# DCDC 2005-2006
# Annual Progress Report

## Decision Center for a Desert City
## SES-0345945

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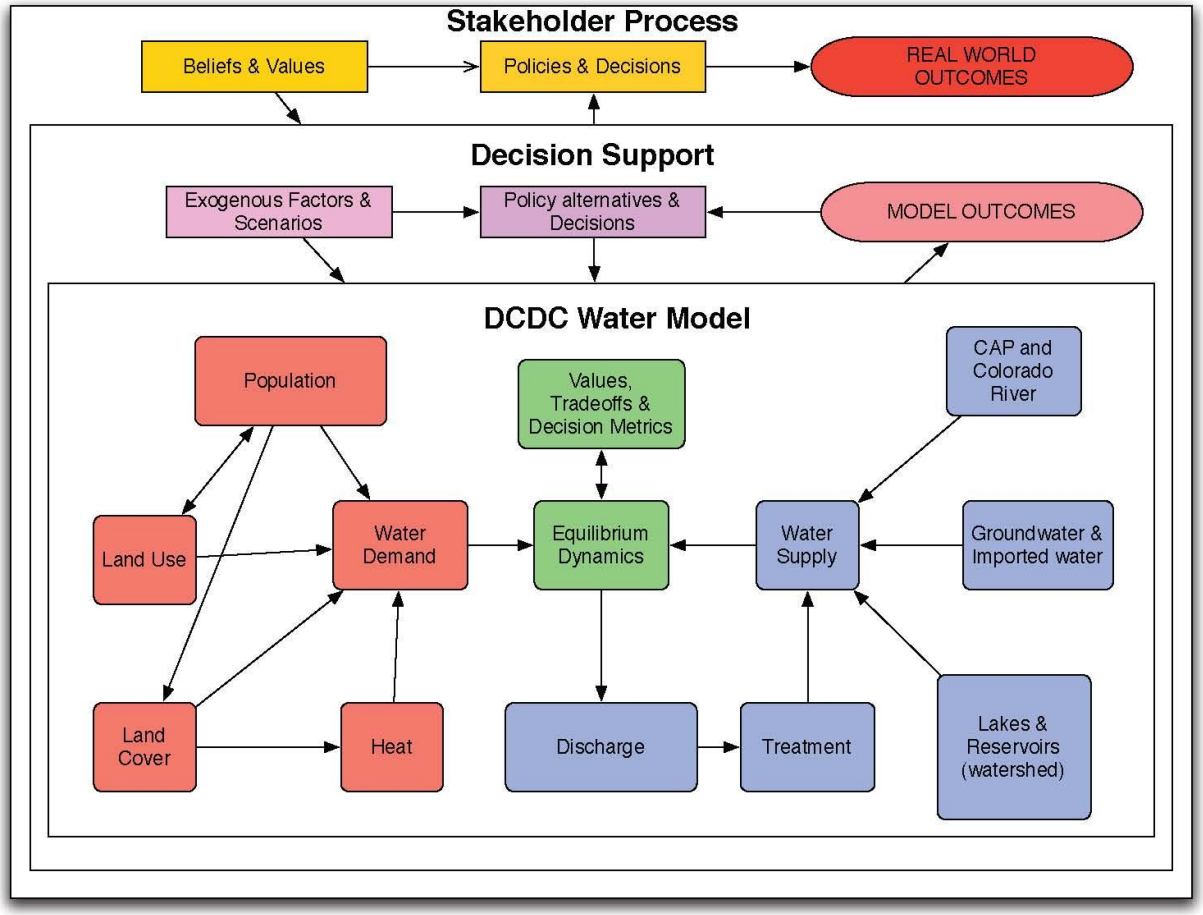
ASU ARIZONA STATE UNIVERSITY

# DCDC 2006

## I. Introduction to DCDC

The Decision Center for a Desert City (DCDC) is one of five research projects funded by the National Science Foundation's Decision Making Under Uncertainty Initiative. Now in its second year of operation, DCDC research, outreach, and educational activities are focused on water management decisions in central Arizona in the face of uncertainties associated with rapid population growth and urbanization, complex political and economic systems, inherent variability in the desert climate, and the specter of global climate change. Although DCDC is, to a certain extent, a regional case study based on the particular historical and political circumstances of metropolitan Phoenix, its research products and decision support tools can be generalized to rapidly growing desert regions worldwide. Testament to this is the example of Christopher J. Graham, a 2005 DCDC REU student, who was recently awarded a Fulbright Fellowship to adapt his work on drought indices in the American Southwest to arid regions in Africa.

Central to DCDC's efforts to link knowledge production and real-world decision making is the development of the DCDC water model (See below)**.**



The model serves to synthesize basic research and knowledge production, engagement with stakeholders in the regional water management community, and the decision support tools that link them together. In Year 2, we devoted considerable effort to producing a preliminary water model that can be visualized and manipulated in Arizona State University's new Decision Theater, an interactive and immersive space where environmental outcomes and model results are visualized in 3-D.

The DCDC Water Model integrates three submodels: (1) a science model that predicts regional water supply and demand, (2) decision-support levers that allow us to observe how model outcomes change in response to exogenous conditions such as technological change and climatic conditions and regional policy decisions, and (3) a stakeholder model that translates model outcomes into real-world decisions. At the end of DCDC's funding cycle in 2009, we envision a fully operational model that translates research findings about climate, decision making, and human vulnerability into scientifically credible scenarios of the future, in which stakeholders use the model for decision making, and decision support tools and research findings can be applied in other high-growth, water-scarce regions.

Uncertainty factors into the model in a number of ways. First, there is uncertainty associated with using historical conditions about physical and human processes to represent the future. These conditions include the variability of runoff in the watersheds, the laws, agreements, and regulations that govern the management of the water storage and delivery system, and patterns of and trends in agricultural and municipal water use. Second, there is uncertainty associated with the assumptions that are inherent in predictive scientific models. And third, the scenario-building effort involves generating a random series of outcomes and then examining outcome spaces for the most robust scenarios–those that perform well across a wide range of future conditions using many different values to assess performance.

Three sets of research questions form the core of DCDC's research program: (1) what are the sources of regional climate variation and change and how do they influence water supply and demand? 2) how do humans, operating as individuals, households, and communities, make decisions using this scarce resource? and (3) what factors put individuals and communities at risk from water shortage?

