Universities Council on Water Resources
Journal of Contemporary Water Research & Education
Issue 174, Pages 139-154, December 2021

Adaptable University-Agency Early-Career Fellowship Program Creates a Win-Win-Win for Wisconsin's Waters

Carolyn B. Voter[1], Francisco J. Guerrero-Bolaño[2], Alexander W. Latzka[3], Bryan M. Maitland[4], and *Jennifer A. Hauxwell[5]

*[1]University of Wisconsin-Madison Aquatic Sciences Center & Wisconsin Department of Natural Resources, Bureau of Drinking and Groundwater; [2]College of Engineering, Pontificia Universidad Javeriana-Oregon State University; [3]Wisconsin Department of Natural Resources, Bureau of Fisheries Management; [4]University of Wisconsin-Madison Aquatic Sciences Center & Wisconsin Department of Natural Resources, Bureau of Fisheries Management; [5]University of Wisconsin-Madison Aquatic Sciences Center; *Corresponding Author*

Abstract: Many of today's water resources challenges are wicked problems, demanding innovative solutions across the science-policy-management nexus. Simultaneously, early-career researchers in water resources face a shifting professional landscape in which academic career paths are sparse but where versatile skill sets relevant to water resources issues in governments, non-governmental organizations, and the private sector are in high demand. Here, we describe an adaptable fellowship model that has proven to be a "win-win-win" for early-career researchers, government agencies, and universities tackling wicked water resources challenges in Wisconsin, USA. The fellowship program recruits post-masters and post-doctoral fellows to lead research on a water resources challenge identified as a high priority by a government agency partner. Fellows receive mentorship from both academic and agency mentors and co-produce actionable knowledge. Costs and administrative responsibilities are shared by the university (Sea Grant/Water Resources Institute) and the host agency. Since its inception in 2015, this program has trained 24 fellows across 11 host programs on issues that range from highly quantitative water quality and hydrogeological questions to qualitative assessments of fisheries management and coastal hazards. In this arrangement, fellows receive collaborative and cross-disciplinary training that prepares them well for diverse career paths, government agencies benefit from new knowledge targeted at pressing water resources management questions, and university institutions accomplish their missions of training researchers and developing actionable knowledge. We describe this model's applicability to other regions and institutions. Ultimately, this type of program benefits society by building long-term capacity for collaboration which addresses wicked water problems.

Keywords: *wicked water problems, professional development, actionable science*

Communities around the world are struggling to tackle sustainability challenges for water resources arising from environmental change at local to global scales. Many of these water resources challenges—such as climate change, harmful algal blooms, groundwater depletion, or emerging aquatic contaminants like per- and polyfluoroalkyl substances (PFAS)—are wicked problems inherently resistant to clear definitions and easily identifiable, predefined solutions (Rittle and Weber 1973). These challenges encompass environmental, social, and public health problems that span broad temporal, spatial, and administrative scales (DeFries and Nagendra 2017). Such underlying complexity generates barriers for traditionally siloed early career researchers, government agencies, and universities attempting to build solutions to contemporary wicked water problems.

Partner Challenges

Early career researchers (ECRs; graduate students and postdocs) in water resources

Research Implications

- Post-graduate fellowships supported by Water Resources Research Institutes or Sea Grant Programs (or other university programs) in collaboration with government agencies create "win-win-win" for early-career scientists, universities, and agencies.
- Early-career fellows conduct water resources research and gain experience that makes them well-rounded and prepared for diverse career paths.
- Agencies can meet high-priority and hard-to-tackle research needs at low cost.
- University institutions support high-level training and mentorship of early-career scientists, and research efforts that can have immediate real-world impact.
- This fellowship framework can be adapted in other states, regions, and countries with wicked water challenges and collaborative and engaged academia-government relationships.

programs and positions face a shifting professional landscape in which academic career paths are sparse, and where there is a growing gap between the knowledge, skills, and attitudes employers want and ECRs have (Fiore et al. 2019; Gardner 2021). In navigating graduate and post-graduate life, ECRs must decide how best to prioritize their many tasks, such as writing scientific publications, building social networks, interacting with stakeholders, connecting their science with end users, and learning new skills. Therefore, as the most vulnerable group in the science system (Laudel and Gläser 2008), ECRs need training and experience in collaborating across boundaries and working across the science-policy interface (Cheruvelil et al. 2014; Maitland et al. 2015). This preparation will best position them for success in a cross-disciplinary future in which wicked problems are tackled in team science settings (Bridle et al. 2013).

Government agencies are tasked with managing and conserving natural resources based on the best available science. However, each agency may have hundreds of outstanding science questions and insufficient funding, staff, equipment, or facilities to answer them internally (Twyman and Contractor 2019). There is thus a need to recruit skilled staff and enable co-productive relationships that produce actionable science; that is, collaborations where scientists, managers, and other stakeholders jointly define a scientific problem, design research to address it, and propose strategies that use the research in management decisions (Beier et al. 2017). Agency professionals find fulfillment in public service and in the complexities of various wicked water challenges. These challenges require understanding and managing difficult technical problems within a tapestry of diverse societal and political perspectives, which can be appealing to some ECRs. But even ECRs with diverse scientific backgrounds oftentimes do not apply to positions in the public service sector. Many factors may account for this disconnect, including perceptions of limited salary flexibility, a sense that the skills and experiences required or rewarded do not match their graduate training, the complexities of the hierarchical structure of government, and/or a lack of awareness of career opportunities beyond the traditional academic path (Muir and Schwartz 2009; Blickley et al. 2013).

Universities are places for pedagogy and intellectual freedom, and serve as hubs for theoretical and applied research aimed at tackling wicked problems. Accordingly, universities are challenged with developing future generations of the scientific workforce for impactful careers, and with linking that workforce to society through relationship-building among government and local stakeholder communities. Part of this challenge rests in preparing ECRs for increasingly common and important non-academic career paths, but such training can inherently be more difficult for faculty who have spent their careers within academia (Hansen et al. 2014). For example, while traditional mentoring of ECRs at universities may include training in team or interdisciplinary science and often emphasizes some engagement outside the university, it is professionals at government agencies that deal with the political and social complexities surrounding water resources challenges on a daily basis. Thus, it can be difficult for university researchers to build stakeholder and community connections for ECRs.

Fellowship as a Solution

As water resources problems increase in severity (DeFries and Nagendra 2017; Reid et al. 2019), innovative solutions are needed that cut across the science-policy-management nexus and engage diverse stakeholders to achieve a goal of building long-term collaborative problem solving capacity (Weber and Khademian 2008; Elliot et al. 2018). Cross-disciplinary team science and co-productive science are two approaches to achieve that goal (Wuchty et al. 2007; Soranno and Schimel 2014; NRC 2015; Van Noorden 2015; Beier et al. 2017). Cross-disciplinary team science is an iterative process that brings together actors from multiple fields to engage in mutual learning with the intent to produce new knowledge and solutions unattainable within disciplinary silos (Steger et al. 2021). Co-productive science provides a framework aimed at actionability, wherein researchers and practitioners collaborate to identify questions, design and execute studies, and identify options for implementing changes that appropriately use the science (Beier et al. 2017). The Wisconsin fellowship model adopts principles from both cross-disciplinary team science and co-productive science to provide novel training for ECRs that prepares them for a future collaboratively dealing with wicked problems (Read et al. 2016; Fiore et al. 2019), and produces actionable science in the process.

