DCDC 2013-2014
Annual Progress Report

Decision Center for a Desert City II:
Urban Climate Adaptation
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ASU DECISION CENTER FOR A DESERT CITY
ARIZONA STATE UNIVERSITY

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Decision Center for a Desert City II: Urban Climate Adaptation

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ASU ARIZONA STATE UNIVERSITY

I. Introduction to DCDC

The Decision Center for a Desert City (DCDC) at Arizona State University (ASU) was established in 2004 with funding from the National Science Foundation (NSF) to advance the scientific understanding of environmental decision making under uncertainty. With additional funding awarded by NSF in 2010, "DCDC II" has expanded its already extensive research agenda, engaged the policy-making community, and built stronger ties between scientific knowledge and decision making enterprises.

DCDC is focused on developing, implementing, and studying interdisciplinary decision-support processes for environmental decision making based on principles derived from social science research. Through an integrated approach to research, education, and community and institutional outreach, DCDC is training a new generation of scientists who can work successfully at the boundaries of science and policy. Broader impacts are realized as research informs innovative solutions to society's pressing environmental challenges. To accomplish these goals, DCDC has built a dynamic bridge between ASU and local, regional, and national policy communities to foster local-to-global solutions for water sustainability and urban climate adaptation.

The vision, mission, and goals are established by the DCDC Co-Directors and Executive Committee in consultation with the External Advisory Committee and with guidance from the National Science Foundation. The vision, mission, and goals are outlined in an NSF-approved strategic plan, which is evaluated regularly to create an adaptive and nimble institution. The vision, mission, and strategic goals establish priority objectives for core research, education, and outreach activities. These goals and objectives are implemented by internal leadership groups—faculty, students, and staff—and success is measured by formal metrics that track progress and ensure accountability.

Institutional Context: Sustainability at ASU

DCDC benefits from its connection to ASU's Julie Ann Wrigley Global Institute of Sustainability (GIOS), which has developed highly visible, trans-disciplinary research projects that convene faculty members from different units and link environmental science, social science, and policy. As the intellectual home of DCDC, GIOS offers access to resources on the leading edge of sustainability science and practice—a field centered on the interconnectedness of economic, social, and environmental systems. Through a wealth of local, national, and international partnerships, GIOS facilitates DCDC's efforts to build scientist-stakeholder relationships and disseminate the principles of managing environment risk more widely. ASU's Decision Theater Network offers a decision laboratory and visualization space for experimenting with, and applying these science-based solutions for societal problems. GIOS fosters solutions to important societal problems through interdisciplinary centers, such as the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project, and offers degree programs in sustainability from its School of Sustainability. GIOS' focus on urban systems examines the potential for broader impacts in a world where more than half the population live in cities and, as such, produces interdisciplinary research that directly supports the vision and mission of DCDC.

Vision

DCDC is an interdisciplinary research center advancing knowledge, education, and community outreach for water sustainability and urban climate adaptation. Within the Center's activities:

- Research, learning and outreach are synergistic activities that feed upon and reinforce one another.
- Discovery occurs at the intersection of basic and applied research where new strategies are found to address societal problems.
- New data collection and analysis are mixed with synthetic discoveries based on integrating existing data, models, and knowledge.
- Problem solving is adaptive and reflexive, building upon past experiences and lessons learned in other centers engaged in the newly evolving field urban climate adaptation.
- Emphasis is placed on feedbacks and nonlinearities that produce unintended consequences and reveal hidden vulnerabilities in complex urban resource systems.
- Scenarios, simulation modeling, and principles of decision making under uncertainty build capacity to anticipate the future.

Mission

- Develop new understandings of how complex urban systems will function in a changing climate.
- Translate climate modeling and research into tools for managing complex urban systems in the face of climate change and other environmental risks.
- Build a boundary organization in which science is informed by and informs policy and decision making.
- Develop and implement learning opportunities at the boundary of science and policy for students interested in urban climate adaptation.
- Communicate the need for urban climate adaptation to decision makers and larger public audiences.

Strategic Goals

- Advance fundamental knowledge about critical linkages and feedbacks in urban resource systems.
- Apply the principles of decision making under uncertainty to environmental decision making.
- Identify critical tradeoffs inherent in managing urban systems in the face of a changing climate.
- Establish best practices for developing, implementing, and disseminating the concept of a boundary organization.
- Mentor the next generation of interdisciplinary scientists skilled in linking knowledge to action.

Evaluation

Evaluation and assessment of federally-funded research centers traditionally focus on outcomes tied to incentives built into university systems such as the number of researchers trained, research proposals submitted, grants awarded, and books, chapters, and journal articles published. DCDC employs these traditional measures to assess performance.

Center activities will be also evaluated by the External Advisory Committee (EAC), composed of experts representing diverse fields and organizations concerned with decision making and climate uncertainty. The EAC meets annually to provide their perspective on Center priorities and effectiveness and make recommendations on DCDC's performance in accomplishing goals for core research, education, and outreach activities.

In addition to traditional performance metrics and advisory committee feedback, an institution focused on participatory research should also consider other metrics, such as increased capacity in social networks and relevance and impact of scientific knowledge. Therefore, evaluations also assess the extent to which DCDC activities build social capital and adaptive capacity by broadening networks of researchers and practitioners, and enhancing salience and policy-making relevance of scientific knowledge. Finally, using in depth observation and process tracing techniques, DCDC activities are evaluated for their impact in solving society's environmental challenges. Combining outcome-based and social-capital evaluation yields a superior measure of the value of knowledge created and the social processes by which knowledge is produced and valued.

During the recent period DCDC has produced:

1. An intellectually-important and impactful body of research, including 61 recent journal articles published (35 in 2013, 15 in 2014 and 11 accepted as of June 1, 2014), 19 book chapters, and 30 presentations to international and national meetings.
2. A major revision of the user interface for WaterSim 5.0, our signature dynamic water-simulation model that serves as an important basis for stakeholder engagement, a point of articulation for interdisciplinary research, and an experimental setting to study decision making under uncertainty.
3. An extensive network of mutually-beneficial relationships with regional water managers and resource decision makers.
4. Productive partnerships with research and education efforts affiliated with ASU's Julie Ann Wrigley Global Institute of Sustainability (GIOS), including the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project, the Decision Theater Network, and the School of Sustainability.
5. A significant and growing set of comparative and collaborative partnerships linking our Phoenix-based case study to water sustainability and urban climate adaptation efforts nationally and internationally.