***Climate Science***

DCDC climate research examines the limits of variability in regional climate conditions and thus determines the upper and lower bounds of the regional water supply. The study area includes the entire Colorado River Basin as well as the watersheds of the Salt and Verde Rivers immediately upstream from Phoenix. The urbanized area depends upon these systems for its annual supply of surface water. Local climatic conditions are relevant to groundwater supplies and to possible feedbacks between the urban heat island and water demand. Year 2 projects included studies of:

- Drought Determinants for the Colorado River Basin
  (Balling and Goodrich)
- Hydroclimatic Indexing for Monitoring Drought
  (Ellis, Garfin, and Balling)
- Spatial Expansion of Phoenix's Urban Heat Island
  (Brazel, Hedquist, Zehnder, Grossman-Clark, Gober, and Lee)

- Impact of Urban Heat Islands on Water Use: The Case of Phoenix Metropolitan Area (Guhathakurta)

***Decision Science***

DCDC decision science research explores human decisions about water use, including the institutional arrangements that govern water allocations in the highly human-managed system of central Arizona, factors that influence household water demand, and stakeholder priorities of and expert perspectives on water resource management. This line of research acknowledges that the results of climatic investigation do not flow directly into decisions about water use and management, but are governed by human perceptions, modes of behavior, and societal arrangements. Year 2 projects included studies of:

- Factors Influencing Residential Water Consumption for the City of Phoenix, Arizona (Wentz and Gober)
- Systems Modeling Approach to Water Supply and Demand (Lant and Gober)
- Expert Perspectives on Science, Politics, and Water Management in Phoenix (Peterson, Howe, White, White, and Corley)
- Decision Research in Water Resources Management: A Multiple-objective, Multiple-stakeholder Analysis (Kirkwood and Keller)

***Vulnerability Analysis***

DCDC Vulnerability analyses address the historical, political, and economic factors that place people and communities at risk from water shortage. Not everyone in the region is equally susceptible to growth- and climate-induced constraints on water, and people will adapt differently to these constraints. Research in this domain ranges from in-depth qualitative studies of peri-urban communities with rampant growth and extremely limited water supplies to highly quantitative agent-based modeling of household and regional responses to increasing price, voluntary conservation campaigns, and mandated public policies that limit pool use and alter landscaping practices. Year 2 studies included:

- Peri-urban Growth, Water Conflicts, and Vulnerability in the Verde Watershed (Collins, Bolin, Youngs, and Tluczek)
- DesertWater: An ABM of Household Water Use in the Southwestern United States (Griffin and Schmidt)

To further these research aims, DCDC collaborates with the Central Arizona-Phoenix Long Term Ecological Research (CAP LTER) on two projects. The first is the development of the second round of the Phoenix Area Social Survey (PASS). PASS is a one-hour Internet- or telephone-based survey of 800 randomly selected Phoenix-area households. Respondents are asked about their knowledge of and attitudes about a range of locally-relevant environmental issues related to land use, air quality, and water resource management. Results from PASS enable DCDC researchers to link public attitudes about drought, water shortage, and growth to larger-scale environmental values; to anticipate public response to policies designed to adapt to long-term water shortage; and to ascertain public values about pool use and landscaping. In addition, DCDC will participate in a joint DCDC/CAP LTER summit on climate change in

summer 2006. The goal is to integrate DCDC's social science expertise with CAP LTER's focus on ecological and biophysical systems to investigate interrelationships between ecological and human systems in response to climate change.

## II. Highlights of Research Activities

Year 2 activities include studies that contribute to our model-building efforts. They further our basic understanding of the physical and social determinants of water supply and demand; of the social, economic, and political processes that govern water resource management at the community and regional scale; and of human adaptation and response to vulnerability from water shortage.

Year 2 projects included the following:

*DCDC Water Model:* The DCDC Water Model 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. The model was constructed using a systems dynamics framework in the software application PowerSIM. The main components of the model consist of supply- and demand-side modeling. Preliminary results have been displayed in the Decision Theater, where the model serves as a 'boundary object' that can be used jointly by the scientific community and water managers for meaningful discourse about future water policy.

*Hydroclimatic Studies:* The Colorado River is the source for approximately 40% of the regional water supply. Climate studies have analyzed the determinants of drought in the Colorado River Basin (Balling and Goodrich, published in Climate Change, 2006) using the Palmer Hydrological Drought Index and have experimented with indicators of drought that are more sensitive to and appropriate for arid conditions (Ellis, Garfin, Balling, and Graham, submitted to Annals of the Association of American Geographers). The Salt and Verde River Basins account for 30% of the region's water supply. Detailed models of the hydroclimatology of this system provide input to the DCDC water model and reveal the sensitivity of water supply to variations in temperature and precipitation provided by the Intergovernmental Panel on Climate Change (IPCC) climate change scenarios.

*Urban Heat Island Studies:* Rapid urbanization and rampant urban sprawl have created an expanding and intensifying urban heat island effect in Phoenix. DCDC projects estimated the spatial expression of the urban heat island (Hartz, Brazel, and Heisler, International Journal of Biometeorology, 2005); predicted the magnitude and extent of the heat island under different land-use policies, landscaping practices, and water conservation scenarios; and estimated the effects of rising temperatures (magnitudes are greater than 11° F during clear and dry atmospheric conditions) on residential water demand. The latter study was presented at the 2005 North American meetings of the Regional Science Association International in Las Vegas.

*Decision Research Studies:* Kirkwood, Keller, and Jones used a multiple-objective decision modeling approach to create a comprehensive catalog of concerns identified by key stakeholders for guiding water resource policy in central Arizona. Results were presented at the 2005 meeting of the Institute for Operations Research of the Management Sciences in San Francisco. In another study, expert perspectives were elicited on the successes of and challenges for Phoenix

water management; the integration of science, politics, and social values in their decision making; and strategies for representing, communicating, and managing uncertainty (White, Corley, and White, submitted to Society and Natural Resources).

*Residential Water Consumption Studies:* Two types of water-use studies support our model-building efforts. Wentz and Gober used least-squares and geographically-weighted regression to identify the determinants of residential water demand in the City of Phoenix. Model coefficients were used to estimate the effects of landscaping practices, pool use, and lot size on regional water demand. Also under development is an agent-based model of household water use based on socio-demographic characteristics such as race, age, income, and education using decision rules about receptivity, sensitivity, and hierarchy (Griffin and Schmidt, in Agent 2005: Generative Social Processes, Models and Mechanisms, 2005).

*Phoenix Area Social Survey (PASS):* DCDC investigators collaborated with CAP LTER scientists on the development of the second round of PASS. Data collection is now underway for 800 Phoenix-area households. The survey queries respondents on their knowledge of, attitudes about, and behaviors toward a set of locally-relevant environmental issues, including urban sprawl, air quality, the urban heat island, and water scarcity. Results will provide insight into the interrelationships between concerns and conceptions of water scarcity, attitudes of water conservation policies, and environmental behavior in terms of water use and landscaping practices.

*Visualization Studies:* DCDC's water model is being adapted for presentation and manipulation in ASU's Decision Theater, and thus it is important to determine whether exposure to 3-D visualization affects problem formulation and decision making. Edsall and Larson conducted a series of tests with students, educators, and policy makers to evaluate the influence of the Decision Theater on the understanding of local water issues and common misconceptions. Preliminary results show that exposure to 3-D visualization in the Decision Theater (as compared to a two dimensional, flat screen in a classroom) had, in some cases, a significant effect on problem formulation and hypothetical decision making. Results will be presented at the 2006 meeting of AutoCarto, the Cartography and Geographical Information Society, in Vancouver, Washington.

*Vulnerability Studies:* This research examines near- and long-term, local and regional water resource issues through analyses of seven rapidly growing Verde Watershed communities and adjacent rural areas. The focus is on groundwater management in the context of rapid peri-urban growth, including resource demands and climatic uncertainty. Unequal risk of water scarcity is seen to arise from social, political, and economic processes that structure and constrain people's daily lives in the context of particular environmental conditions.

