CAP LTER 2004–2007

Central Arizona–Phoenix LTER

Pattern and Process of a Socioecosystem

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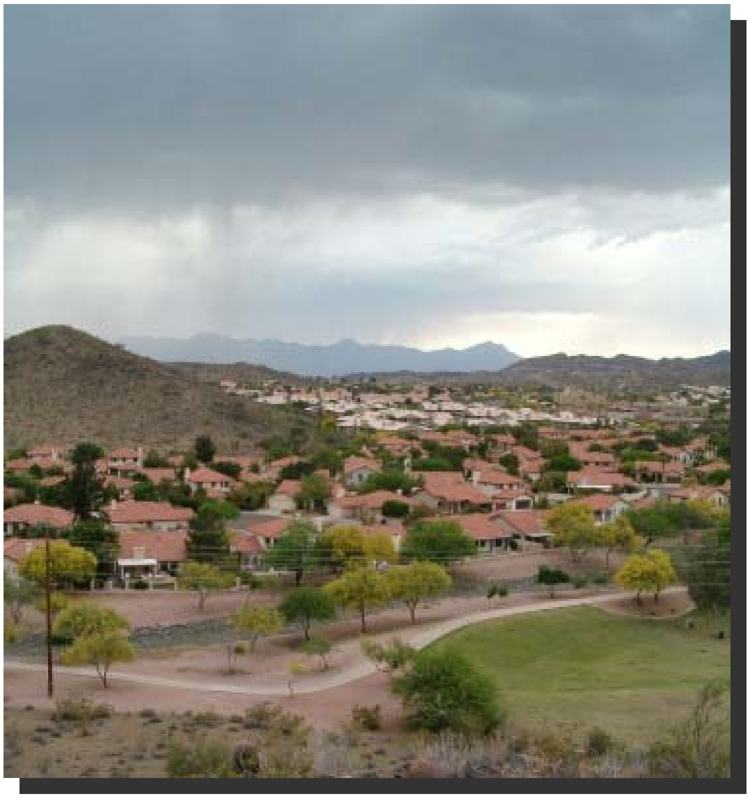

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CAP LTER 2004-2007

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I. Overview/History/Context

As the Central Arizona–Phoenix LTER enters its tenth year, we look back on a decade of transformation within ecology. No longer are cities, the most profoundly human-dominated ecosystems, considered unacceptable subjects of ecological study. Instead, ecologists recognize the importance of including humans as part of the nature we study, and urban ecologists in CAP and its sister urban LTER, the Baltimore Ecosystem Study (BES), have been key to this transformation (Collins *et al.* 2000, Grimm *et al.* 2000, Pickett *et al.* 2001, Grimm and Redman 2004, Redman *et al.* 2004, Pickett *et al.* 2005).

The overall question driving our research is, **how do the patterns and processes of urbanization alter the ecological conditions of the city and its surrounding environment, and how do ecological consequences of these developments feed back to the social system to generate future changes?** As the fifth-largest and fastest-growing city in the US, Phoenix is an excellent location for such a study. Phoenix was established after the Civil War, initially as a small town surrounded by irrigated farmland. Continued agrarian expansion predated the explosive growth of housing in the second half of the 20th century. Thus, land-use change and legacies are important foci for this research. However, parallel and massive changes in hydrosystem and transportation infrastructure and other designed features of the built environment, imports of non-native species and construction of yardscapes, and demographic and other societal changes in the 24 cities of our region also are important press events (Collins *et al*. 2007) that have produced an environment that differs radically from the one encountered by Anglo-Americans in the mid-19th century.

Established on an alluvial plain at the confluence of the Salt and Gila rivers, Phoenix enjoys more abundant surface water than one might expect for a desert city. Hence, Phoenix residents exhibit the highest water use in the nation and probably the world; and a great deal of the human modification of the environment derives directly from this water use (Gammage 1999, Larson *et al.* 2005). Indeed, water is the most important factor controlling diversity, organismal populations, primary productivity, trophic dynamics, and ultimately, human settlement patterns in our desert city. Hence, the first and most general answer to our overall question is that humans water the desert and thereby reduce its harshness. How this change in the environment in turn feeds back to the people is a problem that has received increased attention in CAP2, with our social survey, neighborhood-level studies, and experimental suburb.

Our primary objectives have not changed since we began to study Phoenix and its desert surroundings from an ecological perspective. They are to: 1) advance ecological understanding through development of ecological theory; 2) understand the structure and functioning of the urban ecosystem; 3) work with decision-makers to develop ecological scenarios that can be used to guide future development of urban environments while sustaining ecological and societal values; and 4) engage the public via the media, public events, and educational initiatives. Objectives 1 and 2 fall under the research category (Section II), while Objectives 3 and 4 will be discussed in Section III, education and outreach. We conclude this background material with sections on project management (Section IV) and information management (Section V), and a list of publications for CAP2 (Appendix A).

II. Research

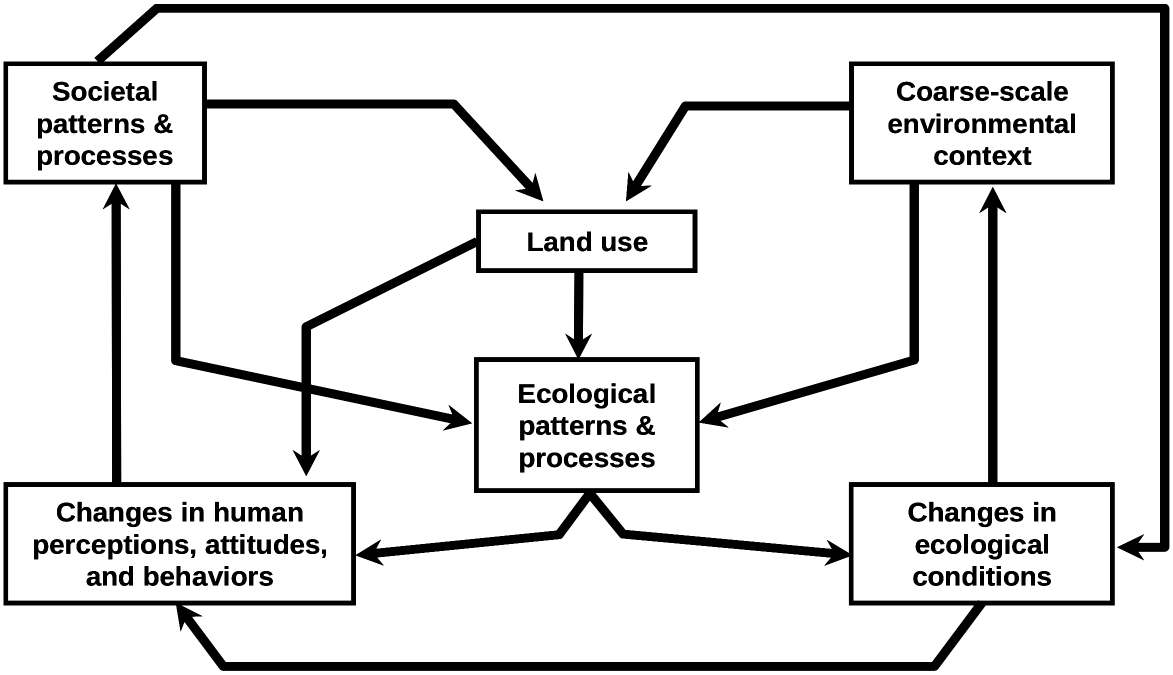
Conceptual Framework

Defining a conceptual framework and models that capture the dynamics of cities as complex, adaptive systems is a substantial challenge. In the first phase of our project, CAP1, we developed a simple box-and-arrow model (Fig. 1) that indicated general classes of constraints, interactions, and feedbacks in coupled socioecological systems (SES). Although land use occupied the central box, CAP researchers discussed and adapted the framework in CAP1 and in our planning retreat for CAP2. Indeed, we have substituted other changes (such as stream modification in Grimm *et al.* 2004, Walsh *et al.* 2005) for the land-use box. Similarly, the constraints and interactions are many and varied.

With the launch of CAP2, we aimed to further develop our conceptual framework to include more social-science theory and to host the many empirical, theoretical, and synthetic efforts represented within the broad range of CAP activities. We held workshops where

Planning retreat. Note conceptual diagrams on wall at left.

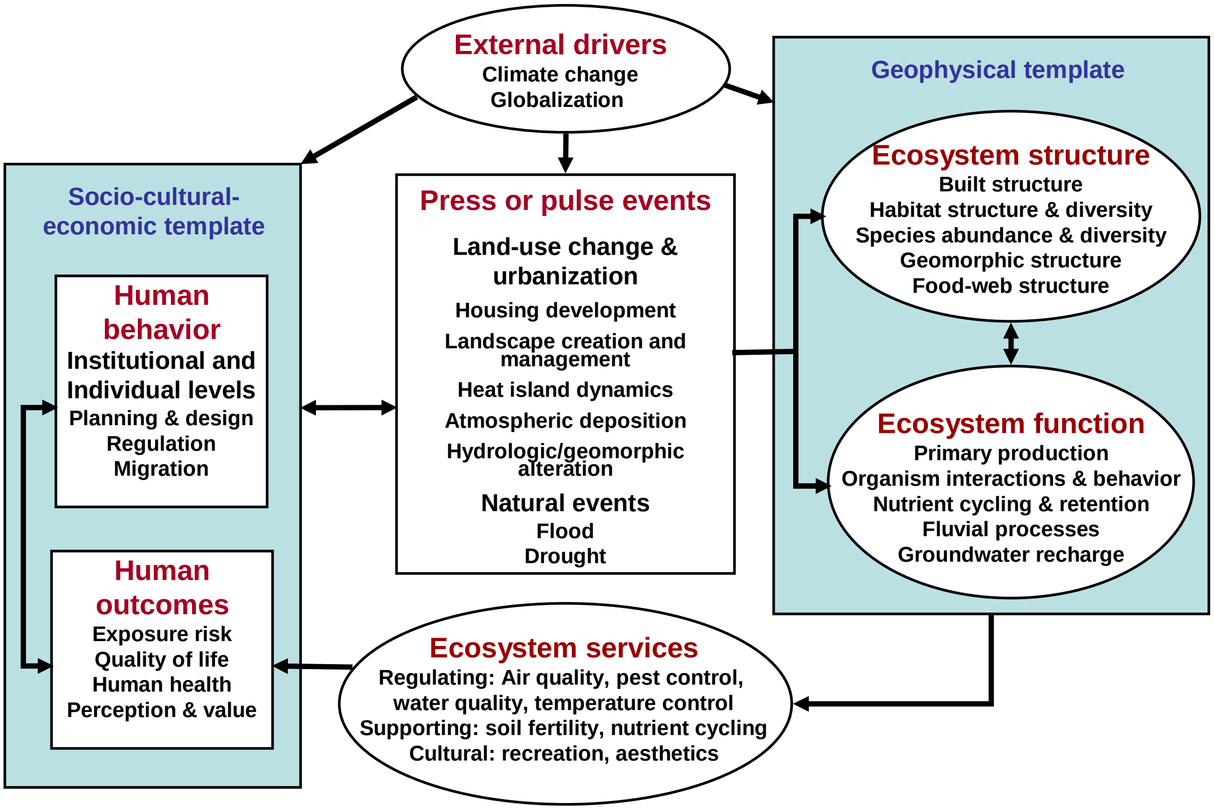
Figure 1. Original CAP LTER conceptual framework (after Grimm *et al.* 2000). In this cycle of interactions, societal patterns and processes and environmental context set constraints on land-use change. Ecological patterns and processes can be described for any given land use in a patch-dynamics framework; however, these ecological patterns and processes are fluid and constantly changing. Therefore, humans perceive and respond to both extant ecological conditions and changes therein. Feedbacks to societal patterns and processes (e.g., through public referenda, voting, application of policy, etc.) close the loop on the societal side; feedbacks from changed ecological conditions to the environment context include such things as effects on the urban heat island on regional weather patterns.



participants presented schematic representations of models used in their research. The intent of these workshops was both to familiarize all researchers with the range of models in current use and to seek commonalities to employ in a more generic conceptual framework. One such model was the LTER network's evolving SES "loop diagram" (Collins *et al*. 2007). As an overarching framework, this model clearly relates to the CAP1 model (Fig. 1), but it incorporates more detail in both the ecosystem (structure and function) and social system (human outcomes and human behavior), expands the range of events (presses and pulses such as land conversion, atmospheric deposition, or fire, not just land-use change), and identifies a focal interaction between humans and ecosystems—the ecosystem services upon which people depend. Subsequent internal CAP workshops have refined this framework to apply to the CAP urban situation, highlighting different parts of the scheme as they apply to our projects (Fig. 2).

Our conception of the larger SES that is the CAP site remains grounded in a hierarchical, patch-dynamics view originating in landscape ecology (Wu and Loucks 1995, Grimm *et al*. 2000, Luck *et al*. 2001, Wu and David 2002). Spatial heterogeneity and spatial distributions of both biophysical and social variables are critical to understanding how the system is changing, for example, in response to continued immigration, extended drought, and worsening air quality. Scale and scaling of human and ecological phenomena have received attention in many CAP projects. Thus, the conceptual framework presented here is viewed as dynamic, potentially

Figure 2. CAP2 conceptual framework (after Integrative Science for Society and Environment [ISSE] 2006). Modifications include the addition of built structure to 'ecosystem structure' and an expanded list of press-and-pulse events that typify urban ecosystems. Separation of the human and ecosystem responses and interactions is for convenience and convention, and not intended to imply that these are not part of the same SES. Ecosystems are perceived and valued through the services they provide. The loop is iterative and continuous, allowing feedbacks and causing further changes in presses, pulses, and ecosystem services.



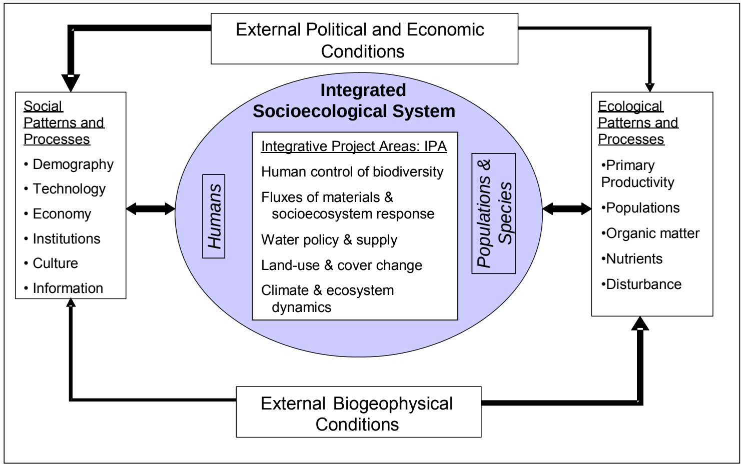
multiscale, and operating within parts as well as for the whole of this heterogeneous SES. Specific models, such as those predicting atmospheric deposition of nutrients, effects of the urban heat island on ecosystem processes, or water shortage under climate change, also fall within this framework.

