DCDC 2011-2012
Annual Progress Report

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 by the National Science Foundation (NSF) to advance scientific understanding of environmental decision making under conditions of uncertainty. Bolstered by new funding from the NSF, "DCDC II" was launched in October 2010 to expand its already-extensive research agenda, further engage the policy community, and forge stronger ties between knowledge and action. In this second phase of DCDC funding, we are developing new fundamental knowledge about decision making from three interdisciplinary perspectives: climatic uncertainties, urban-system dynamics, and adaptation decisions. Simulation modeling and boundary organization studies are cross-cutting themes and will be core DCDC activities.

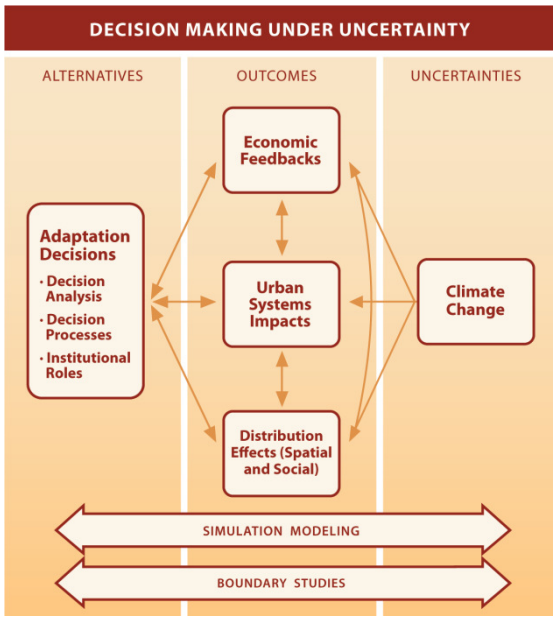
To date, DCDC II has produced: (1) an intellectually-important and impactful body of basic research, including over 100 articles, books, and book chapters; (2) a major revision, upgrade and release of WaterSim, our signature dynamic water-simulation model that serves as an important basis for stakeholder engagement and decision support, 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 Global Institute for Sustainability (GIOS), including the Central Arizona–Phoenix Long Term Ecological Research (CAP LTER) project, the Decision Theater, and the School of Sustainability; and (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.

As our mission has evolved to focus not only on water sustainability but also urban climate adaptation, DCDC researchers now work to develop scientific knowledge and decision-support tools and processes for anticipatory planning. Through an integrated approach to research and education, DCDC trains a new generation of scientists who work successfully at the boundaries of science and policy. DCDC II continues to build bridges between science and policy to foster local-to-global sustainability solutions.

This year marked several significant milestones in leadership and administration for DCDC. In a planned transition phased in over the past year and a half, founding Director and PI Patricia Gober stepped down to assume a new position as Professor, Johnson Shoyama Graduate School of Public Policy, University of Saskatchewan. Gober, however, maintains a research faculty appointment with Arizona State University and continues to contribute to DCDC as senior project personnel. Assuming the role of Principal Investigator and Director is Dave White, who has been with DCDC since its inception; first as senior project personnel in DCDC I, then as co-PI and Associate Director for DCDC II. Charles Redman continues his role as co-PI and co-Director, positions he has held since DCDC was established. Additionally, Kerry Smith and Kelli Larson have been added to the Executive Committee, which also includes, along with White and Redman, co-PIs Margaret Nelson and Craig Kirkwood.

Research Activities

We have organized DCDC II to understand water, climate and environmental decisions in a complex, dynamic urban system and structured our research in terms of an integrated decision process. DCDC II's conceptual approach posits that the uncertainties of climate change affect individual and societal alternatives (adaptation decisions), which function through an urban system with economic feedbacks and distributional (social and spatial) consequences. Points of focus for our interdisciplinary research agenda are: 1) climatic uncertainties, 2) outcomes (economic feedbacks, urban system dynamics, and distribution effects), and 3) adaptation decisions. Activities cutting across these themes are simulation modeling and boundary studies.



Climatic Uncertainties

During the first phase of DCDC, researchers identified and addressed major climatic uncertainties facing Phoenix, including inter-annual drought, climate change, and the urban heat island. We explored the sensitivity of urban water demand to variations in climate to clarify the effect of this uncertainty on our region and its spatiotemporal variability. In DCDC II, we are refining climate and hydrological models to represent the physical characteristics and hydraulic dynamics of our watersheds; to understand and predict the impact of land use and climate change on water supplies; and to inform decision making and climate adaptation strategies.

To accomplish these goals, we added hydrologist Enrique Vivoni to our collaborative group. Vivoni is leading an interdisciplinary team of post-doctoral researchers and graduate students to investigate geographic regions that generate our water supply and the impact of land use/land cover change and climate change scenarios on water supplies and extreme events including floods and droughts. Critical questions guiding this work are: What are the combined effects of climate and land cover change on water supply? Are there tradeoffs in land use management that can mitigate climate impacts on water supplies? This research utilizes a numerical watershed model to explore these tradeoffs and to provide inputs to related DCDC decision-making research.

In one stream of research, Vivoni's team is using a distributed hydrologic model (TIN-based Real-time Integrated Basin Simulator) to quantify and predict the land surface (or watershed) responses to meteorological forcing by combining meteorological measurements or forecasts and geospatial data into a predictive model. This work uses projections of climate change impacts on streamflow forecasts in Beaver Creek, Arizona. This area is representative of the Salt and Verde River systems as it includes diverse land cover and soil distributions, regional terrain variations in the Mogollon Rim, and hydrologic conditions of both ephemeral and perennial stream flows. Model simulations allow researchers to address climate and land cover changes or manipulations in a spatially-explicit manner to examine runoff generation and streamflow in channels, soil moisture distribution in all landscapes, summer evapotranspiration losses, and recharge of shallow groundwater systems.

In a second line of research, Vivoni's team is evaluating streamflows during the North American monsoon. The summer monsoon is a significant water supply source and flood hazard in the Salt and Verde River System that has received limited attention. Researchers are conducting simulations using high resolution data in nested watersheds and at forest locations to reproduce the flood hydrograph in the model and compare results from ground data, NEXRAD and NLDAS (satellite) products. The results of this research can inform water managers and other stakeholders about the availability of summer flows for reservoir operations.

Vivoni's team is also working along with DCDC PI Dave White and researchers from ASU's Decision Theater and the North American Center for Transborder Studies on a project in cooperation with investigators from the Center for Water in Latin America and the Caribbean (CALCA) at Tecnológico de Monterrey (Tec). This project, which leverages NSF funding with an investment from the FEMSA Foundation, exemplifies our commitment to interdisciplinary research, comparative studies, international collaborations, and science-policy boundary-spanning activities. This project draws upon and extends lessons learned from science-policy engagement in central Arizona to address scientific questions of critical policy importance to multiple stakeholders in Monterrey, Mexico. Hydrologists and social scientists from both Tec and ASU have developed and implemented a stakeholder engagement process to inform modeling efforts. Vivoni's team is undertaking a reconstruction of a major flood event associated with Hurricane Alex (2010) using meteorological data sets and the outputs from the application of the hydrologic model tRIBS. Modeling activities are focused on scenario building to address impacts of different management decisions, identification of priority conservation areas (PCAs) and future management areas (FMAs).

Moving forward, DCDC will expand our hydrologic research to refine climate and hydrological models, along with parallel stakeholder engagement and science-policy research efforts. In August 2012, we will add two new post-doctoral researchers to support these and related efforts: Hernan Moreno, who is currently completing his Ph.D. under Vivoni's supervision in the School of Space and Earth Exploration at ASU, and Ted Bohn, who will be joining ASU from the University of Washington. Bohn has received notification of support from NSF for a SEES Fellowship and will work under the direction of Vivoni and White.

Environmental Economics – Water Demand Research

Economist Kerry Smith continues to lead a dynamic program of research in environmental economics, benefiting from sustained and meaningful interaction with stakeholders from the water management community. This research informs the design and evaluation of alternative price and non-price measures for promoting water conservation and evaluating climate-adaptation policies. In the past year, Smith and his team (including Zhao, Klaiber, Brent) have made progress on several related initiatives focused on economic and non-economic factors that influence residential water demand. They developed a new method for estimating price elasticities that can accommodate the complexities of increasing block pricing structures (Klaiber et al. in review, *Land Economics*).

