WATER RESOURCES

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WICKED WATER PROBLEMS

AMERICAN
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ASSOCIATION

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Wicked Water Problems

Guest Editors: Sharon B. Megdal and Lisa Beutler

This issue of *Water Resources IMPACT* was inspired by an AWRA 2020 Annual Conference panel session on wicked water problems. From this jumping-off point, the issue brings you articles on how to understand wicked water problems in various contexts. Two articles discuss the complexities imposed by the COVID-19 pandemic, and the issue also spotlights wicked water problems affecting the Navajo Nation, where water insecurity is widespread. Several of the authors consider how we can begin to address wicked water problems—an ongoing challenge, given that wicked problems are not susceptible to one-and-done solutions. We hope this issue provides a better understanding of wicked problems from multiple perspectives and provides practitioners with realistic tactics to address the wicked water problems in their own spheres.

About the cover: Water bed dried up from river in Wasatch Mountains. Photo credit: Pureradiancephoto at iStock.com.
Page 3 photo credit: Furo_felix at iStock.com.

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PRESIDENT'S MESSAGE

Scott Kudlas, AWRA 2021 President

I AM DELIGHTED TO PROVIDE MY FIRST PRESIDENT'S Message to introduce the January issue of *IMPACT* focusing on "Wicked Water Problems." Wow, and what an issue it is! This topic is particularly important to me as a practitioner who has struggled over a 30-year career—whether working to restore the Chesapeake Bay or address overallocation of coastal groundwater—to work through complex, and sometimes wicked, water problems. I am so proud to be a part of an association that acknowledges the critical importance of collaborative, multidisciplinary, adaptive approaches to solving problems. I hope that many of you reading this issue had the opportunity to participate in the 2020 AWRA Annual Conference, where we had a thought-provoking, highly interactive panel on this very topic, featuring Lisa Beutler, Betsy Cody, Michael Campana, and Sharon B. Megdal. The panel and its interactive virtual dialogue was a highlight of the Annual Meeting for many attendees. This issue is a continuation of that dialogue, with contributions from each member of that panel.

I am confident that this issue of *IMPACT* can serve as a resource for those interested in understanding the unique nature of wicked problems and seeing examples of colleagues working with others to make progress managing problems that have defied traditional solutions. Sharon B. Megdal kicks us off with a wonderful reflection on her experience with the panel at the Annual Conference. She shares her observations about processes for addressing wicked water problems, along with some key takeaways from the audience interactions. Lisa Beutler follows with a foundational primer on wicked problems. As an early adopter of this systems-thinking approach, she has been a thought leader in our community on the topic. She deftly provides guidance on what is a wicked problem and what is not. I have always found that naming something helps me identify pathways to progress, and Lisa gives us thoughts on how to do both.

Betsy Cody turns the wicked-problem lens toward California's two largest water supply projects—the federal Central Valley Project (CVP) and the state-owned and -operated State Water Project (SWP)—and questions whether the management of these two projects can be defined as wicked problems. She illustrates the historical and ongoing efforts undertaken to balance multiple—and often competing—demands on these systems as they have evolved over time. Other highly informative contributions in this issue include a pair of articles on efforts by the Navajo. Chief et al. discuss the development of a resilience framework to address food-energy-water insecurities that considers Indigenous perspectives. They note, unfortunately, that "Existing resilience frameworks aim to co-manage resources and keep Indigenous people within an unjust and colonial system." Cordova-Tulley et al. provide firsthand insight into the conditions that create the daily water challenges faced by the Navajo—challenges that already exceed tribal capacity and budgets—and how COVID-19 has magnified them. While there is not enough space here to do all the articles justice, read on, and you will find other great content provided by Carol Collier, Alan Kolok, Amber Wutich, and Wendy Jepson. Finally, as Sharon Megdal so aptly states, "Indeed, the articles in this issue of *Water Resources IMPACT* reinforce the idea that working together respectfully and with open minds increases our capacity to address the many wicked water problems that confront us."

A few comments on upcoming AWRA offerings: If you liked the article by Cordova-Tulley et al., please consider registering for the 2021 Joint AWRA and National Capital Region Annual Water Symposium. The authors will be one of the highlighted offerings at this April 15–16, 2021, virtual event. Does the concept of intertwined issues that challenge traditional solutions stimulate you intellectually, and are you interested in making connections with professionals from outside your own discipline? If so, please register for our 2021 Virtual Summer Conference entitled "Connecting Land and Water for Healthy Communities." This will be an exciting event as AWRA is working in collaboration with the Babbitt Center for Land and Water Policy at the Lincoln Institute of Land Policy, the American Planning

Association, and the American Water Works Association. This conference, scheduled for July 19–21, 2021, is truly an interdisciplinary opportunity you cannot afford to miss. For our up-and-coming student members, who represent the future of our association, we have a series of virtual workshop offerings just for you. The first of these student and young professional workshops begins March 30, 2021. Check the AWRA website for more information.

Before I sign off, I wanted to point out that this issue of *IMPACT* reflects some themes that you will be hearing more about during my year as your president. As a community of interdisciplinary water professionals, AWRA is dedicated to bringing you timely content that fosters conversation and connects you to people and resources that can help us understand the nature of challenges so that we can work to address them. AWRA leadership recognizes the need to welcome diverse voices in our water community. I hope you will notice that our content and events increasingly offer perspectives from women, people of color, and Indigenous peoples. Keep a look out for other meaningful diversity, equity, and inclusion initiatives from your Board of Directors. We also recognize the importance of inclusive stakeholder engagement processes with all of our members, including the volunteer leaders of our technical committees and state sections, and our students. I urge you to participate as these opportunities develop. Participation is key to understanding the nature of our challenges as an association so we can tackle the issues we face and grow our community.

And lastly, we have new leadership at *Water Resources IMPACT*. Michael E. Campana is the new editor-in-chief, and Heidi Fritschel is the managing editor. ■

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FEATURE

Takeaways from the 2020 AWRA Annual Conference Panel on Wicked Water Problems

Sharon B. Megdal

I HAVE BEEN FASCINATED BY THE WICKED WATER problems framework since I was introduced to it in 2016, when Lisa Beutler gave a keynote address at the University of Arizona Water Resources Research Center's annual conference. I frequently use this framework to provide context to efforts to tackle challenging water issues, which are not solved but rather mitigated through the work of multidisciplinary teams. In my many lectures on the topic, I have tended to focus more and more on process factors that contribute to identifying and evaluating policy options and building consensus on pathways forward. During 2020, I spoke on this topic many times, and a highlight was the interactive panel discussion convened on November 9 as part of the annual conference of the American Water Resources Association (AWRA). Though we miss the kinds of interactions we have at in-person conferences, we've come to recognize that virtual platforms for conference delivery do have some advantages. Such platforms facilitate the sharing of thoughts, questions, and feedback from multiple people (often simultaneously) in real time and can actually enable more participation than might occur at a typical in-person session. Indeed, a robust and fun discussion ensued at the panel, featuring Lisa Beutler, Betsy Cody, Michael Campana, and yours truly, as well as an engaged group of participants. This article shares some of my observations about processes for addressing wicked water problems, along with key takeaways from the audience interactions.

In my brief prepared comments, I spoke about wicked water problems in the Colorado River Basin and the Middle East (see Figures 1 and 2). Examples from the Colorado River Basin include a basin-wide imbalance in supply and demand, groundwater overdraft and groundwater invisibility in central Arizona, lack of attention to water for nature (environmental flows), and the Navajo Nation's lack of water and water infrastructure. I also cited four examples from the Middle East: lower Jordan River flows and the condition of the Dead Sea, wastewater treatment in some areas, water provision and sources for the West Bank, and water supplies in Jordan. In the face of such problems, developing information collaboratively enables people to get on the same page in terms of characterizing problem(s) and identifying options to mitigate them. Partnerships within states and regions, across states, between nations, and with tribal nations are critical to building consensus on action pathways. Key factors that contribute to mitigating wicked water problems are functioning cooperative mechanisms, relationships based on trust and mutual respect, meaningful engagement of stakeholders, good communication, persistence, and patience. Sharing experiences and lessons learned also contributes to identifying and assessing alternative opportunities.

Figure 1. The low water levels and white "bathtub rings" at the site of Hoover Dam are evidence of 20 years of poor hydrologic conditions in the Colorado River Basin, where many are working to address the wicked problem of demand-supply imbalance. Photo credit: Sharon B. Megdal

After Lisa Beutler provided some background on wicked water problems, she asked the session participants to list their wicked problems in the virtual platform's chat feature. Here is what respondents listed (in the order in which responses came in): communication and effective management; emerging substances of concern; getting all the data together; surface water and groundwater interactions with limited data; flood mitigation when decisions are highly localized and resources are highly centralized; getting agreement on facts and science; "solving" the nitrate issue in Nebraska; figuring out how to integrate seasonal to multiyear weather forecasting into water resource operations; recycling and conservation counter each other; microplastics; algae in Lake Ontario; climate change; environmental regulatory rollbacks and politics; assessing equity impacts of pollution on surface water quality; communicating risk; complex and unknown; regulations are a single-issue driver aimed at multifaceted issues; agricultural behavior change interventions in the Chesapeake Bay; defining groundwater sustainability; people; conflicting stakeholder interests; public wants measurable goals; and the water we are swimming in.

Figure 2. Mitigating wicked water problems, like those that plague the Lower Jordan River and the Dead Sea, demands cooperation, relationships based on trust and mutual respect, meaningful engagement of stakeholders, good communication,persistence, and patience. Photo credit: Christopher Sprake, iStockphoto.

As panelist Michael Campana spoke of the wicked water problem of groundwater depletion, Lisa asked another interesting question of the audience. She asked people to indicate on a scale of 1 to 10 (with 10 being highest) the level of anxiety they felt as he spoke about the possibility that some groundwater users will just deplete the aquifer. The average response was 9.2. Perhaps even more notable was the extent to which audience members became engaged in sharing their perspectives with the panelists and each other, something that does not typically happen during an in-person panel session.

The approximately one-hour discussion that followed the panelists' prepared remarks included interesting oral and written exchanges. There was substantial discussion of the importance of inclusive stakeholder engagement processes. The audience underscored the need for diverse voices in water dialogues. In some processes in Japan, someone noted, certain participants are asked to represent the future. While policy makers come and go, staff experts and stakeholders, including citizen scientists, remain involved in the search for approaches to mitigating wicked water problems. Someone else pointed out that perspectives can vary even within a sector, such as agriculture, suggesting that it is important that processes err on the side of more rather than less involvement. Another participant suggested focusing on wicked water *opportunities* rather than *problems*. The advantage of this framing is that it pushes us to address problems rather than only describing them.

