

Catalyzing Frontiers in Water–Climate–Society Research

A View from Early Career Scientists and Junior Faculty

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“We have to ask ourselves, are we doing the right thing? Or are we using scientific information to do the wrong thing more precisely?”

—ROGER PULWARTY (Director, NOAA National Integrated Drought Information System),
NCAR Jr. Faculty Forum, July 2010

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Changes in the availability and distribution of water have substantial effects on humans and the ecosystems upon which we depend. While we have always experienced variability in the availability of water across a variety of time scales, anthropogenic climate change will likely bring substantial additional effects on water cycles and water resource management, such as changes in timing, amount, and patterns of precipitation; decreasing snow packs; enhanced droughts; and more frequent and intense floods and storms, among others. The scientific community faces the challenge of helping societies plan for climate and water uncertainties in the context of complex and changing socioenvironmental processes such as multiple and competing water demands, population growth, land-use changes, and energy extraction and production. Meeting this challenge requires utilizing the strengths of diverse disciplines and working in synergistic collaboration with key stakeholders.

In the spirit of this effort, a group of 27 junior faculty and early-career scientists, composed of social scientists, atmospheric scientists, and hydrologists, met in Boulder, Colorado, in July 2010 for a Junior Faculty Forum sponsored by NCAR (www.asp.ucar.edu/ecsa/jff/jff10.php). Expert presentations and discussions focused on adaptation of human societies and water systems to climate change. In this article, the members of this group present a synthesis of our ideas and recommendations for catalyzing scientific frontiers in use-inspired water–climate–society research.

We realize that there are some who have been working on this intersection and deserve to be credited, but doing so is beyond the scope, word limit, and style of this article. To address this, we created a

supplementary website, www.ral.ucar.edu/projects/wcs, which includes many of the seminal works across multiple disciplines that we encourage readers to visit for references and additional resources. We intend this site to be dynamic, and we invite readers to contribute to it via the “Submit a Resource” function in order to populate the site with what the peer community deems most relevant.

THE WATER–CLIMATE–SOCIETY NEXUS.

“We move water around to satisfy our needs in places we want to live. So, for adaptation, the places that we move water from, if they’re vulnerable to climate change, we are also vulnerable.”

—ROGER PULWARTY (Director, NOAA National Integrated Drought Information System),
NCAR Jr. Faculty Forum, July 2010

Water is critical for all human and natural systems, from ecosystems and environmental sustainability to agriculture, food security, and public health, as well as to energy production and industry. Water is part of the fundamental dynamic, thermodynamic, and physical processes of the climate system, with complex nonlinear interactions and feedbacks across a broad range of spatial and temporal scales. Water is thus a primary nexus between climate and society, and the impacts of climate change on societies are likely to manifest most severely through impacts on water resources and societal responses to these impacts.

The anticipated hydrological, ecological, and societal impacts from climate change challenge a number of long-held assumptions in water resource management. Climate change science teaches us that long-term planning (e.g., decadal or longer) can no longer rely on the past as a primary predictor of future conditions (i.e., assumptions of stationarity must be replaced with considerations of nonstationarity). We are likely to see climatic and hydrologic conditions that are outside of our range of direct experience, even for short-term planning (e.g., days, months, a year, 5–10 years), and could ultimately shift to a new “normal” or baseline state. The uncertainties in climate change projections and impacts on social and ecological systems present profound scientific and planning challenges. One scientific challenge is to develop robust scenarios of future climate impacts on hydrology. Predicting human behavior adds layers of complexity to projecting future impacts, vulnerability, and adaptation to environmental changes. It

also presents challenges as to how we organize the production of scientific knowledge on climate and water and its use in society.

Adaptation to climate change will require innovative, flexible institutional and organizational structures to meet the challenges presented by complex patterns of change. It will also necessitate overcoming the difficulty of integrating various worldviews and ways of knowing across disciplines and cultures. The heavy reliance on highly uncertain model outputs at scales relevant to decision making along with a broad array of management regimes from water to energy underpin this challenge. Climate change adaptation compels the need for a new relationship between society and science that drives advances across all disciplines. Historical analogues are often invoked to show the human capacity for such huge endeavors (e.g., the race to space, the Manhattan Project); however, the scale and pace of climate change on multiple time and space scales require a degree of unity beyond anything accomplished in the past. This is of greatest concern given the barriers that can cause inaction or resistance to proactive change in societal systems.