Demonstrating his national leadership on this topic, Smith in May 2012 organized a conference held at DCDC on "Understanding Residential Water Use: New Approaches to Analyzing, Projecting, and Managing Demand." The meeting convened leading economic and social scientists from around the country along with municipal water providers from major western cities including Phoenix, Mesa, Tucson, and Seattle. Presentations focused on cutting-edge research on price and non-price incentives; the economic value of residential water; and understanding behavioral responses to water policy.

Scientists and policy makers engaged in interactive dialogue to identify opportunities for innovative collaborative research.

Urban Systems Dynamics

Society's response to climate change, in the form of adaptation decisions, affects urban systems by making cities more or less resilient, distributing risk, and altering the trajectory of the economy. Urban system dynamics research at DCDC investigates interrelationships of climate, water, and urban form and implications for decision making under uncertainty and urban climate adaptation.

In recent work, DCDC post-doctoral scholar Ariane Middel, in collaboration with Anthony Brazel, Chris Martin, Subhrajit Guhathakurta (now with Georgia Tech), and Ph.D. student Kathrin Häb (University of Kaiserslautern, Germany) examined how microclimate varies with urban form and land cover. This research seeks to identify the most effective urban form and design strategies to reduce residential energy and water use during the summer months. Taking advantage of the North Desert Village experimental neighborhood (associated with CAP LTER) at Arizona State University's Polytechnic campus as a test bed, they simulated microclimatic conditions for four residential landscape designs (native, xeric, oasis, mesic) using the ENVI-met model. In addition, they developed six urban form scenarios representing a cross-section of typical residential neighborhoods in Phoenix in terms of building density and characteristics. Combined ENVI-met model runs of urban form and landscaping scenarios will give insight into potential mitigation and adaptation strategies against UHI effects at a micro-scale. Finally, the team will run eQuest for the combined scenarios using ENVI-met model outputs as boundary conditions to assess the effect of urban form and design on building energy use. Preliminary results will be presented at the 8th International Conference on Urban Climate (ICUC8) to be held in Dublin in August 2012.

In their ongoing NOAA-funded collaboration with Portland State University, Patricia Gober, Ariane Middel, Anthony Brazel, and Soe Myint explored the tradeoff between outdoor water use and temperature amelioration in Portland and Phoenix (Gober et al. in press, *Urban Geography*). This case study is an extension of last year's effort (Middel et al. in press, *International Journal of Climatology*) that investigated how land cover alterations change the surface energy balance and create distinct urban climates. Again, the team used the Local-Scale Urban Meteorological Parameterization Scheme (LUMPS) to quantify the relationship between the amount of vegetation, resulting outdoor water use, daytime heating and nighttime cooling, and subsequent cooling efficiency of water during hot, dry summer months (June in Phoenix, July in Portland). Furthermore, they analyzed tradeoffs in both cities under three land use scenarios (green city, xeriscaping, and densification) and three climate change scenarios.

In another recently completed study involving the LUMPS model, Ariane Middel and colleagues investigated the daytime cooling efficiency of various land cover in Phoenix (Middel et al. in press, *Climate Research*). The team simulated the hourly urban energy balance for two hot summer days for 11,025 90 x 90m grid cells in the urban core. They evaluated the modeling results using surface temperatures from Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) imagery and reference evapotranspiration values from a meteorological station in the study area. To examine the cooling-water use tradeoff of different land cover configurations, the team adopted a cooling efficiency measure based on sensible and latent heat flux differences. They also determined the time of sensible heat flux transition (time when the sensible heat flux turns negative) for each grid cell to investigate the sensible heat reversal at night.

Distributional Effects – Vulnerability, Resilience and Risk

People and places experience different vulnerabilities to climate change not only due to variations in exposure but also due to different sensitivities and capacities to respond to climatic shocks and stresses.

In the second year of DCDC II, we continued our research on vulnerability to heat stress and adaptation strategies and co-benefits. This work extends the highly productive line of DCDC research on the urban head island in Phoenix (see Chow, Brennan, and Brazel 2012, *Bulletin of the American Meteorological Society*) to examine climate change impacts on extreme heat events. In recent work, Darren Ruddell, former DCDC postdoc and now faculty member with University of Southern California, and colleagues analyzed historical threshold temperatures for central Phoenix to uncover anthropogenic interference in temperature thresholds and historic atmospheric processes (Ruddell et al. in review, *Climate Research*).

Geographers Patricia Gober and Kelli Larson continued work derived from their NOAA-funded collaboration with Portland State University. Recent research compared vulnerability of water systems in Phoenix, Arizona and Portland, Oregon (Larson et al. in review, *Environmental Management*). Their analysis compared the two cities on the basis of exposure to climate change and urbanization, sensitivity to the associated impacts, and adaptive capacity to cope with the realized or anticipated impacts. Comparing metropolitan regions that face similar stresses under different land and water management profiles provides insights into the water/land use nexus and implications for integrated planning across land and water domains.

Adaptation Decisions – Decision Science and Policy

In addition to research *for decision making*, our decision science and policy team is engaged in research *on decision making* in water sustainability and urban climate adaptation. One line of decision science research is led by Erik Johnston, School of Public Affairs and Co-Director of the Center for Policy Informatics, and Ajay Vinze, W. P. Carey School of Business. This work examines cooperative behavior and collaboration amongst diverse stakeholders to achieve collective goals. Their research employs an experimental approach utilizing an adaptation of WaterSim as well as the ASU Decision Theater.

Our decision science and policy research is also guiding the training and education of the next generation of public administrators, who will be critical to the implementation of climate adaptation strategies. Increasingly, urban environmental policy makers make decisions in the face of climatic uncertainty. Policy professionals no longer operate under a “plan and predict” paradigm. Rather, policy makers must anticipate climate change impacts and plan for a range of potential future conditions. This research examines the effects of information technology, including computer model-based decision support systems such as WaterSim, on decision making. The goal of understanding decision making under uncertainty is to train public administrators who are skilled at understanding complex challenges that involve high uncertainty, stakeholder interdependencies, policy resistance, and slow feedback cycles.

Adaptation Decisions – The Psychology of Environmental Decision Making

Our team of psychologists, led by Ed Sadalla, Douglas Kenrick, and Steven Neuberg from the Department of Psychology and Susan Ledlow from the School of Sustainability, works with doctoral student Becca Neel and numerous undergraduate students. They employ both evolutionary and sociocultural models in an active research program including several interrelated experiments examining the psychology of water/energy use and perceptions of climate change beliefs and science.

Recent work examines self-presentational barriers to low water use residential landscaping (Sadalla et al. in review, *Journal of Environmental Psychology*) as well as priorities in residential water use (Sadalla et al. in review, *Environment and Behavior*). Another ongoing study examines the influence of gender and social norms on climate change beliefs. Preliminary findings suggest that information about women's climate change beliefs is important in influencing public opinion. Additionally, findings from ongoing work in collaboration with noted psychologist Robert Cialdini suggest the potential to influence the majority to adopt minority behaviors by presenting information on growing trends. Moving forward, this group has initiated a collaboration with economist Kerry Smith on research at the intersection of psychology and economics that will examine perceptions of urban density and the discounting of negative events.

Adaptation Decisions – Institutional Roles

Institutions—the rules, norms and shared strategies that shape human behavior – are critical to decision making because they both constrain and enable choices and influence the preferences of actors. Relatively little is known, however, about the effects of institutional structure on the receptiveness to adopt more flexible water policies for urban climate adaptation. Our team of researchers, including Hallie Eakin, Rimjhim Aggarwal, Abby York, and Amber Wutich use institutional analysis to study the capacity of urban governance systems to anticipate and adapt to a changing climate.

This year, we initiated a new line of research to examine agricultural water conservation and institutional constraints on adaptation. The agricultural sector uses as much as three-quarters of the water in Arizona; by all accounts, the future of agriculture is a critical issue for climate adaptation and water sustainability. Along with collaborators from University of Arizona Cooperative Extension and the Arizona Cotton Growers Association, Eakin, Aggarwal, and York are examining how water policy affects farmers' engagement with adaptation to future scarcity. This work is supported by DCDC and leverages funding against a complementary NOAA-CSI grant. This research was presented in a poster at AAAS 2012 in Vancouver, BC and Adaptation 2012 in Tucson, AZ.

In another line of research that links DCDC and CAP LTER, anthropologist Amber Wutich continued her leadership on The Global Ethnohydrology Study (Wutich et al. in review a,b; Brewis et al. in review; Crona et al. in review). This is an interdisciplinary multi-year, multi-site study that examines the range of variation in local ecological knowledge of water issues, also known as "ethnohydrology." The research was initiated in Phoenix with DCDC support. With additional leveraged resources, the project has expanded to examine cross-cultural understandings of water institutions, or the rules and norms used to distribute water, and water scarcity, including scarcity in relation to climate change. Research is now also being conducted in four ecologically, culturally and politically distinct world regions: tropical South America, North America, Europe and Oceania.

