



DCDC 2009-2010  
Annual Progress Report

Decision Center for a Desert City  
SES-0345945

*Compiled by*  
Patricia Gober  
Charles Redman  
Bill Edwards  
Sally Wittlinger  
Nick Gerbis  
Annissa Olsen

Submitted to the  
National Science Foundation  
Via Fastlane  
August 31, 2010

**DCDC 2009-2010**  
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**Decision Center for a  
Desert City**

Principal Investigators/Directors:

Patricia Gober  
Charles Redman

Executive Committee:

Patricia Gober  
Charles Redman  
Robert Balling  
Bob Bolin  
William Edwards  
Monica Elser  
Grady Gammage  
Craig Kirkwood  
Margaret Nelson  
Kerry Smith  
Elizabeth Wentz  
Dave White

Staff:

Katja Brundiers  
Bill Edwards  
Arianna Fox  
Nick Gerbis  
Estella O'Hanlon  
Annissa Olsen  
David Sampson  
Michael Tschudi  
Sally Wittlinger

Teams:

Climate Change and Urban Heat Island  
Education and Outreach  
Science and Policy  
Modeling and Evaluation  
Vulnerability  
Water Demand and Decision Making



## I. Introduction to DCDC

In 2004, the National Science Foundation (NSF) established the Decision Center for a Desert City (DCDC) at ASU to advance the scientific understanding of water decision making in the face of climate uncertainty and other environmental risks, using Phoenix as an experimental research and outreach laboratory. We structured DCDC as a boundary organization at the interface of science and policy to play a translational role, converting the products of climate science into tools for better decision making under uncertainty. To date, DCDC efforts have resulted in: (1) a critical mass of basic research, including over 200 articles, books, and book chapters, 60 of them appearing in 2009 and 2010; (2) WaterSim, a dynamic water-simulation model that serves as an important basis for community engagement, a point of articulation for interdisciplinary research, and an experimental setting to study decision making under uncertainty; (3) a network of relationships with regional water managers and resource decision makers; and (4) a significant and growing set of comparative and collaborative partnerships linking our Phoenix case study to climate adaptation efforts nationally and globally.

As the mission of DCDC evolved to focus on urban climate adaptation, our vision of knowledge production, science-policy engagement, and community outreach matured. We have conceptualized research, learning, and outreach as synergistic activities that feed upon and reinforce one another. Our priority has been on discoveries at the intersection of basic and applied research in what has come to be called Pasteur's Quadrant. We have sought to maintain a balance between new data collection and analysis and synthetic activities that integrate existing data, models, and knowledge. Attention increasingly has been focused on feedbacks and nonlinearities that produce unintended consequences and reveal hidden vulnerabilities in complex urban resource systems, as for example, when cities seek to solve their warming problems with increased water use for vegetated landscaping (Gober et al. 2010a).

Climate research and policy making over the past 20 years have revealed that fundamental disagreement about the underlying natural and social forces that shape the future and uncertainties associated with climate modeling will *increase rather than resolve* over time. As we have better understood this reality, we have built capacity to address multiple potential futures through scenarios, simulation modeling, and the principles of decision making under uncertainty.

### Research Activities

#### Simulation Modeling: WaterSim

We have built and implemented WaterSim, a simulation model, to investigate how alternative climate conditions, rates of population growth, and policy choices interact to affect future water supply and demand conditions in Phoenix. 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 Gober et al. (in press at *Environment and Planning B*). We have always considered that WaterSim will evolve as our understanding increases, and thus, the focus of the modeling effort has been responsive to feedback from stakeholders and the research needs of DCDC participants.

During the past year, the current version, WaterSim 4.0, has been developed to investigate inputs and outputs at the water-provider level and restructured as a multi-language library to make future modifications more straightforward to implement. The scaling to the water-provider level was implemented in response to stakeholder inputs that water decision making in the Phoenix area is primarily local in scale. WaterSim 4.0 is comprised of: (1) a Microsoft C# interface; (2) a C# library module; and (3) a simulation model written in FORTRAN that houses the rules and algorithms to estimate surface water supplies (and the allocation thereof), groundwater designations, and therefore estimates of water supply, water demand, and groundwater pumping.

The model currently runs simulation using an annual time-step, but monthly estimates can be generated for many of the principal output variables. WaterSim 4.0 produces water supply and use patterns for 33 Phoenix Metropolitan Area water providers. Other improvements in version 4.0 include: (1) expansion of the Salt-Verde reservoir operations submodel to include a more robust estimate of reservoir release based on provider designations, and inclusion of new conservation space allocations; (2) the addition of a city infrastructure module that tracks water movement among the various city “elements” such as surface water treatment plants, water supplies, residential and commercial water use (indoor and outdoor), and waste water treatment plants, to name a few; (3) new modules to estimate the total dissolved solids (TDS) of the water resources used by water providers; and (4) an approach to estimate the electricity used in moving the Central Arizona Project (CAP) water along the CAP aqueduct to Phoenix.

## **Decision Science and Policy**

The goal of DCDC’s decision-science program is to investigate and develop decision analytic frameworks for complex problem formulation for water resource management. The decision science team, led by Craig Kirkwood from the W. P. Carey School of Business and Robin Keller from the University of California-Irvine’s Merage School of Business, has conducted basic research on decision making as well as incorporated integrated methods of prescriptive decision analysis within DCDC’s larger research program. A recent article in *Systems Engineering* presents an approach for efficiently assessing stakeholder perceptions of evaluation concerns in the first stage of problem structuring for decisions involving complex systems (Keller et al. 2010). This research used output from a Web survey to assess the appropriateness of a set of evaluation concerns for water policy including an analysis of variations among stakeholder group priorities. While the specific outputs from this study are directed at Central Arizona water resources decision making, the basic approach can be used in other policy settings.

During the past year, Keller, Kirkwood, and former UC-Irvine postdoc Jay Simon completed and submitted for publication research to develop and implement new decision-analysis methods for problems with geographically varying outcomes (Simon et al. in review at *Operations Research*). This research has developed new quantitative results and applied these results to illustrative applications in water resource decision making and other policy-oriented settings. In addition to this decision research, efforts during the past year to integrate decision analysis concepts into climate and WaterSim research have resulted in publications that explicitly address climate uncertainties through scenarios and multiple evaluation attributes. These publications include Gober et al.'s (2010b) presentation of a new paradigm for long-term water planning and Gober and Kirkwood's (2010, in press in the *Proceedings of the National Academy of Sciences*) study of water sustainability in the Colorado River Basin.

### **Human-Climate Interactions in the City**

Building on previous urban heat island research and a growing interest in the interactions between urban energy and water, DCDC researchers broke new ground in their understanding of urban resource systems and climate impacts on them. Central to this research is how to redesign cities to accommodate climate impacts. An early focus on water expanded to the energy and carbon impacts of various urban designs. DCDC-funded planner Subhrajit Guhathakurta, engineer Eric Williams, and graduate student Stephane Frijia quantified the tradeoffs between high density, high-rise buildings that save land and energy for transportation and low-density, low-rise buildings that have less embedded energy and more benign direct climatic impacts but engender more automobile travel. Collaborating with DCDC postdoctoral fellow Ariane Middel, they refined their ideas and methods for a successful proposal to the Civil Infrastructure Systems (CIS) Program at the NSF. The funded project aims to clarify how urban form, land-use patterns, and type of structures influence a city's energy needs and greenhouse gas emissions. The analysis will track the evolution of a network of energy use as an area develops and account for life cycle impacts in construction and manufacturing processes, end-of-life buildings, roads, and vehicles. This project illustrates DCDC's role as an incubator of interdisciplinary research about urban climate adaptation. It is focused on a critical tradeoff for decision making, links DCDC's longstanding interests in human-climate interactions to life cycle analysis, and leverages a relatively modest DCDC investment in exploratory research into a freestanding, long-term research initiative.