In general, the discussion was robust and upbeat. I truly appreciated the extensive exchange of ideas on process and participation. Based on the discussion at this session, along with those at other sessions I attended, I was motivated to write an entry in my *Reflections* series entitled "The Importance of Dialogue, Process, and Participation." In the concluding paragraph of my essay, which can be accessed here (https://tinyurl.com/yy6dqmq6), I wrote: "It was interesting to see how so much of the discussions focused on the crucial role of inclusive processes to identifying pathways to solutions to wicked problems. Participation is key to understanding the nature of our challenges so we can tackle the issues we face as a society." Indeed, the articles in this issue of *Water Resources IMPACT* reinforce the idea that working together respectfully and with open minds increases our capacity to address the many wicked water problems that confront us. ■

Sharon B. Megdal is director, Water Resources Research Center, and professor, Department of Environmental Science, at the University of Arizona. The geographic scope of her water policy and management work focusing on water-scarce regions ranges from local to international. Having recently completed 12 years as an elected member of the Central Arizona Project Board of Directors, her current professional service includes serving as an AWRA director and president of the International Arid Lands Consortium.

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Wicked Is a Special Kind of Problem: What It Is and What to Do about It

Lisa Beutler

WICKED PROBLEMS ARE CONFOUNDING. By-products of human behavior, they intersect, shape shift, and defy routine corrections. Calling a problem wicked, particularly in North America, speaks to scale. It ascribes excess. It proclaims that something that has gone beyond reasonable or predictable limits. Most major societal problems—such as inequality, political instability, death, disease, or famine—are wicked. These problems are overwhelming and consequential. Centuries of effort have been unsuccessful in eradicating them. In recent years, many water issues have been described as wicked problems.

The first time most people encounter the word "wicked," explains Merriam Webster (see http://bit.ly/3nRkJov), is in a fairy tale. Wickedness is "an epidemic in children's literature." Wickedness implies a degree of occultism and mystery. It describes morality or the negative or extreme characteristics of an object. "Wicked" is a fitting word for both the year 2020 and many water resource issues.

"Wicked" problems (H. J. W. Rittel, 1972), or "messes" (e.g., Russell Ackoff, "The Future of Operational Research Is Past," 1979), are complex sets of problems in which many different potential issues are intertwined or linked. They defy normal problem solving. Wicked problems involve incomplete or contradictory knowledge, differing values, multiple assessments of the situation, and a range of stakeholders with relationships among them. These problems plague us where we live and work and ripple out beyond our domains into the larger world. It's a rare water manager who hasn't, at some point, been exasperated by one problem or another. But just because a problem is hard to solve or conflict laden doesn't mean it is wicked. To be wicked, a problem must have an indeterminate scope and scale. The first step in addressing it is to understand what type of problem it is; a correct diagnosis facilitates selecting the proper solution.

Theories of Wicked Problems

Horst Rittel, an urban planner, described wicked problems in his paper "Dilemmas in a General Theory of Planning" (1973). He offered a 10-point checklist that could be used to help planners determine if they were working with something wicked. Table 1 provides Rittel's full list along with examples or explanations of the characteristics used to define wicked problems.

Russell Ackoff, Rittel's contemporary, focused on operations research (OR) and organizational theory. OR is the application of scientific, and especially mathematical, methods to the study and analysis of problems involving complex systems. Because wicked problems are conglomerations of complex systems, created by humans, Ackoff's ideas can be used to help address wicked problems.

OR theories are essentially the models that outline the underlying order, or sets of rules, for how systems operate. These models allow those studying systems to assess the probability of events and outcomes and/or take appropriate action when correction is needed. Understanding these models can improve decision making.

Ackoff believed the prevailing theories of OR were not robust enough to account for the behavior of systems when humans were involved. He noted that OR assumed rational behavior when it may not be applicable. He began describing "messes" to prove his point. His messes were the same types of issues Rittel had described. Wicked problems and messes, they both asserted, were different from regular problems.

Ackoff's messes are systems of problems where "the sum of the optimal solutions to each component problem taken separately is not an optimal solution to the mess." The behavior of a mess "depends more on how the solutions to its parts interact than on how they act independently of each other." He proclaimed, "Managers do not solve problems; they manage messes." And, like Rittel, he concluded, "Effective management of messes requires a particular type of planning, not problem solving."

The path to addressing wicked problems or messes predominantly involves synthesizing rather than analyzing. This approach requires considering things as a whole rather than as component parts. It also requires understanding that these problems cannot be solved. As Ackoff explained, "The objective of such efforts should

Table 1. Rittel's Characteristics of Wicked Problems

Characteristic	Examples/Explanations
1. Wicked problems have no definitive formulation.	Poverty in a town in Texas is grossly similar but discretely different from poverty in Nairobi. No practical characteristics describe "poverty."
2. It is hard to measure or claim success.	Wicked problems bleed into one another. Because the boundaries of the problems are fluid and intertwined, impacts of actions are difficult to isolate, articulate, or define.
3. Solutions to wicked problems can be only good or bad, not true or false.	Responses are dynamic. There is no optimum or idealized end state to arrive at. Instead, approaches to wicked problems should be tractable ways to improve a situation rather than solve it.
4. Every wicked problem is unique. There is no template to follow.	Although history may provide a guide, teams that approach wicked problems must literally make things up as they go along. These teams are building the plane while they fly it.
5. There is always more than one explanation or definition for the problem.	Wicked problems are intertwined; there is no singular point of view. The applicability of explanations depends on the individual perspective of the observer.
6. Wicked problems are a symptom of other problems.	The interconnected quality of socioeconomic political systems illustrates how, for example, a change in education will cause new behavior in nutrition.
7. No mitigation strategy for a wicked problem has a definitive scientific test.	Humans invented wicked problems, but science exists to understand natural phenomena.
8. Solutions to wicked problems are frequently a "one-shot" design effort.	Significant intervention changes the design space enough to minimize the ability to engage in trial and error.
9. Those attempting to address a wicked problem must be fully responsible for their actions.	Responsibility and accountability should be linked.

be to produce systems that can pursue ideals effectively and do so in a way that provides continuing satisfaction to the participants."

Water planners have historically focused on forming an understanding of the way individual parts of the water system work and then altering and reattaching the parts to produce desired results. This machine-age approach was the foundation of most Western water public works projects. In this mechanistic world, there were correct answers for problems. Decision makers worked from facts. Professional standards outlined the best course of action. Actions could be tested and were repeatable.

However, the world isn't a machine. Living systems are not so predictable. A wicked problem is like a Facebook relationship status—complicated. People don't live within the confines of mathematical equations. Life involves trade-offs based on differing values and the way the benefits or adverse impacts of any decision accrue to its range of stakeholders.

What to Do

The first step in addressing a wicked problem is to correctly diagnose it. Complicated or complex problems alone do not constitute a wicked problem, although wicked problems are composed of complex systems of systems. Rittel's checklist is the right starting point for the diagnosis.

Rittel believed wicked problems could be mitigated through the process of design. He prescribed the use of three tools: empathy, abductive reasoning, and rapid prototyping.

The first, empathy, flows from forged relationships and an understanding of the values to be expressed in decision making. Water managers and their stakeholders aim for one or more desired benefits. As an example, a community may value improved health and safety, economic vitality, ecosystem integrity, equity and justice, and/or enriching experiences like recreation, inspiring viewsheds, or spiritual fulfilment. The application of water management values is contextual, and, while values are often thought to be enduring, they may evolve over time. To illustrate, the primary goal of early Western water development was to make the land "productive." Even today there are heated discussions about whether or not it is desirable for any water to ever reach the ocean. The definition of "productive" has changed over time, as have the values applied to water and the land.

The second tool, abductive reasoning, is sometimes referred to as "taking your best shot." This type of reasoning exceeds the comfort level of every analyst who has spent years honing their deductive reasoning (the act of applying a general rule to a specific application) or inductive reasoning (the extrapolation of the specific to the general). Those working with wicked problems always begin with an incomplete set of observations because they can never fully know the magnitude of a problem's interrelated and intersecting issues. Planners are required to extrapolate the likeliest possible explanation for what is occurring. Decision making is based on the imperfect information at hand.

The third tool is rapid prototyping, which allows ideas to be tested. The probable impact of any action applied to a wicked problem is estimated but uncertain. The only given is that any action will change the system in which it is being tested. As with Schrödinger's cat, interactions with the problem will change the problem. Wicked problems must be adaptively managed.

Methods to address wicked problems demand the application of interdisciplinary collaboration and perseverance. They require knowledge of science, economics, statistics, technology, medicine, politics, and more. Approaches are both place based and content based. Ackoff writes, "Effective treatment of messes requires the application of not only Science with a capital 'S,' but also all the arts and humanities we can command."

Wicked Problems Require a New Kind of Work

Wicked problems are not fixed with one-and-done solutions. Addressing wicked problems requires changes in the way we work.

Worldwide, stakeholders demand collaborative, multidisciplinary approaches. They need to understand the assumptions being made to compensate for what they know is inadequate information. Underlying values must be brought to the surface, and trade-offs and adaptive approaches must be proposed. Collaborative, multidisciplinary approaches have already improved some water outcomes (particularly for transboundary water and groundwater), even if larger conflicts among competing values remain unresolved.

Because these wicked problems must be continuously managed, effective responses may include approaches designed to build more system resilience. Resilient systems better resist ongoing stressors and recover more quickly from inevitable adversity.

Responding to wicked problems also requires increasing our capacity to manage uncertainty. Certainty is hard to find when wicked problems demand action without the benefit of complete information. There is no static state, as every intervention changes the problem being addressed.

While wicked problems may not be solvable, some wins may be possible. Successes may occur within subsets of a system. With significant collaboration and multidisciplinary approaches, temporary relief may also be experienced at larger scales. However, because humans are involved and the universe is in a constant state of change, what worked yesterday might not work tomorrow. Moving forward, practitioners may benefit from reframing their approach to wicked problems as a journey, not a destination. ■

Lisa Beutler, an AWRA past president and executive facilitator at Stantec, is no stranger to wicked problems. She helps communities and organizations solve problems and make decisions. A nationally recognized conflict resolution and public policy specialist, she has worked on some of the most complex water resources issues in the United States.

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FEATURE

Public Health, Wicked Water Problems, and Maslow's Hierarchy of Needs

Alan Kolok

AT MY FORMER POSITION AT THE UNIVERSITY OF Nebraska Medical Center, I had the opportunity to lecture to College of Public Health students about the interaction between water and public health. One of the graphics I presented was a map of the United States that illustrated each major river basin in a different color. The watersheds were composed of a latticework of tiny headwater streams that comingled to form a great river basin. The illustration was impressive and could be easily mistaken for a capillary bed perfusing a living tissue with blood. I was fond of saying to the students that more than oil or any other liquid, water is the lifeblood of our nation as it drives our economy—one of our greatest natural assets, but also one of our biggest threats to public health.

Throughout history the relationship between water and public health was comparatively simple: maintain one water system for drinking and irrigation and a second system, quite separate from the first, for the removal of biological waste. When this basic edict was violated and the two systems comingled, cholera, dysentery, and typhoid infections spiked, and people died. As urban communities grew, it became progressively more and more difficult to keep the two water streams apart. For example, as Chicago's population increased during the 19th century, its intake structures for potable water extended farther and farther out into Lake Michigan to avoid being contaminated with the wastewater that was being dumped into the lake from the open sewer system that was the Chicago River. Finally, in 1900, when Chicagoans tired of the endless reengineering and recurrent public health crises, they simply reversed the flow of the Chicago River, sending their waste down the Mississippi River toward St. Louis. An expensive, politically charged solution to be sure, but one that in effect amounted to little more than keeping a contaminated stream of water separate from an uncontaminated one.

