Central Arizona–Phoenix
Long-Term Ecological Research: Phase 2

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CAP LTER PHASE 2
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I. Overview of Results and Broader Impacts

Overview

CAP2 is the second phase of the Central Arizona–Phoenix Long-Term Ecological Research (CAP LTER) project (NSF #DEB-0423704). As one of two urban sites funded in the US LTER network, CAP LTER is advancing knowledge and theory in urban ecology through long-term monitoring, long-term experiments, and associated research projects. With other scientists globally, CAP LTER scientists are also expanding the horizons of socioecological research (Redman et al. 2004; Haberl et al. 2006).

The CAP LTER study area is located in the 6400-km^2 central Arizona and metropolitan Phoenix region, embedded in the Sonoran Desert, and situated in a broad, alluvial basin where two major desert tributaries of the Colorado, the Salt and Gila Rivers, converge. The basin, dotted with eroded volcanic outcrops and rimmed by mountains, once supported a vast expanse of lowland desert and riparian systems and now houses the fifth-largest city in the USA. Annual precipitation (~18 cm) falls in two distinct seasons, resulting in high biodiversity in desert areas. Undeveloped desert in the valley floor is dominated by widely spaced, low shrubs, primarily creosote, bursage, and brittle bush, while a rich and denser Saguaro-Palo Verde forest covers the foothills. Urbanization has replaced native desert vegetation with mostly irrigated exotics, with ramifications for higher trophic levels.

In this report, we highlight projects within each of the integrative project areas, which were chosen to encompass the traditional LTER core areas while embracing an interdisciplinary approach. We also report progress on over-arching monitoring and experimental programs that cross all of the project areas, and on development of data resources and information technology. We have made progress in ecosystem modeling applied to the desert region and in models of urban growth specific to Phoenix. In CAP1, we established an extensive long-term integrated field inventory (Survey 200), to be repeated every five years, and this year we continued to analyze data from the second survey, conducted in spring 2005. Experimental work at North Desert Village, a residential area on the ASU Polytechnic campus, has proceeded and the initial research results have shed light on household landscape perceptions.

CAP LTER participants have published 238 journal articles, books, and book chapters since the project's inception in 1997 through August 2007. Since the last annual report, CAP scientists have published 46 articles, books or book chapters, in addition to 22 currently in press and 17 in review. Over 300 individuals have been involved with the project since 2004, including 76 faculty members, 9 senior project managers, 12 post-doctoral scholars, and 40 technicians, support staff, and K-12 education personnel. Sixty-eight graduate students have been involved in the project, including 33 fellows in the Integrative Graduate Education and Research Traineeship (IGERT) in Urban Ecology, which is housed in the Global Institute of Sustainability (GIOS) at Arizona State University, the home of CAP LTER. A total of 88 undergraduates have been involved in CAP LTER since 2004, 73 as student workers on various research and education initiatives, 14 as Research Experience for Undergraduates (REU) students, and one as a fellow of the Ecological Society of America's Strategies for Ecology Education, Development, and Sustainability (SEEDS) program.

Finally, CAP has leveraged funding for several large projects that complement its basic science emphasis. Active during 2006-2007 were: "Agrarian Landscapes in Transition," a multi-LTER project (NSF-BCE, Redman *et al.* 2002); "Decision Center for a Desert City" (NSF-SBE's Decision-Making Under Uncertainty program; Gober *et al.* 2003); a study of the effects of elevated nitrogen and organic carbon deposition in and around the urban ecosystem (NSF-Ecosystems, Grimm *et al.* 2005); and a study of the effects of urbanization on trophic dynamics (NSF-Ecology, Faeth and Sabo 2005).

Broader Impacts

CAP LTER's broader impacts are in three main areas: raising national awareness and profile of urban ecology, education and outreach, and decision making in Greater Phoenix. Individual scientists from CAP have been tapped extensively to contribute to international discussions of urbanization and sustainability; for example, Redman is a member of the international U.S. National Committee on the Scientific Committee on Problems of the Environment (SCOPE). Briggs has been an active participant in NEON and LTER planning activities, and Grimm has been involved in efforts to establish a joint center of sustainability between Arizona State University and the Chinese Academy of Sciences. CAP LTER's program at the K-12 level, Ecology Explorers, has over 100 teacher-participants at 94 public schools (encompassing 25 school districts), 4 charter schools, and 2 private schools. Several faculty members and graduate students participate in ASU's Community of Undergraduate Research Scholars program by mentoring undergraduate students in urban research. We have 19 active fellows, 9 associates, and 11 graduated fellows (emeriti) in our Integrative Graduate Education and Research Training (IGERT) program in urban ecology. Finally, close to 20 community partners are engaged in CAP LTER, such as Salt River Project, Maricopa Association of Governments, the U.S. Geological Survey (USGS), and several local municipalities. Details on our education and outreach efforts appear in sections VI and VII of this report.

The role of CAP in decision making in Greater Phoenix has been enhanced by funded projects that promote community and governmental outreach. While preserving our scientific objectivity, we have benefited from the establishment of projects that are more directly linked to local and regional government. For example, the Greater Phoenix 2100 (GP 2100) project and the Decision Center for a Desert City draw on CAP LTER data to help policy makers and others envision the long-term future of the greater Phoenix region. In addition, our information-management team continues to play a leadership role in developing new IT tools for handling ecological data.

II. Research Activities

Research Design and Approach

Although our program is fundamentally ecological (*sensu* Likens 1992), we include humans among the organisms interacting and participating in fluxes of energy and materials and contend that an ecological study must monitor and interpret change from a perspective that includes humans as part of nature (Cronon 1995; Kinzig et al. 2000, Kaye et al. 2006). Research thus must integrate the social sciences, encompass longer time horizons, and be informed by flexible models and multi-scaled data (Wu and Li 2006).

To fully integrate these components, we have organized our research under five integrative project areas (IPAs):

- Land-use and land-cover change (LULCC)
- Climate-ecosystem interactions (CLIM-ECOS)
- Water policy, use, and supply (WATER)
- Fluxes of materials and socio-ecosystem response (FLUXES)
- Human control of biodiversity (BIODIV)

Several projects are affiliated with multiple IPAs and are described below under the heading "Crosscutting Research": **Survey 200**, the **North Desert Village (NDV) Experiment**, and the neighborhood-scale **Phoenix Area Social Survey (PASS)**. In addition, we report on research activities conducted by formal and short-term working groups within CAP LTER.

Land-Use and Land-Cover Change (LULCC)

Land use and land cover define the context of the socioecosystem, and alterations in their patterns underlie most other ecosystem changes. We ask: *How have land use and land cover changed in the past, and how are they changing today? How do land-use and land-cover changes alter the ecological and social environment in the city, and how do human perceptions of these changes alter future decision-making?*

The LULCC IPA's developing understanding of the answers to these questions sets the stage for all other IPA research. In this report, we highlight findings from the following research:

- **Effects of urbanization on landscape pattern and processes**
- **Legacies on the landscape**
- **Phoenix Area Social Survey results**

Although the PASS is a crosscutting initiative, preliminary results from this survey will be listed under this IPA.

Climate-Ecosystem Interactions (CLIM-ECOS)

Climate is an important driver of processes in most ecosystems, therefore an understanding of microclimate is fundamental to much of our research. Studies of climate-ecosystem interactions (hereafter, CLIM-ECOS) are conducted at multiple scales from single organism to region. Research under this IPA centers on the following questions: *How does human-driven, local climate change compare with longer-term trends and/or cycles of climate in the region? How do regional drivers influence local climate as urbanization proceeds? What are people's perceptions of their local environment, including climate, and how does that affect their assessment of neighborhood or regional quality of life? What are the interactions among local management, local climate, net primary production and vegetation processes?*

Among the research projects addressing these questions in 2005-2006 were:

- **Plant flowering phenology in the Phoenix metropolitan area**
- **Urban heat island**
- **Modeling urban impervious surface areas in relation to urban heat island effects**
- **Mesoscale atmospheric research**

As well, work has continued on publishing analyses from the **Neighborhood Ecosystem Project**, an outgrowth of the PASS project, which is funded through a NSF Biocomplexity and the Environment planning grant (Jenerette et al. 2007; Harlan et al. 2006; Harlan et al. in press; Harlan et al. in review). This project is an interdisciplinary study of the impact of urbanization on human-ecological-climate interactions in Phoenix. Ongoing work on the effect of landscape treatments on net primary production (NPP) and microclimates under the **North Desert Village Experiment** (see project description below) also fall under this IPA.

Water Policy, Use, and Supply (WATER)

Humans now appropriate 100% of the surface flow of the Salt River (Phoenix's river) and are increasingly exploiting groundwater resources and surface waters from more distant basins (e.g., the Colorado River). Controlled management and engineering shift the characteristic spatiotemporal variability of the hydrologic system. The WATER IPA examines the following: *What are the ecological and economic consequences and potential vulnerabilities of shifts in the hydrologic system? What institutional responses best address vulnerabilities arising from shifts in the hydrologic system?*

Within the WATER IPA, we examine landscape water management, water supply and delivery, riparian restoration, and resilience of the socioecosystem to water-related stress or catastrophe. Active projects during 2006-2007 included:

- **Modeling fluxes of water and salt through the urban infrastructure**
- **Drought and water conservation policy in the arid metropolitan Southwest**

Work on aquatic biogeochemical processes and water quality, undertaken in the FLUXES IPA, is closely associated with the work under this area. Work in the WATER IPA is also well integrated with the Decision Center for a Desert City (DCDC), which focuses on water-management issues in the Phoenix area. One such effort begun this year was an initiative that examines policymaker responses to a systems dynamic model known as **WaterSim**. **WaterSim** produces profiles of water shortage conditions under different climate change scenarios, drought conditions, population growth rates, and policy decisions. In this three-year project, the simulation model is shown to Arizona water decision-makers in the ASU Decision Theater, a 3-D visualization facility. Data collection consists of a series of individual and focus groups interviews focusing on the knowledge, values and political constraints underlying decision-making, environmental perceptions, and the use of scientific data in decision making. Researchers are currently analyzing results from the 2007 sessions.

Material Fluxes and Socio-Ecosystem Response (FLUXES)

Material fluxes and biogeochemical linkages have been studied for decades in relatively undisturbed ecosystems, but not in urban ecosystems where human-generated fluxes of nutrients and toxins are coupled with nonhuman biogeochemistry. Questions driving this IPA are: *How do urban element cycles differ qualitatively and quantitatively from those of nonhuman-dominated ecosystems?; What are the sociospatial distributions of anthropogenic toxins and other pollutants in the CAP ecosystem, and what hazards to organisms (plants, animals, humans) result from these distributions?; Do citizens and decision makers accurately perceive these hazards?*

FLUXES is one of the most active IPAs in CAP LTER, and accordingly, it includes many projects. In this report, we highlight the following studies:

- **Environmental risk and justice**
- **Water chemistry of lakes and rivers following winter storm events**
- **Atmospheric deposition**
- **Decoupled biogeochemical cycles: Ecological response to C and N deposition from the urban atmosphere**
- **Belowground nutrient pools and dynamics in xeriscaped yards**
- **Nutrient transport and transformation in urban watersheds**

Work continued on some ongoing initiatives, such as the **lichen resurvey with heavy metal analysis,** which builds on work completed under CAP1 by Zschau et al. (2003). New research, funded under a 2007 NSF Social Science Supplement, has begun that seeks to untangle the variability in urban ecological processes through examining **socioecological drivers of residential landscape management and ecosystem responses**.

Human Control of Biodiversity (BIODIV)

Ecological approaches to studying human control of biodiversity (hereafter, BIODIV) have typically focused upon habitat loss and disturbance brought about by humans at high-population densities. We move beyond these approaches to ask: *How do human activities, behaviors, and values change biodiversity and its components—population abundance, species distribution and richness, community and trophic structure? In turn, how do variations in biodiversity feed back to influence these same human values, perceptions, and actions?*

Studies during 2006-2007 that addressed these questions include:

- Behavior, ecology and evolution of the western black widow
- Trophic dynamics
- Assessing arbuscular mycorrhizal fungi
- Role of transportation corridors in plant migration
- Urban bird dynamics
- Ecological and social interactions in urban parks
- Foraging decisions, bird community structure, and an urban-rural gradient
- Bird census data

The BIODEV team actively participated in **Survey 200** and the **NDV Experiment**, both also described under "Crosscutting Research." Long-term monitoring of bird and arthropod populations has also been a key to CAP research and has continued through this report period. A study of avian populations and neighborhood social variation has been folded into the **PASS** study, and researchers began collecting data in the PASS neighborhoods in winter 2006 and spring 2007. Findings from all of these studies relevant to the aims of the BIODEV IPA will be reported in this IPA's research findings section.

Crosscutting Research

Ongoing research activities include those that cut across and contribute to several IPAs, such as the **Survey 200**, extensive sampling conducted every five years; the **NDV Experiment**; the neighborhood-scale **PASS;** and work recently initiated on **critical ecosystem services**. Although these activities are carried out in a distinct manner, the findings from these research endeavors are integrated into IPA research and are reported as such.

We also have several long-term and short-term working groups, not all of which fall cleanly within the IPA structure. Working groups active during 2006-2007 include: **long-term experiments** and **knowledge exchange**. Here we summarize activities of those working groups, with findings reported under appropriate IPAs.

Survey 200. The Survey 200 is an extensive field survey that provides a snapshot of broad-scale spatial variations in key ecological variables across the CAP region. Designed to be repeated every five years, it also is a central component of CAP's monitoring of ecosystem change over time. The survey has been carried out in 2000 and 2005, and included the following core measurements:

- Plants identified to species
- Plant size measurements
- Soil coring for physicochemical analyses
- Insect sweep-net sampling
- Mycorrhizal diversity.

All plant-voucher specimens have been identified to species and filed in the ASU Vascular Plant Herbarium. Pictures of cacti have been identified as far as possible and also filed in the herbarium. Data are entered and quality controlled in the database, slides of the sites are labeled and filed. Processing and analysis of the soil-core samples collected during the survey is nearly completed. In addition to the nutrient and organic-matter analyses conducted in 2000, all soil samples from the survey in 2005 have been analyzed for trace elements using ICP-MS, with a focus on heavy and trace metals. The first analyses of plant diversity have been conducted and the results are in press (Majumdar et al. in press).

The NDV Experiment. The NDV community landscape experiment at ASU's Polytechnic campus is designed to give a platform for CAP LTER researchers to study human–landscape interactions. Four residential landscape design/water delivery types established in blocks of six households each (mini-neighborhoods) recreate the four prevailing residential yardscape types found across the study area during the last five years of research (Martin et al. 2003; Cook et al. 2004). These are:

- Mesic/flood irrigation: a mixture of exotic high water-use vegetation and shade trees with turf grass.
- Oasis: a mixture of drip-watered, high and low water-use plants on granite substrate, and sprinkler-irrigated turf grass.
- Xeric: individually watered, low water-use exotic and native plants on granite substrate.
- Native: native Sonoran Desert plants on granite substrate and no supplemental water.

Six additional households are monitored as no-plant, no-water controls. Major research questions include: *How do landscape design and irrigation methods affect NPP and under-canopy microclimate, soil nutrient pools and fluxes, insect abundance and diversity, bird activity?, and how does landscape design affect direct human-landscape interactions in terms of both perceptions and behaviors?*

During summer 2005, the landscape and irrigation systems for each of the treatment areas were completed. During spring 2006, micrometeorological stations were installed in the central common area of each treatment. Data continually monitored include soil temperature, soil heat flux, and volumetric water content of soil at 30 cm depth. Air temperature at 2 m height and soil-surface temperature (recorded by an infrared thermometer at 2 m height) are also monitored regularly. Landscape irrigation application volumes are recorded monthly.

Data from the pre-treatment social survey have been analyzed, and findings from this round of research have been published (Yabiku et al. in press; Casagrande et al. 2007). The follow-up social survey began in spring 2006 and continued through summer and fall 2006. Data from this survey are being entered and analyzed.