Geographers Patricia Gober, Anthony Brazel, and Kelli Larson and postdoc Ariane Middel continued the work on a collaborative project with Portland State University funded by NOAA. The project addresses tradeoffs and feedbacks inherent in water-conservation programs designed to curb outdoor water use. Managers seeking to reduce outdoor water use face a difficult choice because a watered landscape ameliorates temperature in many cities, particularly those with hot, dry climates. The Phoenix-Portland project uses a neighborhood-level, energy balance model, Local-scale Urban Meteorological Parameterization Scheme (LUMPS), to estimate latent heat (energy used to evaporate water) and derive nighttime and daytime cooling rates across almost 200 Census block groups in each of the two cities. Results pinpoint where and when outdoor water provides the most efficient urban cooling and estimates how much additional

water is needed to retain existing temperatures under climate-change scenarios. A workshop to share results with Portland water and land managers is planned for October 2010. Other LUMPS research projects are Gober et al.'s (2010a) study of the use of watered landscapes for urban heat island mitigation, Middel et al.'s paper (in review at the *Journal of Urban Technologies*) on land-cover modification scenarios, and Myint et al.'s study (in review at *Remote Sensing of Environment*) about remote sensing techniques for land-cover classification.

### **Governance and Cooperation as a Climate Adaptation Strategy**

Fragmented and outdated water governance is a significant barrier to climate adaptation in Phoenix and indeed across the West. Western water rights and the institutions that evolved to administer them grew out of the settlement patterns and climate conditions of the 19<sup>th</sup> and early 20<sup>th</sup> centuries. Many of these legal frameworks and water institutions are ill-equipped to manage water in an era of climate uncertainty and large-scale urbanization. The issue of how to foster more cooperative governance has motivated several recent DCDC research efforts.

Geographers Alan Murray, Patricia Gober, Sergio Rey, and Luc Anselin, modeler David Sampson, and graduate student Paul Padegimas developed a spatial-optimization model to support water-supply allocation between providers when some are in deficit while others are in surplus. The model uses output from WaterSim 4.0 at the provider level to examine the impacts of cooperation on deficit conditions for 33 providers under varying climate-change scenarios.

A second line of research about governance and cooperation involves psychologist and postdoc Athena Aktipis, sociologist Dave White, anthropologist Lee Cronk from Rutgers University, and anthropologist Amber Wutich. They approached the topic of regional cooperation from an interdisciplinary, crosscultural perspective. The research team drew inspiration from the Maasai, East African pastoralists who live in semi-arid and savannah regions subject to frequent, unpredictable, and lengthy droughts. Despite their challenging environment, the Massai have thrived for many generations, managing environmental risk with social institutions, particularly a sharing norm called osotua. Osotua relationships are imbued with respect, restraint, and a sense of responsibility. Osotua gifts are given in respect to requests that are based on real need and do not exceed the amount requested. The team developed a risk pooling game and investigated whether framing of resource transfers as osotua interactions affects the number of requests, size of requests, willingness to respond to requests and the overall viability of economic actors within the system. Team members organized a workshop on March 29, 2010 to integrate psychological and decision science perspectives into the experiment, and they will present a paper describing the conceptual framework and methodology for their approach at the Annual Meeting of the American Anthropological Association in November 2010.

## **Environmental Economics: Water Demand Research**

Economist Kerry Smith continues to lead an active research program centered on water-demand and the valuation of energy-water interactions. Smith organized a conference on April 19–20, 2010: Economic Evaluations of Water/Energy Interactions for Policy, co-sponsored by DCDC and CEESP (Center for Environmental Economics and Sustainability Policy). The objective was to evaluate the methods used in water management, including integrated river management, water and energy policies, and project evaluation. One original objective was to further the collaboration between the Elforsk Project, directed by Professors Bengt Kristrom and Per Olov Johansson at the University of Umea in Sweden, and ASU. Conference participants considered the economic evaluation of dam removal for large and small river systems, issues associated with planning an assessment for the Klamath River, methods used in evaluating benefit and costs for large-scale projects, and aspects of the interactions between water and energy policies.

Smith, working with Aaron Strong and Allen Klaiber (previous CEESP postdocs who are now faculty members at the University of Iowa and Penn State), along with an undergraduate research fellow Michael Kaminsky, developed a new method to estimate the price elasticity of demand for water by residential customers. The strategy exploits temporal variation in water rates due to cost changes over time that do not lead to changes in the design of the block rate structure. It does not require the detailed assumptions associated with a mixed discrete/continuous structural demand model such as presented in Olmstead et al. (2007). In addition, Klaiber and Smith completed preliminary hedonic property value models for Maricopa County that indicate subdivisions with significant mesic vegetation yield higher land values than xeric subdivisions. Research continues on this line of inquiry.

In an exceptionally valuable addition to the entire DCDC research program, Smith negotiated a data-sharing agreement with the water departments for the Cities of Glendale, Phoenix, and Tucson and is working on agreements with Scottsdale, Peoria, and Mesa. The goal is to assemble a dataset of water use from a variety of local water providers so that the effects of various price and non-price policies can be examined systematically.

## **Environmental Psychology: Why People Make the Decisions They Do**

A team of psychologists at ASU, including Susan Ledlow, Ed Sadalla, Douglas Kenrick, and Steven Neuberg, employ an evolutionary perspective to demonstrate that people make decisions according to a set of principles that were functional in the environment in which human cognition, emotion, and behavior evolved (Kenrick et al. 2009).

Evolutionary models suggest that people make unsustainable resource decisions because sustainability was not an issue in the environment to which humans adapted. Humans evolved with strong tendencies to focus on consequences that were immediate and certain. These ideas are applied to assumptions regarding economic rationality and utility optimization. While traditional economic models assume a rational decision

maker, “functional” approaches focus on evolved motives and the ecological context in which decisions are made.

In Year 6, they studied water use in the Phoenix area, where water is relatively inexpensive and conservation efforts rely more on persuasion than pricing to change water consumption behaviors. The research was designed to explore which water uses are regarded as necessities (that would be more difficult for people to curtail), and which as luxuries (that would be easier for people to curtail). To that end, they conducted an experiment on residential water consumption choices, using a “tradeoff” paradigm to explore the relative perceived values of different water choices. Research questions were: (1) What are the perceived necessities associated with water usage? (2) What aspects of water usage are regarded as relative luxuries? (3) Are there sex differences in perceived necessities and luxuries? (4) Does “environmental orientation” influence the perception of luxuries and necessities?

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

Science policy interactions and boundary organizations research examines the co-production of knowledge and policy for environmental decision making. Our approach draws upon theoretical perspectives from science and technology studies, political science, and sustainability science. Research activities explore three interconnected domains: *boundary work*, or the boundary-ordering devices, processes, and methods that link science and policy; *boundary organizations*, or institutional forms positioned in the overlapping space of scientific research and political decision making and public action; and *boundary objects*, hybrid constructs that integrate elements from scientific and political worlds to facilitate the negotiation and exchange of multiple types of knowledge and action.

In an article in *Science and Public Policy*, White et al. (2010) examined decision makers’ assessment of the credibility, salience, and legitimacy of WaterSim as a boundary object. Overall, decision makers were critical with respect to the credibility of the knowledge and informational assumptions imbedded in the boundary object; they were skeptical about the salience of the boundary object to their immediate decision making needs; and they were fairly evenly divided about the boundary object’s legitimacy. This research demonstrated divergent perceptions of credibility, salience, and legitimacy between different decision making groups as well the likelihood that tradeoffs exist between credibility, salience, and legitimacy in the design and functioning of boundary objects. The research facilitated the redesign of WaterSim to better address decision-maker needs. In a *Field Methods* article, Wutich et al. (2010) compared focus groups and individual responses for gathering information from decision makers on sensitive topics such as competence, risk, and gate-keeping. Decision makers were more reticent in focus groups than in individual responses for the discussion of very sensitive topics *unless* the group discussion provided an opportunity to make real progress on water policy problems. The study suggests that multi-method research may be appropriate for research on sensitive issues. In an article in *Environmental Science and Policy*, Larson et al. (2009) examined divergent perspectives on water resource sustainability among three groups at the science-policy nexus: the general public, policy experts and scientific



experts. This study identified differences in affective environmental concern, cognitive risk perceptions, and policy attitudes between the samples.

In 2009 and 2010, we have moved in new directions to: (1) more fully collaborate with stakeholders to co-produce knowledge, (2) expand the range of boundary processes studied to include scenario construction and sustainability assessments, (3) map diversity of stakeholder perceptions, (4) foster international collaborations, and (5) transfer lessons from DCDC to other boundary organizations. Boundary organizations researchers are studying the co-production of science and decision making through a series of collaborative scientist-manager workshops on scenario construction, uncertainty, climate modeling, and water management in Phoenix (described in Outreach Activities). Researchers Arnim Wiek and Kelli Larson examined Phoenix water management stakeholder perceptions and cross-perceptions, developed a conceptual model of the water governance structure, and created a set of sustainability principles and challenges for regional water governance. In another project, DCDC researchers Dave White and Katja Brundiers along with Decision Theater Director George Basile and Senior Manager Sandra Epstein developed an international collaboration with researchers from Tecnológico de Monterrey, Mexico. This collaborative project seeks to integrate watershed observation, hydrological flood modeling, and stakeholder engagement in the San Juan River Basin. The collaboration includes the Centro del Agua para America Latina y el Caribe (CALCA) FEMSA Foundation and the Inter-American Development Bank (IBD).