Research Design and Approach

Our program is fundamentally ecological (*sensu* Likens 1992). Because humans are among the organisms interacting and participating in fluxes of energy and materials, we 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 multiscaled data (Wu and Li 2006b).

To fully integrate these components, we have organized our research under five integrative project areas (IPAs) that represent the intersection of the primarily ecological core areas with social-science core areas (Fig. 3; Redman *et al.* 2004). Five research strategies form the foundation of endeavors within these IPAs: long-term monitoring; experiments; comparative ecology; models; and data mining.

Figure 3. Integrative project areas (IPAs, listed in the box within the integrated SES) are research topics at the intersection of traditional LTER core areas (right) and proposed new socioeconomic cores areas (left) (after Redman *et al.* 2004).



It is worth noting the suite of CAP LTER's long-term monitoring efforts (Appendix B), which include arthropod pitfall trapping at 27 sites across the project area; Survey 200, which takes place every five years (see "Crosscutting Research"); the Phoenix Area Social Survey (PASS), which is also conducted every five years (see "Crosscutting Research"); point-count bird census at core sites; and water sampling at five locations.

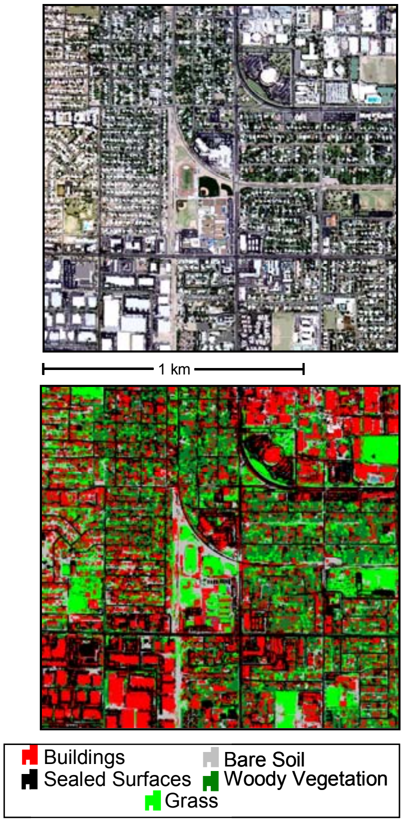
IPA: Land-Use and Land-Cover Change (LULCC)

Land use and land cover define the context of socioecosystems, 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 does LULCC alter the socioecological environment in the city, and how do human perceptions of these changes alter future decisionmaking?* CAP scientists have made tremendous progress on representing and analyzing LULCC.

Remote sensing, using satellite imagery and aerial photography, has been a foundation for ongoing projects in this IPA. Several studies have explored methods for mapping and classifying LULCC (Stefanov and Netzband 2005, Wentz *et al.* 2006, Möller and Blackschke 2006, Walker and Blaschke *in press*) and have used these data for modeling and measuring change (Buyantuyev *et al.* 2007). Research efforts toward establishing classification schemes include the

high-resolution, urban-forest classification for Phoenix project (Walker and Briggs 2007; Fig. 4) and an associated study in Leipzig, Germany. Researchers developed the former to delineate woody vegetation in an arid urban ecosystem using high resolution, true-color aerial photography. They adopted an object-oriented approach that groups similar, adjacent pixels into polygonal objects. These objects were spectrally analyzed for discrimination between woody vegetation and all other objects. Accuracy assessment within subclasses showed highest producer's accuracy for tree species with large, dense foliage. An associated and ongoing initiative will create a **high-resolution land-cover classification** scheme for use in social, ecological, and geographical studies (Walker and Blaschke *in press*).

Figure 4. High-resolution urban landcover classification. The top image is the raw, true-color image; the lower is the generalized classification.



Related research on **modeling urban impervious surface areas in relation to urban heat island effects** investigates the effectiveness of the multiple end-member 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. Initial results from this study suggest that the MESMA approach is reliable, and the algorithm picked the signatures effectively.

Scale is an important consideration in **landscape pattern analysis** (Wu *et al.* 2006a, Wu 2007), a major aspect of landscape ecology for over two decades (Li and Wu 2007). A recent investigation of the effects of thematic resolution on landscape-pattern analysis (Buyantuyev and Wu 2007) illustrates this point very well. Researchers created a series of maps based upon the 15-year time series data of LULCC for the CAP study area, which were derived from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM+) imagery via an expert system approach (Stefanov *et al.* 2001). 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.

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 net primary production (NPP) at broad spatial scales using remotely sensed Normalized Difference Vegetation Index (NDVI) data (Buyanteyev and Wu *in preparation*). The procedures developed will form an important basis for long-term investigation of changes in NPP. The research team found that land transformations in CAP create a large number of land covers with NPP rates considerably higher than those of natural vegetation, especially during dry years. At the same time, NPP in urban and agricultural land covers is far <u>less variable</u> than in the outside desert, due to mainly human ameliorations. Thus, this is a prime example of how human action controls not just rates, but variability of ecological processes. Finally, analyses of MODIS NDVI and climate data have provided important insights into the interactions among vegetation patterns, climate variability, and urbanization.

One of the earliest studies completed in CAP's first phase was the **historic land-use** project, which produced five maps of changes in desert, agricultural land, urban land, and designated open space between 1912 and 1995 (Knowles-Yánez *et al.* 1999). This year saw completion of **historic land-use, Phase II**, which provides a much more detailed, spatially based analysis of land-cover change over the past 30 years (Keys *et al.* 2007). Documenting a dramatic outward shift (from central Phoenix) in high-value land over this period, researchers also concluded that a central place model of urban growth is appropriate for Phoenix; that is, despite its 24 municipalities, the city of Phoenix itself is the most important nucleus of the region.

LULCC research conducted with a leveraged grant has explored **legacies on the landscape**—how prehistoric human land use influenced long-term ecological change in the region—using expertise from ecology and anthropology (Briggs *et al.* 2006). Creation of agricultural fields associated with the Hohokam culture >1000 years ago in the northern portion of our site (Schaafsma and Briggs 2007) resulted in silt deposits as large as 181,760 m^2, which contrast to other soils with a 62 to 80% sand content. Using analyses of soil, pollen, and topography, the research team concluded 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.

IPA: Climate-Ecosystem Interactions (CLIM-ECOS)

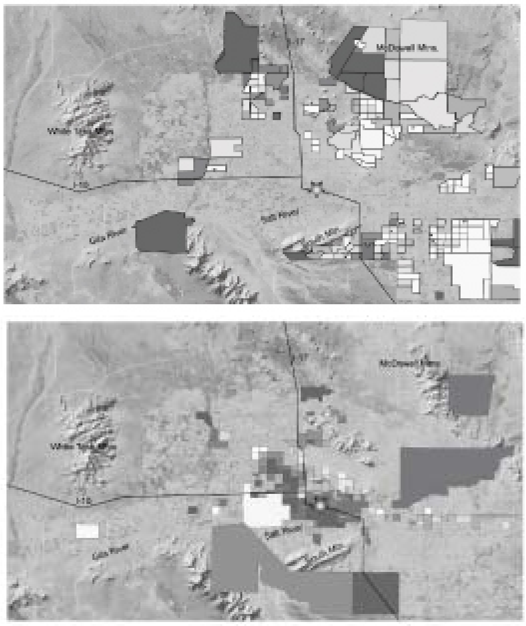
Climate is an important driver of processes in most ecosystems. Studies of CLIM-ECOS are conducted at multiple scales from single organism to region. Research under this IPA centers on the following questions: *How does human-driven, local climate change compare with longer-term trends and/or cycles 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?* We have found that the temperature increase associated with the past 50 y of urbanization exceeds any rise yet attributable to global climate change, and has both ecological and social effects.

Investigation of the **urban heat island** (UHI) effect has occupied CAP scientists for many years (Brazel *et al.* 2000, Baker *et al.* 2002) and has spawned CAP-leveraged research endeavors, such as the Neighborhood Ecosystem Project and research conducted jointly with the NSF-funded Decision Center for a Desert City (DCDC). The UHI in Phoenix is mainly a nighttime phenomenon, with a substantial rise in nighttime low temperatures having occurred over the past 50 years. ASTER images have been used to estimate spatial distributions of nighttime temperatures in urban areas (Hartz *et al.* 2006b). Variations in air temperature in Phoenix between 1990 and 2004 can be explained by surface effects related to type of urban development (Brazel *et al.* 2007). 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.

The **Neighborhood Ecosystem Project**, an outgrowth of the PASS and UHI research, was funded through a CAP-leveraged grant from the NSF's Biocomplexity competition (Harlan *et al.* 2006, Jenerette *et al.* 2007, Harlan *et al. in press*; Harlan *et al. in review*). Researchers collected data regionally in census-tract units (~1 mi^2 or 2.6 km^2) over an area of approximately 2,400 km^2, as well as for eight smaller and more homogeneous neighborhoods defined by census-block groups. Remotely sensed satellite imagery (vegetation abundance and surface temperature), US Census data(population characteristics), and a digital-elevation model of the region's topography were used for regional estimations of temperature. For the eight PASS neighborhoods, in addition to scaling the regional data down to block-group boundaries, the team also monitored microclimates using portable air temperature/dew point loggers for 12 consecutive months (recorded at 5-min intervals). Key findings include:

- Population density, thought by many climatologists to be the most visible indicator of human activity affecting climate, was less important than socioeconomic status (Fig. 5) for predicting the spatial distribution of summer temperatures across the region.
- Vegetation abundance mediates the relationship between socioeconomic status of neighborhoods and heterogeneity in microclimates.
- Lower-income, inner-city neighborhoods and a middle-income neighborhood on the urban fringe had higher heat-stress index scores and experienced a greater number of heat-stress hours during a three-month summer period in Phoenix. In lower-income neighborhoods having the highest exposure, residents had the least access to heat-mitigation strategies like air conditioners, reflective roofs, and swimming pools.

Figure 5. Surface daytime temperature (°C) in greater Phoenix by median annual household income for US Census tracts, 2000. Upper panel, highest quartile; lower panel, lowest quartile. Darker color = hotter temperature; range, 26 to 47 °C. These images illustrate that median income is significantly associated with summer temperature (r = 0.36), with higher-income communities being on average cooler than lower-income neighborhoods.

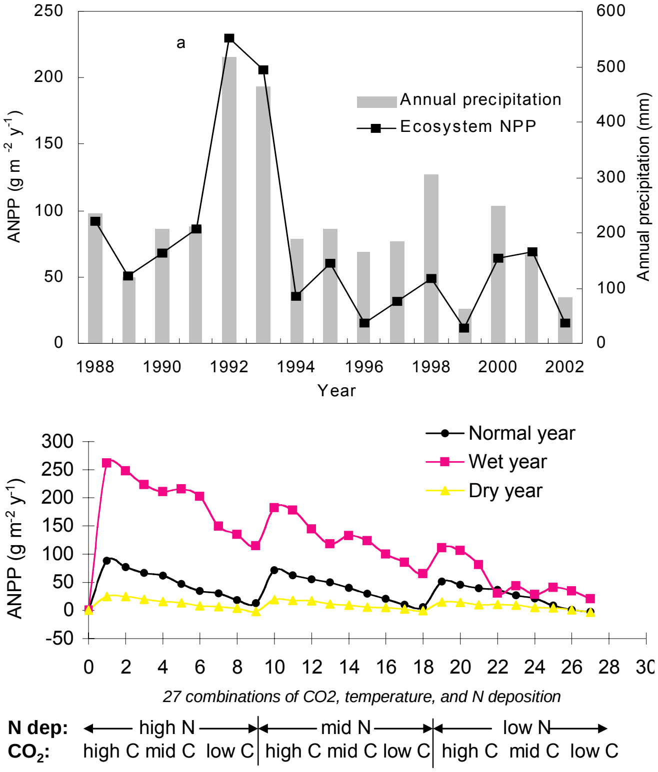


Mesoscale atmospheric research continues to advance within CAP LTER as researchers focus on understanding physical processes through which urbanization leads to modified environmental conditions. Research by Grossman-Clarke *et al.* (2005; *in press*) investigates the ability of a modified version of the fifth-generation Pennsylvania State University/National Center for Atmospheric Research Mesoscale Meteorological Model (MM5) to simulate characteristics of the urban planetary boundary layer 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.

The role of climate in enabling or retarding primary production has been examined through ongoing work on the effect of landscape treatments on aboveground net primary production (ANPP) and microclimates under the **North Desert Village Experiment** as well as long-term monitoring of **land-use effects on urban tree primary productivity.** Data are collected on trees once a year at 50 sites throughout Phoenix area. Research at other sites has examined ANPP of landscape trees planted in urban parking lots (Celestian and Martin 2004, Celestian and Martin 2005), the effects of landscape management on ANPP (Stabler and Martin 2004, Stabler and Martin *in review*;), and surface mulches.

Researchers are developing **simulation models of land-use change** (focusing on urbanization) and coupling them with **process-based ecosystem models** to investigate how urbanization-induced environmental changes affect ecosystem functioning. Using a physiologically based ecosystem-process model developed and validated for desert (Shen *et al.* 2005), researchers asked how urbanization-induced environmental changes in air temperature (T_{air}), carbon-dioxide (CO_2) concentration, and N deposition separately and/or interactively affect ANPP, soil organic matter (SOM), and soil N in outlying and remnant desert. Realistic values for T_{air}, CO_2, and N deposition were based on empirical and modeled prior results (Brazel *et al.* 2000, Fenn *et al.* 2003, Idso *et al.* 2001). The study illustrates how urban ecosystems provide a unique "natural laboratory" to study potential ecosystem responses to anthropogenic environmental changes. Because urban heat islands, CO_2 domes, and high rates of N deposition now affect large cities and their environments, to some extent cities portend the future of the global ecosystem (see also Redman and Jones 2005). Model results (Fig. 6) illustrate the importance of water availability in the desert ecosystem, stimulation of ANPP by N and CO_2, and negative effects of elevated temperature (Shen *et al. in press*).

Figure 6. Top: simulation of aboveground net primary production (ANPP) among years, with a -2.4% error at the ecosystem level. Bottom: interactive effects of T_{air}, N and CO_2 on ANPP, showing the primary control by water availability (e.g, wet vs. dry years).



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. 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?* To date, research has shown that modifications of the hydrosystem are large, and there is a mismatch between efforts in water-conservation education and people's behavior with respect to water conservation. Work of the WATER IPA is highly intertwined with that of the DCDC, which focuses on water-management issues in the Phoenix area and is closely aligned with studies of aquatic biogeochemical processes and water quality undertaken in the FLUXES IPA.

One focus of CAP research is to understand factors that promote resilience of socioecological systems. To that end, CAP and DCDC researchers have studied the vulnerabilities of water systems and institutions in the context of their association with the Resilience Alliance, forming a conceptual basis for empirical studies (see Anderies *et al.* 2006, Cumming *et al.* 2006, Walker *et al.* 2006).