The principle is the same with respect to groundwater: keep the waste stream out of the drinking water supply. In 1854 physician John Snow gained considerable professional notoriety by doing just that. At the time, regions of London were experiencing a cholera outbreak that would kill well over a thousand residents. When the outbreak moved to the Soho neighborhood, Snow disabled the Broad Street pump, thereby eliminating the possibility that the townsfolk could drink contaminated water. By doing so, he squelched the epidemic, heralded the germ theory of disease, and secured his spot in history as one of the founders of epidemiology.

Importantly, the historic relationship between water and infectious diseases is virtually never a wicked water problem. A wicked water problem is characterized by incomplete or contradictory knowledge, diversity in the opinions of community members involved, a large economic burden, and water issues interconnected with other social and economic problems. Historically, when a cholera or typhoid epidemic broke out, there wasn't a lot of contradictory knowledge or dissenting opinions. Rather, the range of water problems exemplifies Maslow's hierarchy of needs, in which a basal need has to be satisfied before higher-order needs can be fulfilled (see Figure 1). In Maslow's classic hierarchy, physiological needs (warmth, rest, food, water) have to be met before higher-level emotional needs (intimate relationships,

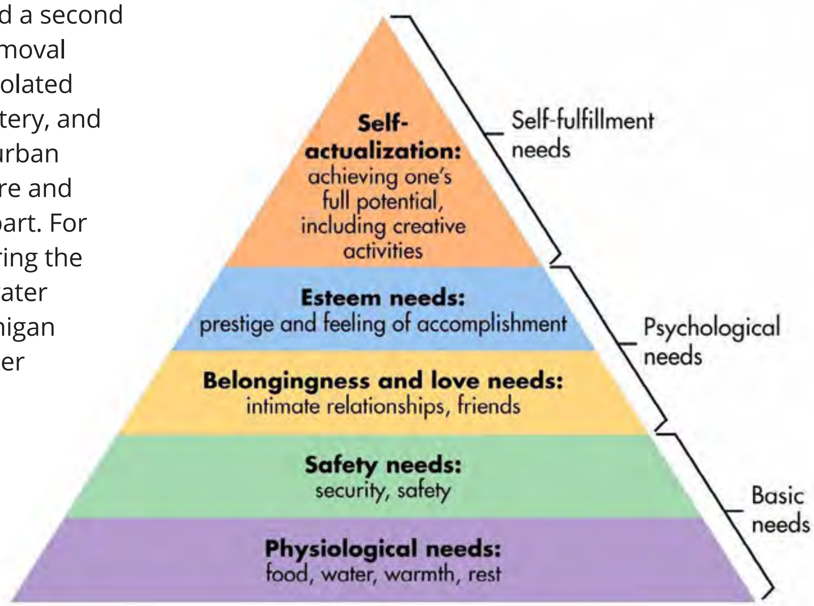

Figure 1. In the context of public health, water problems exemplify Maslow's hierarchy of needs, in which basic needs (such as freedom from disease) must be satisfied before higher-order needs (solutions to wicked water problems) can be fulfilled. Source: Adapted from Androidmarsexpress, Maslow's Hierarchy of Needs2.svg, CC BY-SA 4.0.

friendships) can be fulfilled. In the case of water and public health, the fulfillment of basic needs (freedom from acute fatal diseases such as cholera) must take place before the fulfillment of higher-level needs (for example, wicked water problems).

This is not to say that wicked water problems related to health don't exist or are unimportant. In fact, in developed countries around the world today, the relationships between water and public health are most often wicked problems, given that the more basal problems, such as cholera epidemics, have for the most part been successfully remediated.

Now the COVID-19 pandemic is holding the discussion of water and public health in check. In fact, much of water resource professionals' current public health–related work is taking a back seat to the immediate public health crisis. Beyond being used as a disinfectant (Wash your hands!), water has played and is playing two critical roles. The first, at the outset of the pandemic, was to assure that drinking water was not a potential source of infection. (It isn't.) The second is to use the presence of the virus in wastewater for epidemiological surveillance. At the University of Idaho, for example, wastewater from different dormitories has been tested for the presence of the virus to identify areas on campus where viral outbreaks could mushroom into super-spreader events. By evaluating the spatial distribution of viral outbreaks, we have been able to keep the infection rate acceptably low and thereby avoided a complete closure of the university.

The COVID-19 epidemic will ultimately end, and when that day comes wicked water problems related to public health will recapture the public's attention. Global climate change has been nudged out of the immediate spotlight by COVID-19, but it will be one of the first threats to resurface. The impacts of climate change related to public health are legion, as droughts, sea-level rise, and changes in the frequency and magnitude of intense storm activity all impact human health either directly or indirectly through a temporary cessation of sanitary and health services. Climate change is also likely to impact public health by changing the global transmission pathways of diseases borne by vectors, including those that have aquatic stages in their life history, such as mosquitos. Of course, climate change—as much a social and political challenge as a scientific one—suffers from all of the symptoms of a wicked water problem.

Beyond climate change, relationships between water resources and public health often become associated with human use and chemical contamination. Each community (for example, households, farmers and ranchers, and industrial manufacturers) not only uses the resource but also creates a unique wastewater stream. Households contribute pharmaceuticals and personal care products to the wastewater stream, while some agricultural uses contribute pesticides and nutrients as residual runoff from landscapes. Wicked problems result when one or more sectors begin to point at the other sectors, each concerned about the potential impacts that the "other" waste stream has on public health.

It would be easy to discount the relatively minute levels of contaminants carried in these wastewater streams as inconsequential if it were not for the fact that toxicological investigations have repeatedly confirmed otherwise. The endocrine-disruptive activities of minute concentrations of estrogenic chemicals have permanently feminized male fish living downstream of wastewater treatment plants, while pesticide cocktails *in situ* have been shown to defeminize female fish. It is also well understood that endocrine-disrupting chemicals can act as initiators of specific types of cancers. Consequently, fear about the relationship between minute concentrations of contaminants and public health is understandable, even if the smoking gun linking environmental exposure to aqueous contaminants with adverse human health outcomes has not been identified.

In terms of Maslow's hierarchy of needs, the basal need for a clean drinking water supply, free from virulent and potentially deadly microbes, has for the most part been accomplished in the United States. From that standpoint, we water resource professionals have moved on, in conjunction with toxicologists, environmental scientists, medical professionals, and civil engineers, to grapple with public health issues that are less immediately fatal or overtly catastrophic and more chronic and long term. Current issues, such as harmful algal blooms or polyfluoroalkyl substances, are very real, consequential, and wicked. As a consequence, our job as water professionals has gotten more nuanced and transdisciplinary, but if we are to continue to make a difference relative to the ultimate health and well-being of the public, it is a job that we must accept. ■

Alan Kolok is director of the Idaho Water Resources Research Institute at the University of Idaho. Prior to 2017, he served as the founding director of the Nebraska Watershed Network at the University of Nebraska–Omaha, and as director of the Center for Environmental Health and Toxicology at the University of Nebraska Medical Center. His primary interests are in geohealth and using water resource information to address public health concerns.

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Chronic Wicked Water Problems in the Navajo Nation Heightened by the COVID-19 Pandemic

Crystal Tulley-Cordova, Nikki Tulley, Bidtah Becker, and Karletta Chief

ON THE NAVAJO NATION, AN ESTIMATED 37,000 PEOPLE lack access to indoor plumbing (http://bit.ly/3bOgx6T) (Figure 1). The Navajo Indian Reservation was established in 1868. Since then, through the power of Navajo advocacy, the Navajo Nation has grown to cover more than 27,000 square miles and is the largest land-based tribe in the United States (https://www.navajo-nsn.gov/history.htm). The states of Arizona, New Mexico, and Utah each reach into the Nation, as each state was created after 1868 (https://on.doi.gov/38Qsebd). The Navajo Nation is a sovereign nation and values a government-to-government status with the United States government.

On the Navajo Nation, it is an enormous challenge for water haulers to adhere to hand-washing guidelines from the Centers for Disease Control and Prevention (CDC): "to prevent the spread of germs during the COVID-19 pandemic, you should wash your hands with soap and water for at least 20 seconds" (http://bit.ly/3nOascQ). For typical American citizens who have access to indoor plumbing, washing their hands for 20 seconds is a small task to mitigate the household risk of COVID-19 transmission and infection. However, for many Navajos who do not have running water, frequent hand washing for 20 seconds is no small matter and creates special challenges.

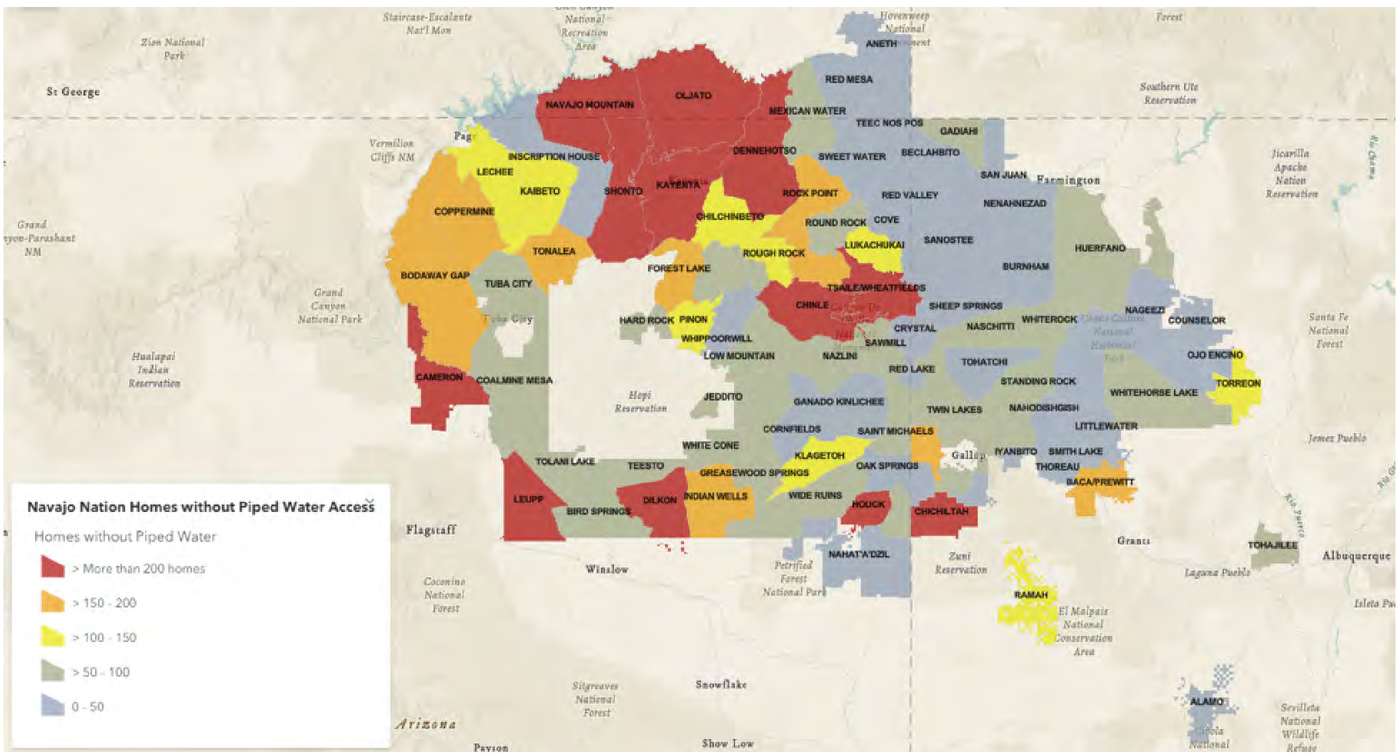

Figure 1. Homes without piped water access in the Navajo Nation. (https://storymaps.arcgis.com/stories/1b4dc0d978c74d97a559e615730d4cd4)

Water haulers must travel 10–50 miles one way to get water. Furthermore, they have to think about when to leave their house without violating daily and weekend curfews imposed by the Navajo Nation in response to COVID-19, while also trying to maintain their livelihoods and work hours. Daily curfews begin at 8 p.m. and end at 5 a.m.; weekend 57-hour curfews start Friday at 8 p.m. and end Monday at 5 a.m. These curfews are stay-at-home orders that restrict any travel.