In what follows, we describe and share lessons from an adaptable fellowship program model, built to encourage cross-disciplinary collaboration and co-productive science, that has proven to be a "win-win-win" for early-career scientists, government agencies, and universities tackling wicked water challenges in Wisconsin, USA. The fellowship program trains ECRs to collaborate among partner groups and stakeholders and emphasizes translating research into actionable, practical solutions, which positions ECRs well for diverse career paths. In the process, agencies can meet high-priority and hard-to-tackle research needs at low cost, and university institutions support high-level training and mentorship of early-career scientists and research efforts that can have immediate real-world impact.

The Fellowship Model

Philosophy

The fellowship program can be conceptualized as a hub for knowledge exchange and social capital (i.e., trust, connections, and shared understanding) embedded in a larger collaboration network between the university and several state or federal agencies (Figure 1). In similar university-government collaboration networks, a small subset of government employees typically serves as a critical but vulnerable link connecting an otherwise highly-fractured network of researchers, managers, and policy experts (Kuehne et al. 2020). From the perspective of Social Network Analysis, this fragmentation is a weakness because strong network cohesion is important for integrating science into policy and management (Roux et al. 2008; Kuehne et al. 2020). Our fellowship program was designed under the hypothesis that strategically adding new nodes in the collaboration network (i.e., fellowships) would enhance the flow of information, resources, and experience (i.e., forms of knowledge exchange; Kuehne et al. 2020) and increase the capacity of the larger collaboration network to address wicked water challenges (via enhanced social capital; Gustaffson et al. 2020).

In our conceptual model, the fellowship program represents a point of convergence for flows of information, resources, and experience from both the university and the agencies (Figure 1). From the agencies, important information flows include identification of actionable research needs, and access to data and the regulatory frameworks that underlie the relevant science-policy issues. From the university, information flows relate to prior work on university research and extension priorities. Both entities provide resources (finances and staff) to support the fellow. Exchanges of experience occur at multiple levels, including between the mentor and fellow as well as between the fellow and stakeholder communities (e.g., regulated groups). The fellowship increases social capital and cohesion by intentionally forging a new link between the university and agency via the fellow-mentor relationship, which enhances the capacity of the larger network to identify solutions to wicked water challenges embodied in the fellowship project.

Both the generation of social capital and the knowledge exchange that take place as part of the fellowship program are supported by pre-existing agreements and partnerships established due to the long-term relationship between the university and the agencies, all of which are reinforced and grow because of these fellowships. In our example, these relationships rest on the operationalization of the "Wisconsin Idea," which is a long-standing tradition that the knowledge produced at the University of Wisconsin should touch the lives of people throughout the State of Wisconsin. The fellowship program contributes to the percolation of these values across different levels of the collaboration network (Figure 1).

Logistics

In Wisconsin, the fellowship program was implemented by the University of Wisconsin-Madison Aquatic Sciences Center (ASC) which houses the Wisconsin Sea Grant College Program and University of Wisconsin Water Resources Institute. Recognizing that these programs had funds available to help pursue actionable water

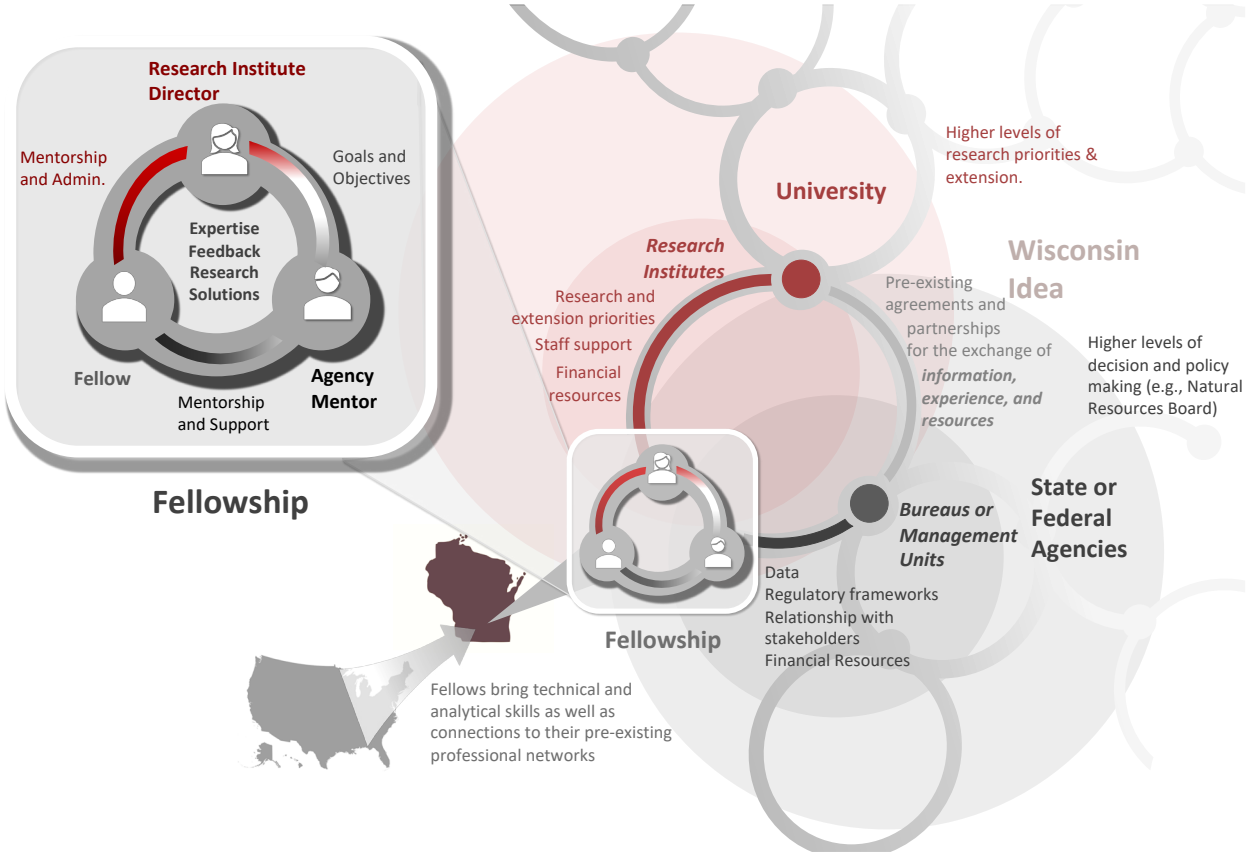


Figure 1. The fellowship program operationalizes the "Wisconsin Idea" across different organizational levels. This program is modeled after the national Sea Grant Knauss Fellows Program and is intended to help attract some of the state and nation's best graduate students in water resources management and analysis to gain key experience in applied actionable science. At the core of the program, there is a close exchange of knowledge (e.g., technical support, definition of goals and objectives), experience (e.g., mentorship), and resources (e.g., administration) within the limited term of the fellowship (1-2 years). Both the Research Institute Director (RID) and the Agency Mentor (AM) are key nodes that connect the fellow (FW) with a larger network within their respective organizations (e.g., Research Institutes and Bureaus and Management Units). The RID also embodies and facilitates the communication of research and extension priorities, liaise and coordinate staff support, and secure financial resources. The AM embodies and facilitates the communication of regulatory frameworks, the relationship with regulated communities, and can help to find additional financial support when needed. The longevity of the program is achieved, partially, by leveraging the results of different fellowships and connecting them with higher levels of research priorities, extension, and policymaking.

science, the ASC formed partnerships with local agencies beginning with the Wisconsin Department of Natural Resources (WDNR) Bureau of Water Quality and the Department of Administration's Coastal Management Program. In later years, a number of additional agencies became involved, including the Bureaus of Fisheries Management, Drinking Water and Groundwater, and Office of Great Waters at WDNR, the U.S. Environmental Protection Agency, and the Wisconsin Department of Health Services. Each of these agencies partners with the ASC and may cost-share to fund, recruit, supervise, and mentor a fellow that leads co-productive research and other activities of value to the agency and relevant to Wisconsin's wicked water challenges (Figure 2). Much of the framework for these fellowships follows recommended best practices for co-productive science (Beier et al. 2017). Throughout this paper, we refer to examples from four primary themes that relate to wicked water issues in Wisconsin (Figures 3-6).