During the next reporting period, the DCDC Co-Directors, Executive Committee, and investigators will continue to implement the vision, mission, strategic goals, and priority objectives for core research, education, and outreach activities established in the proposal and NSF-approved strategic plan. Additionally, we will implement recommendations contained in the NSF Mid-term Site Review report and the 2014 External Advisory Committee report.

In March 2014, the DCDC External Advisory Committee visited Tempe to conduct their annual review and evaluation. The committee is comprised of nationally and internationally recognized scholars as well as policy makers and is chaired by William Easterling, Dean, College of Earth and Mineral Sciences, The Pennsylvania State University. This provided DCDC an opportunity to review our recent accomplishments and to receive oversight and recommendations. The overall tone, assessment, conclusions, and recommendations were positive, supportive, and challenging.

To summarize the committee's main comments:

- There is consensus on the committee and among NSF program officers that DCDC is a quality and successful program. The committee chair conveyed the sentiment that the review was "very favorable" and that they have "100% confidence in leadership" and have seen consistent improvement in the quality of work presented.
- The committee also challenged us to focus on the path forward. That is, focus on *strategic thinking* about future research questions and intellectual directions.
- The committee was particularly impressed with our efforts to address the recommendations of the 2013 mid-term site review report and prior EAC assessments.
- The EAC noted that the DCDC synthesis report represents a significant step toward integrating findings but challenged us to make additional efforts at distilling the most essential interdisciplinary findings that emerge from analyzing multiple studies.
- The education program—including the Community of Graduate Scholars, the undergraduate Internship for Science-Practice Integration, and the annual Advanced Water Educators Workshop—is unanimously regarded as a remarkable success and the committee was particularly impressed with the students they met during their visit.
- The committee recognized "clear progress" on WaterSim, calling the new version (WaterSim 5.0) and the new web-based and cross-platform user interface, "a complicated and sophisticated model but simple and elegant." Moving forward, the EAC recommended continued engagement with the policy community to improve the model for applied management decision making and to develop model capacity to evaluate a discrete set of interconnected policies.

Selected specific priorities for the coming year include:

- Enhance the use of WaterSim as a research model for advanced scenario analysis using ensembles that represent a range of climate impacts on water supplies to evaluate policy interventions.
- Conduct a series of structured usability studies, including interview studies, survey research, and quasi-experimental designs, to evaluate the new WaterSim user interface, as well as alternative visualizations for sustainability indicators and other model outputs, with a focus on contributing to the scientific understanding of the effects of user interfaces and visualizations on environmental decision making under uncertainty.
- Publish the results of the synthesis effort in a high-profile and high-impact journal.
- Enhance our existing collaboration with the CAP LTER project focused on green infrastructure, the urban heat island, and landscape design for ecosystem services.
- Our K-12 education efforts will focus on working with middle and high school teachers to develop curriculum that utilizes WaterSim for educational purposes including teaching about systems thinking and the use of models.
- Our outreach team, along with researchers, will conduct a formal assessment of stakeholder engagement efforts to document the societal impacts of science.

II. Research Activities

Sociohydrology

Recent sociohydrology research used the WaterSim model to investigate how alternative climate conditions, rates of population growth, and policy choices interact to affect future water supply and demand in central Arizona. This research developed an advance scenario analysis approach, using ensembles to explore uncertainty in projected climate impacts on surface and groundwater supplies and anticipated human responses and feedbacks. Complementary research, led by Pat Gober, applied and developed the sociohydrology framework in the context of the Saskatchewan River Basin in Canada using simulations from the Alberta Water Resources Management Model. These coordinated activities facilitate comparative analysis of sociohydrology modeling efforts in the US and Canada and demonstrate the role of policy enforcement in determining water availability.

DCDC developed a new online WaterSim user interface and visualization. The interface is configured for use on a wide number of devices, ranging from tablets to desktop computers to the Decision Theater drum, a 260-degree faceted seven screen display. The interface was designed to: allow the user to choose the level of detail and complexity that is displayed for various controls, from a high level of detail to a simple summary; allow DCDC to easily redesign and add future components to the platform as the underlying WaterSim model evolves; and meet the needs of a wide range of users, from teachers to professional water managers to research scientists. The prototype interface was unveiled to the External Advisory Committee (EAC) and NSF program officer at the annual EAC meeting in March 2014, and is currently undergoing refinement based on structured stakeholder feedback. It is scheduled for full public release in fall 2014.

NSF SEES Postdoctoral scholar Ted Bohn and faculty members Enrique Vivoni and Dave White are examining the socio-ecological interactions of land use and the magnitude and timing of evapotranspiration within the North American Monsoon (NAM) region. They are employing a combination of the Variable Infiltration Capacity (VIC) large-scale hydrologic model and time-series of observed land surface characteristics derived from Moderate Resolution Imaging Spectrometer (MODIS) imagery over the NAM region, during the period 2000-2012. DCDC is organizing a workshop on “Land Use and Moisture Transport in the North American Monsoon: Implications for Sustainability in the US and Mexico.” This workshop will review research on the physical mechanisms for the link between land use and moisture transport and identify gaps and scientific products that could help society respond to and/or manage the land use impacts on monsoon variability for the benefit of the US-Mexico border region; review analyses of land and water governance within the NAM region and discuss the potential implications of this phenomenon for sustainability on both sides of the border; and lay the groundwork for a white paper publicizing our findings and for future scientific collaborations on this subject.

Hydrologist Enrique Vivoni continues to lead a team investigating the geographic regions that generate the central Arizona water supply and the impact of land use change and climate change scenarios on water supplies and extreme events including floods and droughts. Vivoni’s team is using a distributed hydrologic model to quantify and predict the watershed responses to meteorological forcing by combining meteorological measurements or forecasts and geospatial data into a predictive model. Recently completed work applies a distributed hydrologic model (tRIBS) to the Beaver Creek watershed of central Arizona to explore the model’s utility for climate change assessments. Current efforts include transferring the approach for water supply and flood hazard forecasts in upland watersheds to Monterrey, Mexico, with the goal of testing stakeholder-generated scenarios related to reforestation

and dam construction. Vivoni is interested in further developing the use of modeling tools for sociohydrological studies built within sustainability science and boundary organization frameworks.