Simulation Modeling – WaterSim Model Development

We continue to develop and refine our signature computer-simulation model, WaterSim, under an open source community framework. This year, we completed and released a new version of WaterSim (5.0) as an open source model that can be downloaded from DCDC's web site. The model development process is guided by the DCDC *WaterSim Steering Committee*, as well as structured dialogue with regional water providers.

WaterSim 5.0 is a demand-driven model with water deliveries from the various sources based on provider-specific rights for each water source. WaterSim 5.0 includes additional sources of water that were not incorporated in earlier versions, including water supplied from reclaimed and reverse osmosis

(RO) reclaimed water sources; water banking as a policy option, where water banked outside the regional aquifer during times of abundance can be used to meet demand when surface water supplies are curtailed (e.g., during drought); and various options for recharging of regional groundwater. The WaterSim 5.0 Application Programming Interface (API) includes C# access to the FORTRAN model's parameters and functions with robust error checking, a mechanism to include an annual feedback loop, and database support for loading model parameters and saving model output. Version 5.0 also includes extensive documentation, including source code for the C# application interface (API) and FORTRAN model, documentation for the API and FORTRAN model parameters, and a sample user interface to the model (including an install program) that can be installed remotely on most personal computers (see http://dcdc.asu.edu/watersim/).

Based on continued engagement with researchers and regional water managers, we continue to work on refinements to WaterSim 5.0. A provider-specific ground water credit based sub-model has been added to reflect the current system of regulating groundwater and requirements for an assured water supply designation. Several indicators of sustainability at the regional and provider level, such as percent and length of deficits, groundwater yield trends, and use of effluent, have been added to the API to make it easier to compare the sustainability of various scenarios. In late 2010, several of the regional water providers received new assured water supply designations, and the water rights for these providers were updated based on these new designations. An extensive process of validation and verification was initiated. Stream flows and water allocations for the CAP and SRP supplies as well as groundwater withdrawal rights and rates were verified. Planning for a fall workshop is underway to introduce the new version of WaterSim to regional water providers, solicit their review and verification of the data input for their community, and review how the model performs for their area under different conditions of supply and demand.

This new version of the model is being used this summer to continue exploring the application of advanced scenario analysis to examine the uncertainty of climate change on regional water management. We developed a scenario generator that can create a large number of scenarios based on varying levels of factors such as climate change or water banking. Tools to analyze these scenario ensembles are being developed and it is anticipated that this summer a paper examining the spatial impacts of water shortages on growth will be developed. Also in the planning stages for this fall is a workshop to explore how the new versions of WaterSim can be used as a tool in sustainability education at the K-12, Community College, and University levels, as well as workshops to explore adding an agriculture and natural environment supply/demand model to WaterSim.

WaterSim is not only a simulation model for decision support for water sustainability and urban climate adaptation but also a research tool. This past year, geographers Alan Murray, Patricia Gober, Luc Anselin, Sergio Rey and others published research using WaterSim 4.0 for decision analysis (Murray et al. 2012, *Water Resources Management*). Their research applies spatial optimization models to support water supply allocation between service provider districts, where some districts experience deficits and others experience surpluses in certain years. The approach seeks to reconcile and integrate projections derived from WaterSim while taking into account current and future climate conditions. The formulated and applied models are designed to help better understand the expected increasingly complex interactions of providers under conditions of climate change.

Boundary Studies – Science-Policy Interactions and Boundary Organizations

From its inception, DCDC was designed to implement, consistently evaluate, and re-conceptualize boundary organization theory for bridging science and policy for sustainability. Our goals are *to*

understand and enhance the linkages between scientific knowledge production and public-policy deliberation and decision making under uncertainty. Also, this cross-cutting area seeks to improve basic understanding of the operation of complex water governance systems and to inform transitions toward sustainability.

In the past year, DCDC researchers continued to advance basic science of the co-production of knowledge and action for environmental decision making under uncertainty. In a pair of papers published this year, DCDC collaborators John Parker (National Center for Ecological Analysis and Synthesis, UCSB) and Beatrice Crona (Stockholm Resilience Center) synthesize theory, concepts and methods from literature on knowledge utilization, boundary organizations, and stakeholder theory (Crona and Parker 2012, *Ecology and Society*; Parker and Crona 2012, *Social Studies of Science*). This work develops a conceptual and methodological toolkit for conducting cross-case comparisons aimed at understanding the social environmental conditions under which learning in boundary organizations does and does not occur.

Also in the past year, DCDC PI Dave White examined the role of framing as a type of boundary work in the development of environmental decision support systems (White in review, *Society & Natural Resources*). As the use of these systems increases, it is critical to understand how framing embedded in decision tools structures discourse and action. This is important because framing impacts what types of questions are asked, what counts as knowledge, which actors are empowered, the forum where decisions are made, and ultimately the outcomes of these decisions. White analyzed the social processes in the development of WaterSim to reveal how modelers and researchers defined the water sustainability problem and implied solutions (i.e., the diagnostic and prognostic frames). Such self-reflexive research of DCDC boundary work is critical for the design (and redesign) of effective decision support tools that are legitimate, credible, and salient to both scientific and policy communities.

In another line of research aimed at expanding the range of boundary processes and objects studied and mapping greater diversity of stakeholder perceptions, sustainability scientist Arnim Wiek has been working in collaboration with geographer Kelli Larson and graduate student Lauren Withycombe Keeler to develop a systemic understanding and evaluation of regional water governance regimes. They developed an analytical framework that puts the focus on what people *do* with water (Wiek and Larson in review, *Water Resources Management*). More specifically, their framework 1) employs a systems-wide perspective on regional water systems; 2) focuses on social actors and investigates what people actually do with water and why, thereby building upon proposals to integrate systems and actors perspectives; 3) explicates values and preferences as they pertain to sustainability while specifying their relevance for all water activities; and 4) advances a comprehensive sustainability perspective, for instance, by expanding the discourse from safe yield to sustainability. Their proposed approach explicitly links and integrates natural science and engineering perspectives on water systems with social science studies of water governance. Moreover, it combines an analytical perspective (i.e., the current situation of the social-ecological system and the governance regime) with a normative perspective (i.e., the sustainability of the current situation, what needs to be changed, and which specific actor groups are implicated), to support policy makers and stakeholders in their efforts to achieve water resource sustainability.

Education Activities

We have integrated DCDC research into learning materials and educational programs, engaging a variety of formal and informal education partners. The Community of Graduate Scholars (CGS) brings together

graduate students from multiple disciplines to build interdisciplinary thinking and communication skills. This goal is accomplished through two semesters of a weekly seminar class and several research activities designed to build research skills. Margaret Nelson worked with five of DCDC's graduate students to organize the Decision Making Under Uncertainty poster symposium for the 2012 AAAS Annual Meeting in Vancouver, BC, where the CGS students presented posters of their work with DCDC. Additionally, graduate fellows associated with the NSF-funded GK-12 Sustainability Science for Sustainable Schools grant used DCDC research methods and findings to create classroom lessons.

Under the guidance of Katja Brundiers (DCDC Community-University Liaison), Margaret Nelson (Co-PI and Vice Dean of Barrett, the Honors College at ASU), Sada Gilbert (Internship Coordinator from the School of Sustainability at ASU), and Liz Marquez (DCDC Program Manager), the Internship for Science-Practice Integration program began its second year connecting with water-management stakeholders by placing students within agencies to carry out research-oriented internship projects. In addition to their internship, students participated in a three-credit hour course to design and implement their own use-inspired research project. To ensure academic rigor and state-of-the-art research ideas, each student met with a DCDC researcher for scientific input and feedback on their projects. Through this program, students were introduced to the concepts and practical aspects of policy-relevant research. The ISPI program included six partnerships with agencies such as city municipalities and nonprofit organizations. Results of students' use-inspired research projects were shared at DCDC's Annual Poster Symposium. The DCDC poster symposium featured research from both of DCDC's educational programs: Community of Graduate Scholars (6 students) and Internship for Science-Practice Integration (6 students). The Symposium attracted a large and mixed audience, including parents, faculty from diverse ASU departments, internship mentors, and related professionals from water-management agencies.

