accessible, and affordable water for both the needs of people and nature.

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
What are the underlying assumptions, values, legal principles that drive our current approach to water management? How do these differ from assumptions, values, and principles in other cultures, especially those indigenous to the geography being studied? If we adopted these differing approaches/perspectives, how might they impact current water systems and approaches to management,and equity and ecosystem health? What can we incorporate into our management practices, and what would be an equitable way of evaluating these questions and incorporating knowledge? How do we ensure that Native knowledge and expertise is valued and incorporated into processes as well as end outcomes?

What is the roadmap toward societal impact? This research could lead to better outcomes in terms of long term sustainability of our water, more thoughtful approaches that avoid problems and impacts proactively rather than waiting to fix them after they've happened, and potentially (if done correctly and in an inclusive and respectful manner) address long-standing equity issues as well as past harms done to Native/indigenous communities through historic mistreatment as well as ongoing erasure/lack of visibility of their culture.

Who needs to be involved in this process, who is not in the room, and how do we engage them? Native/indigenous experts, social scientists with expertise on how water is

viewed/managed in other countries/cultures. With Native/indigenous experts in particular, we need to build in fair compensation, pathways to at least some degree of "water back," as well as ensuring that interactions are carried out in a culturally competent way that recognizes historical relationships and harms and avoids processes that feel extractive and one-sided.

Builds:

1. Perhaps consider some focus on adaptive governance and poly centric governance as these are key to resilience.
2. Tragedy of the commons. Some settings may be more suitable for joint management than others. Private well owners may not want oversight.

Appendix H. Working Document for ***Infrastructure*** Theme

The content provided here is a direct copy of the working document with which the participants engaged. The workshop organizers did not modify any content; we did lightly edit the formatting. Participants did not necessarily answer all questions, and any blanks were left by the participants. The brainstorming in Session 2 was used as motivation for the activities in Session 3. For the Session 3 prompts, participants were provided with the content in Appendix E, but that content was not reproduced verbatim in the working documents.

Working Document: Session 2
Infrastructure

Instructions:

- *Please have your camera on and quickly introduce yourself (name, expertise, experience, commitment, passion?) (5-10 minutes).*
- *You will have a total of 60 minutes in this breakout session.*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the end of the alphabet?)*

What is the Theme: Infrastructure
Who's in this working group? ● Aaron Deslatte ● Anna Gemolas ● Sankar Arumugam ● Vincent Tidwell ● Eve Labalme ● Erik Porse
What are the key / prioritized challenges that should be addressed within this theme? ● Management & governance ● Technological solutions ● Fit-for-purpose ● Robustness and resilience of infrastructure: "Safe to fail" or "Fail to be safe" ● Waste-to-resource (eg. energy, nutrients from wastewater treatment) - multisectoral collaboration ● Improving cross-sector planning ● *Education on consumption & usage?*

- Decentralization vs centralization
- Reducing carbon footprint of infrastructure
- Accessing energy and nutrients embedded in wastewater
- Key performance metrics for infrastructure through advanced technology
- Political, financial, and managerial feasibility of new designs
- Rural drinking water delivery and wastewater management

What are the research questions that would be appropriate for these challenges? How might you articulate the research questions?

- What are scalable data models for water management?
- How do we udevelopse scalable datathese models (dynamic systems analysis and AI) to optimize or "fit" infrastructure designs/investments to local environmental/community characteristics for improved water management?
- What new technologies are necessary to operate systems of decentralized and centralized water infrastructure?
- What is the allocation of water amongst sectors in 21st century industrialized and industrializing regions?
- How to engage the public in improved operations of infrastructure systems?
- How to engage the public in cooperation between regions and sectors of water management?
- How do we develop smart infrastructure systems, that utilize both data and AI models seamlessly, for improved water management incorporating human feedback?

If we could solve these challenges, what would be the positive <u>societal</u> outcomes? *Amongst other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.*

- Human access to safe, affordable water and sanitation services
- Sufficient water available for essential products and services
- Water of sufficient quality and quantity to support evolving ecosystems
- Reducing carbon footprint
- Improved financial management and capital availability for water agencies

If we could solve these challenges, what might be the anticipated transformative <u>scientific/technical</u> outcomes? THINK BIG. What will be disruptive?

Direct impacts over the next 3 years:

- Adequate funding and trained personnel to implement needed system transitions and changes
- Strong models to support decision-making that combine data, machine learning, and operations
- Risk-informed planning of infrastructure operations using new data

Subsequent impacts over next 10 years:

- Water infrastructure that is net-zero or net-positive carbon/energy
- Water use that is net-zero or net-positive impact on the environment

- More lifeline and backup systems for water management

How will this meet the NSF *acceleration* criteria (discuss speed and scale)?

- Public engagement and cooperation towards improved operations can increase the speed of adoption and change
- Adequate funding and workforce development provides resources for water management agencies to implement solutions
- Integration of data and information models will necessarily involve the IT sector, which is a fast-moving industry with scalable products

What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
OR, What is stopping us from realizing the future you envision?
OR, What is needed to get us started?

- Adoption of water use efficiency and conservation is a highly political and potentially controversial question
- Tensions between new and potentially-risky investments with sources of funding and credit ratings
- Tensions between current and future priorities for adequate and sustainable water
- Lack of collective vision of a modern water infrastructure and who is driving that vision?
- Continuity in administrative priorities for local and regional water management

What expertise is needed?

