



DCDC 2010-2011  
Annual Progress Report

Decision Center for a Desert City II:  
Urban Climate Adaptation  
SES-0951366

Principal Investigators  
Patricia Gober (PI, Co-Director)  
Charles Redman (Co-PI, Co-Director)  
Craig Kirkwood (Co-PI)  
Margaret Nelson (Co-PI)  
Dave White (Co-PI, Assoc. Director)

Submitted to the  
National Science Foundation  
Via Fastlane  
July 24, 2011

## DCDC 2010-2011

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### Principal Investigators:

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Charles Redman (Co-PI, Co-Director)  
Craig Kirkwood (Co-PI)  
Margaret Nelson (Co-PI)  
Dave White (Co-PI, Assoc. Director)

### Executive Committee:

Patricia Gober  
Craig Kirkwood  
Liz Marquez  
Margaret Nelson  
Charles Redman  
Dave White

### Staff:

Katja Brundiers  
Bill Edwards  
Liz Marquez  
Estella O'Hanlon  
Annis Olsen  
Ray Quay  
David Sampson  
Sally Wittlinger

### Teams:

Adaptation  
Decision Analysis  
Decision Processes  
Institutional Roles in Decision Making  
Boundary Studies  
Education and Resource Development  
Outcomes  
Distributional Effects  
Economic Feedbacks  
Urban System Impacts  
Uncertainties  
Climate Change



## 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 and is poised 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 will develop 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 has produced: (1) a critical mass of basic research, including over 200 articles, books, and book chapters (65 of these appearing to date in 2010–2011); (2) WaterSim, a 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 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 and implement decision-support processes for environmental decision making. 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.

## Research Activities

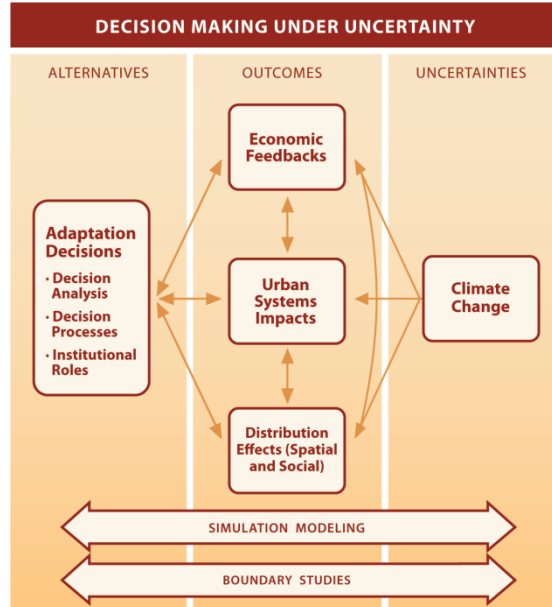
We have organized DCDC II around water and other resource decisions in a complex, dynamic urban system and structured our research in terms of an integrated decision process. DCDC II's conceptual approach posits that the uncertainties of climate change affect individual and societal alternatives (adaptation 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 initial phase of DCDC, researchers identified and addressed major climatic uncertainties facing Phoenix, including interannual drought, climate change, and the urban heat island. We have explored the sensitivity of urban water demand to variations in climate to clarify the effect of this uncertainty for 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. We will determine the key areas that generate our water supply (what happens if land use/cover changes), the importance of precipitation intensity (what happens to extremes under future climate change), the importance of snow versus rain (what happens to precipitation types under future climate change and what are the impacts on water supply), and the potential effects of changing land-use conditions with wildfires, urban development, and agricultural policies.

In the first year of DCDC II, climate scientist Robert Balling and colleagues continued their successful line of research developing a basic understanding of physical processes that underlie climate and drought conditions in the Southwest. In an article in *Theoretical and Applied Climatology*, Svoma et al. (2010) developed a high-resolution model for estimating soil moisture for the Salt River Basin. Two articles appeared last year in *Physical Geography* that used various spatial analytical methods to assess drought trends in the Southwest and conterminous US (Balling and Goodrich 2010; Svoma and Balling 2010). In an article in *Theoretical and Applied Climatology*, Balling and Goodrich (2011) examined variations and trends in precipitation intensity in the conterminous US.

In a second line of climatic-uncertainties research supported under DCDC II, climatologists Andrew Ellis and Robert Balling and their team worked closely with Water Resource Operations personnel from Salt River Project (SRP) to assess how projected changes in runoff under various climate-change scenarios might threaten surface-water replenishments of the SRP reservoir system. They developed and authored a reservoir simulation model (ResSim; FORTRAN programming language on a UNIX platform) incorporating the same parameters and operational guidelines as embodied in the SRP Long-Term Drought Planning Model (LTDPM), allowing efficient exploration of many climate and runoff scenarios. This collabor-



ation resulted in supplementary funding from SRP to test the model using historical data and compare with LTDPM results, confirming equivalent ability to reflect key periods of drought vulnerability.

### **Environmental Economics – Water Demand Research**

Economist Kerry Smith continues to lead a dynamic research program focused on economic and non-economic factors that influence residential water demand. 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 have been developing a structural model of residential land use for the Arizona “Sun Corridor” region, progressing as data have become available. The model will enable an integrated assessment of long-term policies that influence household water behavior. Special attention is being devoted to interactions between public land and water policies.

Two sets of research were completed during the first year of DCDC II. The first study exploits the systematic changes in price schedule with season and the panel structure of water records to measure price responsiveness without requiring detailed consideration of the increasing block rate structure. To our knowledge, this is the first time this strategy has been recognized. A second new contribution involves using the linked housing data and water meter records for Phoenix and Tucson water departments that resulted from cooperative data-sharing agreements with each water department. The research exploits the logic of propensity score matching to control for the structure and landscape influences on water demand and extracts the first “pure” price schedule assessment.

Research in progress has led to several intermediate insights. First, structural-modeling work has demonstrated an important interaction that influences preliminary estimates of households’ tradeoffs for enhancements in amenities. This interaction arises due to linkages between the spatial scale of the definition of a community and the spatial scale of the measure used for landscape-related amenities (including proxies for ecosystem services). A second, intermediate insight concerns the potential for important effects of endogeneity in measures of spatial amenities and un-observable variables describing site attributes due to household residential choices in response to the features of the alternative neighborhoods available. Research to date has adapted the Abbott-Klaiber (2010) framework to test the importance of these effects.