A joint CAP-DCDC initiative examines **policymaker responses to WaterSim,** a systems-dynamic model that profiles water shortages under different climate-change scenarios, drought conditions, population growth rates, and policy decisions. Data collection to examine policymaker responses consists of a series of individual and group interviews focusing on the knowledge, values, and political constraints underlying decision-making, environmental perceptions, and the use of scientific data in decision-making. First shown to Arizona water decision-makers in our Decision Theater, a 3-D visualization facility, WaterSim is now available online (http://watersim.asu.edu) as DCDC researchers realized the importance of engaging the larger public in our regional water dialogue.

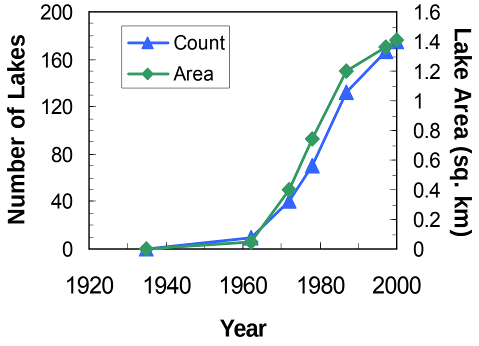
This year marked Phase 1 of a multiyear project **modeling fluxes of water and salt through the urban infrastructure.** The goal is to understand urban hydrologic flux by modeling water supply and use and associated salt fluxes. Researchers built a dynamic model to integrate collected water supply and usage data based on the same platform (PowerSim) used in the **WaterSim** project. They intend to integrate the two models to provide a spatially explicit understanding of water and salt fluxes. Phase 1, focused on Scottsdale, is completed and data are being analyzed. During Phase 2, the research team will replicate the model for Goodyear, a city located at the urban fringe that has less access to surface water, uses more low-quality (high salt content) groundwater, and has fewer infrastructure and treatment capabilities.

Progress has also been made in investigating water-policy issues through a project on **drought and water conservation policy in the arid metropolitan Southwest**. For 10 of the most populous cities in our region, researchers examined how the number and type of conservation programs correspond to water-use rates, and how water-use and conservation policies changed over time. Results show that a high number of conservation policies and programs in an individual city do not correspond with reduced annual rates of water consumption. Cities with the most conservation programs have high rates of water use, while those with fewer programs rank low in consumption (Hirt *et al. in review*). Our investigations continue to track the historical changes and geographic patterns of water-conservation policies in the CAP region.

Although the rivers of Phoenix were once perennial, upstream dams have resulted in no instream flow in the Salt River since 1938; tributaries to the Salt are intermittent and dammed as well. As the city has grown, many lakes fed by canals and groundwater have been created for recreational and aesthetic purposes. The current state of GIS information from governmental planning organizations on **surface water distribution in the CAP LTER** was assessed by comparison with spectral identification of permanent lakes using ASTER data. The analysis revealed extensive errors and misclassification in existing data layers and found almost 1,000 lakes in the Phoenix metro area, nearly all of which have been established after 1950.

Extensive modification of small streams and mid-sized rivers in the region, coupled with lowered groundwater tables, has resulted in large shifts in the hydrogeomorphic template of urban streams. As part of a project studying **urban watersheds,** researchers investigated hydrogeomorphic consequences of historical land-cover changes in one urban watershed (Roach *et al. in review*) and used the CAP conceptual framework to develop hypotheses about how human activity alters stream-riparian ecosystems (Grimm *et al.* 2004). Major changes in the study watershed include: 1) construction of the Central Arizona Project canal has severed flow paths between the upper and lower halves of the watershed; 2) an older canal in the lower half also reduces hydrologic connections between upstream and downstream reaches; 3) nearly 180 lakes have been constructed in the watershed, paralleling population growth (Fig. 7); and 4) construction of a greenway and artificial lakes has fundamentally changed the connectivity between stream and floodplain (Roach *et al. in review*). Consequences of these geophysical changes have been investigated in the **nutrient retention and transport in urban watersheds** project (see FLUXES).

Figure 7. Increase in the number and areal extent of lakes in the Indian Bend Wash watershed, 1940–2000. From Roach *et al.* (*in review*).

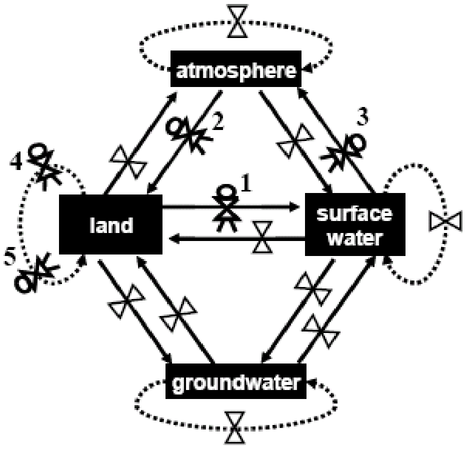


Researchers also assessed **channel morphology and instability along the urban fringe** on the Hassayampa River, located at the western edge of the study area. They documented the natural hydrologic processes that maintain the current geomorphic structure and assessed flood risk. Analysis of aerial photography from 1934–2004, and geomorphology revealed minimal flood hazard to a proposed development of over 200,000 new homes along the river (Block and Arrowsmith, *in preparation*).

IPA: 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*

Figure 8. Transfers of materials between four major compartments in urban biogeochemical cycling. Bow ties signify controls on processes; stick-figure bow ties refer to predominantly human controls (after Kaye *et al.* 2006).

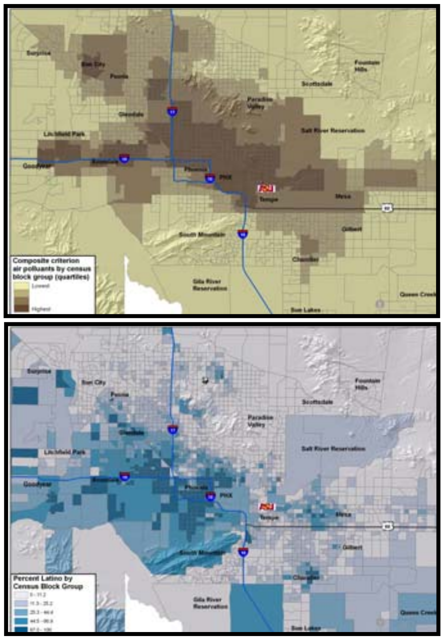


distributions?; Do citizens and decision-makers accurately perceive these hazards? We have found evidence that urban biogeochemistry is unique (Kaye *et al.* 2006) and that sociospatial distributions of toxic materials disproportionately affect the poor and ethnic minority populations (Bolin *et al.* 2002; Grineski *et al.* 2007).

The movement of nutrients, toxic substances, and other materials through the CAP ecosystem must consider transfers among atmospheric, land, water, and groundwater pools, with the land compartment and its resident dominant species being the primary contributor of new materials that enter into biogeochemical cycles (Fig. 8). Much of our work on nutrient and material distributions in soils is conducted under Survey 200 (reported under "Crosscutting Research") and is only briefly summarized here. The fluxes IPA also closely interfaces with the CLIM-ECOS IPA in modeling ANPP and other ecosystem responses to increased atmospheric CO_2 and N deposition, and with the WATER IPA in transport and transformation of materials in urban watersheds. Researchers are working to extend the findings from purely biogeochemical studies to an understanding of the impacts on the human population.

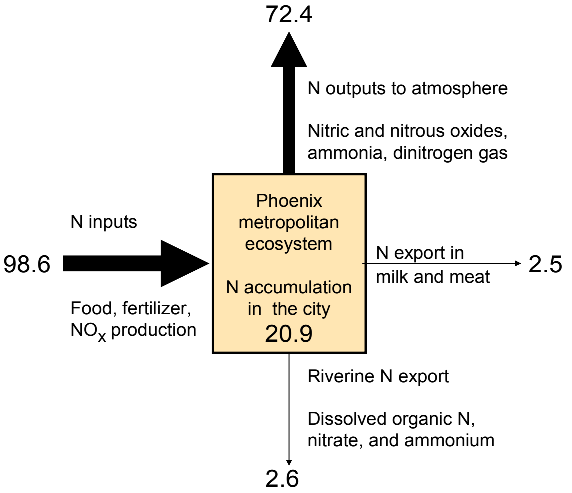
The **environmental justice and risk** project explores the differential impacts of environmental disamenities in the Phoenix area. Amongst other studies, researchers have conducted research on criteria air pollution in Phoenix (Grineski *et al.* 2007). This research revealed distinct sociospatial inequalities in exposure to pollutants and demonstrated clear environmental injustices along ethnic and class lines (Fig. 9). Neighborhoods with lower socioeconomic status and higher proportions of renters and Latinos generally experience higher levels of criteria air pollution. Freeways and the airport are critical sources of pollution. 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 discussed in Bolin *et al.* (2005), these differential impacts reflects historical patterns of development in Phoenix, which have culminated in a spatial segregation based on class, race, ethnicity, amenities, and disamenities.

Figure 9. Spatial distributions of (top) criteria air pollutants and (bottom) % Latino in the population.



One of our earliest projects constructed an elemental mass balance for the nutrient, nitrogen (N). This budget provides context and suggests important questions for CAP's biogeochemical research. The N mass balance for CAP (Baker *et al.* 2001) showed large anthropogenic N inputs (imported food and fertilizer, and NO_x produced from extensive automobile use), large engineered gaseous outputs, and accumulation of N in unknown compartments of the CAP ecosystem (Fig. 10).

Figure 10. Simplified depiction of N mass balance for the CAP ecosystem. After Baker *et al.* (2001).

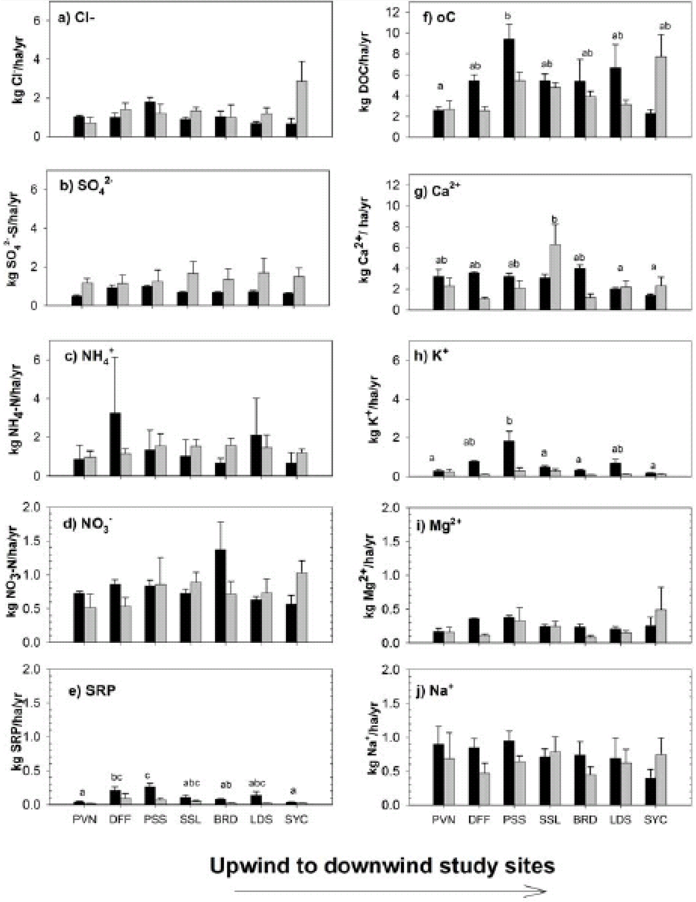


Atmosphere–land transfer

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^-, S O_4^{3-}, H^+, Ca^{2+}, Mg^{2+}, Na^+, and K^+ across the CAP region, including the developed urban core and outlying desert (Fig. 11). 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.

Figure 11. Mean annual nutrient loads as wet (gray) and dry (black) deposition. Different lower-case letters indicate significant differences in total loads (i.e., wet + dry deposition) among sites across the CAP region ($p<0.05$, Tukey HSD). Note differences in scales. PSS, SSL, and BRD are urban or urban-fringe sites.



- 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: 5 upwind, 5 in the core, and 5 downwind of the city, with a flux tower and filter-bank sampler installed at 1 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 creosote (*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.

Material storage and cycling on land

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).

Several independent lines of evidence, including those described in the Survey 200 results (see "Crosscutting Research") suggest strongly that the main effect of urbanization on soil N and organic C storage has been an increase (Hope *et al.* 2005, Jenerette *et al.* 2006b, Lewis *et al.* 2006a, Zhu *et al.* 2006, Kaye *et al. in press*). Although conventional wisdom holds that both agricultural and urban land uses should decrease soil C, it is unsurprising that irrigating and fertilizing crops or lawns in a desert environment increases soil nutrient and carbon stores.

In addition to nutrients, soil studies have examined distributions of metals (see also Survey 200 results). Using lichen tissue is an ingenious method of detecting metals deposited from the atmosphere; the **lichen resurvey with heavy metal analysis** extends work completed under CAP1 (Zschau *et al.* 2003) and will continue to examine lichens from around Maricopa County (inside and outside the metro area) as part of our long-term monitoring efforts.

Land–water transfer and material export

Aquatic core monitoring includes a field-sampling program to quantify the concentration and flux of nutrients, major ions, salts, and select contaminants imported to and exported from the CAP study area via surface-water systems. Five sampling sites (three upstream and two downstream of the urban area) are sampled 6-12 times per year to capture seasonal and, when possible, discharge-related variations in water chemistry. Summary conclusions from this study are that patterns in upstream–downstream water chemistry relate to the functioning of the Phoenix metro area as a whole. The presence of this urban center has altered biogeochemical cycling in lotic ecosystems significantly. For example, water retention by the city was particularly high during the severe drought of most of the past 7 years, and was higher than the retention of salts, DOC, TDN, TP, indicating that these constituents accumulated in the water as it moved through the city (Edmonds *et al. in preparation*). The urban area thus exports these biologically reactive ions, whereas it retains conservative ions.

Continued long-term measurements will enable CAP researchers to investigate the relative importance of human management and hydrologic controls under climate variability and change and increased urbanization. Three sources of high export concentrations from the city are: 1) urban surfaces exposed to high rates of atmospheric deposition of N and C that supply high nutrient concentrations to local waterways; 2) contaminated groundwater pumped to the surface; and 3) disposal of human food and waste, via highly concentrated WWTP effluent, is released into the river system. Human activity and decision-making thus exert control over variation in nutrient exports, especially during dry climatic conditions. This represents a potential feedback between environmental change and ecosystem engineering by humans.