- Data science and modeling
- Financial management
- Interdisciplinary and integrated systems analysis
- Small business development and entrepreneurship for water solutions, how to capitalize new water innovations
- Industrial operations
- Expertise for bringing research to address applied policy questions
- Policy implementation
- Behavioral models of decision-making and adoption

Why/How do these challenges meet the NSF *convergence* research criteria?
NSF Convergence Accelerator website

- *Multi-disciplinary research that is not specific to any current NSF program.*
- *Translational research that addresses a challenge of national interest.*

- Integrated water infrastructure has been emphasizing cross-disciplinary thinking for two decades
- Data and information models are an important contributor
- Better water management directly impacts human lives
- Critical contemporary issues for water (industrializing and industrialized countries) are

really about broad access to secure water supplies
- Water is a national security interest and critical international humanitarian issue

Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? *(particular emphasis outside academia highly suggested)*

- Water management agencies
- Residents (documented and undocumented)
- Corporations
    - IT industry
    - Industrial operations
    - Materials technology
- Fundings (traditional banks, investment capital, municipal bond funders)
- Regional planning organizations
- Regulatory agencies
- Media- traditional and non-traditional

What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? *(This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation ,etc.)*

- Inequitable water rights and access based in precedent
- Equitable cost of water access
- Rural communities that lack access
- Environmental access to water- Having environmental needs as an equal place at the table
- Privacy issues in data management of sensitive information (consumption)

How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.

- Global water leaders are shaping indicators and levers (Economist Global Water Index)
- Other NSF programs for risk management, civil infrastructure design
- Other federal agencies (USDA, DOE National Laboratories, Standards
- Energy production
- Other industrial sectors
- Water management agencies must be involved in innovations and changes
- Private non-profit sources of capital (those focused on climate resilient investments)
- U.S. Executive Branch (White House Action Plan on Global Water Security)

Please be prepared to give a 3-minute summary in plenary. We will hear summaries from each group when we reconvene. *(we will screen share your document and give you an indication of 30 seconds and out of time remaining)*

Working Document: Session 3
Infrastructure

Instructions:

- *If you have new members in your group, please quickly introduce yourselves (name, expertise, experience ??)*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the beginning of the alphabet?)*

Goal: please write a short funding call for each of the research questions (from the session 2 document below). Please address the questions in the blue boxes below - one research question per box, feel free to add as many boxes as needed *(you can refer to the KIStorm page "Session 3 Goals" for more details).*

Note: If you find out that a research question won't end up working for the convergence accelerator, that's okay – you can modify it so that it will work, or you can move on to the next research question.

What is the research question?
How can the adoption of smart systems modernize and optimize our national water infrastructure –to increase capacity, decrease cost, and increase sustainability? How can data models be used in water management and which technologies best enable this data-driven water infrastructure, integrating the human response (smart system include monitoring, networks, sensors, AI, automation, real-time data-based decision making)

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
Much disparate work going on in this space, but no one group is connecting all of the projects. We need to connect the dots and tie the pieces together as a "system" that is can be replicated and scaled, affordably. There is also a big gap in environmental justice–the equitable opportunity to optimize for all communities (not dependant on ability to invest). (System affordability and diversity of business models, community engagement).

Innovation in this space is rapidly moving and is mature enough to now benefic our water infrastructure with less risk than early adopters. Gains can be quickly realized by focusing on this area.

What is the roadmap toward societal impact?
Increases water quality, quantity, equitable access, sustainability, cost benefits, communications, Transparency with consumers related to appropriate data in the modern system).

Who needs to be involved in this process, who is not in the room, and how do we engage them?

- Tech Community (Amazon Web Services, Google, Microsoft,
- NGOs: Water.org, Charity: Water,
- Government Agencies: EPA, NASA, NOAA, USGS, USDA,
- Water Resilience Coalition

What is the research question?
How do we optimize our water infrastructure to increase capacity in a climate resilient approach? How do we better prioritize investments in our water infrastructure for modernization, capacity expansion, and climate resilience (in the face of uncertainty to the future?) How do we do it in a way that is equitable, engages the community, and enables fit-for-purpose water).

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.

- THIS IS VERY TIMELY: with the influx of infrastructure funding across the US–we need to ensure its used appropriately, with a lens to the future (and accounting for those areas of uncertainty).
- Do we have a vision and model of a modern water infrastructure that takes a holistic view of all of the stakeholders who influence the water infrastructure. We are struggling to bring the right groups together at diverse scales, diverse sectors. Very aligned to the work in governance of water.

What is the roadmap toward societal impact?
Through the right investments in the modernization of our water infrastructure, we get the path to optimize our water so that all people have daily, equitable access to safe and affordable water and all industry have enough water to produce the products, services and food in which we rely. We are maximizing our investment (from taxes to water consumers) in the best areas to make the system more resilient and sustainable.
Who needs to be involved in this process, who is not in the room, and how do we engage them?

- Water Utilities
- Water Investors
- Water innovators
- NGOs; Nature Conservancy, World Resource Institute,
- Large industrial water users (key sectors within the U.S.)
- Economist Water Optimization Index (or global Water expert panel)

Builds:

1. Even in the US - there are ~40 million private well users. That infrastructure is private. When does it make sense to have centralized piped water supply in low population density areas? Probably not everywhere.
2. I like your future looking focus. Thinking about the long-term sustainability of infrastructure is essential.

Concern:

1. Just like before, talking about quite a bit and hard to tell where the focus is. And where is political power in your analysis?

Appendix I. Working Document for ***Water Quality*** Theme

The content provided here is a direct copy of the working document with which the participants engaged. The workshop organizers did not modify any content; we did lightly edit the formatting. Participants did not necessarily answer all questions, and any blanks were left by the participants. The brainstorming in Session 2 was used as motivation for the activities in Session 3. For the Session 3 prompts, participants were provided with the content in Appendix E, but that content was not reproduced verbatim in the working documents.

Working Document: Session 2
Water Quality

Instructions:

- *Please have your camera on and quickly introduce yourself (name, expertise, experience, commitment, passion?) (5-10 minutes).*
- *You will have a total of 60 minutes in this breakout session.*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the end of the alphabet?)*

What is the Theme: Water quality
Who's in this working group? ● Lilit Yeghiazarian, UC ● Jenny Murphy, USGS ● Lex van Geen, LDEO/Columbia ● Steve Jons, DuPont Water Solutions R&D ● Joseph Hoover, University of Arizona
What are the key / prioritized challenges that should be addressed within this theme? ● Emerging and legacy contaminants ● Geogenic contaminants (arsenic, uranium) ● Land use, including urbanization, agriculture ● Contaminated recharge ● Will climate impact water quality significantly and if so how? ● Increased groundwater pumping

- Affordable means for attaining (e.g. treating, selecting) good water.
- Access to information and trust in water quality (regardless of source)

What are the research questions that would be appropriate for these challenges? How might you articulate the research questions?