### **Urban Systems Dynamics**

Urban planner Subhrajit Guhathakurta led a team that included engineer Eric Williams, DCDC II postdoc Ariane Middel, and several graduate students, to develop a dynamic network model to examine trends in energy use and carbon emissions associated with urban form, land-use patterns, buildings, and travel behavior. Their networked infrastructure model integrates energy use in separate categories (vehicles, travel infrastructure, buildings) into a dynamic network where each activity node depends upon other nodes of both similar and different activities. Their analysis addresses questions about human-climate interactions in the city such as: how do different urban forms and land-use patterns contribute to energy use and GHG emissions; how do urban energy use and GHG emissions evolve as a community changes over time; and how do socioeconomic characteristics of the population influence patterns of land use and travel behavior and their implications for energy and emissions?

In another recently completed study, Guhathakurta and colleagues advanced three aspects of life cycle assessment (LCA) of residences: functional unit, technological progress, and scaling properties. They explored these issues through a case study of energy use of detached homes in Phoenix. This research

relates residential energy use to unit size, characteristics, and neighborhood urban form. The objective is to inform planning of energy-efficient and low-carbon residential communities in the US. Additionally, this team developed a parametric LCA model that can estimate the embedded energy and GHG emission in the material manufacturing and construction processes for most types of single-family homes in Phoenix.

Geographers Patricia Gober, Anthony Brazel, Soe Myint, and postdoc Ariane Middel continued their NOAA-funded collaboration with Portland State University. Recent work examines how changes in land use/cover alter the local surface energy balance and contribute to distinct urban climates. The objective is to identify the extent to which current land cover and regional climate controls the surface energy balance. The researchers are using a Local Scale Urban Meteorological Parameterization Scheme (LUMPS) to analyze the relative attributions of local weather extremes and land-cover variations on the urban energy balance. Several articles from this effort are under review, and one published article (Myint et al. 2011) describes the remote sensing that underpinned the land-cover classification.

### **Distributional Effects – Vulnerability, Resilience and Risk**

People and places may experience different vulnerabilities to climate change because of variations, not only in exposure, but in sensitivity and capacity to respond to climatic shocks and stresses. In the first year of DCDC II, we extended our research on vulnerability to heat stress.

The expanding and intensifying urban heat island partly motivates this work, but takes on added significance as climate change threatens to increase temperatures further. Recent work documents warming in Phoenix and deleterious impacts as critical temperature thresholds are passed. Another study developed an index of vulnerability based on physical exposure to heat stress and adaptive capacity of the population to cope and showed that Phoenix's minority populations became more vulnerable to excessive heat between 1990 and 2000 (Chow et al. 2011). Sociologist Sharon Harlan and DCDC postdoc Darren Ruddell examined human vulnerabilities and health impacts of heat stress and air quality in cities and the potential co-benefits of mitigation and adaptation strategies (Harlan and Ruddell 2011).

### **Adaptation Decisions – Decision Science and Policy**

During this past year, Craig Kirkwood, along with L. Robin Keller (University of California, Irvine) and Jay Simon (Naval Postgraduate School), completed research (extending Simon's 2009 doctoral dissertation) to develop and implement new analysis methods for decision problems with geographically varying outcomes. Also this year, Kirkwood, Gober, and others produced several articles using WaterSim for decision analysis. These included a study of the robustness of various water policies in the face of climate uncertainty (Gober et al. 2010), a vulnerability assessment of climate-induced water shortage in Phoenix (Gober and Kirkwood 2010), and a description of WaterSim development and use for policy analysis (Gober et al. 2011).

A second line of decision science and policy research supported by DCDC, led by Erik Johnston and Yushim Kim of the School of Public Affairs and Ajay Vinze from the W. P. Carey School of Business, examines cooperative behavior and collaboration amongst diverse stakeholders to achieve collective goals. Governments have increasingly adopted inclusive processes to engage non-state actors, and especially active engagement of citizens and communities, to solve local policy challenges. The success of this inclusive approach depends upon whether, and to what extent, all involved individuals, interest groups, communities, and government agencies collectively deliberate and work together. The study

team used WaterSim and the Decision Theater to conduct experiments exploring the potential of an IT-facilitated communication environment on cooperative behavior.

### Adaptation Decisions – The Psychology of Environmental Decision Making

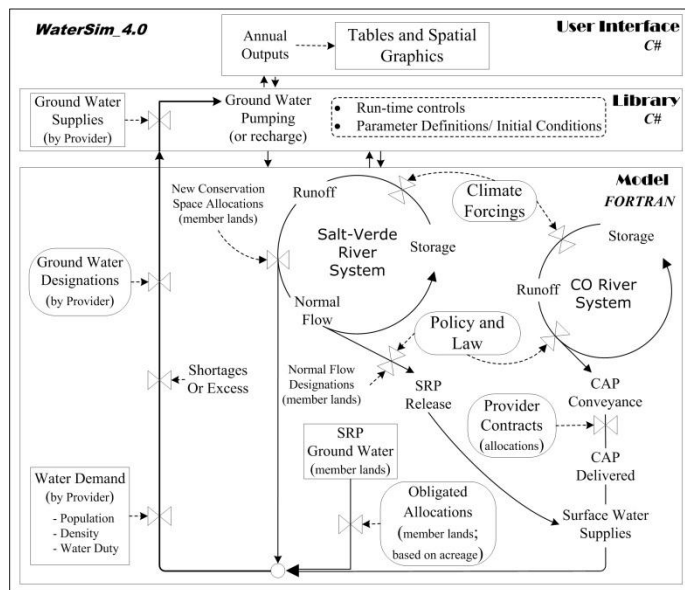
In DCDC II, we added a team of ASU psychologists including Susan Ledlow, Ed Sadalla, Douglas Kenrick, Steven Neuberg, and graduate and undergraduate students. They employ both evolutionary and sociocultural models to understand environmental decision making. In year one of DCDC II, the psychology team conducted several studies to examine: 1) priorities in residential water use in the Phoenix area; 2) social symbolism of landscaping; 3) framing effects in advertisements for conservation behavior; 4) belief in climate change and perceptions of climate-change consensus; and 5) temporal discounting in the valuation of the long-term payback of energy-efficiency upgrades.