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 and enables detailed examination of temporal export patterns. Researchers focused their work on the Salt River, which is usually dry due to upstream diversion but receives flow from upstream dams during large storm events, and Tempe Town Lake, an artificial lake constructed in 1999 in the bed of the Salt River that is supplied with water from canals (which carry the water of the original Salt River, plus Colorado River water and groundwater). Lake managers maintain the lake level 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. 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. 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 of arid river systems. 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 large storm events in the Salt and Verde watersheds.

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.

Material storage and cycling in aquatic features of the urban landscape

To determine the fate of excess N (i.e., input>output by mass balance; Fig. 10), our researchers are attempting to identify the location of landscape "hot spots" (*sensu* McClain *et al.* 2003) of N retention and transformation in the urban environment. Riparian-stream ecosystems that are the most likely sites of N retention in desert landscapes (Belnap *et al.* 2005, Fisher *et al.* 2004) have been completely eliminated from the urban landscape (Grimm *et al.* 2004). Once-perennial rivers of Phoenix no longer flow; instead, extensive canals and nearly 1,000 new lakes, nearly all of which have been established since 1950 (Larson and Grimm, *in preparation*), are the dominant aquatic features. These may be effective sites of N retention (Larson *et al.* 2005, Roach *et al. in review*, Roach and Grimm *in preparation*), or hot spots may be shifted to more terrestrial recipient systems like neighborhood retention basins (Zhu *et al.* 2004). Moreover, extensive modification of streams in the region, coupled with lowered groundwater tables, has resulted in large shifts in the hydrogeomorphic template of urban streams such that they likely no longer function like their non-urban counterparts (Grimm *et al.* 2005).

As part of the second Lotic Intersite Nitrogen eXperiment (**LINX2),** experiments, in which $^{15}NO_3$ is added continuously to a stream over 24 h, were conducted in IBW as well as in Highline Canal (a small, cement-lined canal with very high flow velocity, high NO_3 concentration, and no riparian vegetation). LINX2 experiments were supplemented with short-term nutrient addition experiments and measurement of natural decline in nitrate and ammonium, in order to develop a preliminary picture of the **capacity of urban streams to remove N.** We found that, in comparison to their non-urban counterparts in the Southwest, these systems are impaired in terms of their ability to remove N, probably owing to the combined effects of hydrogeomorphic modification, reduced NPP, and higher nutrient and toxic loads (Grimm *et al.* 2004, Grimm *et al.* 2005).

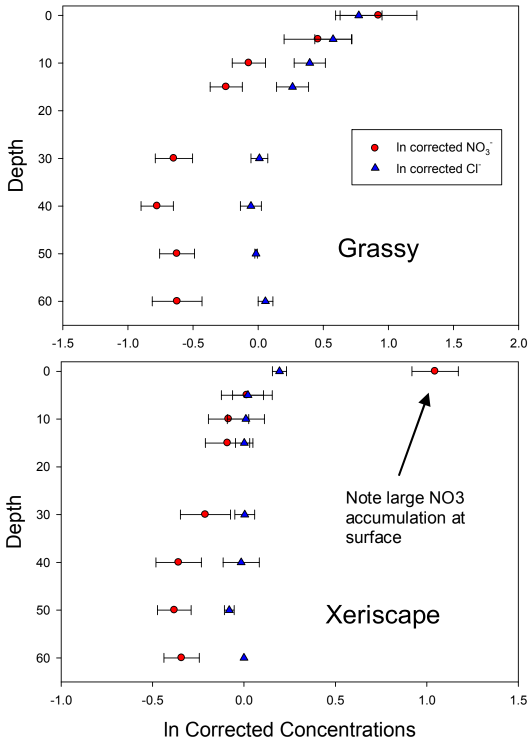
A series of experiments was conducted in the Indian Bend Wash watershed, examining artificial lakes, channelized stream segments, and turf-dominated floodplain as potential hot spots of denitrification, an important N-removal mechanism, and to learn what factors controlled potential rates of denitrification (Roach and Grimm, *in preparation*). Mass-specific potential denitrification rates were significantly higher in lakes than in streams or floodplains. Nutrient limitation bioassays revealed, however, that NO_3^- limited denitrification in lake sediments whereas in floodplain soils the process was limited by the prevalence of anaerobic conditions created by water additions. Although rain is rare in the desert, irrigation is common and thus annual denitrification in the floodplain can be substantial. The main finding from this work was that floodplains are the most active locations in terms of N removal via denitrification.

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.

Transfers of materials to groundwater

N has accumulated in groundwater in the CAP ecosystem (Xu *et al.* in press), consistent with mass-balance results showing an overall ca. 21 kg ha^{-1} y^{-1} accumulation of N (excess of input over output; Fig. 10). Nitrate is a potent pollutant, and many groundwater wells within Phoenix metro have concentrations substantially above the drinking-water standard of 10 mg/L. Thus, studies of N removal in aquatic systems are important as they may represent the last line of "defense" against infiltration of high nitrate loads to groundwater. Research in retention basins is examining profiles of nitrate and chloride, a conservative hydrological tracer, to determine how much of the N that enters the basin infiltrates to groundwater. This work shows that nitrate accumulates on soil surfaces in xeric retention basins, but is consumed in both basin types at lower depths (Fig. 12). CAP researchers also are developing collaborations with cities to monitor stormwater in ephemeral stream channels, which are primary sites of groundwater recharge.

Figure 12. Profiles of NO_3 and Cl in grassy (top) and xeric (bottom) retention basins. Divergence of NO_3 profiles from Cl indicate consumption (NO_3<Cl) or accumulation (NO_3>Cl) in the soil.



The past year saw completion of a preliminary estimate of the salt balance for CAP. Findings indicate an accumulation of salt in both groundwater and soils, especially in agricultural regions. This interesting result recalls the ancient Hohokam civilization, which was said to have "collapsed" in part due to salinization of soils from long-term crop irrigation. CAP LTER researchers are interested in determining whether modern Phoenix can be more resilient in the face of this sort of ecosystem change.

IPA: Human Control of Biodiversity (BIODIV)

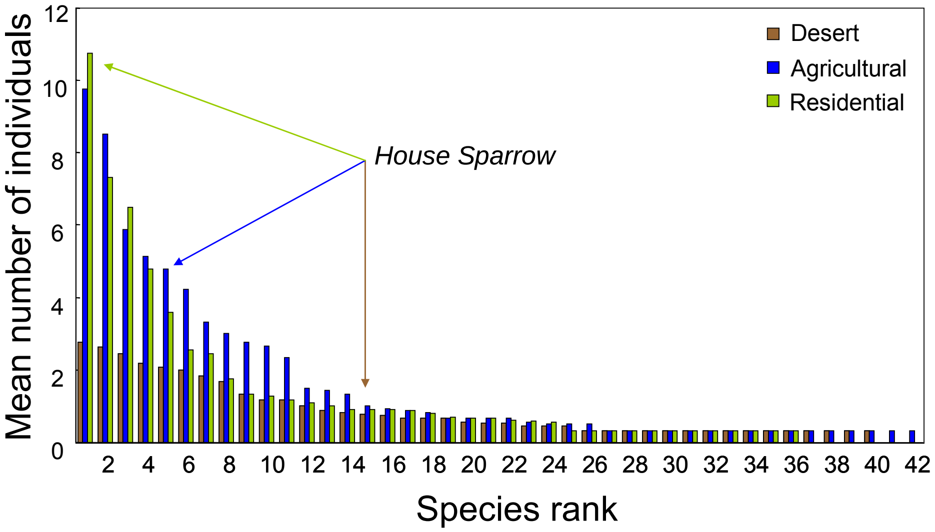
Ecological approaches to studying human control of biodiversity have typically focused upon habitat loss and disturbance brought about by humans at high population densities. We move beyond these approaches to ask: *How do human activities, behaviors, and values change biodiversity and its components—population 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?* Major changes in biodiversity, trophic structure, and abundances of organisms are found in CAP, yet not all of these conform to the typical "misconceptions" about urban floras and faunas (Shochat *et al.* 2006b). BIODIV research, employing both monitoring and experimentation, has focused upon arthropods, birds, mycorrhizal fungi, and vascular plants. Since much research makes use of **Survey 200** data, research results on biodiversity also appear under "Crosscutting Research.".

Long-term monitoring of ground arthropod biodiversity, since CAP's inception, has aimed to determine the patterns of ground-arthropod diversity and abundances by various lands-use types (desert, desert remnant, agricultural fields, industrial, and mesic and xeric suburban yards) in the study area. Agricultural fields and mesic residential yards generally support the greatest number of individuals and taxa, show the best separation from other types in ordination analyses, and have the greatest number of significantly associated taxa in indicator-species analysis (Cook and Faeth 2006). Of the urban habitats under investigation, these two heavily irrigated and highly productive land-use types stand apart from the others for most community measures. Outlying desert sites also support significantly associated taxa, including those not often found in desert parks and members of higher trophic levels less common in the city. Despite this finding, outlying desert and desert parks support similar taxon richness. Xeric residential yards and commercial sites have no taxa unique to them. Although these results may be a function of Phoenix's context, the water-limited Sonoran Desert, CAP researchers urge broader consideration of highly modified urban landscapes as wildlife habitat.

In the CAP study area, urbanization generally leads to increased and more stable water availability, resulting in increased plant productivity. Our researchers constructed simple mathematical models to assess the affect of urbanization on 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 research demonstrates how theoretical mathematical models can contribute greatly to further exploration of questions about trophic dynamics in urban ecology, not only in the CAP area, but also other urban systems.

One of the greatest challenges in urban ecology is to explain the global reduction in biodiversity in urban settings. Current analyses suggest 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, more species are lost than gained. **Bird census data** from both CAP LTER and BES show a clear picture: wildland communities are more even than urban communities (Fig. 13). When all species in each community are sorted from most to least common, the 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 (Shochat *et al.* 2004b), suggesting a robust pattern that is not only cross-site, but cross-taxon.

Figure 13. Dominance-rank curves for birds from CAP's bird monitoring program. Urban communities are much more dominated by a few "winner" species compared to the much more even desert communities (Shochat *et al*. 2004a).



Researchers interpret this pattern to mean that urban settings favor a few species that become abundant and consume most available resources, out-competing many other species. Thus, more than habitat change, competitive interactions may lead to extinction of many native species from urban settings. One of the most important mechanisms of co-existence is temporal partitioning and the ability of subordinate species to exploit more food from a given patch than dominant species. However, in urban settings, the dominant species appear to be extremely efficient foragers (Shochat *et al.* 2004a), and subordinate species may not find sufficient resources in urban settings to allow for a long-term existence. Future research on urban wildlife should focus on species interaction, as moderate control of the abundance of key species (three to four dominant species) may allow the coexistence of many native species that can adapt to the urban habitat structure, but suffer from high competition.

Research on **urban bird dynamics** attempts to shed light on questions of avian community structure. 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. Following the call by Shochat *et al.* (2006b) 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 in terms of access to food, body condition, and reproductive success, 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 regulate urban bird populations.

Researchers are taking another approach to examining the underlying mechanisms and driving factors of urban bird diversity in Phoenix through a project on **foraging decisions, bird community structure, and an urban–rural gradient**. By employing experimental studies, specifically experiments on the giving-up density (GUD) at artificial food patches, they are uncovering some of the causal relationships between urbanization and biodiversity. The GUD quantifies a forager's perception of costs and risks associated with a patch, as well as the quality of the habitat. Because of increased human subsidies (water), researchers predict that birds foraging in mesic designs with dense vegetation will have significantly lower GUDs than birds in xeric designs. In addition, birds in mesic designs will experience lower perceived predation risk than bird communities in xeric designs, and GUDs will show no difference between microhabitats of bush (shelter from predators) and open habitats.

The central objective of the **ecological and social interactions in urban parks** study is to use small, neighborhood parks in Phoenix to determine: 1) the ways in which human values, use, and management influence ecological processes; and 2) the ways ecological characteristics and processes influence human attitudes and activities and the services they value. Elucidating this coupling in Phoenix parks is itself a significant step towards understanding the complexities of human-nature interactions. The information gathered in addressing the central objective can and should be used to assess potential trajectories for ecological processes. The research team's second objective is to develop trajectories for potential changes in ecosystem services in the Phoenix metro area, given economic and demographic trends, and signal of human-nature interactions among different social groups. They evaluated bird diversity (species richness and abundance) in 16 parks and neighborhoods. Species richness is highest in upper income neighborhoods and parks, intermediate in middle-income areas, and lowest in low-income areas (Kinzig *et al.* 2005). Avian communities in low-income neighborhoods are largely nested subsets of those appearing in upper- and middle-income neighborhoods, with the disappearance of insectivorous species in the more depauperate communities and the idiosyncratic appearance of avian species associated with livestock. Work continues on analyzing data from a social survey of park users. Related comparative research in Phoenix and southeastern Michigan examines how urban residents restructure local ecosystems to attract birds (Lepczyk *et al. in review*).

Additional research efforts include the **biodiversity and neighborhood social variation** project, which establishes avian long-term monitoring at sites co-located with PASS neighborhoods. This project will allow researchers to monitor changes over time in the relationship between biodiversity and neighborhood social variation. Long-term point-count bird censusing has been initiated in these neighborhoods over the last year. Other work on a multipart research project, **the behavior, ecology and evolution of the western black widow** (*Latrodectus hesperus*), focuses on differing behaviors and genotypes of urban versus desert black widow spiders. Initial results indicate that kin recognition and avoidance of cannibalizing full siblings may be strong selective factors shaping patterns of cannibalism in solitary spiders like the black widow. 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 are increasing.

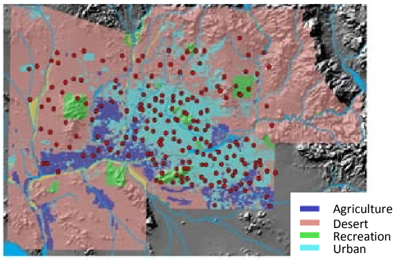
Crosscutting Research

Several projects are affiliated with multiple IPAs. These include long-term monitoring through **Survey 200** and the neighborhood-scale **PASS** as well as our long-term experiment, the **North Desert Village (NDV) Experiment**, and preliminary work on **Ecosystem Services**.