- What is the fate, transport, and health impacts of emerging contaminants?
- Identification of sources, e.g. microbial source tracking. Prevention and permitting (this is synergistic with policies /governance)
- Measurements, analysis, and information dissemination.
- Laboratory vs. field kit measurements
- Cost/benefit of expanding centralized system vs. decentralized water systems
- Water treatment vs. targeting by uncontaminated aquifers

If we could solve these challenges, what would be the positive <u>societal</u> outcomes? *Amongst other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.*

- Improved health, access, and equity
- Increased accountability of water providers
- Increased trust in water supply
- Increased public knowledge and dialog on water reuse and treatment options

If we could solve these challenges, what might be the anticipated transformative <u>scientific/technical</u> outcomes? THINK BIG. What will be disruptive?

Direct impacts over the next 3 years:

- Improved testing devices enabling information sharing
- Increased understanding of fate, transport, and health impacts of emerging contaminants.
- Better evaluation of relative risk for prioritization

Subsequent impacts over next 10 years:

- Better/cheaper water treatment technology
- Improved efficiency and usability for decentralized systems/individual users
- Improved water quality for a variety of applications and decreased human exposure to deleterious chemicals

How will this meet the NSF <u>*acceleration*</u> criteria (discuss speed and scale)?

- Addresses need of many users who don't have access to good quality water (and many can't find out)
- Requires government, academic, industry, and community partnerships
- NSF investment will speed along development of testing devices and systems

What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
OR, What is stopping us from realizing the future you envision?

What expertise is needed?

- Chemical/biological sensor expertise
- Hydrology
- Engineering
- Marketing
- Risk assessment
- Social science
- Policy making

Why/How do these challenges meet the NSF *convergence* research criteria?
NSF Convergence Accelerator website

- *Multi-disciplinary research that is not specific to any current NSF program.*
- *Translational research that addresses a challenge of national interest.*
- Both technical and social issues will need be addressed to meeting Need for continued maintenance of water treatment systemschallenges of disseminating water quality information or meeting their needs.
- Finding acceptable solutions across multiple groups with diverse interests and culture

Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? *(particular emphasis outside academia highly suggested)*

- Scientists with appropriate expertise
- Commercial interests (that may be distributors)
- Water suppliers, domestic well users
- Community

What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? *(This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation ,etc.)*

- Whether across the globe or within the US, water quality issues are more likely to impact regions of less means.
- It has been more difficult to provide actionable information to members of less advantaged groups.
- Water quality solutions are less likely to be afforded by people in disadvantaged groups.

How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.

- SBE on behavioral responses to information (incl. water quality)
- NSF EAR Hydrologic sciences
- USGS Water Mission Area, Integrated Water Availability Assessments Program

Please be prepared to give a 3-minute summary in plenary. We will hear summaries from each group when we reconvene. *(we will screen share your document and give you an indication of 30 seconds and out of time remaining)*

Working Document: Session 3
Water Quality

Instructions:

- *If you have new members in your group, please quickly introduce yourselves (name, expertise, experience ??)*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the beginning of the alphabet?)*

Goal: please write a short funding call for each of the research questions (from the session 2 document below). Please address the questions in the blue boxes below - one research question per box, feel free to add as many boxes as needed *(you can refer to the KIStorm page "Session 3 Goals" for more details).*

Note: If you find out that a research question won't end up working for the convergence accelerator, that's okay – you can modify it so that it will work, or you can move on to the next research question.

(1) What are the barriers to access to high quality drinking water for all?

What are the relative health impacts of potential contaminants?
How do the barriers (below) influence the occurrence and distribution of potential contaminants?
Testing methods for contaminants

Barriers

- Aging infrastructure
- Lack of infrastructure
- Lack of real-time sensing systems for microbial contaminants
- Affordability
- Plans and policies that may not be informed by data
- Inequity and resource distribution
    - Do we have the necessary people and groups at the table?
- Data siloing and accessibility
- Limited knowledge about fate, transport, and health impacts of emerging contaminants.
- Access to information, information transparency, lack of testing
- Risk perception
- Slow regulation process (US)
- Transient nature of acute contamination events

- Agricultural and industrial discharges

Gaps and needed partnerships to address the research objectives.

- Available, inexpensive, and reliable testing at the tap
- Investment for developing these sensors - private market unclear
- Individual household, community/libraries-based devices
- Automated monitoring and machine learning
- Data issues (bias in data collection, transparency in making decisions for pricing, access rights to data, ethics, privacy, maintenance, connectivity limitations (lack of cell or broadband coverage), etc)
- Affordable removal technology for various technologies

Roadmap toward societal impact

- Development and implementation of activities and education that increase awareness, trust and understanding of risk perception
- Internet of Things as an enabling technology
- ML/AI technologies to capture spikes in acute water contamination events
- User friendliness of devices

Who needs to be involved in this process

- Consumers, including overlooked communities
- Government
- Industry (water supply, sensor development, treatment technology)
- Partnerships with public and private water utilities (provide publicly accessible water quality data)
- Schools K-12, kids of all ages, teachers
- Science museums

(2) How could surface and groundwater pollution be reduced?

Barriers

- Insufficient regulations
- Lack of measurements, focus on key nutrients and select chemicals
- Spatial distribution of measurement locations are uneven
- Historically acceptable pollution

Gaps and needed partnerships to address the research objectives.

- Desirability of a pervasive network of water quality sensors and data dissemination/analysis for decision making. Accomplishing will require academic, industry, and technology. Subsequently, system maintenance and information dissemination. Where to place sensors can be concern.
- Land management practices, and enforcement. Engagement with farmers and cooperative extensions,
- Broader framework to engage community leadership in site selection for water quality monitoring

Roadmap toward societal impact

- Sensors and knowledge of pollution is a good first step.