Monica Elser, education team leader, collaborated again this year with the University of Arizona's (UA's) water-education programs (Project Wet, Cooperative Extension, and the Water Sustainability program) to deliver a two-day Advanced Water Educator Workshop on ecosystem management. The 2012 workshop was the seventh in a series that provides community partners with timely information about water issues and connects university scientists (DCDC, ASU, UA) with educators. DCDC has hosted this activity annually since 2006, highlighting such topics as management (2006), climate change and decision making (2007), water re-use (2008), energy-water nexus (2009), water and the future of agriculture (2010), and public perceptions of water (2011). Monica had the opportunity to participate in the 2012 Tri-Agency Climate Change Education PIs Meeting, which included individuals representing projects currently funded by the NSF Climate Change Education (CCE) and Climate Change Education Partnership (CCEP) programs; the NASA Global Climate Change Education (GCCE) and NASA Innovations in Climate Education (NICE) programs; and, relevant projects funded by NOAA's Environmental Literacy Grants program.

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II. Findings of Research Activities

Economic Approaches to Analyzing, Projecting, and Managing Residential Water Demand

Economist Kerry Smith's recent research has produced new approaches for analyzing, projecting and managing residential water demand. Applying their new model to data obtained through a cooperative agreement from the City of Phoenix, three significant findings emerged (Klaiber et al. in review). First, differences in seasonal weather conditions affect the estimated price elasticities and this effect is separate from the influence of weather in the months directly related to the quantity response. Second, price responses vary with the size of the water customer; large customers are typically less responsive to price changes than small customers. Third, seasonal differences in price responses can be larger than the prior research has implied.

Tradeoffs between Water Use, Land Cover, and Urban Heat

Patricia Gober, Ariane Middel, Anthony Brazel, and Soe Myint and colleagues from Portland State University investigated a pressing urban sustainability question: how do land cover characteristics and climate affect urban heating and outdoor water use? The team developed three land-cover and climate scenarios each for Phoenix and Portland, and used the LUMPS model to simulate the urban energy balance. Gober et al. (in press, *Urban Geography*) report model outcomes showing that reduced vegetation cover decreases outdoor water use, but increases urban heating at night in both cities. Both water use and nighttime urban cooling seem to be less sensitive to climate than to land-use. Study results further indicate that a densification of the study areas, i.e. substituting impervious surfaces with buildings, is the most efficient cooling strategy.

DCDC post-doctoral scholar Ariane Middel, Anthony Brazel, Shai Kaplan, and Soe Myint used the LUMPS model to systematically analyze the daytime trade-off between water demand of various landscapes in Phoenix and the amount of cooling achieved (Middel et al. in press, *Climate Research*). Results of this tradeoff study indicate that the high heat storage capacity of impervious surfaces delays the sensible heat flux reversal at night up to three hours. Areas in Phoenix with high impervious cover and little vegetation (e.g., industrial sites) have negative cooling efficiencies. Overall, the urban core in Phoenix is slightly more cooling efficient than the Sonoran desert, but efficiencies do not improve much with vegetation fractions above 20%. Simulation results suggest that heterogeneous neighborhoods with drier landscaping are the best landscapes to balance cooling and water use in Phoenix. However, this tradeoff needs to be further investigated considering other factors, such as human vulnerability and energy use, particularly in the face of a changing climate.

Climate Impacts on Urban Heat Island and Extreme Heat Events

Multiple papers by DCDC researchers have produced new findings and methods for understanding climate impacts on the urban heat island and extreme heat events. Ruddell et al. (in review, *Climate Research*) documented warming trends among temperature thresholds, resulting in warmer winters, hotter summers, and more intense heat wave conditions; disjointed associations between global climate systems (ENSO and PDO) with frost and misery days, signaling anthropogenic interference between temperature thresholds and historic atmospheric processes; and potentially significant and wide-spread adverse impacts on many local environmental, economic, and social systems as a result of pronounced changes in threshold temperatures. Ruddell also developed a mixed method multi-scale analysis for extreme heat (Ruddell in review, *Population and the Environment*).

Cooperation and Information Technology in Environmental Governance

WaterSim serves as a key point of engagement with regional stakeholders and the public-at-large and as an experimental object to study how computer models and scientific visualization affect perceptions and

policy. Recent work by Erik Johnston, School of Public Affairs, and Ajay Vinze, WP Carey School of Business produced new findings about cooperation and information technology in environmental governance. In a new article Hu et al. (in press, *Journal of Community Informatics*) found that when people deliberated about regional water sustainability using a communal display of WaterSim in the Decision Theater they showed more cooperative behavior in a social dilemma scenario than those who deliberated on the same challenge presented on WaterSim on individual computer displays. These findings have implications for regional water planning and urban climate adaptation, which requires cooperation and coordination among a diverse set of actors and institutions.

Another paper forthcoming in *Journal of Public Affairs Education* (Hu, Johnson, and Hemphill in press), reports that interactive computer simulations like WaterSim provide context and creative learning environments for students to individually and collectively apply systems thinking in information-rich environments with instant feedback channels. The findings show that public administration students were able to quickly grasp the complexity associated with interdependent stakeholders with divergent interests, uncertain future conditions, and policy options that reflect competing values. However, the authors also noted some unintended consequences. Using interactive simulations may limit the scope of deliberation topics to only those highlighted by the simulation. Thus, the paper concludes with a discussion of some ethical concerns related to the use of computer simulations as part of an education exercise.

Psychology of Residential Water Demand and Climate Adaptation

During the past year, the psychology team contributed to enhanced understanding of environmental decision making under uncertainty. Findings from a series of psychology experiments on residential water demand raise some concerns about the efficacy of water conservation programs and provide guidance for more effective communication. Sadalla et al. (in review, *Journal of Environmental Psychology*) found that water intensive landscapes led to a greater number of consistently positive attributions than did water conserving landscapes. In particular, homeowners selecting high water use landscapes were rated higher in family orientation, sexual attractiveness, and extraversion. Some support was found for the hypothesis that high water use landscapes led to higher attributions of homeowner status. These results support the idea that landscaping choice is guided by self-presentational considerations, and that such considerations could impede the adoption of low water use landscapes.

In a second paper, Sadalla et al. (in review, *Environment and Behavior*) employed a trade-off paradigm to examine priorities in residential water use. The study found that indoor water uses, especially those related to health and sanitation, were consistently higher priorities and that under a restricted budget, residents may be willing to forgo a significant amount of outdoor water use. The findings imply that campaigns to reduce outdoor water use would not meet with as much resistance as campaigns to reduce indoor water use. Longer-term Phoenix-area residents, however, have greater priorities on outdoor water use for lush, *mesic* landscaping and may be more resistant to conservation programs.

The Key Role of Institutions in Urban Climate Adaptation

Findings from institutional analysis of agricultural systems (Bausch, Conners, and Eakin 2012, AAAS) highlight the importance of a multilevel governance structure with decision makers at different levels with varied time horizons, perceptions and attitudes about climate change. Additionally, irrigation districts have emerged as key actors in anticipatory (adaptive) planning. The findings suggest that the Arizona Groundwater Management Act (GMA) and associated policies do little to encourage reduced water use. Rather, security of water rights and current access to CAP water mitigates farmers'

perception of, and concern with, climatic water stress. The research suggests that peri-urban farmers are adaptive and flexible in face of variable economic circumstances (e.g., via land leasing) but this sector may not respond to climate change and water scarcity in ways typically assumed by policy makers. Rather, signals of environmental change will be channeled through energy prices, infrastructure constraints, and water prices.

Knowledge Systems, Learning, and Social Processes in Boundary Organizations

DCDC research generated several significant findings related to knowledge systems, learning and social processes in boundary organizations. Crona and Parker (2012, *Ecology and Society*) used social network analysis and a scale of knowledge utilization, to determine that different numbers and types of social interactions can have significant, independent effects on the use of scientific knowledge in governance systems. Policy makers with greater numbers of contacts with academics participating in the boundary organization were more likely to utilize information produced within DCDC to govern water resources, as were policy makers who discussed DCDC research with other policy makers. Furthermore, the fact that greater numbers of contacts among policy makers had an independent positive effect on knowledge utilization also suggests that in discussing the DCDC research with their peers, policy makers may become aware of salient research projects and these discussions may also enhance perceptions of the legitimacy, saliency, and credibility of the information provided. Such peer-to-peer contacts may thus be vital for the external reputation of an organization and may be an important factor in its success or failure. Finally, they concluded that depoliticized arenas created by DCDC appeared to have contributed to both lowering cultural barriers between stakeholder groups and aligning their interests, while significantly fostering the growth of social networks and increasing interaction among stakeholders. Boundary objects also helped to align stakeholder interests and enhance learning, but only via active facilitation by key liaisons brokering between the divergent interests of bridging organization stakeholder groups.