Human-environmental geographer Kelli Larson seeks to understand the bases of environmental judgments and decision making. She has developed a tripartite model of affective, cognitive, and conative judgments to explain the sociocultural basis for environmental judgments (Larson et al. 2011b). In a another paper in *Environment and Behavior*, co-authored with graduate student Dorothy Ibes and DCDC Associate Director Dave White, Larson examined gendered perspectives about water risks and policy strategies (Larson et al. 2011a). Incorporating an array of perspectives on human-ecological problems and possible solutions helps to ensure that sustainability policies are socially accepted and culturally appropriate.

### Simulation Modeling – WaterSim Model Development

In DCDC II, we have continued to implement and refine our signature computer-simulation model, WaterSim, to investigate how alternative climate conditions, rates of population growth, and policy choices interact to affect future water supply and demand conditions in Phoenix. We designed WaterSim not only as a decision-support tool but as a hybrid boundary object designed to link science and policy to improve environmental decision making under conditions of uncertainty. As such, the modeling effort incorporates structured ongoing feedback from stakeholders and researchers.

WaterSim is a hierarchical model that uses supply from surface and groundwater sources and demand from residential, commercial, and agricultural sectors, incorporating the rules that govern reservoirs, aquifer use, and land-use change. Gober et al. (2011) in *Environment and Planning B* and Sampson et al. (2011) in *Journal of Environmental Management* described the development of WaterSim. The current version of the model, WaterSim 4.0, is comprised of (1) a Microsoft C# interface; (2) a C# library module; and (3) a simulation model (FORTRAN) that houses the rules and algorithms to model water supply and demand, all at the water provider-level. WaterSim 4.0 runs on an annual time-step, but monthly estimates can be



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generated for many of the output variables. WaterSim 4.0 produces water supply and use patterns for 33 Phoenix Metropolitan Area water providers.

DCDC II's *WaterSim Steering Committee* developed recommendations for model improvements based on feedback from the research community and community partners. The new version of WaterSim, which will include a Microsoft.Net-based standalone model (which does not require PowerSIM) with a documented application interface (API), is being developed in FORTRAN and C#.

### **Simulation Modeling –Hydrological Modeling**

DCDC II also supported Enrique Vivoni's team from the School of Earth and Space Exploration to apply a distributed hydrological model of the Beaver Creek Basin in Arizona using the Triangulated Irregular Network (TIN)-based Real-time Integrated Basin Simulator (tRIBS). These model applications will help us detect and predict the consequences of land-use change and climate change on watershed hydrology. Activities to date include the development of full-scale model simulations of the Beaver Creek Basin for June through September 2006. Vivoni has processed model forcing for additional summer periods (2007–2009) and will examine that period in the future. Model calibration with respect to the observed streamflow at three gauging stations is underway and will add confidence to the model's predictive ability when applied to future scenarios. These simulations use high-resolution parameter fields that describe the watershed topography, soils distribution, land cover/use, and meteorological forcing.

### **Boundary Studies – Science-Policy Interactions and Boundary Organizations**

From the outset, we structured DCDC as a boundary organization designed to understand *and* enhance the linkages between scientific knowledge production and public-policy deliberation and decision making. Led by Dave White, our efforts have contributed to basic understanding of the co-production of knowledge and action for environmental decision making under uncertainty. Research activities explore three interconnected domains:

- *boundary work* – boundary-ordering devices, processes, and methods linking science and policy
- *boundary organizations* – institutional forms overlapping scientific research and political decision making and public action
- *boundary objects* – hybrid constructs, integrating scientific and political elements to facilitate the exchange of knowledge and action.

In the past year, we have advanced scientific understanding of science-policy interactions by: (1) collaborating to a greater extent with stakeholders to co-produce knowledge; (2) expanding the range of boundary processes and objects studied; (3) mapping diversity of stakeholder perceptions; (4) fostering international collaborations; and (5) transferring lessons from DCDC to other boundary organizations. In June 2011, White presented a paper to the International Symposium on Society and Resource Management summarizing the state of knowledge for boundary-organization research and addressing major epistemological and methodological issues in the field.

DCDC postdoc Bethany Cutts, Dave White, and Ann Kinzig published an article in *Environmental Science and Policy* (Cutts et al. 2011) that integrates concepts from boundary organization theory with a participatory geographic information systems framework. Using a participatory action research approach, the researchers analyzed water information maps as a boundary object and assessed changes in the saliency, legitimacy, and credibility of the maps through a stakeholder engagement process. This research not only refined boundary organization theory but met our goal of more active co-production of knowledge and action.



In a continuing effort to examine boundary work through scenario construction and sustainability assessments, Arnim Wiek, Kelli Larson, and DCDC doctoral student Lauren Withycombe conducted an appraisal of the Phoenix water system using a layered conceptual model. The model specified principles of water sustainability in order to assess long-term sustainability. The goals of this research are to: 1) analyze the regional water system in Phoenix, including roles and activities for all relevant stakeholders; 2) define where stakeholders engage; 3) document why stakeholders take the actions they do; and 4) identify the impacts of the first three on water sustainability and urban climate adaptation.

This year, we began collaborating with Colin Polsky and Clark University PhD student Katherine Foo, who traveled to Phoenix August 2010 for the DCDC II strategic-planning retreat. This summer, the Clark team, which also includes seven undergraduate and four graduate students funded through Polsky's other existing projects, is producing a set of stakeholder-led scenarios of near-term future (coming two to three decades) of socioecological landscape interactions. This effort is divided into two groups of activities, one grounded in Geographic Information Science (GISci) and one in social science. These activities will cement relationships with Boston-area stakeholders, expanding the analytical scope of scenario production and assessment beyond water and climate. These activities parallel scenario construction and assessment efforts in Phoenix led by DCDC researchers Arnim Wiek, George Basile, Grady Gammage, Jr., Dave White, and others, which will enable comparisons between Boston and Phoenix.

### **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 Undergraduate Research Scholars (COURS) and Community of Graduate Scholars (CGS) programs bring together undergraduate and 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.