In addition, washing hands more frequently requires more water, more water-hauling trips, and hence increased expenses due to gas and vehicle wear and tear. Inadequate access to piped water in the Navajo Nation is now more significant than in non-pandemic times.

For many decades before the pandemic, the Navajo Nation was working diligently to address lack of water access, including by establishing Navajo water rights; constructing, rebuilding and maintaining local Navajo water sources (such as groundwater wells and the Navajo-Gallup Water Supply Project); improving water quality; supplying livestock water; and reducing water contamination, among many other activities. Addressing these daily water challenges before the pandemic already exceeded tribal capacity and budgets. The COVID-19 pandemic's impact spiked in May and November 2020 (http://bit.ly/3oV6lNz) and has now superimposed life and death implications on the preexisting clean water access gaps and water quality challenges on the Navajo Nation. As a result, COVID-19 has placed even greater pressure on an already stressed working system that required innovative partnerships and collaboration.

For the Navajo Nation, water access remains a wicked problem exacerbated by the following factors: a vast landscape, a rural and low-density population, limited economic development, limited personnel support, unsettled water rights, and legacy waste. The Navajo Nation's rural nature adds a layer to this wicked water challenge by adding operation, maintenance, and replacement costs. Such costs could address a variety of issues, including off-grid desalination technology, water development projects to serve homes, and regional water system projects to develop a thriving nation with a strong economy and the concomitant services expected in the year 2021.

Water rights settlements promise financial support for water projects that are variable in size. However, adjudication and settlement of tribal water rights are easier said than done, especially for a tribal nation that spans three states, straddles the upper and lower Colorado River Basin, and includes areas of the Rio Grande Basin and multiple sub-watersheds. Funding for operation, maintenance, and replacement is minimal—if it exists at all—for water settlement–funded projects, as the primary focus of water development projects usually consists of capital costs.

The complexity of wicked water problems on the Navajo Nation is being addressed with limited resources and overextended staff. Through partnerships, water access issues are being managed; still, there is an even greater desire to enhance services for the Navajo people living on the Navajo Nation and to address Colorado River management issues in a meaningful and fully engaged way.

Finally, the legacy of uranium mining to date is one of the most significant wicked water problems the Navajo Nation faces, adding another layer to this wicked problem of lack of access to clean water. From 1944 to 1986 nearly 30 million tons of uranium ore were mined and removed from the Navajo Nation (http://bit.ly/39DxOwU), where the Environmental Protection Agency has mapped 521 abandoned uranium mines (https://bit.ly/38TQkly). In addition to abandoned uranium mines and water-quality challenges associated with past mining efforts, the Navajo Nation faces a severe problem of brackish water in its southwestern region. This is the largest region in Arizona with total dissolved solids concentrations ranging from 1,000 to more than 10,000 milligrams per liter (https://bit.ly/3nTSdCL). The Navajo Nation continues to address naturally occurring brackish water challenges through partnerships with federal agencies and academic institutions.

Fortunately, the Coronavirus Aid, Relief, and Economic Security (CARES) Act provided funding for states and tribes to help relieve severe pandemic impacts. The Navajo Nation received CARES funds in May 2020, and Navajo leaders decided to use those funds to address the lack of running water on the Navajo Nation and help protect Navajo members from contracting the virus. Tribal leaders asked for public comment from Navajo citizens on its expenditures. After weeks of deliberation, hearings, and discussions between the Navajo Nation executive and legislative branches, the Navajo Nation allocated about $130 million of its approximately $714 million CARES funds for shovel-ready water projects. Although many desperately needed water projects could have benefited from this influx of funds, it was nearly impossible for many projects to expend the funds by the original federal deadline of December 30, 2020, given the time needed to procure services and supplies and complete tasks. As a result, water projects that were shovel-ready and closer to the ending stages of completion were identified to receive funding. However, by December 21, 2020, only one-third of the initial allocation for Navajo water projects had been expended.

The United States Indian Health Service (IHS) was more successful in quickly mobilizing and constructing transitional water points across the Navajo Nation because of its capacity to mobilize engineers from across the United States and use their experience in water access for developing communities. The U.S. IHS allocated more than $5 million from IHSappropriated CARES funds; by October 2020, they had constructed 59 transitional water points. Additionally, 37,000 water storage containers and approximately 3.5 million doses of water disinfection tablets are being distributed (http://bit.ly/3ilHb8a). These actions have brought safe water points closer to many Navajo residents and decreased average travel time and distance to haul water by 38 minutes and 35 miles, respectively (http://bit.ly/3ilHb8a). The construction of these watering points in the limited time available was aided by interagency collaboration among tribal,

Figure 2. A grandmother and grandson collect water at one of 59 recently built transitional water points developed by the the Navajo Nation COVID-19 Water Access Coordination Group (NNWACG). The actions of the NNWACG, a partnership of 21 entities, have brought safe water points closer to many Navajo residents and shown that more can be done to address the long-standing wicked water problems that have persisted in the Navajo Nation. Photo credit: Nikki Rae Tulley

federal, state, university, and nonprofit allies through the development of the Navajo Nation COVID-19 Water Access Coordination Group (NNWACG) (see Figure 2). NNWACG is a partnership of 21 entities focused on bringing safe water to Navajo residents. Using IHS CARES Act funding, the time and effort invested by Navajo Nation allies during the COVID-19 pandemic clearly demonstrate that more can be done together to address the wicked water problems that have persisted in the Navajo Nation for decades. Now we must turn to develop long-term sustainable access to clean water for these American citizens.

Thanks to the advocacy and regular media interviews by the Navajo Nation president and other Navajo Nation representatives, the disproportionately severe impacts of the COVID-19 pandemic on the Navajo Nation, and on Indigenous people generally, are now better known among the general U.S. population, as is the blatant reality of a historical lack of access to essential services and health care. However, the depth of this wicked problem is less well understood as it directly relates to legacy mining, rural population, expansive landscapes, and unsettled water rights. During a global pandemic, a Navajo person should not have to choose between washing their hands to prevent contracting COVID-19 or drinking clean water for their healthy survival. ■

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First place goes to Clare McClellan at Portland State University. She is a teaching assistant and a research assistant for PSU's interdisciplinary Oregon Water Stories Project. Her research and professional experience in the water resources field combine social and environmental sciences to work towards more sustainable, resilient, and equitable human and natural water systems.

Our runner-up is Hamed Khorasani at the University at Buffalo. He is a PhD candidate in the Urban Water and Environmental Flows research group at the Department of Civil, Structural and Environmental Engineering. His research is focused on water quality modeling and its applications in water resources management. He received his master's and bachelor's degrees, respectively, from the University of Tehran and Tabriz University in Iran.

FEATURE

California Water: A Wicked Water Problem

Betsy A. Cody

FOR DECADES, TWO OF CALIFORNIA'S LARGEST WATER supply projects—the federal Central Valley Project (CVP) and the state-owned and operated State Water Project (SWP)—have faced management problems that seem to defy solutions. Various attempts have been undertaken to balance multiple and often competing demands on these systems. Often these efforts have been short lived or undone by changing circumstances. But is management of these projects a "wicked problem" according to definitions by Rittel and Webber in their 1973 paper "Dilemmas in a General Theory of Planning" (https://tinyurl.com/y3xgc3hh) and Jon Kolko in his 2012 book *Wicked Problems: Problems Worth Solving* (https://www.wickedproblems.com/)?

California's Largest Water Supply Projects: An Overview

The two projects, winding their way through California, together serve nearly 30 million people and more than 3 million acres of irrigated land. The CVP serves primarily agricultural land, while the largely parallel SWP serves mainly municipal areas—cities, towns, and industries (see Figure 1).

Both projects divert water from some of California's largest rivers and from one of the largest estuaries on the West Coast of North America—the delta confluence of the Sacramento and San Joaquin Rivers with San Francisco Bay, known as California's Bay-Delta (see Figure 2). Project operations, including their diversions from the Bay-Delta, are coordinated by law.

CVP and SWP operations and management have been challenged for decades. Salinity intrusion, dating from the 1950s, remains a key concern to this day. By the late 1980s precipitous declines in hallmark and economically important salmon fisheries resulted in their eventual listing as threatened or endangered under federal and state endangered species acts. In the early 1990s disagreements between the state and federal

Figure 1. Federal, state, and local water supply infrastructure in California. Federal infrastructure is shown in red, state in blue, and local in green. Source: California Department of Water Resources (hereafter California DWR), California Water Plan.

Figure 2. Legal boundary of the Sacramento–San Joaquin Delta, outlined in red. It extends from Sacramento in the north to just south of Tracy, and stretches west to its confluence with San Francisco Bay near Suisan Marsh. Source: California DWR.

governments on compliance with the federal Clean Water Act—in particular, operational impacts on water quality, including flows—nearly shut down pumps that are used to export water from the Bay-Delta.

Since the early 1990s attempts to balance the many competing system demands and uses of water supplied by the projects have been unable to resolve conflicts. These conflicts are exacerbated by recurring multiyear droughts, intense storms, changes in temperature and in snowmelt and runoff patterns, increases in population and development pressures, and changing societal values. At least one fish species (delta smelt) is on the verge of extinction, and several salmon species are threatened or endangered.

Figure 3. The potential influx of large, rain-laden storms or unseasonal snowmelt in winter, even in overall dry years, complicates reservoir management. Safety rules governing water releases from major federal and state dams and reservoirs dictate when and under what circumstances water must be released to make room to store stormwater and subsequent runoff and avoid downstream flooding. Yet if such storms never materialize, valuable water stored for other uses is no longer available for use in later dry months. This has occurred several times, even in drought years, and has resulted in criticism of CVP and SWP reservoir operations. Such events in California and elsewhere have led to increased calls for Forecast-Informed Reservoir Operations (FIRO). Source: NBCnews.com.

Efforts to craft compromises are typically tentative. Changes to system operation benefiting objectives in one area often negatively affect others elsewhere in the system. The result is a knotty problem where attempts at solutions—or a push on one side—result in newfound or predictable problems elsewhere.