### **Vulnerability, Resilience, and Risk**

DCDC supported two lines of vulnerability research, one focused on the risk of water shortage and the second on vulnerability to heat stress, both extensions of the water/temperature mediation research described in the human-climate interaction section above. Sociologist Bob Bolin, DCDC postdoc Mohan Seetharam, and graduate student Brian Pompeii used a spatially explicit version of WaterSim to examine the security of local water systems under scenarios of climate change, population growth, and consumption patterns. Individual water providers differ in physical exposure to climate change based on their supply sources and in social vulnerability based on different consumption patterns and rates of growth. The root causes of vulnerability to water scarcity are found both in biophysical systems that determine surface and groundwater availability and in the social, economic, and historical aspects of institutions, people, and places. Thus, different adaptive abilities will be required to cope with declines in water availability and price increases under conditions of scarcity. Bolin et al. (2010) appears in the journal *Local Environment*.

A growing body of our research now focuses on vulnerability to heat stress in Phoenix. The expanding and intensifying urban heat island partly motivates this work, but takes on added significance as climate change threatens to increase temperatures further. DCDC postdoc Darren Ruddell, with geographer Anthony Brazel and students Desiree Hoffman and Omayya Ahmed, documented warming winters, hotter summers, and more intense heat-wave conditions between 1896 and 2009 (Ruddell et al. in review at *Climate Research*). Geographers Winston Chow, Wen-Ching Chuang, and Patricia Gober developed an index of vulnerability based on physical exposure to heat stress and

adaptive capacity of the population to cope and showed that the city's minority populations became more vulnerable to excessive heat between 1990 and 2000 (Chow et al. in review at *Professional Geographer*). Other recent studies have shown the highest risk of exposure to extreme heat is among elderly, minority, and low-income residents (Ruddell et al. 2010). Recent work also links increasing temperatures to perceptions of discomfort and health concerns (Ruddell et al. 2010; Ruddell in review at *Professional Geographer*; Ruddell et al. in review at *International Journal of Urban and Regional Research*).

### **Climate Modeling: Fine Tuning and Evaluation**

Climate scientists developed a deeper understanding of the physical processes that underlie drought conditions in the Southwest. Ellis et al. (2010) used a hydroclimatic index to create a historical record of drought coverage and analyzed the linear trend and relationships with key climate teleconnections. Svoma et al. (2010) linked with regional and hemispheric teleconnections with soil moisture trends in the Salt River watershed; Svoma and Balling (2010, in press) studied trends and patterns of precipitation variability; Balling and Goodrich (2010, in press) used advanced spatial analytical methods to characterize the recent extended drought in the Southwest and found a strong regional focus on the Colorado River Basin; and Balling and Goodrich (in review at *Theoretical and Applied Climatology*) studied the variation in precipitation intensity in the Southwest.

With the arrival at ASU of hydrologist Enrique Vivoni, we expanded DCDC's natural-science team to include a hydrological component. Vivoni is developing a distributed hydrological model of the Salt/Verde basins using a Triangulated Irregular Network (TIN)-based Real-time Integrated Basin Simulator (tRIBS). Results of this modeling effort will allow for a more spatially explicit assessment of the effects of climate change on these major water sources and integration of the effects of changing land-use conditions on upstream watersheds.

### **Environmental and Cultural History: The Context for Water Decision Making**

Historian Paul Hirt, geographer Kelli Larson, and graduate student Annie Gustafson have collaborated on a series of papers that define the historical and cultural context for water decision making and pinpoint the limits of current water institutions and governance systems for long-term water sustainability. Their most recent effort, published in the *Journal of Policy History*, explored the systematic weakening of provisions of Arizona's Groundwater Management Act, a much-heralded law to end groundwater overdraft by 2025 (Larson et al. 2010). Their historical analysis documented how the Arizona Department of Water Resources, the state legislature, and municipal water providers systematically eroded conservation standards and made inadequate progress toward reducing urban water demand. Their paper argued that the prevailing culture of consumption remains firmly in place in the form of high water-use rates, weakened regulations for reducing water demand, perpetual attention to the use (not conservation) of renewable water, and continued searches for additional water supplies to support growth and economic development. Their work is a reminder of deep-rooted

historical traditions and cultural barriers that confront decision makers who seek climate-adaptation strategies.

Also in Year 6, Hirt and graduate student, Dan Killoren, conducted a qualitative, longitudinal analysis of the process used to negotiate American Indian water rights. Research findings will contribute to a better understanding of the group dynamics, planning tools, and policy innovations that were critical to the negotiation and settlement process. Case studies and best practices drawn from the research will provide water managers, policy makers, and researchers with examples of successful conflict resolution mechanisms that can improve water resource management and policy in the future.

## **Education Activities**

We integrated DCDC research into learning materials and educational programs, engaging a variety of formal and informal education partners. Monica Elser, education team leader, worked with The University of Arizona's water-education programs (Project Wet, Cooperative Extension, and the Water Sustainability program) to deliver two-day Advanced Water Educator Workshops on the following topics: water management (2006), climate change and decision making (2007), water re-use (2008), the energy-water nexus (2009), and water and the future of agriculture (2010). Annual workshops attract about 25 participants from the region's water education community. DCDC has served as the host agency, and each year several DCDC researchers participate in the event.

We continued to work with area students on urban sustainability as related to the urban heat island (UHI), and in collaboration with the NSF-funded GK-12 Sustainable Schools program on water use and conservation in neighborhoods, schools, and homes. We also shared our research products by delivering learning modules directly to students. These modules were based on WaterSim on the Web, the Southwest Water Information Project Atlas, and an urban-sustainability unit that challenges students to design an urban environment to mitigate UHI effects. DCDC also developed and implemented sustainability-learning modules in area high schools and partnered with ASU's School of Sustainability and its Sustainable Schools Program. In February 2009, we developed and presented a user-friendly version of WaterSim at the NSF exhibit site at the AAAS meetings in Chicago. Over 100 visitors, including journalists, scientists, and leaders of other institutions, visited the booth to test-drive WaterSim and ask questions. Information based on research by DCDC scientists continues to be incorporated into activities/lessons that the GIOS education-outreach team implemented. In addition, a team of scientists led by Ajay Vinze from the College of Business is developing a sustainability game based on WaterSim for use in the ASU Executive MBA program.

Activities for graduate and undergraduate students are integrated into DCDC research projects, and DCDC faculty members mentored students. In addition, undergraduate students are required to participate in the Community of Undergraduate Research Scholars (COURS) seminar taught by Margaret Nelson, Associate Dean of the Barrett

Honors College. This seminar helps students integrate their disciplinary training with the knowledge and skills needed for interdisciplinary collaboration. More specifically, students are required to: (1) craft a clear statement of the broader impact of their work, drawing from the many disciplinary perspectives; (2) build skills that enable them to think across disciplines and produce solution-based research; (3) conduct an original research project in conjunction with a faculty or postdoctoral mentor; and (4) present research in a capstone poster session at the end of each academic year. These poster sessions are held in conjunction with DCDC water-climate briefings and draw between 50 and 75 ASU faculty and community partners.

Graduate students work as research assistants with faculty members and are required to participate in the interdisciplinary Community of Graduate Scholars (CGS) seminar also taught by Associate Dean Nelson and DCDC staff member Katja Brundiers. The goals of CGS are to enhance interdisciplinary research and build collaborative work skills. In 2010, the CGS group organized a panel discussion on bridging the boundary between art and science and attracted a new audience of humanists and artists to DCDC. The purpose of this panel discussion was to (1) demystify the art/science collaboration, (2) explore the potential benefits and challenges, and (3) leverage the perspectives of artists to water and climate issues locally.