New this year, Katja Brundiers (DCDC Community-University Liaison), Margaret Nelson (Co-PI and Vice Dean of Barrett, the Honors College at ASU), and Amy Lively (Internship Coordinator from the School of Sustainability at ASU), developed and implemented the first "Internship for Science-Practice Integration" program (ISPI). The ISPI program connected DCDC 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 seven partnerships with agencies such as city municipalities, private companies, and nonprofit organizations, as well as students from three different departments. Results of students' use-inspired research projects were shared at DCDC's Annual Poster Symposium. The poster symposium featured research from all DCDC's educational programs: Community of Graduate Scholars (4 students), Community of Undergraduate Research Scholars (18 students), and Internship for Science-Practice Integration (7 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. Highlighting the early success of the ISPI program, one intern from the inaugural

class, Josh Abbott, was asked to speak about his experiences working as a DCDC intern with the City of Mesa to the Arizona Board of Regents, the governing body for Arizona's three state universities.

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 public perceptions of water. The 2011 workshop was the sixth in a series that provides community partners with timely information about water issues and connects university scientists (DCDC, ASU, UA) with the water-stakeholder community. 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), and water and the future of agriculture (2010).

Margaret Nelson worked with DCDC graduate students to organize the Decision Making Under Uncertainty poster symposium for the 2011 AAAS Annual Meeting in Washington, DC. 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.

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## II. Findings of Research Activities

### Effects of Climate Change on Soil Moisture and Precipitation in the Southwest

A series of studies by DCDC climate scientists have clarified the effects of climate change on soil and precipitation conditions in the Southwest. Taken together, these studies document the effects of warming and drying trends on soil and precipitation and help characterize the climatic uncertainties for our region.

Svoma et al. (2010) found evidence of increased surface pressure over the Salt River Basin during the latter half of the 20th century, which may be a catalyst for drier conditions. Balling and Goodrich (2010) identified a highly statistically significant trend toward increased drought in the Southwest; the trend is particularly strong over the Colorado River Basin. Svoma and Balling (2010) found that precipitation variability appeared to have increased in the critical winter season in the Southwest. Results from the US provide empirical support for the many modeling studies simulating an increase in precipitation variability given continued global warming. Balling and Goodrich (2011) found evidence in support of an upward trend in precipitation intensity as the planet has warmed.

### Energy Implications of Urban Housing Design

Subhrajit Guhathakurta, Eric Williams, Master's student Stephane Frijia, and postdoc Ariane Middel developed a parametric lifecycle analysis model to estimate the embedded energy and GHG emissions in the material manufacturing and construction processes for single-family homes in Phoenix. Embedded energy is defined as the total energy required for an entire product lifecycle. It includes the extraction and transport of raw materials, manufacturing, construction, and deconstruction. Study results for the lifecycle analysis of single-family homes showed a linear relationship between embedded energy and dwelling size. For one-story buildings, energy use per area ranges from 5.34 GJ/m<sup>2</sup> to 6.45 GJ/m<sup>2</sup>. For two-story buildings, the range is 4.85 GJ/m<sup>2</sup> to 5.79 GJ/m<sup>2</sup>. Thus, embedded energy increases linearly with increasing dwelling size (floor plan), but is smaller for two-story buildings compared to one-story buildings. The group's findings document that 18 to 30% of the total lifecycle energy can be attributed to materials and construction processes, as opposed to the 0.4 to 11% found in other studies.

### Land Cover, Climate, and the Summer Surface Energy Balance in Phoenix and Portland

Ariane Middel, Anthony Brazel, Patricia Gober, and Soe Myint used a Local Scale Urban Meteorological Parameterization Scheme (LUMPS) to analyze the relative attributions of local weather extremes and land-cover variations on the urban energy balance (Middel et al. 2011, *International Journal of Climatology*). Results show that incoming solar radiation is an important driver of the surface energy balance in LUMPS and should be considered in the generation of climate scenarios. Results suggest that land-cover manipulation could offset influences of weather extremes on evapotranspiration in Portland to a certain degree, but not in Phoenix. These findings suggest the importance of the spatial and climatic context in the urban design process to mitigate the effects of urbanization.

### Residential Water Demand

Economist Kerry Smith's research on structural demand models for residential water demand (Strong and Smith 2010) has been extended in two ways. First, he has developed a quasi-experimental framework for exploiting periodic changes in water rates to estimate price elasticities that vary with size of user and weather conditions. Findings confirm that elasticity varies with scale (amount of water consumption) and weather conditions (both precipitation and temperature) when estimating demand and overall

seasonal drought conditions. Second, postdoc Min Qiang (Kent) Zhao and Smith have developed a propensity score matching estimator to link residential properties based on the structural and land attributes of the homes. This process allows residential water demand to be compared controlling for water-using appliances and proxy measures for outdoor uses in Phoenix and Tucson. This method matches comparable homes, controls for differences in weather conditions, and evaluates the effects of the overall price schedule on water demand. The results indicate the Tucson schedule, after controlling for factors influencing indoor/outdoor uses and differences in weather conditions, leads to a significantly lower level of water consumption.

Research on housing prices in Maricopa County by Klaiber and Smith has established several findings related to water policy. They estimated the effects of mesic (wet) versus xeric (dry) landscapes at the subdivision level on home sales prices from the 1990s through 2006. After controlling for structural attributes, distance from the central business district and other amenities, they find a robust and significant premium for mesic landscapes and discounted prices for xeric.

In a subsequent analysis, Klaiber and Smith used the same data with PRISM temperature data to investigate the heat-island effect. Using an extension of the Abbott-Klaiber (2010) adaptation of random effects modeling structure, Klaiber and Smith found that a significant number of homeowners in Maricopa County are willing to pay ~3% premium for homes with one degree lower nighttime temperatures. This would be about \$50 per month. It is larger than estimates developed using stated preference methods with the Phoenix Area Social Survey in 2006.

### **Social Symbolism of Landscape Preference**

Two studies of the social symbolism of landscaping preferences showed consensus among participants that a desert landscape conveys a less attractive, lower-status, family-unfriendly image. This effect was strong and occurred in both experiments. Respondents perceived that environmentalism, money savings, and ease of maintenance motivated the choice of desert landscaping whereas grass landscaping reflected a desire to interact with one's neighbors and to raise a family. Results of the first study were presented at the Association for Psychological Science meeting in Washington, DC, in May 2011.