Central Valley Project Management: A "Wicked Problem"?

Management of the federal CVP is a complex task involving many different factors, interested parties, and interconnected issues. But is it a wicked problem? As other articles in this edition of *Water Resources IMPACT* note, not all complex problems are wicked, as conventionally defined. Following is a look at CVP management using Kolko's four specific criteria: (1) Is there incomplete or contradictory knowledge? (2) Are many people and opinions involved? (3) Is there a large economic burden? (4) Is the problem interconnected with other problems?

Incomplete or contradictory knowledge? Yes.

Disagreements exist about nearly every aspect of California water supply management. Subjects of controversy include the causes of water shortages, species decline, whether some species can be saved from extinction, and who or what is to blame for each issue. Others disagree on the impact changes in water project operations and management might have on different parties—for example, what jobs will be most affected, what income can be restored or offset, or what might be forever lost? Often incomplete or contradictory knowledge and data can be found at the heart of these disagreements, playing into parties' arguments and delaying or complicating management decisions.

To complicate matters, the life cycle, habits, and needs of many threatened and endangered species are not always definitive and require more research. Similarly, knowledge of oceanic and atmospheric conditions and patterns that affect marine mammals, fisheries, and other species, as well as weather events and hydrologic and soil conditions that affect water use and availability, are constantly studied and improved upon (see Figure 3). This is also true of freshwater ecosystems, where changes in water flows, temperature, turbidity, and pollution levels all have known and unknown effects on species and uses that depend on them. Where knowledge is incomplete, speculation can ensue, and disagreement often follows.

Contradictory knowledge is often found when it comes to assessing impacts of management choices and decisions, especially economic impacts. Different parties with varied interests often rely on different models, assumptions, and methods to make their points, sometimes using the same federal and/or state or privately provided data and sometimes developing their own. The combination of incomplete information, contradictory knowledge, and opinions based on those differences often leads to contradictory and incompatible proposals for solutions.

Many people and opinions involved? Absolutely.

Many people, opinions, interests, sectors, and perspectives are involved, including agriculture, energy, commercial and recreational fisheries, recreation, tourism, flood mitigation, and environmental, municipal, and industrial concerns. Individuals representing these varied interests may participate directly, weighing in when federal and state decisions are announced and/or during development, or be represented via association with industry groups or not-for-profit organizations, or through other means.

Conflicts revolve around different opinions. Some argue water shortages are human caused as a result of regulatory decisions; others, that they are the result of extreme hydrologic conditions in any given year; and still others, that they represent longer-term climate-induced trends. Some point to different factors contributing to dramatic species declines, such as warming ocean conditions, pollution from different sources (such as cities and towns versus agricultural runoff), and large and frequent water diversions affecting water-quality factors (such as temperature, flows, and turbidity), and ultimately argue over which causes are most to blame.

Large economic burden? Yes.

Large financial and economic burdens exist all around these issues. From commercial and recreational fisheries losses, to environmental effects on other recreation and forms of water-based tourism, to water quality, to large agricultural losses at the farm and producer levels—hundreds of millions of dollars can be lost due to water shortages or cutbacks in times of drought and through water management decisions in dry and wet years. Losses are not always easily measured. Economic gains and losses are typically easier to assess than intrinsic values such as the nonfinancial value of natural systems and their benefits to humans. For example, the CVP serves seven of California's top 10 agricultural counties, generating billions of dollars in revenue annually. Yet much of that water also supports water-based recreation and tourism and provides critical habitat for commercial and recreational fisheries (see Figures 4 and 5), multiple threatened and endangered species, and species important for their subsistence, cultural, and historical value to various Native American tribes.

Changing societal perspectives on what is valuable in its developed or natural state are also at play. New laws and regulations aimed at matching evolving societal values are subject to resource allocation decisions often made decades ago. Mostly constructed between 1937 and the 1970s, CVP infrastructure was authorized before many modern environmental laws were enacted or consistently implemented.

Interconnected with other problems? Yes.

The coordinated management of the CVP and SWP has many social, cultural, and geopolitical connections. Cities, towns, counties, and Indigenous populations and all that they represent—from housing, transportation, and growth policies to the more easily identified effects on water uses and water users, both human and not—rely on California's vast water resources wealth. Increased growth and demand have put tremendous pressure on the system to deliver more, even while that system sometimes has less to offer. Management is also intertwined with varying cultural issues, such as a growing divide in societal preferences between urban and rural areas, ongoing disputes over priorities related to in- and off-stream water uses, water allocations for tribal use, and how to grapple with a complex system that was designed and mostly constructed before the advent of state and federal environmental laws that

Figures 4 and 5. CVP and SWP management are important to many industries, including agriculture, fisheries, and tourism. Sources: Sacbee.com and California Dept. of Fish and Wildlife, respectively.

now govern their use. Finally, management is also interconnected with geopolitical issues such as U.S. foreign policy and trade, climate change, and related sea-level rise. Figure 6 illustrates areas that are at risk of being inundated by rising sea levels and more frequent and intense flooding.

Conclusion

Since the early 1990s multiple attempts have been made to address recurring tensions over the environmental impacts of these two large water supply projects—notably, their effects on water quality and threatened and endangered species—and over reduced water deliveries to project water users. But the management of these systems is a wicked problem. As result, efforts to address these issues have often resulted in large-scale actions that have ultimately failed to overcome persistent challenges. Perhaps other articles in this issue of *Water Resources IMPACT* will shed light on other, promising paths forward. ■

Betsy A. Cody is an independent consultant focusing on Western water and federal lands historical and legislative research and policy. Her experience includes 27 years with the Congressional Research Service, a legislative branch "think tank" serving the U.S. Congress.

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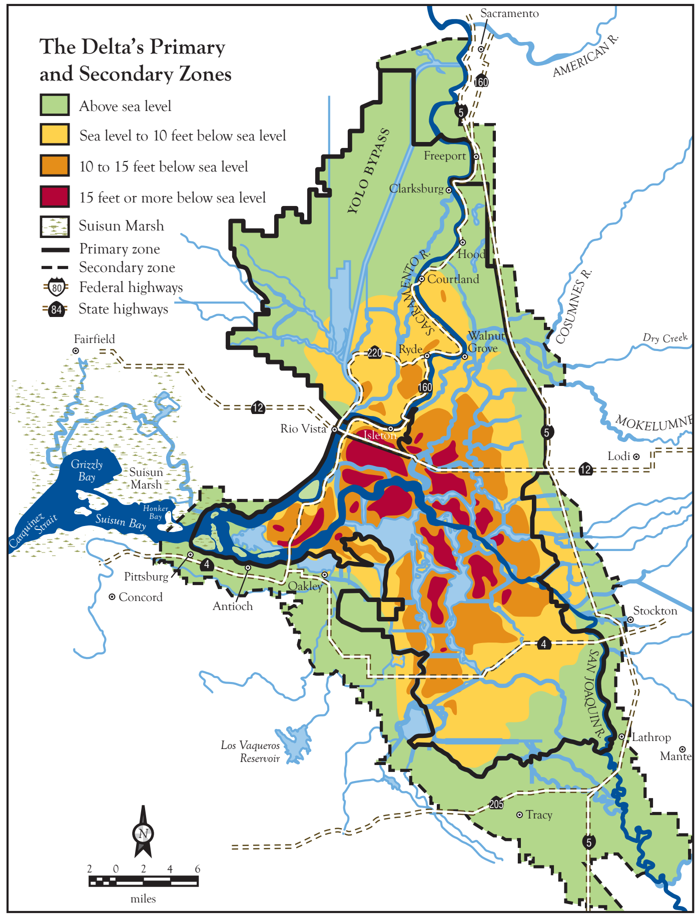

Figure 6. Land subsidence in the Sacramento–San Joaquin Delta. Land below sea level is vulnerable to projected rising sea levels and catastrophic flooding due to levee breaches and large storms. Source: Public Policy Institute of California (subsidence levels, California Department of Water Resources, 1995).

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FEATURE

Social Infrastructure and Its Invisible Potential for Addressing Wicked Water Problems

Amber Wutich and Wendy Jepson

THE MYTH OF 100% WATER COVERAGE in the United States and Canada was shattered in 2020. That research, led by University of Oregon Associate Professor Katie Meehan and 22 experts, showed that many households rely on water sources that are expensive, unsafe, unreliable, and inaccessible. Water insecurity is more common for renters and people living in mobile homes, for disaster migrants and others living in substandard housing, for American Indians and First Nations, for Black and Hispanic communities, and for people living in colonias and disadvantaged unincorporated communities. How to serve these water-insecure communities is a wicked problem: it's social and political, complex and ever-changing, and clear causes and solutions are hard to isolate.

Social infrastructure—made up of cultural norms, informal institutions, and social networks—is an invisible strategy, already in place in many communities, that may address water insecurity. Our research shows that social infrastructure can amplify a range of water self-provisioning techniques, including rainwater harvesting, water sharing, and informal water vending, to offer sustainable options. These are not speculative solutions: we know social infrastructure in water provisioning works because people are already using it on the ground. But drawing on social infrastructure to address water insecurity more broadly requires policy makers, municipalities, and states to rethink their roles and responsibilities to ensure water security for all.

Rainwater harvesting is a physical infrastructure solution that often has the goal of water conservation (see Figure 1). As the work of Michigan State's Lucero Radonic shows, municipal programs encouraging rainwater harvesting have relatively higher uptake in middle- and upper-income communities. Many low-income communities also harvest rainwater for household consumption and use. In such cases, people often pay for and install rainwater-harvesting equipment without the support of tax rebates and other state programs. Rotating credit and labor associations are a form of social infrastructure that can help people save money and share labor to install these systems. In rotating credit associations, people band together to save money and take turns receiving a lump sum from the group. In rotating labor associations, a group of people takes turns working together on major home or business labor tasks. Cultural norms set up systems for rotating labor and credit—who you can ask, how much you contribute, and when you cash out. In the United States, these self-organized credit and labor systems are common. One example is in Mexican immigrant and Mexican-American populations, who use a rotating credit system called a *tanda*. While such systems are already

Figure 1. Many people in low-income communities pay for and install rainwater-harvesting equipment without the support of tax rebates and other public programs. Social infrastructure such as rotating credit and labor associations could help people amass the resources to install these systems. Photo credit: Pixanoo on iStock.com

informally in use, they could be harnessed to help low-income communities implement rainwater harvesting as a form of water self-provision.

Water sharing is a household-to-household transfer of available water. Studies by Pennsylvania State University's Asher Rosinger and colleagues show that up to 85% of households in water-insecure communities participate in water sharing. In the United States. Water sharing appears to be particularly prevalent after disasters. After Hurricane María in Puerto Rico, a team of researchers led by Arizona State's Anaís Roque found that many households relied on social networks for water. Social infrastructure can strengthen this practice by supporting communities in establishing water-sharing norms or helping to build consensus about norms among neighbors. Such norms could include, for example, the expectation to help a neighbor if you have extra water or to reciprocate if someone helps you. With such norms in place, water sharing can become a reliable and even nurturing form of community-based water self-provisioning.