THE NEED FOR A BIGGER TOOLBOX.

A spectrum of research, from basic to applied to participatory, is needed to develop a dynamic and usable “toolbox” of innovative approaches, methods, and technologies that are truly integrative. Table 1 includes some of the frontiers in water–climate–society research that we see as vital to this enterprise. We must insure a balance of opportunities for research from myriad disciplines without prioritizing certain ones at the expense of others, which can otherwise lead to disciplinary “turf wars.” Using the example of optimizing water systems in the arid American West, alterations to water system design and operation might be implemented under a more robust, comprehensive adaptation strategy instead of outdated “command and control” top-down strategies that can either negate or conflict with smaller-scale ecosystem or community processes. Water management systems based on stationarity assumptions (i.e., that water and climate cycles remain within a certain range of variability) could be replaced by analytical and numerical strategies and techniques based on a nonstationarity framework, borrowing from understanding in geography and applied and physical climatology. This would necessarily involve water managers to integrate the science with real-world applications and expectations.

TABLE 1. Scientific frontiers of water–climate–society science (see www.ral.ucar.edu/projects/wcs for additional details and frontiers).

Scientific frontier	Description	Examples	Recommendations
Incorporating non-stationarity into water research and planning	These methods include the use of paleoclimate or historic data to expand the model range of hydrologic variability beyond the instrumental measurement record.	Multiple hydroresearch projects in Europe funded nationally or by the European Union (see Kundzewicz 2011)	Research on the development and implementation of new water-management strategies that are inherently flexible and adaptive enough to account for nonstationarity.
Adaptation mainstreaming	Incorporating adaptation science and strategies into existing decisions and policies.	Mainstreaming adaptation to climate change into water resources management and rural development (www.cakex.org/virtual-library/1132)	Require applied research to understand how to mainstream adaptation initiatives into water resource-related areas such as agriculture, flood control, wastewater management, ecosystem health, fisheries, human health, and energy by supporting these initiatives as they are underway.
Evaluation	Adaptation research and planning is incomplete without a better understanding of whether scientific information is usable and is leading to better decision making.	“Usable Science” handbook (http://cstpr.colorado.edu/sparc/outreach/sparc_handbook)	Require the development and improvement of robust theoretical frameworks for defining performance indicators (i.e., what constitutes successful adaptation?), and longitudinal empirical work to assess how climate information is perceived and if it benefits users.
Demand-side climate adaptations such as research on “virtual water”	Virtual water means accounting for the exchanges of water for goods and services produced in one place but used in another.	The Water Footprint Network (www.waterfootprint.org/?page=files/home)	Account for the effects of climate change and create a full “water footprint” of local and remote consumption of water sources, especially as urban populations grow and increasingly depend on virtual water to sustain them.
Water–energy–climate nexus research	Exploring the links between energy needs for water use and water needs, for energy extraction and production, and the implications under climate change.	The Water–Energy Nexus in the Western States (www.sei-us.org/publications/id/370)	More research on this critical topic for sustainability to understand the complex linkages and tradeoffs between climate–water–energy under different energy-use scenarios and as new energy technologies evolve.

Although disciplinary pieces have been and continue to be developed, a completely interdisciplinary, participatory framework to address nonstationarity is not currently available.

A common barrier to interdisciplinary work is the simple fact that disciplines often hold different points

of view or entry points into problems, define concepts differently, and have conflicting priorities and scales of analysis. As an example, consider use of terms such as “small scale” and “large scale” that can exist even within disciplines, such as the time and spatial scales of weather phenomena versus longer-term, larger-

scale processes of climate. Therefore, a first step in interdisciplinary work is to assure use of shared concepts or, where that is not entirely feasible, to offer explicit explanations of the language that is used by each discipline. To define the language we use herein, adaptation means a process and/or an outcome of decision making that results in the fundamental, long-term systemic change of a social system in response to or in anticipation of climate variability or change. Adaptation assessment includes understanding the vulnerability of systems to suffer harm from climate variability and changes to hydrological cycles and water resources. It also examines adaptive capacity, which implies the potential of a system or population to modify its features and behavior so as to better cope with existing and anticipated climatic stresses.