Survey 200

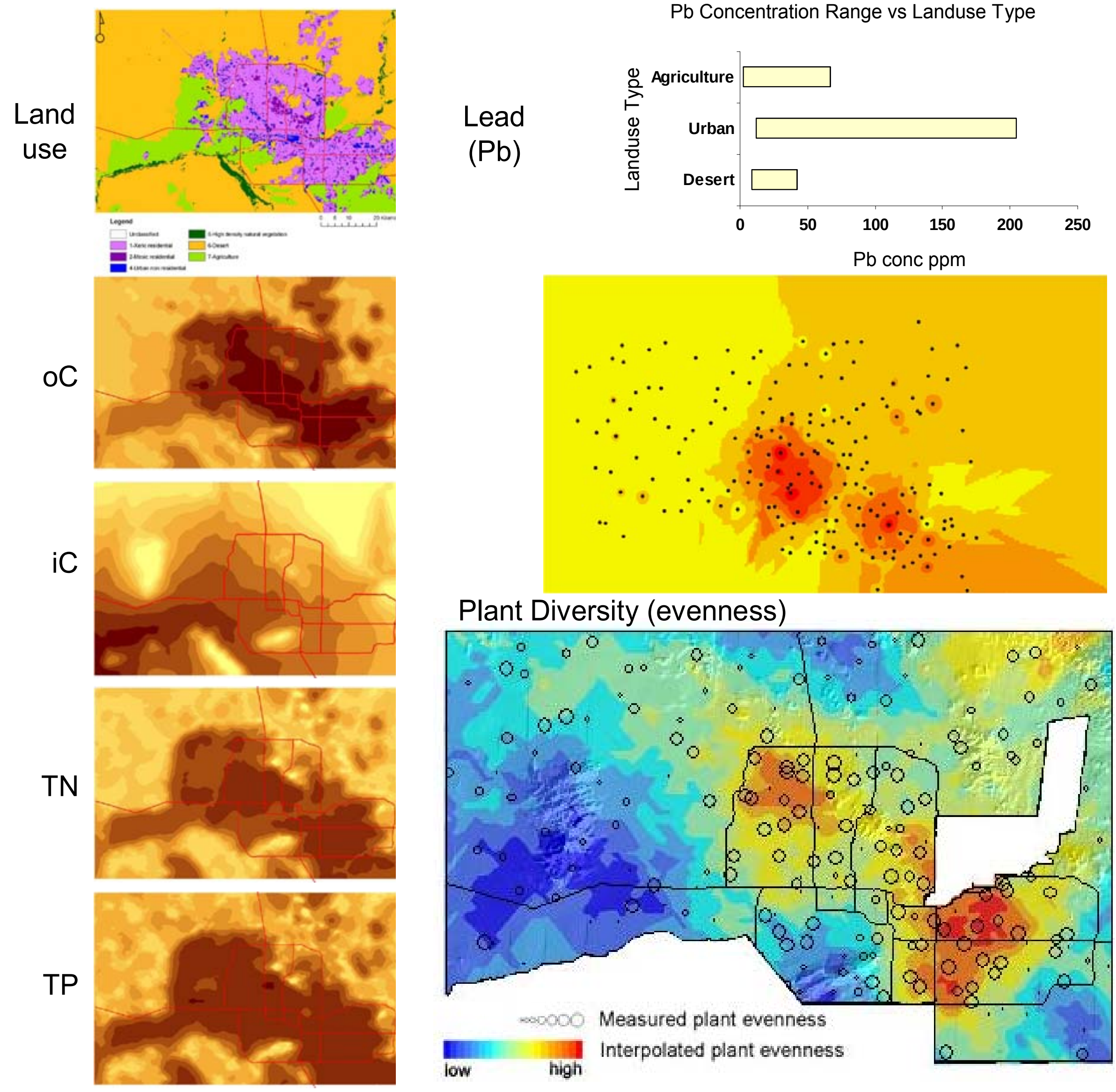
A central component of CAP's monitoring system, Survey 200 is an extensive field survey that provides a snapshot of broad-scale spatial variations in key ecological variables across the CAP study are (6,400 km^2 of central Arizona; Fig. 14). We assigned 204 points using a probability-based, tessellation-stratified, dual-density (3:1) design, which allows post-sampling spatial modeling to reveal data structure (e.g., Majumdar *et al. in press* a, b) rather than using a priori-stratification by land cover. The survey was carried out in 2000 and 2005 and included the following core measurements in 30 m x 30 m plots surrounding the points: plants identified to species; plant size measurements; soil coring for physicochemical analyses; insect sweep-net sampling; and mycorrhizal diversity.

Figure 14. Distribution of Survey 200 points within the CAP study area.



Analysis of Survey 200 soils from the 2000 sample show that: 1) spatial autocorrelation in soil nitrogen (N) found in the desert breaks down in the urban area (Hope *et al.* 2005, Oleson *et al.* 2006); 2) urban and agricultural soils have accumulated inorganic N, total N, organic carbon (C), and total organic matter (Jenerette *et al.* 2006b, Zhu *et al.* 2006, Kaye *et al. in press*; Fig. 15); 3) even desert soils in and around the city also have accumulated inorganic N (Zhu *et al.* 2006); 4) variables that potentially explain distributional patterns of soil nutrients in the urban sites and across the entire region include many reflecting human choice and action, such as impervious surface area, presence of turf and trees, current irrigation, and legacies of past land use (Hope *et al.* 2006, Oleson *et al.* 2006, Kaye *et al. in press*).

Figure 15. Various recent results from Survey 200. Left panels (2000 data): land use categories, and modeled spatial distribution of soil nutrients and inorganic C (Majumdar et al, *in press* a; Kaye *et al. in press*). Right top and middle panel: lead (Pb) distribution in soils across the CAP study area in 2005, summarized by land-use class and showing spatial distribution (Zhuo *et al. in preparation*). Bottom right: one measure of plant diversity, evenness, plotted for 2005 (Walker *et al. in preparation*). Both right panel maps were generated using kriging in GIS.



Hierarchical Bayesian modeling has been used to scale data to the region (Kaye *et al. in press*, Majumdar *et al. in press* a; Fig. 15). This scaling enables models that are flexible enough to accommodate the diverse factors controlling soil chemistry in desert, urban, and agricultural ecosystem and, thus, may be an important tool for ecological scaling that spans land-use types. A second approach to scaling compared sample collection at a finer grain within land-use categories (i.e., patches) to the Survey 200 data (Jenerette *et al.* 2006b). The multiscale analysis of soil properties showed that variation in total soil N, soil organic matter, and δ^{15}N content differed significantly between patch and regional scales. Most variation in the urbanized patch types was exhibited among patches while, for the native desert, most variation was observed within individual patches. These differences show urbanization's impact upon scaling relations.

For plants, spatial modeling of the Survey 200 data revealed that replacement of desert vegetation with largely exotic species has resulted in a much greater variation in plant genera from site to site (β diversity), as well as higher total diversity (γ diversity) across the region (Hope *et al.* 2006). Landscaping choices (i.e., additions of non-native plants, water and fertilizer) have modified traditional ecological resource availability-diversity relationships. Rather than natural-resource supply, plant diversity correlates positively with economic resources (median family income in our analysis). This "luxury effect" means that as income increases, households create landscapes with higher plant diversity (Hope *et al.* 2003). Urbanization thus disrupts the geomorphically controlled patterns in desert-plant communities and soils. Instead, local factors related largely to human-management practices determine ecological variables (and, by inference, processes). Data analyses from 2005, when all plants including annuals were recorded to species level, are underway and reveal new patterns of diversity (Fig. 15).

Survey 200 data have been used in a variety of other research initiatives. For example, **trace element distribution** was measured from soils collected in conjunction with the 2005 survey. Certain elements, such as lead, cadmium, copper, and silver, correlate positively with urbanization (Fig. 15), while others, such as vanadium, strontium, and beryllium, seem to show little or no land-use variation. Arsenic and chromium have multiple sources from the natural geological background and human activity. Atmospheric deposition as well as irrigation history, might also contribute to accumulation of some elements. Soil samples also were analyzed for **pollen concentration**, and these data were compared to extant plant distributions (Stuart *et al.* 2006). Urban-landscape management strongly influences pollen distribution in the desert: almost 40% of the desert pollen assemblage derives from urban "imports." At the same time, pollen from *Ambrosia*, almost exclusively a desert plant, was found in roughly the same concentrations in urban samples as that of *Pinus* and *Ulmus*. Researchers in CAP's Microbial Observatory (Rainey *et al.* 2005; www.biology.lsu.edu/webfac/frainey/raineylab/capltermo/caplter.htm) recovered bacterial isolates surviving doses of 30 kGy from Sonoran Desert (Survey 200) soil, compared to much lower tolerance of ionizing radiation by bacteria from a Louisiana forest soil. The results show that organisms with heightened DNA repair capacity have a selective advantage in arid environments. This research also expanded knowledge of the diversity of ionizing-radiation-resistant bacteria (Rainey and Ward-Rainey 2000, Albuquerque *et al.* 2005). Finally, comparison of the **arbuscular mycorrhizal (AM) fungal community** between urban and desert soils reveals a significant overlap in AM fungal species composition, despite much greater numbers in desert sites. AM fungal species composition was also similar between urban sites with indigenous and non-indigenous plants (Sorenson similarity coefficient = 0.94).

North Desert Village Experiment

The North Desert Village (NDV), an experiment in an actual housing development, provides a unique platform for study of human–landscape interactions. Four residential-landscape design/water-delivery types (treatments) established in blocks of six households each (mini-neighborhoods) recreate the four prevailing residential yardscape types found across CAP's study area (Martin *et al.* 2003; Cook *et al.* 2004; Fig. 16). These are:

Figure 16. Examples of two of the landscape types at NDV, mesic (top) and native (bottom).

- Mesic/flood irrigation: a mixture of exotic high water-use vegetation and shade trees with turf grass.
- Oasis: a mix of drip-watered, high and low water-use plants on granite substrate and sprinkler-irrigated 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 ANPP and under-canopy microclimate, soil nutrient pools and fluxes, insect abundance and diversity, and bird activity? How does landscape design affect direct human-landscape interactions in terms of both perceptions and behaviors?*

Landscape and irrigation systems for each treatment area were completed in summer 2005. In spring 2006, we installed micrometeorological stations 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. Volumes of water applied in landscape irrigation are recorded monthly.

We have analyzed data from the pre-treatment social survey; findings (Casagrande *et al.* 2007, Yabiku *et al. in press*) include the following:

- Women rate desert landscapes significantly lower than men, likely due to the gender division of labor in many households that allocates outdoor work to males in the household and housekeeping and childcare to women.
- People with desert aesthetics (i.e., people who agree with the statement, "the natural desert is beautiful") rate native desert landscapes significantly higher, showing that aesthetics matter, even when controlling for factors such as gender, education, and environmental values.
- People who have lived in the Phoenix area longer have significantly lower ratings of desert and xeric landscapes, agreeing with prior research that finds longer-term residents in the Southwest prefer more water-intensive landscapes.

- People with more pro-environmental values (as measured by the New Ecological Paradigm, Dunlap *et al.* 2000) are more averse to mesic landscapes with large expanses of grass, perhaps believing that mesic landscape is not a sustainable land use in the desert.
- People with young children (ages 0–6) rated the mesic landscape significantly higher;

The follow-up social survey began in spring 2006 and continued through the summer and fall. Researchers and technicians have begun entering and analyzing these data, with results forthcoming.

The NDV research team is working on a new, integrated project focusing on **ecosystem services of landscape treatments**. Using data from a variety of sources, including infrared surface temperature measurements, the researchers will analyze which of the four landscapes optimize the tradeoffs between the following ecosystem services: temperature moderation and energy use, water use, aesthetics and quality of life, and carbon sequestration. This research will contribute to an academic and public dialogue about the values of various landscape types in the Phoenix area. Although conservationists have pressed for the conversion of mesic to xeric landscapes, this research will illuminate energy-water tradeoffs in such a conversion.

Phoenix Area Social Survey (PASS)

PASS parallels the Survey 200 as a major component of our long-term monitoring program. In 2001, eight social scientists and one biophysical scientist conducted a pilot social survey of 302 residents in eight neighborhoods in Phoenix (Kirby *et al.* 2006; Larsen and Harlan 2006). Their goal was to better understand how human behavior shapes an urban socioecosystem. PASS is supported now by LTER supplements and a contribution from the DCDC, but is slated to become part of our core budget.

An expanded team of 20 CAP LTER and DCDC social and biophysical scientists designed the second wave of PASS in 2005. 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; and 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 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 quality of life and vulnerability to environmental hazards for diverse human populations?*

Neighborhoods surveyed for PASS in 2005 were selected from all Survey 200 sites classified as urban (n=94). Forty neighborhoods were carefully chosen 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 identified a random sample of 800 households to recruit for participation in the study. Respondents 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.

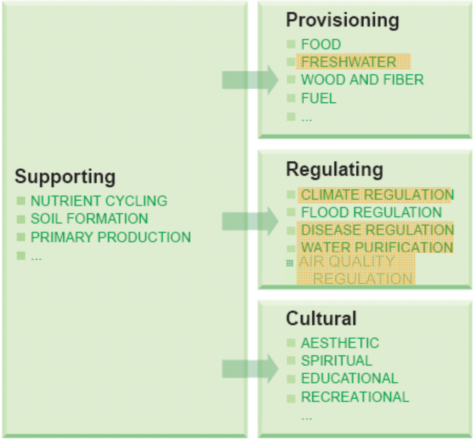
Initial results, compiled into a report, will be distributed to households participating in the study and posted on our website. Selected preliminary findings include:

- Relatively few adults have deep roots in the Valley. Respondents move around frequently, with a large minority envisioning another move within two years. If they had a choice of where to live, three of four people would stay in Arizona, but only one of three would stay in the Valley.
- Valley residents are concerned about the impact of population growth. Long-term residents are more likely to believe the Valley is reaching its limits, whereas those who live on urban fringe are more likely to see room for expansion.
- The quality of the local environment is a substantial concern for many residents, although people are divided about the issues of primary concern: about 60% of respondents are very worried about conservation of land and water and even more are concerned about worsening air pollution. Despite their concerns, many believe settlement density is too high and do not believe that they can reduce their own domestic water consumption.

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 (Fig. 17), 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.

Figure 17. The MA framework for ecosystem services; highlighted services were those identified by CAP as critical.



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III. Education and Outreach

K-12 Education

We reach out to the K-12 community through **Ecology Explorers,** which aims to enhance teachers' capabilities to design lessons and activities that use scientific inquiry and encourage an interest in science. Each summer, month-long internships involve groups of teachers in learning to develop hands-on lesson plans that use methods and protocols similar to those used by our scientists for vegetation surveys, ground arthropod investigations, bird surveys, and plant/insect interaction studies. These teachers then work with their students to collect data, enter it into a database, share data with other schools, and to develop hypotheses and experiments to explain their findings. Such activities were the focus of a Spring 2007 *Arizona Republic* article about an Ecology Explorers' teacher who had implemented a pitfall trap protocol as a part of a lesson plan on invertebrate biodiversity.

From an initial collaboration with 12 schools in 1998, **Ecology Explorers** now includes over 100 teachers in 25 school districts, 4 charter schools, and 2 private schools. 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 underrepresented minorities (African-American, Native American, 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 in the academic year. We work with teachers in their classrooms as well as hold day-long workshops based on teacher requests. During 2006-2007, 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.

Ecology Explorers employs a range of methods for program evaluation (Banks *et al.* 2005). These include pre- and post-program teacher surveys that gauge teacher expectations and response to our summer internships, and follow-up surveys and interviews that indicate how teachers have implemented their teaching plans during the school year. The pre- and post-internship surveys suggest that the internships are highly successful at meeting the teachers' desired outcomes from attending the program. Other surveys found that a large percentage of the teachers were able to implement parts of the Ecology Explorers program, most notably the protocols and many of the extension activities.