Institutional Analysis and Development

An interdisciplinary team that includes Hallie Eakin, Rimjhim Aggarwal, and Abby York is conducting institutional analyses to study the capacity of urban governance systems to anticipate and adapt to a changing climate. Their research combines the Institutional Analysis and Design (IAD) framework with the socio-cognitive Model of Private Proactive Adaptation to Climate Change to explain how water governance institutions and subjective motivations structure adaptation decisions in the agricultural sector. Eakin, Aggarwal, and York are examining how water policy affects farmers' engagement with adaptation to future scarcity. In addition to scientific products, including journal articles and an AAAS poster presentation, the team produced outreach products including a panel discussion, a feature in Green Living magazine, a television interview on Arizona Horizon (PBS), and an educational video on water security and the worth of Arizona agriculture.

Water Economics Research

Economist Kerry Smith oversees an active research program in water economics, benefiting from sustained collaboration with municipal water service departments. Along with collaborators, including geographer Billie Turner, Smith and team are pursuing two main avenues of research. The first focuses on residential water demand and the second on the land cover/water nexus. The goals of this research are to make water demand research more useful for policy and decision making by anticipating landscape transitions and to understand the implications for water management decision making.

Ethnohydrology

In cooperation with the CAP LTER program, DCDC continued to support The Global Ethnohydrology Study (GES) led by anthropologist Amber Wutich. This project examines cross-cultural understandings of water institutions, water scarcity, climate change uncertainty, and water reuse across ecologically, culturally, and politically distinct world regions. Recently completed research examines gender and children's perceived water futures in the desert Southwest and cross-cultural perceptions of water solutions. New research, involving Wutich, along with Dave White, Kelli Larson, and graduate student Laurel Kruke, is using GES data collected from eight countries around the world to conduct a cross-country analysis of climate change skepticism.

Boundary Work for Water Sustainability and Urban Climate Adaptation

A long-term integrative research project, led by Arnim Wiek, Dave White, Kelli Larson, and Lauren Keeler, has developed a new participatory, mixed-method approach linking survey research, qualitative scenario analysis, and dynamic simulation modeling using WaterSim to construct distinct, coherent, plausible, and desirable governance scenarios of the Phoenix region in 2030. The new methodological advance developed by DCDC provides a framework for comparing governance regimes across systems and regions, while the scenarios are intended to inform transition-oriented policy making through stakeholder engagement. In other boundary work research, White and colleagues analyzed the role of uncertainty in water policy discourse with a focus on expanding social scientific understanding of the effects of multiple types and dimensions of uncertainty, beyond climatic, on decisions.

Collaborative Governance

Our decision science research team is led by Erik Johnston, School of Public Affairs and the Center for Policy Informatics, and Ajay Vinze, W.P. Carey School of Business, along with post-doctoral researcher Dara Wald and graduate students from the Schools of Public Affairs and Computing, Informatics, and Decision Systems Engineering. Their recent work examines the influence of designed deliberative spaces and participatory platforms on prosocial behavior and collaborative decision making.

Findings of Research Activities

Sociohydrology

Vivioni's group applied a distributed hydrologic model to the Beaver Creek watershed of central Arizona to explore its utility for climate change assessments (Hawkins et al. in prep). Model calibration and testing was performed using radar-based precipitation data during three summer seasons. Using the calibrated model, they investigated the watershed response during historical (1990-2000) and future (2031-2040) summer projections derived from a mesoscale model forced with boundary conditions from a general circulation model under a high emissions scenario. Results indicate the following spatially-averaged changes across the two projections: an increase in air temperature of 1.2 °C, a 2.4-fold increase in precipitation amount and a 3-fold increase in variability; and a 3.1-fold increase in streamflow amount and a 5.1-fold increase in variability. Nevertheless, only relatively minor changes were obtained in the spatially-averaged evapotranspiration. To explain this result, they used the simulated hydroclimatological mechanisms to identify that higher precipitation limits radiation through cloud cover leading to lower evapotranspiration in regions with orographic effects. This challenges conventional wisdom on evapotranspiration trends and suggest that a more nuanced approach is needed to communicate hydrologic vulnerability to stakeholders in this semiarid region. Using the physically based, spatially distributed tRIBS model, this group also examined the potential impacts of 4FRI on the hydrology of Tonto Creek, a basin in the Salt-Verde-Tonto system, which provides much of the water supply for the Phoenix Metropolitan Area (Moreno et al. in review). Long-term (20 year) simulations indicate that forest removal can cause significant shifts in the spatio-temporal patterns of various hydrometeorological components, causing increases in net radiation, surface temperature, wind speed, soil evaporation, groundwater recharge, and runoff, at the expense of reductions in interception and shading, transpiration, vadose zone moisture and snow water equivalent, with south facing slopes being more susceptible to enhanced atmospheric losses (sublimation and ET). The net effect will likely be increases in mean and maximum streamflow, particularly during El Niño events and the winter months, and chiefly for the most impervious scenarios. Overall, forest thinning can lead to net loss of surface water storage by vegetation and snow pack increasing the vulnerability of ecosystems and populations to larger and more frequent hydrologic extreme conditions in these semi-arid systems.

Institutional Analysis

Eakin, Aggarwal, York, and their group combined the Institutional Analysis and Development (IAD) framework with the socio-cognitive Model of Private Proactive Adaptation to Climate Change, which posits a process by which individuals perceive risk and their own adaptive capacity (Smith-Heisters 2014). They applied the combined model-framework to a case in Arizona using unstructured interviews with area experts and a survey of farmers. Indicators of adaptive capacity include an interest in learning and knowledge (+); risk-taking and experimentation; adaptive management (+); and decision and constraints (-). Farmers are less certain about capacities in face of future change (-). They found a strong commitment to community and vocation, which supports motivation for farm persistence in a dynamic

economic context. Factors affecting sensitivity to hydro-climatic change include diversity of water portfolio (CAP/IGFR/Salt-Verde-Gila/Effluent); management of water rights; infrastructure maintenance; and land use and distribution (urban/ag).