Most agencies develop or maintain a list of research needs—typically water challenges with underlying scientific questions—that could

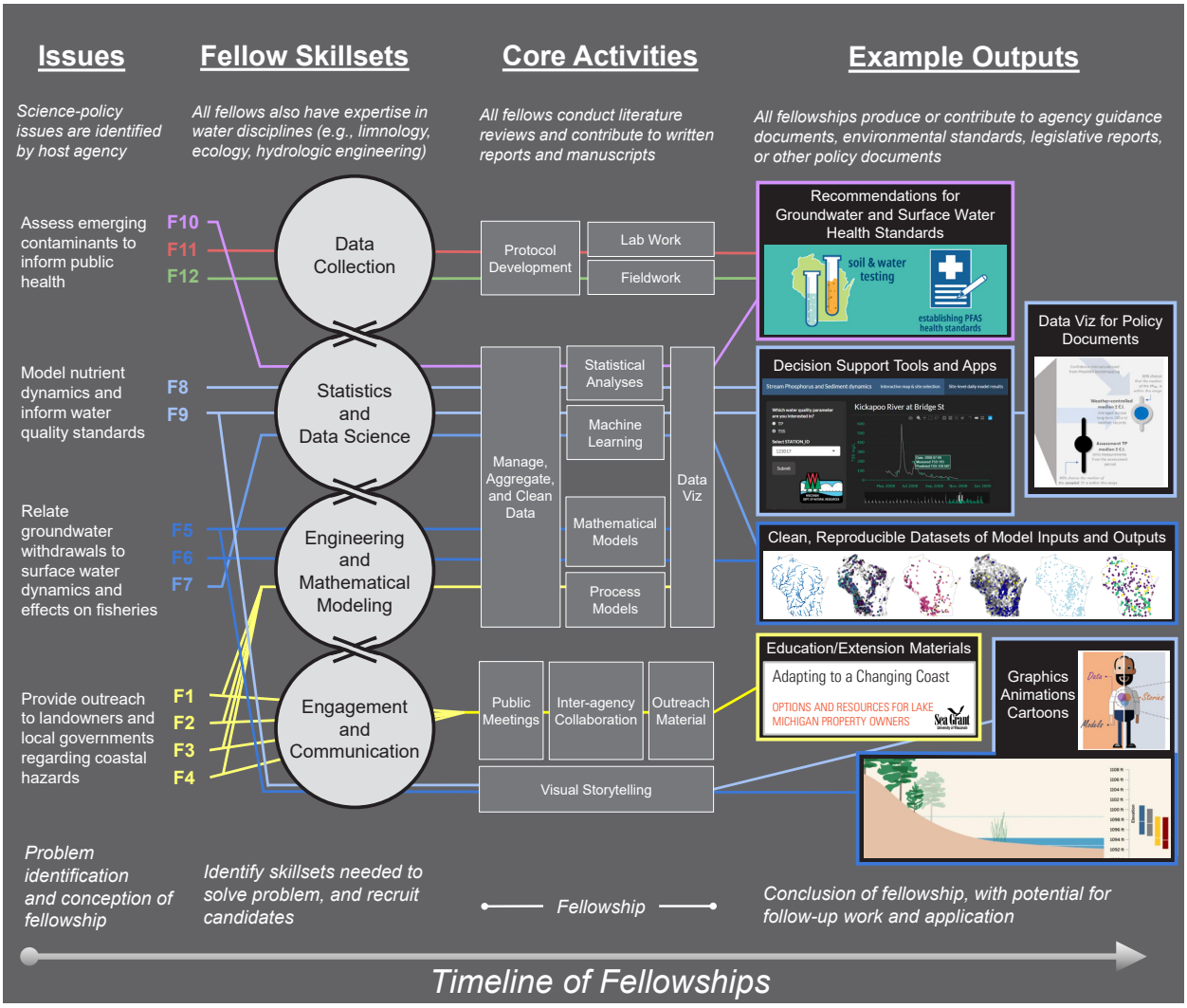


Figure 2. Conceptual layout of fellowship timelines highlighting some different wicked water issues, the key skill or skills of fellows recruited to tackle those issues, the fellows' core activities and some example outputs they produced. Specific fellows and their dominant skillsets, activities, and at least one output per fellow are shown as lines, with colors and numbers matching those in figures 3-6. Variable routes through this matrix highlight the flexibility of approaches to single fellowships and the usage of multiple skillsets to produce different products. Output images adapted from publications from WDNR and WI DOA or provided by authors.

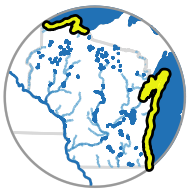
directly inform management decisions or policy, and the university institutions and its funders often have overlapping goals. Finding fellowship projects within this overlap is mostly an organic process, where conversations between agency and university staff converge on research needs that are high-priority, actionable, eligible for all funds to be used, and well-suited for an early-career researcher to tackle. Before a fellowship is formalized, one to three potential projects are identified.

Funding must also be arranged and agreed upon in advance, as fellowships would not occur without sharing of administrative and financial responsibilities. In many cases, neither agencies nor the university institutions have enough funds available to support full-time fellowships independently, but can often support anywhere from 25-75% of their costs annually (Figures 3-6). While the university formally houses the fellow and pays their full salary, agencies go through their own internal budget approval processes and enter into Memoranda of Understanding or issue Purchase Orders to the University for their portion of the costs. Typically, the total cost of a fellowship includes full-time salary, fringe benefits, indirect costs depending on the funding source, and any travel funds the agency deems necessary for conferences or off-site meetings, although the agency can also pay those charges directly.

Once a fellowship project and funding arrangements are agreed upon, fellow recruitment proceeds as a joint effort. First, a primary mentor and mentorship team are identified across the agency and university. Often a subset of this team—at least the mentor and usually one or two subject matter experts—will serve as the core technical working group in partnership with the fellow. This core working group collaborates on a job posting that is nationally advertised by the university and shared by all partners, and then collectively ranks and interviews qualified applicants to best match the disciplinary expertise and key skill sets suited

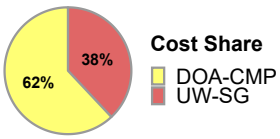
Coastal Processes

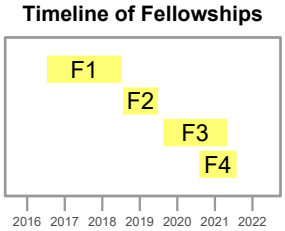
Coastal hazards such as erosion, flooding, and coastal storms are an increasing concern for Wisconsin's coastal communities. Fellows engage with technical staff at local and state governments and interested coastal property owners to provide technical guidance on understanding and estimating the risk of these coastal hazards.



Fellowship Logistics

All fellows stationed with Wisconsin Costal Management Program and Mentor 1, providing a continuous line of support and new expertise for key WCMP initiatives, like the new update of the Wisconsin Coastal Processes Manual.