In his analysis of framing processes in the development of WaterSim, White (in review, *Society and Natural Resources*) identified a prognostic frame alluding to resource management and efficiency, which defined the "sustainability problem" as an unpredictable and long-term water supply shortage caused by prolonged drought, climate change impacts, and population growth. The diagnostic frame implies the solutions to achieve sustainable groundwater management as residential demand management and retirement of agricultural lands and conversion of agricultural water to municipal uses. The analysis finds that while such framing touches on issues that are directly relevant to the primary policy framework, it does not necessarily open up the discourse to novel or innovative sustainability solutions. Findings demonstrate that framing in a decision support system reflects the perspectives of those involved in the initial design of the tool. Thus, designers that aim to develop robust tools that engage a wide spectrum of stakeholders should make strides to involve diverse perspectives early and often or risk particular views being reified and "hard coded" into their systems.

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III. Education and Development

K-12 Education

In conjunction with Arizona Project WET, the Water Sustainability Program, and UA's Water Resources Research Center, DCDC hosted 25 teachers at the seventh annual Advanced Water Educator Workshop on July 18-19, 2012. The workshop enhanced educator knowledge of riparian systems, created wetlands and ecosystem management. Specific areas addressed as they related to this topic included:

- What are riparian system functions?
- What is the value of sustaining natural riparian systems?
- How are ecosystems managed?
- How do created wetlands and riparian systems fit into the water resources picture?

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

In its second year, the Internship for Science-Practice Integration (ISPI) was guided by Katja Brundiers, DCDC Community-University Liaison, Margaret Nelson (Co-PI and Vice Dean of Barrett, the Honors College at ASU), Sada Gilbert, Internship Coordinator from ASU's School of Sustainability, and Liz Marquez, DCDC Program Manager. The ISPI program bridges the University with water-management stakeholders by placing students in internship projects with a research component. In addition, students participate in a three-credit hour course in which they design and implement their own original, use-inspired research project. The second year of the ISPI program included six partners: Arizona Department of Water Resources, University of Arizona Cooperative Extension Center, City of Mesa (2), City of Scottsdale, and City of Tempe.

Graduate Education

Since the inception of DCDC II, we have supported 13 graduate students from: School of Sustainability (4), School of Geographical Sciences and Urban Planning (2), School of Sustainable Engineering and the Built Environment (2), School of Human Evolution and Social Change (1), Department of Psychology (1), School of Public Affairs (1), and School of Computing, Informatics, and Decision Systems Engineering (2). During DCDC I, we supported 87 students from a broad reach of disciplines.

We required graduate research assistants to participate in the 1-credit hour Community of Graduate Scholars (CGS). This seminar is designed to bring students into a cross-disciplinary dialogue to build their skills toward interdisciplinary thinking and communication. This is accomplished through two semesters of a weekly seminar class where the students create and complete a joint project. One specific goal of the seminar was to facilitate collaboration with graduate students from the other NSF-funded DMUU centers. This past year, Margaret Nelson, Co-PI and Vice Dean, Barrett, the Honors College at ASU, worked with DCDC graduate students to organize the Decision Making Under Uncertainty (DMUU) poster symposium for the 2012 AAAS Annual Meeting in Vancouver, BC.

Postdoctoral Fellowships

Since the launch of DCDC II, we have supported two postdoctoral fellows.

Darren Ruddell received his Ph.D. from the School of Geographical Sciences and Urban Planning and was funded jointly by DCDC and the Central Arizona–Phoenix LTER. Ruddell's research interests focus on issues of climate and society in the urban environment. Ruddell uses geospatial technologies to investigate physical and social dimensions of climate and health at multiple scales of analysis (e.g.,

regional, neighborhood, household). Ruddell just completed his first year as Lecturer with the Spatial Sciences Institute at the University of Southern California.

Ariane Middel received her Ph.D. in Computer Science from the University of Kaiserslautern, Germany. Since joining DCDC in 2009, she has collaborated with climatologists and geographers on research aimed at understanding the functional relationships between water use, energy use, and land-cover characteristics. Specifically, Ariane's research interests focus on how urban form, design and landscaping affect urban climate at the micro-scale and local scale. This understanding facilitates the targeting of more effective planning strategies for mitigating the urban heat island.

In August 2011, we look forward to two new postdoctoral fellows joining our team: Hernan Moreno, who is currently completing his Ph.D. under Vivoni's supervision in the School of Space and Earth Exploration at ASU; and Ted Bohn, who will be joining ASU from the University of Washington. Bohn has received notification of support from NSF for a SEES Fellowship and will work under the direction of Vivoni and White.

IV. Outreach Activities

Water/Climate Briefings

DCDC hosts Water/Climate Briefings on a regular basis. These briefings are a regular forum for the water-policy community, DCDC researchers, and students to exchange knowledge and ideas. The typical format is a panel of experts and community partners discussing issues such as the urban heat island, water re-use, and the energy-water nexus, followed by audience participation and questions. Since the launch of DCDC, we have hosted four to seven briefings each year, with panelists representing the scientific and professional perspectives. This year's DCDC Water/Climate Briefing theme focused on a branch of behavioral research situated at the intersection of psychology and economics. Our researchers are exploring the mental processes that shape our choices, behaviors and attitudes, and employ both evolutionary and sociocultural models to understand environmental decision making. Briefings in 2011–12 included:

October 26, 2011: *The Psychology of Environmental Decision Making* with Susan Ledlow, Ph.D., School of Sustainability and Kelli Larson, Ph.D., School of Geographical Sciences and Urban Planning and School of Sustainability. Ledlow and Larson presented research ranging from human environment interactions and water resource governance to aspects of human nature that might facilitate, or hinder, our ability to make sustainable decisions.

November 30, 2011: *Our Energy-Efficiency Paradox: Psychological Barriers to 'No-Brainer' Solutions.* The highlight of our Water/Climate Briefing series was the keynote presentation by Elke U. Weber, Ph.D., Jerome A. Chazen Professor of International Business, Columbia University; Director, Center for Research on Environmental Decisions, Earth Institute; and Director, Center for the Decision Sciences. Of all environmentally-relevant decisions, the adoption of energy-efficiency technologies would appear to be a 'no-brainer,' yet these solutions are vastly underused. In this talk, Dr. Weber highlighted the psychological reasons for this paradox and suggested ways in which we can harness cognitive limitations to spark greater adoption of win-win solutions.

December 6, 2011: *Cotton, Condos, and Climate: Agriculture and Arizona's Water* with panelists Paco Ollerton, a local cotton grower; Jim Holway, Director, Western Lands and Communities, a Lincoln Institute of Land Policy-Sonoran Institute joint venture; Brian Betcher, Manager, Maricopa-Stanfield Irrigation and Drainage District, Pinal County; and Joe Sigg, Director of Government Relations, Arizona Farm Bureau. This panel of agriculture, water resource practitioners, and professionals discussed how decision-makers in Arizona are comforted by the idea that water can be diverted from farms to cities in the face of future water scarcity. The assumption has been that historic trends in farm retirement will continue into the future, releasing water for urban use. However, rapid changes in economic, environmental and policy conditions now challenge this assumption.

April 17, 2012: *The Economics of Water Demand: The Dynamics of Water Use and Price.* Panelists included V. Kerry Smith, Regents Professor with W. P. Carey School of Business, Department of Economics; Doug Frost, Principal Planner, Water Services Department, City of Phoenix; and Gary Niekerk, Director of Corporate Citizenship, Intel Corporation. This discussion centered on how price is often suggested as a simple, straightforward tool for encouraging people to use water more efficiently. However, the economics of water demand are not that simple. Water is used for many purposes. Water is used to meet the basic necessities of life, consumption and hygiene. Water is used to create an atmosphere that suits our lifestyles, landscapes and pools, and perhaps long hot showers. Water is used for economic gain, from creating places attractive to customers to washing silicon chips. The sale of

water is also used to finance the infrastructure and costs associated with making water available to a community. Each of these water uses has its own economic dynamics based on behaviors and motivation for water use which can vary among the consumers in each category. At the same time, the economics for each of these water uses are related, changes in one can affect the other. Thus, decision making about the price of water is not as clear as it may initially appear. The goal of this climate briefing was to increase the awareness of the complexities associated with the price of water by facilitating a discussion about the differences and relationships that exist in the economics of different water uses.