Urban Water Dynamics

Researchers developed an analytical framework for testing the ecological homogenization hypothesis, and applied the framework to the case of residential lawn care (Polsky et al. 2014). This set of land management behaviors are often assumed—not demonstrated—to exhibit homogeneity. Multivariate analyses were conducted on telephone survey responses from a geographically stratified random sample of homeowners, equally distributed across six US metropolitan areas. Two behaviors were examined: lawn fertilizing and irrigating. Limited support for strong homogenization was found at two scales (i.e., multi- and single-city; 2 of 36 cases), but significant support was found for homogenization at only one scale (22 cases) or at neither scale (12 cases). These results suggest that US lawn care behaviors are more differentiated in practice than in theory. The analytical approach introduced here should also be productive for other facets of urban-ecological homogenization. In related work, researchers found that, overall, informal norms and customs at varying scales more strongly influence landscaping decisions than codified rules in Phoenix (Larson and Brumand 2014). While residents appreciate diverse yard types, dominant norms involve pervasive expectations for neatness as well as varied plant choices grounded in historic traditions and personal experiences. Legacy effects and paradoxes concerning water conservation and urban homogenization also emerged from this research.

Water Economics Research

In collaboration with the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project, Fishman and Smith (2013) evaluated whether a well-recognized index of environmental attitudes, the New Ecological Paradigm (NEP), is consistent with the outcomes assumed in economic sorting models. Findings confirm the key linkages using correlations between the averages (across survey respondents) of the NEP, income, and community specific price indexes as “aggregators” of the influence of local public goods.

Ethnohydrology

Wutich et al. (2014) examined how development status and water scarcity shape people’s perceptions of “hard path” and “soft path” water solutions. Based on ethnographic research conducted in four semi-rural/peri-urban sites (in Bolivia, Fiji, New Zealand, and the US), the authors employed content analysis to conduct statistical and thematic comparisons of interview data. Results indicate clear differences associated with development status and, to a lesser extent, water scarcity. People in the two less developed sites (Bolivia, Fiji) were more likely to suggest hard path solutions, less likely to suggest soft path solutions, and more likely to see no path to solutions than people in the more developed sites (New Zealand, US). People in the two water-scarce sites (Bolivia, US) were less likely to suggest soft path solutions and more likely to see no path to solutions (but no more likely to suggest hard path solutions) than people in the water-rich sites (Fiji, New Zealand).

Boundary Work for Water Sustainability and Urban Climate Adaptation

Arizona water decision makers expressed both scientific and political understandings of uncertainty in their evaluations of WaterSim (White et al. 2014). Rather than seeing the distance between scientific and political perspectives as unbridgeable, the water decision makers saw WaterSim as an opportunity to structure discussion and narrow the gap between scientific and political dimensions of uncertainty. White and colleagues surveyed Arizona decision makers to understand their visions for a desirable

future for the water system (White et al. in review). Principle components analysis was used to identify patterns underlying responses about preferences for each domain of the system and correlation analysis was used to evaluate associations between themes across the domains. The results revealed two distinct visions for water in central Arizona—one in which water experts and policy makers pursue supply augmentation to serve metropolitan development, and another in which broadened public engagement is used in conjunction with policy tools to reduce water consumption, restore ecosystem services, and limit metropolitan expansion.

Research Performance Objectives and Accomplishments

Disseminate research through an average of 30 publications per year in books, chapters, and peer reviewed journal articles.

- Published 61 peer-reviewed journal articles (35 in 2013, 15 in 2014 and 11 accepted as of June 1, 2014), and 19 book chapters.
- Articles were published in leading journals such as *Ecology and Society, Environment and Behavior, Environmental Management, Frontiers in Ecology and Environment, Global Environmental Change, Hydrology and Earth System Sciences, Journal of Environmental Psychology, Land Economics, Landscape and Urban Planning, PLOS One, Proceedings of the National Academy of Sciences USA, Society and Natural Resources, Sustainability, Sustainability Science, The Professional Geographer,* and *Water Resources Management.*

Make an average of 20 presentations to national/international conferences per year.

- Disseminated scientific findings through 30 presentations to national and international conferences.
- Presentations made to leading conferences including recent presentations to: American Association for Advancement of Science; American Geophysical Union; Long-Term Ecological Research All Scientists Meeting; Association of American Geographers; American Meteorological Society 94th Annual Meeting; Water Resources Research Center Conference.
- DCDC PI and co-director Dave White participated in a panel for the Clinton Global Initiatives University held at ASU on March 21-23, 2014.

Leverage DCDC funding by developing and submitting 2-4 proposals per year where a DCDC investigator is Co-PI or lead PI. Serve as key partner in 2-4 proposals per year with a DCDC investigator in a supporting role.

- As of June 2014, DCDC co-investigators are PI or Co-PI on over $8.1 million dollars in active leveraged grant funding.
- Notable recent awards to DCDC participants include grants from NSF Water Sustainability and Climate (WSC) program (Kelli Larson, co-PI); NSF Virtual Organizations as Sociotechnical Systems (VOSS) program (Erik Johnston, PI); US Geological Survey (Enrique Vivoni, PI); and Salt River Project (Paul Westerhoff, PI).
- Dave White is a co-PI for the ASU proposal with the National Geospatial Intelligence Agency (proposed $19.9 million cooperative agreement). The project, led by Nadya Bliss in ASU's Office of Knowledge Enterprise and Development, will utilize ASU's Decision Theater and DCDC's WaterSim incorporating a visual analytics approach to enable policy makers, decision makers, and analysts to anticipate complex behaviors.

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III. Education and Development

K-12 Education

Decision Center for a Desert City, Arizona Project WET, Water Resources Research Center, and Maricopa County Cooperative Extension from the University of Arizona host water educators each summer to reach out to K-12 educators and provide them with teaching methods and new ideas related to sustainability, water, and climate change. The 2014 workshop, "Using Technology to Better Understand our World" will enhance educators' knowledge about how scientists, engineers, and water managers use technology to gather and analyze data resulting in more efficient water use. Additionally, graduate fellows associated with the NSF-funded GK-12 Sustainability Science for Sustainable Schools grant continue to use DCDC research in creating classroom lessons.