## III. Highlights of Research Findings

*Drought Determinants:* Balling and Goodrich (Climate Change, 2006) used principal components analysis to independently assess the influence of various teleconnections on the basin-wide and subregional winter season Palmer Hydrological Drought Index (PHDI) and on precipitation variations in the Basin. They found that the Pacific Decadal Oscillation (PDO) explains more variance in the PHDI than El Nino-Southern Oscillation (ENSO), the Atlantic

Multidecadal Oscillation (AMO), and the planetary temperature combined for the basin as a whole. Altogether, the teleconnection indices accounted for only 19% of the variance in PHDI, leaving large uncertainties in drought forecasting.

*Drought Indexing:* DCDC scientists developed a new drought index based on the hydroclimates of the Colorado River Basin. The new index developed by Ellis et al. focuses on the difference between the natural input of water, or precipitation, and the natural climatic demand for water, or evapotranspiration. Comparisons between the new index and the popular Palmer Drought Severity Index (PDSI) and the Standardized Precipitation Index (SPI) showed that the newly developed index responds more quickly to short-term hydroclimatic changes than the PDSI. The new index better represents drought severity than does the SPI by accounting for the effect of temperature in the form of climatic demand for water. Measurement and monitoring of drought in the Colorado River Basin is crucial to the Phoenix-area water supply because the Colorado River contributes approximately 40% of the average annual supply and because legal agreements regarding the use of the river dictate that Arizona's share will be the first to be curtailed in the event of basin-wide shortfalls.

*Urban Heat Island and Residential Water Demand:* The urban heat island effect, the rise in nighttime temperatures associated with large-scale urbanization, has raised temperatures by up to 11° F in Phoenix during clear and dry atmospheric conditions. DCDC scientists investigated whether the spatial variation in summer nighttime temperatures resulting from the urban heat island affect residential water use. Results indicate that an increase of one degree in nighttime temperature (average daily lows in June) leads to an increase of 677 gallons in average annual demand for water in single-family units in Phoenix, after accounting for other factors that also lead to increased water use. Given that there were almost 780,000 single-family units in the Phoenix area in 2000, each one-degree increase in temperature (induced by the heat island effect) increases region-wide water consumption by 1,600 acre feet, or about .3% of total residential consumption.

*Determinants of Residential Water Consumption:* Municipal water records at the census tract level were obtained from the City of Phoenix and related to information from other sources about lot size, the presence of pools, household size, and landscaping style. We used ordinary least-squares regression to identify the determinants of single-family residential water use in Phoenix in 2000 and geographically-weighted regression to determine whether the behavior of nearby areas affects local water demand. Results substantiate the significance of household characteristics (size), urban design features (lot size and pools), and landscaping practices (mesic vegetation) on residential water demand and point to a strong spatial bias in water consumption. Households tend to use water at a level comparable to their neighbors, irrespective of their demographic and urban design features. Thus, planning decisions may have different effects in different parts of the city. Model parameters will be used to estimate demand under different urban-growth and planning scenarios.

*Decision Research in Water Resources Management:* We used a multiple-objective decision modeling approach to create a comprehensive catalog of concerns identified by key stakeholders for guiding water resource policy. Preliminary review of the data shows significant variation in the concerns of stakeholders, with municipalities placing higher priority on water security while environmental groups place higher value on factors that impact the natural/physical environment. Most respondents had a fairly specific focus for their policy and decision interests, and these foci

varied greatly across the range of stakeholders. Results suggest that water stakeholders will interpret DCDC model results differently, depending upon the relative priority they place on sufficiency of supply, environmental impacts, social-economic impacts, political impacts and governance, health and safety, socio-economic impacts, and broader impacts that extend beyond the capacity of any one relevant agency.

*Expert Perspectives on Science, Politics, and Water Management:* With the ultimate goal of improving the interface between scientists, managers, policy makers, and citizens, we conducted semi-structured, in-depth interviews with water managers from the Greater Phoenix area. Using qualitative analysis, we constructed conceptual maps illustrating water managers' understandings of key themes, including water supply, drought, growth, the role of government, science and policy, and uncertainty and decision making. Most of those interviewed cited growth as a challenge to Arizona's water future, but believed that the Phoenix area is well-equipped to sustain further growth and tolerate potential droughts. Uncertainty factored highly in experts' opinions, with most mentioning incomplete or inaccurate data on environmental variability to be a key concern.

*Vulnerability to Water Scarcity:* Large-scale population growth in and urbanization of central Arizona has increased the stress on water resources in peri-urban communities in the upstream watershed of the Verde River. A team of DCDC scientists conducted interviews with water managers and residents of six communities to identify their response to increasing water scarcity. Their research is informed by the theories of political ecology, in which environmental change and ecological processes shape, and are shaped by political and economic processes; and by vulnerability analysis, which focuses on the differential ability of individuals and groups to anticipate, cope with, adapt to, and recover from chronic or acute environmental hazards. Preliminary results reveal that communities respond to water scarcity by seeking to expand their water frontiers, purchasing water rights and pumping groundwater in more remote locations. In making their own municipal water systems more secure, the larger, more urban communities increase the vulnerability of outlying areas, raise the risk of scarcity for more remote populations, and increase social inequalities.

### *Findings from Educational Activities*

*Water Education Provider Survey:* Understanding how water education organizations interact with each other provides insight into the information sharing structure of water educators. The network of connections between organizations can be represented as a social system.

Results reveal that the dominant objective for water education across all types of organizations (water providers, non-profits, governments, and private industry) is teaching about outdoor water conservation and groundwater. Respondents eschewed advocacy objectives, participation in public debates about growth and the region's water future, and meaningful discussion regarding the use of reclaimed water. One respondent from a municipal water provider commented that the public 'is very nervous about using [reclaimed water] and they want to know if anyone has ever gotten sick or if anyone has ever died related to the use of reclaimed water and it's very hard to find that information when you're just trying to Google for it.'

Pedagogical concerns related to the needs of or affecting the behavior of Spanish-speaking, low-income, high-income, and geographically distant populations were common. Major challenges

are the lack of content on drought, climate change, urban water systems, and low-water irrigation use. These topics are at the core of DCDC's research program, and they suggest a pressing need to translate research results into educational materials that are applicable across a wide range of audiences.

*Community of Undergraduate Research Scholars:* The Community of Undergraduate Research Scholars (COURS) Program included four REUs funded by DCDC. One of the goals of COURS is to build student ability to think across disciplines and to consider the broader impacts of research. Success is gauged in two ways: (1) comparison of a pre-test to two mid-year assignments, and (2) comparison of the pre-test to a post-test. Results of these comparisons reveal that COURS students improved their understanding of how their research is relevant to other disciplines and to broader public and theoretical issues. Students also improved their understanding of the broader impact of research outside their field of expertise.