The NDV research team has begun work on a new, integrated project focusing on ecosystem services of landscape treatments at NDV. Using data from a variety of sources, including infrared surface temperature measurements, the researchers will analyze which of the four NDV landscapes optimizes the trade offs between the following ecosystem services:

- temperature moderation and energy use

- water use
- aesthetics and quality of life
- carbon sequestration

This research will contribute to an academic and public dialogue about the values of various landscape types in the Phoenix area. While water conservation advocates have pressed for the conversion of mesic to xeric landscapes, this research will illuminate the energy-water tradeoffs in such a conversion.

Phoenix Area Social Survey (PASS): In 2001, eight social scientists and one biophysical scientist, all affiliated with the CAP LTER, conducted a pilot social survey of 302 residents in eight neighborhoods in Phoenix (Kirby et al. 2006; Larsen and Harlan 2006). The goal of the study was to increase understanding of how human behavior shapes the dynamics of an urban socioecosystem. PASS parallels the Survey 200 as a major component of our long-term monitoring program. Following the pilot study, we received two supplemental NSF grants in 2004 to enlarge the sample and continue the social survey. The NSF-funded Decision Center for a Desert City (DCDC) made an additional financial contribution to the study. Subsequent surveys, conducted every four to five years, will be part of our core budget.

An expanded team of 20 CAP LTER and DCDC social and biophysical scientists, academic professionals, and graduate students designed the second wave of the PASS in 2005. PASS survey questions engage human perceptions, values, and behaviors concerning the environmental domains emphasized in the IPAs and the focal interests of DCDC:

- Water supply and conservation
- Land use, preservation and growth management
- Air quality and transportation
- Climate change and the urban heat island.

In addition, the survey continues to question residents about community sentiment and perceptions of their neighborhood social, built, and biophysical environments. The intellectual goals of PASS are to help us address the following questions: *How do human communities form, adapt, and function in a rapidly urbanizing region? How do human knowledge, values, and preferences affect behaviors that transform the preexisting ecosystem into an urban landscape? How do spatial variations in ecosystem characteristics relate to social class inequalities and cultural differences across the urbanizing area? How do changes in social, economic, and environmental systems affect the quality of life and vulnerability to environmental hazards for diverse human populations?*

The sample selection of neighborhoods for PASS was accomplished in 2005 by the classification of all Survey 200 sites as either urban or non-urban. Forty neighborhoods were carefully selected from among the 94 urbanized sites to represent a balanced design of neighborhoods by location, income level, ethnic composition, and age. The Institute for Social Science Research (ISSR) at ASU mapped all dwellings within each neighborhood and selected a random sample of households to recruit for participation in the study.

Respondents (in 800 randomly selected households in 40 neighborhoods that are co-located with Survey 200 field sites) began completing the PASS in spring 2006. The survey, which takes 30 to 60 minutes to complete, was available to respondents as an online, telephone, or face-to-face interview in English and Spanish. ISSR staff administered the PASS and managed survey data.

An initial data analysis, including responses frequencies, is complete and more detailed analyses are underway. The research team has compiled the initial research results into a report, which will be distributed to households participating in the study and posted online at the CAP LTER website.

Work has also begun on additional research associated with the PASS. In spring, researchers surveyed scientists associated with GIOS with an instrument similar to the PASS. The objective of this research, funded through a 2006 Supplement, was to obtain a dataset from "experts" and compare it to the responses from the wider PASS sample. Another initiative, funded through a CAP LTER summer grant and an NSF REU, examined safety and crime in parks within PASS neighborhoods. Data collection and analysis for these new initiatives continues.

Critical ecosystem services: A focus on ecosystem services provides a platform for coupling social and ecological research in CAP and in the LTER network. We conducted an analysis of **critical ecosystem services**, based upon the Millennium Ecosystem Assessment (MA)'s global appraisal of the consequences of ecosystem change for human well being. Although the MA assessed over 30 different services in four categories, not all services are of equal importance in all regions. To assess critical ecosystem services in the CAP LTER study region, researchers convened in three teams—an ecological team, a social science (values) team, and a technology team. We defined critical ecosystem services to be those that were ecologically degrading, or degraded but restorable; were highly valued by residents; and had no reasonable substitutes. On this basis, CAP scientists identified five critical ecosystem services for the Phoenix region: fresh-water provisioning; air-quality regulation; climate regulation; water regulation; and disease regulation. These critical services interact with each other positively and negatively. For instance, enhancing fresh-water provisioning through water conservation can exacerbate the urban heat island. Based on this work, we plan to further investigate changes in ecosystem services and the way in which ecosystem services influence human outcomes and actions.

Working groups within CAP LTER have tackled various research and outreach challenges during 2006–2007. The **Knowledge Exchange working group** has met quarterly to discuss and implement ways of promoting knowledge exchange between CAP LTER and entities outside of the university. Working closely with the Sustainability Partnerships at GIOS, this working group agreed to invite one policymaker or practitioner per year to present at the CAP LTER All Scientists Meeting (ASM) and drafted some longer-term objectives for knowledge exchange. A small sub-group of the **Models and Conceptual Development working group** met to discuss and formulate a new conceptual model for CAP LTER. The new model chosen, based on the LTER Planning Grant conceptual framework, will be unveiled at a CAP ASM in late August 2007. In addition, three members of the modeling group are engaged in research under a subcontract with the University of Washington and funded through a NSF Biocomplexity grant, **Urban Landscape Pattern: Complex Dynamics and Emergent Properties**. In this work, researchers have proposed to apply a dynamic probabilistic relational modeling approach to representing the urban landscape. The **Long-Term Experiments** working group held a daylong meeting in May to discuss research management and data analysis for work conducted at North Desert Village.

III. Highlights of Research Findings

The following CAP2 findings are presented within their interdisciplinary, integrative project areas.

Land-Use and Land-Cover Change (LULCC)

Reports from previous years have detailed findings from remote sensing applications. These included work on **high-resolution urban forest classification system for Phoenix** (Walker and Briggs 2007; Walker and Blaschke in press) and the use of spectral vegetation indices and linear spectral mixture analysis (SMA) to estimate vegetation cover (Buyantuyev et al. 2007). **Modeling land-use change and ecosystem responses** has also been an important component of CAP research on land-use and land-cover change (Shen et al. 2005; Shen et al. in review), as has **historic land-use** (Keyes et al. 2007). This year's report features other aspects of CAP research, work on landscape pattern, and landscape legacies, as well as preliminary results from the **PASS**.

The research objectives of the **effects of urbanization on landscape pattern and ecosystem process** project are to compare urban land cover classes with undisturbed Sonoran desert ecosystems in terms of patterns of primary production at broad spatial scales using remotely sensed Normalized Difference Vegetation Index (NDVI) data. Researchers have addressed the following questions: 1) What are the characteristic features of MODIS NDVI temporal signatures that distinguish different land cover classes in the rapidly urbanizing arid region? 2) Does urbanization lead to a greater potential of carbon sequestration compared to undisturbed ecosystems in the area? 3) What urban/agricultural land cover classes have the highest production in the area and what are their inter-annual variations? 4) What area temporal lags and duration of precipitation events that trigger vegetation growth in different land covers? The research team found that land transformations in Central Arizona create more land covers with rates of primary production considerably higher than those of natural vegetation, especially during dry years. At the same time, vegetation growth and primary production in urban and agricultural land covers is far less variable than in the outside desert due to mainly human ameliorations. NDVI relationships with precipitation in Sonoran desert are characterized by larger time lags and rainfall aggregation periods. Such relationships are affected by soil texture characteristics. Finally, analyses of MODIS NDVI and climate data have provided important insights into the interactions between vegetation patterns, climate variability, and urbanization in the area.

CAP research continues to examine means of representing and analyzing land-use and land-cover change. Work (Wu 2007; Wu et al. 2006) has emphasized the importance of scale in landscape analysis and has examined the issues and challenges in landscape pattern analysis, a major aspect of landscape ecology for over two decades (Li and Wu 2007).

Recent research has contributed to this dialogue through an investigation of the effects of thematic resolution on **landscape pattern analysis** (Buyantuyev and Wu 2007). Researchers employed the 15-year time series data of land-use and land-cover change for the CAP study area derived from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) imagery through use of an expert system approach (Stefanov et al. 2001) to create a series of maps. They then used these maps to calculate a suite of 15 landscape metrics, including patch density, edge diversity, patch size coefficient of variation, and landscape shape index. The results showed that landscape maps made with the same classification but different levels of detail are likely to result in significant differences in landscape characterization of the same geographic area for the same time period. For a given research problem, there may not be an optimal thematic resolution or

level of detail, but researchers should be aware that there are some thematic resolutions with a better balance between the amount of detail and the degree of uncertainty.

Other research associated with CAP LTER has explored **legacies on the landscape** – how prehistoric human land use has affected long-term ecological change in the region, a research initiative using expertise from ecology and anthropology (Briggs et al. 2006). One aspect of this research examines the creation of agricultural fields associated with the Hohokam culture well over a thousand years ago in the northern portion of the CAP LTER study site (Schaafsma and Briggs 2007). Here, silt deposits as large as 181,760 m^2 stand in contrast to other soils with between 62 to 80% sand content. Using analyses of soil, pollen, and topography, the research team focused on how silt was deposited in these areas. They conclude that prehistoric farmers created these silt fields through channeling flood waters into areas with previously non-arable land, possibly using living fences of riparian vegetation (e.g. *Salix* and *Populus*), the pollen of which is present in the record only after the inception of agriculture in the area.

Research conducted outside the CAP area but of relevance to understanding present-day patterns of land cover in the CAP region focuses on woody plant expansion in desert grasslands (Briggs et al. 2007). This research, based in the Agua Fria National Monument, found that woody vegetation (mostly composed of mesquite, juniper and cactus) more than doubled from 1940 to 2001 in the study area, most likely due to overgrazing by domesticated animals and suppression of fire. The largest increase in woody vegetation occurred on slopes less than 6° and in the elevation range from 1142 to 1183 m. Briggs et al. (2006) found a relationship between the absence of rock cover near prehistoric dwelling sites (pueblos) and woody plant density, which decreased with proximity to the pueblos. They postulated that rock cover provided "safe sites" for woody vegetation. This work demonstrates that the current distribution of plants in the area is still influenced by human alteration of the landscape even 600 years after the abandonment of the pueblos.

Preliminary analysis of the new **PASS** 2006 data have begun to yield interesting findings that will be incorporated into a final report (in press) and pursued in more in-depth articles. Although these findings cut across IPAs, highlights are presented here.

- Relatively few adults have deep roots in the Valley. Respondents move around frequently from place to place within the Valley. A large minority envisions another move within two years. If they had a choice of where to live, three of four people would stay in Arizona, but only 1 of 3 would stay in the Valley.
- Compared to the strong sense of national identity that most respondents felt, their local attachments were weaker. It is possible that the lack of deep historical roots in the Valley and frequent moves impair the sense of belonging for many people, since respondents who have lived longest in the Valley also have the highest sense of belonging here. Interestingly, groups who live with neighbors like themselves – retirees and Mexican immigrants – feel a stronger sense of belonging in their neighborhoods than others. With Arizona being a predominantly conservative state, respondents who identify themselves as conservatives apparently feel a greater sense of local belonging than others.
- Valley residents were concerned about the impact of population growth on the Phoenix region. The people who had lived here longer were more likely to believe the Valley is reaching its limits. People who live on the edge of urban development are more likely to see room for expansion.

- Although a large majority of residents did not believe the Valley s environment is capable of dealing with the impacts of growth, there were differences in public opinion. The starkest contrasts were between lower- and higher-income households and between self-described conservatives and liberals. Because higher income households and liberals were less confident in the environment s ability to cope, they may be more likely to favor changes in policies and behaviors to deal with growth.
- A very high proportion of Valley residents believed that the desert is special place. Appreciation of the local natural environment grows stronger as people live longer in the Phoenix metropolitan region.
- The quality of the local environment was a substantial concern for many residents, although not everyone shared the concerns to the same degree or about the same issues. People were divided about issues pertaining to land and water conservation. The responses suggest that approximately 60% of respondents were very worried about conservation of land and water and even more were concerned about worsening air pollution. Nevertheless, many people thought settlement density is too high and did not believe that they could reduce their domestic water consumption.
- There was high agreement among respondents that air quality is becoming worse and summer temperatures are rising over time. Perhaps air quality and heat were of wider concern than land and water conservation to many people because their households are directly affected by health concerns that are related to these problems. One of three households reported that someone had asthma and one of four households reported that someone had experienced heat-related illness in the past summer.
- Most respondents rated natural and social causes of environmental problems as being much more important than household activities. For example, climate conditions, such as drought and sunny days were seen as major contributors to potential water shortages and rising temperatures, while household activities, such as yard watering and using air conditioners were seen as minor contributors. The pattern of survey responses reveals that residents may not be aware of how much some of their daily activities impact the environment. They tend to blame nature and general social trends for creating critical problems that face the Valley. These kinds of perceptions may pose a challenge to getting people to change everyday behaviors that could make a difference in the environment.
- Respondents strongly supported voluntary actions to address environmental problems in the Valley, such as public education and developing technological solutions to resolve potential water shortages, rising temperatures, and air pollution. Most respondents strongly opposed economic solutions, such as raising the price of water, gas, electricity, or imposing fees on urban fringe development. There was also significant opposition to regulatory policies, especially restrictions on residential activities, such as outdoor water use.

Climate-Ecosystem Interactions (CLIM-ECO)

Newly-initiated work examines **plant flowering phenology in the Phoenix metropolitan area**. Research on changes in plant phenology, the seasonal timing of environmental-mediated growth and reproduction in plants, has increased dramatically as investigators seek to understand the effects of climate change at multiple scales (Neil and Wu 2006). One scale examined has

been the urban scale, typically through studies of rural-urban gradients or rural and urban comparisons. Some researchers have linked earlier flowering in urban areas to impacts of the urban heat island. However, little research has been conducted at a finer scale to examine spatiotemporal patterns within cities. There also has been a paucity of research on the causes and processes of changing flowering phenology, although the few existing studies have examined temperature, moisture, and photoperiod. To address some of these issues in an arid environment, CAP researchers have studied two plants, *Parkinsonia microphylla* (palo verde tree) and *Larrea tridentate* (creosote bush), at different land-use types and across the rural-urban gradient in the Phoenix metropolitan area. A preliminary analysis suggests that:

- Land use affects spatio-temporal flowering patterns of some plants.
- Flowering patterns of both plants may be sensitive to temperature.
- Changes in flowering phenology may affect seed production and success.

An examination of historical data from the ASU Herbarium indicates an advancement of blooming over the last century. The researchers enumerate the ecological, human health, and economic consequences of changes in flowering phenology, drawing on work by Baker et al. (2002) for some discussion of economic impacts.

Investigation of the **urban heat island** (UHI) effect has occupied CAP scientists for many years (e.g., Brazel et al. 2000; Baker et al. 2002) and has spawned CAP-leveraged research endeavors, such as the Neighborhood Ecosystem Project (Harlan et al. 2006; Jenerette et al. 2007; Harlan et el. in press) as well as the climate research conducted in conjunction with DCDC. A recent study (Brazel et al. 2007) analyzed climate and urban-growth variables to explain variations in air temperatures around the Phoenix area between 1990 and 2004 and found that significant temperature variation could be explained by surface effects related to type of urban development. Researchers determined that an overall spatial urban effect was in the order of 2-4°C with average increases of 1.4°C per 1000 home completions.

This builds on previous CAP research (Hartz et al. 2006a) that assessed the use of ASTER images to generate accurate data on the impact of residential development on thermal patterns. The study areas for this research included three residential neighborhoods/developments of varying housing densities and landscaping types adjacent to one another in Scottsdale. Researchers used a combination of methods: ASTER images, walking transects, and a fixed station observational sampling network with hand-held thermographic images for ground measurements. They found that the most densely-developed neighborhood had a higher nighttime temperature than the other two neighborhoods, consistent with findings in other studies of a similar nature (Harlan et al. in press). Through a comparison and assessment of data gathering methods, they concluded that ASTER images could be used successfully to estimate relative nighttime temperatures in urban areas, especially for the evening hours, which is when UHI formation is the most prominent. ASTER daytime images are less accurate representations of ground level temperatures.