Collaborative Science and Policy Workshops

In collaboration with the Arizona Water Institute, UA, and ASU's Decision Theater, DCDC hosted a series of workshops in 2009–2010 dealing with climatic uncertainty and climate modeling for scientists and water stakeholders, "Planning for Climate Change through an Integrative Approach to Water Planning, Climate Downscaling, and Robust Decision Making." At the conclusion of this workshops series, and based on interest in maintaining dialogue, we agreed to continue to organize stakeholders and scientists under the umbrella of the Arizona Climate and Water Resource Alliance (ACWRA), supported jointly by DCDC at ASU and CLIMAS at UA.

The inaugural ACWRA workshop was held May 12, 2011. The goal was to bring together a wide group of water-resource managers from across the region to discuss implications of widespread groundwater pumping events and candidly explore the implications of such events and the future research and discussion needed to address these implications. Participants focused on questions such as: "How low would aquifer levels go if everyone was to pump groundwater to the maximum extent allowed during such a long-term drought event?" and "How long would they remain at these levels after such an event?"

Future programming will be organized around extreme storms and their impacts of reservoir storage and floodplain management. The next ACWRA workshop is being planned to explore this growing research area and to develop a strategy acceptable to scientists and stakeholders to produce science products that meet the needs of the science community, water providers, and floodplain managers.

Water Innovation Consortium

The Water Innovation Consortium is a unique collaboration between ASU (DCDC and Decision Theater), Tecnológico de Monterrey (CALCA), and FEMSA Foundation to engage scientists and stakeholders in Monterrey, Mexico. The project develops a model for an Integrated Basin Observatory through surface and groundwater modeling, stakeholder engagement, and strategic decision support. Partners conducted a workshop on February 17, 2011 in Monterrey that brought together 25 scientists, stakeholders, and decision makers for presentations and discussions. A follow-up workshop is planned for later in 2011. In June 2011, Project PIs Dave White and Patricia Gober met with the representatives of FEMSA Foundation and another meeting held with the FEMSA CEO and delegation in August 2011 to discuss extensions of the current project.

The Urban Heat Island: Adaptation and Mitigation Strategies for a Cooler Valley

On October 18, 2011, Arizona Indicators, a project of ASU's Morrison Institute for Public Policy, in conjunction with the Sustainable Cities Network Green Infrastructure Workgroup meeting, presented The Urban Heat Island: Adaptation and Mitigation Strategies for a Cooler Valley at the Decision Center for a Desert City. Panelists included: Harvey Bryan, Professor, The Design School, Herberger Institute for Design and the Arts, ASU; Carol Johnson, Planning Manager, City of Phoenix Planning and Development Department; Chris Martin, Professor, Department of Applied Sciences and Mathematics, College of Technology and Innovation, ASU; and Dave White (moderator), Associate Director, Decision Center for a Desert City, ASU.

This panel discussion expanded upon the Arizona Indicators Policy Points piece, The Urban Heat Island: Jeopardizing the Sustainability of Phoenix, written by DCDC Research Analyst and Data Manager, Sally Wittlinger. In a desert city such as Phoenix, summertime heat is a way of life, but how much does the built environment contribute to the intensity of the heat on a summer night? In urbanized Phoenix, nights don't cool down as much as in the surrounding rural areas and on more and more summer nights, the official Phoenix temperature fails to drop below 90 degrees. Climate plays a huge role in the comfort and quality of life of residents, with numerous implications for tourism, energy demand, water use, and the vulnerability of low-income families.

Math and Climate Research Network Workshop

ASU Professors Alex Mahalov and Eric Kostelich brought their Math and Climate Research Network Workshop to DCDC on March 5-7, 2012. The Math and Climate Research Network links researchers across the US to develop the mathematics needed to better understand the Earth's climate.

It is generally accepted in the scientific community that the world is undergoing a significant change in its climate. The issues and problems of the science that seeks to understand the earth's climate, and how it is changing, have a significant mathematical dimension. The Mathematics and Climate Research Network (MCRN) is a virtual organization of leading researchers in mathematics and geosciences whose mission is to establish a new area of applied mathematics tailored to the needs of climate research.

The network consists of researchers at "nodes" across the US, together with several collaborating government and university labs and centers in the US and beyond. Network researchers have a collective expertise that cuts across the relevant areas of applied mathematics and climate science. They will collaboratively lead a group of postdoctoral research fellows, graduate and undergraduate students to create a cadre of strong mathematicians with the interdisciplinary expertise required to analyze problems that have their origin in climate issues.

MCRN is funded by an award from the National Science Foundation's Division of Mathematical Sciences, and is administered through the Renaissance Computing Institute.

Understanding Residential Water Use: New Approaches to Analyzing, Projecting and Managing Demand Conference.

On May 11, 2012, ASU economist Kerry Smith convened leading economic and social scientists from around the country along with municipal water providers from major western cities including Phoenix, Mesa, Tucson, and Seattle. Presentations focused on cutting-edge research on price and non-price incentives; the economic value of residential water; and understanding behavioral responses to water policy. Scientists and policy makers engaged in interactive dialogue to identify opportunities for innovative collaborative research.

Annual DCDC Poster Symposium

On April 25, 2012, Decision Center for a Desert City hosted its annual poster symposium. A highlight of the spring semester, graduate students enrolled in the Community of Graduate Scholars (CGS) and undergraduate research fellows participating in the Internship for Science-Practice Integration (ISPI) program presented the results of their DCDC research projects.

Community of Graduate Scholars posters

- Envisioning Water Futures in the Greater Phoenix Area: What Do We Want The Future To Look Like? – Lauren Withycombe Keeler (CGS), Arnim Wiek, Dave White, Kelli Larson, and Kendon Jung
- Psychological Barriers to Water Conservation: The Case of Desert Landscaping – Rebecca Neel (CGS), Edward Sadalla, Susan Ledlow, Anna Berlin, Samantha Neufeld, Yexin Li, and Claire Yee
- Half Full? Buffering Central Arizona Farmers from Signals of Environmental Change – Julia C. Bausch (CGS), John P. Conners, and Hallie Eakin
- Distributed Hydrologic Modeling of Semiarid Basins in Arizona: A Platform for Climate Change Assessments – Gretchen A. Hawkins (CGS) and Enrique R. Vivoni
- A Decision Making Game to Guide Water Sustainability Related to Policy Outcomes – Geetali Dudhbhate (CGS), Erik Johnston, Ajay Vinze, Rashmi Krishnamurthy, Dweepika Desai, and Qian Hu
- Interactive Computer Simulations for Public Administration Education – Rashmi Krishnamurthy, Qian Hu, and Erik Johnston

Internship for Science-Practice Integration posters

State-level ADWR (general governance approaches)

How Do We Catalyze Adaptive and Innovative Practices in Public Regulatory Agencies?

- McKenzie Ragan, Internship Fellow, School of Sustainability
- Michael J. Lacey, Internship Provider, Arizona Department of Water Resources
- Dave D. White, Faculty Mentor, Decision Center for a Desert City

Inter-city comparison: Planning approach 1, scenario construction as adaptive planning approach

How Scenario Planning Will Benefit Scottsdale Water Resources' Master Planning Process

- Ariel Pepper, Internship Fellow, School of Sustainability
- Beth Miller, Internship Provider, City of Scottsdale
- Ray Quay, Faculty Mentor, Decision Center for a Desert City

Inter-City level: Planning approach 2, collaborative management—problem perception and potential solution-options

Prevalent Perceptions of Water Use in Arizona

- Colin Russell, Internship Fellow, School of Sustainability
- Mark Holmes, Internship Provider, City of Mesa
- Erik Johnston, Faculty Mentor, School of Public Affairs

What Factors Motivated the Creation of the Colorado and Kansas Water Congresses?