Climate change adaptation assessment necessarily implies working within a context of decision making and human responses to change. Water–climate–society adaptation research requires an interdisciplinary, problem-oriented focus by the very nature of the questions involved. For example, understanding how water and populations in the western United States might respond to climate change implies that climatologists, hydrologists, social scientists (and other scientists and engineers), and stakeholders must all address pieces of the problem in an iterative and ongoing fashion. We know, for example, that the Colorado River Basin “Law of the River” compacts were negotiated in a relatively wet time period and when society did not understand or have data on long-term climate trends to place early twentieth-century streamflow amounts into perspective. Despite our best efforts, we still see a chasm between scientific understanding about anthropogenic climate change risks and water resource management and governance in the western United States. This multifaceted and complex problem has catalyzed efforts in academia (e.g., the Western Water Assessment at CU Boulder: <http://wwa.colorado.edu>); the federal government (the Bureau of Reclamation Colorado Basin Study: www.usbr.gov/lc/region/programs/crbstudy.html); and nonprofits (e.g., Carpe Diem West; <http://carpediemwest.org>), to name a few, who are evaluating various aspects of the same water–climate–society problem. Yet, truly interdisciplinary, integrated social–natural sciences adaptation research is on the periphery at best, and at worst it is nonexistent.

While the study of climate-change adaptation is now several decades old in some corners of academia (e.g., in human geography, economics, political sci-

ence), connecting this science to practice is in its infancy when viewed on a societal scale. The array of adaptation literature that exists offers specific recommendations and case studies, but also warns of those adaptation models that fail when disconnected from context and social and policy priorities (which is, unfortunately, the rule rather than the exception). When we are working with common definitions and understandings, physical and social scientists can better address problems of adaptation and vulnerability. However, the level of support and capacity for such interdisciplinary efforts lags behind the need. Within academia, where there is considerable potential for pursuing transformative, interdisciplinary work, it may be a “risk” for early-career academics and scientists to pursue such work, given the need to cross disciplinary (and often departmental or programmatic) boundaries. This problem also applies to the difficulty of funding agencies or sponsors finding appropriately qualified reviewers of interdisciplinary proposals, as well as journal editors who must find reviewers who are knowledgeable in various disciplines. Increasingly, interdisciplinary proposals and journal submissions are reviewed by people who are likely very competent in their respective fields, but perhaps do not have the cross-disciplinary understanding to provide fair and/or substantive critiques of submissions outside their purview. In our view, a question that needs to be addressed is: What can be done to move past such institutional barriers?

THE PATH FORWARD. There is a clear need to engage in interdisciplinary research in order to address complex issues related to water, climate, and society. This in itself is not new, and yet many barriers remain for early career academics that inhibit engaging in such efforts. The infrastructure of our research institutions, such as university departments, funding programs, and government and nongovernment research organizations, often do not readily facilitate researchers to work collaboratively or develop a basic understanding of the theories and methodologies of other disciplines. Compounding this problem is the challenge of identifying avenues and outlets for conducting applied research within academic settings (such as is found within industry and other partnerships).

For those wishing to engage in collaborative, interdisciplinary research that addresses pressing societal problems, how do we break disciplinary and institutional inertia and move forward? The appeal

of interdisciplinary research between climatologists, hydrologists, and social scientists is attested to by the cutting-edge ideas and work of the NCAR Junior Faculty Forum participants and speakers and the new and innovative water–climate–society initiatives that are already underway at universities and institutes in the United States and elsewhere (many examples are included in Table 1 and the supplementary website). However, the sustainability of these efforts is part of a much needed—yet slow to transform—culture change. The lessons learned from successful previous interdisciplinary initiatives can guide subsequent projects. Based on forum participants’ experiences, we have compiled four general suggestions for tackling the applied and interdisciplinary realm of water–climate–society research challenges.