To date, DCDC has employed seven postdocs: three geographers (Tim Collins, Mohan Seetharam, Darren Ruddell), a planner (Ariane Middel), an economist (H. Allen Klaiber), a civil engineer (Seung-Jae Lee), and a psychologist (Athena Aktipis). Our postdoc mentoring activities have focused on professional and career development and were designed to help fellows: (1) participate in community-based research about decision making under uncertainty; (2) deepen expertise in their discipline and in interdisciplinary collaborative research; (3) gain an understanding of the role of a tenure-track faculty member in an American university; (4) mentor undergraduate and graduate students; (5) build a network of collaborators and coauthors; (6) establish an independent research program; and (7) participate in the social and cultural life of a Research I university. Postdocs forged research programs with faculty members and students and produced a critical mass of journal articles related to DCDC's mission. Tim Collins is now an assistant professor at the University of Texas at El Paso. Mohan Seetharam works for the Conservation Governance and Policy Ashoka Trust for Research in Ecology and the Environment in India. H. Allen Klaiber is an assistant professor in the Department of Agricultural Economics and Rural Sociology at Penn State. Seung-Jae Lee is a postdoc at the National Renewable Energy Laboratory in Golden, Colorado.

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## II. Findings of Research Activities

### Exposure to WaterSim

WaterSim serves as a key point of engagement with regional stakeholders and the public-at-large and as an experimental object to study how scientific visualization affects perceptions and policy. In one recent study, Erik Johnston from the ASU School of Public Affairs and Ajay Vinze from the WP Carey School of Business asked: (1) whether and to what extent exposure to WaterSim increased knowledge about water supply and demand in metropolitan Phoenix and (2) how two different IT-facilitated interaction environments influenced collaborative behavior in resource-dilemma scenarios. Their findings revealed that, after interacting with WaterSim, participants' knowledge about water supply and demand increased from 3.35 to 4.63 on a scale of 5, a statistically significant learning outcome. Subjects who interacted with a shared display of WaterSim in the Decision Theater showed higher collective orientation than people interacting with a laptop version of the model. Results underscore the value of WaterSim in promoting learning, joint understanding, and collective action toward shared environmental challenges.

### Decision Making Under Uncertainty

Formal decision methods were used to structure the critical tradeoffs between short-term lifestyle and long-term sustainability in water resource decisions. In the March 2010 issue of the *Annals of the Association of American Geographers*, Gober et al. (2010b) proposed a new paradigm for water planning that would incorporate the deep uncertainties associated with climate change and future water-supply conditions in the Southwest. Climate-model results for the Salt/Verde Basins were downscaled and used as inputs to WaterSim, and a decision framework was used to organize results. Simulation experiments showed that: (1) current levels of consumption cannot be supported without unsustainable groundwater use under most climate model scenarios; (2) feasible reductions in consumption would allow the region to weather the most pessimistic of the climate projections; (3) delaying action reduces long-term sustainability of the groundwater resource under some climate scenarios; and (4) adaptive policy with appropriate monitoring to track groundwater provides sufficient warning that the need for use restrictions is approaching and avoids the need for drastic, ad hoc actions.

In a forthcoming special issue of the *Proceedings of the National Academy of Sciences* dealing with water sustainability in the Colorado River Basin, Gober and Kirkwood (2010, in press) investigated the impacts of climate-change conditions on both the Salt/Verde and Colorado River systems and clarified the risks associated with climate change and how well different management strategies would address these risks. Results show that policy action will be needed to attain water sustainability in 2030, even without reductions in river flows caused by climate change factored into the analysis. Most importantly, there is not a single most likely or optimal future for Phoenix under all potential scenarios, but rather a set of tradeoffs that decision makers must confront about how best to manage risk in the face of uncertainty about future conditions.

### Energy Implications of Urban Densities



Subhrajit Guhathakurta, Eric Williams, and Stephane Frijia quantified energy impacts of varying urban designs using data about the built environment, energy use, and transportation patterns. A preliminary study of 52 Census tracts in Phoenix showed that single-family homes represent 33% of livable space, but account for 55% of total electric power consumed while townhomes comprise 45% of livable space but account for only 18% of electrical power consumed.

### **Smart Design for Urban Climate Adaptation**

In an article in the *Journal of Planning Education and Research*, Guhathakurta and Gober (2010) used path analysis to examine interrelationships and feedbacks among residential land use, the urban heat island, and water use in Phoenix. They found that (1) impervious surfaces contributed to increased water use by exacerbating the urban heat island and (2) larger lots containing pools and mesic vegetation increased water demand by reducing diurnal temperature variation. They concluded that smart design of urban environments needs to move beyond simplistic water and vegetative solutions for mitigating uncomfortably hot temperatures to consider interactions among surface materials, land use, urban heat island, and water use.

### **Residential Water Demand**

Three important results emerged from Kerry Smith's team on the empirical analysis of the elasticity of water demand (Klaiber et al. in review at *Water Resources Research*; Klaiber et al. in review at *Economic Letters*; Smith, in review at the *Journal of Economic Analysis and Policy*). First, there are clear differences in price responsiveness by size of water user. Second, there are pronounced seasonal differences in price responsiveness. Finally, there is some evidence of differences in price responsiveness with the level of seasonal precipitation. Especially dry seasons (low precipitation) exhibit somewhat less price responsiveness. This research has led to three papers and multiple presentations at national and international meetings.

### **Water as a Luxury or Necessity**

The environmental psychology team conducted an experiment using a tradeoff paradigm to explore the relative perceived values of different water choices. Results from this study indicated that most respondents considered several indoor water uses as necessities while outdoor water uses tended to be regarded as luxuries (depending on the participant's duration of residence in the valley). Water for native plant and animal protection was considered a luxury by both males and females. Subjects who scored high on the *New Environmental Paradigm*, a measure of environmental orientation, were more likely to spend money for native plant and animal protection. Results of this study indicated that in residential settings, some types of outdoor water uses may be more easily curtailed than some types of indoor water use. Regression analysis revealed that longer duration of residence was related to the idea of outdoor watering as a necessity. Policy ramifications are that campaigns to shift from high- to low-water use landscape treatments may be more successful among recent migrants than long-term residents.

## **Heat Stress and Disadvantaged Urban Populations**

Multiple studies using a variety of modeling and empirical techniques document that Phoenix's disadvantaged populations are disproportionately exposed and vulnerable to increasing heat stress. Darren Ruddell, Sharon Harlan, Susanne Grossman-Clarke, and Alexander Buyantuyev used a Weather Research and Forecasting (WRF) model to simulate air temperature thresholds for excessive heat exposure and conducted a social survey about perceived temperatures and heat problems during Summer 2005 (Ruddell et al. 2010, *Geospatial Techniques in Urban Hazard and Disaster Analysis*). Results showed that the highest exposure to extreme heat was among elderly, minority, and low-income residents. Winston Chow, Wen-Ching Chuang, and Patricia Gober constructed maps of vulnerability to extreme heat in Phoenix in 1990 and 2000 and related these maps to demographic changes in the city (Chow et al. in review at *The Professional Geographer*). The total population of Phoenix residents living in heat vulnerable areas rose by 16% from 1990 to 2000, with the ethnic Hispanic population with the highest exposure grew by 153%, followed by African Americans at 48%. The number of highly vulnerable, non-Hispanic whites decreased from 285,000 to 228,000, a drop of 20%.

## **Spatial Optimization Modeling for Water Supply Allocation**

Geographers Alan Murray, Patricia Gober, Sergio Rey, and Luc Anselin, modeler David Sampson, and graduate student Paul Padegimas developed a spatial-optimization model to support water-supply allocation between water providers when some are in deficit while others are in surplus (Murray et al. in review at *Water Resources Management*). The model uses output from WaterSim 4.0 at the provider level to examine the impacts of cooperation among 33 providers under various climate-change conditions. Results show that cooperative agreements would reduce spot shortages at the provider level that would occur even without climate change. In addition, they would reduce deficits if climate change were to moderately reduce river flows in Phoenix's major source regions, but have little effect under the most pessimistic scenarios because there are few surpluses available for reallocation.