Who needs to be involved in this process

- Industry, farmers, ag groups, regulators, public
- Scientists

Builds

1. A barrier to high quality drinking water can be a lack of regulatory levers to address water quality issues, for instance with secondary contaminants such as odor/color, and issues generally that originate from premise plumbing where property owners may not have incentives to test/address.
2. try to work in notions of trust (rational and misguided) and get beyond information deficit model
3. Please look at note on genetic elements (specifically ARGs: antibiotic resistance genes) as a contaminant of concern
    a. Microbial pathogens
    b. Geogenic in groundwater (arsenic, uranium)
    c. From supply system (lead)
    d. Emerging contaminants (PFAS, pharmaceuticals, microplastics)
    e. Nutrients
    f. Algal toxins

Appendix J. Working Document for ***Natural Hazards*** Theme

The content provided here is a direct copy of the working document with which the participants engaged. The workshop organizers did not modify any content; we did lightly edit the formatting. Participants did not necessarily answer all questions, and any blanks were left by the participants. The brainstorming in Session 2 was used as motivation for the activities in Session 3. For the Session 3 prompts, participants were provided with the content in Appendix E, but that content was not reproduced verbatim in the working documents.

Working Document: Session 2
Natural Hazards

Instructions:

- *Please have your camera on and quickly introduce yourself (name, expertise, experience, commitment, passion?) (5-10 minutes).*
- *You will have a total of 60 minutes in this breakout session.*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the end of the alphabet?)*

What is the Theme: Natural Hazards (or "Water-Related Hazards" to avoid the problems with "what is natural")
Who's in this working group? ● Courtney Flint ● Romaric Odoulami ● Beth Hall
What are the key / prioritized challenges that should be addressed within this theme? ● US drought challenges/US flood challenges ● Providing index-based insurance (IBI) for drought relief, particularly in sub-Saharan Africa ● How might we manage the compound and cascading hazards associated with water? ● Observational, in situ data is not dense enough to capture localized natural hazards to better understand cross-themed research (new challenge)
What are the research questions that would be appropriate for these challenges? How might you articulate the research questions? ● What innovative strategies are useful for addressing post-disaster wellbeing,

livelihoods, and water management?
- How can complex systems-based approaches address multi-faceted, compound, and cascading water-related hazards/disasters?
- What are the metacoupled impacts (i.e. human-nature interactions across space) of place-based extreme water-related events or their timing? (e.g., impacts to transportation, navigation, supply chains, etc.).
- How does climate change impact compound water-related hazards?
- Can innovative post-disaster management tools (e.g., index-based insurance) be implemented more broadly for sustainable climate change adaptation?
- What are the interactions between extreme water hazards, such as drought and flood?
- How can the lack of local observational data be accounted for when examining local and/or high-resolution detail on the relationships between natural hazards, water resources, and their impacts?

If we could solve these challenges, what would be the positive <u>societal</u> outcomes? *Amongst other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.*

- Increased wellbeing and decreased vulnerability and inequity.
- Avoid the severe impact of prolonged droughts leading to deep economic impacts (economic droughts), which could impact livelihoods through provision of direct cash payouts (e.g., via index-based insurance).
- Adaptive water and climate change hazard governance strategies.
- Increased resiliency and preparedness among vulnerable communities, populations, and ecosystems
- Innovations could lead to opportunities to take advantage of extreme precipitation events to enhance capture/storage.

If we could solve these challenges, what might be the anticipated transformative <u>scientific/technical</u> outcomes? THINK BIG. What will be disruptive?

Direct impacts over the next 3 years:

- Deeper convergent research approaches
- Clarified needs and goals for data integration across disciplines, sectors and hazard areas

Subsequent impacts over next 10 years:

- New mechanisms and platforms for data integration across sectors and hazard areas
- Increased training and preparedness priority for vulnerable communities and populations

How will this meet the NSF <u>*acceleration*</u> criteria (discuss speed and scale)?

- Requires convergent approaches (integrated disciplines and expertise to address real-world problems)
- Involves beyond science stakeholders

What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
OR, What is stopping us from realizing the future you envision?
OR, What is needed to get us started?

- Siloed approaches keep us from seeing and addressing complex systems interactions across hazards and broader societal contexts
- Lack of high spatial density observational data to capture detail within vulnerable communities/locations

What expertise is needed?

- Transdisciplinary/convergent approaches (social-economic and physical science as well as insurance sector and broader societal and policy actors)
- Information/data management and cyberinfrastructure expertise
- Communication strategies to reach vulnerable populations without pervasive information access
- Co-production / focus group experience
- Geospatial expertise focused on societally relevant and inclusive tools and techniques to represent societal complexity (rather than extant publicly available static indicators)
- Expertise in co-developing needs assessments with communities in order to target research (including participatory research) and interventions.

Why/How do these challenges meet the NSF *convergence* research criteria?
NSF Convergence Accelerator website

- *Multi-disciplinary research that is not specific to any current NSF program.*
- *Translational research that addresses a challenge of national interest.*

- These questions get at real-world problems from an integrated, transdisciplinary approach.

Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? *(particular emphasis outside academia highly suggested)*

- Insurance sector (to assist with innovative index-based approaches to drought, etc.)
- Local-regional emergency managers in order to provide contextual knowledge of cross-sector needs, issues, and interactions.
- Leaders within vulnerable communities who communicate with at-risk populations

What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? *(This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation ,etc.)*

- Lack of data/information access to many vulnerable communities / populations (e.g., rural, low-income)
- Lack of data collection priority within vulnerable community locations/areas
- Index-based insurance (IBI) cost may increase as climate change increases the likelihood of water related disasters making insurance more difficult for the most

vulnerable to access IBI
- Mechanism used in quantifying risk to price IBI should be more equitable and inclusive (use an approach to offer cover to those with less resources)
- Need to avoid creating winners and losers (perceived or real) when implementing innovative approaches to hazards (e.g., insurance-based approaches).