Undergraduate Education

The Internship for Science-Practice Integration (ISPI) program at Decision Center for a Desert City (DCDC) bridges the world of academia with the world of water management by placing students within agencies to carry out projects with a use-inspired research component. Program partners include agencies such as city municipalities, companies, and not-for-profit organizations. Under the guidance of Dr. Margaret Nelson, students are introduced to the concepts and practical aspects of policy-relevant research. In spring 2014, DCDC supported ten students in the ISPI program, who were placed with partner agencies including City of Phoenix, City of Goodyear, City of Tempe, University of Arizona Cooperative Extension, Arizona Municipal Water Users Association, and Audubon Arizona.

Graduate Education

The Community of Graduate Scholars (CGS) is a year-long, one-credit course, guided by Dr. Margaret Nelson (Vice Dean, Barrett, The Honors College), that gives graduate students the opportunity to become leaders in transdisciplinary approaches to research, policy, and community engagement. Students work on DCDC projects, as well as related efforts at ASU. Students are involved in multiple projects, examining the relationships among them, and thus learn to articulate and promote integrated perspectives.

DCDC faculty members are involved in interdisciplinary collaborations that offer rich opportunities to graduate students. Each CGS student works on a research team that includes faculty members and both graduate and undergraduate students; this work provides them with the intellectual depth necessary to contribute to DCDC's research. The program is structured to build dialogue, thought, and action across disciplines. Through the CGS seminar, students become familiar with the issues, perspectives, and language of the researchers within DCDC, as well as with issues that emerge from interdisciplinary collaborations. The 2013-2014 Community of Graduate Scholars included 9 students (6 women, 3 men) who presented their research posters at the AAAS conference held in Chicago in February 2014.

Postdoctoral Fellowships

Opportunities for training and professional development for postdoctoral fellows are guided by the NSF approved DCDC Postdoctoral Mentoring Plan. Our postdoctoral mentoring plan focuses on professional and career development, encompassing the six core competencies outlined by the National Postdoctoral Association. We will guide postdocs through a structured process of interdisciplinary engagement and collaboration, welcoming them as new doctorates and mentoring them so that, after two years, they are ready to establish their own independent research programs at a research university. Each postdoctoral scholar completes an Individual Development Plan for Postdoctoral Fellows, derived from the National

Postdoctoral Association. This IDP ensures that the postdoc and his/her mentor develop a shared strategy for training and career advancement. Each DCDC postdoctoral fellow subsequently provides biweekly updates to the faculty mentor and undergoes an annual performance self-assessment as well as a formal evaluation by DCDC PI/PD Dave White. Postdocs are encouraged to participate in professional development activities such as the Preparing Future Faculty program, career development and proposal writing workshops offered by the ASU Office of Knowledge Enterprise Development, and training from the ASU Office of Research Integrity and Assurance. During the reporting period, DCDC supported two postdoctoral fellows.

Hernan Moreno joined DCDC in August 2012 after graduating from ASU with his Ph.D. under the direction of Dr. Enrique Vivoni in the School of Earth and Space Exploration. Hernan's focus includes modeling and projections of water resources for Arizona under varying conditions of climate and land use change. This work focuses on the estimation of climatic and hydrologic uncertainties to contribute to scientific knowledge as well as to inform decision making in water policy. Stakeholders and academic experts are involved in participatory modeling as an interactive process with benefits for both researchers and practitioners. Specific activities involve the setup of a distributed hydrological model (tRIBS) for the Verde, Tonto and Salt River basins and selection of the appropriate spatial resolution for reducing the computational load, hydrologic calibration and validation using historical information, downscaling of IPCC future climate scenarios and consideration of future vegetation thinning and change. Coupling of climate and landcover scenarios in the hydrologic projections will allow creating a platform for decision making, a connection with reservoir models and DCDC's WaterSim model. Such a platform will integrate the different scenarios (precipitation, temperature, vegetation cover, etc.) with corresponding basin outputs (discharges, evapotranspiration, groundwater, soil moisture, snow, and runoff) in a friendly and free source-code GUI for stakeholder engagement and use.

In June 2013, **Ted Bohn** arrived to ASU from the University of Washington to work with DCDC. Bohn has been awarded an NSF SEES Fellowship to work under the direction of Enrique Vivoni and Dave White. Using a coupled land-atmosphere model, Bohn's work studies the impacts of changes in land cover/land use in northwestern Mexico on moisture recycling and transport to both the US and other areas of Mexico. This work will also assess the feasibility of employing land use decisions to influence the North American monsoon and thereby reduce regional vulnerability to climate variability and change.

Education Performance Objectives and Accomplishments

Support at least six graduate research assistants per year and sponsor them in the Community of Graduate Scholars seminar.

- Supported 9 graduate research assistantships.
- These students have produced 2 PhD dissertations.
- Of the graduate research assistantships supported, 6 positions have been held by women and 5 come from historically underrepresented groups in STEM.

Support at least four REUs per year and sponsor them in the Community of Undergraduate Research Scholars.

- Supported 2 REUs. The investment in the REU program was downsized to shift support the Internship for Science-Practice Integration program.

Host an annual poster symposium showcasing the work of graduate and undergraduate students.

- Hosted poster symposium showcasing work of graduate and undergraduate students at DCDC.

Place and oversee at least three DCDC internships in local resource agencies.

- Supported 10 undergraduate students through the Internship for Science-Practice Integration program.