## **Drought Monitoring and Prediction**

Ellis et al. (2010) used a hydroclimatic index to create a historical record of drought coverage and analyzed the linear trend and relationships with key climate teleconnections. An increase in drought in the warm portions of the year is exclusively the result of climatic warming. In recent decades, a significant increase in the drought coverage occurred earlier in the year, during the spring, primarily as a function of warming, but in combination with a decline in precipitation for a significant portion of the basin. The El Niño (La Niña) phase of the El Niño-Southern Oscillation (ENSO) phenomenon is associated with a smaller (larger) area of drought during fall and winter, and the ENSO phase during the preceding six months is a significant predictor. The area of drought within the Colorado River Basin is larger (smaller) during the warm (cold) phases of the Atlantic Multi-decadal Oscillation (AMO) and the Pacific Decadal Oscillation (PDO), although the relationship with the PDO is weak. Monthly AMO values

for the two years preceding drought provide minor predictability. Decadal averages of drought coverage closely follow those of both the AMO and PDO index. However, the nature of the PDO-drought relationship is reversed over the two halves of the historical record, possibly indicating a dominance of the AMO over the PDO in influencing drought in the region. Teleconnection-drought relationships are stronger for the southern portion of the basin. Trends in drought coverage, the current phases of the AMO and PDO, climate-change projections of regional warming, and the likelihood of continued rapid population growth could result in significant water resource problems in the Colorado River Basin.

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### **III. Education and Development**

#### **K-12 Education**

In conjunction with the University of Arizona's Water Resources Research Center, DCDC hosted 35 teachers at the fifth annual Advanced Water Educator Workshop on July 17–18, 2010. The workshop focused on the water and the future of agriculture, covering four topics: (1) water rights and regulations; (2) infrastructure and change; (3) economics, agriculture, and growth; and (4) the sustainability of food production.

#### **Undergraduate Education**

We have funded 17 REU students to participate in ASU's Community of Undergraduate Research Scholars (COURS) program sponsored by the Barrett Honors College over the past six years. Facilitated by DCDC investigator and Barrett Honors College Associate Dean Margaret Nelson, COURS included students from DCDC, the Southwest Consortium for Environmental Research and Policy, the Integrative Graduate Education and Research Training program in Urban Ecology, the Biocomplexity project, and other NSF-sponsored projects. COURS students met weekly for multidisciplinary discussions of research, participated in a range of research activities related to their respective projects, and prepared research posters for presentation at a culminating event hosted by DCDC. The COURS program epitomizes DCDC's goal of linking undergraduate education to research and decision making in a collaborative and interdisciplinary context.

#### **Graduate Education**

A total of 56 graduate students from the School of Life Sciences, School of Geographical Sciences and Urban Planning, School of Sustainability, W.P Carey School of Business, School of Design Innovation, School of Human Evolution and Social Change, the Consortium for Science, Policy & Outcomes, and the departments of History, Political Science, Geology, Psychology, Computer Science, and Communications served as research assistants in DCDC projects. To facilitate greater collaboration among DCDC graduate students, we require participation in a one-credit graduate seminar (Community of Graduate Scholars). The seminar is aimed at sparking cross-disciplinary dialogues and perspectives among graduate students working on sustainability and water issues. One specific goal of the seminar was to organize panel discussions involving researchers from the other DMUU centers. In 2010, the CGS hosted a public panel discussion in April 2010 on Promoting Art/Science Collaborations to Enhance Interdisciplinary Learning. The panel featured a documentary about the interdisciplinary experience of the CGS students who have worked with students from the arts on their projects and a discussion with Julie Anand, Assistant Professor of Photography; Fern Tiger, Principle and Creative Director, FernTiger Associates and Professor of Practice at ASU; and Arnim Wiek, Assistant Professor, School of Sustainability.

## **Postdoctoral Fellowships**

To date, DCDC has hosted seven postdoctoral fellows:

Darren Ruddell, a recent PhD recipient from the School of Geographical Sciences and Urban Planning, was funded jointly by DCDC and the Central Arizona Phoenix LTER. He worked on vulnerability to heat stress and on the interactions between urban design and energy and water use.

Ariane Middel received a PhD in Computer Science 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 urban heat island mitigation strategies.

H. Allen Klaiber received his PhD from North Carolina State University. He worked with economist Kerry Smith on methods for evaluating and interpreting measures of the change in residential property value with spatially delineated amenities; developing a new method for measuring the responsiveness of residential water demand to prices; and developing a structural economic model of the role of land-use policy in lowering water demand. He is now an assistant professor in the Department of Agricultural Economics and Rural Sociology at Penn State.

Athena Aktipis received her PhD from University of Pennsylvania's Department of Psychology. She works with the psychologists (Ledlow, Neuberg, Sadalla, and Kenrick). She is also collaborates with White and Wutich on an anthropological study of risk pooling behavior and strategies.

Tim Collins, a postdoctoral fellow in 2005–2006 for sociologist Bob Bolin on rural-vulnerability issues, is now an assistant professor of Sociology at The University of Texas at El Paso.

Mohan Seetharam worked on rural and urban vulnerability issues in 2006–2007 and is now employed by Conservation Governances and Policy Asoka Trust for Research on Ecology and Environment in India.

Seung-Jae Lee worked with Patricia Gober, Elizabeth Wentz, and Robert Balling during his tenure at DCDC. He coauthored four major research articles (Brazel et al. 2007; Lee et al 2008; Lee and Wentz 2008; Lee et al. 2010) using his expertise in Bayesian Entropy Maximum modeling. Lee is a now a postdoctoral fellow at the National Renewable Energy Laboratory in Golden, Colorado.

Students won prestigious awards in the process of or as an offshoot of their DCDC research:

Brian Pompeii won Honorable Mention at the AAAS meetings in February 2009 for his poster, "Water Privatization and Socially Constructed Scarcity." He also won the President's Award for Outstanding Study Paper at the Association of Pacific Coast Geographers meeting in September 2008 for "Mapping Future Water Supplies in Phoenix, Arizona."

Christopher J. Graham, a 2005 DCDC REU student working with Andrew Ellis, was awarded a Fulbright Fellowship to adapt his work on drought indices in the American Southwest to arid regions in Africa.

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## IV. Outreach Activities

### Water Climate Briefings

DCDC sponsors four to seven facilitated panel discussions of regional water issues annually. At these events, ASU faculty members and graduate students mix socially and professionally with professional water managers and, more importantly, are presented with alternative points of view. We divide the presenters evenly among academic scientists, water professionals, and other outside speakers. Two years ago, we moved from a presentation to a panel format to facilitate dialogue between audience members and panelists. The new format is popular with participants and more consistent with our mandate to provide a space where regional water issues can be openly debated and divergent viewpoints aired.

During six years of funding, we hosted 39 Water Climate Briefings, engaging over 2,500 participants. In the past year, briefings included:

**December 2, 2009.** Irrigated Agriculture in Arizona: Past, Present and Future in Light of Arizona Water Supplies and Water Management Strategies. Panelists were Nicholas Kilb, (Agricultural Planner, Arizona Department of Water Resources); Chris Udall (Executive Director, The Agri-Business Council of Arizona); and Jim Holway (Joint Venture Director, Sonoran Institute) served as Facilitator. The panel explored ways of furthering gains in water efficiency for irrigated agriculture while ensuring the economic viability of farming.

**January 27, 2010.** Regional Water Governance. Panelists were Karen Smith (Deputy Director, Arizona Department of Water Resources); Holly Richter (Chair of their Executive Committee of the Upper San Pedro Partnership and Program Director at The Nature Conservancy); Teresa Makinen (Director, East Valley Water Forum); and Abigail York (Professor, ASU's School of Human Evolution and Social Change) served as Facilitator. The panel used two regional initiatives—the East Valley Water Forum and the Upper San Pedro Partnership—to showcase the potential for regional governance to ensure sustainable water supply.

**February 17, 2010.** Future Scenarios of Agriculture and Water in Central Arizona. Panelists were Carol Johnson (Head of the Phoenix Planning Department); Arnott Duncan (Duncan Family Farms & Sunfresh Farms, Goodyear); Grady Gammage, Jr. (Partner of Gammage & Burnham PLC, Senior Fellow of ASU's Morrison Institute of Public Policy and Sandra Day O'Connor College of Law); John Hetrick (Principal Analyst, Salt River Project); and Rimjhim Aggarwal (Professor, ASU School of Sustainability), who served as Facilitator. The panel commented on three scenarios for the future of agriculture in Central Arizona (Nearly Las Vegas, Urban-Agriculture Partnerships, and Powered by Arizona). These scenarios were developed by students in the School of Sustainability with input from local farmers, water managers, regulators, and planners.