	Fellow:	Mentor:	University:
What was your goal for the fellowship?	"To understand the needs of stakeholders facing coastal hazards. This knowledge will help me better connect the latest hazards science to inform action and policy (F1)."	"Assistance with the years-long effort and very heavy lift of updating the Wisconsin Coastal Processes Manual (M-F1,2,3,4)."	"To add to the capacity of both WCMP and Sea Grant staff to tackle challenges related to Great Lakes water levels and other hazards."
What did you get out of the fellowship?	"The opportunity to pursue science communication that encourages informed decision making (F4)." "Relationships with local, state, federal and university partners in WI and across the Great Lakes (F1)."	"The expertise the fellows brought and their ability to work with scientists and experts throughout the writing, editing, and reviewing process is leading to what I think will be an incredible product (M-F1,2,3,4)."	"Sea Grant has always had a great relationship with WCMP, but we've been able to leverage our efforts even better by having fellows with a presence in each office."

Figure 3. Description, logistics, and testimonials from current and past fellowships associated with a theme of Coastal Processes.

for the particular water challenge (Figure 2).

After an offer is accepted, the partner roles diverge. Because the university administratively houses the fellows, they work directly with the fellow and agency on negotiations, start date, and formally hiring the fellow. Once hired, fellows are physically stationed at the host agency and focus the majority of their time on their core research or related activities, but they also gain science-policy exposure by attending agency meetings, participating on teams and working groups, and becoming generally integrated within the agency's work setting (Fellows Section, Figure 2). In most cases, the agency provides mentorship, institutional and technical training, and supervision (Agency and Mentors Section), while the university and its institutions take on an administrative and professional development support role (University Section). Many fellows also network across university faculty and other researchers, or with external stakeholder groups, local units of government, and non-profit organizations. Due to the distributed nature of the mentorship team, fellows keep their collaborators and cohort of fellows up-to-date with weekly emails summarizing their main activities, upcoming activities and events, and the "coolest thing" from the week. First month and quarterly meetings led by the fellow are scheduled to highlight progress and next steps, and to gather feedback and suggestions from the host agency and university mentor team to enhance co-production at all steps of the project. The fellowship timeline may be extended to better accommodate project or fellow needs, but is generally not longer than one or two years.

Fellows

Fellows are selected for their scientific expertise, ability to manage projects and work independently, and interest in actionable research. Each fellow is a recent masters or doctoral graduate with a strong background in a field related to the priority

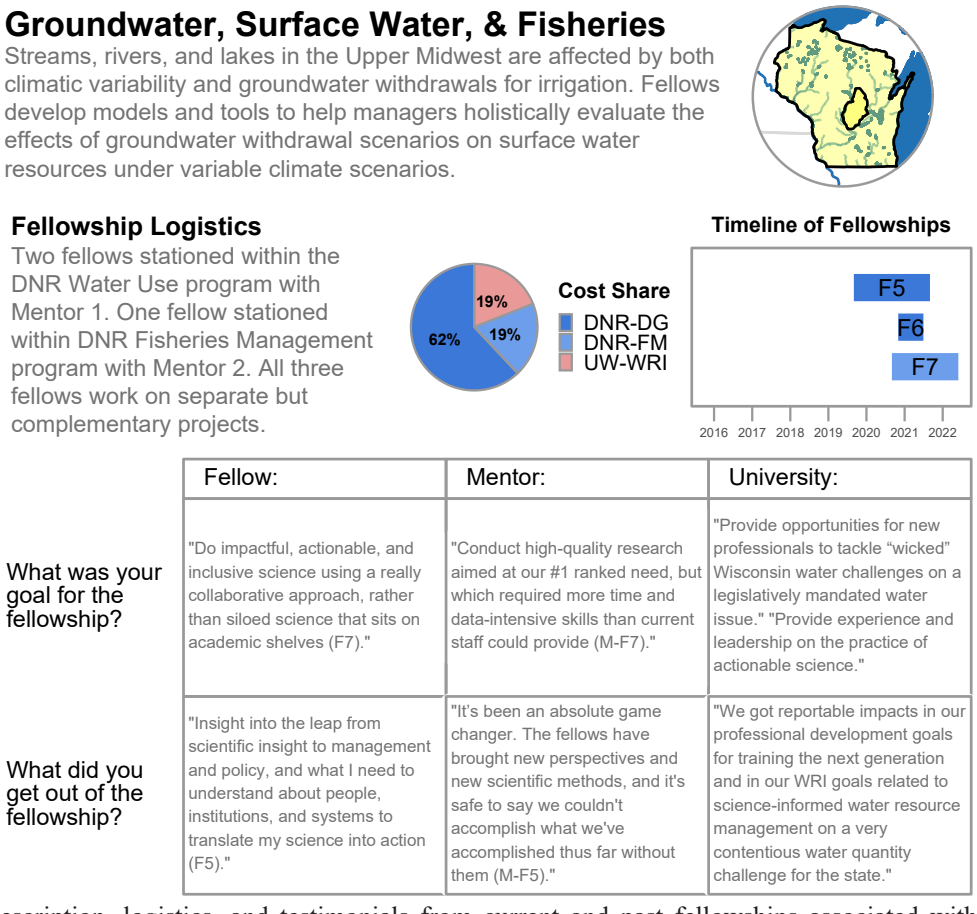


Figure 4. Description, logistics, and testimonials from current and past fellowships associated with a theme of Groundwater, Surface Water, and Fisheries.

water challenge and excellent written and verbal communications skills. They may also have specific analytical skills deemed important by the agency mentor(s), such as proficiency in R, Python, or other coding languages, expertise in physically-based or statistical modeling, or experience designing laboratory experiments. Although these are science-policy fellowships, fellows rarely enter with a formal background in policy; instead, most are recruited on the basis of their technical skills in aquatic sciences- or water resources-related fields, but tend to have an appreciation for and interest in policy. As recent graduates, the fellows typically bring close ties to academic communities and a fresh perspective on the water resources challenges with which the agency is dealing. Because fellows are employees of the university, they also enter with some measure of independence from the political pressures facing the agency, which can be an asset when working on some wicked water challenges.

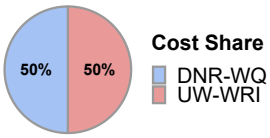
In return for the investment of their time and skills, fellows learn how to combine applied technical work with stakeholder engagement in a co-productive research environment to make their science actionable. Fellows expand their professional networks to include new local, state, federal, and university partners and become skilled at communicating across disciplines to these partners and other stakeholder communities. They also gain considerable breadth in their scientific skills, since projects often tackle broad water resources challenges that require fellows to step outside their comfort zone to answer questions. The breadth of this experience contrasts with the highly specialized training of traditional academic positions and makes fellows marketable to a wide range of jobs. Of the ten fellows who have completed or are nearing the end of their fellowship, three have become specialists at an agency or university program with which they worked as a fellow (WDNR, Wisconsin Sea Grant), three are (or will soon be) faculty members at a

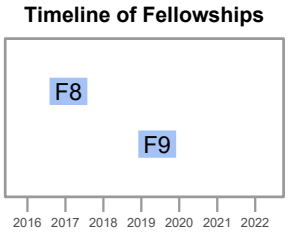
Water Quality

Two of the most common causes of impairment in WI streams are phosphorus and suspended solids. But both of these are highly dynamic, fluctuating with precipitation, runoff, and stream discharge. Fellows developed models and tools that predict stream water quality to lay groundwork for setting new water quality standards.

Fellowship Logistics

Two fellows at the DNR Bureau of Water Quality, with the second fellow's models building off those of the first. Additionally, the first fellow built an online application, and the second incorporated visual story-telling techniques into policy communications.