IV. Outreach Activities

2013-2014 Water/Climate Briefings
Theme: Communicating Sustainability in Complex Systems for Public Policy

September 4, 2013 - Challenges of Communicating Sustainability in Complex Systems for Public Policy

- Jonathan Koppell, Dean, College of Public Programs, ASU
- Michael Schoon, Assistant Professor in Environmental Policy, School of Sustainability, ASU
- Doug Toy, Water Regulatory Affairs Manager, City of Chandler
- Dave White, Moderator, Co-Director, Decision Center for a Desert City, ASU

October 16, 2013 - Effective Communication of Scenarios and Scenario Analysis for Decision Making

- Mohammed Mahmoud, Geologist/Hydrologist, Central Arizona Project
- Arnim Wiek, Associate Professor, School of Sustainability, ASU
- Wally R. Wilson, Chief Hydrologist, Water Resources Management, Tucson Water
- Ray Quay, Moderator, Director of Stakeholder Relations, Decision Center for a Desert City, ASU

November 6, 2013 - Extreme Climate Events: Long-Term Droughts in the Southwest

- Special Guest Speaker: Iris Grossman, Research Scientist, Center for Climate and Energy Decision Making, Carnegie Mellon University

December 2, 2013 - Keynote Address: Visualizing Climate Change to Develop Local Solutions

- Keynote Speaker: Stephen R. J. Sheppard, Director of Collaborative for Advanced Landscape Planning (CALP), University of British Columbia

February 5, 2014 - Communicating Complex Information to Enhance Decision Making

- Andy Terrey, Project Coordinator, Water Resource Department, City of Phoenix
- Erik Johnston, Associate Professor of Policy Informatics, School of Public Affairs, ASU
- Manjana Milkoreit, Postdoctoral Fellow, Walton Sustainability Solutions Initiative, ASU
- Dave White, Moderator, Co-Director, Decision Center for a Desert City, ASU

March 5, 2014 - Arizona Water Supply Sustainability: In-state Water Transfers

- Michael J. Lacey, Director, Arizona Department of Water Resources, State of Arizona
- Patrick L. Morgan, Manager, Yuma Mesa Irrigation and Drainage District
- Paul Muthart, General Manager, Pasquinelli Produce Company, Yuma, AZ
- Dave White, Co-director, Decision Center for a Desert City, ASU
- Ray Quay, Moderator, Director of Stakeholder Relations, Decision Center for a Desert City, ASU

Institutional Outreach and Community Engagement

January 17, 2014 - Co-hosted Keynote Speaker for CAP LTER All Scientists Meeting and Poster Symposium
At the Central Arizona–Phoenix Long-Term Ecological Research Project's 16th annual All Scientists Meeting and Poster Symposium, co-hosted Joyce Coffee, Managing Director of the Notre Dame Global Adaptation Index (ND-GAIN), for her keynote address: "Adaptation Implementation: Efforts to Parlay Research into Action in Three Sectors."

April 28, 2014, DCDC Annual Poster Symposium
The DCDC Poster Symposium is one of the highlights of each spring semester. Student posters present the results of various research projects conducted by students enrolled the Internship for Science-Practice Integration (ISPI), the Community of Graduate Scholars (CGS), and other undergraduate research.

The Arizona Climate and Water Resources Alliance (ACWRA)
The goal of the ACWRA is to develop scientific knowledge relevant to decision making for anticipating and adapting to climate change impacts on central Arizona. ACWRA has been supported by the Arizona Water Institute, DCDC, the UA Climate Assessment for the Southwest, and local and regional water utilities. As a result of this collaborative engagement process, ACWRA, ASU and UA developed and submitted a research proposal to secure external funding from NOAA's 2014 SARP program. This funding would have allowed us to implement the joint research and policy agenda concepts for extreme long-term drought as developed by the Coalition. This proposal made it through NOAA's first review but unfortunately under final review, it was not funded.

In 2013, under another NOAA grant, CLIMAS and DCDC worked with the City of Flagstaff to better understand the implications of extreme rainfall events after forest fires. Based on this experience, DCDC and CLIMAS received a grant from the Bureau of Reclamation to conduct a series of workshops, to be held in the fall of 2014, which would begin to explore a similar approach for extreme storm events and be used to better understand the impact of climate change on catastrophic flood events resulting after forest fires. This project will widen the scope of ACWRA to include stakeholders in Colorado and New Mexico, with a focus on communities at or near the urban-forest interface.

Arizona Indicators
Arizona Indicators, a project managed by Morrison Institute for Public Policy, is a community partnership with sponsorship by Arizona State University and Arizona Community Foundation, Valley of the Sun United Way, and The Arizona Republic. Arizona Indicators presents interactive data visualizations and mapping tools, public opinion data, and timely policy analysis. DCDC contributes to the Sustainability and Transportation indicators. In addition, DCDC staff continue to contribute various publications regarding the sustainability indicators.

Website and Social Media
DCDC maintains an active website and social media presence to improve visibility of our research and events.

- The DCDC and WaterSim websites provide an intuitive experience for guiding users to our Research, Education, and Outreach, as well as to DCDC Publications and the WaterSim Model. Visit http://dcdc.asu.edu, http://watersim.asu.edu, and http://watersim3.asu.edu.

- We have also developed a social media strategy using our Twitter account (@DCDC_ASU), with currently more than 285 followers, to tweet and re-tweet news pertinent to DCDC's mission. Visit https://twitter.com/DCDC_ASU.
- The DCDC Google Scholar page tracks citations of DCDC publications and provides access to view publications by our colleagues. Visit http://scholar.google.com/citations?hl=en&user=h2jqgykAAAAJ.
- We use Vimeo to share video of meetings and events with those not able to attend in person. Visit https://vimeo.com/user9066498.
- During the reporting period, DCDC created a LinkedIn account inform our professional community of events and publication, and to keep in touch with our students, staff, and community partners. Visit https://www.linkedin.com/groups/ASU-Decision-Center-Desert-City-5030974.

Community and Institutional Outreach Performance Objectives and Accomplishments

Host 8-10 Water/Climate Briefings per year.

- Hosted 6 Water/Climate Briefings. During the reporting period, there have been more than 420 attendees to the Water/Climate Briefings.
- Video of the briefings are available online through the DCDC website and Vimeo channel (http://vimeo.com/user9066498/videos).

Collaborate with the Sustainable Cities Network to increase the use of WaterSim for long-term water planning.

- Collaborated with DCDC stakeholders including Arizona Department of Water Resources (ADWR) and the Sustainable Cities Network (SCN) to increase the use of WaterSim for regional water planning.

Produce public education materials and briefs for climate adaptation, risk management, and decision making under uncertainty.

- Developed social media strategy integrated with GIOS and ASU platforms including presence on Google Scholar, Twitter, Vimeo, and LinkedIn. February 2014, published a DCDC technical report, "Water Reuse in Central Arizona," the culmination of a partnership with Intel Corporation, CH2M HILL WaterMatch, and the Julie Ann Wrigley Global Institute of Sustainability at ASU.
- October 2013, published a DCDC technical report, "Advancing Science in Support of Water Policy and Urban Climate Change Adaptation at Arizona State University's Decision Center for a Desert City: A Synthesis of Interdisciplinary Research on Climate, Water, and Decision-Making Under Uncertainty," which summarizes and synthesizes research findings and achievements of DCDC after almost a decade of research and science-policy interactions.