***Training and Development***

DCDC funded four undergraduate students to participate in the Community of Undergraduate Research Scholars (COURS) Program, an interdisciplinary program co-sponsored by the Barrett Honors College and the Global Institute of Sustainability (GIoS) and supervised by Barrett Honors College Associate Dean Margaret C. Nelson. COURS integrates undergraduate students into ongoing research projects, provides an interdisciplinary environment that enhances cross-disciplinary communication and appreciation for the broader impacts of scientific work, and results in concrete research products. All COURS students, including the four from DCDC, prepared research posters for presentation at a capstone event on May 3, 2006, featuring an outside speaker and widespread participation from DCDC, CAP LTER, and IGERT faculty. The titles of the DCDC-related poster presentations are listed below:

- The Effects of 3D Visualization on Lay Perspectives of Environmental Issues by Matt Kruger*, Kelli Larson, Rob Edsall, and Jessica Block
- Expert Perspectives of Science, Politics, and Water Management in Phoenix by Arianne Peterson*, Peter Howe*, Margaret White, Dave White, and Elizabeth Corley
- Towards an Understanding of Rural Water Perceptions and Micro-Politics in Cottonwood, Arizona by Melanie Tluczek*, Bob Bolin, Tim Collins and Yolonda Youngs

  * DCDC REU students

To date, 20 graduate students from the School of Life Sciences, the Center for Science, Policy and Outcomes, and the Departments of Geography, History, Political Science, Psychology, and Communications have participated in DCDC projects. To facilitate greater collaboration among graduate students working on DCDC projects, we will require all research assistants to participate in a one-credit graduate seminar, Community of Graduate Scholars, in Fall 2006 and Spring 2007.

DCDC has two post-doctoral fellows associated with research projects. Timothy Collins, a recent Ph.D. recipient from the ASU Department of Geography, works with the Vulnerability Team on in-depth case studies of how peri-urban communities adapt to water scarcity. Seung-Jae Lee, a Ph.D. from the Department of Environmental Sciences and Engineering from the University of North Carolina, specializes in environmental modeling, geostatistics, and data uncertainty. Lee

recently joined the DCDC modeling team utilizing his expertise on studies of the urban heat island and land use prediction.

## IV. Education and Outreach

### Education

*Graduate Education:* To date, 20 graduate students from the School of Life Sciences, the Center for Science, Policy and Outcomes, and the Departments of Geography, History, Political Science, Psychology, and Communications have participated in DCDC projects. To facilitate greater collaboration among graduate students working on DCDC projects, we will require all research assistants to participate in a one-credit graduate seminar, 'Community of Graduate Scholars,' in Fall 2006 and Spring 2007. The purpose of the seminar is to bring together graduate students working on sustainability and water issues and to build cross-disciplinary dialogues and interdisciplinary perspectives. One goal of the seminar is to organize a poster symposium for the 2007 AAAS meetings and include students from across the DMUU centers.

*Undergraduate Education:* In 2005-2006, DCDC funded four REU students who participated in the University's Community of Undergraduate Research Scholars (COURS) program sponsored by the ASU Barrett Honors College. 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 (SCERP), the Urban Ecology Integrative Graduate Education and Research Training (IGERT) program, the Biocomplexity project and other NSF sponsored projects. The 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 on May 3, 2006, hosted by DCDC. More than half of these students will present their posters at a national meeting. The COURS program epitomizes DCDC's goal of linking undergraduate education to research and decision making in a collaborative andinterdisciplinary environment.

*K-12 Education:* The DCDC Education Team conducted a Water Education Provider Survey to identify water education providers (WEPs) and to determine the audiences, content, goals, and communications tools used by these local organizations. DCDC's K-12 education program aims to enhance the activities of these groups and ideally will use their networks to disseminate and test new learning tools and strategies. The response rate was 28.6% for individuals and 41.7% for organizations, with 22 surveys being completed and returned from 20 different organizations. Results of the survey indicate that existing providers use conventional methods of information dissemination such as booths at community events, print media, television, newsletters, and teacher workshops. Emphasis is on factual messages that promote water conservation. Existing WEPs are disinclined to participate (or be seen to participate) in debate about water and lobbying for water policy.

On December 7, 2005, we hosted a Water Educators Forum where 19 participants discussed their needs in relation to DCDC's research products. Particular interest was expressed in scientific materials that connect land use change with the urban heat island and its effects on water consumption, that create scenarios of the future based on drought on conservation practices, and that employ GIS and satellite maps and images.

In conjunction with the University of Arizona's Water Resources Research Center and the Salt River Project, the region's major water supplier, DCDC will host the Advanced Water Education Workshop for approximately 30 formal and non-formal educators on July 17 to 19, 2006. The goal is to create materials that enhance learning about climate change, drought, reclaimed water and the effects of urban growth on water scarcity.

## Outreach

### *Community Partners-Collaborative Research*

*Salt River Project:* (Ongoing) 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. SRP is also a partner with DCDC and UA's Water Research Research Center on a summer 2006 workshop for teachers to be 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 2005. City representatives presented two DCDC monthly Water/Climate Briefings.

*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 team 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 state-wide initiative to facilitate cross-university research about water resource management. Focus thus far is on developing the Arizona Hydrologic Information System.

*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 community 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.

*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***

The Decision Center for a Desert City (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 will convene 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 will be used to help DCDC develop research priorities and to provide regional water managers with information regarding potential vulnerabilities.

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. In Summer 2006, a senior undergraduate research student from York University (Ontario, Canada) will spend a month working on the Southwest Water Information Project to assist with online interactive atlas development.

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. Underway currently in the DT is the development of a prototype for the DCDC Water Model, including different climate-change and technological conditions as well as policies and decisions about the nature of urban growth and the built environment.

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, which is currently in the field, asks 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. 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. A summer 2006 summit is planned to develop a research agenda to investigate human and ecological adaptations to future climate change.

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.

Decision research at DCDC includes a partnership between L. Robin Keller (University of California at Irvine Graduate School of Management) and ASU faculty. The multi-objective decision analysis work performed in Year 1 is the foundation for developing decision-focused evaluation metrics for use with the models that are being developed within DCDC.

The Community of Undergraduate Research Scholars (COURS) provides opportunities for undergraduate students enrolled in the Barrett Honors College to contribute to DCDC research. DCDC hosted a poster session highlighting the interdisciplinary work of more than a dozen students. Faculty associated with DCDC, IGERT, the Southwest Consortium for Environmental Research and Policy (SCERP), CAP LTER and other NSF-funded projects oversaw the research presented.

DCDC is partnering with UA's Project Wet and the Salt River Project to host a summer teacher training workshop, where 30 teachers from K-12 schools in the Phoenix Metropolitan area will develop new learning materials based on local environmental issues such as water scarcity, water recycling, and the urban heat island. The new learning materials will be based upon DCDC research, data sets, and outreach activities.

***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 will sponsor an internship in 2006-07. The student will create a planning tool, such as a groundwater model or GIS database.

*City of Mesa:* (2006-07) Under DCDC auspices and supervision, the City of Mesa Utilities Department will sponsor an internship for an undergraduate student. The intern will be assigned to work under a Water Resources Specialist in the Resources Division of the Utilities Department to assist in the development of the Division's Reclaimed Water Master Plan.

*AZ Groundwater Replenishment District:* (2006-07) Under DCDC's auspices and supervision, the Central Arizona Groundwater Replenishment District will sponsor an internship for undergraduate students. The intern will serve on a team responsible for annual reporting processes and provide assistance in establishing
and implementing a conservation grant program for the District.

**Outreach Activities**

DCDC's water/climate briefings continue to draw participants from the academic and practitioner communities. Speakers in Year 2 included community partners and academic colleagues whose topics served to increase the understanding of decision making processes in water resources management. Five briefings were held in Year 2 with total attendance of nearly 300 individuals.