Water vending happens when entrepreneurs sell water to households using tanker trucks, water points, or even handcarts. While an effective form of water delivery, water vending can be expensive and unreliable—especially for low-income households. Research led by Arizona State's Amber Wutich and Melissa Beresford with Cinthia Carvajal from the Graduate Institute of International and Development Studies (Geneva, Switzerland), shows that the cost and unpredictability of vended water can be improved through the use of social infrastructure. In this case, water vendor unions or professional organizations can play a key role: when organized, water vendors tend to work collaboratively to find solutions to improve the efficacy and affordability of water vending. Another way social infrastructure can improve water vending is through community oversight. Neighborhood organizations can negotiate with water vendors for improved prices and service. In the United States, a good example of this is homeowner associations (HOAs) that commonly contract with service vendors and negotiate on behalf of their members.

We need to be aware of the dangers of unintended and unequal consequences. Water sharing, for example, is a highly stressful form of water self-provisioning. It can be embarrassing to admit you need water, and humiliating to be denied help. The possibility of denied water requests makes this an unpredictable form of water acquisition. Water vending can be corporatized, as Texas A & M's Wendy Jepson and Heather Brown Lee demonstrate, forcing the poor to pay more for each unit of drinking water and disincentivizing other public water improvements. And rainwater harvesting systems that are fully self-funded by low-income households are ultimately an environmental injustice because they shift the cost of water infrastructure investments onto those least able to pay. In these ways, it is important to design social infrastructure interventions with a core commitment to justice and equity.

A major advantage of social infrastructure approaches is that these are community based and socially and culturally appropriate. This isn't social engineering. It is not outsiders imposing a one-size-fits-all solution to a problem they don't understand. This advantage means that community acceptance of social infrastructure is likely. But social infrastructure is not a simple, low-cost fix either. Using social infrastructure as part of a solution to water insecurity does not absolve authorities of the responsibility to provide a social good. In short, we need to be aware of asking too much of communities that are already suffering. We should never expect low-income communities to survive on self-provisioning alone. Engaging social infrastructure demands different services and support from state agencies, water utilities, and policy makers to ensure the safety of all drinking water resources. Leveraging social infrastructure for water security is about recognizing what people are already doing and amplifying it—while at the same time reworking how the larger society can best support and enhance the benefits in policy and practice. ■

Amber Wutich is an anthropologist, President's Professor, and director of the Center for Global Health at Arizona State University. Her two decades of community-based fieldwork are concerned with how inequitable and unjust resource institutions impact people's well-being, especially under conditions of poverty.

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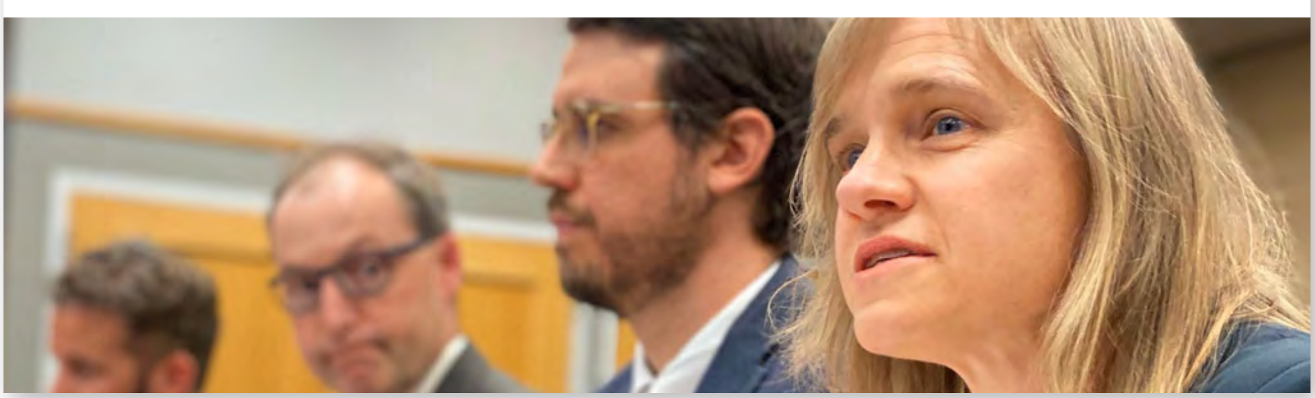

Addressing Food-Energy-Water Insecurities of the Navajo Nation through University-Community Collaboration

Karletta Chief, Robert Arnold, Andrew Curley, Joseph Hoover, Murat Kacira, Vasiliki Karanikola, Kelly Simmons-Potter, and Elizabeth Tellman

COVID-19 HAS AMPLIFIED FOOD, ENERGY, AND WATEF (FEW) insecurities across the world and disproportion impacted Indigenous communities. In the United States, COVID-19 is rampant within the Navajo Nation the largest tribe in the United States, where the rate of poverty (38%) is more than twice that of the state of Arizona (15%). Navajo tribal officials cite the lack of healthy foods and running water as reasons for the prolific virus transmission, resulting in one of the highest COVID-19 infection rates in the United States. The Navajo Nation is a rural food desert, with only 13 grocery stores for a population of nearly 200,000 tribal citizens spread across 27,000 square miles of remote terrain (population density is 8 per square mile, on average). Comorbidities such as diabetes and cancer are prevalent owing to environmental exposure from abandoned mines. Native Americans have the highest rate of diabetes of any U.S. ethnic group, and arsenic-contaminated waters on tribal lands, including the Navajo Nation, increase the risk o diabetes, chronic kidney disease, and cardiovascular disease. Furthermore, nearly 40% of remote Diné (Navajo) homes lack electricity, and more than 30% lack running water. The Diné haul water from potable and non-potable sources 5–50 miles away, incurring an enormous expense of $13.30 per 100 gallons. These and other challenges make it difficult for Diné communities to respond to and recover from perturbations such as pandemics and disasters.

Resilience is the ability to maintain the desired structure and function of a FEW socio-ecological system under perturbation, such as that associated with COVID-19. Yet outside of health metrics, FEW resilience frameworks often fail to consider Indigenous political, social, and cultural perspectives. Existing resilience frameworks aim to co-manage resources and keep Indigenous people within an unjust and colonial system. Engaging Indigenous perspectives on Indigenous resilience may, for example, improve research on and management of sustainable water resources and make it easier to address FEW insecurities among Native American communities. FEW technologies can augment Native communities' capacity to adapt in ways that transform the system state into a desired structure and function, thus increasing resilience at the scale of the household, the community, and the tribal nation (see Figure 1).

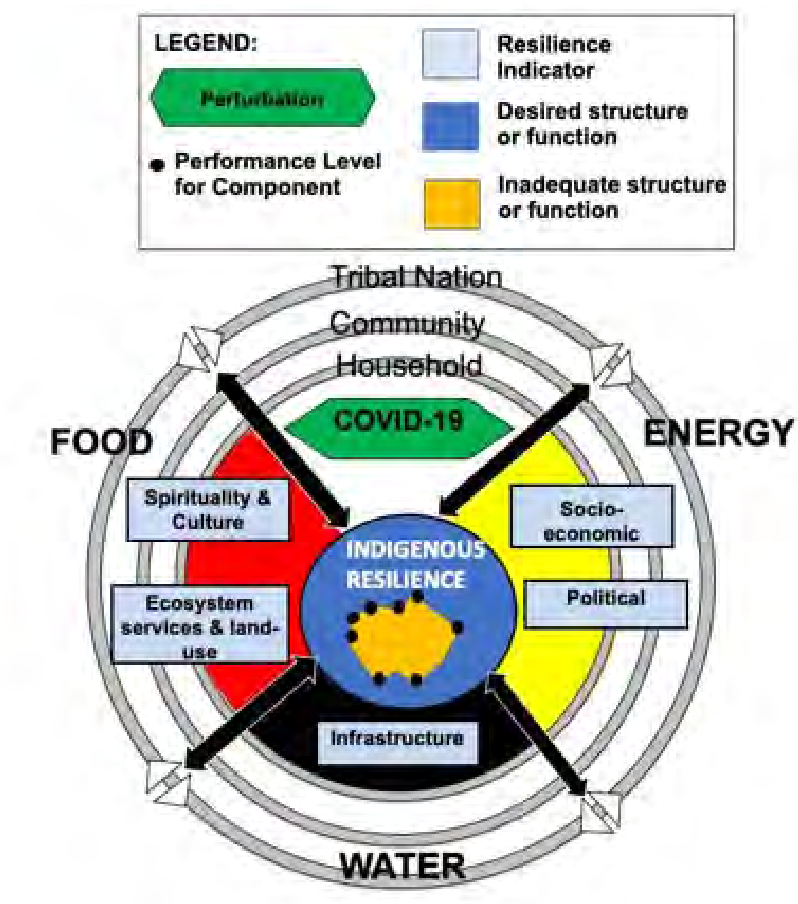

Figure 1. System state under perturbation, placed in a medicine wheel to represent FEW Indigenous resilience framework with indicators at household, community, and tribal nation levels. Two-way arrows signify interactions, and different colors represent Indigenous worldviews and cultural values.

Partnerships, including those involving research and education, are critical to addressing FEW insecurities in

Native American communities. Since 2017 the University of Arizona has partnered with the oldest tribal college in the United States, Diné College, to develop a solar-powered water and greenhouse unit to address FEW challenges on the Navajo Nation while training graduate students and tribal college students. This training program is funded through a five-year National Science Foundation Research Training grant entitled "Indigenous Food, Energy, and Water Security and Sovereignty (Indige-FEWSS)." The central goal is to empower Indigenous people with FEW security through water treatment systems and CEA technology that provide skilled jobs and improve quality of life.

Figure 2. Diné College students undergo training on the solar water unit, with the greenhouse in the background. Photo credit: Torran Anderson.

Each water treatment unit, powered by solar panels, uses pressure-driven nanofiltration to treat non-potable water and provide water security to approximately 30 families. The brine produced by the water purification unit is suitable for specific agricultural purposes, while the excess energy can be used for nighttime illumination and water heating. The greenhouse unit uses controlled-environment agriculture (CEA) technology to support year-round production of highly nutritious, high-yield food crops. Photovoltaic technologies for light collection, light management, and energy production can enhance CEA deployment, particularly in remote locations challenged with access to power. Two of the solar nano-filtration units were constructed, and one was deployed at Diné College in 2019 for Diné College Land Grant Office's educational and community outreach purposes. The greenhouse unit at Diné College is under construction.

Now, during the pandemic, Indige-FEWSS is working collaboratively with the Navajo Nation to implement first-generation, research-based solar water and greenhouse units at three Navajo chapters, with the goal of household-scale deployment (see Figure 2). Designs are scalable, sustainable, and premised on Navajo priorities. The units will be site-specific—dependent on local water quality, solar characteristics, and population served—but easily adapted for deployment at other sites. Solar water and greenhouse technology in remote areas can reduce FEW insecurities that have been amplified during the pandemic, thus enhancing Navajo resilience.