V. Contributions

Contributions within the Discipline

Geographical Sciences

Decision Center for a Desert City researchers have made notable intellectual contributions to the discipline of geography, enhancing basic understandings of linkages and feedbacks in coupled human-natural systems. In a recent contribution to human-environment geography, Gober et al. (2014) conducted interviews with water stakeholders to identify divergent understandings of the concept of water security, ranging from narrow conceptualizations focused on reliability, quality, and quantity, to more expansive sustainability-oriented perspectives about broader social and economic dimensions of resource development. This work helps to clarify the definition of water security, an ambiguous and contested term, but one that is increasingly used to frame scientific and policy discourse for water resources.

Our researchers contributed to urban geography by examining the assumption made by advocates of "smart growth" that compact urban development significantly reduces residential per capita water use. In a study of factors influencing residential water consumption in multifamily housing in Tempe, Arizona, results from Wentz et al. (2013) show that apartments used an average of 593 liters per occupied bedroom per day (July 2007 data). The statistical model explained nearly 50 percent of the variance in summertime water use based on pool area and presence of in-unit dishwashers and washer-dryers; no statistical relationship was detected among water use, age of complex, and vegetated landscape. The research provides empirical support for the relationship between urban form and water use and identifies concrete strategies for efficient multifamily water use policies.

Geographers Chao Fan and Soe Myint made a methodological advance in the analysis of remote sensing imagery used in urban geography in a study comparing spatial autocorrelation indices and landscape metrics as measures of urban landscape fragmentation (Fan and Myint 2014). Their work identified a clear relationship between autocorrelation (Getis statistic and local Moran's *I*) and fragmentation (FRAGSTATS), providing a new methodology for urban planners and resource managers to characterize effectively landscape fragmentation using continuous data.

Sustainability

DCDC scientists have been influential in shaping the emerging science of sustainability with significant theoretical, methodological, and educational contributions. In a recent feature in *Ecology and Society*, Redman (2014) reviews, analyzes, and compares key assumptions and constructs from resilience theory and sustainability science. He provides a set of recommendations aimed at students and young professionals to move forward and develop these complementary frameworks. Redman comments on six domains of action for resilience and sustainability scholarship (systems dynamics, strategic competency, inclusiveness, prioritizing outcomes or system dynamics, community input, and the past as a laboratory for innovations).

Sustainability scientists Arnim Wiek and David Iwaniec synthesized existing literature to develop a concise framework to guide sustainability visioning, which is essential for a range of solution-oriented sustainability science practice such as scenario planning (Wiek and Iwaniec 2013). Key features of quality criteria for sustainability suggest that visions should be: visionary, sustainable, systemic, coherent, plausible, tangible, relevant, nuanced, motivational, and shared. Wiek and Iwaniec also compiled

methods, tools, techniques, and procedures for constructing and evaluating sustainability visions and reviewed exemplary visioning studies.

In a contribution to both sustainability research and sustainability education, Brundiers, Wiek, and Kay (2013) examine the role of so-called "transacademic interface managers." The authors conceptualize this boundary-spanning position as a way to facilitate research with stakeholder participation while creating educational opportunities. They present a comprehensive proposal for an interface manager, including the task portfolio, necessary capacities, and educational training program. The article provides practical guidance to universities on organizing efforts at science/policy interface management and frames new career avenues for students.

Anthropology

Recent DCDC research has advanced the discipline of anthropology through the development of the field of ethnohydrology – the examination of the range of variation in local ecological knowledge of water issues (Vins et al. 2014; Wutich et al. 2014; Wutich et al. 2013). Recent ethnohydrology research has contributed to the theoretical expansion of environmental justice by elucidating the link between water insecurity—including drought, failing water institutions, and inadequate sanitation—on emotional distress and mental illness (Wutich 2013).

Contributions outside the Discipline

Creating usable scientific knowledge to address contemporary water sustainability and the challenges of urban climate adaptation requires integration across multiple academic disciplines, including decision science, economics, psychology, geography, planning, anthropology, ecology, hydrology, and engineering. While specific DCDC research projects may focus on fundamental disciplinary questions, the overarching approach is to foster an interdisciplinary dialogue among social scientists, environmental scientists, and engineers to catalyze innovative scientific approaches. For example, WaterSim serves as one point of articulation where researchers unite disciplinary knowledge from geography, hydrology, and climatology, along with priorities and concerns from affected decision makers and other stakeholders.

In one recent example of interdisciplinary research, a team including engineers Professor Paul Westerhoff and graduate student Jacelyn Rice (School of Sustainable Engineering and the Built Environment) collaborated with anthropologist Amber Wutich (School of Human Evolution and Social Change) and environmental social scientist Dave White (School of Community Resources and Development) on a study linking societal perceptions of wastewater reuse in three cities (Atlanta, Philadelphia, Phoenix) with estimates of the actual extent of wastewater occurrence in water supplies in the corresponding cities. While many analysts have called for increased rates of reuse as a solution to water supply sustainability in urban areas, especially in the arid West, public perception and acceptance are recognized as two of the main hindrances for the successful implementation of water reuse projects. Little is known, however, regarding the public's awareness of the occurrence of de facto reuse, including how it affects public perception of water reuse. Thus, such interdisciplinary research provides an important contribution to both scientific and policy discourse.

Development of Human Resources

The Decision Center for a Desert City provides a fruitful interdisciplinary environment for the training and professional development of faculty, postdocs, K-12 teachers, graduate and undergraduate students, and staff. Promising early-career faculty, nationally renowned senior faculty, postdoctoral scholars, and students work in interdisciplinary teams to advance fundamental research and development of decision support tools for water sustainability and urban climate adaptation.