**March 1, 2010.** Sustainable Water Reuse in Arizona. Panelists were Channah Rock (Water Quality Extension Specialist, Soil, Water and Environmental Science Department, The University of Arizona); Chuck Graf (Senior Hydrologist, Arizona Department of Environmental Quality); Chris Hassert (City of Scottsdale, Water Resources, Planning & Engineering Director); Guy Carpenter (Project Manager, Carollo Engineers, National Director WateReuse Association), who served as Facilitator. The panel discussion addressed the current and future investments in water reuse, perceptions and attitudes, regulatory and economic challenges, and environmental needs.

**September 1, 2010.** Understanding Urban Heat Islands (UHI). Panelists were Karen Collins (Water Sustainability Analyst, Water Business Development, Salt River Project); Sharon Harlan, (Professor, School of Human, Evolution and Social Change, ASU); and Steve Rossi (Principal Water Resources Planner, Water Services Department, City of Phoenix). Darren Ruddell (Postdoc, Decision Center for a Desert City and CAP LTER, ASU) served as Facilitator. The panel addressed the water, energy, social, and human-comfort challenges presented by Phoenix's intensifying and expanding urban heat island.

## **Workshops**

In collaboration with the Arizona Water Institute, The University of Arizona, and ASU's Decision Theater, DCDC hosted a series of four workshops in 2009-2010 dealing with climatic uncertainty and climate modeling for scientists and water stakeholders. Topics included: (1) the role of paleo-hydrology for scenario construction and water resource planning; (2) the types of uncertainties that impact on decision-making beyond climate and modeling uncertainty; (3) basics of climate downscaling and hydrological modeling, and (4) preliminary results from The University of Arizona's GCM downscaling and hydrological modeling. The series also included two informational workshops for funding partners. Workshops attracted approximately 20 participants and included scientists from ASU and The University of Arizona and representatives from Arizona cities, Bureau of Reclamation, Salt River Project, Central Arizona Project, and the Arizona Department of Water Resources.

**In October 2009,** DCDC hosted a collaborative workshop with representatives of the Chinese Research Foundation and the Chinese Academy of Sciences. The visit included a field trip to Grand Canyon National Park, a narrated helicopter tour over the Salt River Basin, and a formal workshop including presentations from DCDC and Chinese scientists. The workshop focused on urban climate adaptation from the perspective of rapidly growing cities in the US and China.

## V. Contributions

### Contributions within the Discipline

#### *Systems Dynamics Modeling*

WaterSim is an integrated collection of quantitative models that represent water consumption and availability in Central Arizona under scenarios of population growth, climatic uncertainty, individual behavior, and policy choices. WaterSim 4.0 is a spatially explicit model that allows analysis of the spatial distribution of risk from water shortage and experimentation with various cooperative strategies to equalize risk across the urban environment. WaterSim serves as a boundary object that can be used jointly by the scientific community and water managers for meaningful discourse about future water policy.

#### *Boundary Organizations Research*

DCDC links geography to the growing literature on boundary organizations research as well as the field of science and technology policy more generally. Patricia Gober organized two sessions at the 2007 AAG meetings to showcase the application of boundary science in geography. The first session highlighted research that influences energy and environmental policy; the second was a panel discussion confronting the challenges of and opportunities for geographers working in policy-oriented fields. Dave White presented a poster at the 2010 AAAS meeting in San Diego highlighting DCDC boundary organizations research.

#### *Human-Natural Coupled Systems*

DCDC has produced a critical mass of urban-environmental research that links physical and human geography. Although the discipline includes scientists, social scientists, and humanists, projects that bridge these aspects of the discipline are limited in number. DCDC links existing knowledge of climate modeling, water-resource management, and human vulnerability. Gober et al. (2010b) published a synthetic article arguing for a new paradigm for water management in the March 2010 issue of the *Annals of the Association of American Geographers*.

### Contributions to Other Disciplines

DCDC seeks to break down disciplinary boundaries to solve complex societal problems. As such, our primary goal is always to advance interdisciplinary knowledge. WaterSim provided disciplinary scientists the opportunity to work on inherently interdisciplinary topics, such as water-resource management, decision making under uncertainty, boundary science, policy analysis, climate adaptation, and vulnerability to risk. A substantial proportion of DCDC research projects involved collaborations of geographers, anthropologists, sociologists, engineers, ecologists, and decision scientists.

Our most successful collaborations occurred in our training programs at various levels. Building interdisciplinary thinking and learning was a major goal in both our Community of Undergraduate Research Scholars (COURS) and our Community of Graduate Scholars (CGS) programs. Students from various DCDC research projects enrolled in formal

coursework, attended weekly sessions to exchange information and cooperate on collaborative projects, and participated in a capstone poster session at the end of the year. Interdisciplinary thinking grew from exposure to concepts and approaches defined by a variety of disciplines and integrated to address common problems. Our experience in DCDC suggests that the new generation of students are open—indeed eager—to integrate different disciplinary perspectives. They do so by focusing on inherently interdisciplinary problems and collaborating on solutions.

### **Contributions to Human Resource Development**

DCDC provided a framework for training graduate students, nourishing interdisciplinary projects, and contributing to the fields of geography, decision research, vulnerability analysis, and agent-based modeling. We are also committed to engaging undergraduate students and K-12 teachers, community organizations, government agencies, and the general public. Graduate students were drawn from a wide range of disciplines, including geography, geology, psychology, history, political science, family science, communications, plant biology, and microbiology.

### **Contributions to Resources for Research and Education**

DCDC's setting within a large public institution has enhanced its ability to leverage research and outreach programs for educational benefit. A total of 56 graduate students have been engaged in DCDC research programs. DCDC is a founding partner and collaborator in the university's Community of Undergraduate Research Scholars (COURS) program. Preparation of the DCDC proposal provided the initial impetus for this innovative program, which integrates undergraduate students into research projects.

### **Contributions Beyond Science and Engineering**

DCDC's mission always included a significant community presence and active participation from the local water-management community. We hosted 39 Water-Climate Briefings; organized and facilitated workshops dealing with climate change, water conservation, and the UHI; 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. Our Center is the place where science meets policy in search of sustainable solutions to the problems of climate change.

## VI. Partner Organizations

*Salt River Project:* (Ongoing) SRP delivers nearly one 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 coverage. 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 Water/Climate Briefings. SRP also partnered with DCDC and University of Arizona's Water Resources Research Center on the first summer workshop for teachers held at DCDC.

*City of Phoenix:* (Ongoing) 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 as well.

*University of Arizona:* (Ongoing) DCDC collaborates with three University of Arizona (UA) research centers dedicated partly or wholly to water and climate research. Researchers from the Arizona Water Resources Research Center (WRRC) participate in the science and technology policy/boundary organization efforts, investigating public perception of drought and water management. DCDC also partners with Climate Assessment for the Southwest (CLIMAS), part of UA's Institute for the Study of Planet Earth on climate research. DCDC and UA's Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) are developing an online digital water-information system. SAHRA's experience with a broad spectrum of stakeholders (both public agencies and private organizations) enhances the relevancy of the project to decision makers.

*Arizona Water Institute:* (Ongoing) The Arizona Water Institute is a state-wide initiative to facilitate cross-university research about water resource management. Focus thus far is on developing the Arizona Hydrologic Information System. In collaboration with the Arizona Water Institute, The University of Arizona, and ASU's Decision Theater, DCDC hosted a series of four workshops in 2009-2010 dealing with climatic uncertainty and climate modeling for scientists and water stakeholders.

*Northern Arizona University:* (2005-06) DCDC co-sponsored the Arizona Water Summit, held at NAU in August 2005, with the Center for Sustainable Environments. This event brought together the state, local, and tribal water management communities to discuss relevant science and policy issues related to water resource management.

*East Valley Water Forum:* (2004-05) The East Valley Water Forum consists of tribal, public, and private water agencies in the East Salt River Valley. They shared their

groundwater-modeling output with DCDC so it could be integrated with agent-based models to produce visualizations for the Decision Theater.

*Arizona Department of Water Resources: (2004-05)* A DCDC-sponsored intern worked 20 hours per week at ADWR to retrieve data on the Phoenix area's water budget. The intern also developed metadata about how ADWR created the water budget. (Ongoing) ADWR has continued to provide data to support DCDC research projects and meet with DCDC staff as needed.

*INTEL: (2004-2005)* The DCDC/Intel partnership pursued three areas of mutual interest: (1) sharing expertise and technology through education, training, seminars, and the Decision Theater; (2) working with industrial-sector water users to promote conservation measures and voluntary goals before mandatory water requirements take shape; and (3) researching the policy and technology driving water management.