- *Tucson Turnaround & Beyond*, was presented May 3, 2006 by David Modeer, Director of Tucson Water. Modeer discussed water use in Tucson and comparative factors with the Phoenix region.

- *A New Plan for Operations of the Colorado River Reservoirs: How the Basin States Proposal Was Developed*, was presented April 5, 2006 by Herb Dishlip of Herb Dishlip Consulting. Dishlip discussed the 2006 agreement between the seven basin states on a drought management plan.

- *Factors Influencing Water Resources Management*, was presented March 1, 2006 by Elizabeth Wentz, Ph.D. of ASU's Department of Geography and L. Robin Keller, Ph.D. of the Paul Merage School of Business at the University of California, Irvine. Results of DCDC research were presented. Wentz presented results of her work with Gober that identified the determinants of residential water demand in the City of Phoenix. Keller presented findings from a survey conducted with Kirkwood that identified stakeholder values in decisions related to water management.

- *Salinity Issues in Arizona*, was presented December 7, 2006, by Carol Erwin of the U.S. Bureau of Reclamation. Erwin presented results of the Central Arizona Salinity Study, and discussed implications for the future of the Phoenix region's water supply.

- *Colorado River Law: Key Points of Tension*, was presented September 7, 2005, by William Swan, attorney. Swan provided an overview of the Law of the River and the ongoing litigation and pending legislation affecting Arizona's rights to the water supply.

DCDC also co-sponsored several lectures with one or more of the academic units at ASU. These collaborations brought 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. Titles of the lectures are listed below:

- *Implications of Climate Change for Human-Dominated Systems* was presented April 13, 2006, by William Easterling, Professor of Geography and Earth System Science and Director, Penn State Institute of the Environment, Pennsylvania State University. Co-sponsors of the lecture were the Department of Geography and the Consortium for Science, Policy and Outcomes.

- *3-D Tel Aviv Dynamics* was presented February 9, 2006, by Daniel Czamanski of the Department of City and Regional Planning, Technion Institute of Technology, Israel. Czamanski is also the Director of the City Complexity Research Lab and Chairman of Czamanski-Ben Shahar and Company. This lecture was co-sponsored by the School of Planning and the Department of Geography.

- *The Virtual London Project* was presented November 8, 2005, by Michael Batty, Director of the Centre for Advanced Spatial Analysis, University College London. This lecture was co-sponsored by the Department of Geography.

- *Representation and Visualization in Environmental Policy* was presented October 28, 2005, by Roopali Phadke and Steven Jackson. Phadke is an Assistant Professor of Policy and Politics in the Department of Environmental Studies at Macalester College, and Jackson is an Assistant Professor of Information in the School of Information at the University of Michigan in Ann Arbor. Co-sponsors of the lecture were GIoS, the Decision Theater, and the Consortium for Science, Policy and Outcomes.

- *Water and Empire in the U.S. and China*: *A Comparative View of Hydraulic Societies*, and *The View from the Grand Canyon: Enlarging our Sense of History* were presented October 12 -13, 2005, by Donald Worster, Hall Distinguished Professor Chair in American History, University of Kansas. These lectures were co-sponsored by the Institute for Humanities Research and the Departments of Geography and History.

- *RAND's Approach to Robust Decision Making: Some Diverse Examples* was presented October 11, 2005, by Mark Bernstein, Ph.D., Senior Policy Researcher at the RAND Corporation. This lecture was co-sponsored by the Decision Theater.

- *Robust Decision Making: Identifying Long-Term Water Resources Management Strategies* was presented October 5, 2005, by David Groves, consultant working for the RAND Corporation and Evolving Logic. This lecture was co-sponsored by the Decision Theater.

- *Shaping the Future* was presented July 21, 2005, by Steven C. Bankes, computer scientist at the RAND Corporation. This lecture was co-sponsored by the Decision Theater.

DCDC will launch the Southwest Water Information Project (SWIP), an online, interactive atlas in mid-summer 2006. SWIP began as a collaborative effort with the University of Arizona's SAHRA program as a regional water information system for cross-city analyses of water issues in Phoenix and Tucson. The online atlas will identify the spatial characteristics of water consumption along with climatic conditions, demographics, and temporal land use changes.

**Dissemination of Research Projects and Results**

Research findings are regularly presented to the local community, as well as to the international academic community. Co-Director Gober regularly presents DCDC research goals and results to community groups, students and other academic institutions. The Web site (http://dcdc.asu.edu) is consistently updated to detail specifics of the project and provide materials from presentations, meetings, and briefings. It also serves as a central repository for other DMUU project details as presented at the December 15, 2005, Investigator's Meeting. Since August 2005, the DCDC web site has seen a substantial increase in both the number of hits (increased 240%) and files returned to users (increased by 260%). The amount of data transferred to remote users increased by 625%. Data transfer figures are actually much higher as data from the DCDC data repository are not reflected in these figures. The average number of visits (from unique IP addresses) the site receives on a monthly basis ranges from 1100 to 1800.

**Community Outreach Presentations and Miscellaneous Activities**

***2005***

Bolin, B., Youngs, Y., Tluczek, M., Collins, T., 2005. Drought, Rural Growth and Vulnerability in the Salt Verde Watershed. Presented at the Annual Meeting of the Arizona Planners Association, Prescott, Arizona. September 27-29, 2005.

Brazel, A., 2005. Latest Urban Climate Research at ASU. Presented at the Greater Phoenix Water Educators Forum, Tempe, Arizona. December 6, 2005.

Gammage, G., 2005. Arizona Technical Advisory Panel. Presented at the Urban Land Institute, Tempe, Arizona. October 5, 2005.

Gammage, G., 2005. Competitiveness Forum, Arizona Association for Economic Development, Phoenix, Arizona. December 8, 2005.

Gammage, G., 2005. Growth and Water. Presented at the Colorado River Water User's Conference, Las Vegas, Nevada. December 15, 2005.

Gammage, G., 2005. Growth, Resources, and Water. Presented at the Association of Pacific Coast Geographers, Phoenix, Arizona. October 19, 2005.

Gammage, G., 2005. Panel Discussion: Groundwater Banking and Recharge. Presented at SAHRA - Sustainability of Semi-Arid Hydrology and Riparian Areas, University of Arizona, Tucson, Arizona. October 26, 2005.

Gammage, G., 2005. Phoenix and New Orleans. Presented to Tulane Architecture Student Visitors, Arizona State University, Tempe, Arizona. November 7, 2005.

Gammage, G., 2005. Responsible Growth. Presented at the Responsible Growth Dinner sponsored by Peggy Neely, Phoenix, Arizona. December 12, 2005.

Gammage, G., 2005. State Trust Land Reform. Presented at the Greater Phoenix Leadership, Phoenix, Arizona. November 17, 2005.

Gammage, G., 2005. Water and Growth. Presented at the Nevada Water Resources Association, Las Vegas, Nevada. October 14, 2005.

Gammage, G., 2005. Where is the Valley Going? Presented to Valley Leadership, Mesa, Arizona. November 4, 2005.

Gammage, G., 2005. Young Leaders. Presented at the Urban Land Institute, Phoenix, Arizona. October, 12, 2005.

Gober, P., 2005. Decision Center for a Desert City. Presented at the Graduate Student Brown Bag, ASU Department of Geography, Tempe, Arizona. November 2, 2005.