Create “metamethodologies” and frameworks. We argue that a productive initial step of any interdisciplinary research team is the development of a metamethodology, or “road map,” for the project. A metamethodology is an agreed-upon set of guidelines to facilitate working together across disciplines while also allowing team members to retain the space for their own rigorous pursuit according to their discipline. Working across disciplines demands the awareness that others are operating with different viewpoints, approaches, and methodological practices, including different time lines and scales of analysis. For example, an anthropologist would require sufficient time to develop and carry out fieldwork and conduct analysis of data and be working at a community scale, while a hydrologist may be using existing data collected over several years or decades and be working within a specific watershed that encompasses multiple communities and scales of governance.

A project metamethodology is an opportunity for investigators to explicitly outline expectations about what deliverables will be achieved and when in the course of a project they will be available. A metamethodology explains how to identify team members from multiple disciplines (i.e., What expertise is needed to answer specific research questions?), establishes a common language for the project (i.e., How is the project operationalizing a term such as “vulnerability?”), and outlines a framework for project development and implementation that clearly delineates the roles and expectations of each team member at each phase. One forum participant gave an example where historians, engineers, hydrologists, and social scientists came together in an interdisciplinary effort

to understand water use in the northeastern United States. At the initial investigators’ meeting, expectations, deliverables, and time lines for each group were mapped out visually, providing a reference for the entire team to see how each discipline’s contribution fit together to satisfy project objectives. The investigators essentially had a “metamethodology” for how the project would unfold, including ensuring adequate time and resources for each discipline’s methodological applications.

Increase education and training across disciplines on applied water–climate–society problems. Developing shared frameworks and methodologies for interdisciplinary research will be facilitated by educational and training opportunities that bring together new and seasoned scholars in the water, climate, and society research communities. From the undergraduate level through the upper tiers of continuing professional development, there are many ways to improve upon the “disciplinary stovepipe” educational methods that have traditionally been the basis of scientific learning. While interdisciplinary programs, such as environmental studies, have been around for many years, some universities have recently developed more integrative programs to train the next generation of researchers and academic professionals in a diverse array of theory, methodology, and ways of conducting water–climate–society research (see www.ral.ucar.edu/projects/wcs for examples).

Expanding opportunities within both traditional and interdisciplinary degree programs may be especially appropriate at the undergraduate level, the state at which many students’ career plans are tentative, and exposure to less traditional opportunities might spark innovation. Some of the “off-the-shelf” mechanisms for providing these opportunities include interdisciplinary minors or concentrations, internships, and double majors, which do not add significantly to a student’s graduation timeline but can yield important dividends. More fundamental restructuring of undergraduate curricula may also be in order, though it is recognized that doing so is challenging because course requirements are influenced by industry standards and accrediting bodies. For example, undergraduate programs in meteorology commonly conform to the American Meteorological Society (AMS)’s guidelines, and AMS has long used the GS-1340 National Weather Service series standards as its basis. However, the AMS Board on Education has the capacity to influ-

ence curriculum change as it periodically examines the undergraduate requirements for a bachelor of science degree in meteorology and offers recommendations that reflect advances in the discipline. This is but one example of a mechanism for expanding innovative curriculum requirements to train students across the social and natural sciences and better prepare them for a career in use-inspired research on these vexing problems.

At the graduate level, the National Science Foundation Integrative Graduate Education, Research, and Traineeship (IGERT) program (www.igert.org) is a good model for creating capacity for cross-departmental, interdisciplinary research and training across the social and natural sciences. The IGERT program provides a mechanism to institutionalize the connections between a group of students and their faculty advisors from different departments around classes and theses that are problem-oriented while still maintaining a firm grounding in their respective home disciplines. There are a number of water-climate-society IGERT programs throughout the United States that are educating a cadre of academics and practitioners to work between the science and decision-making interface. See www.ral.ucar.edu/projects/wcs/#g for a list of graduate programs that includes several IGERTs that focus on water-climate-society interactions. The challenge for those who want to stay in academia is to get adequate training in their home discipline to land a faculty position, because departments still tend to hire based on disciplinary criteria. IGERT faculty, however, would ideally work with their departments to create more flexibility for a new cadre of interdisciplinary faculty.