Another microclimate study on UHI focused on resort climatology in Phoenix (Hartz et al. 2006b). Tourism is an important economic activity in the metropolitan area and is the second most important industry for Phoenix, bringing in over $5 billion annually (cited in Hartz et al. 2006b). Most tourists rely on weather and climatic information provided by the National Weather Service (from the main meteorological station at Sky Harbor Airport), but this information may not be an accurate reflection of the microclimates experienced at particular resorts, particularly during the flanks of the spring and fall seasons. Researchers placed

temperature-humidity datalogger devices on the grounds of seven large and well-known resorts in the Phoenix metropolitan region in proximity to recreational or outdoor use areas in the resorts. Using a human comfort model called OUTCOMES – OUTdoor COMfort Expert System (Heisler and Wang 2002), they were able to estimate human comfort levels at given temperatures. The research team found that there were considerable differences between standard meteorological information given to consumers and actual conditions at resorts. They suggest that tourism operators use data from weather stations closer to the resort location and emphasize the ameliorating effects of landscaping type and altitude on climate, particularly during the periods of time immediately adjacent to the hot summer months.

Urban development has increased the amount of impervious surfaces in the Phoenix area as farmland and deserts have been converted into residences, commercial buildings, sidewalks, parking lots, and roads with little ability to absorb storm water. This modification of the urban landscape is directly related to the development of the urban heat island effect (Brazel et al. 2000) and also has important implications for storm water runoff. Research on **modeling urban impervious surface areas in relation to urban heat island effects** investigates the effectiveness of the multiple endmember spectral mixture analysis (MESMA) sub-pixel classifier in quantifying varying amounts and distributions of soil, impervious, vegetation, and shade in urban and suburban areas using Landsat ETM+ data (Myint and Okin in review). Urban impervious surface areas (e.g. cement parking lots, asphalt roads, shingle rooftops) can only be recorded as either present or absent in each pixel when using traditional per-pixel classifiers. Sub-pixel analysis approaches that can provide the relative fraction of surface covers within a pixel may be a potential solution to effectively identifying urban impervious areas. Spectral mixture analysis approach is probably the most commonly used approach that models image spectra as spatial average of spectral signatures from two or more surface features. However, spectral mixture analysis does not account for the absence of one of the surface features or spectral variation with pure materials since it utilizes an invariable set of surface features. The multiple endmembers spectral mixture analysis (MESMA) approach addresses these issues by allowing endmembers to vary on a per pixel basis. CAP researchers employed the MESMA technique in this study to model Landsat TM reflectance in the Phoenix metropolitan area. They collected field spectra of vegetation, soil, and impervious surface areas with the use of a fine-resolution Quickbird image and pixel purity index tool in ENVI software. These were modeled as reference endmembers in addition to photometric shade that was incorporated in every model. Results from this study suggest that the MESMA approach is reliable, and the algorithm picked the signatures effectively.

Mesoscale atmospheric research continues to advance within CAP LTER. Researchers have focused on understanding physical processes through which urbanization leads to modified environmental conditions. Research by Grossman-Clarke et al. (in press) investigated the ability of a modified version of the fifth generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Meteorological Model, also known as MM5, to simulate characteristics of the urban planetary boundary layer (PBL) for the Phoenix metropolitan area under typical summer conditions. This model allows researchers to simulate the spatial distribution of air temperature, humidity, and wind speed. As described in Grossman-Clarke et al. 2005 and in the 2006 CAP LTER report, a new land classification system was introduced into MM5 to properly account for the spatial extent, nature and heterogeneity of urban land cover in the Phoenix area, as well as changes to surface energetics. MM5 was further modified through the replacement of the original Medium Range Forecast PBL scheme by

another version that resolved problems of poor surface momentum flux representation in the original. Using data from extensive meteorological and atmospheric chemistry field studies carried out by other researchers in the late 1990s and early 2000s in Phoenix, the researchers evaluated the performance of the model. They found that the modified version of MM5 consistently improved model performance for near-surface and upper air temperatures and wind speed compared with the original version of the model. The research team concluded that the model can be applied with high confidence in interdisciplinary studies regarding the influence of urbanization on weather in Phoenix.

Water Policy, Use, and Supply (WATER)

Work within this IPA shares strong linkages with research under the Decision Center for a Desert City (DCDC), and many CAP researchers contribute to both projects. Research within this IPA also overlaps with the biogeochemistry work discussed under the FLUXES IPA.

This year marked the first stage of a multi-year project **modeling fluxes of water and salt through the urban infrastructure.** The goal of this project is to understand urban hydrologic flux by modeling water supply and use and associated salt flux through answering the following questions:

- What are the sources of water and salt in the system?
- Where do water and salt travel within the system?
- How does water usage vary with seasons?

Key activities under this project included building a dynamic model to integrate collected water supply and usage data; simulating variations of water usages for irrigation, swimming pools, and evaporative coolers; analyzing salinity problems of golf course irrigation; and comparing the costs and benefits of landscape irrigation. The model developed during this project is based upon the same platform (PowerSim) as used by DCDC in the WaterSim project with the intent to be able to integrate the two models to provide a spatially-explicit understanding of water and salt fluxes.

The project team decided to focus on a single municipality, the City of Scottsdale, which has all the components of a modern arid-region urban water infrastructure system: supply of water from Colorado River through Central Arizona Project (CAP), groundwater withdrawals, surface water delivered through the Salt River Project (SRP), rainfall, runoff, wastewater, and reclaimed water. The water flux model was run with 2005 data. Major findings from the first phase of this project are:

- Although Scottsdale only received 9.2 inches precipitation in 2005, precipitation brought the largest amount of water to Scottsdale, followed by the Central Arizona Project (CAP) supply, groundwater supply, Salt River Project (SRP) supply, and reclaimed water supply. Most water left the city through evaporation and transpiration. Of the about 100 thousand tons of salt brought into Scottsdale, the Central Arizona Project brought the highest amount, around 38 thousand tons. Around 60 thousand tons of salt in irrigation water was left in the vadose zone, which could result in two serious consequences: the salt will finally reach aquifers and increase groundwater salinity and the high salinity could potentially destroy soil structure.
- Simulations of water demand in 2005 matched actual water demand for most months. This means that the simulation can be used for projection of daily or monthly water demand and can be incorporated in the dynamic model of water and salt flux.

- Through investigating current golf course irrigation practice and simulating salt concentration change in turfgrass root zone, researchers found that the salinity of irrigation water fluctuated around 1000 mg/l (total dissolved salt, TDS) and the salinity of soil moisture in root zone fluctuated around 3000 mg/l (TDS). The sodium adsorption ratio (SAR) of soil moisture in root zone was found in a range of 6.5 – 9.5, which means under current golf course irrigation practice the high salinity in irrigation water would not pose threat to soil since 12 is the threshold above which potential damage to soil physical structure will occur.
- Even though citizens have been encouraged to cut landscape irrigation to save water for future use, landscape irrigation can help reducing cooling electricity demand by providing shading and evaporative cooling. The cooling energy consumption of a typical two-story residential house was simulated, which found that annual cooling electricity could be reduced by 960 kWh with a landscape whose annual irrigation water demand is 466 m^3. To transport 466 m3 water to a residence for landscaping purposes, 785 kWh is used if water is imported from Colorado River and 566 kWh is used if reclaimed wastewater is used. Therefore, there is a net energy saving of 175 kWh or 394 kWh associated with landscape irrigation.

Researchers are engaged in data mining and integrating generalized models to support the water and salt flux model. Next year, the research team will replicate the model for Goodyear, a city located at the urban fringe, which has less access to surface water, uses more low quality (high salt content) groundwater, and has less infrastructure and treatment capabilities. Further activities include regionalizing the model and exploring how it can be integrated into DCDC activities.

Progress has also been made in investigating water policy issues in the CAP LTER study area through a new project, **drought and water conservation policy in the arid metropolitan Southwest**. With a multi-year drought in progress, political leaders in Arizona have started to pay closer attention to water conservation and related issues. Governor Napolitano of Arizona has recently called for a "culture of conservation" to make the best use of the state's scarce water resources. CAP LTER research has evaluated municipal water conservation policies and programs in the greater Phoenix region using secondary data, GIS, interviews, and historical analysis (Hirt et al. in review). For ten of the most populous cities in the study area, researchers examined the type of municipal conservation programs in relation to water consumption in gallons per capita per day (GPCD), how the number and type of conservation programs correspond to water use rates, and how water use and conservation policies changed over time in the region.

Results show that a high number of conservation policies and programs in an individual city does not correspond with a reduction in annual rates of water consumption. Municipalities with the most conservation programs have high rates of water use, while those with fewer programs rank low in GPCD. An alternative conservation program, the Non-Per Capita Conservation Program (NPCCP), was created in 1992 for municipal providers that could not meet the GPCD targets required by the GMA. Instead of focusing on water use standards, the alternative NPCCP program requires cities to adopt a suite of "reasonable conservation measures," most of which are voluntary information-based programs. Comparing the number conservation programs to rates of water consumption, the highest-ranking cities in both categories were those that joined the NPCCP program in 1997. Three out of four of the NPCCP cities have a higher than average number of conservation programs *and* higher water use rates. Additionally, non-NPCCP cities

decreased their water use (GPCD) by an average of 15% between 1985 and 2005 while the NPCCP cities only decreased by an average of 1.5% during the same time period. Preliminary findings indicate that municipalities' inability to meet regulatory standards for per capita water use have resulted in changes to conservation programs in the region, rather than consistent reductions in per capita water use over time due to regional water management policies. These changes indicate a shift from top-down command and control regulatory standards toward information-based best management practices, largely due to the threat of law suits and complaints from water providers who could not achieve regulatory standards for municipal conservation (e.g., specific water use targets). Investigations are still underway to understand historical changes over time and geographic patterns in water conservation policies in the CAP region.

Material Fluxes and Socioecosystem Response (FLUXES)

Rapid urbanization, increased industrial and vehicular emissions, and a valley situation which allows pollutants to concentrate and settle have all contributed to serious air pollution problems in the Phoenix metropolitan area. The area has been in violation of Environmental Protection Agency (EPA) standards for atmospheric pollutants such as carbon monoxide and particulate material greater than 10 microns (PM10). Research (Grineski et al. 2007) on **environmental justice and risk** in Phoenix has investigated the spatial distribution of pollutants, specifically three criteria pollutants associated with industrial activities: nitrous oxides (NO_x), ozone (O_2), and carbon monoxide (CO). Researchers hypothesized that neighborhoods with low incomes and higher proportions of racial/ethnic minority groups would exhibit higher levels of modeled criteria air pollutants than other neighborhoods. An environmental modeler at ASU's Fluid Dynamics Laboratory collaborated on the research, using the Community Multiscale Air Quality (CMAQ) to create a spatial data set of the three criteria pollutants, which the team employed in its analysis. They coupled these data with factors created from 11 demographic variables at the US Census block group level. One factor, neighborhood socio-economic status (SES – created by combining median home value, median sale price of homes, and median household income), figured importantly in research results. Neighborhood SES alone is a significant negative predictor of CO, NO_x, and O_2 as well as a composite of all three pollutants; block groups with lower neighborhood SES have higher levels of these pollutants. Housing tenure (renters) and the proportion of Latino immigrants are significant for the three pollutants and the composite. Interestingly enough, significance of the proportion of Native Americans varies among the models; for ozone, the relationship is negative, indicating that areas with higher proportions of Native Americans have significantly lower levels of that pollutant. The researchers conclude that their analysis shows clear environmental injustices along ethnic and class lines. Neighborhoods with low SES and higher proportions of renters and Latinos generally experience higher levels of criteria air pollution. They note that freeways and the airport are critical sources of pollution and that housing in areas proximate to these land uses have lower values and as such are likely to enter the rental market, rather than remain as owner-occupied housing. As noted in earlier research (Bolin et al. 2005), this is reflective of historical patterns of development in Phoenix, which have culminated in a spatial segregation based on class, race, ethnicity, amenities and disamenities.

Urbanization is often accompanied by modifications to urban watersheds. CAP research on the **water chemistry of lakes and rivers following winter storm events** investigates the relationship between water management and water quality on rivers and lakes in the desert

southwest. Researchers focused their work on the Salt River, a normally dry channel that receives flow from upstream dams during large storm events, and Tempe Town Lake, an impounded portion of the Salt River that was filled with water from the Central Arizona Project canal (Colorado River water) and opened to the public in 1999. Lake managers maintain the water level in the lake through periodic additions of water to replace evaporative losses. Research examined the biogeochemistry of Tempe Town Lake over time and the Salt River after large storm events. In addition, the investigators were interested in how the hydrology and solute transport mechanisms in an arid river, such as the Salt River, are different from well-studied tropical and temperate systems. Using river and lake water samples collected at multiple time scales, the team tested mass balance models (developed for river flow in other climates) based on unique chemical signatures and constructed a chemical budget for Tempe Town Lake. Their methods included measuring each water sample in the field for basic chemical analysis using meters, and running samples in the lab on a variety of laboratory instruments: an ion chromatograph for major ions, an inductively coupled plasma mass spectrometer for dissolved metals, and an isotope ration mass spectrometer to measure stable isotopes of oxygen and hydrogen for inputs into the predictive model. Results show that it is possible to identify management practices during flow and lake evolution in urban watersheds, although it is necessary to modify existing models to accommodate dynamics in arid river systems. After characterizing different inputs to the systems, the researchers were able to quantify the degree to which they affect the composition of river and lake water and concluded that a stream reach scale mass balance approach is capable of identifying small contributions from humans based on component chemistry. Preliminary results from the chemical budget model show that researchers are in a position to identify components which could significantly alter the composition of Tempe Town Lake. A simple water balance model is currently being used to test the chemical budgets within Tempe Town Lake following serious storm events in the Salt and Verde Watersheds.

The **atmospheric deposition** project examined the magnitude and spatial variability in the concentration and flux of wet-deposited NO_3^-, NH_4^+, organic C (oC), PO_4^{3-}, Cl^-, SO_4^{3-}, H^+, Ca^{2+}, Mg^{2+}, Na^+, and K^+ across the CAP region, including the developed urban core and outlying desert. Researchers also examined patterns of coarse dry particulate deposition to provide minimum estimates on levels of dry deposition of these ions. The team analyzed six years of data, with the following findings (Lohse *et al. in review*):

- Mean annual fluxes of wet and dry N deposition were relatively low and did not differ significantly across sites, whereas wet and dry deposition of oC were significantly elevated in the urban and downwind desert compared to the upwind sites.
- Elevated fine-particle and vapor-phase NH_4NO_3 and oC concentrations were observed in the urban core in fall and winter, indicating dominance of gaseous-phase N.
- Lower-than-predicted dry deposition of N to the urban core may be explained by the dominance of gaseous-phase N in hot, arid environments and volatilization of dry deposition from surrogate surfaces.
- The scale of urban enhancement of nutrient and carbon inputs to surrounding desert ecosystems appears to be limited to the CAP study region and could be important for nutrient budgets and cycling in these nutrient- and carbon-poor ecosystems.

Results from the six-year study of atmospheric deposition have informed new research investigating the effects of urban deposition on desert-ecosystem processes, **Decoupled biogeochemical cycles: Ecological response to C and N deposition from the urban atmosphere** (CNDep)**,** a project funded separately by NSF (Ecosystem Studies). In this project, researchers have developed new methods for measuring bulk deposition in the arid urban environment, which replace the previously used wet-dry bucket collectors. They are evaluating this method against a filter-bank method that uses eddy correlation-based estimates of deposition velocity, combined with specially designed samplers to measure gaseous and aerosol components being deposited. Deposition collectors are deployed at 15 sites: five upwind, five in the core, and five downwind of the city, with a flux tower and filter-bank sampler installed at one intensive site for each position. Results for the first year's deposition measurements suggest that the new collectors also underestimate dry deposition in the urban core; therefore, work is proceeding to incorporate use of the filter bank samplers and eddy-correlation measurements into the long-term monitoring program of CAP LTER.