Service at Salado is a service-learning initiative that involves Arizona State University (ASU) undergraduate students working with children in after-school clubs serving children in grades 4 through 8. Together with City of Phoenix staff, undergraduate facilitators and interns teach schoolchildren about the ecology of the Rio Salado Habitat Restoration Area, which was once a dump site and now is a lush, riparian corridor. Children pursue projects that relate to the Rio Salado and present them at an end-of-semester celebration that brings together all participants. Examples of these projects can be found on the **Service at Salado** website http://caplter.asu.edu/explorers/riosalado.

Since it began in 2004, over 400 children have participated in **Service at Salado**. One outcome, as measured by a recent evaluation, is that children have become more attached to the Rio Salado Habitat Restoration Area. This is important because the program serves a largely minority population (87% of program participants are Hispanic) in the Rio Salado area that is underserved by neighborhood parks and recreation areas. By involving children in exploring and understanding this natural habitat area, the program seeks to enhance young people's curiosity about the environment and their civic responsibility toward preserving habitats.

Graduate, Undergraduate, and Post-Doctoral Research Education

Graduate students play important roles in CAP research. We cast a wide net to involve graduate students in projects, providing them with both formal funding and resources and support not related to direct funding. Seventy students have been involved since the start of CAP2, including 33 Fellows of the Integrative Graduate Education and Research Training (IGERT) program in urban ecology. Since 2004, 32 theses and dissertations (17 completed) have been associated with CAP. Similarly, we engage undergraduate students as research assistants and as researchers; 88 undergraduates have been associated with CAP since 2004, the large majority (73) as student workers but 14 as researchers under the Research Experience for Undergraduates (REU) programs of CAP, IGERT, and associated grants, and one fellow of the Ecological Society of America's Strategies for Ecology Education, Development, and Sustainability (SEEDS) program.

Our objectives for undergraduate and graduate programs are: 1) to integrate students into research and relevant learning experiences by offering funded research opportunities, 2) to create student-centered interdisciplinary opportunities, and 3) to promote the professional development of these students. Each summer, we support REU students through supplement awards, but we also have undergraduate researchers worked on CAP projects who are funded through various other initiatives. These include the IGERT REU program (where students work with IGERT Fellows) and the School of Life Sciences Undergraduate Research (SOLUR). Students doing research during the academic year are eligible to join the Community of Undergraduate Research Scholars, a year-long program that exposes these researchers to other student researchers across all fields and gives them opportunities to learn how to present their work, culminating in a poster session. Graduate students have many opportunities to explore interdisciplinary issues through the IGERT program, but also gain experience as CAP Research

Associates or in the summer grad grant program. Students who are financially supported by CAP are asked to contribute some time to field and educational projects; through these opportunities they learn about other research and K-12 educational activities.

Post-doctoral scholars are normally hired on to the project as a whole, and then make decisions on their own about where to focus their activities. We have generally supported one social scientist and one to two biophysical scientists at any given time, although with additional leveraged projects, the corps of post-docs has been as large as nine at a single time. We expect post-docs to develop associations with one or more laboratories or working groups, and this has led to some very successful collaborations. We currently support two post-doc-level scientists; our last social-science post-doc was hired just this year by ASU's School of Human Evolution and Social Change.

Knowledge Exchange and Collaborations

CAP LTER actively promotes knowledge exchange and collaboration among scientists at ASU and beyond, between the project and public and private entities, and with the general public. One means of sharing knowledge with the public has been through media outlets. CAP LTER has received considerable press attention at the university, local, state, and national levels. For example, in Fall 2006 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 at the 2006 Ecological Society of America conference. Stories on this experiment and its initial results appeared in print and online 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. As ASU's new School of Sustainability attracted attention from news agencies, CAP LTER garnered mention in interviews, podcasts, and statements by ASU President Michael Crow and others.

From our inception, we have focused on meaningful community outreach through a series of community partnerships. Many individuals and organizations have permitted short- and long-term monitoring on their sites. Local municipalities, such as the cities of Scottsdale, Tempe, and Phoenix, have actively supported CAP research on water quality. In all cases, we were granted access to research sites and shared data. Many state agencies have collaborated with CAP researchers or lent assistance. We have a data-sharing arrangement with the Arizona Department of Water Resources, and the Arizona Department of Environmental Quality has assisted with atmospheric-deposition studies. Access to public land is critical for our research and the Arizona State Land Department has been a willing partner. State entities are also involved in learning experiences for our students through internships, most notably the Arizona Department of Game and Fish has participated in the REU program.

In addition, CAP LTER participants partner with a wide range of institutions on associated projects. We have substantial collaborations, through workshops and publications, with scientists at the Baltimore Ecosystem Study, 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, Chinese Academy of Sciences, and other institutions in China. 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.

Many visitors to CAP LTER (Appendix C) 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, Kookmin University (South Korea), National University of Mexico, and other institutions visited to learn about our approach to urban ecology. CAP scientist Hall shared similar information during a visit to the University of Cape Town, South Africa. Staff and researchers also held discussions with the Embassy of France in the US with a view to establishing future research linkages with the *Zones Ateliers* program in that country as well as exploring an initiative on sustainable urban studies that will be launched in 2008 with a workshop involving US and French scientists.

Finally, our home in the Global Institute of Sustainability (GIOS) has allowed it to link to myriad initiatives within and outside of the University. In Fall 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.

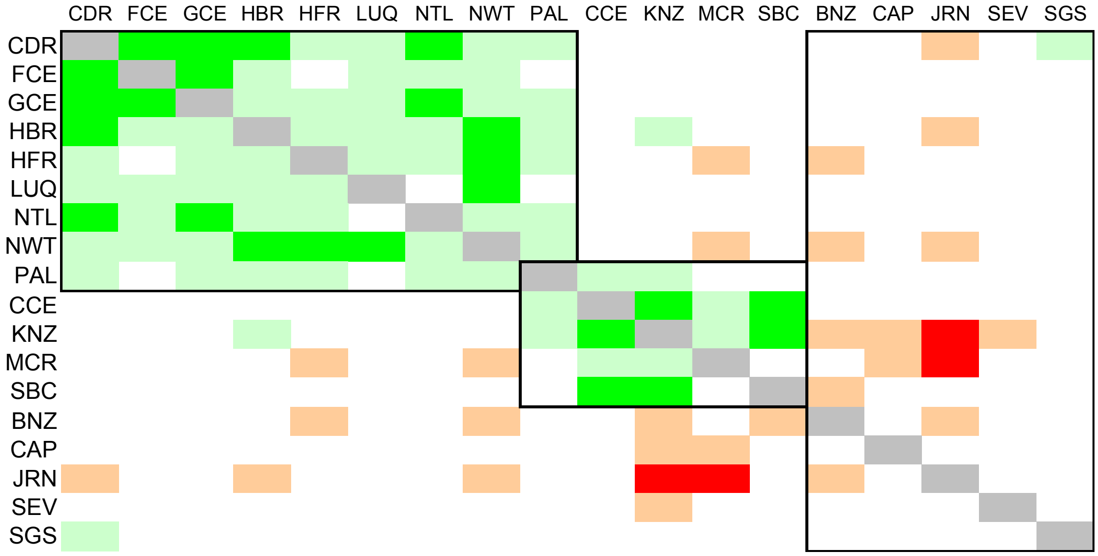
We have also begun an active relationship with the Sustainability Partnership, a consulting arm of the GIOS, that engages policymakers, resource managers, and industry leaders in planning and responding to the challenges of urban growth, environmental protection, resource management, and socioeconomic development. The Sustainability Partnership is collaborating with developers and urban planners on the eastern and western edges of Greater Phoenix and planning projects of mutual benefit.

IV. Network Activities

As the LTER network has moved to a new phase of **synthesis and network-level science**, CAP LTER has been actively involved in many initiatives. We hosted an initial workshop to begin writing the LTER planning proposal, and four of our scientists participated in the Meeting of 100. Grimm served on the Conference Committee and was involved in writing the ISSE document (Collins *et al.* 2007), and Harlan instigated the refinement of the “social box” in the ISSE conceptual framework (e.g., Fig. 2), which previously lacked detail or distinction between human outcomes and human actions. We argue that it is the example and push from sites like CAP and BES that has fomented such interest in the socioecological interactions that now form a platform for looking ahead to new, synthetic LTER research. Redman has been a key member of the LTER Social Science committee, formed shortly after we became a site, that has presented many of the ideas that developed into the ISSE and current LTER network proposal (see also Redman *et al.* 2004, Gragson and Grove 2006). Boone and Grimm both are members of the writing team for the latter, and Grimm served on the Executive Committee for three years and chaired the nominating committee to identify candidates for the new position of Science Council Chair.

CAP was a leader in organizing the May 2007 workshop in which **critical ecosystem services** were compared across the LTER network. Critical ecosystem services most often identified by sites were: provisioning services (food, freshwater); regulating services (water regulation, climate regulation); and cultural services (recreation & ecotourism, inspiration, sense of place). Pair-wise comparisons between sites revealed (Fig. 18, outlined sets): 1) a cluster of strongly similar sites that identified these "most popular" critical services (Cedar Creek [CDR], Florida Coastal Everglades [FCE], Georgia Coastal Ecosystems [GCE], Hubbard Brookd [HBR], Harvard Forest [HFR], Luquillo [LUQ], North Temperate Lakes [NTL], Niwot Ridge [NWT], Palmer Station [PAL]); 2) a second set of mainly coastal sites (California Current Ecosystems [CCE], Konza Prairie [KNZ], Santa Barbara Coastal [SBC], Moorea Coral Reef [MCR]) sharing strong similarities; and 3) arid and semi-arid sites (Central Arizona–Phoenix [CAP], Jornado Basin [JRN], Sevilleta [SEV], Short Grass Steppe [SGS]) plus a boreal forest site (Bonanza Creek [BNZ]) that tended not to be strongly similar to any other sites, or to each other.

Figure18. Results of network analysis of critical ecosystem services. Green boxes indicate similarity and red-orange boxes dissimilarity; the darker colors signify a strong similarity or dissimilarity.



CAP researchers also are participants in the long-running Lotic Intersite Nitrogen eXperiment, LINX. The second LINX project involved measurement of N cycling parameters in urban streams across the US; urban sites from CAP included Indian Bend Wash and the Salt River, where base runoff from urban water use plus seepage from Tempe Town Lake support a small perennial stream in the massive bed of the otherwise dry Salt River. Results from this work are reported under FLUXES.

Redman is lead PI on the leveraged Biocomplexity (CNH) project, "Agrarian Landscapes in Transition," which enjoys participation of six LTER sites plus the Nature Conservancy. This project investigates changing land use and socioecological systems associated with conversion of current or former agricultural land due to urbanization or suburbanization, and how these trajectories vary by location. The project will result in a synthesis volume comparing these trajectories across time and space (Redman and Foster *in press*).

Other cross-site initiatives involve our education program and social science collaborations. Education Manager Monica Elser is involved in the Teaching Ecological Complexity project which includes the Andrews, Shortgrass Steppe, Jornada, and Luquillo sites (http://www.ecoplexity.org/home). A February 2007 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 on the ecology of environmental justice in metropolitan areas.

V. Project Management

Box 1: Project Management Team

Nancy Grimm, Co-Director and Lead PI
Charles Redman, Co-Director
Stevan Earl, Site Manager
Monica Elser, Education Manager
Corinna Gries, Information Manager
Lauren Kuby, Communications Manager
Marcia Nation, Project Manager
Brenda Shears, Associate Director, GIOS
Linda Williams, Finance Manager

CAP LTER is managed by a team under the leadership of the two project co-directors, Nancy Grimm and Charles Redman (Box 1). Of the individuals that make up the management team, two (Earl and Nation) are dedicated primarily to CAP LTER, while the others (with the exception of Grimm) have additional responsibilities in GIOS. The work of the management team is supported by other personnel, technical staff, and graduate student assistants (Appendix D), who are paid by CAP LTER, GIOS, or other entities at ASU as part of the ASU's contribution to the project. For example, Kuby and Shears head a highly successful grant proposal-preparation team that prepares most of the CAP-leveraged proposals for funding.

The CAP LTER Project Management Team meets monthly in the academic year and as needed in the summer to discuss management issues pertaining to the project, such as NSF supplement proposals, potential ASU and external partnerships, and the allocation of project funds. Given the diversity of work responsibilities within the team, a major purpose of the monthly meetings is communication, allowing the team to trouble-shoot potential problems and seize opportunities.

Although the Project Management Team typically makes NSF-supplement decisions, other funding decisions are made elsewhere and communicated to the team. Each year, we fund one month or less of summer salary for five to seven facility members, half of whom are scientists with long involvement in the project and half new faculty. The project co-directors decide about summer salaries, based upon applications submitted in February.

The IPA and working group leaders allocate academic year and summer graduate RAs based upon applications submitted in the late fall. Each IPA is allocated one academic year graduate RA per year, making it necessary for IPA leaders to communicate with their colleagues on what research should be supported with the assistantship. The five summer graduate research assistantships are not allocated by IPA but competitively. An IPA and working group leader meeting in early winter serves not only as a decision-making forum but also as a forum for sharing information about ongoing research across the IPAs.

CAP LTER also funds five to seven summer research grants for graduate students in competitive process involving a short research proposal. Committees made up of a diverse group of scientists, including younger scientists, review the applications and provide written feedback to the applicants. A group of postdocs and management-team staff decide upon summer and academic-year Research Experience for Undergraduates (REUs), based on faculty and student applications.

Although funding decisions are an important aspect of project management, creating research synergies within and outside of the project is an equally, if not more, important task. These synergies are achieved in different ways. Formal working groups and informal working groups (Appendix E) bring together researchers working on common projects, such as the **NDV experiment**. Monthly **All Scientists Meetings** (ASMs) attract 40 to 100 participants, including community partners, and feature presentations and discussions of project results. IGERT Fellows are required to attend this series. A recent effort of the Knowledge-Exchange Working Group will bring local policymakers and practitioners to speak to CAP scientists at ASMs. The **Annual Poster Symposium** is a day-long event showcasing our research, attended by researchers, students, K-12 teachers, community partners, and state and local agencies, which features a keynote speaker and poster presentations by projects with CAP LTER, DCDC, other entities within the university, and public agencies (view posters at http://caplter.asu.edu/home/symposia.jsp). In selected years, we hold a **Summer Summit** or retreat at an off-campus site to address overarching theoretical and scientific issues. In Summer 2006, the summit engaged 28 scientists from CAP LTER and the DCDC in exercises that addressed the question: *how will the urban socioecological system respond to regional climate change?* Outcomes from this initiative include a NSF research proposal and a workshop series on the Economics of Climate Policy sponsored by Arizona's largest electric utility.