*Lincoln Institute for Land Policy: (2004-05)* DCDC partnered with the Lincoln Institute for Land Policy on a land-use workshop that developed three K-12 education modules: (1) long-term climate change in Phoenix, (2) GIS interfaces to explore the urban heat island, and (3) a thermal-mapping activity.

## **Other Collaborators**

*Center for Science, Policy and Outcomes: (Ongoing)* 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. In fall 2006, CSPO convened a workshop of scientists actively studying water resource management in the Southwest with a goal of identifying the major stressors on the Phoenix metropolitan area water supply. Workshop results were used to help DCDC develop research priorities and to provide regional water managers with information regarding potential vulnerabilities. In 2007, CSPO expanded the geographic scope of their 2006 research. Specifically, CSPO performed background research to identify key areas of uncertainty about water supply and assess the comprehensive picture of demand in the region to include the entire lower Colorado River Basin. They produced a White Paper covering the current knowledge of stressors on this region's water supply and predictions about future changes. This paper also created a ranking of stressors on Central Arizona water resources.

*Global Institute of Sustainability: (Ongoing)* 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.

*Decision Theater:* (Ongoing) Founded simultaneously with DCDC, the Decision Theater 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.

*Central Arizona – Phoenix Long Term Ecological Research:* (Ongoing) DCDC and the CAP LTER partnered in the design and implementation of the second round of the Phoenix Area Social Survey (PASS), a survey of 800 randomly selected Phoenix-area households. The survey asked respondents about their knowledge of, attitudes toward, and behaviors about a set of locally-relevant environmental issues, including urban sprawl, air quality, the urban heat island, and water scarcity. Results will allow DCDC researchers to test hypotheses about the interrelationships among environmental knowledge, attitudes and value systems, and ultimate behavior regarding water use and conservation practices. In 2007, DCDC and CAP LTER expanded the PASS project to include GIOS scientists and public sector professionals. A summer 2006 summit developed a research agenda to investigate human and ecological adaptations to future climate change. 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.

*University of California, Irvine, Paul Merage School of Business:* (Ongoing) 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 was the foundation for developing decision-focused evaluation metrics for use with the models that have been developed within DCDC.

*Community of Undergraduate Research Scholars:* (Ongoing) ASU's Community of Undergraduate Research Scholars (COURS) provides opportunities for undergraduate students enrolled in the Barrett Honors College to contribute to DCDC research. In 2010, DCDC hosted the fifth annual COURS poster session, highlighting the interdisciplinary work of both undergraduate and graduate students.

*Project Wet:* (Ongoing) In 2006, DCDC partnered with University of Arizona's Project Wet and the Salt River Project to host the first summer teacher training workshop in 2006, where 30 teachers from K-12 schools in the Phoenix Metropolitan area developed new learning materials based on local environmental issues such as water scarcity, water recycling, and the urban heat island. The new learning materials were based upon DCDC research, data sets, and outreach activities. This successful workshop has been repeated each summer and is always filled to capacity. The fifth Advanced Water Educator's Workshop, with the theme of Water and Agriculture, was held in June 2010.

*ASU President's Office: (2006-08)* 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.

*ASU's Morrison Institute for Public Policy: (2008-2010)* The Metropolitan Phoenix Indicators Project evolved into the Arizona Indicators, now administered by the Morrison Institute. DCDC continues to contribute data to this project.

*Other ASU research and academic units: (Ongoing)* DCDC regularly co-sponsors lectures and symposia with other ASU research and academic units. These events bring together individuals from industry and multiple academic disciplines to explore and discuss topics such as robust decision making, historic perspectives of water in societies, visualization in environmental policy, and climate change in human-dominated systems.

### **Community Partners-Personnel Exchanges**

*City of Tempe: (Ongoing)* City of Tempe supplies household-water-use data for DCDC analysis. Under DCDC's auspices and supervision, the Tempe Water Utilities Department sponsored an internship in 2006-07. The student investigated the potential water savings under various landscape water conservation scenarios.

*City of Mesa: (2006-07)* Under DCDC auspices and supervision, the City of Mesa Utilities Department sponsored an internship for an undergraduate student. The intern worked with a water resource specialists in the Resources Division of the Utilities Department. The intern assisted in research focused on scenario assessment for Mesa's long-term groundwater management plan.

## VII. DCDC Participants

### *Principal Investigators/Project Directors*

Patricia Gober, School of Geographical Sciences and Urban Planning, School of Sustainability

Charles L. Redman, Global Institute of Sustainability, School of Sustainability

### *Co-Principal Investigators*

Bob Bolin, School of Human Evolution and Social Change

Grady Gammage, Jr., Morrison Institute for Public Policy

Thomas Taylor, Mathematics and Statistics

### *Senior Personnel: Manager*

Bill Edwards, Executive Administrator

### *Senior Personnel: Core Scientists*

J. Marty Anderies, School of Life Sciences

Brad Armendt, Philosophy

Richard Aspinall, School of Geographical Sciences

Robert Balling, School of Geographical Sciences and Urban Planning

Anthony Brazel, School of Geographical Sciences and Urban Planning

David Casagrande, Global Institute of Sustainability

Elizabeth Corley, School of Public Affairs

Andrew Ellis, School of Geographical Sciences and Urban Planning

Monica Elser, Global Institute of Sustainability

Gregg Garfin, Institute for the Environment, University of Arizona

William Griffin, Family & Human Development

Corinna Gries, Global Institute of Sustainability

Suzanne Grossman-Clarke, Global Institute of Sustainability

Subhrajit Guhathakurta, School of Geographical Sciences and Urban Planning

Ed Hackett, School of Human Evolution and Social Change

Sharon Harlan, School of Human Evolution and Social Change

James Holway, Global Institute of Sustainability

Jana Hutchins, Institute for Social Science Research

Kathy Jacobs, SAHRA, University of Arizona; Arizona Water Institute

Donald Keefer, W.P Carey School of Business, Supply Chain Management

L. Robin Keller, University of California, Irvine, The Paul Merage School of Business

Peter Killeen, Psychology

Ann Kinzig, School of Life Sciences

Craig Kirkwood, W.P Carey School of Business, Supply Chain Management

Michael Kuby, School of Geographical Sciences and Urban Planning

Tim Lant, Global Institute of Sustainability/Mathematics

Kelli Larson, School of Geographical Sciences and Urban Planning, School of Sustainability

Peter McCartney, Global Institute of Sustainability

Margaret Nelson, Barrett Honors College

Joan McGregor, Philosophy



Rob Melnick, Global Institute of Sustainability, Morrison Institute for Public Policy  
Ray Quay, City of Phoenix  
Anshuman Razdan, Partnership for Research in Spatial Modeling  
Jeremy Rowe, Information Technology  
Charlene Saltz, University of Arizona  
Daniel Sarewitz, School of Life Sciences  
Kerry Smith, W.P Carey School of Business, Economics  
Barbara Trapido-Lurie, School of Geographical Sciences and Urban Planning  
Elizabeth Wentz, School of Geographical Sciences and Urban Planning  
Dave White, School of Community Resources and Development  
William Verdini, College of Extended Education  
Joseph Zehnder, Department of Geography

*Postdoctoral Research Associates*

Timothy Collins, School of Geographical Sciences (ASU)  
H. Allen Klaiber, Economics, North Carolina State University  
Seung-Jae Lee, Environmental Sciences & Engineering, University of North Carolina at Chapel Hill  
Ariane Middel, Computer Science, University of Kaiserslautern, Germany  
Darren Ruddell, School of Geographical Sciences and Urban Planning (ASU)  
Mohan Seetharam, Graduate School of Geography, Clark University

*Visiting Fulbright Scholar*

Mayank Kumar, Satyawati College, University of Delhi

*Other Collaborators*

Luc Anselin, School of Geographical Sciences and Urban Planning  
Rimjhim Aggarwal, School of Sustainability  
C. Athena Aktipis, Department of Ecology and Evolutionary Biology, University of Arizona  
James Buizer, Office of Sustainability Initiatives  
Netra Chhetri, Consortium for Science, Policy & Outcomes  
John Crittenden, Civil & Environmental Engineering  
Beatrice Crona, School of Human Evolution and Social Change  
Lee Cronk, Department of Anthropology, Rutgers University  
Michael Crow, President, Arizona State University  
Rob Edsall, School of Geographical Sciences  
Priscilla Greenwood, Department of Mathematics  
Paul Hirt, Department of History  
Erik Johnston, School of Public Affairs  
Doug Kenrick, Department of Psychology  
Yu-shim Kim, School of Public Affairs  
Susan Ledlow, Global Institute of Sustainability  
Chris Lukinbeal, School of Geographical Sciences  
Chris Martin, Department of Applied Biological Sciences  
James Middleton, College of Education  
Soe Myint, School of Geographical Sciences and Urban Planning