Gober, P., 2005. Decision Center for a Desert City. Presented at the Graduate Student Brown Bag, ASU Department of Anthropology, Tempe, Arizona. November 17, 2005.

Gober, P., 2005. Decision Center for a Desert City. Welcoming Address presented at the Water Educators Forum, Tempe, Arizona. December 6, 2005.

Gober, P., 2005. Metropolitan Phoenix: Place Making and Community Building in the Desert. Keynote address, presented at the Annual Meeting of the Association of Pacific Coast Geographers, Phoenix, Arizona. October 17, 2005.

Grossman-Clarke, S., Zehnder, J. A., 2005. Remote Sensing Derived Land Use/Cover Data for Urban Modeling in MM5 and WRF. Presented at the Fifth WRF Land Surface Modeling Workshop, National Center for Atmospheric Research, Boulder, Colorado. September 13-15, 2005.

Guhathakurta, S., 2005. Simulating and Visualizing Phoenix Urban Futures with URBANISM Modeling Environment. Presented at the Jornada Basin Long Term Ecological Research site, New Mexico State University, Las Cruces, New Mexico. December 2, 2005.

Guhathakurta, S., Gaver, S., Gober, P., Grossman-Clarke, S., Zehnder, J., 2005. The Impact of Urban Heat Islands on Water Use: The Case of Phoenix Metropolitan Area. Presented at the North American Meetings of the Regional Science Association International, Las Vegas, Nevada. November 11, 2005.

Keller, L. R., Kirkwood, C., Jones, N., 2005. Decision Research in Water Resources Management: A Multi-Objective, Multi-Stakeholder Analysis. Presented at the The Institute for Operations Research and the Management Sciences (INFORMS), San Francisco, California. November 13, 2005.

Zehnder, J. A., 2005. Modeling the Urban Heat Island. Presented at the Arizona Planning Association Conference, Prescott, Arizona. September 29, 2005.

***2006***

Collins, T., Youngs, Y., Tluczek, M., Bolin, B., 2006. Growth and Groundwater in Highland Arizona: The Political Ecology of a Contested Resource. Presented at the Hawaii International Conference on Social Sciences, Honolulu, Hawaii. May 31-June 3, 2006.

Gober, P., 2006. Decision Center for a Desert City. Presented to the Chinese Academy of Sciences, Tempe, Arizona. April 24, 2006.

Gober, P., 2006. Demographic Trends and the Future of Phoenix. Presented at the National Association of Real Estate Investment Managers, Phoenix, Arizona. March 7, 2006.

Gober, P., 2006. Facilitating Undergraduate Research in an Interdisciplinary Environment. Keynote address presented at the Annual Meeting of the Council for Undergraduate Education, DePaw University, Greencastle, Indiana. June 24, 2006.

Gober, P., 2006. Joining Physical and Human Geography to Re-imagine Urban Systems. Presented at the University of Minnesota, Department of Geography, Minneapolis, Minnesota. February 2, 2006.

Guhathakurta, S., 2006. The Impact of Urban Heat Island on Water Use: The Case of Phoenix Metropolitan Area. Presented at the City of Phoenix Urban Heat Island Task Force, Phoenix, Arizona. March 6, 2006.

Hedquist, B. C., 2006. Spatial Expansion of the Greater Phoenix Urban Heat Island: 1990-2004. Presented at the 102nd Annual Meeting of the Association of American Geographers. Chicago, Illinois. March, 2006.

Holway, J., 2006. Ensuring Sustainable Water Supplies for New Growth. Presented at the American Planning Association National Conference, San Antonio, Texas. April 22-26-2006.

Kirkwood, C. W., Keller, L. R., Jones, N. S., 2006. Water Resource Management Priorities for Central Arizona Water Experts. Presented at the ASU Decision Center for a Desert City Water Briefing, Tempe, Arizona. March 1, 2006.

Larson, K. L., 2006. Attitudes Toward Water Resource Protection: Differences Between Participants and Non-Participants of Place-Based Urban Ecosystem Research. Presented at the Consortium Symposium, Portland, Oregon. January, 2006.

Larson, K. L., 2006. Human-Environment Research on Urban Ecology and Water Resources: A Developing Agenda and Evolving Conceptual Frameworks. Invited colloquium presentation at Portland State University, Department of Geography, Portland, Oregon. January, 2006.

Larson, K. L., 2006. Human-Environment Research: Implications for Policy & Public Outreach Panel: Environmental Research, Education, and Action: Make a Difference. Presented at the Fulbright Scholar Enrichment Seminar. February, 2006.

Quay, R., 2006. Use of Scenario Planning to Address Uncertainty in Water Resource Planning, Presented at the American Planning Association National Conference, San Antonio, Texas. April 22-26, 2006.

Wentz, E., Gober, P., 2006. Factors influencing water consumption for the City of Phoenix, Arizona. Presented at the Association of American Geographers, Chicago, Illinois. March, 2006.

Zehnder, J., 2006. Phoenix in the Future: Sustainability in a Rapidly Urbanizing Region. Presented at the Phoenix College Library Forum Discussion. February 9, 2006.

**Publications and Products**

***Books***

Gober, P., *Metropolitan Phoenix: Place Making and Community Building in the Desert*, bibl. University of Pennsylvania Press, Philadelphia, PA., (2006).

***Articles Published***

Allen, P., Torrens, P. M., "Knowledge and complexity", *Futures*, vol. 37, (2005), p. 581.

Anderies, J., Walker, B., and Kinzig, A.P., "Fifteen weddings and a funeral: Case studies and resilience-based management", *Ecology and Society*, vol. 11, (2006), p. 21.

Batty, M., Torrens, P. M., "Modeling and prediction in a complex world", *Futures*, vol. 37, (2005), p. 745.

Collins, T., "Households, forests, and fire hazard vulnerability in the American West: A case study of a California community", *Global Environmental Change B: Environmental Hazards*, vol. 6, (2005), p. 23.

Cumming, G. S., Cumming, D. M., Redman, C. L., "Scale mismatches in social-ecological systems: Causes, consequences, and solutions", *Ecology and Society*, vol. 11, (2006), p. 14.

Grossman-Clarke, S., Zehnder, J.A., Stefanov, W.L., Liu Y. and M.A. Zoldak, "Urban modifications in a mesoscale meteorological model and the effects on near surface variables in an arid metropolitan region", *Journal of Applied Meteorology*, vol. 44, (2005), p. 1281.

Hedquist, B. C., Brazel, A. J., "Urban, residential, and rural climate comparisons from mobile transects and fixed stations: Phoenix, Arizona", *Journal of the Arizona-Nevada Academy of Science*, vol. 37, (2006), p. 77.

Jacobs, K. L., Garfin, G. M., Lenart, M., "More than just talk: Connecting science and decisionmaking", *Environment*, vol. 47, (2005), p. 6.

Killeen, P. R., "An alternative to null-hypothesis significance tests", *Psychological Science*, vol. 16, (2005), p. 345.

Killeen, P. R., "Replicability, confidence, and priors", *Psychological Science*, vol. 16, (2005), p. 1009.

Kinzig, A.P., Ryan, P., Etienne, M., Elmqvist, T., Allison, H., & Walker, B.H., "Resilience and regime shifts: Assessing cascading effects", *Ecology and Society*, vol. 11, (2006), p. 20.