Civic engagement with the Navajo Nation in this project involves a multipronged, bidirectional approach connecting community, government, nonprofit, and educational entities across the FEW sectors. These activities emphasize data sharing and transparency; coordination of the co-design, optimization, and deployment of the solar water and greenhouse technology; and data-driven decision support tools. The Indige-FEWSS partnership engages community members and high school and tribal college students in FEW learning (see Figure 3). Civic engagement builds upon prior collaborations with the Navajo Nation, including the

Figure 3. Earl Tulley shares Navajo cultural knowledge with Indige-FEWS trainees in Blue Gap, Arizona, as part of a spring break culture immersion trip to the Navajo Nation. Photo credit: Mari Cleven.

Gold King Mine Diné Exposure Project. Coordination among partners goes a long way toward breaking down barriers. Sharing the knowledge required to tackle FEW insecurities through culturally appropriate communication is key to building capacity.

The Navajo Nation continues to view FEW insecurities as a priority in COVID-19 response and mitigation. University of Arizona team members have expounded on the role of off-grid technologies to improve water access and quality. For decades, the Navajo Nation has worked with the Indian Health Service on centralized water projects and rural water sanitation projects. Although solar energy is available in a small fraction of Diné homes, off-grid water and food technologies have yet to be implemented across the Navajo Nation. To ensure that FEW technologies are co-designed and appropriate for remote Diné communities and that the technologies are owned and maintained by the Navajo people, involvement of Navajo civic partners is critical. Navajo tribal government programs work to secure funding, provide services, and make FEW policy decisions. Navajo nonprofits on the ground work closely with Diné communities in implementing FEW projects and training. Tribal colleges educate students and community members on FEW. The key goals of these collaborative activities are to (1) share knowledge, best practices, and data that inform decisions and policies, and (2) implement FEW technologies to make a real-world impact while increasing Navajo resilience.

Over time, integrated, connected, resilient FEW units for remote Diné communities will provide efficient, economically achievable opportunities for dispersed water purification capacity and food-producing greenhouse technology powered by solar energy. Through university-community partnerships involving robust community engagement, technologies can be deployed in remote locations as well as more urbanized locations. Trained Diné citizens will contribute to a diverse and globally competitive workforce and increase the participation of underrepresented minorities in science, technology, engineering, and math (STEM) fields. Resilience will be enhanced by addressing FEW insecurities through a framework that can assist not only the Navajo Nation but other Indigenous and non-Indigenous communities nationally and globally. ■

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Trustworthy Engagement

Carol Collier and Alexis Schulman

LOOKING BACK, IT SEEMS THAT ENVIRONMENTAL protection was easy 50 years ago. In the 1970s environmental laws were just being written, but the new U.S. Environmental Protection Agency and the strengthening state environmental departments knew what the problem was. You could see it, smell it, taste it, and hear it. It was "easy" to regulate because the pollution was coming out of pipes into the water and factory stacks into the air. Scientists could monitor the discharges and effluents, and agency "SWAT teams" could round up the offenders and issue permits, consent orders, and fines. For years, many people thought that protection of the environment was solely the responsibility of state and federal agencies and that these agencies were controlling the large industrial dischargers that were obviously causing all the problems.

It turns out that regulations were a good start, but they also fell short: there was still a need to regulate multiple industries and municipalities discharging to one water body, develop methods to assess an individual smokestack's impact on moving air currents, and figure out how large a pollutant load a system could absorb before showing signs of stress. Because some pollutants had different impacts on humans than on ecological communities, different standards would be required. As analytical methods improved, scientists found chemical impacts at lower concentrations. And how should so-called cumulative effects—where pollutants are relatively benign individually but dangerous together—be handled?

In water resources, for example, as point sources came under better control, it became obvious that the problem of nonpoint source pollution was far more intractable. How could we combat the heavy metals, fertilizers, bacteria, and grease entering streams from city streets, highways, farms, and the suburban housing developments that were popping up everywhere? What control did state or federal environmental agencies have over things like housing developments? In the Mid-Atlantic and Northeast United States, land use control is held predominantly at the local level, by individual municipalities. Municipalities with zoning regulations would establish what land uses (residential, industrial, commercial) were allowed in what parts of a township or borough (and there are more than 2,500 municipalities in the Commonwealth of Pennsylvania alone.)

Unfortunately, while high-end residential developments were often separated from potentially polluting industrial uses, many lower-cost housing developments, home to predominantly Black and brown Americans, were made fenceline communities, immediately adjacent to these industrial sites. If a waste-to-stream plant is sited in an urban area surrounded by residential development (as was the case in Chester, PA), shouldn't it be subject to higher standards than one sited in a less populated area appropriately zoned for industrial use? Many of our regulations did not take this social context into account.

Fast forward to today. We in the water world know how complex water management is and understand that our emergent challenges cannot be mitigated with our conventional toolbox alone (and government agencies may not always be staffed to work with individual landowners, farmers, and local communities). Top-down regulations are not well matched to the wicked problem of nonpoint source pollution, where sources are diffuse, vary over time, and include multiple sectors, actors, and scales; where stakeholders are unlikely to agree; and where uncertainty abounds—including about where the pollution is even coming from! In cases like this, work is needed at all levels and across all sectors. We need to set our sights on a new environmental regime where regulations are considered a floor, not a ceiling.

So how do we build up from that floor? The answer is **trustworthy engagement**. We need to build trust to go beyond regulation and help the local community own the issue. As a friend often says, "Progress moves at the speed of trust."

Some scholars and practitioners urge attention to the conditions, or enabling capacities, that support effective local action and implementation. This idea knits together a range of interrelated management approaches and frameworks, from adaptive management to collaborative planning to Nobel Prize winner Elinor Ostrom's

Figure 1. Scientists from the Academy of Natural Sciences of Drexel University head back after conducting an algae assessment at a stream restoration site on the Paulins Kill River in northern New Jersey. The Academy partners with regional conservation groups to evaluate, protect, and monitor streams for the Delaware River Watershed Initiative. Photo credit: Tess Hooper for ANS.

institutional analysis framework. For example, Patterson et al. (*Journal of Environmental Management,* Vol. 128, 2013) identify nine key factors that have been shown to enable management action: (1) entrepreneurship and leadership, (2) reflection and adaptation, (3) collaboration, (4) resourcing, (5) engagement, (6) knowledge building and brokerage, (7) institutional arrangements, (8) vision and strategy, and (9) history and contingency.

In the Delaware River Basin, which covers portions of New York, Pennsylvania, New Jersey, and Delaware, the William Penn Foundation kick-started the Delaware River Watershed Initiative, a project that looks to create these enabling conditions for watershed action that will culminate in water-quality improvements across the basin (see Figure 1). Started in 2013, the project now engages more than 60 nongovernmental organizations. The focus is protection and improvement of water quality for the aquatic and human communities through protection of forests, where water quality is very good, and restoration of areas impacted by agricultural runoff or suburban stormwater. It is based on a backbone of science, but the glue consists of collaboration, engagement, and trust building.

The watershed associations, land trusts, and scientists are learning how to engage landowners and local governments:

- They are working with farming communities on ways to protect the local stream while increasing the productivity of fields. Often finding a community champion respected by his or her neighbors really helps.
- They are working with forest owners to understand the true value of their tree stands, especially if these stands are managed for carbon capture, water quality, and habitat.
- They are connecting with municipal officials to strengthen environmental ordinances and provide technical assistance when needed. Best paths are through a sympathetic town supervisor or staff member or through the building of a coalition of like-minded residents.

We, as the scientists on the team, are finding a whole new language and approach. So often our audience consists of professional peers reading published articles, but think how much more productive it is to also be able to communicate with those on the ground who can make a meaningful local difference.

All individuals should have the opportunity to understand their local environment, how it fits into the larger system, and the impact of their own footprint. They deserve to have the knowledge to care and the capacity to make a difference. We can help accomplish that through trustworthy engagement. ■

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Captain's Log: Spaceship Earth 2021

Eric J. Fitch

We travel together, passengers on a little space ship, dependent on its vulnerable reserves of air and soil; all committed for our safety to its security and peace; preserved from annihilation only by the care, the work, and, I will say, the love we give our fragile craft. We cannot maintain it half fortunate, half miserable, half confident, half despairing, half slave—to the ancient enemies of man—half free in a liberation of resources undreamed of until this day. No craft, no crew can travel safely with such vast contradictions. On their resolution depends the survival of us all. —Adlai E. Stevenson, U.S. ambassador to the United Nations, last major speech, to the Economic and Social Council of the United Nations, Geneva, Switzerland, July 9, 1965

Nihil sub sole novum [There is nothing new under the Sun]. —Ecclesiastes 1:9

THE YEAR 2021, LIKE ANY OTHER, ENTERED WITH GREAT expectations and great fears, but the events of the past year have served to exaggerate both extremes this year. Given my affection for sci-fi in general and Star Trek in particular, I frame this column as a ship's log on the state of Spaceship Earth and the course forward.

Spaceship Earth is a concept that goes back to George Henry's 1879 book *Progress and Poverty*. In the 1960s the concept was brought into popular consciousness by Kenneth Boulding, Buckminster Fuller, and Carl Sagan, who reflected on images of the Earth as a whole from the Apollo Moon missions and deep-space probes. The idea of Earth as a vast limitless body with frontiers where we could travel and live began to be looked at as antiquated; if humankind were to survive and thrive, we would have to work together and steward the globe. We are living in a small place with finite resources, like travelers living on a spaceship making our way through space.

The volume of our spaceship is largely off limits to us. All of humankind and life itself lie within the biosphere—the realm of life. The biosphere, a thin "onion skin" surrounding the planet, stretches 12 kilometers up into the atmosphere and 11 kilometers down into the oceans, but life's comfort zone is much narrower. The biosphere is supported by inputs from the lithosphere (rock/soil), atmosphere (air), and hydrosphere (freshwater and saltwater). Humankind relies on these four spheres, and as our numbers and technological prowess have increased, so has our role in managing and maintaining the life support system we depend on. Here's where our annual captain's log turns critical.

In the journal *Frontiers in Conservation Biology*, a select group of environmental scientists has just published a snapshot of current environmental stewardship of the biosphere (that is, maintenance of the life support system) under the title "Understanding the Challenges of Avoiding a Ghastly Future" (January 2021: Volume 1: Article 615419). They state, "Humanity is causing a rapid loss of biodiversity and, with it, Earth's ability to support complex life. But the mainstream is having difficulty grasping the magnitude of this loss, despite the steady erosion of the fabric of human civilization."

The scientists make several key points: First, biodiversity loss now constitutes a sixth mass extinction event, driven by humankind's impacts on the biosphere. Although many people believe Earth is too big for humans to impact, we know that is not true. Second, the key driver of this impact is ecological overshoot: the size of the human population and its overconsumption of limited resources, regardless of the consequences for the biosphere and environment. Third, international efforts, in particular with regard to climate disruption, are failing. Fourth, a key driver of this failure is political impotence, particularly in regimes dominated by interests that will lose economically (in the comparative short term). Finally, survival of the biosphere in an optimal form (including maintenance of a habitat that supports humankind) increasingly depends on keeping climate change below critical tipping points, especially below a mean increase of 2 degrees Celsius in global temperature, and absolutely below a 4-degree mean increase. Passing these tipping points will result in negative changes to the biosphere that will accelerate species extinction and catastrophic degradation of human habitat.