Work with “boundary organizations.” “Boundary organizations” is a term for entities that bridge the scientific community with implementation and policy-making organizations. [NCAR Jr. Faculty Forum speakers came from such boundary organizations as the Institute for Social and Environmental Transition (ISET), the Stockholm Environment Institute (SEI), and The Rand Corporation (RAND); visit www.ral.ucar.edu/projects/wcs/#c for their URLs and other examples.] In many cases, these organizations transfer basic research into useful information for management and policy; in other cases, they span coalitions and act as policy entrepreneurs. Since boundary organizations connect academic science and real-world policy and decision making, they can facilitate research to

- span the boundaries of existing organizational networks in commerce, research, planning and development;
- communicate the needs and interests of decision makers to the climate and hydrologic modeling community to improve research and models;
- devise new methods of planning for long-term impacts that take into account uncertainty, risk, and equity; and
- communicate relevant research outcomes and model projections to diverse audiences with competing interests.

Because of their unique role, boundary organizations need to integrate rigorous research and analysis from a broad set of disciplines in order to adequately address the intersection of human agency, system dynamics, and processes of change that give rise to vulnerability. These organizations also recruit individuals with strong interdisciplinary backgrounds and offer new opportunities for collaboration as well as alternative career paths to individuals interested in pursuing research in non-academic settings.

Find champions for institutional reform. Despite the emergence of educational programs, training opportunities, and venues for engagement with stakeholders and decision-makers, much of the academic scientific community remains entrenched in career pathways and incentive structures that make it difficult for individuals who engage in applied research transcending disciplinary boundaries to achieve tenure. Again, not all tenure-track individuals or professional researchers need to engage in such work, but for those who do wish to engage in collaborative, problem-oriented research, alternative incentives are needed to evaluate, encourage, and reward such research. These incentives could include interdisciplinary review panels at funding agencies, interdisciplinary journals and/or special issues of journals, specialized tenure-track positions, new degree programs, and restructured departments. It should also include job review and promotion systems that *truly value* (via appropriate metrics) interdisciplinary research as well as working with stakeholders and the alternative outcomes and outreach this requires. Examples of such outcomes and outreach include gray literature, reports, communicating results to stakeholder meetings, and multimedia products as much as traditional benchmarks such as getting external funding, presenting

at academic conferences, and having peer-reviewed articles published in traditional disciplinary journals. Those who have the capacity to develop or support such incentives are typically senior scholars with experience working on interdisciplinary research who can encourage promotion and tenure requirements that recognize interdisciplinary research and teaching, serve as program managers for funding agencies, help academic administrators identify opportunities for new degree programs, and edit and promote interdisciplinary journals. The recent increase of interdisciplinary climate-oriented journals by AMS and others—*Weather, Climate, and Society*; *Nature Climate Change*; *Wiley Interdisciplinary Reviews: Climate Change*; and others (see www.ral.ucar.edu/projects/wcs/#d for examples)—is indicative of the growing interest in such venues for social–natural sciences interdisciplinary research. Academic champions have been fostering opportunities in numerous cross-disciplinary endeavors for years, but more are needed to overcome ongoing institutional inertia to adequately address the complexity of water, climate, and society.

OUR VIEW IN CLOSING. In summary, we believe that meeting the challenge of adapting water resource management and governance to climate change requires exploring new frontiers of science necessary to inform and guide policy and decision making. To advance these new frontiers requires judiciously removing organizational and institutional barriers that impede interdisciplinary, participatory research with key stakeholders and decision-makers. It entails creating new incentives and structures that promote productive, ongoing, collaborative relationships between scientists and decision makers. Building resilience and adapting to climate variability and change will take focused time and effort along with evaluation and reflection as we collectively learn more about the effectiveness of our actions and policies to mitigate and adapt to climate changes. The nature of water–climate–society problems is dynamic, and so we must also evolve in our pursuit of knowledge and in the conduct of science to respond to the challenge.

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FOR FURTHER READING

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Please see our supplementary website for additional references and resources: www.ral.ucar.edu/projects/wcs.