Redman, C.L., and Jones, N.S., "The environmental, social, and health dimensions of urban expansion", *Population and Environment*, vol. October, (2005), p. 1.

Sanabria, F., Killeen, P. R., "Freud meets Skinner: Hyperbolic curves, elliptical theories, and Ainslie Interests", *Behavioral and Brain Sciences*, vol. 28, (2005), p. 660.

Torrens, P. M., "Simulating sprawl", *Annals of the Association of American Geographers*, vol. 29, (2006), p. 248.

Torrens, P. M., Benenson, I., "Geographic automata systems", *International Journal of Geographic Information Science*, vol. 19, (2005), p. 385.

Walker, B.H., Anderies, J.M., Kinzig, A.P., and Ryan, P., "Exploring resilience in social-ecological systems: Comparative studies and theory development", *Ecology and Society*, vol. 11, (2006), p. 12.

Walker, B.H., Gunderson, L., Kinzig, A.P., Folke, C., Carpenter, S., & Schulze, L., "A handful of heuristics: Propositions for understanding resilience in social-ecological systems", *Ecology and Society*, vol. 11, (2006), p. 13.

Walker, B.H., Kinzig, A.P., Anderies, J.M., and Ryan, P., "Introduction", *Ecology and Society*, vol. 11, (2006), p. 1.

***Articles in Press***

Bush, J., Guhathakurta, S., Keane, J., Dworkin, J., "Examination of Phoenix regional water supply for sustainability and economic carrying capacity", *Natural Resources Journal*, (2006).

Garrick, D., Jacobs, K. L., "Water management on the Colorado River: From surplus to shortage in five years", *Southwest Hydrology*, (2006).

Hartz, D. A., Brazel, A. J., Heisler, G. M., "A case study in resort climatology of Phoenix, Arizona, USA", *International Journal of Biometeorology*, (2006).

Killeen, P. R., "Beyond statistical inference: A decision theory for science", *Psychonomic Bulletin & Review*, (2006).

Killeen, P. R., "The problem with Bayes", *Psychological Science*, vol. 17, (2006).

Kinzig, A.P., Ryan, P.,Etienne, M., Elmqvist, T., Allison, H., & Walker, B.H., "Resilience and regime shifts: Assessing cascading effects", Special Issue in *Ecology and Society*, (2006).

Larson, E. K., Grimm, N. B., Gober, P., Redman, C. L., "The paradoxical ecology and management of water in the Phoenix, USA metropolitan area", *Ecohydrology & Hydrobiology*, vol. 5, (2006).

Torrens, P. M., "A geographic automata model of residential mobility", *Environment & Planning B*, vol. 37, (2006).

***Articles Accepted***

Balling, R.C., Jr., and G.B. Goodrich, "Analysis of drought determinants for the Colorado River Basin", *Climatic Change*, (2006).

Hartz, D., Prashad, L., Hedquist, B. C., Golden, J., Brazel, A. J., "Linking satellite images and handheld infrared thermography to observed neighborhood climate conditions", *Remote Sensing of Environment* (Urban Thermal Special Issue), (2006).

Torrens, P. M., "A geographic automata model of residential mobility", *Environment & Planning B*, (2006).

Torrens, P. M., Nara, A., "Modeling gentrification dynamics: A hybrid approach", *Computers, Environment and Urban Systems*, (2006).

***Articles Submitted***

Ellis, A.W., G Goodrich, and J.A. Skindlov, "An ensemble method for forecasting seasonal precipitation: Winter variability on Arizona watersheds", *Weather and Forecasting*, (2006).

Ellis, A.W., Garfin, G., Balling, R.C., and Graham, C.J., "A hydroclimatic concept for monitoring drought derived from the climate of the Southwestern United States", *Annals of the Association of American Geographers*, (2006).

Garrick, D., Jacobs, K.L., Garfin, G.M., "Decision making under uncertainty: Shortage, stakeholders and modeling in the Colorado River Basin", *Journal of the American Water Resources Association*, (2006).

Wentz, E., and Gober, P., "Factors influencing water consumption for the City of Phoenix, Arizona", *Water Resources Management*, (2006).

White, D.D., Corley, E.A., and White, M.S., "Water managers' perceptions of the science-policy interface in Phoenix, Arizona USA", *Society and Natural Resources*, (2006).

***Chapters***

Holway, J.M., and Jacobs, K.L., "Managing for sustainability in Arizona, USA: Linking climate, water management and growth," bibl. McGraw-Hill, (2006). Chapter Submitted of Collection: Mays, L., "Water Resources Sustainability"

Redman, C. L., "The urban ecology of metropolitan Phoenix: A laboratory for interdisciplinary study," bibl. Washington, D.C., National Research Council, 163-192, (2005). Chapter Published of Collection: Entwisle, B., Stern, P. C., "Population, Land Use, and Environment: Research Directions"

Torrens, P.M., "Agent-based models," bibl. New York, CRC Press, (2006). Chapter In Press of Collection: Warf, B., "Dictionary of Human Geography"

Torrens, P.M., "Geosimulation and its application to urban growth modeling," bibl. London, Springer-Verlag, 119-134, (2006). Chapter Published of Collection: Portugali, J., "Complex Artificial Environments"

Torrens, P.M., "Remote sensing as dataware for human settlement simulation," bibl. New York, John Wiley and Sons, 693-699, (2006). Chapter Published of Collection: Merrill, R. J., Hipple, J. D., "Remote Sensing of Human Settlements"

***Theses and Dissertations***

Collins, T., "The production of hazard vulnerability: The case of people, forests, and fire in Arizona's White Mountains," bibl. Ph.D. Dissertation, Department of Geography, Arizona State University, K. McHugh, advisor. Winner of the Gilbert F. White Award of the Hazards Specialty Group of the AAG, (2005).

Graham, C. J., "Hydroclimatic indexing method for drought monitoring," bibl. (2006) Fulbright Award-winning Honors Thesis, Department of Geography, Arizona State University, Tempe, AZ

***Conference Proceedings***

Edsall, R., Larson, K., "Decision making in a virtual environment: Effectiveness of a semi-immersive 'Decision Theater' in understanding and assessing human-environment issues," bibl. Cartography and Geographical Information Society, (2006). Submitted to: "Proceedings of AutoCarto 2006, Vancouver, WA, June 25-28, 2006"

Griffin, W.A., and Schmidt, S.K., "Simulating decisions of water usage in uncertain times in the Southwestern US: An ABM of strategies and population level actions," bibl. Argonne National Laboratory, The University of Chicago, (2005). Published of Collection: Macal, C. M., North, M. J., Sallach, D. C., "Agent 2005: Generative Social Processes, Models, and Mechanisms. October 13-15, 2005"

Jacobs, K. L., Colby, B., Meko, D., Nijjsen, B., "Enhanced water supply reliability through improved predictive capacity and response," bibl. American Geophysical Union, (2005). Published of Collection: "American Geophysical Union Fall Meeting, San Francisco, CA, December 7, 2005"

***Posters***

Hartz, D. A., Hedquist, B. C., Prashad, L., Golden, J., Brazel, A. J., 2005; Linking satellite (ASTER) images and thermography to observed neighborhood climate conditions for use in urban heat island research. Association of Pacific Coast Geographers, Annual Meeting. Phoenix, Arizona. October, 2005.