	Fellow:	Mentor:	University:
What was your goal for the fellowship?	"Dip a toe into science-policy in an agency setting to see how it felt, while adding to my analysis and application development skill sets and research portfolio (F8)."	"My goal was to conduct cutting-edge research and package the results in a format that would be directly usable by agency staff (M-F8,F9)."	"Provide an opportunity for fellows to make scientific contributions and to develop relationships and trust with water resource managers across the state so that they learned how to make the science actionable."
What did you get out of the fellowship?	"I haven't left the DNR since my fellowship. I've found a work setting where my skills and knowledge help make a difference, while maintaining work-life balance (F8)."	"Both water quality fellows brought new perspectives to our program. Their contributions over a short timeframe will have lasting benefits in a wide variety of program activities (M-F8,F9)."	"Fellows provided leadership in understanding stream water quality, learned how to do science that served stakeholders, and learned how to do science in a way that leads to societal impacts, a Sea Grant and WRI goal."

Figure 5. Description, logistics, and testimonials from current and past fellowships associated with a theme of Water Quality.

range of institutions (M1, D/PU, R1), one is in a traditional academic postdoctoral position, one is a science communications liaison at an independent research institute, and one is a data scientist at a disaster response start-up.

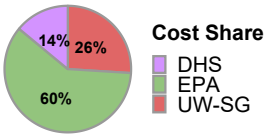
Although each fellow's scientific expertise is unique, all fellows share an ability to manage projects and work independently and an interest in connecting their science with stakeholder and community needs. These traits are key to success because, although fellows usually have a main project on which they focus, they experience more competing demands for their time than would be typical in a traditional academic post-graduate training experience or an entry level position. In those settings, shepherding research through the policy-making process is rarely pursued due to lack of professional incentives or lack of access to the policy-making process. In these fellowships, policy impact is an overarching objective, but the process can be frustrating unless the fellow appreciates the broader social, political, and economic contexts in which policies are created. On a day-to-day basis, fellows are routinely looped into other agency initiatives and meetings and often spend as much time and energy on relationship building and scientific communication as they do on the science itself. Many fellows are able to publish peer-reviewed papers, write grants, or walk away with other traditional markers of academic success, but these are generally not the main goals or outputs of the fellowship. Fellows must understand this, manage their time carefully, and value the additional skills they develop in co-productive science. Guidance from agency mentors is also critical in helping fellows learn to be realistic about what can be accomplished in the short 1-2 year time frame of a fellowship and helping them prioritize the experiences that will best position them for future success in careers focused on actionable science.

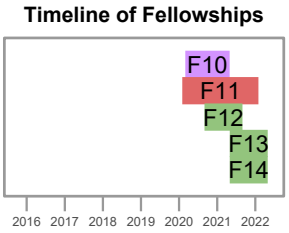
Emerging Contaminants

Emerging contaminants (e.g., pesticides, PFAS) are of concern in Wisconsin, but by definition much is unknown about their extent and toxicological effects. Fellows develop protective groundwater standards, delineate the extent of contamination, and improve toxicological understanding of new and emerging contaminants.

Fellowship Logistics

One fellow at WI-DHS developed groundwater standards, another at UW-Madison investigated the extent of PFAS contamination in Green Bay, and three fellows at the US EPA explored toxicological effects on ecosystems and human health.





	Fellow:	Mentor:	University:
What was your goal for the fellowship?	"To work with EPA experts to apply my scientific and technical expertise to develop quantitative tools to improve ecological risk assessment of contaminants (F12)."	"To contribute to the development of an early career scientist with interest in ecotoxicology and to hire someone with a high degree of expertise to further develop an ecotoxicological model for fish (M-F12)."	"Provide an opportunity for a scientist to apply expertise to statewide challenges and learn how to do science that informs policy, as it is done in collaboration with resource managers with whom the fellow has built trust."
What did you get out of the fellowship?	"Keeping an open line of communication and being part of this bridge between academia and a state agency has really pushed us to accomplish mutually beneficial work (F11)."	"Without the fellow's insights & expertise, this would not have been a successful project. We were also able to apply for a CDC grant to enhance our capacity to address health hazards (M-F10)."	"The fellow provided leadership in helping the state develop PFAS groundwater standards. We made great connections with a new state agency that has led to new fellowships in other water areas and hired the fellow as a permanent scientist."

Figure 6. Description, logistics, and testimonials from current and past fellowships associated with a theme of Emerging Contaminants.

Agency and Mentors

The host agency and its designated mentor(s) serve multiple key roles to support the fellowship. The agency's investment includes operational funding, workspace and supplies, and supervision and mentorship. Funding is often cost-shared across the host agency and university institutions which helps cement the collaborative relationship. It has been typical of agencies to provide at least 50% of the costs for the fellows (e.g., Figures 3-6), including salary, benefits, travel funds, and indirect fees. Agencies have viewed these financial expenses as worthwhile and have taken on more of the costs as the program has grown. Six fellows have been extended after their initial appointment at 100% cost to the agency, and one fellow was recruited and appointed for two years entirely on agency funds. A key attribute that makes these fellowships appealing to early-career scientists interested in engaged, actionable research is the close connection they develop with their host agency. For this connection to form, agencies often provide office space, a computer, software, institutional credentials, and other supplies to integrate the fellow into their work setting. Finally, and most importantly, the agency and its staff serve the role of day-to-day supervisor and mentor—their level of commitment and involvement in this role determine how successful the fellowship will be in meeting agency needs and in developing the skills and experiences of the fellow. In all fellowships to date, agency mentors help the fellows understand the management context for their problem. Mentors also assist with the fellows' core work responsibilities (Figure 2), ensuring that they have access to and an understanding of relevant data, equipment, policies, and external stakeholder groups. Finally, agencies must be prepared to involve the fellow in activities beyond the scope of their core work. These activities create synergistic opportunities for the fellow to expand their professional networks and to experience how the agency and staff conduct their core work and how policy and management decisions are made.

The return on this investment is substantial: the agency meets high-priority needs through co-productive research leading to crucial knowledge and deliverables that can immediately be acted upon or used to inform future work. At any given time, an agency may have numerous research-related needs. For example, the WDNR undergoes a biennial research agenda-setting process, in which each program determines all its current outstanding research needs or questions that could inform management or policy. In 2021, the WDNR Bureau of Fisheries Management, for example, identified and ranked over 200 research needs, only 10 of which were then assigned to existing research staff, leaving many questions unanswered unless pursued through external collaborations. Even high-priority questions may not be addressed by existing staff if skill sets do not align, or if the question may be better pursued by an external, independent partner. Some research needs are well suited for more traditional academic projects with less engagement from agency staff, or through other relationships like U.S. Geological Survey (USGS) Cooperative Research Units, but others require more agency involvement and/or a fresh perspective. Fellowships can help solve each of these limitations. Between 2015 and 2020, after several court cases regarding high-capacity wells, two DNR programs identified high-priority research needs aimed at better understanding well effects on streams and trout fisheries. In fact, one study on the effects of wells on lake levels was mandated by the state legislature. But this study and others on streams demanded a great deal of time and expertise, and could benefit from an outside, independent perspective. Therefore, three fellowships were created to focus on different aspects of these questions (Figure 4). Moreover, fellows often submit grant proposals for follow-up research that ties in additional priorities. One of these three fellows was recently invited to submit a full proposal for a $400k federal grant, and other fellows have brought in $250-750k to work on issues related to their fellowships. Agency representatives have expressed that fellows tend to bring fresh ideas that can "shake up" long-standing and potentially outdated ways of thinking within the agency.