VI. Information Management

GIOS maintains a fully staffed eco-informatics lab that supports several NSF-funded projects. Although it may be difficult to determine the exact amount of staff time dedicated to CAP, this approach leverages efforts among projects. Team members include the CAP information manager, who also serves as director of the lab, a systems administrator, a web developer, a web master, student programmers, and a student GIS technician who is dedicated to CAP exclusively.

GIOS provides shared online storage space for its personnel and projects located on ASU's High Performance Computing Cluster (HPC). On a virtual server at the same location, a MySQL database server, an eXist XML database server, and the Apache production web server with Tomcat and PHP are maintained. The HPC is Linux based and the facility provides for security, basic software maintenance and backups. In the lab, we run a Linux development server and a windows machine with ArcIMS map server. The lab supports ca. 60 PCs and laptops, printers, and audio/visual equipment in two meeting/class rooms.

A central management database is used by all projects to manage research team members and personnel, projects, publications, datasets, and images. Originally developed for CAP, all projects now use the ACCESS front-end management application and code to display web content. Project managers maintain the database, however, an online "intranet" application allows researchers themselves to manage publications, biosketches, and research projects and submit annual reports.). This approach of a central database is beginning to pay off as researchers are involved in several large NSF-funded projects at GIOS and are producing publications based on collaborations relevant to more than one of the projects.

Management of short-term research data follows one of the following well-defined work flows. Researchers anticipating a large amount of collected data contact the information manager to set up a database and online PHP input application. The information manager then stays involved with pre-processing the data for analysis in collaboration with the researcher. However, most research projects are completed before the data are submitted to the information manager. These data are then cleaned and transferred to a normalized relational database. In both cases, the resulting databases are documented by the information manager in MySQL, and a reverse-engineering tool is used to produce the EML metadata file. The EML files are stored in a native XML database (eXist) and managed for search and display via a controlled keyword vocabulary. GIS datasets are documented using the ESRI metadata editor, exporting the metadata and converting them via XSLT stylesheet into EML and stored in eXist as well.

CAP-funded data are expected to be submitted to the information manager within two years of study completion (Appendix E). Data collected by graduate students for a thesis are expected to be submitted after they complete their degree. Once archived and documented, the data are publicly available for download on the web site. Exceptions are made only for sensitive data as determined by the originator, but this rule applies mostly to human-subjects research. Conditions of use are posted on the web site and are included in the metadata files. All research that has at least in part been funded by CAP falls under these general LTER guidelines, and the project or information manager remind researchers of these rules before they submit their annual report.

Long-term monitoring datasets are maintained on the database server at all times. Technicians collecting the biodiversity data ad are responsible for entry. Data-entry screens are provided online in PHP on the CAP website. Chemical analyses for water and atmospheric deposition monitoring are run by CAP technicians in the Goldwater Environmental Laboratory, and results are entered by the technicians as well. Recently, however, analytical instruments were purchased for the environmental lab which will now allow automatic upload of results to the database. Barcoding of samples is currently being implemented to enable the automation of data integration between field and lab. The CAP website provides query interfaces to access and download data from these large datasets.

The CAP website (http://caplter.asu.edu) provides access to all data mentioned above. Most of the major categories (personnel, publications, research projects, datasets, images, protocols) are searchable and access is provided from several perspectives (e.g., research projects, publications and datasets are listed for each person, protocols and datasets are listed for each research project, an interactive map shows research projects and images for particular sites). In password-protected areas, data entry applications are provided for all long-term monitoring projects and some short-term research projects. An ‘admin’ area provides documentation of the information management routines and management applications to upload data to the LTER network databases (publications, climDB, datasets etc.), harvest climate data, and generate specially formatted output from the database for annual report submission in Fastlane.

In collaboration with our outreach and education program, **Ecology Explorers**, several web applications have been developed. A data center allows students and teachers to enter bird and arthropod data, which then can be viewed in a graphing application. Recently, we developed a prototype online mapping tool for plant distribution.

On the LTER network level, the information manager is active as co-chair of the Information Manager Committee. She also heads up the IMC website committee in which we are exploring the content management system DRUPAL for innovative ways to improve communication and foster collaboration. This project is expected to provide experience with DRUPAL to the point that it can be used by the general LTER research community.

Related Projects in Collaboration with CAP

Many ongoing GIOS projects are collaborating with CAP LTER. For example, we are developing an improved spatial data-management system for implementing a spatially enabled open-source database, open source MapServer, and OGC data exchange standards.

Under other funding, lab staff is developing an online EML editor. This editor (http://intranet.lternet.edu/im/project/MetadataEditor) is entirely based on W3C endorsed XML technologies, employing XForms for editing EML files stored in a native XML database. Inigo San Gil from the LTER Network Office is collaborating on this project.

Working with ASU's Computer Science Department, lab staff is working to improve dataset search engines. Text analysis algorithms have been applied to EML files, publications, and general textbooks to automate concept linking for more successful keyword searches. Once a keyword is entered, the search engine provides a list of related keywords that the user can connect with logical "and" and "or" to either narrow or expand the search (http://149.169.202.24:8080/ecologyse).

Initiated in CAP 1, then separately funded by NSF BDI and in part by other NSF grants, the Southwest Environmental Information Network (http://seinet.asu.edu) has become a center for biodiversity information. "SEINet" contains 14 natural-history collections that are now searchable, and curators from three more have recently inquired about connecting to the network.

The Arizona Hydrologic Information System is in its early stages of development as the central project of the Arizona Water Institute, a new initiative of the Governor's office. The architecture will be aligned closely enough with the Consortium of Universities for the Advancement of Hydrologic Science to assure seamless data exchange. CAP data will be integrated into the system as appropriate.

APPENDIX A
PUBLICATIONS, DISSERTATIONS, AND THESES

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*.

Janssen, M., and J. Anderies. In press. Robustness of social-ecological systems in spatial and temporal variability. *Society and Natural Resources.*

Kaye, J., A. Majumdar, C. Gries, A. Buyantuyev, N. B. Grimm, D. Hope, W. Zhu, D. Jenerette, and L. Baker. In press. Hierarchical Bayesian scaling of soil properties across urban, agricultural, and desert ecosystems. *Ecological Applications.*

Lewis, D. B., and N. B. Grimm. In press. Hierarchical regulation of nitrogen export from urban catchments: interactions of storms, landscapes, and N pools *Ecological Applications*. Accepted pending revisions.

Majumdar, A., C. Gries, and J. Walker. In press a. A non-stationary spatial generalized linear mixed model approach for studying plant diversity. *Biometrics*.

Majumdar, A., J. P. Kaye, C. Gries, D. Hope, and N. B. Grimm. In press b. Hierarchical spatial modeling and prediction of multiple soil nutrients and carbon concentrations. *Communications in Statistics – Simulation and Computation*

McCrackin, M.L., T.K. Harms, and N.B. Grimm. In press. Responses of microbes to resource availability in urban, desert soils. *Biogeochemistry*: accepted with revisions.

Shen, W., J. Wu, N. B. Grimm, J. F. Reynolds, and D. Hope. In press. Effects of urbanization-induced environmental changes on desert ecosystem functioning. *Ecosystems.*

Walker, J. S., R. C. Balling, J. M. Briggs, M. Katti, P. Warren, and E. M. Wentz. In press. Birds of a feather: A story of urban and exurban population biology. *Computers, Environment, and Urban Systems.*

Walker, J. S., and T. Blaschke. In press. Object-based land cover classification for the Phoenix metropolitan area: Optimization vs. transportability. *International Journal of Remote Sensing.*

Xu, Y., L. Baker, and P. Johnson. In press. Effect of land use changes on temporal trends in groundwater nitrate concentrations in and around Phoenix, Arizona. *Ground Water*.

Yabiku, S., D. G. Casagrande, and E. Farley-Metzger. In press. Preferences for landscape choice in a Southwestern desert city. *Environment and Behavior*.

In Review

Hall, S. J., D. Huber, and N.B. Grimm. In review. Soil N_2O and NO emissions in an arid urban ecosystem. *Journal of Geophysical Research.*

Harlan, S. L., S. Yabiku, L. Larsen, and A. Brazel. In review. Household water consumption in an arid city: affluence, affordance, and attitudes. *Society and Natural Resources.*

Hirt, P., A. Gustafson, and K. L. Larson. In review. The mirage in the Valley of the Sun. *Environmental History*.

Lohse, K. A. D. Hope, R. Sponseller, J. O. Allen, and N. B. Grimm. Atmospheric deposition of nutrients across a desert city. *Environmental Science and Technology.*

Machabée, L. G., A. P. Kinzig, and J. J. Jacob. In review. Park and yard landscaping preferences in Phoenix, Arizona, U.S.A.: An exploration of socio-demographic differences. *Landscape and Urban Planning*.

Majumdar, A., J. Kaye, C. Gries, and D. Hope. In review. Does urbanization affect soil-nitrogen and soil-carbon concentrations? *International Journal for Management Systems.*

Marussich, W. A., and S. H. Faeth. In review. Urbanization shifts trophic dynamics of arthropod communities on a common desert host plant. *Oikos*.

Musacchio, L., and J. Wu. In review. Developing synchronicity in urban ecology as sustainability science: Linking ecology, design, and planning. *Frontiers in Ecology and the Environment*.

Myint, S. W., and G. S. Okin. In review. Modeling urban land covers using multiple endmember spectral mixture analysis. *Remote Sensing of Environment*

Roach, W. J., R. Arrowsmith, C. Eisinger, N. B. Grimm, J. B. Heffernan, and T. Rychener. In review. History of anthropogenic modifications to hydrology and geomorphology of an urban desert stream. *BioScience*.

Roach, W. J., and N. B. Grimm. In review. Anthropogenic and climatic drivers interact to shift nutrient limitation along an urban lake chain. *Freshwater Biology*.

Shochat, E., J. Lobo, J. M. Anderies, C. L. Redman, P. S. Warren, S. H. Faeth and C. H. Nilon. In review. Productivity, inequality, and biodiversity loss in human-dominated ecosystems. *Ecology Letters*.

Stabler, L., and C. A. Martin. In review. Landscape management affects woody plant productivity and water use in an urbanized desert ecosystem. *Ecosystems*.

Wu, J., L. Zhang, and G. D. Jenerette. In review. Quantifying the spatiotemporal patterns of urbanization: A case study in metropolitan Phoenix, USA. *Landscape and Urban Planning*.

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APPENDIX B:
LONG-TERM MONITORING AT CAP LTER

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
Arthropods	27 sites	4 times per year: Jan, Apr, July, and Oct	-Ground-dwelling arthropods
Birds	56 core sites and	2 times per year: Jan and Mar	-Point-count bird census
Birds	40 PASS neighborhoods	2 times per year: Dec and Feb	-Point-count bird census -Vegetation survey
Primary productivity tree survey	50 sites	Winter	-Tree biovolume -Tree condition
Survey 200	204 sites	Every 5 years in the spring	-Photo documentation -Vegetation composition -Vegetation cover -Soil: physical, chemical and biological -Habitat/built structure -Human activity
North Desert Village	4 treatment areas	Continuous	-Air temperature -Ground surface temperature -Soil temperature -Soil heat flux -Soil water content
North Desert Village	4 treatment areas	Monthly	-Landscape water use -Electricity use -Dwelling surface temperature
North Desert Village	4 treatment areas	Annually, with exception of bird and arthropod monitoring (as above)	-Birds -Arthropods -Primary productivity
Atmospheric deposition	15 locations (upwind, core, and downwind of greater Phoenix)	4 times per year	-Ammonium -Nitrate -Dry deposition -Wet deposition
Water-quality monitoring	5 locations at major influents (Salt and Verde rivers, CAP canal) and effluents (Salt and Gila Rivers)	6 times per year	-Nutrients -Major cations/anions -pH -Temperature -Specific conductance -Particulates

Monitoring Program	Number of Sampling Locations	Sampling Frequency	Variables Measured
Groundwater-quality monitoring	1 experimental plot along Gila River	6 times per year	-Water quality
Land-use and land-cover	CAP LTER site	Every five years	-Land use change -Land cover change
Microclimate	AZMet stations	Data mined as needed	-Growth and intensity of urban heat island -Decline in frosts and freezes
Phoenix Area Social Survey (PASS)	40 neighborhoods	Every 5 years	-Water supply and conservation -Land use, preservation and growth management -Air quality and transportation -Climate change and the urban heat island

APPENDIX C
SELECTED LIST OF VISITORS TO CAP LTER

Samuel Atkinson, University of North Texas
Mary Cadenasso, University of California, Davis; BES
Jianming Cai, Chinese Academy of Sciences
John Chamblee, University of Georgia; CWT
Dan Childers, Florida International University; FCE
Scott Collins, University of New Mexico; SEV (with graduate students)
Avinash Chuntharpursat, South African Environmental Observation Network
Kirstin Dow, South Carolina University; BES
Christopher Field, Carnegie Institution of Washington
Bojie Fu, Chinese Academy of Sciences
Peter Groffman, Institute of Ecosystem Studies; BES
Gail Hollander, Florida International University; FCE
Philippe Jamet, Embassy of France in the United States
Anthony Joern, Kansas State University; KNZ
Eun-Shik Kim, Kookmin University, South Korea (with undergraduate students)
Morgan Grove, U.S. Forest Service; BES
Angus Paterson, South African Environmental Observation Network
Timothy O'Connor, South African Environmental Observation Network
Kai Lee, Williams College
Charles Lord, Boston College; BES
Pamela Mattson, Stanford University
Elinor Ostrom, Indiana University
Elodie Pasco, Embassy of France in the United States
Johan Pauw, South African Environmental Observation Network
Steward Pickett, Institute for Ecosystem Studies; BES
Isabel Ramírez, National Autonomous University of Mexico
Anu Riikonen, Swedish University of Agricultural Sciences, Sweden
Roberto Sanchez-Rodriguez, University of California, Riverside
Kirsten Schwartz, Rutgers University; BES
Brent Steel, Oregon State University; AND
Xiaoke Wang, Chinese Academy of Sciences
Ernst von Weizsäcker, University of California, Santa Barbara
Annika Wuolo, University of Helsinki, Finland
Jeff Williamson, Phoenix Zoo