How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.
- This work could integrate NSF efforts in decision and risk management, earth systems science, critical infrastructure, DISES, etc.
- Emphasis on co-production between end user and researchers/developers

Please be prepared to give a 3-minute summary in plenary. We will hear summaries from each group when we reconvene. *(we will screen share your document and give you an indication of 30 seconds and out of time remaining)*

Working Document: Session 3
Natural Hazards

Instructions:
- *If you have new members in your group, please quickly introduce yourselves (name, expertise, experience ??)*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the beginning of the alphabet?)*

Goal: please write a short funding call for each of the research questions (from the session 2 document below). Please address the questions in the blue boxes below - one research question per box, feel free to add as many boxes as needed *(you can refer to the KIStorm page "Session 3 Goals" for more details).*

Note: If you find out that a research question won't end up working for the convergence accelerator, that's okay – you can modify it so that it will work, or you can move on to the next research question.

How can complex systems-based approaches address multi-faceted, compound, and cascading water-related hazards/disasters?

The very essence of complex hazards are their multifaceted interactions and potential cascading impacts that can trigger additional hazards and their consequences. Given the ubiquity of water and how essential it is, there are few sectors or social entities unaffected in a place experiencing a water-related hazard event. For example, climate change may bring extreme precipitation

events causing flooding in headwaters. These waters may overwhelm aging dam infrastructure posing risk of dam failure (and downstream dam failure) and leading to intense downstream vulnerability to critical infrastructure, ecosystems, and populations. Additionally, there may be impacts felt far beyond inundation zones along networks related to water use, supply changes, power grids, etc.

This research question on complex, compound water-related hazards calls for research that bridges disciplines related to water-related hazards using systems approaches to better understand the linkages across sub-systems and new innovative approaches to manage this complexity and move from states of vulnerability to greater resilience. Beyond scientific domains, it is essential to engage beyond science to professional and local entities and expertise to inform collaborative problem identification, integrated and co-designed and co-implemented research to most directly address compound hazards. Moving beyond theoretical approaches to place-based and real-world hazard contexts is essential for convergent research. By conceptualizing hazards through to the consequence of an event for vulnerable infrastructure, ecosystems, and populations, a diverse array of research stakeholders can be identified along with clearly identifying key societal outcomes. A nexus of scientific (earth science, hydrology, engineering, social, etc.), professional (i.e. emergency/hazard managers, critical infrastructure managers), and representatives of vulnerable ecosystems and populations related to compound, nested, or cascading hazards is needed. The difficult part is to avoid an unwieldy number of participants. Addressing barriers to participation such as jargon, timing, resources, etc. are key to attracting key individuals and entities into the research space. Innovative approaches such as citizen science, stakeholder assessments and analysis, and community-based research can help to bring in diverse perspectives along the research timeline. It is key to bring the diverse array of research specialists together early in the process to help form a cohesive articulation of research goals and problem framing. Advanced geospatial techniques will be crucial for capturing complex linkages and integrating data. By involving diverse and place-based stakeholders involved in hazard mitigation and event response and recovery, this research can provide critical information and roadmaps for reducing social, ecosystem, and infrastructural vulnerabilities.

What is the research question?
What innovative strategies are useful for addressing post-disaster wellbeing, livelihoods, and water management?

Please flesh out the research question a bit more.
Post-disaster management is a key process,which requires innovative measures in the way hazard-induced damages to human and natural systems are addressed. It is, therefore, important to identify or develop innovative tools that could be used to better assist in the way peoples, their livelihood and wellbeing, water resources, and other natural systems are managed especially in the aftermath of a weather or climate hazard, which often could have a significant impacts on both human and natural system across the globe. As anthropogenic greenhouse gas emissions continue to rise, which is likely to increase the risk of severe weather and climate hazards across the world. It is, therefore, imperative to better our understanding of how this risk will manifest and impact human and natural systems in most parts of the world, especially in

regions - mostly in the developing world - that are the most vulnerable to the impacts of climate change with less adaptive resources. Understanding how this risk is changing and will continue to change in the future is important in inducing preparedness and designing innovative adaptation strategies, which could assist in alleviating post-disaster management.

We want to highlight research that fills critical gaps that can only be addressed through diverse partnerships. Please be specific about the gaps and needed partnerships to address the research objectives.
The focus here is to assess how the risk of water-related weather and climate extremes under anthropogenic forcings has changed and will continue to change in the future. Also it is important to address some of the critical knowledge gaps related to post-disaster management, water resource management through the evaluation and testing of existing post-disaster management tools/strategies in the context of climate change - testing their limits under anthropogenic influences in the present and future climate conditions. It is important to improve these tools/strategies when possible and suggest and test new ones.

What is the roadmap toward societal impact?
Being able to clearly articulate the following is crucial:
(i) Who are the end users (beneficiaries)?
(ii) Where is in the most need of such tools (Developing world and/or marginalised regions across the developed world)?
(iii) Why is such action required?

Who needs to be involved in this process, who is not in the room, and how do we engage them?
It is crucial to adopt an interdisciplinary and/or transdisciplinary approach here by assessing climate change risks from the perspective of both those working in the risk management sector, early warning systems, other related sectors by developing a collaborative research with those in practice (e.g., insurance sector, post-disaster management organisations, etc.). Establishing advisory boards and research partners in these sectors early and often in the research process is key to engagement and meaningful collaboration.

How can the lack of local observational data be accounted for when examining local and/or high-resolution detail on the relationships between natural hazards, water resources, and their impacts?

While there are vast data sources related to water resources as well as characterizations of ecosystems and populations at risk to water-related hazards, these datasets are often plagued by problems related to scale, data resolution, units of analysis, and vague or conflicting data goals and purposes.