The research in which these and all fellows partake is cross-disciplinary, team-based, and co-productive, with the mentor and host agency involved and invested in the research outcomes. This means that like any professional or supervisory relationship, the mentor-fellow dynamic must be collegial with open lines of

frequent communication. Most fellows and their primary mentors have worked in the same office and had informal meetings or work sessions on a weekly basis. This level of investment is rare when research is conducted externally. However, this participatory framework allows host agency staff to be more engaged with the research, helping ensure that questions, methods, and management recommendations are relevant, and is critical for the fellow's fresh perspectives to gain traction. Ultimately, management staff are more likely to understand and use the resulting information in subsequent processes, management decisions, and policies.

One attribute of these fellowships that allows for the research to be actionable is the possibility for outputs and deliverables to be designed to meet agency needs (Figure 2). While all fellowships create or contribute to the development of guidance, policy, or law and often result in manuscripts, other specific outputs are flexible. They can range from usable, reproducible datasets to decision support tools, outreach materials, innovative graphics, and visualizations. Often, these outputs are not prescribed at the beginnings of fellowships and tend to emerge organically depending on the fellow's expertise and the agency's needs. For example, both water quality fellows frequently met with local resource managers and policymakers to identify new outputs that met their needs (Figure 5). The first fellow tackled the challenge of making statewide modeling results useful at local scales through the design and implementation of a customized Shiny application tailored to specific questions posed by managers. This effort led to an agency-wide implementation of Shiny and other data visualization and dashboarding tools. The second fellowship coincided with policy writing and related outreach, in which it became a challenge to describe the science underlying the proposed policy. The fellow was able to use his background in science communication and innovative custom graphics to develop visual appendices that made complex statistical models and data understandable to lay readers.

University

The university serves as the central hub of the program and provides coordination, publicity, funding, and human resources support for each fellowship. In the Wisconsin fellowship model, the university is represented by the University of Wisconsin-Madison Aquatic Sciences Center (ASC), which hosts both the Wisconsin Sea Grant College Program and University of Wisconsin Water Resources Institute. ASC staff regularly reach out to agency contacts to pitch the program and help identify agency needs that are well-suited for a fellowship project. As word has spread about the value of the fellowship program, less outreach to agencies is required. In fact, ASC staff are now often approached by agency staff with ideas for new fellowships. The university covers up to 50% of the costs for the first year of a fellowship, with the agency covering the remaining costs, though sometimes the agency will cover up to 100% of costs (e.g., if a fellowship is extended for a second year or if the agency has funding and the university has already allocated all of its fellowship funding for the fiscal year). In all cases, the university employs the fellow as a postdoctoral fellow or research intern (for post-master's fellows) which provides the fellows with access to university employee resources and benefits (e.g., healthcare, libraries, seminar series, bus pass program). Human resources support is provided by the ASC. At key milestones during the fellowship, the ASC communications team provides publicity for the fellow and project. Cohort-building activities (e.g., weekly update emails, joint conference presentations, biennial recognition ceremonies) are generally coordinated by the ASC as well.

In return for this investment, the university advances its mission of training and supporting scientists in conducting impactful, actionable research. While the traditional model of post-graduate academic training focuses exclusively on research skills, this fellowship model places new scientists in positions where they develop a diverse portfolio of skills by doing co-productive science. Embedded in agencies and working side-by-side with agency staff, fellows learn to communicate across disciplines, build trust with communities, and orient their research to address questions with both scientific and management relevance. This prepares fellows for a more impactful future career, thus fulfilling the university's core mission with additional tangible benefits for centers like the

ASC, which compete for federal merit funding that is awarded based on performance and community impact. In addition, the fellowship program can lead to new or stronger relationships between current staff at the university and agencies. For example, while the Wisconsin Sea Grant and Wisconsin Coastal Management Program have always had close ties, having a fellow connected with both offices has helped both programs stay abreast of emerging initiatives and better leverage outreach blasts to promote each program (Figure 3). Wisconsin Sea Grant has thus far hired two former fellows as new outreach/subject-matter experts after national searches, in part due to the unique skills and relationships the candidates formed with agencies and stakeholders during their fellowship experience. Another fellow was hired by the agency they worked with (WDNR) for the same reasons.

In the Wisconsin fellowship model, the university's ability to fund fellowships has benefited from support and synergies between the Sea Grant and Water Resources Institutes. First, because ASC administers both the National Oceanic and Atmospheric Administration (NOAA)-funded Sea Grant program and the USGS-funded Water Resources Research Institute for Wisconsin, nearly all water resources-related challenges fall within its purview. Second, leaders at the ASC value the program and set aside approximately $35-40k of the federal NOAA and USGS base funds each year. Between the commitment of leaders at the ASC and the flexibility of the dual programs, thus far it has always been possible for the university to match agency funds as needed to support the first year of most new fellowships. Last, the dual fellowships provide, at minimum, a two-fellow cohort and twice the impact of a single program fellowship. The rapid growth in the fellowship program is, in part, due to the diversity and impact that two programs have accomplished together; in addition, there is increased efficiency in all aspects of fellowship administration.

The fellowship model has evolved substantially over time, so it has also been important for the university to be opportunistic and flexible when pursuing new fellowships. Although the intention was always to cost-share a post-graduate fellow with an agency, the pilot fellowship was a graduate student project assistant entirely funded by the ASC in order to demonstrate the potential of the program. Subsequent fellowships have generally included a 50% cost-share with an agency and employment at UW-Madison, but exceptions are routine. For example, two fellows are primarily associated with Wisconsin Sea Grant-funded research projects (i.e., 100% funded by the university). In addition, the ASC partnered with a prestigious legal scholar to provide partial funding for two new law school graduates hired by UW-Milwaukee's Center for Water Policy. These fellows will be employed through UW-Milwaukee, but were recruited in conjunction with the ASC and will be a part of the ASC cohort of fellows. This partnership between the ASC fellowship program and a top legal scholar was valuable for attracting outstanding law-policy candidates who are capable of approaching wicked Wisconsin water challenges from a policy/legal angle with a legal skillset.

Strong personal and professional connections between ASC staff and agency staff have helped build trust and smooth potential stumbling blocks. An inelegant aspect of the program's design is that a fellow's formal supervisor is at the university, but their project, mentor, colleagues, and desk are at the agency. If a fellow or mentor is not working out, it can be difficult for the university supervisor to identify or correct the issue without strong relationships and good communication. Occasionally, mentors have left the agency or changed roles mid-fellowship, requiring the university supervisor to find other agency staff to step in as mentors and continue to move the project forward. This has worked best when the university supervisor has good relationships with other agency staff who are also invested in the project.

Extending the Fellowship Model

Comparable Programs

There are other fellowship programs operating around the country that endeavor to match highly qualified ECR candidates with non-academic mentors and host agencies to tackle wicked problems. Many federally funded fellowship programs are administered through NOAA and USGS. At the federal level, NOAA supports fellowship programs through Sea Grant (Knauss

Fellowship), through a partnership between Sea Grant and the National Marine Fisheries Program (Marine Resource Economics / Population and Ecosystem Dynamics), and through the Office of Coastal Management (the Coastal Management, Coral Reef Management, Digital Coast, and Margaret A. Davidson Fellowships), as well as myriad state fellowship programs run by state-level Sea Grant College Programs. The USGS oversees the Pathways Internship program which provides high school- to graduate-level students with opportunities to work in agencies that provide scientific support for decision making, as well as the Mendenhall Research Fellowship Program, which provides post-graduate fellows with cutting-edge research experiences in partnership with USGS scientists.