Alan Murray, School of Geographical Sciences and Urban Planning  
Steven Neuberg, Department of Psychology  
Robert Pahle, Global Institute of Sustainability  
John Parker, Barrett Honors College  
Gianfranco Piras, School of Geographical Sciences  
Sergio Rey, School of Geographical Sciences and Urban Planning  
Ed Sadalla, Department of Psychology  
Charles Schmidt, School of Geographical Sciences  
Nancy Selover, School of Geographical Sciences and Urban Planning  
Paul Torrens, School of Geographical Sciences  
Ajay Vinze, W.P. Carey School of Business, Information Systems  
Enrique Vivoni, School of Earth and Space Exploration  
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 Sustainability

*Research Technical Personnel*

Steven Brautigan, Decision Theater  
Aashish Chaudhary, Decision Theater  
Charlie Collins, Decision Theater  
Dustin Hampton, Decision Theater  
Jiuxiang Hu, Decision Theater  
Shea Lemar, Information Technology  
Wayne Porter, Global Institute of Sustainability  
Robin Schroeder, Global Institute of Sustainability  
Michael Zoldak, Institute for Social Science Research

*Public Outreach Personnel*

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

*Research Support Personnel*

Alex Garcia, Global Institute of Sustainability  
Nick Gerbis, Decision Center for a Desert City  
Karen Gronberg, Global Institute of Sustainability  
Nikol Grant, Global Institute of Sustainability  
Deirdre Hahn, Decision Theater  
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  
Linda Newsom, Decision Center for a Desert City  
Estella O'Hanlon, Decision Center for a Desert City  
Rick Poulsen, Global Institute of Sustainability  
David Sampson, Decision Center for a Desert City  
Michelle Schwartz, Decision Center for a Desert City

Susan Siddall, Global Institute of Sustainability  
Philip Tarrant, Global Institute of Sustainability  
Michael Tschudi, Decision Center for a Desert City, Global Institute of Sustainability  
Mary Whelan, Informatics and Cyberinfrastructure Services, ASU Libraries  
Sally Wittlinger, Decision Center for a Desert City

*Graduate Research Associate*

Srushti Abhyankar, Department of Computer Science and Engineering  
Leena Admane, School of Design Innovation  
Omaya Amad, School of Sustainability  
Stacey Avent, School of Human Evolution and Social Change  
Suresh Ayyalsamy, Family and Human Development  
Neil Barton, School of Geographical Sciences  
Anna Berlin, Department of Psychology  
Christina Brelsford, School of Sustainability  
Edgar Cardenas, School of Sustainability  
Jagadeesh Chirumamilla, School of Geographical Sciences  
Winston Chow, School of Geographical Sciences and Urban Planning  
Erin Comparri, School of Geographical Sciences  
Hermes Cubaque, School of Geographical Sciences and Urban Planning  
Bethany Cutts, School of Life Sciences  
Stephanie Deitrick, School of Geographical Sciences and Urban Planning  
Jillian Elder, School of Geographical Sciences  
Vanessa Escobar, School of Earth and Space Exploration  
Stephane Frijia, School of Geographical Sciences and Urban Planning  
Meredith Gartin, School of Human Evolution and Social Change  
Chris Graham, School of Geographical Sciences  
Anne Gustafson, Department of History  
Shannon Gysberg, School of Geographical Sciences  
Zeenat Hasan, School of Human Evolution and Social Change  
Gretchen Hawkins, School of Sustainable Engineering and the Built Environment  
Brent Hedquist, School of Geographical Sciences  
Qian Hu, School of Sustainability  
Dorothy Ibes, School of Geographical Sciences and Urban Planning  
Dan Killoren, School of Historical, Philosophical and Religious Studies  
Won Kyung Kim, School of Geographical Sciences and Urban Planning  
Chinmay Kurane, School of Geographical Sciences and Urban Planning  
Vasudha Lathey, Environmental Design/Planning  
Paul Maliszewski, School of Geographical Sciences and Urban Planning  
Christy Mercer, School of Sustainability  
Kim Michel, School of Life Sciences  
Kevin Murphy, School of Geographical Sciences and Urban Planning  
Rebecca Neel, Department of Psychology  
Mark Neff, School of Life Sciences  
Megan O'Shea, School of Earth and Space Exploration; School of Geographical Sciences  
Paul Padegimis, School of Geographical Sciences and Urban Planning  
Jamie Patterson, School of Geographical Sciences

Brian Pompeii, School of Geographical Sciences and Urban Planning  
Krista Ranby, Department of Psychology  
Sandra Rodegher, School of Sustainability  
Darren Ruddell, School of Geographical Sciences  
Shana Schmidt, Family and Human Development  
Clea Senneville, School of Sustainability  
Cheryl Sexton, Family and Human Development  
Clarie Smith, School of Human Evolution and Social Change  
Jesse Snook, W. P. Carey School of Business, Economics  
Bharath Sollaapuram, Geographic Information Systems  
Subramanian Swaminathan, School of Geographical Sciences  
Victoria Turner, School of Geographical Sciences and Urban Planning  
Margaret White, School of Life Sciences  
Lauren Withycombe, School of Sustainability  
Yolanda Youngs, School of Geographical Sciences  
Sianan Zhang, School of Sustainability  
Lilah Zautner, School of Geographical Sciences

*Other Grads*

Jessica Block, Geology  
Hoi Cheung, College of Design  
Kade Hutchinson, Geology (Decision Theater)  
Steve Swanson, School of Human Evolution and Social Change

*Community of Undergraduate Research Scholars (COURS)*

Matthew Covert, Political Science  
Zach Dorn, School of Sustainability  
Laila El-Ashmawy, Civil Engineering  
Malaya Fletcher, School of Life Sciences  
Ariana Fox, School of Life Sciences  
Desirae Hoffman, School of Geographical Sciences and Urban Planning  
Peter Howe, School of Geographical Sciences  
Allyn Knox, School of Life Sciences  
Matt Kruger, Political Science  
Jason Loose, School of Social Transformation  
Nicholas Moore, School of Geographical Sciences  
Arianne Peterson, School of Human Evolution and Social Change  
Jonathan Scolaro, School of Architecture  
Melanie Tluczek, School of Human Evolution and Social Change  
Adrienne Uphoff, School of Sustainability  
Rebecca Watkins, School of Life Sciences  
Eva Wingren, School of Human Evolution and Social Change

*Other Undergrads*

Lubinka Andonoska, Public Administration  
Hillary Butler, School of Life Sciences  
Avneet Buttar, Computer Information Systems

Uven Chong, Mechanical Engineering  
Laura Hand, Public Administration  
Brian Keegan, W.P. Carey School of Business  
Andrew Knochel, Urban Planning  
Jason Loose, Asian Languages  
Santiago Manriquez, Interdisciplinary Studies  
Adam McDaniel, Global Institute of Sustainability  
Eric Moore, W.P. Carey School of Business, Finance  
Caroline Newcombe, Civil Engineering  
Mitchell Norgan, Department of Psychology  
Annissa Olsen, School of Music  
Michelle Rupp, Political Science  
Rosanne Servis, English  
Manual G. Valenzuela, Education

*Community Partners*

Nancy Crocker, University of Arizona, Maricopa County Cooperative Extension  
Michael Ellegood, Maricopa Flood Control District  
Mitchell Haws, Bureau of Reclamation  
John Hetrick, Salt River Project  
Ray Quay, City of Phoenix  
Dallas Reigle, Salt River Project  
Kerry Schwartz, University of Arizona, Water Resources Research Center

*Organizational Partners and Other Collaborators*

American Indian Policy Center (ASU)  
Arizona Department of Water Resources  
Arizona Town Hall  
Arizona Water Institute  
ASU President's Office  
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  
Intel  
Lincoln Institute for Land Policy  
Maricopa Association of Governments  
Montgomery & Associates  
Salt River Project  
Sustainable Cities Network (ASU)  
University of Arizona (WRRC, CLIMAS, SAHRA, Project Wet)