There is a need to expand integrated data management, analysis, and visualization related to water resources and connections across hazards, sectors, and vulnerabilities, particularly at local scales. This effort will require relationships and partnerships with locally-focused entities who produce and maintain high-resolution data relevant to water resources and local to regional contexts. Often, local governmental and non-governmental entities have place-based data collections that are not connected with large spatial or temporal data systems. Combining interdisciplinary teams of water scientists with place-based experts with local to regional professional knowledge, new platforms can be created to integrate multi-scale data and to identify critical gaps needed to advance time-sensitive research and to protect vulnerable communities and locations. Attention to high-resolution and place-based data can help to ground-truth macro-level data and evaluate the accuracy of predictions based on lower-resolution data.

Information/data management experts and those with cyberinfrastructure expertise are essential to this endeavor, as are those with technical communication skills to ensure that platforms and data sources are accessible and usable to those who need them most for hazard mitigation, preparedness, and event response and recovery. Co-produced research on the integration of local and high-resolution data related to water resources and their broader contexts is essential, and is predicated on the early and consistent interactions among all key entities. These pathways ensure multifaceted and targeted flows toward societal benefits, vulnerability reduction and enhanced resilience.

NOTE FOR SESSION OVERALL - I would propose we emphasize “hazards” rather than “natural hazards” as the interaction between natural, built and social forces are essential to hazards framing.
(C Flint)

Build:

1. How to fund hazard mitigation with respect to water? Currently neither hazard funding streams or water funding streams take account of this interaction.

Appendix K. Working Document for ***Water Valuation and Pricing*** Theme

The content provided here is a direct copy of the working document with which the participants engaged. The workshop organizers did not modify any content; we did lightly edit the formatting. Participants did not necessarily answer all questions, and any blanks were left by the participants. The brainstorming in Session 2 was used as motivation for the activities in Session 3. For the Session 3 prompts, participants were provided with the content in Appendix E, but that content was not reproduced verbatim in the working documents.

Working Document: Session 2
Water Valuation and Pricing

Instructions:

- *Please have your camera on and quickly introduce yourself (name, expertise, experience, commitment, passion?) (5-10 minutes).*
- *You will have a total of 60 minutes in this breakout session.*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the end of the alphabet?)*

What is the Theme: Water Valuation and Pricing
Who's in this working group? ● Mitchell Strauss ● Sally Letsinger

What are the key / prioritized challenges that should be addressed within this theme?

- Equity (some have more, some have less, some use more, some use less).
- Access to (clean) water as a human right.
- Capacity to pay.
- Valuing what we have and what it will cost to retain and improve it in the event of degradation so that pricing by water providers is looked at on a fully-loaded basis prior to considering political pressures to keep prices artificially low.
- Water markets can cover a variety of approaches to incentivizing action to reducing dangerous water degradation (quantity or quality).
- Construct a water market, relating to similar elements as contained in carbon market.
- Create a credit that can be traded and used ultimately to assist in funding investment (internationally) in water projects.
- Prioritization of water projects might include measures of equity, such as for countries with most need (e.g., financial, scarcity of available water resources) could be variables to consider.
- Promotion of water literacy, akin to financial or ecological literacy
    - Only with water literacy as a condition could such a system be equitable - otherwise it would be yet another imposed and opaque system where public engagement would be very limited
- Could this initiative become a living case study for business schools and universities?
- In the sort of market where this approach would be likely to be trialed, corruption would be a key challenge - how to tackle that?
- What would the governance mechanism look like?
- Could there be some form of break/brake mechanism for when and where the reviews showed pinch points or abuses?
- How would learning/lessons be spread between similar initiatives?

What are the research questions that would be appropriate for these challenges? How might you articulate the research questions?

NOTES

- Determining water activity or footprints of uses, sectors, activities (including real and virtual water). Real water example: irrigation water; virtual water example: agricultural commodity that is exported from the source watershed (e.g.the water in a fattened mature animal).
- Determining appropriate offsets as some activities are positive and some are negative to a water usage bottom line.
- Determining mechanisms for implementing offsets (like purchasing offsets for energy consumption - analogous for water)
- Look for analogies with wetland mitigation banking
- Sectors, such as: https://indiana.clearchoicescleanwater.org (pledges, but likely need incentives)
- Incentives (carrots) - rebates, subsidies, tax rebates other rewards/awards
- Tie water market to energy/carbon markets for sectors where water/energy intersect (are related). Think planting trees. Or water and energy (circular) relationships within agricultural animal products (Calculate activity/effect/CO2/gallons of water)

- Quantifying available quantity and quality. Energy is required for reclamation/remediation.
- Issues, actions, and markets are spatially variable
- Quantifying actions, scaling actions.
- Publicize existing partial solutions such as proposed by Aqua for All https://aquaforall.org/wp-content/uploads/2021/07/Aqua-for-All-Carbon-credits.pdf
- Enable more investing entities to participate in the financing of water mitigation and adaptation solutions including retail investors (Kiva.org style) investing through to the international capital markets including real investments in addition to derivative type transactions.
- Voluntary water credit market between entities, and different pricing through verified water markets.
- Verified water footprints - verified water reductions are a reduction in water uses from a project that is independently audited (i.e., verified or certified) against a third-party certification standard.
- Consider tax benefits based on true water value for water preservation or restoration by individuals or corporations.
- A water market would allow investors and corporations to value their existing water footprint in a more robust way including reporting to shareholders and ultimately to trade water credits and offsets, reduce their corporate consumption/usage, or provide tax rebates based on fully-loaded value opportunities.
- Local water markets, implemented through utilities, should adhere to equity-based pricing. Those less able to pay should receive preferential consideration and those that squander should pay more. Develop mechanisms to share publicly.
- Does neglect of abundant current water resources lead to future water scarcity (e.g., allowing abundant groundwater resources to be contaminated, requiring the need to drill into deeper aquifers, which are briney and will require future desalination)? How do we stare at and plan for these future costs if behavior doesn't change?
- Existing similar work: https://wires.onlinelibrary.wiley.com/doi/10.1002/wene.358

If we could solve these challenges, what would be the positive societal outcomes? *Amongst other ideas, please consider education & training, diversity, equity, and inclusion when answering this question.*

- Collective action can be aggregated into substantial amounts of water
- Goal of finding a way for wasteful industries to pay for the damage done by overconsumption and/or degradation.
- Least developed countries or those with scarce water resources might have more financial resources as a benefit of valuing and trading water credits to fund engineering and other investment solutions to address their issues.
- Help in meeting the SDG6 for water and sanitation

If we could solve these challenges, what might be the anticipated transformative scientific/technical outcomes? THINK BIG. What will be disruptive?