### **Social and Cultural Bases of Ecological Perspectives**

In a series of papers dealing with social and cultural bases of ecological perspectives, Kelli Larson, Dave White, and colleagues developed a theoretical model that includes: (1) *affective* concern about the risks of water scarcity; (2) *cognitive* perceptions about the causes of resource shortages; and (3) *conative* support for alternative policies. Findings showed that women expressed significantly greater emotional concern about water scarcity than did men (Larson et al. 2011a, *Environment and Behavior*) and that ethnicity and ecological worldviews significantly influence affective, cognitive, and conative judgments about water issues in metro Phoenix (Larson et al. 2011b, *Human Ecology Review*).

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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 sixth annual Advanced Water Educator Workshop on June 28–29, 2011. The workshop focused on public perception of water issues covering four main topics: 1) psychological underpinnings of (un)sustainable behaviors; 2) gauging public perception; 3) consumer responsibility; and 4) cross-cultural perspectives on water quality and equity. 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 Community of Undergraduate Research Scholars brings students into cross-disciplinary dialogues to build their skills toward interdisciplinary thinking and communication. We accomplish this goal through two semesters of a weekly seminar class and activities that build their research skills.

New this year, Katja Brundiers, DCDC Community-University Liaison, Margaret Nelson (Co-PI and Vice Dean of Barrett, the Honors College at ASU), and Amy Lively, Internship Coordinator from ASU's School of Sustainability, have developed and implemented the first "Internship for Science-Practice Integration" program (ISPI). The ISPI program bridges the University with water-management stakeholders; it places 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 first year of ISPI program included six partners: Arizona Department of Environmental Quality, Arizona Cooperative Extension Center, City of Mesa, City of Phoenix, Salt River Project, and The Nature Conservancy.

#### Graduate Education

Since the inception of DCDC II, we have supported 10 graduate students from: School of Sustainability (4), School of Geographical Sciences and Urban Planning (2), School of Sustainable Engineering and the Built Environment (1), School of Human Evolution and Social Change (1), Department of Psychology (1), and School of Public Affairs (1). During DCDC I, we supported 87 students from a broad reach of disciplines.

We required graduate 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 2011 AAAS Annual Meeting in Washington, DC. The session included participation from graduate students from the Center for Research on Environmental Decisions, the DMUU project at Columbia University.



## **Postdoctoral Fellowships**

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

Darren Ruddell received his PhD from the School of Geographical Sciences and Urban Planning and has been 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 recently accepted a position as Lecturer with the Spatial Sciences Institute at the University of Southern California.

Ariane Middel received her PhD from the University of Kaiserslautern, Germany. She collaborated with the climate group on research aimed at understanding the functional relationships between water data and land-cover thermal characteristics. This understanding facilitates the targeting of more effective strategies for mitigating the urban heat island.

## 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. Briefings in 2010–11 included:

**October 6, 2010:** *Public Awareness and Knowledge Regarding Water Issues*. Panelists: Donna Di Francesco, Conservation Specialist, Environmental & Sustainability, Water – Use it Wisely Program, City of Mesa; Shaun McKinnon, Journalist, *The Arizona Republic*; Amber Wutich, Assistant Professor, ASU’s School of Human Evolution and Social Change; Bethany Cutts, Postdoc, Environmental Science & Policy, UC Davis (facilitator). This panel provided an overview on outreach and educational activities that contribute to demand-side management.

**December 1, 2010:** *Covering Your Bets: Water Management in an Age of Uncertainty*. This University-wide keynote lecture was delivered by Patricia Mulroy, General Manager, Southern Nevada Water Authority, to an audience of 200. Following this public speech was a high-level, invitation-only workshop with DCDC scientists and water-management partners. Workshop participants shared best-management practices and identified solutions-focused research needs.

**February 2, 2011:** *Water/Energy Nexus: Innovative Industry Collaborations*. Panelists: Karen Collins, Water Sustainability Analyst, Water Business Development, Salt River Project; Henry Day, Environmental Department Leader at Arizona Public Service - Palo Verde; Mike Pasqualetti, Professor, ASU’s School of Geographic Sciences and Urban Planning; and Ray Quay, Research Professional, DCDC (facilitator). The panelists discussed increasing water and energy efficiency, creating savings, and enhancing environmental protection, and balancing competing future needs.

**February 9, 2011:** *Groundwater as a Strategic Resource: Managing Overdraft or Planned Depletion?* This presentation featured Christopher Scott, School of Geography and Regional Development and Udall Center for Studies in Public Policy at UA. He examined three interlinked drivers of aquifer depletion: 1) climate change and variability that influence groundwater recharge and water demand; 2) electrical energy supply for pumping; and 3) growing populations’ need to secure water supplies of adequate quantity and quality.

**March 23, 2011:** *Synergies of Water Planning in Urban and Rural Ecosystems*. Panelists: Aaron Citron, Project Manager, AZ Land and Water Trust; Dan Childers, Professor, School of Sustainability, Director Central Arizona–Phoenix Long-Term Ecological Research; Dave White, Associate Professor, School of Community Resources and Development, Associate Director, DCDC; and Robert Marshall, Director, Center for Science & Public Policy, The Nature Conservancy (facilitator). Panelists discussed integrated approaches for water-management strategies that conceptualize “water supply for urban and rural ecosystems.”

**April 6, 2011:** *American Indian Water Rights Settlements in Arizona: Lessons for Resolving Water Conflicts*. Panelists: Thomas Buschatzke, Water Resources Management Advisor, City of Phoenix; David Roberts,

Manager, Water Resource Management, Salt River Project; and Daniel Killoren and Paul Hirt, ASU's School of Historical, Philosophical, and Religious Studies, ASU (facilitators). The panelists shared first-hand experiences from their involvement in the settlement process and discussed the implications for future water planning.

Moving forward, we plan to tie Water/Climate Briefings to themes for the entire academic year and highlight the current DCDC research portfolio. Each briefing will be tailored for specific audiences and purposes. An annual Keynote will be delivered by a renowned scientist or policy professional to present a "grand challenge" for the science-policy community to catalyze deliberation. The Keynote will be followed up in subsequent Water/Climate Briefings to explore basic science questions and policy implications of responding to the grand challenge.