The CNDep project has also established long-term fertilization plots upwind, within, and downwind of Phoenix, which are part of the CAP long-term experimental program. Preliminary results do not reveal any impact of N or P addition over one (dry) season; however, compared to upwind sites, extractable nitrate (NO_3^-) pools in control-plot soils from interplant spaces are 5.6 and 1.8 times larger for urban core and downwind sites, respectively. Furthermore, ratios of C:N in foliar tissue of *Larrea tridentate*, a dominant perennial shrub, are lower in the urban core (17.4) compared to downwind (21.8) and upwind (21.5) sites, consistent with the hypothesis that the urban atmosphere acts as an important source of N to primary producers.

Ongoing CAP research on **belowground nutrient pools and dynamics in xeriscaped yards** focuses on a common Southwestern landscaping practice, xeriscaping. Researchers seek to learn whether soil that has been intensely managed for several decades functions like the undisturbed desert when native plants and spatial heterogeneity characteristic to the Sonoran desert are restored. They have established 15 research sites to compare undisturbed desert outside the city with undisturbed urban desert remnant parks and xeriscaped yards that were preceded by grass lawns and agriculture. Key questions include: How are available soil resources affected by proximity to the urban core?; how are available soil resources affected by direct human management like irrigation and fertilization?; and how does the distribution of soil resources vary across a gradient of human activity? In preliminary work, researchers found that pools of extractable inorganic N (ammonium plus nitrate) are elevated within the urban core. Mean inorganic soil N is 13.3 µg NO_3-N/g dry soil in the outlying desert, but 32.86 µg NO_3-N/g dry soil in urban desert remnants and 27.42 µg NO_3-N/g dry soil in xeriscaped yards. In addition to elevated inorganic N, net potential N cycling rates are higher in urban desert than in outlying desert. These results are consistent with results from **Survey 200** (Zhu *et al.* 2006). They also are supported by results from a leveraged project that examined soil pools of C and N as a function of land-use legacies. Results from this study show that housing development is associated with increased soil N and organic C, and further that there is a "signal" of higher N and organic C in formerly agrarian land that persists for up to 80 years postdevelopment (Lewis *et al.* 2006).

Studies of **nutrient transport and transformation in urban watersheds** have focused on spatial variation in N export across metro Phoenix. Individual storm characteristics greatly affect the amount of N exported, yet these effects are modulated by watershed characteristics, such as percentage impervious surface and configuration of N-retaining patches (Lewis and Grimm *in press*). This research supports an original CAP LTER hypothesis, that urbanization increases

spatial heterogeneity of nutrient exports. Detailed investigations in the Indian Bend Wash (IBW) have found that storms and human management interact to determine the chemistry of the stream and lakes. During storms, N concentration is diluted compared to the high N concentration of groundwater used to fill the lakes in the IBW lake chain (Roach and Grimm, *in review*). In contrast, phosphorus (P) concentration is elevated in stormwater runoff. These patterns have consequences for aquatic ecosystem functioning in terms of primary production. Although nutrient limitation was not previously demonstrated to occur in IBW except during summer low flow, when P was limiting (Goettl and Grimm, *in revision*), a higher-frequency (especially after floods) analysis of nutrient limitation to phytoplankton showed frequent shifts from P limitation, to N limitation, or to co-limitation both in time and in space (Roach and Grimm, *in review*). Thus, the complexities of water addition to this system (by natural floods or human-mediated additions) drive the dynamics of aquatic production through alterations in nutrient limitation.

Retention basins are a designed "aquatic" feature of the urban landscape, now required in new developments above a certain size. Designed to contain up to a 100-year flood from their watersheds, retention basins often have dry wells that hasten the movement of water (and its associated material load) to groundwater. CAP scientists have found that these ecosystems have high potential rates of denitrification (Zhu *et al.* 2004), which vary with basin design (e.g., grassy/mesic or gravel-covered/xeric designs). Grassy basins have much higher soils organic C, supporting greater abundance and activity of denitrifiers (E. K. Larson, unpublished). Ongoing studies focus on a set of 32 retention basins in the Paradise Valley School District. Future research will quantify the **value of ecosystem services**, such as recreation, storm handling, climate regulation, and water-quality regulation, provided by retention basins.

Human Control of Biodiversity (BIODIV)

Research on human control of biodiversity is a particular strength at CAP LTER. This year's report includes findings from new initiatives, such as research on black widow spider behavior and evolution, as well as ongoing investigations of avian community dynamics and trophic dynamics, which have already spawned a number of publications (Cook and Faeth 2006; Faeth et al. 2005; Warren et al. 2006a.; Warren et al. 2006b.; Shochat et al. 2004a; Shochat et al. 2004b; Shochat 2004).

A CAP scientist and undergraduate students initiated work on a multi-part research project, **the behavior, ecology and evolution of the western black widow** (*Latrodectus hesperus*), in summer 2006, which focuses on differing behaviors and genotypes of urban versus desert black widow spiders. Although data are still being gathered and analyzed to answer some of the central research questions, a few preliminary results have emerged from an examination of cannibalism in black widows. Spiders have served as excellent model organisms for the study of cannibalism. Factors such as relatedness, population density, heterospecific prey availability, and size/stage differences can influence cannibalism. These past works have examined social, subsocial and wandering spiders. However, an overwhelming majority of spider species are solitary for much of their life history, encountering potential cannibals/conspecific prey only briefly in mixed sibling groups after egg sac hatching and prior to dispersal. As such, the research team hypothesized that kin recognition (i.e. avoidance of cannibalizing full siblings) may be a strong selective factor shaping patterns of cannibalism in solitary spiders such as the black widow. Data indicate that full siblings reside significantly closer to each other than unrelated spiderlings (often subduing prey together). Despite this proximity difference, cannibalism occurred significantly more rapidly between unrelated spiderlings than between

related spiderlings. Finally, researchers found an intriguing family effect on full-sibling cannibalism with some "low-cannibalism families" taking, on average, 10 times longer to cannibalize each other than "high cannibalism families." These results are set in the context of the modern-day role of black widows as urban pests occurring in increasingly dense populations where levels of sociality (e.g. web sharing) are increasing.

In the CAP study area, urbanization generally leads to increased and more stable water availability, resulting in increased plant productivity. A CAP graduate student and faculty members constructed simple mathematical models to address the question of how urbanization affects ecological communities, with emphasis on **trophic dynamics**. The models assume water as the limiting resource, as it is in the desert, thereby directly influencing plant carrying capacity. The simplest model is a tri-trophic system with a linear functional response on herbivore and predator level. The second model is similar, but with a type II functional response on the same levels. The third model consists of producer, herbivore and an omnivore level, the two last with type II functional response. All models are able to incorporate bird predation on both consumer levels. The models were compared using bifurcation analysis, focusing on plant carrying capacity, trophic biomass and predation by birds, and give results that are testable in field experiments. The researchers have demonstrated the utility of theoretical mathematical models in urban ecology. Some or all of these three models can contribute greatly to further exploration of questions researchers may have about trophic dynamics, not only in the CAP area, but also other urban systems. This work provides a good foundation for integrating empirical data from the CAP urban ecosystem.

The **assessing arbuscular mycorrhizal (AM) fungi** project has focused on assessing the diversity of these important fungi in the Phoenix metropolitan area and the surrounding Sonoran desert. Soil samples have been collected from Survey 200 sites, the Desert Botanical Garden experimental landscape plots, and North Desert Village. Researchers have used these samples to set up trap pot cultures in the greenhouse (used to stimulate spore formation), and have extracted and identified spores. Key research questions include:

- How do land use and vegetation types affect AM fungal diversity?
- How do AM fungal communities change through time after urbanization?
- How do sampling effort and spatial heterogeneity impact assessment of AM fungal communities in urban ecosystems?

Recently published findings show that sampling effort can have a major impact on assessing AM fungal species richness and composition (Whitcomb and Stutz 2007). Researchers determined that 15 samples would be necessary to detect 70-80% of species present at a sampling site. This indicates that sampling effort and strategy can affect perceptions of AM fungal community structure in urban sampling sites. These results have the potential to alter the way researchers collect soil samples to assess AM fungal local community structure.

The social science research team at **North Desert Village** completed a second wave of resident surveys in late fall 2006 and are in the process of analyzing these data. Analysis continues on aspects of the first wave (pre-treatment) survey data (Casagrande et al. 2007; Yabiku et al. in press), and on observational data collected in spring 2005. As reported last year, one initiative has merged the PASS and NDV datasets to shed light on residential landscape preferences in the Phoenix oasis (Larson et al. in review). This analysis has revealed that:

- Landscape preferences represent residents' desires for comfortable landscapes of leisure while reflecting diverse tastes and lifestyles.

- Ecological benefits are associated with a variety of landscape types as residents explain the environmental value of their preferences and socially construct "nature" in their yards.
- Familiarity with the Phoenix oasis reinforces the human-nature dichotomy, resulting in preferences for mesic landscapes among long-term residents of metropolitan Phoenix.

Researchers have also examined whether or not daily meteorological conditions at **North Desert Village** affect people's outdoor activities. Using the observational data and hourly data on meteorological conditions from the Williams Gateway Airport, CAP researchers sought to answer the following questions:

- What specific meteorological conditions affect outdoor activity?
- What demographic groups are the most influenced by meteorological conditions?
- What outdoor activities are the most influenced by meteorological conditions?

Preliminary results suggest that visibility is a factor influencing human outdoor activity; as visibility increased, people engaged in more outdoor activities ($p<.01$). This effect of visibility was stronger for children. Surprisingly, temperature and humidity showed no significant effects on human outdoor activity. One explanation is that people choose to spend less time outdoors when there are conditions that happen to reduce visibility: pollution, fog, haze, and impending rain. People may not be consciously avoiding "low visibility conditions" may avoid being outdoors on days that are less appealing based on "how it looks outside," rather than actual temperature and humidity.

While the potential importance of corridors has been acknowledged for both native and non-native species, little is known about how they actually function in developed and fragmented landscapes. The combination of the particular conditions along road and freeway verges and the characteristics of the plants that reach these corridors will ultimately determine which species, native or not, will be able to move within cities and developed areas as well as to and from cities and surrounding undeveloped areas. Research on **the role of transportation corridors in plant migration** began with the selection of 20 sites along the four major freeways in the cardinal directions around the Phoenix Metropolitan Area. Initial soil chemistry results from samples collected at these sites show that levels of plant-extractable nitrate are significantly increased in the surface soil located directly adjacent to the asphalt (ANOVA using log surface soil concentration; $F=5.556$, $P=0.005$). There were also significant differences between sites located adjacent to different land uses, with the sites located in the more densely developed city areas having higher nitrate levels than those at the edges of developed areas. The urban residential sites had the highest levels, followed by croplands, then lower density "fringe" development, and desert sites had the lowest levels of extractable nitrate (ANOVA using log surface soil concentration, $F=123.67$, $P<0.001$; Fisher's multiple comparison, all combos $P<0.001$). Intensive sampling at a single site revealed that the pattern of nitrogen deposition is more complex than the general sampling results showed. Available nitrogen levels were highest approximately 2m away from the asphalt edge, indicating there may be a "shadow effect" before nitrogen particulates begin to deposit on the roadside after being emitted from autos. Available nitrogen levels then taper off rapidly to a distance of approximately 12m, where a change in topography to a shallower slope coincides with a slight increase in available nitrogen. This may indicate that soluble nitrogen is moving downslope with water runoff and concentrating at the base of the slope. It is likely that in the typically nitrogen-limited Sonoran Desert, the addition of

nitrogen as a result of exhaust from combustion engines is significantly impacting which plant species are most likely to grow along the roadsides. This raises the question of whether heavily traveled roadsides in naturally nutrient-limited ecosystems should be considered as potential vegetation reserves, since intense maintenance would likely be needed to maintain a native community. Perhaps these areas are best landscaped with species unlikely to move along the highway corridors, whether native or not.

Research continues on **urban bird dynamics**. Earlier research (Shochat 2004) formulated a "credit card theory" to explain why urban bird populations exceed food resources. The credit card theory hypothesizes that with their "permanent income," urban birds, just like humans, "live on their credit." Knowing when and where to find food each day, they can afford to increase their clutch size and fledge more young. The fledglings will suffer high competition, but have a fair chance to survive on the long term. To summarize, continuous input of resources changes the rules of the evolutionary game in the urban environment. Key points in the "credit card theory" follow:

- Urban bird density overmatches resource abundance.
- Population size does not crash to the K (carrying capacity) in terms of bird density.
- Such a situation must have a cost, and the cost is in body condition. Urban birds should be leaner on average than wildland birds.
- Natural selection removes lean individuals from the population in widlands, but not in cities. The unhealthy lean individuals persist because they manage to find enough food each day to keep them going.
- Lean individuals cannot reproduce. Thus, the urban population must have a few winners and many losers. Only the winners reproduce. The losers "float".
- In the wildland losers do not survive. They starve or being removed by predators. Wildland populations consist of many winners and fewer losers.

While the "credit card theory" follows some rationale, it is not clear whether it is an accurate representation of actual processes. Following the call by Shochat et al. (2006) for mechanistic approaches in urban ecology, CAP researchers developed a mathematical model to test whether "urban" conditions can cause the flip between losers and winners, so that the losers outnumber the winners under urban conditions (Anderies et al. 2007). The model shows that urban conditions indeed flip the loser/winner ratio, but that both the bottom-up effect (high food predictability) and top-down affect (reduced predation pressure) can lead to this pattern. It is likely that both factors control urban bird population regulation. The importance of this research goes beyond the theoretical framework. The use of a mechanistic approach is rare in urban community ecology. The model suggests a mechanism for a global pattern, the inflated population density, as well as for the differences in foraging behavior between urban and wildland birds observed in CAP. Further, that so many losers can float on the long term and remain in the system may have significant influence on community structure and may explain another well established pattern in urban settings – the loss of diversity.

Comparative research under the **ecological and social interactions in urban parks** project has yielded further results on human influence on avian biodiversity. Humans often engage in activities on their property that can directly or indirectly influence population dynamics and ecological process, including gardening to attract birds and butterflies, installing ponds or bird baths, keeping pets indoors, and perhaps most commonly, feeding birds. Yet, researchers know little about the spatial or temporal distribution of these human resource subsidies or the factors

that motivate people to engage in them. As a first step to understanding the spatial distribution of bird-related activities, a research team sought to assess how often and in what ways people elect to participate in three activities that influence birds (Lepczyk et al. in review). In parallel studies in southeastern Michigan and Phoenix, Arizona, they surveyed 3,800 people regarding their participation in bird feeding, planting vegetation for birds, and allowing cats outdoors. In both regions, a large proportion of respondents fed birds (66% in Michigan and 43% in Arizona) and planted vegetation to attract birds (55% in Michigan and 42% in Arizona), whereas fewer allowed cats outdoors (26% in Michigan and 18% in Arizona). The predominant food types were commercial seed mixtures in both locations, with regional differences in specific food types. Striking differences between the two regions came in the levels of engagement in each activity, with Michigan respondents much more likely to feed birds and participating in more bird-related activities than Arizona respondents. Although many factors varied across rural-to-urban gradients, the urban landscape in Michigan was nearly identical in all ways to the Arizona sample, all of which was urban. This suggests the possibility of general characteristics in the ways that urban residents restructure local ecosystems.

One of the greatest challenges in urban ecology is to explain the global reduction in biodiversity in urban settings. Our current analysis suggests that habitat destruction per se may not be sufficient to explain this pattern. Urban settings have diverse habitat structure, high resource and water abundance, and as such serve as a proper habitat for many species. Yet, while community composition shifts, in most cases we lose more species than we gain. Our **bird census data** from both CAP-LTER and BES (Shochat in prep.) show a clear picture: Wildland communities are more even than urban communities. When all species in each community are sorted from most to least common, wildland community profile is almost linear, or slightly skewed, whereas urban (and agricultural) community profile is highly skewed and has a hyperbolic shape. A similar pattern exists for spider communities from CAP (Shochat et al. 2004b.), suggesting that this pattern is robust, and is not only cross-site, but also cross-taxa.