Direct impacts over the next 3 years:

- Increase investment for water-related projects

- Additionality – that is, achieve more than what would have ordinarily happened in a business as usual context
- Realistic and credible baseline – for determining reductions in usage and enhancement in quality of water
- Robust monitoring and verification (MRV)
- Strong registry systems for tracking units
- Have permanence requirements or mitigations for reversal risks

Subsequent impacts over next 10 years:

- Affordable and available and potable local water supplies
- Incentives to keep water clean (higher value)
- Avoid mass atrocities that could occur when resources become scarce and people are willing to kill for them. (see: https://www.devex.com/news/devex-newswire-how-climate-change-and-mass-atrocities-are-linked-104248)

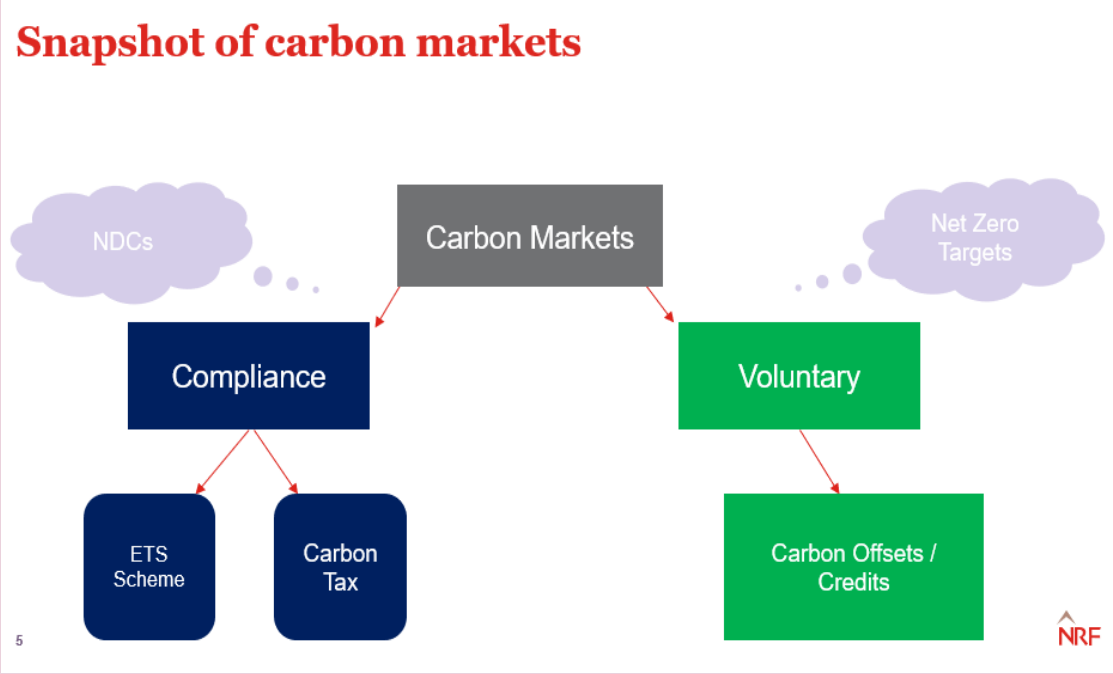
How will this meet the NSF *acceleration* criteria (discuss speed and scale)?

- Jump-starting this inevitable research is vital to a more robust understanding of the value of existing water, the cost of usage, the hidden cost of degradation.
- As nations have come together and supported with commitments to address climate change related to greenhouse gasses, they will become armed with better information to disseminate to the public and the investment community of the size, value and urgency of addressing water challenges
- Valuation of water can arm the public and taxing authorities with the options and tools available to stave off the economic and human toll of failing to address the issues.

What are all the obstacles/hurdles within these challenges that must be addressed/considered in order for you to succeed?
OR, What is stopping us from realizing the future you envision?
OR, What is needed to get us started?

Water markets don't exist, yet…
Challenges - local sustainability solutions (e.g., engineered) should be evaluated for watershed-wide impacts, and those activities that are positive should carry positive compensation and negative follow-on results may carry negative financial consequences (e.g., downstream water users should be assured that the water supply won't be interrupted by upstream storage).

If we replace the word carbon with water we can envision a better way forward. Water credit prices would need to adhere to a rubric or objective to meet certain goals/ambitions. For example, the global weighted-average carbon price is only $28/ton, too low to incentivize tangible decarbonization - so these calculations and pricing need to be balanced to be appealing investors.



What expertise is needed?

- Economists
- Energy/water expertise
- Sector/market expertise to trace water footprints, project lifespans, use trends/projections
- Policy experts
- Financial innovators from the capital markets to develop products
- Insurers
- Health professionals (water quality and cost avoidance)

Why/How do these challenges meet the NSF *convergence* research criteria?
NSF Convergence Accelerator website

- *Multi-disciplinary research that is not specific to any current NSF program.*
- *Translational research that addresses a challenge of national interest.*

- This topic is a multi-disciplinary topic. Water-use sector experts/scientists/engineers, economists, finance and policy experts ideally identify parameters necessary to begin to treat water in the same way we look at carbon preferably contemporaneously.

Who are the stakeholders (or potential partnerships) that need to be involved in the discussions on this topic (publics, industry, non-profit, government, academia, etc.) and why? *(particular emphasis outside academia highly suggested)*

- First step is to include those that can provide a rubric to value water
  - Sector experts including scientists and engineers
  - Economists
  - Academics
  - U.N. Framework Convention on Climate Change, IMF, World Bank, the IFC,

G7 DFIs. World Bank and IMF experts can prompt policy changes at a broader range of institutions. (The IMF sits at the center of a global web of financial institutions and regulators, including central banks.)