### **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 Change Alliance (ACCA), supported jointly by DCDC at ASU and CLIMAS at UA.

The inaugural ACCA 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 ACCA 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 a meeting is planned for August 2011 with a FEMSA delegation including the corporate CEO to discuss extensions of the current project.

### **WaterSim Exhibit at the ASU's Museum of Anthropology**

The director and curator of exhibitions at ASU's Museum of Anthropology featured a touch-screen version of WaterSim as part of the exhibit "Choosing a Future with Water: Lessons from the Hohokam" that was launched in association with the March 2011 Resilience Conference. The exhibit advanced visitor understanding of long-term climate adaptation (and maladaptation) in Greater Phoenix.

### **Watering the Sun Corridor Report**

*Watering the Sun Corridor* was intended to raise DCDC's formal participation in local policy analysis and discussion. It was produced by DCDC I Co-PI Grady Gammage, Jr. in collaboration with the Morrison Institute for Public Policy. In addition to DCDC, other funders were the Sonoran Institute, Lincoln Institute of Land Policy, AMEC Engineering, and the Salt River Project. The report examines the future growth of Arizona's urban corridor from Phoenix and Tucson and analyzes current and potential water resources to support that growth. Official release date is August 15, 2011.

### **Annual COURS Poster Symposium**

May 4, 2011: The COURS Annual Poster Symposium is a programmatic highlight of each spring semester. Twenty-nine students presented the results of their research projects conducted as part of the Community of Undergraduate Research Scholars, the Internship for Science-Practice Integration, and the Community of Graduate Scholars.

## V. Contributions

### Contributions within the Discipline

#### Geographical Sciences

A recently published report from the National Research Council (*Understanding the Changing Planet: Strategic Directions for the Geographical Sciences*) noted that a major theme in the geographical sciences is “how to understand and respond to environmental change and the human role in these changes.” DCDC’s research, student training, and outreach are at the forefront of this theme, as DCDC: 1) links traditional water science practiced by climatologists and hydrologists with social scientists concerned with human activities and behaviors, (2) focuses on urban climate adaptation which is, by definition, a response to environmental change, (3) introduces DMUU approaches to the field of geography, and (4) demonstrates the value of participatory processes for environmental decision making and as a research topic. DCDC publications are cited in the report as examples of the way urban land use/cover affect human outcomes (Guhathakurta and Gober 2007) and the value of science-policy engagement (Gober et al. 2010; White et al. 2008).

#### Systems Dynamics Modeling

WaterSim is a hierarchical model that represents supply from surface and groundwater sources and demand from residential, commercial, and agricultural user sectors, incorporating the rules that govern reservoirs, aquifer use, and land-use change. The development of WaterSim is described in recent articles by Gober et al. (2011) in *Environment and Planning B* and by Sampson et al. (2011) in *Journal of Environmental Management*. The current version of the model, WaterSim 4.0, is comprised of: 1) a Microsoft C# interface; 2) a C# library module; and 3) a simulation model (FORTRAN) that houses the rules and algorithms to model water supply and demand, all at the water provider-level. WaterSim 4.0 runs on an annual time-step, but monthly estimates can be generated for many of the output variables. WaterSim 4.0 produces water supply and use patterns for 33 Phoenix metro-area water providers. WaterSim 4.0 is a spatially explicit model that allows researchers to examine water sustainability and urban climate adaptation between communities and across multiple geographic scales by assessing exposure to risk, sensitivity, and adaptive capacity. The model also serves as a type of boundary object (White et al. 2010) to link science and policy communities.

#### Science-Policy Interactions and Boundary Organizations Research

In recent years, DCDC researchers have made significant contributions to the conceptual understanding of the linkages between science and policy through empirical-studies boundary work (Wutich et al. 2010), boundary organizations (White et al. 2008), and boundary objects (White et al. 2010). Recent efforts have enhanced boundary-organization theory by linking it with its concepts from the participatory geographic information systems framework (Cutts et al. 2011, at *Environmental Science and Policy*). Dave White presented a paper to the 17th International Symposium on Society and Resource Management summarizing the state of knowledge and outlining an agenda to enhance theoretical sophistication and methodological rigor of science-policy research.

#### Environmental Economics

Led by economist Kerry Smith, DCDC has advanced basic understanding of environmental economics, developing unique methods to extract the first “pure” price-schedule assessment to better understand

residential water demand. This research is made possible through cooperative data-sharing agreements with municipal water departments, illustrating our approach to use-inspired research that not only advances basic social science but contributes to policy solutions for pressing sustainability challenges. In 2010, Smith was named Regents' Professor, the highest faculty honor awarded at ASU, conferred on faculty members who have made pioneering contributions in their areas of expertise, achieved a sustained distinction in their field, and enjoy national and international recognition for their accomplishments.

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## Contributions to Other Disciplines

As an interdisciplinary project, DCDC II links decision analysis, economics, psychology, geography and 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 from geography, hydrology, climatology,

decision analysis, and policy analysis to address inherently interdisciplinary questions about water-resource sustainability and urban-climate adaptation.

In another example of interdisciplinary contributions, DCDC researchers, led by sustainability scientist Arnim Wiek, are using participatory and integrated methods that combine WaterSim modeling with scenario analysis/construction, visioning techniques, and sustainability assessment. These methods integrate novel concepts of anticipatory governance with sustainability research and problem-solving to create distinct scenarios of water futures in central Arizona. This work provides DCDC researchers with distinct scenarios for subsequent analysis and another point of contact for scientists and policy makers.

### **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 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. For instance, DCDC-inspired courses in ASU's School of Geographic Sciences and Urban Planning include "Water Resource Geography and Policy" by Kelli Larson and "Geography of Phoenix" by Pat Gober. In ASU's School of Sustainability, Pat Gober and Rimjhim Aggarwal taught "Water Sustainability," and Aggarwal and Hallie Eakin co-taught "Adaptation, Resilience and Transformation."