- Kena Fedorschak, Internship Fellow, School of Sustainability
- Mark Holmes, Internship Provider, City of Mesa
- Erik Johnston, Faculty Mentor, School of Public Affairs

Engaging businesses as multiplier of solutions

The Relationship between Restaurants and Sustainability: Marketing the Tempe FOG Program

- Michael Nicastro, Internship Fellow, School of Sustainability
- David McNeil, Internship Provider, City of Tempe
- George Basile, Faculty Mentor, School of Sustainability

Smartscape: Using Education as a Tool for Reducing Water in Desert Landscapes

- Michael Alan Babcock, Internship Fellow, School of Sustainability
- Summer Waters and Haley Paul, Internship Provider, University of Arizona Cooperative Extension
- Kelli Larson, Faculty Mentor, School of Geographical Sciences and Urban Planning and the School of Sustainability

Contributions within the Discipline

Geographical Sciences

DCDC researchers have produced a critical mass of urban-environmental research that links physical and human geography. This year, a major review and synthesis of urban heat island research, co-authored by DCDC senior project personnel Tony Brazel, was published in *Bulletin of the American Meteorological Society* (Chow, Brennan, and Brazel 2012). The article synthesizes several decades of UHI research in Phoenix, including work conducted by DCDC and CAP LTER. The article reviews theoretical contributions from documenting, modeling, and analyzing the physical characteristics of the UHI; interdisciplinary investigation into its biophysical and social consequences; and assessment and evaluation of several UHI mitigation techniques. The authors identified a transition over time from single-discipline, inductive research to interdisciplinary, sustainability research with significant policy implications. Additional articles published during the past year evaluated xeriscaping as a sustainable UHI mitigation strategy (Chow and Brazel 2012) and examined the spatial, temporal and demographic dimensions of vulnerability to extreme heat (Chow, Chuang, and Gober 2012).

Systems Dynamics Modeling

WaterSim 5.0 is a demand-driven water simulation model developed in an open-source community framework. The WaterSim 5.0 Application Programming Interface (API) includes C# access to the FORTRAN model's parameters and functions with robust error checking, a mechanism to include an annual feedback loop, and database support for loading model parameters and saving model output. Version 5.0 also includes extensive documentation, including source code for the C# application interface (API) and FORTRAN model, documentation for the API and FORTRAN model parameters, and a sample user interface to the model (including an install program) that can be installed remotely on most personal computers (see http://dcdc.asu.edu/watersim/).

Science-Policy Interactions and Boundary Organizations

In the past year, DCDC made several contributions to advance theory and methods related to knowledge systems, learning and social processes in boundary organizations. Crona and Parker (2012) developed a new method, using social network analysis and a scale of knowledge utilization, to quantify the effects of social interaction on the use of scientific knowledge in environmental governance. Parker and Crona (2011) re-conceptualized boundary organizations theory to account for the dynamics of a university context.

Environmental Economics

Economic factors will play a critical role in urban climate adaptation, and DCDC research has contributed new insights into the design and implementation of climate policy that encourages economically sensible adaptation. In a new chapter forthcoming in the NBER book, *The Design and Implementation of U.S. Climate Policy*, environmental economist Kerry Smith evaluates adaptation policies that rely on economic incentives (Smith in press). Smith argues that economic analysis of capacity planning, as a response to climate change, cannot be undertaken independently from the consideration of how substitute services are priced. Such considerations offer the potential to create incentives that can feedback to influence the amount of economic activity and associated greenhouse gas emissions and thus both the pace of climate change and the demands for the services facilitating adaptation.

Contributions to Other Disciplines

As an interdisciplinary project, DCDC II links decision science, economics, psychology, geography, planning, anthropology, ecology, hydrology, and engineering. Although specific research projects often focus on disciplinary questions, the overarching approach is to foster an interdisciplinary dialogue among social and environmental scientists to catalyze innovative scientific approaches. WaterSim serves as one point of articulation where researchers unite disciplinary knowledge to address inherently interdisciplinary questions about water-resource sustainability and urban-climate adaptation.

Contributions to Human Resource Development

DCDC provides a powerful framework for training and professional development for faculty, postdocs, K-12 teachers, graduate and undergraduate students, and Center staff. Promising early-career faculty, nationally-renowned senior faculty, postdocs, and students work in teams to the benefit of all. DCDC 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. Each year about 25 K-12 teachers attend the annual Advanced Water Educator Workshops, which empowers teachers with the most-current scientific understanding to inform their curriculum. The DCDC Internship for Science Practice-Integration places undergraduate students within partnering agencies to carry out internship projects with a research component. This experience allows students to build their professional skills and cultivate professional networks.

Contributions to Resources for Research and Education

Situated within a large public research institution, DCDC is able to leverage research and outreach programs for educational benefit. Faculty members have expanded their courses to include consideration of decision making under uncertainty for water sustainability and urban climate adaptation and, in some cases, developed new courses to highlight DCDC topics.

Course	Faculty Member	Department
Geography of Phoenix	Patricia Gober	School of Geographical Sciences and Urban Planning
Water Sustainability	Patricia Gober and Rimjhim Aggarwal	School of Geographical Sciences and Urban Planning/School of Sustainability
Human Dimensions of Sustainability	Kelli Larson	School of Sustainability
Water Resource Geography and Policy	Kelli Larson	School of Geographical Sciences and Urban Planning
Geographic Research Methods	Kelli Larson	School of Geographical Sciences and Urban Planning
Society and Sustainability	Kelli Larson	School of Sustainability
Society and the Environment	Kelli Larson	School of Geographical Sciences and Urban Planning
Workshops on Urban Ecology and Water	Kelli Larson	School of Sustainability
Food Systems Sustainability	Hallie Eakin	School of Sustainability
Adaptation, Resilience and Transformation	Hallie Eakin and Rimjhim Aggarwal	School of Sustainability
Sustainable Use of Environmental Resources	Rimjhim Aggarwal	School of Sustainability
Society and Sustainability	Arnim Wiek	School of Sustainability
Sustainability Methodology	Arnim Wiek	School of Sustainability
Participatory Intervention Research on Climate Change	Arnim Wiek	School of Sustainability

Course	Faculty Member	Department
Mitigation		
Community of Graduate Scholars	Margaret Nelson	School of Sustainability
Seminar on the role of information technology, including computer model-based decision support systems such as WaterSim, on decision making	Erik Johnston	School of Public Affairs

Contributions Beyond Science and Engineering

The mission of DCDC has always included a significant degree of stakeholder involvement and active participation from the local community. We have hosted dozens of Water/Climate Briefings; organized and facilitated workshops dealing with climate change, water conservation, and the urban heat island; and participated in myriad public events ranging from real-estate forums to informal salons and public gatherings. DCDC has become the most influential forum for public discussion of water problems in central Arizona; it is *the* place where science meets policy in search of sustainable solutions to the problems of climate change.

Internet Dissemination

Decision Center for a Desert City utilizes their website (http://dcdc.asu.edu) as a way to archive and inform the public, stakeholders, and researchers. WaterSim (http://watersim.asu.edu) is a simulation of water supply and demand for the Phoenix Metropolitan area that integrates information about climate, land use, population growth, and water policy. In 2011, Decision Center for a Desert City began promoting through social media (http://twitter.com/#!/DCDC_ASU) DCDC research & activities linking back to the website with a priority to increase followers and the quality of engagement. In 2012, we established a Google Scholar page for Decision Center for a Desert City which tracks DCDC publications and citations (http://scholar.google.com/citations?h1=en&user=h2jqgykAAAAJ).

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VI. Partner Organizations

Arizona Cotton Growers Association: The ACGA is collaborating with Hallie Eakin, Rimjhim Aggarwal, and Abby York to examine how water policy affects farmers' engagement with adaptation to future scarcity. This work is supported by DCDC and leverages funding against a complementary NOAA-CSI grant.

Arizona Department of Water Resources: ADWR has continued to provide data to support DCDC research projects and meet with DCDC staff as needed. ADWR representatives collaborate on modeling output (MODFLOW), which is being integrated with WaterSim. Michael Lacey, Assistant Director at ADWR serves on DCDC's External Advisory Committee. ADWR provided an undergraduate internship for our ISPI program. ISPI Fellow, McKenzie Ragan, was mentored by Mike Lacey as she studied, observed, and analyzed factors influencing innovation and adaptation that affects U.S. public natural resource regulatory agencies such as ADWR.

Bureau of Reclamation: BOR representatives have been active members in the collaborative workshop series in 2009–2010 dealing with climatic uncertainty and climate modeling for scientists and water stakeholders and will continue to participate in the newly formed Arizona Climate and Water Resource Alliance (ACWRA).

City of Mesa: The City of Mesa and Mark Holmes, City of Mesa, Water Resources Department, generously hosted two of our ISPI Research Fellows, Kena Fedorschak and Colin Russell. During their internship, these two students focused on factors motivating the creation of the Colorado and Kansas Water Congresses and how these factors might relate to prevalent perceptions of water use in Arizona. Kathryn Sorensen, City of Mesa, serves on DCDC's External Advisory Committee.