- (Local) water pricing - local government, utilities - to be based on the value of water (and the cost to achieve appropriate uses), equity considered
- National/International -people who worked on the Paris Agreement
    - Interagency Water Working Group(IWWG) (US government entities/agencies with interest in water, coordinated by the U.S. Department of State)
    - Engage developers of and follow the path that led to the Paris Climate Accord (identify experts, stakeholders)
- Foundations/Not-for-profit sector
- Investment advisors

What are key issues in equity, diversity, inclusion, and justice that need to be considered in this topic? *(This can include a wide variety of topics, including environmental justice, community engagement, citizen science, representation ,etc.)*

- Water as a human right regardless of ability to pay.
- Global water cycle. This is an international challenge faced by haves and have nots, both of water and the capacity to finance interventions to sustain water.
- Scarcity of potable water leads to political upheaval and migration in addition to health issues and death.

How would this team's work connect to or leverage other initiatives or programs? Examples include other NSF programs, other funding agencies or governmental organizations, or non-profit or international efforts.

- The work done on climate internationally by corporations, certifiers and verifiers can easily be stretched and adapted to accommodate water parameters.
- Water footprints per activity and per sectors will need to be identified, so sector-specific knowledge will be needed
- Other energy/food/water programs might be related

Please be prepared to give a 3-minute summary in plenary. We will hear summaries from each group when we reconvene. *(we will screen share your document and give you an indication of 30 seconds and out of time remaining)*

Working Document: Session 3
Water Valuation and Pricing

Instructions:

- *If you have new members in your group, please quickly introduce yourselves (name, expertise, experience ??)*
- *We find it helpful to select one person to act as scribe (perhaps the person whose last name starts closest to the beginning of the alphabet?)*

Goal: please write a short funding call for each of the research questions (from the session 2

document below). Please address the questions in the blue boxes below - one research question per box, feel free to add as many boxes as needed *(you can refer to the KIStorm page "Session 3 Goals" for more details).*

Note: If you find out that a research question won't end up working for the convergence accelerator, that's okay – you can modify it so that it will work, or you can move on to the next research question.

Develop a new valuation methodology for water and determine whether a water-credit scheme like carbon can lead to the ability to trade within a water market yielding investment dollars for water projects. Any carbon valuation might include contemporaneously a water valuation, costs and savings on a fully-loaded basis.

Water valuation should consider long-term costs (e.g., water degradation, future infrastructure) and long-term benefits (e.g., quality enhancement) should be taken into consideration by rate-setters. If you can quantify savings, you can incentivize others (e.g., foundations) to pay for outcomes based on those savings.

Failure to study this is to not act.

Water utility personnel, politicians, and regulators are missing a full toolbox in valuing water. Local water valuation does not currently include the full lifespan of the utility or the consequences of degradation of quality or depletion of supply (i.e., good water is worth more than bad water; avoiding water degradation and averting associated future infrastructure is more valuable than not anticipating the degradation).

Once water can be fully valued, there is an opportunity for financial innovators to create tradable securities or derivatives based on specified outcomes. These may initially be supported with soft money, non-financial return seeking funds, from foundations that seek societal improvement over financial return. Utilities and others who have water can more properly value good potable water at a higher value if it lacks contaminants and potentially borrow against an enhanced value of assets. Accounting downgrades for less valuable water would encourage spending to bring the asset values up.

Research call should require proposers to outline how they would scale local water valuation up to a global water market. In addition, how they would attempt to replicate a carbon-market approach to water based on quantity and quality.

Knowledge gaps in this sector are among and between local water utilities and their stewardship of regional water supplies, as well as the connection of local water management to national and international sectors that intersect with water (e.g., xx).

Positive societal impact follows from the research team identifying the connections between sectors and builds a road map to scale and aggregate solutions by creating toolboxes/dashboards for multiple variables to be assessed by stakeholders (utilities,

investors), resulting in the ability to value water and establish tiered pricing systems designed with equity and water as a human right in mind.

A proposal team would ideally include local utilities (or regulators familiar with setting water pricing rates using existing considerations), water scientists, environmental regulators, financiers, actuaries, infrastructure experts or engineers, economists, and other communities that can contribute to all facets of water valuation (e.g., indigenous communities).

An important part of the proposal review would be an assessment of the constitution of the research team and the way and timing that the team would integrate stakeholders and the level of collaboration proposed with those stakeholders and practitioners.

A separate funding call for a thought consortium to develop tools for promotion of water literacy, akin to financial or ecological literacy. Water literacy is needed at different scales and is directly related to stewardship and valuation.

The premise is that only with water literacy as a condition could water markets be equitable - otherwise it would be yet another imposed and opaque system where public engagement would be very limited.

How can we help governments provide carrots to states, businesses and individuals to value husbandry of water? Tax systems, performance payments, staggered pricing for excessive users, weighted financial benefits for water users to use less quantity -speaks to adoption of water saving locally.

A proposal should include an initiative to develop a living case study for business schools and universities. Topics to work through would be how to avert likely corruption that could be a key challenge in the sort of market where this approach would be likely to be trialed.

Proposal needs to consider governance mechanisms including recommendations on how engagement of entities that currently verify (and certify) carbon, auditing firms and accounting standards boards and organizations might assist in oversight.
These entities might assist to create a braking mechanism (possibly through the verification process) for when and where the reviews showed pinch points or abuses.

The proposal should address the optimal methodology for disseminating the learning/lessons and address how ideas might be spread between similar initiatives.

The proposal should address the deliverables and the timing of dissemination of the knowledge to the public. As an example, the proposal should address the timing of the development of the priority water valuation tools with a sense of the urgency of the work so that the results may be shared publicly as soon as practicable to encourage building on the knowledge with a broader range of input.