Scientific societies also play an important role in overseeing fellowships intended to train future researchers and practitioners to cut across the science-policy-management nexus. At the graduate level, the fellowship program run by the Great Lakes Environmental Observation Network (GLEON) trains cohorts of graduate students to exploit the rich information content of large and diverse data sets, operate effectively in diverse international teams, and communicate outcomes to a broad range of audiences (Read et al. 2016). The American Association for the Advancement of Science hosts six fellowships that, while not restricted to ECRs, provide firsthand learning experiences at the intersection of science and society to train better scientists. At the post-graduate stage, the Smith Conservation Research Fellowship Program in the U.S. and the Liber Ero Fellowship Program in Canada support ECRs for two years to conduct and communicate world-class research that informs conservation and management issues.

An important drawback of some society-based fellowships is that they do not have explicit agency partners involved in the project. For example, the GLEON Graduate Fellowship program is more centered on formal transdisciplinary training for students through workshops than "on-the-job" training. Where there is an explicit agency partner, the onus is often on the fellow to develop a project, which in turn can result in a loss of continuity and longevity when a fellow completes or moves on from the project. For example, society-based programs like the Smith and Liber Ero Fellowships have fellows explicitly identify a practitioner mentor during their proposal, but the individual projects are independent from one another with very little overlap. The above issues result in deeper problems for fellowship programs operating within the researcher-agency-university interface and attempting to solve systemic, societal challenges: a lack of continuity between fellows tackling similar problems (i.e., vertical project integration through time), and a lack of synergy among projects (i.e., horizontal integration across projects). In other words, typical fellowship programs and projects, despite substantial effort, often operate as a fractured network of researchers, managers, and policy experts that can stymie the development of long-term collaborative problem-solving capacity. In contrast, the Wisconsin fellowship model is structured around a coordination hub (in our case, the university) such that new fellows are strategically added to a broader—and continually growing—collaboration network to enhance knowledge exchange and social capital. Accordingly, we suggest the overall structure of the Wisconsin fellowship model as a robust option for other regions and jurisdictions aiming to holistically address wicked water challenges.

Adapting the Model Elsewhere

The first step in adapting this fellowship model beyond Wisconsin is identifying which entity serves as the coordination hub (i.e., the "university" role). This entity should be relatively insulated from shifting political pressures and thus able to provide critical continuity across fellowship projects. We suggest that university programs are well-suited to this role for several reasons. Importantly, universities have well-established mechanisms for hiring postdoctoral and post-master's degree researchers (including international researchers) and there is almost always an ability to hire for these roles provided funding can be obtained. In addition, many university programs serve as hubs for researchers in other ways, which can facilitate connections between academic experts and fellows who are physically located in government agencies. University programs also tend to have broad missions that allow for flexibility in addressing water resources challenges.

University centers which jointly administer Sea Grant and Water Resources Research Institutes are clearly well-suited to serve as the coordination hub, but land-grant extensions, fisheries and wildlife cooperative research programs, and university-specific umbrella groups such as water consortiums or environmental research institutes may also be good fits for the role. Many private research institutes, scientific societies, and non-profit organizations already administer fellowship-type programs and may also make good coordination hubs, particularly at the national level. Administering and recruiting for the fellowship program should be an explicit part of someone's job description, with others in the organization supporting the fellowship program in the same way that other long-standing initiatives are supported (e.g., via human resources, financial management, and communications assistance). It is ideal if the main point person is well-connected to university-based research; in the Wisconsin fellowship program, the university point person is also responsible for overseeing the ASC's research portfolio and identifying critical research needs related to the ASC's mission.

Once an appropriate coordination hub and point person are identified, the next step is for the point person to begin establishing connections with agency partners. Importantly, the groundwork for university-agency partnerships and the scoping of individual fellowship projects must occur before a fellow is identified. This ensures that ultimate responsibility for the collaboration rests with established staff and can persist beyond the short tenure of the fellow. It also allows for higher-level strategizing and problem solving; short-term projects done by individual fellows can be vertically integrated through time and horizontally integrated across major themes or challenges. When a fellow at last arrives on the scene, they are free to be a true innovator and disruptor; a new node in the larger collaborative network that can infuse new ideas into established ways of thinking. At the same time, the fact that the agency has identified the project as a priority, committed resources to the fellow, and invested in developing a close, personal relationship with them ensures that the fellow's ideas are not dismissed, but instead gain traction. This overarching emphasis on enhancing social capital within the collaboration network, in addition to generating new knowledge targeted at critical needs, is key to building long-term collaborative problem-solving capacity for societies.

Conclusion

To tackle the world's wicked water problems, society needs collaborative teams of scientists working across the science-policy-management nexus to effectively co-produce knowledge and solutions across disciplinary and jurisdictional boundaries. Multiple cohorts of Wisconsin water resources fellows have completed their fellowships with bolstered confidence in collaborative capacity, leadership, communication skills, and scientific expertise. They have produced a wealth of peer-reviewed research manuscripts, government reports, software products, and data visualizations, and have parlayed their experiences into a wide range of jobs in academia, government, and the private sector. From the agency perspective, the program has been "an absolute game changer" due to the new perspectives, new scientific methods, and new knowledge fellows have contributed to key agency priorities. The university and its institutions have developed a training program that prepares early-career researchers for non-academic positions and for co-producing actionable science. Thus, each partner involved in the Wisconsin Water Resources Fellowship Program achieves their own "wins." But more importantly, a gestalt has emerged: By growing a collaboration network of early career researchers, agency staff, and university experts, the Wisconsin fellowship program has fostered strong relationships that have ultimately bolstered long-term capacity to collaboratively tackle wicked water problems across the state and beyond.

Acknowledgements

Funding for fellowships and for the authors' contributions to this manuscript was provided by: the University of Wisconsin Sea Grant Institute (under grants from the National Sea Grant College Program, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, and from the State of Wisconsin, federal grant numbers NA18OAR4170097 and NA14OAR4170092), the University of Wisconsin

Water Resources Institute (under grants from the U.S. Geological Survey, U.S. Department of the Interior and from the State of Wisconsin, federal grant numbers G11AP20115 and G16AP00092), the Wisconsin Department of Natural Resources, the Wisconsin Department of Administration's Coastal Management Program, the Wisconsin Department of Health Services, and the United States Environmental Protection Agency. Special thanks to James Hurley for advancing the concept for and building capacity to develop a statewide fellowship program, as well as to Adam Bechle for his support of the program and contributions to the initial scoping of the manuscript. Thanks also to Kate Angel, Sarah Balgooyen, Adam Bechle, Matthew Diebel, Matthew Etterson, Nate Pollesch, Lydia Salus, and Sarah Yang for providing quotes for the vignettes, and to Nate Pollesch, Matthew Diebel, and anonymous reviewers for reviewing the manuscript.

Author Bio and Contact Information

Dr. Carolyn B. Voter (corresponding author) is a Wisconsin Water Resources Science-Policy Fellow with the Wisconsin Department of Natural Resources, Bureau of Drinking Water and Groundwater, Water Use Section. As a graduate student, she piloted the fellows program as a Wisconsin Water Resources Science-Policy Fellow in the Wisconsin Department of Natural Resources, Bureau of Drinking and Groundwater, Groundwater Section. She may be contacted at cvoter@wisc.edu or by mail at University of Wisconsin-Madison Aquatic Sciences Center, 1975 Willow Dr., Madison, WI 53706.

Dr. Francisco J. Guerrero-Bolaño is a courtesy Faculty Member in the College of Forestry (Oregon State University). He recently worked as Science Communication Liaison for the National Center for Ecological Analysis and Synthesis (NCEAS) and COMPASS. He was a Water Science-Policy Fellow at the Wisconsin's Department of Natural Resources (WDNR) between 2018-2019 with the Bureau of Water Quality. He may be contacted at francisco.guerrero@oregonstate.edu or by mail at Peavy Forest Science Center, 3100 SW Jefferson Way, Corvallis, OR 97333.