City of Phoenix: DCDC collaborates closely with the City of Phoenix's Water Services Department, sharing the results of different but complementary water modeling efforts. In addition, the City has provided an immensely useful data set that includes municipal water use by different types of users across census tracts between 1990 and 2009. City representatives have given presentations and served as panelists at the DCDC Water/Climate Briefings. City of Phoenix Water Services Department staff have co-authored research proposals with DCDC investigators.

City of Scottsdale: Working with Elizabeth Miller, Water Resources Advisor for the City of Scottsdale, Water Resources Division, our ISPI Fellow, Ariel Pepper explored integrating scenario planning concepts into water master planning processes.

City of Tempe: The City of Tempe supplies household water use data for DCDC analysis. In addition, the City of Tempe, Water Utilities Division, provided an internship position for ISPI Fellow, Michael Nicastro. With the assistance of David McNeil, Environmental Services Manager, Michael conducted background research and reached out to the Tempe restaurant community to analyze their interest in the fats, oils, and grease pilot program.

East Valley Water Forum: EVWF consists of tribal, public, and private water agencies in the East Salt River Valley. EVWF participates in collaborative science-policy workshops with DCDC and other regional water stakeholders.

Global Water: Global Water owns and operates private water and waste water utilities in the greater Phoenix area and presently serves approximately 40,000 connections. Global Water will collaborate with

DCDC on research and education, and outreach activities by providing and sharing data on water and other resources; offering student internships; providing staff time; and sharing best practices and decision making tools that advance from these activities. Graham Symmonds of Global Water serves on DCDC's External Advisory Committee.

Lincoln Institute of Land Policy: DCDC partnered with the Lincoln Institute of Land Policy and the Sonoran Institute in supporting the publication of *Watering the Sun Corridor*, a Morrison Institute of Public Policy report to assess water security in the Sun Corridor of Central Arizona.

Maricopa Association of Governments: MAG is composed of the 25 incorporated cities and towns in Maricopa County and the contiguous urbanized area, three Indian communities, Maricopa County, and the Arizona Department of Transportation. MAG collaborates with DCDC research, education, and outreach activities by providing and sharing data.

Maricopa County Flood Control District: MCFCD representatives participate in scientist and stakeholder activities and attend DCDC Water/Climate Briefings. The MCFCD also provides data for DCDC research.

Salt River Project: SRP delivers nearly 1 million acre-feet of water to a service area in central Arizona and operates an extensive water-delivery system that includes reservoirs, wells, canals, and irrigation laterals. SRP has provided a wide range of information to DCDC scientists, including hydrological data, public attitude surveys that reveal household perception of drought and responsiveness to conservation messages, reports of water duties (usage rates) associated with different land uses, water delivery data, and irrigation coverages. SRP climatologists and water managers are among the most regular participants at the DCDC Climate/Water Briefings and SRP representatives continually give presentations that spark discussion at Water/Climate Briefings.

University of Arizona (CLIMAS, SAHRA, WRRC): DCDC collaborates with three University of Arizona research centers dedicated partly or wholly to water and climate research. DCDC partners with Climate Assessment for the Southwest (CLIMAS), part of U of A's Institute of the Environment. Their mission to improve the region's ability to respond to climatic events and climate change complements DCDC's goal of managing the uncertainty associated with drought, climate variability, and global climate change. DCDC will partner with CLIMAS in the newly formed Arizona Climate and Water Resource Alliance (ACWRA). DCDC works with the U of A's Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA), whose experience with a broad spectrum of stakeholders (both public agencies and private organizations) helps enhance the relevancy of the project to decision makers. Researchers from the Arizona Water Resources Research Center (WRRC) participate in investigating public perception of drought and water management.

University of Arizona (The University of Arizona Cooperative Extension, Maricopa County): A collaborative internship program between DCDC and the University of Arizona Cooperative Extension in Maricopa County provided Michael Babcock, School of Sustainability undergraduate, the opportunity to analyze the Smartscape program, which aims to reduce water use among landscape professionals.

University of Arizona (Arizona Project Wet): Project Wet participates in the annual DCDC Advanced Water Education Workshops. This successful workshop has been repeated each summer and is always filled to capacity. The seventh Advanced Water Educator Workshop, with the theme of Ecosystem Management, was held in July 2012.

Other Collaborators

ASU President's Office: DCDC and other university constituents, under the guidance of the Office of the University President, partnered with the Arizona Republic to create the Metropolitan Phoenix Indicators Project, a set of data presented in an impartial manner to illuminate the current state of the economic, social and cultural life of our region. DCDC is in the seventh year of collaboration on this project, renamed Arizona Indicators, which is now administered by ASU's Morrison Institute of Public Policy. (See: http://www.arizonaindicators.org).

Center for Science, Policy and Outcomes (ASU): DCDC collaborates with ASU's Center for Science, Policy and Outcomes (CSPO), an internationally known organization involved in studying the linkages between science and technology and society.

Central Arizona Project Long Term Ecological Project (CAP LTER): DCDC and CAP LTER work together on the Phoenix Area Social Survey (PASS), an ongoing interdisciplinary project examining community formation, growth, and interaction with the natural environment. Closer collaboration between DCDC and CAP LTER, ASU's two large urban environmental research programs, offers the opportunity for integration of DCDC's inherently social science approach to urban modeling with CAP LTER's more ecological approach.

The Center for Integrated Solutions to Climate Challenges at Arizona State University: DCDC is assisting with the development of the Center for Integrated Solutions to Climate Challenges at ASU (The Climate Center at ASU), a boundary organization interfacing science, policy, and practice. The Center brings together researchers, policy makers, and public and private stakeholders to identify and inform both research and next-generation data needs, as well as build teams for the integration of research, data, and data infrastructure as it relates to the nexus of critical challenges and climate variability, uncertainty, and change. Their initial focus will be on the challenges of air quality, water, health, energy, food systems, planning, infrastructure, and economics facing cities, such as Phoenix, Arizona, located in desert environments.

Decision Theater (ASU): Founded simultaneously with DCDC, the Decision Theater (DT) at Arizona State University is a learning and decision space in which the latest understanding of complex social, economic, and natural processes and their interactions are visualized. DCDC works closely with DT to translate DCDC science and modeling into visualizations applicable for the general public and decision makers. DCDC's WaterSim is presented in the Decision Theater, and DT was used as the setting for a project to evaluate WaterSim as a decision support tool.

Global Institute of Sustainability (ASU): DCDC is administered by and closely collaborates with ASU's Global Institute of Sustainability (GIOS). GIOS serves as the bridge to other relevant NSF-sponsored projects, especially the Central Arizona Phoenix Long-Term Ecological Research (CAP LTER) project, the Urban Ecology Integrative Graduate Education and Research Training (IGERT) program, the cross-site Biocomplexity in the Environment project on Agrarian Landscapes in Transition, and the Sustainability Partnership Enterprise. As GIOS expands, international researchers are being asked to participate in its programs, including DCDC.

Morrison Institute for Public Policy (ASU): The Metropolitan Phoenix Indicators Project evolved into the Arizona Indicators, now administered by the Morrison Institute. DCDC continues to contribute data to this project. In addition, Grady Gammage, Jr., a Morrison Institute Senior Research Fellow, recently

completed *Watering the Sun Corridor*, a report that was co-sponsored by DCDC and included contributions from DCDC researchers.

Sustainable Cities Network (ASU): Sustainable Cities Network (SCN) is a regional organization whose community members work together to discuss, solve and overcome everyday sustainability challenges facing cities and the overall region. In partnership with DCDC, SCN will have the opportunity to offer valuable municipal staff feedback, access to local resources and research opportunities, and a centralized meeting forum via workshops and network meetings to reach community sustainability practitioners with important DCDC findings. At the same time, SCN and its members will benefit from this collaboration by having access to real-time research and scientific knowledge on water and resource related topics that will aid municipalities in making more informed water and sustainability decisions.

VII. DCDC Participants

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Bureau of Reclamation
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Center for Science, Policy and Outcomes (ASU)
Central Arizona–Phoenix Long Term Ecological Project [CAP LTER] (ASU)
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City of Phoenix
City of Scottsdale
City of Tempe
Decision Theater (ASU)
East Valley Water Forum
Global Institute of Sustainability (ASU)
Global Water
Lincoln Institute of Land Policy
Maricopa Association of Governments
Maricopa County Flood Control District
Morrison Institute for Public Policy (ASU)
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