Informatics

The Informatics Lab at GIOS has been involved in the development of data management and use applications with initiatives associated with CAP LTER, the Southwest Environmental Information Network (SEINet), and the Arizona Water Institute. The Lab has developed new online keying application within SEINet, which provide major improvements over traditional matrix based online keys like the Description Language for Taxonomy (DELTA) intkey. The underlying data model combines hierarchical taxonomic information obtained from the Integrated Taxonomic Information System (IT IS) with the traditional character and character state information. This allows for strict normalization of information and character inheritance within taxonomic groups which greatly reduces data entry and management efforts. In addition, this approach allows for easy integration of new species if the key is to be expanded geographically. It also provides the means to dynamically build keys based on a subset of species and makes the key very user friendly as characters may be added and dropped dynamically depending on where in the keying process a user is.

Last year, the Arizona Water Institute received funding for water related research and the development of an Arizona Hydrologic Information System. This tri-university effort (University of Arizona, Northern Arizona University, and Arizona State University) is developing infrastructure for data storage, curation and access. A federated data storage system is accessed via web services which provide the data in standard format modeled according to the Consortium

of Universities for the Advancement of Hydrologic Science (CUAHSI) standards. One full time programmer and two computer science grad students are now working at GIOS to develop a metadata editor and management system, web services accessing groundwater data from the Arizona Department of Environmental Quality and data in the Salt River Project flood warning system, and a search engine for data sets.

The work on an online EML editor under this project is of particular significance to CAP LTER. The lack of an online EML editor has meant that researchers have difficulty editing their metadata. While there are some older systems available, such as that used by the National Biological Information Inventory, none have been designed with LTER sites in mind. The new design is broad enough to be applied successfully to LTER sites. The team is developing the editor using the Orbeon XForms scripting language native to Java Server Pages. This technology is entirely based on XML concepts and lends itself to modeling a web page by intuitive selection of nodes from an expanded EML schema with display name, description, validation, widget type, and pre-population. The editor accesses EML files in a native XML database and saves every change immediately.

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V. Research Training and Development

CAP LTER's university setting enhances the ability to conduct, communicate, and synthesize our research activities. Faculty members have expanded their courses to consider urban ecology and, in some cases, have designed new courses to accommodate CAP LTER research interests. In addition, postdoctoral associates and graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, lab processing and analysis. The Goldwater Lab for Environmental Science accommodates CAP LTER's analytical needs and provides graduate-student training on instruments housed in its facility. Opportunities for summer support for graduate research and undergraduate research experiences are available. Theses and dissertations completed and in progress are listed below. Additional information is included in Contributions to Human Resource Development section below.

Theses and Dissertations

In Progress

Bang, Christofer. The effects of urbanization on structure, diversity and trophic dynamics in arthropod communities (Ph.D., School of Life Sciences, S. Faeth).

Buyantuyev, Alex. Effects of urbanization on the landscape pattern and ecosystem processes in the Phoenix metropolitan region: A multiple-scale study (Ph.D., School of Life Sciences, J. Wu).

Davies, Rachel. The effects of urbanization on belowground ecosystem processes in the Sonoran Desert. (M.S., School of Life Sciences, S. Hall).

Gade, Kris. Plant migration along freeways in and around an arid urban area: Phoenix, Arizona (Ph.D., School of Life Sciences, A.P. Kinzig).

Gonzalez, Daniel. Dry deposition of speciated and size-segregated ambient fine particles measured using eddy correlation mass spectrometry (Ph.D., Department of Chemical Engineering, J. Allen).

Gustafson, Annie. Sustainable desert cities: A comparative analysis of water resource management in Phoenix and Tucson (Ph.D., History, P. Hirt).

Hedquist, Brent. Spatial and temporal dynamics of the urban heat island in Phoenix, Arizona (Ph.D., Geography, A. Brazel).

Larson, Elisabeth. Water and nitrogen in designed ecosystems: Biogeochemical and economic consequences (Ph.D., School of Life Sciences, N. B. Grimm).

Lerman, Susannah. Residential landscapes and bird community structure: Understanding the patterns and processes. (Ph.D., Graduate Program in Organismic and Evolutionary Biology, University of Massachusetts, P. Warren).

Neil, Kaesha. Effects of urbanization on the spatiotemporal pattern of plant flowering phenology in the Phoenix metropolitan area. (Ph.D., School of Life Sciences, J. Wu).

Schaasfma, Hoski. Environmental legacies of ancient farming in the Sonoran Desert (Ph.D., J. Briggs).

Sweat, Ken. The use of lichens as biomonitors or heavy metal air pollution patterns in Arizona. (Ph.D., School of Life Sciences, T. H. Nash).

Tomalty, Roger. Solar radiation modeling and spatial variability in CAP LTER and its impacts on surface processes (Ph.D., Geography, A. J. Brazel).

Walker, Jason. Socio-ecological effects of urban forest structure in Phoenix (Ph.D., School of Life Sciences, J. Briggs).

Completed

2007

Bigler, Wendy. 2007. Historical biocomplexity in irrigation agriculture. The Akimel O'Odham (Pima) and the Gila River, Arizona (Ph.D. ,Geography, R. Dorn).

McLean, Brandon. Geochemical consequences of management on water resources in central Arizona, USA. (M.S., School of Earth and Space Exploration, E. Shock).

Miller, James 2007. Local and regional climate change in the Mojave Desert, USA. (Ph.D., Geography, A. Brazel).

Zhang, Peng. 2007. Urban water supply, salt flux, and water use. (M.S., Civil and Environmental Engineering, J. Crittenden and P. Westerhoff).

2006

Bills, Robert. 2006. Effects of urbanization on community structure and functioning of arbuscular mycorrhizal fungi. (M.S., School of Life Sciences, J. Stutz)

Block, Jessica. 2006. 3-D Visualization for water resources planning and for Salt River paleo-geomorphology in central Arizona (M.S., School of Earth and Space Exploration, J R. Arrowsmith).

Grineski, Sara. 2006. Social vulnerability, environmental inequality and childhood asthma in Phoenix, Arizona. (Ph.D., B. Bolin).

Parker, John. 2006. Organizational collaborations and scientific integration: The case of ecology and the social sciences (Ph.D., Ed Hackett).

Singer, Catherine. 2006. Effects of landscape surface mulches on desert landscape microclimates and responses of three Southwest desert plants to landscape surface mulches and drip irrigation. (M.S., School of Life Sciences, C. A. Martin).

Stiles, Arthur. 2006. Structure and distribution of Sonoran Desert plant communities in metropolitan Phoenix, Arizona. (Ph.D., Plant Biology, S. Scheiner).

White, Jacqueline. 2006. Resilience of the plant community and seedbank in an urbanized riparian corridor (Salt River Phoenix, Arizona) (M.S., School of Life Sciences, J. Stromberg).

2005

Collins, Timothy. 2005. The production of hazard vulnerability: The case of people, forests, and fire in Arizona's White Mountains. (Ph.D., Geography, K. McHugh).

Roach, W. John. 2005. How anthropogenic modifications influence the cycling of nitrogen in Indian Bend Wash (Ph.D., School of Life Sciences, N. B. Grimm).

2004

Hartz, Donna. 2004. A case study of suburban development and microclimate variability in a desert urbanized environment (M.A., Geography, A. Brazel).

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Prasad, Lela. 2004. Urban materials and temperature: Relating ground and air variables to land use, socioeconomics and vegetation in Phoenix (M.A., Geological Sciences, J R. Arrowsmith).

VI. Education and Outreach

Education and outreach activities are woven throughout CAP LTER. We are committed to sharing what we learn with community organizations, governmental agencies, industry, and the general public.

K-12 Education

We reach out to the K-12 community in a program called **Ecology Explorers** that aims to:

- develop schoolyard ecology programs where students collect data similar to CAP LTER data, enter results into a database, share data with other schools, and develop hypotheses and experiments to explain their findings;
- improve science literacy by exposing students and teachers to real research conducted by University-level scientists;
- enhance teachers capabilities to design lessons and activities that use scientific inquiry and encourage interest in science;
- provide access to and promote the use of CAP LTER-generated materials and information;
- encourage collaboration between CAP LTER researchers and the K-12 community

From an initial collaboration with 12 schools in 1998, **Ecology Explorers** has grown to include over 100 teachers in 25 school districts, 4 charter schools, and 2 private schools. Popular summer workshops and internships have engaged over one hundred teachers and thousands of their students in our schoolyard sampling protocols for the vegetation survey, ground arthropod investigation, bird survey, and plant/insect interaction study. The program is aligned with the Arizona State Education Standards, including science, math, writing, social science and technology standards. The website continues to be updated (http://caplter.asu.edu/explorers), and the teacher s manual was updated to reflect the new Arizona Science Standards. This summer program engages CAP LTER personnel, ASU personnel and community partners.

Ecology Explorers continues to provide teacher training in ecology to schools that have underserved, minority populations. On average, the schools where Ecology Explorer participants teach have 39% of their students enrolled in the free or reduced lunch program. About 42% of students in these schools are from under-represented minority groups (African-American, Native American and Hispanic). Hispanic students account for the vast majority (around 80%) of minority students on average.

A hallmark of the **Ecology Explorers** program is continued teacher support during the academic year. We work with teachers in their classrooms as well as hold day-long workshops based on teacher requests. This year, our major focus was a request by the newly-formed Sonoran Desert Center to help develop high-school level curriculum for students visiting their site. Our GK-12 fellow worked closely with several high school teachers in the Deer Valley Unified School District to develop lessons and test them both in the field and with follow-up in the classroom.

The **Ecology Explorers** program employs a range of methods for program evaluation (Banks, Elser and Saltz 2005). Pre- and post-program teacher surveys gauge teacher's expectations and response to the summer internship program, while follow-up surveys and interviews indicate how teachers have implemented their teaching plans during the school year. The overall results of the pre- and post-internship surveys suggest that the internships are highly successful at meeting the teachers' desired outcomes from attending the program. The academic year surveys found that a large percentage of the teachers were able to implement parts of the Ecology Explorers program during the academic year, most notably the protocols and many of the extension activities. One of these teachers, who implemented a pitfall trap protocol as part of a lesson plan on invertebrate biodiversity, was featured an *Arizona Republic* article.

We are also working to develop a one-day teacher workshop to share CAP LTER research with a larger number of teachers across the Valley. In this effort we are partnering with the Arizona Foundation for Resource Education.

We have developed two programs in conjunction with ASU's Science Service Learning. Programs that engage students from high-minority, low income schools in CAP LTER-related project. One program, **Service at Salado** (http://caplter.asu.edu/explorers/riosalado), formed four after-school clubs that engaged over 121 children in local environmental projects. **Service at Salado** works closely with staff of the City of Phoenix Rio Salado Habitat Restoration Project. During 2006-2007, this endeavor involved 27 ASU undergraduate students working as club facilitators and interns. Events in November and April allowed student participants to present their projects to each other, Rio Salado staff, and representatives from other public and non-profit organizations. Projects from each of the clubs can be found at the Service at Salado website at http://caplter.asu.edu/explorers/riosalado.

The children participating in the Service at the Salado program completed a pre- and post-surveys relating to attachment to place (the Rio Salado Habitat Restoration area) and civic responsibility. Results from the past year indicated that the students did become more attached to the Rio Salado, an important finding since this area lies adjacent to their neighborhoods, which are typically lacking in recreational and environmental education facilities. There was no significant change in civic responsibility. The data from several years of this program is currently being analyzed. Of the over 400 students that have participated in this program, 87% are Hispanic.

The second service learning program, the Phoenix Flyways project, involves students during the school day in learning about natural history in the urban setting of Phoenix as well as rural sites through studies of birds and their migratory movements between environments. Informal conversations with the ASU undergraduate interns revealed a perception that the students gained an understanding of local birds and their connection to local conservation projects. Since its inception in 2005, over 125 students have participated in this program, 82% of whom are Hispanic.

Knowledge Exchange

The **Global Institute of Sustainability** (**GIOS**) is the home base of CAP LTER, as well as the Decision Center for a Desert City, the Urban Ecology IGERT, the Decision Theater, the Urban Environmental Monitoring of 100 Cities, and many other programs. GIOS' outreach efforts engage academic, business, and governmental groups in dialogues about pressing environmental issues affecting our rapidly growing desert metropolis. In October 2006, ASU launched the new School of Sustainability (an entity under GIOS) as the first academic school in

the country to be focused upon sustainability science and studies. CAP LTER retains strong linkages to the School through its faculty and anticipates involving its graduate and undergraduate students in CAP research over time.

GIOS produces a weekly e-newsletter digest, "Sustainability Digest," with events, announcements, and job postings that are of interest to the university and community. To inform residents at the **North Desert Village** experimental suburb about ongoing research, CAP LTER management produces an occasional newsletter on this initiative and distributes letters to households living in the study areas.

In addition, there are initiatives under GIOS that strive to apply the work of university researchers to the business of the private and public sectors. For example, the Sustainable Materials and Renewable Technologies (SMART) program based at GIOS is working closely with private industry and state and local agencies to minimize the impacts of rapid urbanization, through existing and emerging technologies and sound policy recommendations. This project involves CAP LTER scientists and builds on urban heat island research conducted under CAP LTER. The Sustainability Partnership (SP), a quasi-consulting arm of the GIOS, engages policy makers, resource managers, and industry leaders in planning and responding to the challenges of urban growth, environmental protection, resource management, and social and economic development. SP is currently engaging developers and stakeholders on the eastern and western edges of the greater Phoenix area in a dialogue with ASU faculty with the aim of developing projects of mutual benefit. CAP LTER has been active in these initial discussions. GIOS plays a central, liaison role in ensuring effective knowledge exchange from academic researchers (i.e., CAP LTER) to decision makers and end users of the science.

Box 1: Potential Research Questions from Summer Summit

- What is the relationship between global climate change and more locally-driven climate impacts in the Phoenix metropolitan area?
- Do drought and other extreme events affect city size and growth?
- What are the external forces potentially affecting the growth and ecology of Phoenix, and how do these figure into climate change scenarios and impacts?
- What do we know about how change and climatic events affect cities in higher income countries?
- What is the relationship between social inequalities and global climate change?
- What will be the impact of global climate change on human population dynamics in the Phoenix metropolitan area?

The highlight of each year is the CAP LTER **Annual Poster Symposium**, held in January or February. This day-long event, attended by researchers, students, K-12 teachers, community partners, and state and local agencies, features a keynote speaker and poster presentations by all supported projects (view posters at http://caplter.asu.edu/home/symposia.jsp).

A **Summer Summit** or retreat is held at an off-campus site in selected years to address overarching theoretical and scientific issues. During summer 2006, the **Summer Summit** involved 28 scientists from CAP LTER and the Decision Center for a Desert City in a set of joint exercises addressing a central research question: *how will the urban socioecological system respond to regional climate change?* The objectives of the Summer Summit were: to develop a conceptual framework to exploit the talents of the two research initiatives to address the interface between urbanization and climate change; to stimulate interactions and synergies among scientists; and to begin work on new research agendas dealing with impacts, responses, and adaptations to regional climate change. An evaluation conducted at the end of the one and a half day summit indicated that participants established important research synergies, and work continues on

refining a common conceptual framework. Box 1 lists some of the potential research questions identified by participants. Already, CAP scientists have been involved in research proposals that relate to topics emerging from the Summer Summit, including a proposal by co-PI Sharon Harlan, "Vulnerability to Urban Climate Change: A System Dynamics Analysis," that was submitted (but not funded) to the Coupled Human-Environment Systems grant competition at NSF. A workshop series on the Economics of Climate Policy, largely sponsored by Arizona Public Service (Arizona's largest electric utility), is planned for fall 2007. As well, CAP LTER's involvement in the National Ecological Observatory Network (NEON) includes a climate change dimension.