Graduate students work within the Community of Graduate Scholars to develop a broad understanding of the research process, develop an intellectual identity and voice, improve communication and presentation skills, and engage with researchers and stakeholders. The graduate students are responsible each year for organizing a panel discussion for one of the DCDC Water/Climate Briefings, providing students the opportunity to work with both faculty scientists and stakeholders to delve into the basic science and applied solutions for water sustainability and urban-climate adaptation. The DCDC graduate students also organize a joint poster symposium for the American Association for the Advancement of Science (AAAS) annual meeting, providing the students an opportunity to network with graduate students, faculty and postdocs from the other NSF-DMUU funded collaborative groups at Columbia University, Carnegie Melon University, and University of Chicago.

The DCDC Internship for Science-Practice Integration places undergraduate students within partner agencies to carry out internship projects with a research component. This experience allows students to build their professional skills and cultivate professional networks. The ISPI program allows students to engage with community organizations, develop research and management skills, explore a profession, and engage with policy and decision making aspects of sustainability science.

Each year, DCDC also provides exposure to science and technology for teachers, as more than 25 K-12 teachers attend the annual Advanced Water Educator Workshops. This workshop empowers teachers with the most-current scientific understanding to inform their curriculum.

Information Resources that Form Infrastructure

DCDC gathers a wide range of raw and preprocessed data to be used in classification systems, spatial analyses and models. These data include: shape files for GIS analysis; subsets from large, geo-referenced databases of census, assessor and climate data; remote sensing images; and water consumption records. DCDC continues to produce data that include simulation model outputs, social data from surveys and evaluations, shape files, maps, and graphics.

DCDC collaborates with the Informatics and Technology group in ASU's Julie Ann Wrigley Global Institute of Sustainability, which has a well-established information management system and an experienced Information Manager responsible for policies, procedures and technology. The research team provides complete metadata for their datasets. Data access level is determined by the data provider and can be set to public or restricted. Restricted access is available only to those with login privileges to the department server. All public data are available for download. Public data are provided in ways that do not incriminate privacy and confidentiality by removing personal information and precise locality information (e.g., data aggregated at the census tract level). The data are archived and data access maintained by the Informatics and Technology group. The computer facilities used are part of ASU's coordinated strategy of providing outstanding stewardship for cyberinfrastructure investment made by federal grants and contracts. All data and derived products are archived in compliance with existing data and metadata standards, and will be accessible through existing data portals. By downloading, users

agree to abide to the data policy and provide a minimum of contact information. If access level is set to restricted, only the data provider's contact information will be available to the public. The Julie Ann Wrigley Global Institute of Sustainability is in the process of enhancing the research IM system to enable project and dataset information to be entered throughout the research project. This system is intended to address a root cause of poor metadata quality: the temporal disconnect between data and metadata preparation. This system will provide a "virtual notebook" for each project that will allow researchers to add project and dataset information as the project progresses rather than collating all this information at project completion.

DCDC maintains an active website to improve visibility of our research and events. The DCDC website provides an intuitive experience for guiding users to our Research, Education, and Outreach, as well as to DCDC Publications and the WaterSim Model. Visit http://dcdc.asu.edu. We have also developed a social media strategy using our Twitter account (@DCDC_ASU), with currently almost 300 followers, to tweet and re-tweet news pertinent to DCDC's mission. Visit https://twitter.com/DCDC_ASU. In 2011, we created a Google Scholar page to track citations of DCDC publications and to view publications by our colleagues. Visit http://scholar.google.com/citations?hl=en&user=h2jqgykAAAAJ. We use Vimeo to share video of meetings and events with those not able to attend in person. Visit https://vimeo.com/user9066498.

Impact on Society beyond Science and Technology

By focusing on linkages and feedbacks between science and environmental decision making, DCDC has broader impacts on society. New scientific knowledge and modeling is developed to inform planning and decision-making strategies to make cities less sensitive to climate risks, more resilient, and more adaptive. New knowledge about decision making in the face of long-term environmental risk aids in formulating approaches to adaptation strategies based on the best-available, social-scientific understanding of individual psychological motivations, community norms, and institutional dynamics.

Collaborative science-policy workshops bring together scientists, consultants, and other stakeholders to facilitate exchange of knowledge and best practices to build social networks and enhance capacity for collaborative research and planning. For example, in December 2013, DCDC facilitated a workshop on "Visualizing Climate Change," linking efforts by ASU and the University of British Columbia to develop new immersive and interactive visualizations to support public awareness and collaborative planning on climate change adaptation.

WaterSim serves as a mechanism for advanced scenario planning and analysis and, in collaboration with ASU's Decision Theater, offers unique opportunities for engagement with a variety of community stakeholders. DCDC continues to use WaterSim and the Decision Theater Network to advance water policy discourse with decision makers. Co-Director Dave White has given presentations to visitors, both in Tempe and in the new Decision Theater located at the McCain Institute in Washington, DC, including representatives from the World Bank, USAID, US State Department, Arizona Governor's Office for Energy Policy, and Arizona gubernatorial candidate Christine Jones, among others. Director of Stakeholder Relations Ray Quay and Research Professional David Sampson presented WaterSim to the Arizona Municipal Water Users Association.

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VI. Partner Organizations

Arizona Cotton Growers Association; 4139 E. Broadway Road, Phoenix, AZ 85040

Arizona Department of Water Resources; 3550 N. Central Avenue, Phoenix, AZ 85012

Arizona Municipal Water Users Association; 3003 N. Central Avenue, Suite 1550, Phoenix, AZ 85012

Arizona Project WET; 350 N. Campbell Avenue, Tucson, AZ 85719

Audubon Arizona; 3131 S. Central Avenue, Phoenix, AZ 85040

Center for Climate Adaptation Science and Solutions (CCASS); 845 N. Park Avenue, Suite 535, Tucson, AZ 85721

City of Goodyear - Water Services; 190 N. Litchfield Road, Goodyear, AZ 85338

City of Phoenix - Water Resources Department; 200 W. Washington Street, Phoenix, AZ 85003

City of Tempe - Water Utilities; 255 E. Marigold Lane, Tempe, AZ 85281

The McCain Institute for International Leadership at Arizona State University; 1777 F Street, Suite 600, Washington, DC 20006

University of Arizona Cooperative Extension – Maricopa County; 4341 E. Broadway Road, Phoenix, AZ 85040

University of British Columbia - Hydro Theatre; Centre for Interactive Research on Sustainability, 2260 West Mall, Vancouver, BC V6T 1Z4

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