### **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.

## VI. Partner Organizations

*Arizona Department of Environmental Quality:* A collaborative internship program between DCDC and the Arizona Department of Environmental Quality (ADEQ) provided Max Krzyzewski, School of Sustainability undergraduate student, an opportunity to identify inconsistencies and vacancies in ADEQ's data reporting process regarding reclaimed water use in AZ.

*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. Tom Buschatzke, Assistant Director of the Water Management Division at ADWR serves on DCDC's External Advisory Committee.

*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 Change Alliance (ACCA).

*City of Mesa:* A collaborative internship program between DCDC and the City of Mesa, Arizona included two School of Sustainability undergraduate students, Emily Allen and Joshua Randall, who focused on: (1) geographical information systems analysis of the East Salt River sub-basin regarding opportunities for recharge that provided detailed mapping opportunities, (2) detailed literary review and summary of the various hydrological and scientific reports within and around the East Salt River sub-basin and (3) collaborative process and opportunities between stakeholders within the East Salt River sub-basin and utilizing the possibility of using the East Valley Water Forum as a potential tool for collaboration. 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. In addition, a collaborative internship program between DCDC and the City of Phoenix provided Courtney Lewis, School of Sustainability undergraduate, an opportunity to analyze supply and demand of the Seven Basin States and identifying similarities and differences of methodologies and recommendations.

*City of Tempe:* The City of Tempe supplies household water use data for DCDC analysis.

*East Valley Partnership:* The Superstition Vistas Area Project, administered by the East Valley Partnership, is one of the largest expanses of property in the U.S. The land is owned by a single owner, the Arizona Land Trust, and covers 275 square miles of undeveloped land on the eastern edge of the metropolitan Phoenix area. This collaboration will produce scenarios of water, energy, transportation, and economic development policy choices for the development of the Superstition Vistas.

*East Valley Water Forum:* EVWF consists of tribal, public, and private water agencies in the East Salt River Valley. They are sharing their groundwater-modeling output with the Decision Science team so it can be integrated with agent-based models to produce visualization for Decision Theater (DT).



*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 will serve 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 gave presentations and sparked discussion at two monthly Water/Climate Briefings. In addition, a collaborative internship program between DCDC and SRP provided Alexandria Detrio, School of Sustainability undergraduate, an opportunity to identify potential future impacts of the Central Arizona Groundwater Replenishment District for SRP and selected customer groups.

*The Nature Conservancy:* A collaborative internship program between DCDC and The Nature Conservancy provided Cherish Connolly, School of Sustainability undergraduate, an opportunity to identify best practices of communities, which reduced contaminants in reused water that is being discharged into rivers.

*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 Change Alliance (ACCA). 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 Jeffrey Jennings, School of Sustainability undergraduate, an opportunity to work with high school students to identify implementation of efficient water management practices and working at water festivals to convey key information on water in Arizona.

*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 sixth Advanced Water Educator's Workshop, with the theme of Water and Public Perception, was held in June 2011.

### **Other Collaborators**

*American Indian Policy Center (ASU):* Representatives were participants in the collaborative workshop series in 2009–2010 dealing with climatic uncertainty and climate modeling for scientists and water stakeholders and attended DCDC Water Climate Briefings.

*Arizona Town Hall:* DCDC and Arizona Town Hall collaborated on the 91<sup>st</sup> Arizona Town Hall, "Land Use Challenges and Choices for the 21st Century." Arizona Town Hall is a private, nonprofit civic organization created in 1962 to increase citizens' understanding of the many facets of the state's economic, cultural and social life. Twice each year, the Arizona Town Hall brings together a wide cross-section of approximately 150 prominent Arizona citizens to consider and discuss a topic of major concern to Arizona's future. Participants at the 91st Town Hall reached consensus that current systems of planning and land-use regulation are inadequate to address Arizona's rapid growth. Collaborative planning among all levels of government--local, regional, state, tribal and federal--is crucial, particularly in managing infrastructure, transportation, education, environmental concerns, energy, and natural and water resources. The background report and consensus statements are available at <http://www.aztownhall.org/reports/91.asp>.

*Arizona Water Institute:* Arizona's three state universities - Arizona State University, Northern Arizona University, and The University of Arizona formed a partnership to position the state as a world leader in water resources management and technology. The primary driver for this initiative was sustaining Arizona's water supply, which is crucial to the state's economy, the health and well-being of its residents, and its natural environment. The Arizona Water Institute (AWI) combined the expertise of Arizona's water managers with the resources of the three universities to support water resources management and technology development in real-world applications. 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. Funding for the Arizona Water Institute was eliminated by the Arizona Legislature and the institute closed in 2009.

*ASU President's Office:* DCDC and other university constituents, under the guidance of the Office of the University President, partner 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 sixth 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.

*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.

*University of California, Irvine; Paul Merage School of Business:* Decision research at DCDC includes a partnership between L. Robin Keller (University of California, Irvine, Paul Merage School of Business) and ASU faculty. The multi-objective decision analysis work performed in Year 1 of DCDC I was the foundation for developing decision-focused evaluation metrics for use with the models that have been developed within DCDC.

## VII. DCDC Participants

### ***Principal Investigators/Project Directors***

Patricia Gober, School of Geographical Sciences and Urban Planning  
Charles L. Redman, School of Sustainability

### ***Co-Principal Investigators***

Craig Kirkwood, W.P Carey School of Business, Supply Chain Management  
Margaret Nelson, Barrett, The Honors College  
Dave White, School of Community Resources and Development

### ***External Advisory Committee***

Michael Lacey, Arizona Department of Water Resources  
Susan Cutter, University of South Carolina,  
Lisa Dilling, University of Colorado-Boulder  
William Easterling, The Pennsylvania State University  
Linda Mearns, National Center for Atmospheric Research  
Ed Miles, University of Washington  
Kathryn Sorensen, City of Mesa  
Graham Symmonds, Global Water