Box 2: Speakers for All Scientists Meetings

September 2006: Graduate summer grant presentations
October 2006: "Modeling Land Change and Sustainability in Human-Environment Systems," Dan Brown, University of Michigan.
November 2006: "Ecosystem Services Project," Ann Kinzig and Charles Perrings, ASU
February 2007: "Conversation about Chaos and Conservation in the Community," Jeff Williamson, Phoenix Zoo.
March 2007: "North Desert Village Research," Scott Yabiku and Chris Martin, ASU
April 2007: "How Much Can Technology Do to Achieve a Truly Sustainable World of 7 Billion Humans?," Ernst Ulrich von Weizsaecker, University of California, Santa Barbara

Monthly **All Scientists Meetings** (ASMs) attract between 40 to 100 participants, including community partners, and feature scientific presentations by visitors or discussions of project results. During 2006-2007, **All Scientists Meetings** presenters were a mixture of CAP LTER researchers and invited guests (Box 2). Dr. Ernst Ulrich von Weizsaecker was co-sponsored through CAP LTER and the **Wrigley Lecture Series** (funded through a private donation). A new effort of the CAP LTER Knowledge Exchange Working Group will bring local policymakers and practitioners to speak to CAP scientists at ASMs. Jeff Williamson, CEO/President and Executive Director of the Phoenix Zoo, was the first of these individuals to speak during an ASM.

Collaborations and Partnerships

Through the communication means and knowledge exchange initiatives described above as well as other initiatives, CAP LTER seeks to maintain and expand its collaborations and partnerships within academia and beyond. In fall of 2006, ASU and the Chinese Academy of Sciences formed the *Joint Center on Urban Sustainability* in Beijing. This formative-stage initiative involves several CAP LTER scientists in fields ranging from landscape ecology to environmental justice.

CAP LTER's participation in NEON moved to a new level when the Santa Rita Range near Tucson was chosen as a core monitoring site. Phoenix will be included in a rural-urban gradient to this core site, and CAP LTER scientists have been active with colleagues at University of Arizona in determining sites for towers along this gradient.

The NSF-funded Decision Center for a Desert City (DCDC) coordinates a program of interdisciplinary research and community outreach to improve water-management decisions. In collaboration with local, state, and regional water managers, DCDC has developed scenarios of different water futures through a systems dynamics model known as **WaterSim** and has shared these with decision makers at ASU's Decision Theater. In a joint research initiative with CAP LTER, scientists are using **WaterSim** to examine the socio-political dynamics that shape environmental decision-making and outcomes in Arizona. In addition to this project, the CAP LTER-DCDC collaboration has taken several forms so far, including a large number of researcher involvement in both projects, joint support for the **Phoenix Area Social Survey**, and

a joint **Summer Summit** in 2006. Director Gober has been a CAP LTER PI since 1997 and DCDC is co-directed by Redman (CAP Co-Director).

Co-director Redman was a participant in the *Social and Socio-Environmental Dynamics Workshop* hosted by ASU's School of Human Evolution and Social Change and the Center for Social Dynamics and Complexity. Workshop participants included a team of nine urban geographers from the French Centre Nationale de Recherches Scientifique (CNRS) and the University of Paris I, a team of four Italian researchers from the University of Modena and Reggio Emilia, and scientists from ASU, Los Alamos National Lab, Santa Fe Institute, University of Arizona, and the University of California, Irvine.

From CAP LTER's inception, we have focused upon meaningful community outreach by establishing a series of community partnerships. Numerous individuals and organizations have permitted short- and long-term monitoring on their sites. Local municipalities, such as the *City of Scottsdale*, the *City of Tempe*, and the *City of Phoenix*, have been actively supporting CAP research on water quality. In all cases, the municipalities have granted CAP access to research sites and have engaged in data sharing for research. Discussions are underway with the *City of Scottsdale* to initiate a storm water quality project in Indian Bend Wash, and the *City of Phoenix*'s Rio Salado Habitat Restoration project staff has approached CAP with the desire to collaborate on studies of vegetation and animals in the restoration area. CAP and the *U.S. Geological Survey* (USGS) have installed a water sampler in Indian Bend Wash cooperatively. The *USGS National Water-Quality Assessment* (NAWQA) program is also participating in our long-term water-monitoring project, collaborating on studies of water quality and storm sampling.

At the state agency level, numerous agencies have collaborated with CAP researchers or lent assistance with research endeavors. The *Arizona Department of Water Resources* has engaged in a data sharing arrangement with CAP, and the *Arizona Department of Environmental Quality* has assisted with atmospheric deposition studies. Public land access is critical for CAP research and the *Arizona State Land Department* has generously permitted access to its land for various projects. State entities are also involved in learning experiences for our students through internships and providing data and assistance with research projects. For example, the *Arizona Department of Game and Fish* has participated in the Research Experience for Undergraduates (REU) program.

Maricopa Association of Governments (MAG), consisting of the 24 incorporated cites and towns, two Indian communities, and Maricopa County, has been an integral partner, supporting the project by supplying GIS information and data and collaborating on investigations into growth planning, land-use projections, and open-space implementation. We have also worked with the *Flood Control District of Maricopa County* in projects involving storm hydrology and storm-water chemistry and are collaborating on research in the Gila River basin.

Salt River Project, a semipublic organization responsible for water management and supplying electrical energy to the region, has a long-term research and outreach relationship with CAP LTER. They have greatly facilitated the work of the land-use team and have contributed greatly to the nitrogen mass balance study and even provided a helicopter to reach several remote Survey 200 sample locations. The *Desert Botanical Garden* has allowed CAP researchers access to its site for experiments on tropic dynamics and nitrogen deposition as well as allowing researchers to erect a flux tower.

In addition, CAP LTER participants partner with a wide range of institutions on associated projects. For example, our research teams have substantial collaborations, through workshops

and publications, with scientists at the Baltimore Ecosystem Study site, Coweeta, Shortgrasse Steppe, Kellogg, Konza Prairie, Jornada, Sevilleta, University of Michigan, The Nature Conservancy, Stanford University, University of Nevada-Las Vegas, UNAM Hermosillo, University of Arizona, University of Melbourne's Center for Urban Ecology, numerous academic and research institutions through Grimm's involvement in the LINX project, and several institutions in China. Several CAP researchers were actively involved as workshop leaders during the LTER All Scientists Meeting in Estes Park, Colorado in September 2006.

Education Manager Monica Elser is involved in the Teaching Ecological Complexity project which involves the Andrews, Shortgrasse Steppe, Jornada, Luquillo and CAP sites. Social scientists at CAP LTER continue to work with their counterparts at the Baltimore Ecosystem Study site on defining cross-site research. A February workshop on environmental justice (funded by the LTER Network Office) brought researchers from the Baltimore Ecosystem Study and Florida Coastal Everglades together with CAP researchers with the aim to produce a proposal for National Center for Ecological Analysis and Synthesis (NCEAS) on the ecology of environmental justice in metropolitan areas. CAP LTER's ecosystem services work and similar work at other sites generated excitement at the LTER All Scientists meeting in September. Subsequently, initial work on expanding the CAP LTER approach to other sites took place during a LTER Network Office-funded workshop in May.

Our education program has established several strong community partnerships. These include those with the Desert Botanical Garden, the Gilbert Riparian Preserve, the Creighton Elementary District, the Phoenix Elementary District, the Roosevelt School District, the Arizona Foundation for Resource Education, the Sonoran Institute, the Sonoran Desert Center and the Southwest Center for Education and the Natural Environment.

Numerous visitors to CAP LTER as well as visits by CAP scientists to other institutions are providing the impetus for future collaborations. Scientists from the South African Environmental Observation Network (SAEON), Kookmin University (South Korea), National University of Mexico, and other institutions visited CAP LTER to learn about our approach to urban ecology. Sharon Hall shared similar information during a visit to the University of Cape Town, South Africa. CAP staff and researchers also held discussions with the Embassy of France in the United States with a view to establishing future research linkages with the *Zones Ateliers* program in that country as well as exploring a new initiative on sustainable urban studies that will be launched in the fall with a workshop involving U.S. and French scientists. CAP and DCDC have participated in initial discussions with the University of Arizona and the Desert Research Institute on defining common research interests toward collaboration on a common research initiative.

Dissemination of Research Results

Since the last annual report, CAP2 participants have produced 58 journal articles (30 published, 14 in press, 14 in review) and 27 book chapters and books (16 published, 8 in press, 3 in review). In addition research results are routinely presented at meetings and conferences in a diverse array of fields. Up to June 2007, 28 presentations and posters were given at regional, national and international conferences, and 47 at LTER-related conferences.

Some of these presentations were by invitation from entities wishing to learn more about CAP LTER. John Briggs gave the keynote presentation at the 5th Annual Urban Ecology and Conservation Symposium organized by the Urban Ecosystem Research Consortium in Portland, Oregon.

The CAP LTER and individual projects continue to receive press attention at the university, local, state and national levels. CAP was the focus of an article in *National Wildlife* that included interviews with Nancy Grimm and Paige Warren. The **North Desert Village** project received considerable press after a presentation by CAP scientists at the 2006 Ecological Society of America conference. Stories on this experiment and its initial results appeared in print and online in media as diverse as *High Country News*, *Scientific American* online, *Plenty* online, *The Arizona Republic*, *Seed Magazine* online and *ABC News* online, as well as some non-English language, online news magazines. CAP researchers Paige Warren and Christopher Boone discussed their comparative research in Phoenix and Baltimore in *Zoogoer*, the magazine of the Smithsonian's National Zoo, and Sharon Hall commented on excess nitrogen in xeric landscapes in *The San Diego Union-Tribune*. *High Country News* featured a story on CAP LTER's urban ecology research, which included discussions of work on environmental risk and justice and spider and bird populations. As the new School of Sustainability attracted attention from news agencies, CAP LTER garnered mention in interviews, podcasts and statements by ASU President Crow and others in his office.

The CAP LTER website continued as a vehicle for communicating research results and data to scientists and the general public. CAP staff has summarized key research findings for the website's Research Highlights section.

Box 3: Selected Other Outreach Activities

- Classroom presentations to elementary through high school students: 1500 students
- ASU Geosciences Day: >100 community members
- Feathered Friends Festival: >100 community members
- Sally Ride Science Festival: > 100 community members
- SEE ASU: > 1000 community members
- Chandler High Schools Science Fest: >50 community members
- Association for the Advancement of Sustainability in Higher Education Conference: >500 students & faculty

Other Outreach

CAP LTER participates in other outreach activities during the year (Box 3). Many of these involved K-12 students and educators, although some were geared to the general public. Through these activities, CAP has reached over 3000 people. In fall 2006, CAP presented a poster during the Association for the Advancement of Sustainability in Higher Education (AASHE) conference held at ASU, which focused upon how CAP trains students in higher education. CAP will continue to find venues for reaching the public, particularly underserved populations in the Phoenix metropolitan area.

VII. CONTRIBUTIONS

Contributions within Discipline

Overarching CAP LTER investigations are contributing baseline data and analysis upon which to build future work and projections for central Arizona. Specific areas where contributions have been made this past year include:

- The **North Desert Village project** includes two major research innovations: 1). The novel design in which humans (resident rental tenants) are incorporated as an integral part of the experimental design, and 2). The use of an adaptive experimental approach. More specific contributions include the installation of micro-meteorological stations within each of the landscape treatment areas to help understand the extent of under canopy microclimate variation related to variation in vegetation density.
- Current environmental literature indicates severe problems relating environmental behavior, values and knowledge. Social science research at **North Desert Village** has already shown why environmental values are important, but researchers also are focusing on the mechanisms by which environmental values become secondary to identity-based, culturally- and socially-constructed norms and behaviors, such as notions of "family." A more detailed understanding of socio-ecological dynamics will emerge as the study continues. This project is unique because researchers are studying a host of variables simultaneously – socio-cultural values, knowledge, social networks, and human behavior – which allows for an integrated analysis of these variables. With data from the second wave of interviewing (post-treatment), researchers will examine if people's values, preferences, and satisfaction with their landscapes change due to the experimental manipulation by CAP-LTER scientists. This aspect of the study is highly innovative because it is rare to have a long-term experimental design within a "real" residential population.
- The **lichen resurvey with heavy metal analysis** is contributing to a better understanding of the uses of lichens as biomonitors of air pollution. This research project has also furthered the application of mass spectrophotometry to questions of environmental contamination and air pollution patterns.
- Work on **modeling fluxes of water and salt through the urban infrastructure** has created a dynamic model that provides a holistic view of urban water supply and water use. The model is being used to examine fluxes in the city of Goodyear, Arizona in an upcoming CAP LTER project and can be applied to different cities to address water and salt flux concerns.
- Research and data on **arbuscular mycorrhizal fungi** have contributed greatly to the understanding of this important group of fungi, which are obligate symbionts of approximately 75% of vascular plants in the world. AM fungi have been shown to impact plant productivity and stress tolerance, but little is known about their diversity in urban areas or the factors that may influence diversity. One problem in assessing AM fungal diversity, as with any soil organism, is determining the appropriate number of samples to take and sampling design. We found that the number of samples needed to adequately assess AM fungal communities were larger than typically collected in soil ecology field experiments. The results of this research will give guidance to researchers working in urban ecosystems as well as other areas in the area of sample number and sampling design.
- Research on **urban bird dynamics** uses a mechanistic approach to understanding avian communities within urban settings. Such an approach is rare in community ecology, and CAP scientists are at the forefront of debates on how to achieve a better balance between observational and mechanistic research in urban ecology (Shochat et al. 2006b.)

- The **water chemistry of lakes and rivers following winter storms** project contributes to a broad array of scientific fields including hydrology, geochemistry, water resource and policy making. Researchers are working with a database that is both much larger than the typical hydro-geological databases and large in spatial extent. Samples were collected over an 11-month span at daily and weekly time scales, uncommon for studies of this kind. Combining hydrology and geochemistry of trace elements is a novel approach.
- The **PASS** contributes to the fields of urban sociology, environmental sociology, urban ecology, and planning and design. PASS provides unique human data on environmental values, behaviors, and preferences that have consequences for the natural and built environments. The spatial identifiers of PASS sample households and neighborhoods are linked to other geo-referenced data sets that can be used to investigate the distribution of environmental amenities and disamenities among social groups.
- **Survey 200** findings provide a probability-based, spatially extensive snapshot of a suite of key ecological variables that is unique in covering the complex landscape of a rapidly urbanizing region and surrounding desert. These data provide a framework for understanding the spatial picture across the CAP region and have been used extensively by a wide variety of project researchers (both faculty and students) over the last 12 months. As the initial primary data papers are published, we anticipate the data will become increasingly known to and used by the wider ecological research community.
- The development of an **online EML editor** will make the task of editing metadata much easier for researchers. Informatics staff at the LNO are interested in how this can be applied network-wide.

Contributions to Other Disciplines

- CAP LTER is a multidisciplinary endeavor and involves scientists from a range of disciplines in examining a common set of research problems. While multidisciplinary projects have their challenges (Baker 2006), they can lead to important syntheses of data and information that would otherwise be impossible under a single disciplinary approach. As a result, contributions often extend beyond disciplinary boundaries.
- For example, under the **drought and water conservation policy** project, research has fostered interdisciplinary collaborations between historians, geographers and key policy and stakeholder informants. A main product of this effort is a conservation program database including nominal data indicating whether or not ten municipalities have different conservation programs and summary information for broad categories of conservation programs (e.g., regulations, conservation/drought management plans, and economic- and information-based programs). This information will be available for future researchers at CAP and may also aid conservation education planning in the region.
- The **Phoenix Area Social Survey** (PASS) is contributing to the growing fields of urban sociology and environmental sociology as well as to biology, plant biology and urban planning. **PASS** provides unique data on human values, behaviors, and preferences that impact natural and built environments. **PASS** is a data resource for ongoing CAP LTER projects, including those on environmental risk, urban parks, and the development of the urban fringe. Researchers have already created a database linking Survey 200 points in

urbanized areas to 1990 and 2000 block-group census data. In addition, this research parallels the ongoing monitoring of ecological conditions.

- Findings from the **NDV Experiment** have applications in fields such as architecture and landscape planning. Researchers are working toward an improved understanding of the effect of different landscaping types on power and water usage - both from the biophysical effects of the landscapes themselves, and on the behavior of residents within different experimental landscapes. For example, will people living in xeric (low water use, desert-like) treatments become more aware of water conservation issues and lower their in-home water use? Subsequent data analysis will focus on how social variables we are studying affect behavior, which ultimately affects biophysical landscape processes.
- **Survey 200** data have been used to develop and improve methodologies in the fields of remote sensing, urban atmospheric science and spatial statistics, with publications/ submissions to peer-reviewed journals in all these fields.
- Work on **modeling land use change and ecosystem responses** and landscape ecology in general has made noticeable contributions to these fields in the US and around the world. For example, the landscape gradient approach to urban pattern analysis has been applied in several studies in China and Europe. Work on urban modeling and land use analysis contributed significantly to the special issue of the journal, *Urban Ecosystems* (Musacchio and Wu 2004) and a book on scaling and uncertainty analysis in ecology (Wu et al. 2006). The Hierarchical Patch Dynamics framework has been used for urban ecology and landscape analysis in several other countries (including, China, Canada, Australia, and Europe).