As the impacts of climate change become more evident, the arguments of the climate change deniers lose weight while the scientific and environmental communities become ever more cognizant of the urgent need for action. The northern polar ice cap is largely disappearing while more and more ice retreats on Greenland and Antarctica. Sea levels are rising, and coastal wetlands and firm lands are disappearing, and with them critical habitat. Storm events are increasing in frequency and intensity. Regions such as the American West are drought stricken, while other areas are experiencing increasing levels of coastal and interior flooding. The safety of humankind, so critically dependent on the fragile biosphere of our Spaceship Earth, demands more enlightened leadership that turns away from denialism and embraces both science that informs our response to the human-made problem of climate change and the urgency of and need for decisive and effective action. ■

GUEST ARTICLE

The Missing Ingredients in the Recipe for Improving U.S. Water Quality: The Leadership and Values of the American Farmer

Mark R. Deutschman

DESPITE DECADES OF EFFORTS TO IMPROVE THE water quality of lakes and rivers within agricultural landscapes, more progress is needed to attain our nation's goal of swimmable and fishable waters. Payments to farmers through various government programs are used to incentivize farmers to implement conservation practices like grass waterways and cover crops to improve water quality. But too few farmers participate in these programs to substantially improve water quality. One reason they cite is the red tape associated with government programs. The lack of progress raises pressure to regulate agriculture rather than relying on the current voluntary approach using incentive payments. Avoiding future regulation means an improved, sensible, voluntary, farmer-led approach is needed to achieve meaningful water quality improvement.

> "Nothing about our efforts to voluntarily protect and improve the water quality of our rivers and lakes within agricultural landscapes makes sense unless you understand and involve the American farmer."
> —Mark R. Deutschman, research director of IWI

The International Water Institute (IWI), a nonprofit organization, is leading a partnership to develop an improved voluntary approach. The partners have a shared vision—a sensible, cost-effective, farmer-led, voluntary approach that actually works. The Mosaic Company funded the partnership, and the IWI has retained SB&B Foods, an agricultural company, to provide guidance.

The partners dubbed the approach the Stewardship Pilot Program (SPP). One of the most important ingredients in the SPP recipe is the participation and leadership of 10 farmers from eastern North Dakota and western Minnesota (see Figure 1). The farmer leaders are helping develop the approach not only by providing information about their operations, but also by critically reviewing the ideas and products coming from the SPP scientists, economists, soil scientists, and agronomists.

Figure 1. Through the Stewardship Pilot Program, farmers in eastern North Dakota and western Minnesota have joined forces with agronomists, scientists, and economists to develop practical options for increasing profits while also improving water quality. Photo Credit: Abbey Wick

Another important ingredient involves providing farmers with access to new, previously unavailable information for making decisions about their operations. Only with the help of farmers can water quality improve. Thus, access to good, credible, defensible information about how farm operation simultaneously affects profitability, stewardship quality, and the amount and quality of runoff from farm fields is key to energizing farmers to take action.

> "My participation in the Stewardship Pilot Program influenced how I approach farming. By tilling my fields less, my operating costs can be reduced and profitability increased. Leaving more crop residue protects the field, reducing soil loss and improving water quality. The SPP provided me with valuable information linking my farming options to profitability and the quality of my care for the land—critical information for my farming decisions."
> —A participating farmer from North Dakota

In January 2019 the producers and SPP scientists and economists began exploring the relationship between farming methods, profitability, stewardship quality, and the quality and amount of runoff leaving farm fields. The farmers used their own financial and operational information to evaluate this relationship.

Like most farmers, those involved in the SPP have a strong desire to continually improve their operations. But they lack a critical tool needed to inform their farming decisions—having a means to describe how well they care for the land. So the scientists working on the approach set out to tackle the major technical challenge of defining stewardship quality, which became one of the new pieces of information available to farmers through the SPP. The definition of stewardship quality focuses on how a farmer's operation affects water, using 14 different criteria. One example is the estimated soil erosion rate compared with the rate at which soil rebuilds. Industry performance standards for the management and application of fertilizer, known as the "4R standards," round out the criteria.

To arrive at a single measure of stewardship quality, scientists combined the 14 criteria into a one number called the Field Stewardship Rating (FSR) (see Figure 2). The FSR ranges from 0 for poor stewardship quality to 10 for excellent stewardship quality, based on a five-year field history. When farmers change their operations or implement conservation practices, the change in the FSR can be used to predict the effects on water.

Yet another ingredient in the approach is an increase in the farmer's decision power. Having several options for farming a field and understanding their consequences is decision power. Large numbers of farmers will voluntarily modify their operations when provided with good agronomic options connected to expected changes in profitability, stewardship quality, and water quality.

The farmers joined forces with the agronomists, scientists, and economists to develop practical options for their operations. Ideas for the options coalesced around preferentially increasing profits rather than improving water quality—markedly different from the current approach of providing incentive payments.

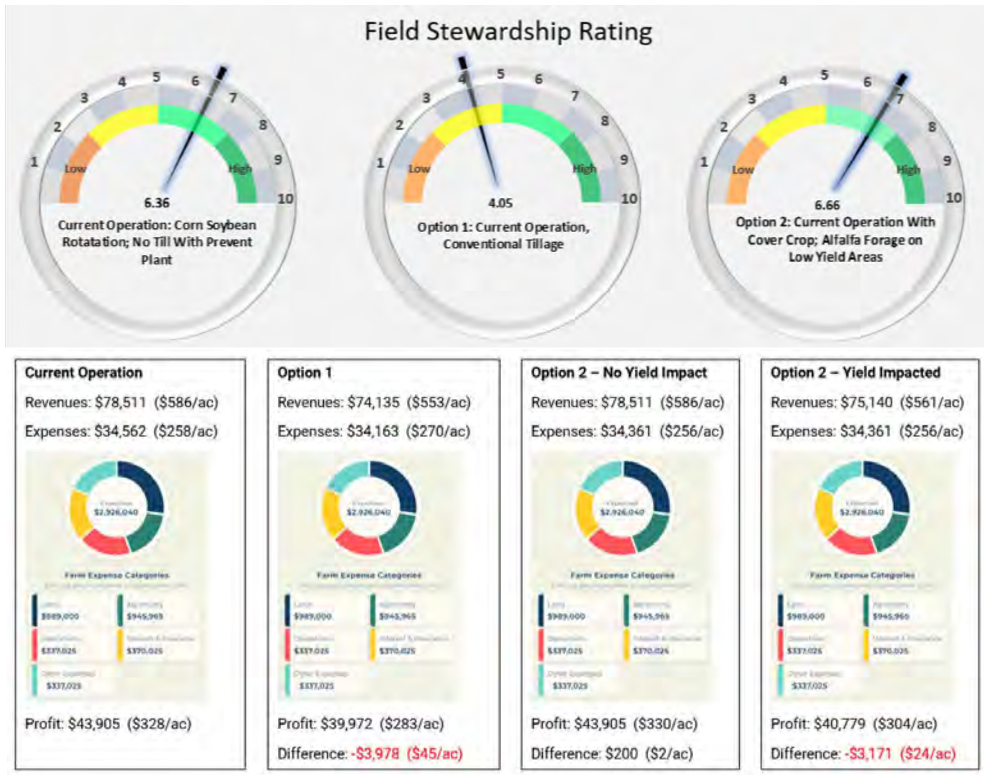

Figure 2. In this sample dashboard provided to a farmer, the top image shows stewardship quality, expressed as the Field Stewardship Rating for the current operation, and two alternative options. The bottom images show profitability.

The farmers, drawing on their own experience and the high-tech information provided by the SPP, devised two options for increasing profitability. Each option included one or more ideas, such as planting different crops on low-yield areas, fertilizing and tilling the land differently, enhancing drainage, and implementing conservation practices. The ideal option is one that simultaneously increases profits and stewardship quality.

Those parts of the field with low yields are obvious locations where profits might easily be increased, and this became the goal. Maps combining precision yield data with aerial imagery and information about soil type, elevation, slope, estimates of soil and nutrient loss, and water ponding areas helped diagnose possible causes of poor yields.

Similar maps proved useful in identifying opportunities for implementing conservation practices. The types, locations, costs, and water-quality value of feasible conservation practices, using the Prioritize, Target and Measure Application (PTMApp: https://nd.ptmapp.iwinst.org/), helped identify additional possible solutions for areas with low yields.

SPP scientists and economists provided each farmer with a report summarizing how each option affects profitability, stewardship quality, and water quality. A dashboard composed of a "speedometer" and a series of charts allows the farmer to rapidly compare their current operation with the two options (see Figure 2).

The SPP approach holds promise for widespread adoption by farmers only if profit and stewardship quality can be simultaneously increased. Preliminary results for 20 farm fields show a simultaneous increase in profitability and stewardship quality. Scientists and economists believe the relationship can be strengthened by being more deliberate about developing options for each field that maximize both profitability and stewardship quality. The relationship can also be improved if a farmer receives revenue for increasing stewardship quality. Corporations wanting to more forcefully support their sustainability claims, as well as conservation organizations wanting to "buy" habitat, could be revenue sources for the farmer when a change in operation increases stewardship quality. Revenue could also come from entities wanting to buy "credit" to improve water quality.

> "The SPP highlighted an important value held by farmers—farmers strive to improve their farm operation and create a legacy of conserving and protecting the soil to enable their children and grandchildren to carry on their agricultural legacy. Decisions are not driven solely by profits."
> —Charles Fritz, executive director of IWI

Some additional work by scientists and economists is needed before the new approach can be broadly applied to improve water quality within watersheds. Scientists continue to work on understanding whether the FSR can be based on fewer than 14 criteria and still properly define stewardship quality. Currently, the FSR can be used to describe stewardship quality only for dryland farming, and scientists are considering adding criteria related to irrigated agriculture. The FSR also needs to be applied to a larger number of fields across differing geographic areas to ensure it properly reflects stewardship quality. And research is needed to show whether the FSR can be tied to soil health.

Realizing meaningful improvement in water quality is possible using the ingredients developed through the SPP to create a new voluntary approach. The leadership of the American farmer is at the center of the approach. Farmers need to be profitable to remain in business, but no farmer participating in the SPP believes maximizing profit is the most important factor when making operational decisions. The most important factor is passing on their farming legacy. Every farmer engaged in the SPP wants to be a good land steward and improve their operation. Farmers now have some new tools to inform their decisions as land stewards and to ensure their legacy is passed on to their children and grandchildren.

As the second phase of the SPP gets underway, the IWI plans to improve the FSR, assess whether profitability and the FSR can be simultaneously maximized, begin connecting the FSR to soil health, explore monetary markets for the FSR, and begin developing technology to deliver information to farmers. The IWI plans to deploy the approach working with farmers in watersheds throughout the United States, to improve farm profitability and realize meaningful improvement in the water quality of our lakes and rivers. ■

Mark R. Deutschman, Ph.D., P.E., is research director for the International Water Institute in Fargo, North Dakota. Mark has had the pleasure of serving public and private sector clients by developing and applying innovative solutions to solve water- and ecology-related problems for more than 30 years. He has undergraduate (University of Montana) and graduate (North Dakota State University) degrees in zoology, capped by a Ph.D. in civil engineering from the University of Minnesota. For more information on the Stewardship Pilot Program or to download the complete report, visit iwinst.org.

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