Balling Jr, R. C., Goodrich, G. B., 2006; Drought determinations for the Colorado River Basin. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/DroughtDeterminants.pdf to view this poster).

Collins, T., Bolin, B., Youngs, Y., Tluczek, M., 2006; Peri-urban growth, water conflicts, and vulnerability in the Verde watershed. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/vulnerability.pdf to view this poster).

Ellis, A., Garfin, G., Balling, Jr., R., Graham, C., 2006; A hydroclimactic indexing concept for monitoring drought. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/DroughtMonitoring.pdf to view this poster).

Guhathakurta, S., 2006; Impact of urban heat island on residential water use. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/impactofUHI.pdf to view this poster).

Hartz, D., Golden, J., Brazel, A., Hedquist, B., Kaloush, K., 2006; Case study of thermographic observations of surface materials' cooling rates and neighborhood design in suburban Phoenix, Arizona. Poster presented at the Sixth Symposium on the Urban Environment, American Meteorological Society. Atlanta, Georgia. January, 2006.

Hedquist, B. C., Comparri, E., 2006; Spatial expansion of the greater Phoenix urban heat island (1990-2004). Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/UrbanHeatIsland.pdf to view this poster).

Kirkwood, C., Keller, L. R., Jones, N., 2006; Decision research in water resources management: A multiple-objective, multple-stakeholder analysis. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/waterresourcemanagement.pdf to view this poster).

Kruger, M., Larson, K., Edsall, R., Block, J., 2006; The effects of 3D visualization on lay perspectives of environmental issues. Community of Undergraduate Research Scholars Poster Symposium, Arizona State University, Tempe, AZ, May 3, 2006. (Please visit http://dcdc.asu.edu/COURS/kruger.pdf to view this poster).

Lant, T., 2006; A system dynamics model for water supply and demand in greater Phoenix. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/watermodel.pdf to view this poster).

Lant, T., Wentz, E., 2006; A spatial decision support tool for regional water managers: scenarios for predicting residential water consumption. Poster presented at the Decision Support Systems Symposium, Tucson, AZ, May 4, 2006.

Larson, K. L., 2006; Geographic, social science & interdisciplinary perspectives on urban ecology: A developing research agenda. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006.

Larson, K. L., Edsall, R., Block, J., Kruger, M., 2006; Environmental awareness and perceptions among lay and expert groups: Cognitive responses to three-dimensional visual information displays. Poster presented at the International Conference on Society and Natural Resources, Vancouver, BC, June, 2006.

Murphy, J. T., Kinzig, A. P., 2006; The Hohokam water management simulation: Collaborative modeling of a complex coupled human/environmental system. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006.

Peterson, A., Howe, P., White, M., White, D., Corley, E., 2006; Expert perspectives on science, politics, and water management in Phoenix. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/expertperspectives.pdf to view this poster).

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Tluczek, M., Bolin, B., Collins, T., Youngs, Y., 2006; Towards an understanding of rural water: Perceptions and micro-politics in Cottonwood, Arizona. Poster presented at the

Community of Undergraduate Research Scholars Poster Symposium, Arizona State University, Tempe, AZ, May 3, 2006. (Please visit http://dcdc.asu.edu/COURS/tluczek.pdf to view this poster).

Wentz, E., Gober, P., 2006; Factors influencing residential water consumption for the city of Phoenix, Arizona. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006. (Please visit http://dcdc.asu.edu/research/Residentialwateruse.pdf to view this poster).

Zoldak, M., Lemar, S., Jensen, R., Hutchins, J., 2006; Workflows: GIS data to a visualization environment. Poster presented at the 8th Annual CAP LTER Poster Symposium, Global Institute of Sustainability, Arizona State University, Tempe, Arizona, January 19, 2006.

***Technical Reports***

Taylor, T., A statistical-temporal analysis of Phoenix Water Data from 2000. http://math.asu.edu/~tom/statsreport/Report.html.

## V. Contributions

*Contributions within Discipline:*

DCDC provides a framework for nourishing interdisciplinary research and training for graduate students. Although original contributions will result from disciplinary research, DCDC's real value added is in providing an intellectual environment and social network that makes it possible to transcend disciplinary boundaries and ask larger questions about the sustainability of urban environmental systems, about decision making in the face of risk and uncertainty, and about human vulnerabilities in the face of resource scarcity.

At the core of these contributions are integrative modeling efforts and decision support tools. Our agent-based model simulates water use in the face of media conservation campaigns and emerging water markets. The model uses the products of our disciplinary research about residential water use, and its results feed into our larger systems dynamics model of water supply and demand. The latter integrates what we have learned about the sensitivity of our water supply to climate change, the sensitivity of demand to the urban heat island, and public attitudes about policy decisions regarding recycled water, pool use, and landscaping choices.

*Contributions to Education and Human Resources:*

DCDC provides a framework for training graduate students, nourishing interdisciplinary projects and contributing to the fields of geography, decision research, vulnerability analysis, and agent-based modeling. Our project is also committed to engaging undergraduate students and K-12 teachers, community organizations, government agencies, and the general public in our interdisciplinary investigation of climate change and human decision making. Graduate students are drawn from a wide range of disciplines, including geography, psychology, political science, family science, communications, plant biology, and microbiology.

*Contributions to Resources for Research and Education:*
DCDC's setting within a large public institution enhances its ability to leverage research and outreach programs for educational benefit. To date, 20 graduate students have been engaged in DCDC research programs. DCDC is a founding partner and collaborator in the university's new 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.

DCDC's close collaboration with the Decision Theater (DT) offers myriad opportunities to link research and education. The DT is not only a setting to view visualizations but also a laboratory for studying and engaging decision makers. We anticipate examining the way research and educational infrastructure melds together in the DT.

*Contributions Beyond Science and Engineering:*
DCDC's core mission is to produce the scientific understanding and support tools that will lead to better water decision making and a more sustainable future for Phoenix, the fastest-growing large metropolitan area in the United States. Results and modeling products can be adapted to other regions experiencing rapid growth, water scarcity, and climatic uncertainty.

DCDC 2005 Annual Report – Appendix A
**Participants 2005-2006**

*Principal Investigators/Project Directors*
Patricia Gober, Geography
Charles L. Redman, Global Institute of Sustainability

*Co-Principal Investigators*
Bob Bolin, Anthrolpology
Grady Gammage, Jr., Morrison Institute for Public Policy
Thomas Taylor, Mathematics and Statistics

*Senior Personnel: Core Scientists*
John Anderies, School of Life Sciences
Brad Armendt, Philosophy
Richard Aspinall, Geography
Robert Balling, Geography
Anthony Brazel, Geography
Elizabeth Corley, School of Public Affairs
Robert Edsall, Geography
Andrew Ellis, Geography
Monica Elser, Global Institute of Sustainability
Gregg Garfin, CLIMAS, University of Arizona
Corinna Gries, Global Institute of Sustainability
William Griffin, Family & Human Development
Suzanne Grossman-Clarke, Global Institute of Sustainability
Subhrajit Guhathakurta, School of Planning
Ed Hackett, Anthropology
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City of Phoenix
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