### ***Senior Personnel: Manager***

Bill Edwards, Executive Administrator  
Liz Marquez, Program Manager

### ***Senior Personnel: Core Scientists***

Luc Anselin, School of Geographical Sciences and Urban Planning  
Robert Balling, School of Geographical Sciences and Urban Planning  
George Basile, School of Sustainability/Decision Theater  
Anthony Brazel, School of Geographical Sciences and Urban Planning  
Hallie Eakin, School of Sustainability  
Andrew Ellis, School of Geographical Sciences and Urban Planning  
Monica Elser, Global Institute of Sustainability  
Grady Gammage, Jr., Morrison Institute for Public Policy  
Subhrajit Guhathakurta, School of Geographical Sciences and Urban Planning  
Douglas Kenrick, Department of Psychology  
Tim Lant, Decision Theater  
Kelli Larson, School of Geographical Sciences and Urban Planning/School of Sustainability  
Susan Ledlow, School of Sustainability  
Alan Murray, School of Geographical Sciences and Urban Planning  
Steven Neuberg, Department of Psychology  
Colin Polsky, Graduate School of Geography, Clark University  
Ray Quay, Decision Center for a Desert City  
Kerry Smith, W.P Carey School of Business; Economics  
Billie Lee Turner II, School of Geographical Sciences and Urban Planning  
Elizabeth Wentz, School of Geographical Sciences and Urban Planning  
Paul Westerhoff, School of Sustainable Engineering and the Built Environment  
Arnim Wiek, School of Sustainability

Amber Wutich, School of Human Evolution and Social Change  
Abigail York, School of Human Evolution and Social Change

***Postdoctoral Research Associates***

Ariane Middel, Computer Science, University of Kaiserslautern, Germany  
Darren Ruddell, School of Geographical Sciences and Urban Planning (ASU)

***Other Collaborators***

Rimjhim Aggarwal, School of Sustainability  
C. Athena Aktipis, Department of Ecology and Evolutionary Biology, University of Arizona  
Bob Bolin, School of Human Evolution and Social Change  
James Buizer, Office of Sustainability Initiatives  
Netra Chhetri, Consortium for Science, Policy & Outcomes  
Beatrice Crona, Stockholm Resilience Centre  
Lee Cronk, Department of Anthropology, Rutgers University  
Michael Crow, President, Arizona State University  
Gregg Garfin, Institute of the Environment, University of Arizona  
Susanne Grossman-Clarke, Global Institute of Sustainability  
Sharon Harlan, School of Human Evolution and Social Change  
Paul Hirt, School of Historical, Philosophical, and Religious Studies  
Jim Holway, Sonoran Institute & Lincoln Institute of Land Policy  
Kathy Jacobs, Office of Science and Technology Policy, The White House  
Erik Johnston, School of Public Affairs  
L. Robin Keller, University of California, Irvine, The Paul Merage School of Business  
Yu-shim Kim, School of Public Affairs  
Anne Kinzig, School of Life Sciences  
Rob Melnick, Global Institute of Sustainability  
Soe Myint, School of Geographical Sciences and Urban Planning  
Robert Pahle, Decision Theater  
John Parker, National Center for Ecological Analysis and Synthesis (NCEAS), UCSB  
Anne Reichman, Sustainable Cities Network  
Sergio Rey, School of Geographical Sciences and Urban Planning  
Ed Sadalla, Department of Psychology  
Daniel Sarewitz, Consortium for Science, Policy & Outcomes  
Kerry Schwartz, Arizona Project WET, Water Resources Research Center, University of Arizona  
Nancy Selover, School of Geographical Sciences and Urban Planning  
Ajay Vinze, W.P Carey School of Business, Information Systems  
Enrique Vivoni, School of Earth and Space Exploration

***Research Technical Personnel***

Alex Garcia, UTO  
Dustin Hampton, Decision Theater  
Ryan Raub, Global Institute of Sustainability  
David Sampson, Decision Center for a Desert City  
Philip Tarrant, Global Institute of Sustainability  
Barbara Trapido-Lurie, School of Geographical Sciences and Urban Planning  
Mary Whelan, Informatics and Cyberinfrastructure Services, ASU Libraries

**Public Outreach Personnel**

Katja Brundiers, Decision Center for a Desert City, School of Sustainability

**Research Support Personnel**

Nikol Grant, Global Institute of Sustainability

Amanda Jung, Global Institute of Sustainability

Julia Koschinsky, School of Geographical Sciences and Urban Planning

Lauren Kuby, Global Institute of Sustainability

Kathy Kyle, Global Institute of Sustainability

Margaret Levit, Global Institute of Sustainability

Estella O'Hanlon, Decision Center for a Desert City

Susan Siddall, Global Institute of Sustainability

Sally Wittlinger, Decision Center for a Desert City

**Graduate Research Associate**

Omaya Ahmad, School of Sustainability

Julia Bausch, School of Sustainability

Geetali Dudhbhate, School of Computing, Informatics, and Decision Systems Engineering

Stephane Frijia, School of Geographical Sciences and Urban Planning

Gretchen Hawkins, School of Sustainable Engineering and the Built Environment

Won Kyung Kim, School of Geographical Sciences and Urban Planning

Christy Mercer, School of Sustainability

Rebecca Neel, Department of Psychology

Andrea Torvinen, School of Human Evolution and Social Change

Lauren Withycombe, School of Sustainability

**Other Graduate Students**

Jessie Snook, W. P. Carey School of Business, Economics

Rashmi Krishnamurthy, School of Public Affairs

**Community of Undergraduate Research Scholars (COURS)**

Danielle Shaffer, School of Sustainability

James Taysom, School of Geographical Sciences and Urban Planning

Courtney Snyder, School of Human Evolution and Social Change

Claire Yee, Department of Psychology

**Other Undergraduate Students**

Annissa Olsen, School of Music

**Organizational Partners and Other Collaborators**

American Indian Policy Center (ASU)

Arizona Department of Environmental Quality

Arizona Department of Water Resources

Arizona Town Hall

Arizona Water Institute

ASU President's Office

Bureau of Reclamation

Center for Science, Policy and Outcomes (ASU)

Central Arizona–Phoenix Long Term Ecological Project [CAP LTER] (ASU)  
City of Mesa  
City of Phoenix  
City of Tempe  
Decision Theater (ASU)  
East Valley Partnership  
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)  
Salt River Project  
Sustainable Cities Network (ASU)  
The Nature Conservancy  
University of Arizona, CLIMAS, SAHRA, WRRRC  
University of Arizona, The University of Arizona Cooperative Extension, Maricopa County  
University of Arizona, Arizona Project Wet  
University of California, Irvine, The Paul Merage School of Business