APPENDIX D
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
Robert 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
Ariel D. Anbar, Earth and Space Exploration	2004-present
James R. Anderson, Engineering	2001-present
Lawrence A. Baker, Water Resources Center, U of Minn.	1997-present
Christopher Boone, Human Evolution and Social Change	2006-present
Alexandra Brewis, Human Evolution and Social Change	2007-present
Megha Budruk, Community Resources	2006-present
David Casagrande, Sociology and Anthropology, W. Ill. U.	2003-present
Phillip Christensen, Mars Space Flight Facility	1997-present
Elizabeth A. Corley, Public Affairs	2004-present
James Collins, Life Sciences	2004-2005
William Cook, Biological Sciences, St. Cloud State U.	2004-present
John C. Crittenden, Engineering	2004-present
James J. Elser, Life Sciences	1997-present
Ananias A. Escalante, Life Sciences	2005-present
Joseph Feller, Law	2004-present
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
Suzanne 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
Jeffrey M. Klopatek, Life Sciences	1997-present
Jennie J. Kronenfeld, Social and Family Dynamics	2004-present
Michael Kuby, Geographical Sciences	2004-present
Leslie Landrum, Life Sciences	1998-present
Kelli Larson, Geographical Sciences	2005-present
Anandamaye Majumdar, Mathematics and Statistics	2004-present
Nancy E. McIntyre, Bio. Sciences, Texas Tech	1997-present
Geoffrey Morse, Integrated Natl. Science	2006-present
Laura R. Musacchio, Landscape Arch., U of Minn.	1999-present
Soe Myint, Geographical Sciences	2006-present
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
K. David Pijawka, Planning	1997-present
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
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
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
Jason Parker, Service at Salado	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.
Cartwright Elementary District
Chandler Unified District
City of Phoenix
City of Scottsdale
City of Tempe
Creighton School District
Deer Valley Unified District
Desert Botanical Garden
Dysart Unified School District
Flood Control District of Maricopa County
Fountain Hills High School District
Gila River Community Schools
Gilbert Unified District
Glendale Union High School District
Isaac Elementary District
Kyrene Elementary District
Maricopa Association of Governments
Maricopa Community Colleges
Maricopa Parks and Recreation Department
Mesa Unified District
Paradise Valley Unified District
Peoria Unified School District
Phoenix Elementary School District
Phoenix Union High School District
Queen Creek Unified School District
Roosevelt School District
Salt River Project
Scottsdale Unified District
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

APPENDIX E
DATASETS

Active Projects

Aquatic Core Monitoring (Continuation of NAWQA) (NU8)

Longterm Water Monitoring
Longterm Water Monitoring: Sites

Atmospheric Deposition (NU_31)

Atmospheric Deposition HNO3 Dry Deposition Fluxes in 1998
Atmospheric Deposition Monitoring, Sites
Atmospheric Deposition NO2 Dry Deposition Fluxes in 1998
Atmospheric Deposition Total Nitrogen from Dry Deposition in 1998
Longterm Atmospheric Deposition Monitoring

Ecology Explorers (ED_13)

Ecology Explorers: Arthropod Dataset
Ecology Explorers: Bird Dataset
Ecology Explorers: Bruchid Dataset
Ecology Explorers: Vegetation Dataset

Effects of Urbanization on the Landscape Pattern and Ecosystem Processes in the Phoenix Metropolitan Region: A Multiple-Scale Study (LU_79)

2000 Annual Precipitation
2001 Annual Precipitation
2002 Annual Precipitation
2003 Annual Precipitation
2004 Annual Precipitation
2005 Annual Precipitation
Average precipitation in April in Central Arizona
Average precipitation in August in Central Arizona
Average precipitation in December in Central Arizona
Average precipitation in February in Central Arizona
Average precipitation in January in Central Arizona
Average precipitation in July in Central Arizona
Average precipitation in June in Central Arizona
Average precipitation in March in Central Arizona
Average precipitation in May in Central Arizona
Average precipitation in November in Central Arizona
Average precipitation in October in Central Arizona
Average precipitation in September in Central Arizona

Mean Annual Precipitation
Monthly maximum air temperature in April (6 year mean) in Central Arizona
Monthly maximum air temperature in August (6 year mean) in Central Arizona
Monthly maximum air temperature in December (6 year mean) in Central Arizona
Monthly maximum air temperature in February (5 year mean) in Central Arizona
Monthly maximum air temperature in January (5 year mean) in Central Arizona
Monthly maximum air temperature in July (6 year mean) in Central Arizona
Monthly maximum air temperature in June (6 year mean) in Central Arizona
Monthly maximum air temperature in March (6 year mean) in Central Arizona
Monthly maximum air temperature in May (6 year mean) in Central Arizona
Monthly maximum air temperature in November (6 year mean) in Central Arizona
Monthly maximum air temperature in October (6 year mean) in Central Arizona
Monthly maximum air temperature in September (6 year mean) in Central Arizona
Monthly minimum air temperature in April (6 year mean) in Central Arizona
Monthly minimum air temperature in August (6 year mean) in Central Arizona
Monthly minimum air temperature in December (6 year mean) in Central Arizona
Monthly minimum air temperature in February (5 year mean) in Central Arizona
Monthly minimum air temperature in January (5 year mean) in Central Arizona
Monthly minimum air temperature in July (6 year mean) in Central Arizona
Monthly minimum air temperature in June (6 year mean) in Central Arizona
Monthly minimum air temperature in March (6 year mean) in Central Arizona
Monthly minimum air temperature in May (6 year mean) in Central Arizona
Monthly minimum air temperature in November (6 year mean) in Central Arizona
Monthly minimum air temperature in October (6 year mean) in Central Arizona
Monthly minimum air temperature in September (6 year mean) in Central Arizona

Environmental Risk and Justice (HU_32)

Environmental Risk and Justice: Facilities 1990 with Toxic Release Inventory data
Environmental Risk and Justice: Locations of the facilities releasing toxic substances 1990
Environmental Risk and Justice: Locations of the facilities releasing toxic substances 1995

Historic Land Use Database (LU_19)

Landuse at one square mile around the survey 200 plots 1970
Landuse at one square mile around the survey 200 plots 1980
Landuse at one square mile around the survey 200 plots 1990
Landuse at one square mile around the survey 200 plots 1995
Landuse at one square mile around the survey 200 plots 2000
Landuse Classification 1912
Landuse Classification 1934
Landuse Classification 1955
Landuse Classification 1975
Landuse Classification 1995
Landuse Classification 2000

Land use effects on Urban Tree Primary Productivity (PP_58)

Longterm monitoring of primary productivity of trees
Longterm monitoring of primary productivity of trees: Sites

Lichen Resurvey with Heavy Metal Analysis (PO11/NU9)

Lichen Resurvey with Heavy Metal Analysis in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Antimony concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Cadmium concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Chromium concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Copper concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Dysprosium concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Lead concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Nickel concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Palladium concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Platinum concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Praseodymium concentration in lichen tissue in Maricopa County
Lichen Resurvey with Heavy Metal Analysis: Distribution of Tin concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Distribution of Zinc concentration in lichen tissue in Maricopa county
Lichen Resurvey with Heavy Metal Analysis: Sites

Longterm monitoring of ground arthropod biodiversity (PO6_10)

Longterm Monitoring of Ground Arthropod Biodiversity
Longterm Monitoring of Ground Arthropod Biodiversity: Sites

Multi-Temporal Remote-Sensing Data Acquisition for CAP LTER Land Cover/Land Use Monitoring and Modeling (GE_20)

Land cover classification using ASTER data - year 2000
Land cover classification using Landsat (MSS) data - year 1973
Land cover classification using Landsat Enhanced Thematic Mapper (ETM) data - year 2000
Land cover classification using Landsat Thematic Mapper (TM) data - year 1985
Land cover classification using Landsat Thematic Mapper (TM) data - year 1990

Land cover classification using Landsat Thematic Mapper (TM) data - year 1993
Land cover classification using Landsat Thematic Mapper (TM) data - year 1998
NDVI (Normalized Difference Vegetation Index) of the 2005 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 1975 Landsat MSS Image
NDVI (Normalized difference vegetation index) Image of 1980 Landsat MSS Image
NDVI (Normalized difference vegetation index) Image of 1985 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 1993 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 1998 Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 2000 Enhanced Landsat Thematic Mapper Image
NDVI (Normalized difference vegetation index) Image of 2003 ASTER Image.
SAVI (Modified Soil Adjusted vegetation index) Image of 2003 ASTER image
SAVI (Soil Adjusted Vegetation Index) Image of 1975 Landsat MSS Image
SAVI (Soil Adjusted Vegetation Index) Image of 1980 Landsat MSS Image
SAVI (Soil Adjusted Vegetation Index) Image of 1985 Landsat Thematic Mapper Image
SAVI (Soil Adjusted Vegetation Index) Image of 1990 Landsat Thematic Mapper Image
SAVI (Soil Adjusted Vegetation Index) Image of 1993 Landsat Thematic Mapper Image
SAVI (Soil Adjusted Vegetation Index) Image of 2000 Enhanced Landsat Thematic Mapper(ETM) Image
SAVI (Soil Adjusted Vegetation Index) of the 2005 Landsat Thematic Mapper Image

Nutrient Deposition Measurements in the CAP-LTER Study Area (170)

Ozone concentrations in 2003
Ozone concentrations in 2004
Ozone concentrations in 2005
Three year average ozone concentrations

Nutrient Transport and Retention in Urban Watersheds (NU_44)

Indian Bend Wash Floodplain 1
Indian Bend Wash GIS Clip Output
Indian Bend Wash GIS CoverDOQQ
Indian Bend Wash GIS GRID1935
Indian Bend Wash GIS GRID1972
Indian Bend Wash GIS GRID1978
Indian Bend Wash GIS GRID1987
Indian Bend Wash GIS GRID1997
Indian Bend Wash GIS GRID2000
Indian Bend Wash GIS Lake Layer
Indian Bend Wash GIS Lake V Layer
Indian Bend Wash GIS Mask II
Indian Bend Wash GIS Park Turf II Layer
Indian Bend Wash GIS Parks Studied
Indian Bend Wash GIS Watershed Canal Union

Indian Bend Wash Parks GIS
Indian Bend Wash Problem Zones
Indian Bend Wash Stream Guages
Indian Bend Wash Vegetation GIS Layer
Indian Bend Wash Watershed cliped GIS

Nutrients and Data Synthesis, Mass Balance (NU7)

Nutrients and Data Synthesis, Mass Balance: Gila-Salt Watershed boundary
Nutrients and Data Synthesis, Mass Balance: Phoenix Dairy Farms
Nutrients and Data Synthesis, Mass Balance: Phoenix Stockyard Locations
Nutrients and Data Synthesis, Mass Balance: Phoenix citrus groves
Nutrients and Data Synthesis, Mass Balance: Phoenix crops
Nutrients and Data Synthesis, Mass Balance: shed_agr

Phoenix Area Social Survey (HU_41)

PASS II project study sites
Phoenix Area Social Survey I
Phoenix Area Social Survey I, Sites

Point Count Bird Censusing (PO_34)

Point Count Bird Censusing
Point Count Bird Censusing: Sites

Survey 200 (PO_27)

Assessing Biodiversity of Arbuscular Mycorrhizal Fungi
Assessing Biodiversity of Arbuscular Mycorrhizal Fungi: Mycorrhiza Sites
Distribution of Ragweed Pollen sampled in Greater Phoenix
HIERARCHICAL BAYESIAN SCALING OF SOIL PROPERTIES ACROSS URBAN, AGRICULTURAL, AND DESERT ECOSYSTEMS
Hierarchical Spatial Modeling of Multiple Soil Nutrients and Carbon in Heterogeneous Land-Use Patches of the Phoenix Metropolitan Area
Survey 200
Survey 200
Survey 200 - Estimating soil properties in heterogeneous land-use patches: A Bayesian approach
Survey 200 - Annuals
Survey 200 - Arthropod Sweepnet Samples
Survey 200 - Cacti
Survey 200 - Historic Landuse
Survey 200 - Human
Survey 200 - Land Use
Survey 200 - Neighborhood Characteristics
Survey 200 - Pollen
Survey 200 - Shrubs

Survey 200 - Soil
Survey 200 - Trees

Completed Projects

Canal Study (NU_35)

Canal Study GRID 1962

Century-scale Channel Change (GE1_5)

Century-scale Channel Change: Photographs of selected reaches of the Salt River in different years since mid 1940s
Century-scale Channel Change: Sites

Comparison Among Residential Patch Transition Types; Before-After (OM_14)

Water Use and Flooding in Phoenix: Comparison of water and carbon dioxide uptake by selected plant species among residential patch transition types

Dissolved organic carbon dynamics in an urban desert stream ecosystem (NU_80)

Dissolved Organic Carbon Dynamics in Sycamores
Dissolved organic carbon dynamics in an urban desert stream ecosystem: Sites

Ecological and Social Interactions in Urban Parks (PP_52)

Ecological and Social Interactions in Urban Parks: Bird surveys in local parks in the CAP-LTER study area
Ecological and Social Interactions in Urban Parks: Sites

Effects of Urban Horticulture on Insect Pollinator Community Structure (PO_26)

Effects of Urban Horticulture on Insect Pollinator Community Structure
Effects of Urban Horticulture on Insect Pollinator Community Structure: Sites

Historic Records of Climate in Valley (GE_16)

Historic Records of Climate in Valley: 50 year climate data summary for the Phoenix metropolitan area

Hohokam Canals as Multi-Use Facilities (LU_17)

Hohokam Canals as Multi-Use Facilities: Pre-historic canal system in the Phoenix metropolitan area

Inorganic Nutrient Dynamics in the Lower Indian Bend Wash watershed (205)

Indian Bend Wash Water Chemistry

Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient (LU_49)

Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient
Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient: CO2 concentration
Land Use Effects on Temperature and Humidity along a Urban-Rural Transect Gradient: Sites

Plant Survey of Current Vegetation (PO13+_11)

Plant Survey of Current Vegetation: Desert Vegetation
Plant Survey of Current Vegetation: Desert Vegetation, Sites
Plant Survey of Current Vegetation: MAP OF SONORAN DESERT PLANT COMMUNITY DISTRIBUTION IN MOUNTAIN PARKS OF THE CAPLTER STUDY AREA, PHOENIX, ARIZONA
Plant Survey of Current Vegetation: MAP OF SONORAN DESERT PLANT COMMUNITY DISTRIBUTION IN THE CAPLTER STUDY AREA, PHOENIX, ARIZONA

Scorpions in Urban Environments (PO_25)

Scorpion Stings in Urban Environments

Spatial/Temporal Change of Climate/Air Quality in Relation to Urban Fringe Development (LU_37)

Spatial/Temporal Change of Climate in Relation to Urban Fringe Development
Spatial/Temporal Change of Climate in Relation to Urban Fringe Development: Sites

Transect Bird Survey with Data Synthesis (PO12_12)

Transect Bird Survey with Data Synthesis
Transect Bird Survey with Data Synthesis: Sites

Urban Storm Runoff (NU_28)

Urban Storm Runoff
Urban Storm Runoff: Sites

Using Leaves as Samplers to Determine the Spatial Distribution of Atmospheric Particles (NU_53)

Using Leaves as Samplers to Determine the Spatial Distribution of Atmospheric Particles: Analysis of Atmospheric Particles on Filters and Mesquite Leaves in El Paso and Phoenix

Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix (PO_23)

Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix
Vertebrate Species Composition of Remnant Desert Islands within Urban Phoenix: Sites