Contributions to Resources for Research and Education

- CAP LTER's setting within a university enhances the ability to conduct, communicate, and synthesize research activities. Faculty members have expanded their courses to include a consideration of urban ecology and, in some cases, have designed new courses to accommodate CAP LTER interests. The multi-disciplinary courses taught in the IGERT in Urban Ecology program are good examples of integrative science in action. Graduate assistants gain exposure to interdisciplinary research, the importance of long-term datasets, metadata, and data archiving, as well as experience in database design and management, and lab processing and analysis.
- The Global Institute of Sustainability, the administrative home for the CAP LTER, houses the Informatics Lab and provides support, management staff, shared office space, and meeting facilities for CAP participants. This infrastructure supports services that enhance the dissemination of project results, foster new collaborations, enable access to project data resources, engage K-12 students in the science of the CAP LTER, and reach out to community members and organizations. Interdisciplinary working groups are organized that often result in the generation of new research opportunities and funding.
- The Southwest Environmental Information Network (SEINet) was created to serve as a gateway to distributed data resources of interest to the environmental research community in Arizona and beyond. Through a common web interface, we offer tools to locate, access, and work with a variety of data including biological collections, ecological research data, GIS data, taxonomic name information, bibliographies, and research protocols. Data collected as part of the Geological Remote-Sensing Lab's (GRSL)

research programs is archived and is available to CAP LTER researchers and graduate students. This archive includes data collected within the study area as well as many other sites through the western US. As such, it represents a rich data resource for faculty members and graduate students. Data products produced by the GRSL are available for use as class and presentation materials and have been used both for K-12 and college-level classes and presentations. The datasets from the historic land-use project can be used for further research as well as in GIS, geography, planning, or other instruction.

- The Goldwater Lab for Environmental Science has been expanded to accommodate the project's analytical needs and provide graduate-student training on instruments housed in this facility.
- Collaborations such as **Ecology Explorers** and **Service at the Salado** share project results with underserved community schools to enrich programming and encourage future educational pursuits in the sciences.

Contributions to Human Resource Development

The CAP LTER provides a powerful framework for training graduate students, nourishing cross disciplinary projects, and contributing to the new and growing field of urban ecology. Our project is also committed to engaging pre-college and undergraduate students, and K-12 teachers, community organizations, governmental agencies, industry, and the general public in our multilayered investigation.

- Since the inception of CAP LTER, close to 30 postdoctoral associates have taken leadership roles in research and outreach activities. The project currently supports two post-doctoral associates, all full-time on CAP LTER. In addition, one post-doctoral associate from GIOS has worked on CAP LTER initiatives. The individuals interact, participate in planning meetings with the co-project directors and project managers, work with faculty members and team leaders, collaborate with graduate students, and organize and coordinate the annual poster symposium and summer summit. They are integral to the research and field experience of CAP LTER and receive training in interdisciplinary collaboration, graduate-student supervision, data collection and analysis, and presentation techniques.
- Five graduate students a semester and during the summer months are involved in CAP LTER, each immersed in the research at hand and working together as a cohort for the project at large. They are drawn from a wide range of university programs, departments, and schools, representing disciplines such as anthropology, biology, curriculum and instruction, engineering, economics, geography, geological sciences, planning and landscape architecture, plant biology, and sociology. Graduate students serve as research associates and are trained in field-investigation techniques, data analysis, scientific writing, oral presentation, interdisciplinary interaction, GIS, and remote sensing.
- In 2004 CAP established a competitive summer graduate student grant program under which a total of 19 grants have been awarded. The awardees present their research finding at a CAP All Scientists Meeting in the fall and often present additional results at the annual poster symposium.
- Faculty members in geography, geological sciences, life sciences, and civil and environmental engineering have delivered additional training through graduate courses designed around CAP LTER activities.

- Students involved in CAP LTER are encouraged to present their research results at various local, national, and international meetings. Students have been presenters in approximately 42% of presentations given by CAP scientists at national and international meetings since 2004. They comprise around 45% of the presenters at CAP poster symposia.
- As active participants in CAP research, students are involved in publishing research results. During the current grant period, a total of 27 papers have been co-authored by students since 2004 and on 15 of these, the student was the first author. These papers have appeared in a wide range of journals, including *BioScience*, *Social Science Quarterly*, the *International Journal of Remote Sensing*, *Frontiers in Ecology and the Environment*, and *Human Organization*.
- Since 2004, CAP LTER faculty members, postdoctoral associates, and senior graduate students have mentored 14 summer and academic year REU students, funded under NSF Supplements or directly from CAP funds, who gained research training via summer projects integral to CAP LTER. Many other REUs become involved in CAP research through other, CAP-leveraged projects. Undergraduates from ASU who are working on CAP LTER projects during the academic year can be part of the new Community of Undergraduate Scholars, a program sponsored by the Global Institute for Sustainability and the Barrett Honors College. Other undergraduate students have benefited by participating in data collection for the PASS, ground arthropod and bird studies, collection and curation activities, and courses that relate to the CAP LTER. Project research has also been incorporated into undergraduate honors and senior theses.
- Monthly All Scientists Meetings (ASMs) provide opportunities for cross-disciplinary interaction and information exchange through science- and results-based presentations. Attendance ranges from 40 to 80 people per meeting and includes faculty members, postdoctoral associates, graduate students, and community partners. Smaller groups of CAP researchers assemble for various projects. Remote Sensing Working Group meetings have been held to foster collaborations among CAP LTER scientists doing research involving remote sensing via discussion of ongoing and planned work, proposal generation, image acquisition, and workshops. Other working groups, such as atmospheric deposition, human feedbacks, soils, and modeling, meet as needed. A new CAP/BES cross-site initiative and the PASS project both use working group formats to plan their study designs.
- The Schoolyard LTER supplement has created special opportunities for K-12 teachers to work alongside LTER researchers in summer internships on several monitoring projects. CAP graduate students and postdoctoral associates have mentored high-school students through a laboratory internship program coordinated by the Southwest Center for Education and the Natural Environment, a collaborative program with the Global Institute of Sustainability. CAP participants serve as judges each year in the Central Arizona Science and Engineering Fair and the American Indian Science and Engineering Fair.

Contributions Beyond Science and Engineering

By taking a long-term view of complex issues that defy simple explanation, not simply the circumstances we find ourselves in today, CAP LTER and its community partners are striving to comprehend the social, economic, and biological forces that drive the processes shaping our

region. CAP LTER activities and research potentially provide information for planning urban growth, especially in sensitive ecosystems. Many results from CAP LTER projects have public policy implications, and working through other projects within GIOS, such as the Decision Center for a Desert City (DCDC), and our partners, we are able to convey these results to decision makers.

- Droughts and water shortages, combined with explosive growth of urban and suburban areas, have created a situation that is being viewed with increasing concern across the western United States. We believe that the publication and communication of our research results will enhance policy-makers' ability to address water-related environmental problems in the Southwest. CAP scientists active with DCDC have been working to communicate these results. In addition, CAP will continue to be active in initiatives forwarded by GIOS and the Sustainability Partnership, such as those involving water managers in Arizona, which gives the project access to important stakeholder groups.
- The **PASS** is a vehicle for increasing knowledge of how residents shape and respond to the local environment, which is a necessary step in devising a more sustainable city. Communities, social lives, values, and behaviors must be understood in order to comprehend the place of humans in the environment. This is vitally important in rapidly urbanizing regions, such as Phoenix. Arid cities face unique environmental challenges that accompany population growth, including extreme heat, limited water resources and shade, and harsh conditions for species survival. Many scientists and policy makers believe that these challenges can be overcome only creating strong, engaged communities that understand and appreciate their biophysical environments.
- Research on the **urban heat island**, including work on populations vulnerable to excessive heat, been shared with policymakers and practitioners through the City of Phoenix Urban Heat Island Task Force. This budding partnership between practitioners and scientists will enhance efforts toward ameliorating the heat island as well as possibly influence new research directions within CAP LTER.
- Avian research under CAP LTER has fostered important links between academic research and the wider community when "citizen scientists" become involved in research. For example, research on **foraging decisions and bird community structure** involved individuals from 21 families in research, including 11 students, whose work was integrated into the curriculum at a Phoenix high school. Other work on urban raptors engaged community members and utility company employees in reporting raptor sightings.
- The social science component of WaterSim, a joint research venture with DCDC, engages policymakers directly in a dialogue about possible water resource futures in the Phoenix metropolitan area.
- Researchers involved in the **water chemistry of lakes and rivers following winter storms** project are working closely with programmers at ASU's Decision Theater to develop a visualization aid that policy makers could use to investigate human impacts into the future.
- **NDV** research seeks to discover whether people's landscape preferences can be changed, or if they evolve over time. Do people prefer mesic to more water-saving designs simply because they are unfamiliar with xeric and native designs? Understanding the

mechanisms behind landscape preferences is important for urban planning as municipalities seek to promote water-saving landscapes. As well, new research on ecosystem services will explore tradeoffs principally between water and energy in landscapes. Researchers anticipate that this will allow them to determine if any landscape is optimal for water and energy conservation.

- Research on **nitrogen deposition** will provide policymakers with information on how to reduce nitrogen loads in urban runoff and surface waters, thus reducing public expenditures on stream restoration.
- CAP scientists' work on residential landscaping has the potential to reach many nontraditional audiences through "backyard ecology" outreach efforts. Recent media attention on the **North Desert Village** experiment indicates that media outlets are eager to report on such findings.
- **Survey 200** data provide regional planners and public policy makers a unique information source for how explosive urban and suburban growth is changing the ecological resources of the CAP region. As data analysis and modeling efforts continue to be refined, they will provide the facility to predict how future urban growth will affect the ecological infrastructure in the region.
- Research on **environmental risk and justice** is shifting from a focus on analyzing the distribution of disamenities and amenities in relation to population groups to a combined analysis of these patterns and the processes that create them as well as equity in public decision making. There has been an increased emphasis on vulnerability analysis in environmental justice work in order to mitigate future environmental inequities. This provides considerable scope for engaging policymakers in research.

VIII. PUBLICATIONS 2006-2007

Journal Articles

In Press

Dugan, L. E., M. F. Wojciechowski, and . L. R. Landrum. In press. A large scale plant survey: efficient vouchering with identification through morphology and DNA analysis. *TAXON*.

Grossman-Clarke, S, Y. Liu, J. A. Zehnder, and J. D. Fast. In press. Simulations of the urban planetary boundary layer in an arid metropolitan area. *Journal of Applied Meteorology and Climatology*.

Harlan, S. L., A. Brazel, G. D. Jenerette, N. S. Jones, L. Larsen, L. Prashad, and W. L. Stefanov. In press. In the shade of affluence: The inequitable distribution of the urban heat island. Invited paper for a special issue on equity and the environment, *Research in Social Problems and Public Policy*.

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APPENDIX A
CAP LTER PARTICIPANTS

	Duration of Involvement
Principal Investigators	
Nancy Grimm, Life Sciences	1997-present
Charles Redman, Sustainability	1997-present
Co-Principal Investigators	
Jonathan Allen, Engineering	2004-present
John M. Anderies, Human Evolution and Social Change	2004-present
Ramon Arrowsmith, Earth and Space Exploration	1997-present
Bob Bolin, Human Evolution and Social Change	1999-present
Anthony Brazel, Geographical Sciences	1997-present
John Briggs, Life Sciences	1999-present
Monica Elser, Global Institute of Sustainability	1998-present
Stanley Faeth, Life Sciences	1997-present
Corinna Gries, Global Institute of Sustainability	2000-present
Sharon Hall, Life Sciences	2005-present
Sharon Harlan, Human Evolution and Social Change	1999-present
Diane Hope, Global Institute of Sustainability	1997-2006
Jason Kaye, Life Sciences	2002-2005
Ann Kinzig, Life Sciences	1999-present
Lauren Kuby, Global Institute of Sustainability	1998-present
Kelli Larson, Geographical Sciences	2005-present
Chris Martin, Applied Biological Science	1997-present
Peter McCartney, Global Institute of Sustainability	1997-2006
Jordan Peccia, Engineering	1997-2005
Brenda Shears, Global Institute of Sustainability	1997-present
Jean Stutz, Applied Biological Science	1998-present
Elizabeth Wentz, Geographical Sciences	2004-present
Paul Westerhoff, Engineering	2004-present
Jianguo Wu, Life Sciences	1997-present
Senior Personnel: Managers	
Stevan Earl, Site Manager	2006-present
Monica Elser, Education Manager	1998-present
Corinna Gries, Information Manager	2000-present
Diane Hope, Field Project Manager	1997-2006
Lauren Kuby, Communications Manager	1997-present

Peter McCartney, Information Manager	1997-2006
Marcia Nation, Project Manager	2006-present
Brenda Shears, Assistant Dir., GIOS	1997-present
Linda Williams, Finance Manager	1997-present

Senior Personnel: Scientists

Braden R. Allenby, Engineering	2004-present
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Christopher Boone, Human Evolution and Social Change	2006-present
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Phillip Christensen, Mars Space Flight Facility	1997-present
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H.J.S. Fernando, Engineering	1997-present
Jonathan Fink, Global Institute of Sustainability	2004-present
Stuart Fisher, Life Sciences	1997-present
Patricia Gober, Geography	1997-present
Susanne Grossman-Clarke, Global Institute of Sustainability	2004-present
Subhrajit Guhathakurta, Planning	2004-present
Edward J. Hackett, Human Evolution and Social Change	1997-2006
Nora M. Haenn, Human Evolution and Social Change	2004-present
Randel Hanson, Justice & Social Inquiry	2004-present
Hilairy Hartnett, Earth and Space Exploration	2004-present
Pamela Hunter, Institute for Social Science Research	2005-2006
Jana Hutchins, Institute for Social Science Research	1997-present
Marcus A. Janssen, Human Evolution and Social Change	2005-present
James Johnson, Integrated Natl. Sciences	2006-present
Paul C. Johnson, Engineering	1997-present
Eric Keys, Geographical Sciences	2004-2006
Andrew Kirby, Social/Behavioral Science	1997-present
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Jennie J. Kronenfeld, Social and Family Dynamics	2004-present
Michael Kuby, Geographical Sciences	2004-present

Leslie Landrum, Life Sciences	1998-present
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Anandamaye Majumdar, Mathematics and Statistics	2004-present
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Thomas H. Nash III, Life Sciences	1997-present
Margaret C. Nelson, Human Evolution and Social Change	1998-present
David L. Pearson, Life Sciences	1997-present
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Everett L. Shock, Earth and Space Exploration	2001-present
Kerry Smith, Business/Econ.	2006-present
Milton Sommerfeld, Life Sciences	1997-present
Juliet C. Stromberg, Life Sciences	1997-present
Sander van der Leeuw, Human Evolution and Social Change	2004-present
Paige S. Warren, Natl. Res. Con., U of Mass-Amherst	2004-present
David White, Community Resources	2005-present
Amber Wutich, Human Evolution and Social Change	2006-present
Scott T. Yabiku, Social and Family Dynamics	2005-present
Joseph A. Zehnder, Geographical Sciences	2004-2007

Post-Doctoral Research Fellows

David Casagrande, Global Institute of Sustainability	2004-2005
William Cook, Global Institute of Sustainability	2004-2005
David Lewis, Global Institute of Sustainability	2004-2005
Jose Lobo, Global Institute of Sustainability	2005-2007
Kathleen Lohse, Global Institute of Sustainability	2005-2006
Louis Machabee, Global Institute of Sustainability	2002-2005
Melissa McHale, Global Institute of Sustainability	2007-present
Maik Netzband, Global Institute of Sustainability	2004-2005
Eyal Shochat, Global Institute of Sustainability	2006-present
Chona Sister, Global Institute of Sustainability	2007-present
Ryan Sponseller, School of Life Sciences	2006-2007
Amber Wutich, Global Institute of Sustainability	2006-2007