Dr. Alexander W. Latzka is a Fisheries Systems Biologist with the Wisconsin Department of Natural Resources Bureau of Fisheries Management. He has been involved in the fellowship program since its first year, first as one of the inaugural fellows (Wisconsin Water Resources Science-Policy Fellow in WDNR Bureau of Water Quality in 2016-17) and now as a mentor to the Wisconsin Water Resources Science Policy Fellow in Fisheries Management. He may be contacted at alexander.latzka@wisconsin.gov or by mail at Wisconsin Department of Natural Resources Bureau of Fisheries Management, 101 S. Webster St., Madison WI 53703.

Dr. Bryan M. Maitland is a Wisconsin Water Resources Science-Policy Fellow placed with the Wisconsin Department of Natural Resources, Bureau of Fisheries Management. He obtained his PhD at the University of Wyoming in August 2020 and is interested in applying ecological data and models to address conservation problems. As a Fellow, he is researching the effects of hydrologic change on stream trout populations across Wisconsin. He may be contacted at bmaitland101@gmail.com or by mail at Wisconsin Department of Natural Resources Bureau of Fisheries Management, 101 S. Webster St., Madison WI 53703.

Dr. Jennifer A. Hauxwell (corresponding author) is the Associate Director of the University of Wisconsin Aquatic Sciences Center, leading the center's administrative team (financial, human resources, and technology) and coordinating the program's research and fellowship activities. She may be contacted at jennifer.hauxwell@aqua.wisc.edu or by mail at University of Wisconsin-Madison Aquatic Sciences Center, 1975 Willow Dr., Madison, WI 53706.

References

Beier, P., L.J. Hansen, L. Helbrecht, and D. Behar. 2017. A how-to guide for coproduction of actionable science. *Conservation Letters* 10(3): 288-296.

Blickley, J.L., K. Deiner, K. Garbach, I. Lacher, M.H. Meek, L.M. Porensky, M.L. Wilkerson, E.M. Winford, and M.W. Schwartz. 2013. Graduate student's guide to necessary skills for nonacademic conservation careers. *Conservation Biology* 27(1): 24-34.

Bridle, H., A. Vrieling, M. Cardillo, and Y. Araya. 2013. Preparing for an interdisciplinary future: A perspective from early-career researchers. *Futures* 53: 22-32.

Cheruvelil, K.S., P.A. Soranno, K.C. Weathers, P.C. Hanson, S.J. Goring, C.T. Filstrup, and E.K. Read. 2014. Creating and maintaining high-performing collaborative research teams: The importance of diversity and interpersonal skills. *Frontiers in Ecology and the Environment* 12(1): 31-38.

Defries, R. and H. Nagendra. 2017. Ecosystem management as a wicked problem. *Science* 356(6335): 265-270.

Elliott, L., M. Ryan, and C. Wyborn. 2018. Global patterns in conservation capacity development. *Biological Conservation* 221: 261-269.

Fiore, S.M., C. Gabelica, T.J. Wiltshire, and D. Stokols. 2019. Training to be a (team) scientist. In: *Strategies for Team Science Success: Handbook of Evidence-Based Principles for Cross-Disciplinary Science and Practical Lessons Learned from Health Researchers*, K.L. Hall, A.L. Vogel, and R.T. Croyle (Eds.). Springer International Publishing, Cham, Switzerland, pp. 421-444.

Gardner, C.J. 2021. Not teaching what we practice: Undergraduate conservation training at UK universities lacks interdisciplinarity. *Environmental Conservation* 48(1): 65-70.

Gustafsson, K.M., I. Díaz-Reviriego, and E. Turnhout. 2020. Building capacity for the science-policy interface on biodiversity and ecosystem services: Activities, fellows, outcomes, and neglected capacity building needs. *Earth System Governance*. Available at https://doi.org/10.1016/j.esg.2020.100050. Accessed September 7, 2021.

Hansen, G.J.A., S. Sadro, M.M. Baustian, and B.A. Stauffer. 2014. Is it time to redefine the "alternative" career path for ecologists? *Limnology and Oceanography Bulletin* 23: 2-5.

Kuehne, L.M., A.L. Strecker, and J.D. Olden. 2020. Knowledge exchange and social capital for freshwater ecosystem assessments. *BioScience* 70: 174-183.

Laudel, G. and J. Gläser. 2008. From apprentice to colleague: The metamorphosis of Early Career Researchers. *Higher Education* 55: 387-406.

Maitland, B.M., S.J. Cooke, and M. Poesch. 2015. Finding the path to a successful graduate and research career: Advice for early career researchers. *Fisheries* 40(8): 399-403.

Muir, M.J. and M.W. Schwartz. 2009. Academic research training for a nonacademic workplace: A case study of graduate student alumni who work in conservation. *Conservation Biology* 23(6): 1357-1368.

National Research Council (NRC). 2015. *Enhancing the Effectiveness of Team Science*. The National Academies Press, Washington, D.C.

Read, E.K., M. O'Rourke, G.S. Hong, P.C. Hanson, L.A. Winslow, S. Crowley, C.A. Brewer, and K.C. Weathers. 2016. Building the team for team science. *Ecosphere* 7(3): e01291.

Reid, A.J., A.K. Carlson, I.F. Creed, E.J. Eliason, P.A. Gell, P.T.J. Johnson, K.A. Kidd, T.J. MacCormack, J.D. Olden, S.J. Ormerod, J.P. Smol, W.W. Taylor, K. Tockner, J.C. Vermaire, D. Dudgeon, and S.J. Cooke. 2019. Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews* 94(3): 849-873.

Rittel, H.W.J. and M.M. Webber. 1973. Dilemmas in a general theory of planning. *Policy Science* 4: 155-169.

Roux, D.J., P.J. Ashton, J.L. Nel, and H.M. MacKay. 2008. Improving cross-sector policy integration and cooperation in support of freshwater conservation. *Conservation Biology* 22(6): 1381-1387.

Soranno, P.A. and D.S. Schimel. 2014. Macrosystems ecology: Big data, big ecology. *Frontiers in Ecology and the Environment* 12(1): 3.

Steger, C., J.A. Klein, R.S. Reid, S. Lavorel, C. Tucker, K.A. Hopping, R. Marchant, T. Teel, A. Cuni-Sanchez, T. Dorji, G. Greenwood, R. Huber, K.A. Kassam, D. Kreuer, A. Nolin, A. Russell, J.L. Sharp, M. Šmid Hribar, J.P.R. Thorn, G. Grant, M. Mahdi, M. Moreno, and D. Waiswa. 2021. Science with society: Evidence-based guidance for best practices in environmental transdisciplinary work. *Global Environmental Change* 68: 102240.

Twyman, M. and N. Contractor. 2019. Team assembly. In: *Strategies for Team Science Success: Handbook of Evidence-Based Principles for Cross-Disciplinary Science and Practical Lessons Learned from Health Researchers*, K.L. Hall, A.L. Vogel, and R.T. Croyle (Eds.). Springer International Publishing, Cham, Switzerland, pp. 217-240.

Van Noorden, R. 2015. Interdisciplinary research by the numbers. *Nature* 525: 306-307.

Weber, E.P. and A.M. Khademian. 2010. Wicked problems, knowledge challenges, and collaborative capacity builders in network settings. *IEEE Engineering Management Review* 38(3): 57.

Wuchty, S., B.F. Jones, and B. Uzzi. 2007. The increasing dominance of teams in production of knowledge. *Science* 316(5827): 1036-1039.