Research Technical Personnel

M. Amy DiIorio, Research technician, CAP LTER	2001-2005
Laura E. Dugan, Research technician, CAP LTER	2005-2006
Roy E. Erickson, Research specialist, CAP LTER	2000-present
Martin J. Feldner, Research technician, CAP LTER	2005
Steven W. Higgins, Research lab aide, CAP LTER	2004

Jill E. Jones, Research lab aide, CAP LTER	2004-2005
Roy M. Jones, Research lab aide, CAP LTER	2004-2005
Hooi Hong Khor, Institute for Social Science Research	2006
Cathy D. Kochert, CAP LTER lab manager	1999-present
Karen Lafrance, Research lab aide, CAP LTER	2006-present
Shalini Prasad, Graphic designer, Global Institute of Sustainability	2005
Phil Puleo, Institute for Social Science Research	2006
Suzanne D. Rester, Research lab aide, CAP LTER	2005-2006
Laura Riley, Research lab aide, CAP LTER	2006-2007
Janaina Scannel, Institute for Social Science Research	2006
Quincy Stewart, Research technician, CAP LTER	2005-present
Valerie Steen, Research technician, CAP LTER	2005-2006
Diana Stuart, Research technician, CAP LTER	2000-2005
Maggie S. Tseng, Research technician, CAP LTER	1997-present
Katrina Wells, Institute for Social Science Research	2006
Sean A. Whitcomb, Research technician, CAP LTER	2005
Kymberly C. Wilson, Research technician, CAP LTER	2006-2007

Informatics Lab

Raul Aquilar, Global Institute of Sustainability	2006-present
Ed Gilbert, Global Institute of Sustainability	2002-present
Corinna Gries, Global Institute of Sustainability	2000-present
Peter McCartney, Global Institute of Sustainability	1997-present
Wayne Porter, Global Institute of Sustainability	2000-present
Cindy Zisner, Global Institute of Sustainability	1997-present

Public Outrearch/Education Personnel

Monica Elser, Global Institute of Sustainability	1998-present
Lauren Kuby, Global Institute of Sustainability	1998-present
Kathryn Kyle, Global Institute of Sustainability	1997-present
Maggie McGraw, Global Institute of Sustainability	1997-present
Tina Salata, Global Institute of Sustainability	2006-present
Charlene Saltz, Global Institute of Sustainability	2000-2006

Research Support Personnel

Tamlin Engle, Global Institute of Sustainability	2005-present
J. Nikol Grant, Global Institute of Sustainability	2001-present
Karen Gronberg, Global Institute of Sustainability	2005-present
Elizabeth Marquez, Global Institute of Sustainability	2005-present
Helen Palmaira, Global Institute of Sustainability	2006-present
Shirley Stapleton, Global Institute of Sustainability	1997-2005
Kathleen Stinchfield, Global Institute of Sustainability	1997-2007

Megan Wilkins, Global Institute of Sustainability	2007-present
Linda Williams, Global Institute of Sustainability	1997-present
Cindy Zisner, Global Institute of Sustainability	1997-present

Graduate Research Associates

Carol Atkinson-Palumbo, Geographical Sciences/IGERT	2004-2007
Marea Baggetta, Life Sciences/IGERT	2004-2005
Christofer Bang, Life Sciences	2006-present
Troy Benn, Engineering/IGERT	2006-present
Wendy Bigler, Geographical Sciences	2004-2007
Robert Bills, Life Sciences	2004-2006
Jessica Block, Earth and Space Exploration	2005-2006
Kendra Busse, Life Sciences	2006-present
Alexander Buyantuyev, Life Sciences	2002-present
Yolanda Chavez-Cappellini, Languages and Literatures	2006
Chichi Choi, Engineering	2007-present
James Clancy, Geographical Sciences/IGERT	2004-present
Tim Collins, Geographical Sciences/IGERT	2000-2006
Elizabeth Cook, Life Sciences/IGERT	2007-present
Bethany Cutts, Life Sciences	2006-present
Kate Darby, Human Evolution and Social Change/IGERT	2006-present
Rachel Davies, Life Sciences	2006-present
Juan H. Declet, Geographical Sciences	2006
Christopher Eisinger, Earth and Space Exploration/IGERT	2003-2005
Michelle Elliott, Human Evolution and Social Change/IGERT	2001-present
Vanessa Escobar, Earth and Space Exploration	2006-2006
Elizabeth Farley-Metzger, Human Evolution and Social Change	2004-2007
Haralambos Fokidis, Life Sciences	2007-present
Sheila Fram, Institute for Social Science Research	2006
Kristin Gade, Life Sciences/IGERT	2004-present
Daniel Gerrity, Engineering/IGERT	2004-2006
Daniel Gonzales, Engineering	2005-present
Sara Grineski, Human Evolution and Social Change/IGERT	2001-2006
Anne Gustafson, History/IGERT	2005-present
Tamara Harms, Life Sciences	2004-present
Donna Hartz, Geographical Sciences/IGERT	2005-present
Brent Hedquist, Geographical Sciences/IGERT	2005-present
Allison C. Huang, Student worker	2004-2006
Scott Ingram, Human Evolution and Social Change/IGERT	2003-present
Darrel Jenerette, Life Sciences	2000-2004
Alethea Kimmel-Guy, Geographical Sciences	2006-present
Elisabeth Larson, Life Sciences/IGERT	2004-present

Susannah Lerman, Natural Resources Conservation, U Mass	2006-present
Jen Litteral, Life Sciences	2007-present
Matthew Lord, Geographical Sciences/IGERT	2001-2006
Wendy Marussich, Life Sciences	2000-2004
Brandon McLean, Earth and Space Exploration	2005-2007
Cathryn Meegan, Human Evolution and Social Change/IGERT	2003-present
James Miller, Geographical Sciences/IGERT	2003-2007
Thad Miller, Sustainability/IGERT	2006-present
Tisha Munoz, Sustainability/IGERT	2006-present
David Murillo, Mathematics and Statistics/IGERT	2007-present
Kaesha Neil, Life Sciences	2006-present
Scott Norby-Cedillo, Sustainability/IGERT	2007-present
John Parker, Human Evolution and Social Change/IGERT	2001-2006
W. John Roach, Life Sciences/IGERT	1999-2006
Darren M. Ruddell, Geographical Sciences	2006-present
Avraj Sandhu, Computer Science	2006
Nilavan Sarveswaran, Engineering	2006
Hoski Schaafsma, Life Sciences/IGERT	2003-present
Shade Shutters, Life Sciences/IGERT	2003-present
Catherine Singer, Life Sciences	2005-2007
Arthur Stiles, Life Sciences	2002-2006
Colleen Strawhacker, Human Evolution and Social Change/IGERT	2006-present
Steve Swanson, Human Evolution and Social Change/IGERT	2001-present
Ken Sweat, Life Sciences	2006-present
Philip Tarrant, Geographical Sciences	2005-2006
Laura Taylor-Taft, Life Sciences	2006-present
Nathan Toke, Engineering/IGERT	2006-present
Roger Tomalty, Geographical Sciences	2004-present
Kelly Turner, Geographical Sciences/IGERT	2007-present
Deva Visamsetty, Computer Science and Engineering	2007
Jason Walker, Life Sciences/IGERT	2005-present
Jacqueline White, Life Sciences	2004-2006
Peng Zhang, Engineering	2006-2007
Xiaoding Zhuo, Earth and Space Exploration	2005-present

Undergraduate Student Workers

Melinda Alexander, Institute for Social Science Research	2006
Cristian Aquino-Sterling, Institute for Social Science Research	2006
Rosario Armenta, Institute for Social Science Research	2006
Mandana M. Behbahani, Life Sciences lab	2006
Kallista Bernal, Institute for Social Science Research	2006
David Borough, Institute for Social Science Research	2006

Julianna Bozler, Service at Salado	2007
Molly Brennan, Institute for Social Science Research	2006
Hillary Butler, Service at Salado	2006
Matthew Cavazos, Institute for Social Science Research	2006
Christina Cole, Institute for Social Science Research	2006
Marc Contijoch, Institute for Social Science Research	2006
Jordan Costello, Service at Salado	2007
Kimberly Cronin, Institute for Social Science Research	2006
Arturo Diaz Hernandez, Institute for Social Science Research	2006
Karla Dille, Institute for Social Science Research	2006
Bradley Durham, Institute for Social Science Research	2006
Courtney Edel, Life Sciences lab	2007-present
Wilford Eiteman-Pang, Service at Salado	2007
Alexandra Flournoy, Service at Salado	2007
Cassandra Fronzo, Institute for Social Science Research	2006
Justin E. Goering, Global Institute of Sustainability	2004-2005
Jonathan Gonzalez, Institute for Social Science Research	2006
Jocelyn Hackett, Institute for Social Science Research	2006
Amy M. Hodge, Global Institute of Sustainability	2004-2005
Daniel Hoyt, Service at Salado	2007
Dillan Isaac, Institute for Social Science Research	2006
Christopher Jarzabek, Service at Salado	2007
Ruth Jensen, Institute for Social Science Research	2006
Marsha Johnson, Service at Salado	2007
Kevin King, Institute for Social Science Research	2006
Crissy Knight, Service at Salado	2007
Mark Leeper, Institute for Social Science Research	2006
Mildred Levine, Institute for Social Science Research	2006
Danielle Lindsey, Institute for Social Science Research	2006
Nazune Menka, Service at Salado	2006
Erin M. Mills, Global Institute of Sustainability	2002-present
Lindsey Miller, Institute for Social Science Research	2006
Clifford Millett, Service at Salado	2006
Kathleen M. Mills, Global Institute of Sustainability	2004-2005
Hanna Milosevic, Service at Salado	2007
Rebecca Minghelli, Service at Salado	2007
Jennifer Monninger, Institute for Social Science Research	2006
Sandra L. Muldrew, Global Institute of Sustainability	2004-2005
Keith Mulvin, Service at Salado	2007
Casey Oakes, Service at Salado	2006
Sean O'Reilly, Service at Salado	2007
Viswesh Parameswanan, Global Institute of Sustainability	2006

Jason Parker, Service at Salado	2007
Chiranjeevi Pavurala, Global Institute of Sustainability	2006-2007
Erika Paulus, Service at Salado	2007
Danielle L. Prybylek, Global Institute of Sustainability	2004-2006
James Quinn, Institute for Social Science Research	2006
Roxanne C. Rios, Global Institute of Sustainability	2004-2005
Jennifer C. Roberts, Global Institute of Sustainability	2004-2006
Juan Rodriguez Martin, Institute for Social Science Research	2006
Heather K. Rothband, Global Institute of Sustainability	2006
Sean Russell, Institute for Social Science Research	2006
Janaina Scannell, Institute for Social Science Research	2006
Sharon Schleigh, Service at Salado	2006
Rosie Servis, Global Institute of Sustainability	2005-2006
Nafis Shamsid-Deen, Service at Salado	2007
Krystin Sheekey, Institute for Social Science Research	2006
Alex Silva, Service at Salado	2007
Sone P. Sithonnorath, Life Sciences lab	2005
Myra Snodgrass, Service at Salado	2007
Rebecca Sommer, Service at Salado	2007
Cynthia Soria, Service at Salado	2006
Emily Starr, Service at Salado	2007
Grayson Steinberg, Institute for Social Science Research	2006
Carena Van Riper, Service at Salado	2007
Francisco Vargas, Institute for Social Science Research	2006
Benjamin Wachter, Service at Salado	2007
Randy Wagman, Institute for Social Science Research	2006
Stephanie Williams, Institute for Social Science Research	2006

Research Experience for Undergraduates (REUs)

Erin Adley, Life Sciences	2004
Bony Ahmed, Life Sciences,	2006-2007
Michelle Ashley Gohr, Life Sciences	2007-present
Megan Kelly, Chemistry	2006-2007
Genevieve Luikart, Environmental Studies, New College of FL	2007
Kathryn McCormick, Life Sciences	2007
Hannah Mensing, Geography	2007-present
Andrew Miller, St. Olaf College	2007
Vivian Miller, Life Sciences	2007
Patrick Ortiz, Life Sciences	2007
Shondra L. Seils, Ecology and Evolutionary Biology, U of AZ	2006
Erica Schwartzmann, Life Sciences	2006-2007
Kristina Waterbury, Life Sciences	2004

Christina Wong, SEEDS student, Occidental College	2006
Thomas M. Zambo, Life Sciences	2006

Ecology Explorers Teachers

Stephanie Arnold, Veritas Preparatory Academy	2005
Amy Bell, Arcadia High School	2005
Debra Bornstein, Desert Sage Elementary School	2005
Kristy Braaksma, Desert Ridge Junior High	2005
John Brands, Desert Ridge Junior High	2005
Matthew Burke, Trevor G Browne High School	2007
Shiloh Carroll, Highland High School	2006
Kara-Anne Carpenter, Chandler Prepratory Academy	2006
Thomas K. Daniels, Kyrene Akimel A-Al Middle School	2005
Cher Fesenmaier, Desert Mountain High School	2005
Kathryn Frederick, Queen Creek High School	2007
Sharon Harrison, Vista Verde Middle School	2006
Kathleen Hartnett, Alta E Butler School	2005
John Jung, Mesa High School	2007
Kimber Kay, Ingleside Middle School	2006
Melissa Mara, Sandra Day O'Conner High School	2006-2007
Stephanie Maynard, Queen Creek High School	2007
Christin McLellan, Willow Canyon High School	2007
Stephanie Morgan, Perry High School	2007
Linda Riggs, Augusta Ranch Elementary	2006
Michele Schiff, Ironwood High School	2005
Clarice Snyder, Camelback High School	2005
Jeffrey Snyder, Washington High School	2005
Lynn Stinson-Keys, Tempe Preparatory Academy	2005
Kiva Stone, Frank Borman Middle School	2005
Jeffrey Taylor, Mesquite Jr High School	2005
Aaron Ullman, Red Mountain High School	2007
Cheryl Vitale, Mesquite Jr High School	2006
Kim Wallis-Lindvig, Boulder Creek High School	2006

Community Partners

Arizona Dept. of Water Resources

Arizona Dept. of Environmental Quality

Arizona Dept. of Game and Fish

Arizona Foundation for Resource Education

Arizona Public Service

Arizona Science Center

Arizona State Land Dept.
City of Phoenix
City of Scottsdale
City of Tempe
Creighton School District
Deer Valley High School District
Desert Botanical Garden
Flood Control District of Maricopa County
Fountain Hills High School District
Gila River Community Schools
Gilbert Public Schools
Glendale School District
Maricopa Association of Governments
Maricopa Community Colleges
Maricopa Parks and Recreation Department
Mesa Public Schools
Peoria Unified School District
Phoenix Elementary School District
Phoenix Union High School District
Roosevelt School District
Salt River Project
Sonoran Desert Center
Tempe Elementary School District
Tempe Preparatory Academy
Tempe Union High School District
The Phoenix Zoo
Tonto National Forest
US Dept. of Agriculture
US Forest Service
US Geological Survey
Veritas Preparatory Academy

Organizations Giving Permission for Sampling on Their Sites

Arizona Dept. of Environmental Quality
Arizona Public Service
Arizona Dept. of Transportation
Arizona State Land Dept.

Arizona State Parks
City of Phoenix
City of Chandler
City of Scottsdale
City of Tempe
Dawn Lake Homeowners Association
Desert Botanical Garden
Dobson Ranch Homeowners Association
Duncan Family Farms
Flood Control District of Maricopa County
Honeywell
Intel
Insight Enterprises
Las Brisas Homeowners Association
Maricopa Co. Dept. of Environmental Services
Maricopa Co. Parks and Recreation Dept.
Morrison Brothers Farms
Ocotillo Homeowners Association
Ross Management Inc.
Salt River Project
Sonoma Farms, Inc.
Tempe Union High School District
Tonto National Forest
Town of Fountain Hills
US Forest Service
US Geological Survey
Val Vista Lakes Community Association
Valley Lutheran Hospital